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ABSTRACT

A course to develop an understanding of the scope of water resource activities, of the need for forecasting, of the National Weather Service's role in hydrology, and of the proper procedures to follow in fulfilling this role is presented. The course is one of self-help, guided by correspondence. Nine lessons are included: (1) Hydrology in the National Weather Service, (2) water management programs, (3) Is there a water shortage? (4) water resources management and control structures, (5) data acquisition and processing, (6) office arrangements, (7) forecasts, (8) dissemination, and (9) administration. (CK)

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HYDROLOGIC SERVICES

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# HYDROLOGIC SERVICES

## Introduction

General -

Many of us tend to think of the National Weather Service's hydrologic work as a part-time program of processing river and rainfall data, and occasionally sweating out a flood. Our job is bigger than this, and is rapidly growing in magnitude and complexity.

This growth stems from several trends: growing population, increasing per-capita use of water, encroachment on flood plains, and expanding water-oriented recreation. The increasing use of water not only burdens a limited supply of water, but also pollutes this same supply.

Water resources are used for many activities: navigation, irrigation, power production, municipal supply, recreation, fish and wildlife, and industrial purposes. These uses must be coordinated with measures for protection from floods, sediment, and pollution. Competition among these many needs requires careful planning, design and operation of water management structures and programs. Operating criteria, and operating decisions, for the proper management of any water management system are based on forecasts. Paradoxically, the more fully developed our rivers become, the greater is the need for river forecasting.

Riverside property owners need forecasts of high stage to protect their property from flooding. Barge operators need forecasts of low stage so that they will not overload their barges. Forecasts of flow may be used to determine the degree of treatment required at sewerage plants. Reservoir operators need forecasts of inflow to the reservoir, and of tributary contributions downstream from the reservoir to regulate releases for water quality control, navigation, and flood control. Hydro-electric load dispatchers need forecasts of river flow to coordinate stream and hydro-electric power generation. Users of seasonal and of supplemental irrigation water need to know how much water they can depend on. Forecasts of velocity help municipal water supply officials schedule their operations so as to miss slugs of polluted water coming from accidental or other releases of wastes or poisons. Sand and gravel operators, and construction companies, need forecasts of stage and velocity. Maintenance departments of riverside railways and highways require forecasts of high stage.

The foregoing list could go on and on. The point is this: To meet all these needs, forecasts of stage, flow, and velocity must be made continually, as far in advance as skill permits.

Need for expanded capability

In some river basins we already make continuous flow forecasts. In others we do not. Many headwaters communities are served by flash-flood warning systems. Hundreds are not. Most of our River District Offices are served by River Forecast Centers. Others are not. At some of our stations everyone knows how to accept a call from a co-operative observer. At others this is not true. At some stations only a few staff members are aware of the availability of non-river services, such as certain hydrologic technical papers and hydrometeorological reports. Some people who call our stations for advice have difficulty in explicitly stating their needs. Some of us are more knowledgeable than others about water resources problems, and can help callers express their needs in meaningful terms.

Purpose

The purpose of this course is to expand your capability and increase your skill. This will be done by developing an understanding of the scope of water resources activities, of the need for forecasting, of the National Weather Service's role in hydrology, and of the proper procedures to follow in the process of fulfilling this role.

Course administration

Briefly, the course is one of self-help, guided by correspondence. There are no prerequisites. There will be a great deal of reading and questions to answer at the end of each lesson. The course is open book and as a trainee completes each lesson, he may go on to the next one as rapidly as he finds time to work on it. If a lesson is not completed satisfactorily, it may be repeated. There is no objection to the trainee receiving help from others on the station or from any source available to him.

The questions at the end of each lesson should be answered on separate sheet(s) of paper so that this training guide will remain intact. Each sheet should include your name, station, lesson number, and amount of time spent on the lesson. Handwriting is acceptable, provided it is neat and legible.

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Lesson 1 - Hydrology in the National Weather Service
Lesson 2 - Water Management Programs
Lesson 3 - Is there a Water Shortage?
Lesson 4 - Water Resources Management and Control Structures

Reference: Who Does What, The Effects of Dams, Reservoirs, and Levees on River Forecasting.

Objective:
1. To learn about the history and status of hydrology in the National Weather Service
2. To become familiar with the subject of water resources management and use in the United States.
3. To learn what methods and programs Federal and local agencies have for managing water resources.
4. To know some of the mechanisms for achieving inter-agency cooperation and to consider other approaches to water management.

Discussion: "Who Does What" is a summary of information obtained from a large number of authoritative sources. The text should be saved for a ready reference to detailed information. Broader aspects of the subject should be retained so that you will remember what you can find in the text, and so that you will have a good general knowledge of who does what.

Work Assignments:

1. Read "Who Does What" as follows:
   - Lesson 1 - Chapter I
   - Lesson 2 - Sections 1-11, Chapter II
   - Lesson 3 - Section 12, Chapter II, Chapter III
   - Lesson 4 - Chapter IV and the Effects of Dams, Reservoirs, and Levees on River Forecasting.
2. Answer questions for each lesson. Lessons 1 through 4 may be submitted separately or as a group.

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Lesson 5, Data Acquisition and Processing

Reference: Weather Service Manual Chapters E-20,21 and H-06 (E-41) the River Data Code (1961 edition) and the attached statement.

Objective: To become more efficient in the very basic function of collecting observations of river and rainfall, processing these reports, and relaying them to interested persons. This includes the placement of precipitation gages, dealing with cooperative observers, and cooperation with other agencies.

Discussion: Many stations have excelled in this work but we have included samples of how the various jobs are done from only a few stations. This should be sufficient to point the way for improvement where it is desirable. Hydrologic data collection varies from the simple routine of accepting a few daily reports during dry weather to processing many reports around the clock when rains are heavy. River District officials need to be aware of the total rainfall-river picture in order to anticipate heavy work loads. It is sometimes necessary to solicit reports as a means of alerting observers. Careful preparation in advance of the flood events is also an important factor in successful data collection.

Special note: WS Manual chapters should be consulted, rather than examples shown in appendices, for current official terminology and instructions.

Work assignments:

1. Read the reference:
2. (a) How many observers report to your station?
   (b) Who visits them and how often?
   (c) What is the average turnover rate of observers?
   (d) When you accept a call from Exville, can you recall the observer's name?
   (e) Is your relay of data to RFC clear, concise and orderly?
3. What other agencies do you exchange data with? To what extent?
4. Briefly describe your established routine for receiving, checking, and relaying river and rainfall reports.
5. Have any of the examples suggested ways you can improve your operation?
6. Answer the questions for this lesson.

## HYDROLOGIC SERVICES

Lesson Five, Data Acquisition and Processing

For a look at how data acquisition may be handled in the future we might consider two networks now in existence. One is the AHOS network used to collect reports in the Washington, D. C. River District Office, and the other is the high speed radio network that collects observations for the drainage basins of Northwest California. The observations collected are automatically transmitted by land lines in the case of AHOS and by radio in California. The latest reports from the whole network can be collected in a matter of minutes. They are in a form which can be handled very easily by manual methods, and it would be a simple matter to arrange for them to be fed directly into computers. When perfected, it is expected that this will be the ideal method of data acquisition. Widespread use of such systems, however, is a long way in the future. In the meantime, we will have to rely on the older methods described in the following pages.

River District Offices are responsible for collecting river and rainfall reports within the boundaries of their river districts and have the responsibility of forwarding these reports to the River Forecast Center. While they have other duties which we mention in later lessons, this is the most basic of all the duties of the River District Office since, obviously, there can be no forecast services without these reports. This can be a rather simple task in a small River District Office that has only a few reports to collect and relay. In other stations there are dozens of daily reports, and perhaps hundreds of special reports made during storms, that require many man-hours of well organized labor.

1. Observations.

Part of the basic network of river and rainfall information is relayed by teletype on service A or service C. Service C synoptic reports show rainfall observations in 6-hour as well as 24-hour amounts. Snow depths and significant water equivalent data are also sent on this circuit. The SR reports give the river stage and tendency and the rainfall for river and rainfall stations scheduled for regular transmission on the service C teletype. The additive data groups on airways reports are used to send 6-hour amounts of rainfall and in certain cases the snow depth. There is a strong tendency to accept these data at their face value, so they should be handled with care, and the final transmission should be checked for typographical errors. Every effort should be made to relay the information that missed the regular schedule as either a delayed message on the regular circuit or a special message on some other circuit such as RAWARC, NADWARN, or the NOAA Weather Wire. A final check of the data should always be made after transmission by teletype to ascertain that the transmitted information shows exactly what occurred.

The snow depth and the water equivalent observations present what may well be the most serious challenge in hydrologic observations. There is often a dearth of good sites where snow information can be measured at a convenient distance from the weather station. The scheduled time for water equivalent measurements is also a time for many other duties which demand the observer's attention. Too often there is a tendency to estimate the depth of snow and convert this figure to water equivalent with the ancient and usually erroneous 1:10 ratio. This practice can play havoc with the hydrologist's calculations of the amount of snow melt that will contribute to runoff.

A much preferred method of evaluating the proper snow information is to have the last person entering on duty before the scheduled observation time make the measurements at a pre-selected site removed from the usually disturbed station site. A much more representative sample for the area can be obtained in this manner. Official time on duty can well begin with this observation.

A few River District Offices are called upon to make and collect observations of evaporation. These observations are made from evaporation pans and special instructions are always given to the observers.

Information on scheduled releases or actual unscheduled outflow from reservoirs is essential to operation of an RFC. Frequently this is obtained directly from the agency operating the dam(s). In other cases the RDO will relay information obtained from a dam tender.

Occasionally, following occurrence of extremely heavy rainfall, there may be a request from the River Forecast Center or the Regional Hydrologist for a bucket survey. In fact, unusual storms should be brought to their attention so a bucket survey will at least be considered. In the bucket survey, rainfall measurements are obtained from many different sources, such as open cans, pails or barrels that happen to be sitting around. In fact, any container from which the depth of rainfall can be interpreted is used. The surveys usually provide a great deal of supplementary data between the rain gages of the regular network. The information thus obtained is valuable for depth-area-duration analyses, forecast procedure development and the planning connected with flood control structures.

2. Cooperative Observers.

Setting up and maintaining a cooperative observer network is an extremely difficult task. The basic reason for this is that we are asking people to do work for us which can be quite a nuisance at various times, and for which we are offering little if any monetary reward.

Many of the techniques given in this section for finding and working with cooperative observers were suggested by Mr. William Meyers, who has many years of experience as Ohio River Network Inspector for the Cincinnati River Forecast Center.

Some of the qualifications to consider while selecting observers are:

1. Age - It is preferable to select a person whose age makes it likely that he will record data over a long period of time.

2. Seek an observer whose daily life fits into the observational program with a minimum of inconvenience. In this respect housewives are excellent.

3. Interest in the National Weather Service program and a public spirited attitude.

4. Dependability - Has prospect been recommended as a conscientious person?

5. Intelligence - anyone can dip a stick in an 8 inch can but filling out the forms can be difficult for some.

6. Physical stamina.

Quite often a person is willing to act as observer but the exposure for the equipment is undesirable making any data acquired of doubtful value. Some of the prerequisites when selecting a site are:

1. Area not subject to flooding.

2. Availability of phone.

3. Good exposure of instruments - see Appendix A for notes on rain gage exposure.

4. Access by observer - It may be necessary to settle for slightly less than the best possible location if by so doing you make it possible for the observer to do our work much more conveniently.

5. Protection from vandalism. A gage should not be placed immediately behind a tavern. On the other hand, it may be used for target practice if it is too isolated.

6. Data requirements - The network must be designed to acquire a good data sample for the area. An evenly spaced horizontal grid is usually not possible. In mountainous areas it is more important to obtain data at various elevations.

7. Continuity of Data. It is extremely difficult to judge how much the data will be affected by moving instruments a short distance. Every effort should be made to avoid moving instruments, especially when a long period of record has been established. When unavoidable moves can be anticipated, it is helpful to obtain some records from the new site before the old one is closed. This enables users to correlate the two lists of data.

When hiring new observers, we should seek people who can use our product. For example, a dam tender would appreciate getting our forecasts of inflow to his reservoir. Another example would be the outpost of a utility company where the attendant could use our general weather forecasts. Cooperating agencies, such as the Corps of Engineers and various river valley authorities, are usually willing to give us the reports collected by them from their precipitation networks.

Other logical sources are:

1. Rural areas

    a. small grocers

    b. small post offices

    c. known weather enthusiasts

    d. housewives

2. Urban areas

    a. city sewage treatment and water works.

    b. known weather enthusiasts

    c. housewives

    d. public institutions

When interviewing a prospect one should:

1. **Explain the fundamental duties of an observer to the prospect and allow him to make up his own mind about accepting the position. Do not high-pressure him.**

2. Explain the need for the data gathered and its various uses. Emphasize his importance.

3. Fee paid observers - mention the fee paid as a token of

recognition for services, not as a salary.

4. Look for indications of dependability. Neighbors' opinions may be better than observers' general appearances or self-recommendations.

Once a selection is made you should:

1. Instruct the new observer thoroughly. Otherwise a new observer may wish to resign because he is confused and feels he can't do the work.

2. Revisit a new observer within a month or so to aid him with any difficulties he may be having.

3. Be liberal with compliments and make them public if possible when the observer is doing a good job. Everyone likes recognition of his work.

In dealing with small-town observers, remember that everyone in town knows who the observer is. Build him up in the eyes of his fellow man. Many observers appreciate getting the forecasts when they call an observation in. This helps enhance their image as the expert on rivers and weather in the local community. Try to get his name published in the type of news story that is shown in Appendix B. Find out his interests and be friendly when you make a visit. Some observers like to palaver when you visit them, others may be strictly business-like. Be careful to point out errors privately, in a very diplomatic way, and only when the time is right.

If a change in the observation program is to be made, go to the existing observer and talk to him about the problem. He may not wish to continue his services under the new setup but he should be given an opportunity to decline. With his help it should be an easy matter to find a replacement, but with his animosity aroused it might be impossible to find one. He might be especially offended if the new setup involved some pay, no matter how minor.

Make the observer realize that he is a part of the National Weather Service and is making a valued contribution. Explain what use is made of his records. Invite him to visit the nearest Weather Service office. RDO's should plan visits that occur between those made by the Field Aid in order to strive for a goal of semiannual visits when possible. Long lapses of time between visits may indicate to the observer that his work really is of no importance. Too many carelessly planned visits indicate a waste of tax money. "When normal routine data collection provides for frequent telephone contact with the observer, there may be less need for frequent visits to the station."

In Appendix C we have several examples of in ions to cooperative observers. These examples cover only the many possible reporting situations. The RDO should be familiar with each type of gage and exposure so that special instructions can be written when standard forms such as WS Forms E-12 or E-13,(formerly 612-19 and 612-18) do not fit the situation precisely. The aim should be to provide each observer with exactly the instructions needed to perform his duties. Extraneous bits of instructional material are merely confusing and time consuming. Of course, these extra bits could be blocked out in a few special cases in order to prevent having to print a special set of instructions for each observer. The written instructions should be presented to the observer in person and discussed thoroughly at that time. They should then be left to serve as a handy reference for the observer. Review these instructions with the observer at each visit to make sure the observer still has them and knows where they are.

In Appendix D we have an example of an observer contact which is used to alert the whole network at the beginning of a season in which special observing needs are likely to occur. Since flood seasons and the coming of winter vary with location, your situation may be different than this. Also, the special instructions that you would like to bring to the attention of your observers may vary from this, but a similar letter should be written at the appropriate time for your District.

Careful records should be kept on the beginning dates that observers start working for us,and periodic reviews should be made to ascertain whether an RDO has any observers who are eligible for the Holm or Jefferson awards. When such an award is presented, every effort should be made to take a reporter along who will write a story on the event and very likely include pictures with the story.

A poor observer who is not working out creates quite a dilemma. Objectivity in handling the situation may take the form of calculating the chance of getting a better observer, versus keeping him with his faults. How do his faults affect the forecast? Does he have redeeming features that balance his faults? Does he have enough influence in the community to discourage other prospects? Or, if he must be replaced, can you somehow arrange to have him help the process?

Selection of gage sites for the ideal exposure can be quite difficult at a cooperative observer location. It is frequently necessary to settle for slightly less than the best possible location if by so doing you make it possible for the observer to do our work much more conveniently. One of the objects of visiting stations is to insure that changes in the exposure have not invalidated the data. There have been cases when trees grew up over a rain gage and changed the exposure completely. In other cases, new buildings may be constructed in a location which would affect the gage drastically.

3. Cooperation With Other Agencies.

In many River District Offices there is opportunity and necessity for cooperating with other agencies. In some cases an agency makes data collections which we would like to have. They will furnish us this data and ask for data and forecasts in return. The Geological Survey, for example, is interested in forecasts of floods so that they can prepare to gage streams at or near their peaks. Thus they are interested in receiving our forecasts and we in return can expect them to furnish us with rating information. In other cases, an agency supports our precipitation network with funds. In return for this financial support they expect to receive the data collected as soon as available.

As mentioned earlier, the precipitation network may well include many stations that were originally climatological stations. This necessitates cooperation between the River District Office and the other NOAA offices, since all would like to use the information observed by a single cooperative observer.

In all cases the river district officials should be aware of the cooperation needed on his part and he should also establish good enough relations with people in other agencies that their cooperation will be easily obtained. Special care should be taken to render the best possible service to other agencies. This will encourage the rapid exchange of data during flood emergencies and make it possible for you to support your River Forecast Center to the best of your ability. In a large River District operation it is a great advantage to have network data collected by other agencies because of the large amount of work involved in numerous telephone calls. While we would prefer to keep personal contact going between ourselves and our own cooperative observers, we appreciate very much the chance to get data that are collected by the other agencies from their own networks.

4. Records.

Some of the main objectives in keeping records of incoming rainfall or river observations are: 1. To be able to pay the observer who made the observation if he is on a pay basis. 2. Adequate records will help prevent mistakes from going unnoticed. 3. Records help to determine which observers are doing a good job in reporting accurately and which observers need assistance on the next visit.

Forms for observers have recently been revised. Instructions for their use will be issued in the Hydrologic Chapters of the new NWS Operations Manual. Appendix F gives an example of a few special forms designed to facilitate the receipt and transmission of reports that can easily be grouped by either basin or collecting agency. It may be possible in some cases to adapt Form E-14A (formerly 612-24A) for this purpose. The list of stations and other information could be preprinted on these forms. The order of stations should be coordinated with your River Forecast Center so that it will best suit the sequence in which the River Forecast Center would like to take these reports. If forms to fit your needs cannot be reproduced locally they should be sent to the RFC or Regional Office for reproduction. Each printing should be dated so that the latest revision can be ascertained.

The method by which a particular River District Office handles these records will vary from one place to another. In Appendix G we are showing the approach to the problem which is used by a couple of RDO's. These may not necessarily show the best routine for your particular office. However, they should give a good idea of the detail to which records should be kept. Records of observers and instruments, as opposed to data, will be covered in a later lesson.

## 5. Quality Control

Quality control can be exercised by the River District official by means of the records mentioned in the last section and by a friendly spirit of assistance when talking with cooperative observers. Quality control must also be exercised within the office itself in the handling of the reports to eliminate obvious errors when they are received and to make sure that they are transmitted in the proper form.

Special care should be taken with records of precipitation and gage heights that are forwarded to EDS and O/H respectively. It is best to correct errors at this stage, which is close to the observational source, before the records are published or punched on cards for automatic data processing.

A large portion of the phoned reports should be compared carefully with reports received on card Form E-14 (formerly 612-24)and with monthly forms. A log of the errors uncovered with this comparison will help to determine which observers should be given special assistance. Another log should show when and by whom the last visit was made to each station. The next visitor (Substation Network Specialist, Electronic Technician, or River District Official) should check these logs and discuss them with the MIC before going on a visit. This will help to determine what corrections should be made in the procedures currently being followed by an observer. It will also help to avoid conflict or duplication of instructions that might be confusing and irritating to the observer.

6. RFC-RDO Communication.

Communication of observations to the River Forecast Center and of forecasts back to the River District Office is extremely important. Data should be organized [illegible] nce required by the River Forecast Center so they can copy [illegible] most efficiently.

Many different forms of communication are available. The telephone has the advantage of two-way communication of ideas while data are being transmitted. However, it demands the attention of one person on each end while in use. Thus it can be very wasteful of man-hours under some situations. Another disadvantage is that it does not furnish a hard copy of the data or forecast being transmitted and leaves room for some misunderstanding. The TWX machine has some advantages, such as 2-way communication and the furnishing of hard copy, but it is becoming much more expensive in recent years. At least one River Forecast Center had its TWX machine removed because of poor service.

Perhaps the best method of establishing communication is through the use of RAWARC, NADWARN,or the NOAA Weather Wire, which is now being installed on a widespread basis, combined with the telephone when necessary. Before such special circuits can be used to the best advantage there must be definite priorities set up for the transmission of observations and forecasts pertaining to floods. The final decision on communications will probably be different with each River Forecast Center but the procedures should be thoroughly understood and documented so that there is no difficulty between the RDO and RFC in this regard.

Arrangements should also be made to take care of emergency situations in which all regular communications break down. Agreements can usually be made with agencies, such as the State Police, which have radio networks that could be used to relay important messages during drastic emergencies when all land lines are inoperative. Various amateur radio operator organizations are usually willing to serve in such an emergency. Plans should be agreed upon before the need arises.

Under the general heading of communication we might also consider various gages that are read remotely by either radio or telephone interrogation. These gages should be routinely checked on at least a weekly basis and serviced as required to insure efficient operation during critical periods.

7. Frequency of Observations and Reports.

The frequency with which stages should be measured varies considerably from one stream to another. In general, stage observations should be taken often enough that a complete hydrograph can be drawn from the reports given the River Forecast Center. A feel for this can be obtained if the RDO attempts to draw hydrographs from the reports which they transmit.

Once-daily reports are certainly adequate when there is little change in the flow. After runoff begins, there should be a report which shows the beginning of the rising limb of the hydrograph. After that time, reports should be obtained every few hours and special effort should be made to determine exactly what the peak (or peaks) was. After the peak, readings can be taken less frequently unless sufficient rain falls to start a new rise.

Insofar as reservoir releases are concerned, arrangements should be made to obtain a report each time the release schedule is changed. Requirements for reporting uncontrolled spill would be about the same as those given the previous paragraph for stream gages. This will help you keep the River Forecast Center advised as to the complete release hydrograph needed to make forecasts of downstream points.

In the ideal situation, rainfall reports would be available from the cooperative observers every six hours on synoptic times. This is of course possible with telemetered gages. In fact, bi-hourly readings are often taken from such gages. With cooperative observers it is frequently difficult to get more than the regular 7 a.m. reading. Depending on the needs, as discussed with the River Forecast Center, observers should be encouraged to report as near to synoptic time as possible. Then during times of significant storms, they can be encouraged to take 3 or perhaps even 4 observations per day as needed.

In general, rainfall that will affect headwater forecast points should be reported more often than rainfall that affects only the main stream. This is because the headwater points tend to crest soon after heavy rainfall ends. After a significant storm, it is especially important to get at least one rainfall report with little or no rain indicated so that the forecaster can be reasonably certain that the storm has ended. Absence of such a report leaves serious doubt in the forecaster's mind.

It is also extremely important that someone be on duty and available to take incoming calls when observers are likely to be reporting. The most discouraging thing that can happen to a cooperative observer is to find no one in the office to take his report, or someone who does not recognize him and refuses the call. Reception of these reports should obviously be very courteous to show appreciation of the service being rendered.

# APPENDIX A

## Gage Exposure

The raingage is here to stay, and we have an obligation to get the best data we can from it. It would be folly and even a fraud to spend millions of dollars analysing rainfall data for billions of dollars of construction if the data were known to be poor - whether it cost five dollars or a thousand dollars to get the data.

Gage catch is subject to many influences. Some of these influences are related to the fabrication of the gage itself: the depth and shape of the funnel, precision of manufacture, the materials it is made of, and so on. Field Aides accept gages as they are built.

The gross scale of a raingage network is determined by meteorologists, climatologists and hydrologists. They decide how many gages should be in a region, and approximately where these gages should be.

That does not appear to leave the Field Aide much latitude. He is given a gage and told where to put it. But exactly how he does this is the most important part of his job, and is the most important aspect of how well the gage does its job.

In choosing sites for precipitation gages several considerations must be made. One is accessibility - both to the Field Aide and to the observer. Another is that the gage must be in a place where it is not likely to get molested. Other considerations can be listed. An important one of these, and the one to be emphasized in this discussion, is proper exposure with respect to best catch.

We all know that the two main influences on gage catch are wind, and the intercepting effect of obstructions. These are more important than the usual variations in design of the gage itself. It will be helpful to discuss them before expanding the subject further.

The effect of wind, of course, is well known. As the air goes past a gage, some passes on each side, and some rises as it flows over the gage. The turbulence and upward movement of the air over the gage tend to reduce the fall of rain and snow into the gage.

Interception usually means that a tree or building, upwind from the gage, catches precipitation that otherwise would fall into the gage. The effect, of course, depends on several influences which have been studied by hydrologists. A tree growing directly over a gage may intercept nearly all of very light rains, and as much as ten percent of very heavy rains. Considerable rain may filter through or get blown off the branches of trees into a nearby gage, though some runs down the trunks or is stored on the surface of leaves. There is a remote chance of excessive drip off the end of a branch into a gage. Buildings or trees entirely surrounding a gage probably hurt its catch less than a single large building near the gage.

When the gage is downwind from a nearby large isolated building, the building may intercept considerable rain, and when the wind is from the opposite direction the gage has no protection and receives the full force of the wind - with poor catch either way. But if the gage is in a courtyard, with buildings all around, this symmetrical shelter breaks the force of the wind from all directions. The intercepting effect of the buildings remains to some extent, but may be less severe than the effect of excessive wind. Even in New York City, with deep narrow canyons among the skyscrapers, umbrellas get wet, though geometric drawings showing raindrop trajectories with strong wind might show no rain falling on the streets. We would not put a raingage in the middle of Fifth Avenue, New York City, but a gage there might catch as much rain as a gage would if it were on the peak of a skyscraper.

The problem of exposure is essentially one of determining the optimum distance from sheltering obstructions. If the gage is too close it suffers from interception loss, and if it is too far it suffers from too much wind effect. It is difficult to generalize and standardize forest clearings, which are seldom neat cylindrical openings. Often there are scattered trees, or combinations of trees and buildings.

Very little work has been published on the intercepting effects of buildings on gage catch, but there is a lot of literature on the effect of wind on catch. In general the effect of wind with snow is about twice what it is with rain. While it is possible for a gage to catch blowing snow during periods of no precipitation, in general the greater the wind the poorer the catch. A good wind shield helps some, but will not correct an inherently poor site. Field studies have shown that, at a site having an average wind speed of 10 mph at the orifice of a shielded gage, the catch of snow was about half of what it was for more fully-sheltered gages nearby. With 40 mph wind the rain catch may be only 30%, and the snow catch less than 20% of what it should be, according to several investigations. At usual anemometer heights the wind would be about twice what it is at the height of the gage orifice.

A gage on a windy ridge may be subject not only to the usual wind influence but, in addition, to the effect of the updraft in the wind flow over the ridge. Also the type, density and spacing, as well as the height and distance of the obstructions influence and complicate the wind-catch relationships.

The official "rules" for exposing gages give us a lot of leeway, but they usually refer to some such criterion as staying away from an obstruction a distance of twice or four times its height. Recent literature, and reports of recent investigations suggest that we may have been too concerned about the effects of obstruction, and not enough concerned with the benefits of shelter from the wind. Recent investigations suggest that half the height might be a better distance than twice the height of trees. The distance from the gage to the trees is measured to the nearest extremities of branches and not the trunk.

Perhaps the worst exposures we have are at some of the first-order stations where gages are still on roofs. Some of the cooperative observer gages, among trees and shrubs, may have better exposure than we have thought. Some of us have been putting out gages for 20 years. Have we accumulated 20 years of experience in siting gages, or have we been practicing the same mistakes for 20 years?

We have a very important responsibility and a tough problem. There seems to be no practicable way to standardize and generalize site characteristics so that sites can be described and measured properly in terms of gage catch. In honesty to ourselves and in obligation to our jobs we cannot say, "Now that we see how little we know about exposure, or now that more shelter seems to be desirable, we won't worry too much about good exposure, but will put the gage right by the door, or wherever the observer thinks it will be most convenient for him."

What we need to do is to improve and calibrate our judgment. Rarely do we have access to measures of true catch, such as screened pit gages, or stages of water-tight lakes having measured inflow and outflow. About the best we can do is compare the catch of gages that are near each other, and identical except for exposure, and assume that the gage catching the most is the best. Except for blunders, such as putting a gage under a dripping roof, this is not a bad assumption, because nearly all the adverse influences on rain catch tend to diminish it, rather than increase it.

# APPENDIX B

This is an example of the type of news story that a river district official can encourage the press to write. It describes river forecasting work and credits the cooperative observers who report to the Pittsburgh River Forecast Office. Since we have not made an exhaustive search of articles of this type, there may well be other very deserving articles that could have been published as part of the course instead of this one. On the other hand, there are no doubt many river district offices that have never participated in writing such a feature story. This is an excellent method of building good will with your cooperative observers.

## THE WEATHERMAN'S VOLUNTEER ARMY

By William Delahan

The Pittsburgh Press, Sunday, July 24, 1966

Just as regularly as the sun comes up, a Weston, W. Va., TV repairman, at 7 o'clock each morning, 365 days of the year, can be found bending over the West Fork River.

But what Arthur Henry lets down into the water isn't a fishing line, it's a weighted gage that indicates the stage of the river.

He's a river observer, phoning his daily findings to Vernon T. Houghton Jr., chief of the Federal-State River Forecasting Service, in Pittsburgh.

Mr. Henry is one of a citizens' corps of 145, under Mr. Houghton, which provides data on stages, rainfall, ice, snow depth and weather in the Upper Ohio River Basin so that up-to-date river forecasts can be issued.

He fell into the volunteer work naturally, inheriting it from his father, a river observer for 30 years, who got the job after Grandfather Henry paved the way.

"If our river observers all quit today and we got two to three inches of rainfall 24 hours later, Pittsburgh could be in for real trouble," points out Mr. Houghton. "The Steel City is the headwaters for a 19,000 square mile drainage area. An inch of rain means 17 million gallons of water."

Mr. Houghton is, of course, responsible for more territory than this for the Upper Ohio Basin takes in a 26,000-mile drainage district, including Western Pennsylvania, Eastern Ohio, part of New York State and Northern West Virginia.

But the river observers, each paid about $12 a month, are only part of the U.S. Weather Bureau's civilian army for the area.

There also are 80 other people -- some of them make three dollars monthly and others zero -- who operate rainfall and temperature reading stations in the same area. They report maximum and minimum temperatures and rainfall to the hundredths of an inch for the bureau's climatological services headquarters in Asheville, N.C. This group of citizens is supervised by the New York regional office of the U. S. Weather Bureau.

Mrs. Jay Swigart, of Butler, wife of the State game commissioner of that name, is one of them. They make their reports monthly, more often if there is a sudden bad turn in the weather.

## Some Are Automatic

"The rain gage is housed in an eight-inch diameter copper can, two feet tall with a rack to hold the measuring stick vertically," explains Robert C. Butler, a meteorologist with the Pittsburgh Weather Bureau. A few are more sophisticated -- automatic, with a pen tracing the rainfall on a chart."

There are self-registering thermometers and a variety of other weather recording equipment.

"The tightly-organized river observer corps was developed after the 1936 Pittsburgh flood," reports Mr. Houghton. "We had some manpower then -- when William S. Brotzman was the weatherman -- but in those days the rule of thumb was followed that 'No news is good news.'

"One of the men we didn't hear from in the 1936 flood had a heart attack, another couldn't get to the gage due to floodwaters. Now, we know that 'No news often can be the worst news.' If we don't hear from an observer and the rainfall is heavy, I call him. Based on observers' reports, if there's an emergency, I then phone the State civil defense director who notifies the civil defense director in the affected counties."

The weather station people, as well as the river observers, know they are to call every time there's half an inch of rain. If it continues without letup and things look bad they start phoning once every six hours.

Mr. Houghton's wife, Lena, long ago learned that her husband's work day isn't the usual eight hours. She's as well acquainted with the river observers in Parker's Landing, Pa., and Philippi, W. Va., as her husband. The reason? The elements don't respect working hours and she takes the phone calls when her husband is away from home. In fact, Mr. Houghton has all the river observers' phone numbers at home and is as likely to phone them from there as in his office in the Federal Building when trouble looms.

The network of river observers, weather stations and their equipment set up by Mr. Houghton after the 1936 flood was a model for the rest of the nation. The chief river forecasters in other parts of America use the same techniques. There are 14 of them.

"As the standards are the same, I could be called upon to help out in an emergency in flood forecasting at Tulsa, Kansas City, Cincinnati, Salt Lake City or Ft. Worth, just a few of the river districts where trouble could hit," points out Mr. Houghton.

## Upgraded Standards

The chief forecaster, who graduated from the University of Pittsburgh in 1932 as a civil engineer, credits weather bureau changes with the upgrading of flood forecasting standards. Chief among them was the hiring of civil engineers and hydrologists. Hydrology is the science dealing with the properties, distribution, and circulation of water on the surface of the land, in the soil and underlying rocks, and in the atmosphere.

Businesses are just as involved with flood damage as homeowners. Just what do you suppose the loss, in a flood, of two boxcar loads of cigarets means in cold, hard cash? It's $800,000.

Commercial needs like this are why Pittsburgh business since 1942 has had its own civilian forecasting service -- a cooperative venture between the Chamber of Commerce and the weather bureau. The C of C phones each member with a flood crest forecast during heavy rainfall.

Floods have a damaging effect on river traffic. Shipments in the thousands of tons are held up when locks and dams cannot be utilized.

Speaking of boxcars -- one of the earliest trouble spots when the Allegheny River rises is the Baltimore and Ohio Railroad warehouse. Flood stage is 23.2 feet there as diesels can't move with water at that stage.

Returning to the river observers and weather station people out in the hinterlands -- they come from all walks of life. There are 13,000 of them across the nation -- housewives, school teachers, waterworks employees, civil engineers and high school students who often do it as a science project, other times from a vocational interest in weather.

"It takes dedication," points out Mr. Houghton. "Often, the equipment is a mile or more from their homes. It means getting up early in the morning and finding a replacement when they go on vacation. The pay isn't much."

Mr. Houghton long ago stopped thinking of the observers as just business associates. Here's an incident that played a part in this.

"I got burned out of my hotel in Warren on a field trip in March 1956," explains Mr. Houghton. "I stood on a corner in my pajamas for hours literally in shock, not knowing what to do.

"Then, along came Gilbert Reier, our observer at Warren for 15 years. The Reiers put me up for the night. They called my wife so she wouldn't hear on the radio about the fire leveling the hotel. It was a good thing because the newscaster said I was missing.

"Then, they notified the police. Mr. Reier borrowed $20 for me from his father and loaned me clothes. All I had was my pajamas.

"That's the kind of people our observers are."

# APPENDIX $C_1$

## INSTRUCTIONS FOR OBSERVERS AT RECORDING RAIN AND SNOW GAGE STATIONS

DUTIES OF OBSERVERS:

1. Inspect the gage daily to make sure that the clock is properly set and running; the pen recording properly, and the bucket in no danger of overflowing. During periods of heavy precipitation additional inspections may be necessary.

2. Change chart and empty the gage bucket each Monday or more often if the gage is in danger of overflow due to successive periods of unusually heavy precipitation. If it is raining hard at usual chart changing time, delay until later. Charts should be changed whenever the bucket is emptied.
(SEE SPECIAL INSTRUCTIONS FOR WINTER CONDITIONS.)

3. Prepare the weekly report form.

4. Mail all used charts together with the weekly report card each Monday in envelopes provided.

5. Inform the Regional Substation Management Section, Regional Headquarters, Garden City, N.Y. immediately if any part of the instrument is damaged, or fails to work properly, or if additional supplies will soon be needed.

6. Mail charts and address all correspondence to:

Regional Substation Management Section
Eastern Region Headquarters
National Weather Service
585 Stewart Avenue
Garden City, N.Y. 11530

PROCEDURE FOR CHANGING CHARTS:

The routine to be followed whenever a chart change is made should become automatic with the observer, and is as follows:

1. Be sure the name of your station, the state, and the date are on the chart to be used.

2. The time used, whether STANDARD time or DAYLIGHT SAVING time, should be clearly indicated on each chart or report.

3. Listen to find out whether the clock is running.

4. Note the time by your watch, and check the time of the chart on the gage with it.

5. Unlock the gage, remove the top, and raise the outer shell.

6. a. If the clock is running and the pen inking, mark the chart by moving the pen up and down slightly.

   b. If the clock is not running, mark the exact place of the pen on the chart with a dot inside a circle. After the chart is removed, note: "Clock stopped" with a line to indicate the place.

   c. If the clock is running but the pen is not inking, mark the exact place of the pen with a dot inside a circle, and, after removing the chart, note, "Pen dry."

7. Swing the pen away from the chart.

8. Empty and replace the bucket. (SEE SPECIAL INSTRUCTIONS FOR WINTER CONDITIONS.)

9. Wind clock, being careful not to wind it too tightly.

10. Remove chart and write correct time and date on it. Example: OFF 9:30 a.m., Jan. 1, 1966.

11. Put on new chart. Make sure that the printed numbers are in an upright position, the chart is down against the bottom flange and is tight on the clock, and the horizontal lines match.

12. Replace clock in gage, being careful to mesh gears carefully.

13. Set to correct time by turning the cylinder counter-clockwise, with the pen slightly raised from the paper, to prevent inking. This is important, as it prevents slack in the gears and a consequent time error.

14. Place drop or two of ink in pen. Pen should never be over 3/4 full.

15. Place pen back on chart.

16. Mark the time by moving the pen up and down slightly. Double-check to see that time setting is correct.

17. Replace outer shell and gage cover.

18. Check chart, pen, and time through observation door.

## SPECIAL INSTRUCTIONS FOR WINTER CONDITIONS

Whenever there is danger from freezing, the following instructions should be followed:

1. The funnel should be removed from the gage top during the winter season, when snow is apt to occur.

2. If for any reason the gage is operated during freezing weather without a non-freezing solution, it should be emptied after each period of precipitation, whenever half an inch or more has been registered. This will help to prevent damage from freezing.

3. During the wintertime, a solution of calcium chloride is to be used in the catch bucket of the recording rain gage. This is used to prevent damage from freezing as well as to melt snow, which otherwise might be blown out of the gage.

4. Whenever a charge of calcium chloride is in the gage, the gage should be emptied only when it is necessary to recharge it, not each time the charts are changed.

5. The following steps are outlined for your guidance when charging the gage:

   a. Remove the bucket from the gage.

   b. Empty one carton of calcium chloride into the empty bucket.

   c. Add one carton of water to the calcium chloride.

   d. Stir well until the calcium chloride is dissolved.

   e. Replace the bucket containing solution in the gage.

   f. Leave pen where it comes to rest after charging.

6. Recharge gage when chart reading and temperature range are as follows:

| Empty gage and recharge when gage reads: | When temperature range expected is: |
|---|---|
| 8 inches | + 32° to + 10° |
| 7 inches | + 10° to - 10° |
| 5 inches | below - 10° |

7. Always note on the chart or report form when the gage is charged. Example: - "Gage charged 8:00 a.m., 12-1-66."

8. Stir the solution whenever the chart is changed. This will help to keep the solution from freezing solid if the temperature should drop below the expected level. When stirring the solution, always lift the pen from the chart.

## TROUBLE

I. PEN

a. Not Recording: This may be caused by failure to replace the pen on the chart or by insufficient ink flowing. If the ink in the pen will not flow, the pen may be cleaned by very carefully drawing the edge of a piece of hard finished bond paper about the thickness of a chart through the point.

b. Too heavy a line: This is due to too much ink in the pen. Ink may be removed by touching the reservoir with a piece of blotting paper.

II. CLOCK

a. Slow or Fast: Adjustment should be made as follows:

1. Mark the sheet by moving the pen up and down slightly.
2. Set the clock to the correct time.
3. Mark the new setting by moving the pen slightly again.
4. Make a note on the chart giving time the clock was adjusted (explain fully).

b. Large Time Error:

The clock may run slightly slow or fast, but if time errors become large, report at once and replacement will be sent. The clock in the recording gage is the critical factor in obtaining a continuous precipitation record. As supplied by the National Weather Service, the clock has been serviced and oiled for use out of doors and at low temperatures, and should be free from troubles for at least eighteen months to two years

c. If the clock has stopped and will not run after being warmed, it should be replaced in the gage and the Regional Substation Management Section in Regional Headquarters notified at once. A useable record can be obtained by visiting the gage after each period of precipitation and, with the pen touching the chart, turning the clock the amount of one hour of record so that the amount of any precipitation occurring will be shown as a vertical line on the chart with a new line for each day or period of precipitation. Suitable entries should be made on the weekly report form. Whenever this is necessary, care must be taken not to jar the bucket and thereby move the pen beyond the vertical line showing the amount of precipitation.

## GENERAL COMMENT

The primary purpose of a precipitation station is the measurement of amount of water that falls in the form of rain, snow, hail, or sleet. Each station is a very important part of a large network of stations and the success of the whole network depends upon the character of the records from each station. In the final analysis, the data recorded on the charts, together with accompanying notes, are all that meteorologists, hydrologists, and engineers have on which to base their judgment. The only record available for your locality is the one you submit.

The characteristics of a good record are:

1. Accuracy. Care and precision in making observations are most important if your record is to have any value whatever.

2. Completeness. The observer is the only person at a station who is in a position to note, as they occur, all events which are necessary for a proper interpretation of the record.

3. Length. The longer a record is kept, the more valuable it becomes.

4. Continuity. Breaks in a record nullify its value for many purposes.

CAUTIONS

1. It is very important that the gage does not overflow, as the clock and the record may be damaged.

2. Care should be takent to prevent damage from freezing.

3. Every chart, even if damaged, must be returned to Substation Management Section at Regional Headquarters.

4. If any part of the instruement is damaged, or fails to work properly, report the facts at once tc the Substation Management Section at Regional Headquarters, in order that proper replacement may be provided or repairs made.

5. Do NOT oil the clock or any part of the gage mechanism.

6. ALWAYS wind the clock each time the chart is changed.

7. ALWAYS check the gage before leaving it. Because of the construction of the chart, it is very easy to make a time error of exactly twelve hours.

8. ALWAYS mail all the used charts together with the report form each Monday.

9. ALWAYS keep a careful record on the precipitation report form.

10. ALWAYS move the drum backward when making the final setting for time.

11. ALWAYS WRITE Substation Management Section at Regional Headquarters whenever supplies are low, or you want additional information, or the gage does not work as well as you think it should. If something seems to be wrong, please give as complete information concerning the trouble as you can. Any letter concerning the gage is official business, and can be mailed in the envelopes supplied, without a stamp. Address all correspondence to:

    Regional Substation Management Section
    Eastern Region Headquarters
    National Weather Service
    585 Stewart Avenue
    Garden City, N.Y. 11530

12. Your cooperation in following all instructions carefully will be appreciated a great deal since, beside making your record more valuable, it will aid us in our job of analyzing thousands of charts each year.

June 21, 1966

APPENDIX $C_2$

OHIO RIVER NETWORK

Reporting Instructions

STATION_______________

Observer_______________

Type: B-3-S

Effective Date__________

Da. Ra. & Ri.-(WSO -HTW)

1. Your regular observation of precipitation should be taken at 7 a.m. each day.

2. Your regular observation of river stage should be taken at 7 a.m. each day.

3. A daily report, immediately after the 7 a.m. observation, should be made by telephone to ____________________________ Telephone No. _______________ COLLECT, along with other substations reports, if any.

4. Extra observations and reports should be made in accordance with instructions below:

   a. Based on precipitation.
      at 1 p.m. when 0.50 inch or more precipitation fell between 7 a.m. and 1 p.m., with other substations reports, if any.
      7 p.m. when 0.50 inch or more precipitation fell between 1 p.m. and 7 p.m., with other substation reports, if any.

   b. Based on river conditions.
      at 1 p.m. or 7 p.m. - When river stage is ____ feet, or above.

5. Always report precipitation and river stage. If no precipitation has occurred report: "No precipitation," followed by river stage.

6. After making your first extra report, continue making reports at 7 a.m., 1 p.m. and 7 p.m. until your final report shows that either the river has gone below ____ feet or that the crest has passed, if the river did not get above ____ feet. If river did not rise as a result of rainfall, continue reporting until your final report shows no additional rain since last report.

7. Special effort should be made to obtain a reading at the crest. This reading should be reported at the next reporting time.

NOTES

1. If you make your report by telephone and have difficulty completing the call, tell the operator that the call should be given priority since the information is needed in preparing flood warnings.

2. When telephone service is not available, telegraph your report "Collect" to Weather Service Office, Huntington, W.Va.

3. A copy of your monthly report form should be mailed on the first of each month to Weather Service Office, Huntington, W.Va. Self-addressed envelopes are furnished you for this purpose, no postage required.

4. When additional supplies of the special forms and envelopes are needed, notify the Weather Service Office, Huntington, W.Va.

5. If you are keeping any other records or making other reports to a Weather Service Office or other agency, please continue to do so unless otherwise instructed.

APPENDIX $C_3$

WEATHER SERVICE OFFICE
Topeka, Kansas

Station ______________

Date ______________

## RAINFALL REPORTING INSTRUCTIONS

### OBSERVATION TIMES

1. Regular daily precipitation observation (EMPTY GAGE).......7 a.m.

2. Check observations during rains (DO NOT EMPTY GAGE).......Noon and 6 p.m.

3. Following exceptionally heavy rains of 2 inches or more .... Any time (Gage will have to be emptied to obtain measurement but amount should be carried forward to next 7 a.m.)

### REPORTING TIMES

1. Whenever 0.50 inch or more precipitation accumulates in the gage either at the morning observation or at the check observations at noon or 6 p.m.

2. After an initial report (0.50 inch or more) continue reporting at each following check or regular observation time until after the rain has ended.

3. At anytime following an exceptionally heavy rain (2 inches or more) particularly if ground is already soaked from previous heavy rains.

Prompt reporting of the morning observation is important. Our office is open 24 hours a day and if at all possible, we would like to have your reports by 7 a.m. or 7:30 a.m. and not later than 8 a.m. so that work can proceed on analyses of reports and preparation of river forecasts. Telephone lines are not as busy early in the morning and there is less chance of delay.

### WHAT TO REPORT

1. Station, name of observer, and time of observation.
2. Amount of precipitation since previous 7 a.m. observation.
3. Form of precipitation-- rain, snow, etc.
4. Amount of precipitation measured at previous 7 a.m. observation (on first report in a series).

5. Weather at time of observation.
6. Depth of snow on ground (if any).

Additional items often of value in computing runoff:

7. Time of beginning and ending of rain, if known.
8. Time of beginning and ending of heavy rain, and approximate amount which fell during that time.
9. Runoff - Whether most of rain is soaking into soil or if there is more runoff than usual.

HOW TO REPORT

1. Telephone COLLECT to TOPEKA 913-CE-4-8659.
2. If delay is encountered, tell operator the call is "PRIORITY 3 EMERGENCY" to obtain PROMPT handling, or "PRIORITY 2 EMERGENCY" to obtain IMMEDIATE handling.
3. Fill out and mail postcard "River and Rainfall Report."

(PLEASE DISCARD PREVIOUS RAINFALL REPORTING INSTRUCTIONS)

SAMPLES OF REPORTS
Topeka, Kansas

| Measurements | | | Telephoned Report |
|---|---|---|---|

Rain commences at 8 a.m. and continued with brief intermissions until 10 a.m. the following day:

| | | | |
|---|---|---|---|
| 1st day: | 7 a.m. | 0 .............. | No report. |
| | Noon | 1.05 .............. | Noon 1.05. 7 a.m. none. Raining, began 8 a.m. |
| | 6 p.m. | 1.70 (0.65 since noon) .. | 6 p.m., 1.70, light rain. |
| 2d day: | 7 a.m. | 1.80 (0.10 since 6 p.m.) .. | 7 a.m., 1.80, cloudy but threatening. |
| | Noon | 0.45 .............. | Noon 0.45. Clearing. Rain ended 10 a.m. |
| | 6 p.m. | 0 .............. | No report. |

* * * * * * * * * * * *

A series of well-spaced showers with heavy rain from 6 a.m. to 8 a.m. the first day and another heavy shower from 5 a.m. to 6 a.m. the second day:

| | | | |
|---|---|---|---|
| Previous day: | 7 a.m. | 0.19 .............. | No report. |
| First day: | 7 a.m. | 0.90 .............. | 7 a.m. 0.90, yesterday 7 a.m. 0.19. Heavy rain now, began 6 a.m. Little runoff. |
| | Noon | 1.02 .............. | Noon 1.02. Clear, Heavy rain ended 8 a.m. |
| | 6 p.m. | 1.43 (.41 since noon) ... | 6 p.m. 1.43, partly cloudy, shower about 4 p.m. |
| 2d day: | 7 a.m. | 2.35 (.92 since 6 p.m.) ... | 7 a.m. 2.35. Light rain. Heavy 5 a.m. to 6 a.m. Heavy runoff. |
| | Noon | 0.22 .............. | Noon 0.22. Clear. Rain ended 8 a.m. |
| | 6 p.m. | 0 .............. | No report. |

* * * * * * * * * * * *

## SAMPLES OF REPORTS

| Measurements | | | Telephoned Report |
|---|---|---|---|

Rain began 5:30 p.m., became heavy 6 p.m., and ended at 8 p.m.:

| | | |
|---|---|---|
| 7 a.m. | 0 .............. | No report. |
| 6 p.m. | 0.15 .............. | No report. |
| 8 p.m. | 3.25 .............. | 8 p.m. 3.25, none at 7 a.m., cloudy, signs of clearing. Heavy rain 6 p.m. to 8 p.m. Very heavy runoff. |

* * * * * * * * * * * *

Rain began during night and ended 6 a.m.:

Previous day: 7 a.m. 0

| | | |
|---|---|---|
| 7 a.m. | 1.23 .............. | 7 a.m. 1.23, yesterday none. Clearing. Rain began after midnight, ended 6 a.m. Little runoff. |

APPENDIX D

UNITED STATES DEPARTMENT OF COMMERCE
NATIONAL WEATHER SERVICE
NATIONAL OCEANIC AND ATMOSPHERIC ADMINISTRATION
River Forecast Center
Bradley International Airport
Windsor Locks, Connecticut 06096

December 1, 1966

To All Observers in the Hartford River District:

In early November a major rainstorm occurred over New England and caused moderate flooding through much of Maine and parts of New Hampshire. We wish to commend all our cooperative observers, and especially those in the areas that experienced flooding, for their timely and continuous reports. Your reports were of inestimable value in the preparation of our river forecasts and warnings.

With the beginning of December, we know that winter cannot be far off. As a matter of fact, some of our northern and high elevation observers have already reported snow. As we have done in the past, now seems to be an opportune time to review some of the more important features of snow season reporting.

1. Please be sure to use the units specified at the top of each of the three precipitation columns on your monthly report form and on the corresponding lines of your daily card.

   a. "24-hour amount rain, melted snow" also line 2 - inches and hundredths.

   b. "24-hour amount snow, sleet, hail" also line 6 - inches and tenths.

   c. "At observation snow, sleet, etc. on ground" also line 6A - whole inches.

2. As soon as the snow season begins, there should be an entry every day in the "snow on ground" column and line 6A, even if it is zero or trace. Continue these entries until spring and all the snow is gone. (See instructions with standard forms before writing a set for your observers.)

3. All 8-inch rain gages should now be exposed without the funnel and inner cylinder, until the snow season is over.

4. Water Equivalent measurements of total snow on the ground are required each Saturday whenever you have 1 inch or more of snow on the ground

at that time. For those of you with a snow tube, this is accomplished by weighing the sample. Others should cut a "cookie" with the outer can and melt the sample, then measure the liquid in the inner cylinder. This water equivalent measurement should be reported on your Saturday card and also noted in the special observation section of your monthly form with the date.

5. It would be helpful if an entry is made for each day on your monthly form, even if it is a zero, when no precipitation has occurred.

Most of you are well acquainted with the above suggestions and are doing a very fine observing job. For the few of you who have been a little uncertain of some of the rules, we hope this letter will be helpful.

As a final note, please continue your excellent record of calling this office whenever .50 inches or more of precipitation falls in 24 hours or less, then a follow-up call every 6 hours until the precipitation ends. The monthly form should be mailed about the 1st of each month.

We appreciate your public-spirited cooperation and assistance in helping the National Weather Service provide this essential river forecasting and warning service to the public.

Greetings and Best Wishes for the Holiday Season from the staff at the Hartford River Forecast Center.

Sincerely yours,

/s/
Warren Silverzahn
Network Supervisor

1970

General River Terminology

Frozen river conditions - Streams covered over completely with ice regardless of thickness of ice. No water in streams visible.

Ice thickness - Average thickness of ice in stream to nearest whole inch.

Shore ice - Ice visible along shorelines but streams not frozen over completely. Open river channel visible.

Floating ice - Ice in streams visible, moving or floating. Approximate size of ice cakes would be desirable (in general terms).

Ice jam - Ice in rivers or streams starting to jam and crowd together. Uusually first indication of ice gorge developing.

Ice gorge - Ice has jammed to form a stationary dam or wall of ice. The wording "ice jam" and "ice gorge" may be used interchangeably, but it appears logical to use the word "jam" as conditions are developing.

Backwater effect - Terminology used when water in streams backs up due to ice conditions restricting flow of water past the ice gorge. Flooding can occur to areas above the ice gorge in such instances without a flood wave moving downstream from above the critical areas.

Flood stage - The river stage, referenced to a nearby river gage, at which flooding occurs in the immediate vicinity of the river gage in question. River stages above the referenced flood stage cause damage. It is the use of the term "flood stage" that alerts the public as to the seriousness of prevailing or expected conditions.

Bankfull stage - River or streams flowing within regular channel but at level with top of banks.

Overbank flow - Rivers or streams above bankfull stage and water overflowing banks. This might indicate some flooding of agricultural or grazing lands or even minor flooding to industrial or residential property in certain locations. However this terminology does not normally include flooding of a serious nature.

Flash flooding - Descriptive term normally used when small headwater streams rise rapidly, overflow their banks and then fall or recede quickly. Normally this would occur after a heavy local thundershower, and flash flooding would be descriptive of the flood situation, local in extent and of short duration.

General River Terminology (Cont.)

Shallow flooding - A term very much similar to overbank flow. Minor or nuisance flooding only and not ordinarily of a serious nature.

Gage height - This is the river level or river stage at a particular river gage station. In most instances a staff river gage is available, a board with enameled or painted lines for each one-tenth or two-tenths feet of elevation, and numbers showing the foot-mark. The height or level of water in the stream, as measured by looking at the staff gage, is the gage height or river stage.

Crest stage - The highest level the water surface in the stream has reached. Once the crest stage has been reached, the river or stream will be expected to hold level for a short period then start to fall or recede thereafter unless affected by additional rainfall or snowmelt.

Rising river - The stream in question is rising.

Falling river - The stream in question is falling.

Stationary river - The level of the stream in question is changing little and the level remains about stationary.

Depth of snow on ground - Average depth of snow on ground at selected locations, nearest inch. Care must be exercised to assure measurements of snow depths do not include drifts.

1970

General Weather Terminology

Showers - Fall of rain of short duration and varying intensity, with periods of no rain (though not necessarily clearing) between showers.

Squall - Sudden violent gusts of wind often attended with rain or snow.

Thundershower - A shower accompanied with thunder.

Thunderstorm - A storm accompanied with thunder. When thunderstorms are expected to be especially turbulent or violent, the modifying terms "heavy" or "severe" may be used.

Ice Storm - Freezing rain which accumulates as an extensive coating of ice on objects at or near the surface of the earth.

Sleet - Precipitation in the form of frozen rain or partly frozen rain.

Snow Flurries - Fall of snow of short duration with clearing between occurrences. Total accumulation of snow expected to be small.

Snow Squall - Brief, intense fall of snow of short duration accompanied by squalls, with periods of no snow.

Little Rain - Small in quantity, amount, or degree, usually short in duration; brief.

Some Rain - An indeterminate or unspecified amount.

Considerable Rain - Rather large in extent and amount.

Occasional Rain - Occurring now and then; irregular intervals.

Intermittent Rain - Occuring at intervals; recurrent; periodic. Usually at more frequent intervals than "occasional." More or less general and of a prolonged character but interrupted by periods without precipitation.

Scattered Rain - Dispersed; separated irregularly in location. Should be referred to area and not to time.

Heavy Precipitation - Amounts of serious consequence. Ordinarily used for rain, snow, or showers in which wind damage is not expected. Forecast will specify an indication of strong winds when applicable.

General Weather Terminology (Cont.)

Heavy Snow - 4 inches or more expected to occur in 12 hours, or 6 inches or more in 24 hours, or 8 inches or more in 36 hours.

Moderate Precipitation - Intermediate amounts of precipitation which may be considered neither light nor heavy.

Winds - Very light (0 - 3 miles per hour)
Light (4 - 14 miles per hour)
Windy (moderate winds) (15 - 30 miles per hour)
Strong winds (31 - 40 miles per hour)
High winds, windstorm, gale (41 - 74 miles per hour)
Hurricane Force (over 75 miles per hour)

# APPENDIX F

1/20/66

STL RDO - RFC DATA SHEET

RIVER STAGES AND PCPN COLLECTED BY RIVER DISTRICT OFFICE

CORPS OF ENGINEERS REPORTS: FROM WBAS PEORIA

| MEREDOSIA | NEW LaGRANGE UPPER-LOWER | OAKFORD | PETERS BURG | GREEN VIEW | SEVILLE | LOWELL | GREEN VALLEY |
|---|---|---|---|---|---|---|---|
| 8A | | | | | | | |
| 4P YDA | | | | | | | |

CORPS OF ENGINEERS REPORTS: FROM CHIC (JOLIET, ILL.) UPPER ILLINOIS RIVER

| LOCKPORT DISCHARGE | FOX DAYTON | KANKAKEE R. KANKAKEE DAM UPPER - LOWER | KANKAKEE R. MOMENCE | IROQUOIS R. CHEBANSE |
|---|---|---|---|---|
| 8A | | | | |

| STATION | CALL | REPORTS 1 3X FS | 7 A.M. STAGE PCPN | SNOW & ICE | YDA 1 P.M. STG PCPN | YDA 7 P.M. STG PCPN |
|---|---|---|---|---|---|---|
| QUINCY | UIN | D/2X/17 | | | | |
| HANNIBAL, MO. 314-221-0341 | HHMO | D/2X/16 | | | | |
| LOUISIANA, MO. | LIMO | D/2X/16 | | | | |
| MORRIS, ILL. | MOIL | D/10/13 | | | | |
| LA SALLE, ILL. | LSIL | D/17/20 | | | | |
| PEORIA, ILL. | PIA | D/18/18 | | | | |
| HAVANA, ILL. | HVIL | D/14/14 | | | | |

ST. LOUIS  STL
MAin 1-4797  TELEMARK: 5 A.M. ______ 7 A.M. ______ YDA 4 P.M. ______
ACTUAL HARBOR GAGE ______ 8 A.M. ______ YDA 4 P.M. ______
MAin 1-3222  CAHOKIA GAGE 3 A.M. ______ 9 A.M. ______ YDA 6 P.M. ______
Sta. 248

DATA FROM UNION ELECTRIC: To MKCR: LAKESIDE POOL FCST ______ ______ ______

(To MKCE) LAKESIDE POOL 7 A.M. ______ CHANGE ______ PCPN ______ INFLOW ______
(To MKCE) OUTFLOW ______ FLOW FCST ______ ______ ______ ______

| STATION | YDA 4 PM STAGE and PCPN | | 7 AM STAGE AND PCPN | | |
|---|---|---|---|---|---|
| SCHELL CITY | | | | | |
| STOCKTON | | | | | |
| OSCEOLA | | | | | |
| STATION PCPN | YDA 4 PM | 7 AM | STATION PCPN | YDA 4 PM | 7AM |
| COLE CAMP | | | MT. HULDA | | |
| LINN CREEK | | | STOVER | | |

DATA FROM CORPS OF ENGINEERS
MEREDOSIA  FLOW 7 AM ______ FCST ______
DAM 22 TW 7PM ______ 7 AM ______ FLOW ______ FCST ______ ______ ______
DAM 24 CLARKSVILLE  POOL 7 AM ______ TW 7 AM ______ PCPN ______
DAM 25 WINFIELD  POOL 7 AM ______ TW 7 AM ______ PCPN ______
DAM 26 ALTON YDA:  POOL 7 PM ______ TW 7 PM ______
ALN (395.48) TDA: POOL 7 AM ______ TW 7 AM ______ PCPN ______

| STATION | CALL | REPORTS 1X/3X/FS | 7 A.M. STAGE PCPN | SNOW & ICE |
|---|---|---|---|---|
| SHELBYVILLE, ILL. | SBIL | D/ /13 | | |
| VANDALIA, ILL. | VLA | 7/ /18 | | |
| CARLYLE, ILL. | CLIL | D/ /21 | TW | 4 PM |
| NEW ATHENS, ILL. | | 6/ /25 | | |
| MURPHYSBORO, ILL. | | 4/ /16 | | |

Day of Week ______ Date ______

STL RDO - RFC DATA SHEET

RIVER STAGES AND PCPN COLLECTED BY RIVER DISTRICT OFFICE

| STATION CALL | REPORTS* 1X/3X/FS | STAGE | PCPN | SNOW & ICE | YDA 1 P.M. STG | YDA 1 P.M. PCPN | YDA 7 P.M. STG | YDA 7 P.M. PCPN |
|---|---|---|---|---|---|---|---|---|
| GREGORY LANDING | D8/2X14 | | | | | | | |
| WAYLAND, MO. WYMO | 2X6/15 | | | | | | | |
| NEW LONDON NLMO | 1X10/2X19 | | | | | | | |
| TROY, MO. TYMO | 7/ | | | | | | | |
| HAZLEGREEN, MO. HZMO | 7/15/21 | | | | | | | |
| JEROME, MO. JRMO | 5/13/15 | | | | | | | |
| STEELVILLE, MO. STMO | 7/10/12 | | | | | | | |
| PACIFIC, MO. PAMO | 6/10/11 | | | | | | | |
| MONTICELLO, ILL. | 10/15/13 | | | | | | | |
| RIVERTON, ILL. | 9/ /13 | | | | | | | |
| PLUMFIELD, ILL. | 10/20/20 | | | | | | | |
| KANE, ILL. | 9/ | | | | | | | |

* Criteria: 0.5" precipitation, and river stage at same time.

1X = daily
3X = three times daily
FS = flood stage

SPECIAL MONDAY REPORT
FOR PURPOSE OF MONITORING AND ASSURANCE OF PERFORMANCE

BDT STATIONS
ST. LOUIS RIVER DISTRICT OFFICE

| STATION | CALL | REPORTS | REGULAR STAGE REPORTS 7 A.M. | 1 P.M. | 7 P.M. | SPEC. STAGES REQUESTED A.M. | P.M. |
|---|---|---|---|---|---|---|---|
| STEELVILLE, MO. 314-775-8725 | STMO | 1 3X FS 5/10/12 | | | | | |
| UNION, MO. 314-LU 3 5175 | UNMO | 5/11/15 | | | | | |
| BYRNESVILLE, MO. 314-BU 5-4948 | | 7/14/ | | | | | |
| **LONDON, MILLS, ILL. 309-486-3521 | | 8/17/ | | | | | |
| **COLMAR, ILL. 309-458-6290 | | 11/20/ | | | | | |

FOR MISSOURI TELEPHONE NUMBERS DIAL 137, then dial your telephone number.
** FOR ILLINOIS TELEPHONE NUMBERS - COLMAR & LONDON MILLS, use the following procedure. Dial 8, after getting dial tone - dial 312-828-4400 (Chicago Oper.), tell her you are the U. S. Weather Bureau at St. Louis and you are calling either Colmar, Ill. or London Mills, Ill. (inform operator that this is an automatic signaling device which is a series of buzzes so that she doesn't disconnect you when no one answers), give her telephone number of either Colmar or London Mills and she will get number for you.

1. 7 A.M. stages will be obtained for ALL stations EVERY MONDAY.
2. At all other times, DJS will notify us when to initiate regular calls.
3. Once special calls are begun when rivers are rising, we will continue to make regular calls according to the REPORTS CRITERIA column, and continue until stages fall below the once-a-day value, or until notified by DJS to stop.
4. 7 a.m. and 1 p.m. stages will be transmitted to MKCR immediately by RAWARC.
5. 7 p.m. calls will usually be held until the next morning.
6. The SPECIAL STAGES will be requested for those OCCASIONS when critical stage observations are needed. The specific observation time will be determined by DJS.

INSTRUCTIONS FOR READING BDT
The river stage is transmitted in tens, units and tenths of a foot only; there are no hundredths in the telephone readout. On calling these gages a tone will be heard, indicating that the receiver has been lifted and the BDT started. In 15-20 seconds a long tone comes on indicating start, then short tone bursts for the tens, a long tone for space between, then short tone bursts for units, a long tone for space between, followed by short tone bursts or tenths. This cycle is immediately repeated once. If there are no short bursts of tone to count between long tones you enter a zero in that place.

Date ______________________

RIVER & RAINFALL STATIONS MINNEAPOLIS DISTRICT

| STATIONS | FS | SUN | MON | TUES | WED | THURS | FRI | SAT |
|---|---|---|---|---|---|---|---|---|
| Aitkin (Miss. R.)............. | 12 | | | | | | | |
| Pillager (Crow Wing).......... | | | | | | | | |
| Sylvan (Crow Wing)............ | | | | | | | | |
| Fort Ripley (Miss. R.)........ | 10 | | | | | | | |
| Little Falls (Miss. R.)....... | | | | | | | | |
| Blanchard (Miss. R.).......... | | | | | | | | |
| St. Francis (Rum R.).......... | 8 | | | | | | | |
| Delano (Crow R.).............. | 8 | | | | | | | |
| Rockford (Crow R.)............ | 10 | | | | | | | |
| Mpls (Miss. R.)............... | 16 | | | | | | | |
| Montevideo (Minn. R.)......... | 14 | | | | | | | |
| Granite Falls(Yellow Medicine) | 6 | | | | | | | |
| Marshall (Redwood R.)........ | 7 | | | | | | | |
| Redwood Falls (Redwood R.).... | 6 | | | | | | | |
| New Ulm (Cottonwood R.)....... | 11 | | | | | | | |
| Rapidan (Le Sueur R.)......... | 15 | | | | | | | |
| Mankato (Minn. R.)............ | 19 | | | | | | | |
| Rochester (Bear Creek)........ | 15 | | | | | | | |
| Rochester (Zumbro R.)......... | 9 | | | | | | | |
| Rochester Sewage (Zumbro R.)... | 12 | | | | | | | |
| Zumbro Falls (Zumbro R.)...... | 18 | | | | | | | |

MSPC No.7
020862

NOTE:
Wisconsin Valley Improvement Co. collects all this and mails it routinely, with one-day lag; but if there is 1" or more of rain Strub calls the Wisconsin Valley Improvement Co. and they give this on phone, Monday, Tuesday, Wednesday, Thursday, Friday and Saturday, and on Sunday, Strub calls at "the mans" home for input.

APPENDIX G 1

ST. LOUIS RIVER DISTRICT OFFICE

SPECIAL PRECIPITATION REPORT FOLDER

When an observer calls in a precipitation report the RDO enters it in blue ink. When the RDO relays this report to the Kansas City River Forecast Center he circles it in blue to indicate information has been forwarded. Upon receipt of NWS Form E-14 (formerly 612-24) Precipitation Cards from observer, the amount is checked in red to validate original report by phone, additional amounts reported by NWS Form E-14 (formerly 612- 24) (less than 1/2 in.) are recorded in red.

# APPENDIX $G_2$

## NOTES ON MAINTAINING RIVER AND RAINFALL REPORTING RECORDS
RFC Hartford, 1970

Functioning of the River Services of the Weather Bureau depends almost equally on three elements: First, collection of synoptic reports and data on weather and river conditions; second, applying these reports to forecast procedures to compute forecasts of river stages and discharges, and, third, disseminating these forecasts to users of all descriptions.

The River District Office is the key to all the functions of the River Services program. The collection of data is a River District function, and the dissemination of forecasts is a River District function. In its area of responsibility, the River Forecast Center makes most of the river forecasts, but, even so, the River District Office retains some forecast functions by adapting key forecasts and, in many cases, issuing flash-flood warnings.

The River Services program cannot function well unless all three of these functions work as they were designed to do. It might well be said, however, that the collection of data is the beginning and foundation of the entire operation. The following is specific advice to all offices and individuals responsible for collecting meteorological and river data for use in the river program.

Have you ever, if you work in a River District Office, gone to great pains to collect a large number of rainfall reports and given a forecaster at a River Forecast Center a complete run-down of storm totals for a period of 36 hours during an important storm? If so, did the river forecaster who received these reports seem to be somewhat less than grateful? You may not have helped him as much as you hoped. River and rainfall reports are governed by certain instructions, which have been very carefully thought out and put down very concisely, and, in order for these reports to be of optimum use, reporting instructions should be followed to the letter.

Reporting instructions are summarized in three National Weather Service forms: E-13 (formerly 612-18) E-12 (formerly 612-19), E-11 (formerly 612-20), which are displayed in the Operations Manual. If these instructions are followed exactly and the data obtained are forwarded to the river forecaster promptly and exactly, then the reporting network is functioning as it should and you can expect optimum results from the river forecast procedures. If the data are confused, garbled, late, in non-standard form, and with large amounts missing, then you cannot expect optimum results from the river forecast procedures. Let us consider, therefore, the best way to insure efficiency in this necessary part of the operation. All River District Offices should, and almost all do, have a river phone and an unpublished number, which is available to the substation observers. More than this, however, if it is at all possible, a specific small space should be reserved in the office for River District operations and every effort should be made to receive the reporting data there.

This River District space should include at least a specific desk drawer. This desk drawer should contain a file of forms such as Weather Service Form E-14 C (formerly 612-24C), which is a river and rainfall telephone report for each station. It is a simple matter to set up a file of these cards for a River District, and, unless the number of stations exceeds 100, such a file will easily be contained in a double drawer in a standard desk.

When a call is received from an observer, usually the telephone operator will ask if you will accept a collect call from such-and-such an individual and such-and-such a town. If you recognize the individual and town, you may well be able to immediately reach for his card. If you do not, accept the call and ask what station is reporting. When you have identified the station, take out the card. Do not write the report on the back of a piece of teletype paper. If you do, you will not know what the observer is supposed to report and, indeed, the report may well be lost in the shuffle during a busy morning. When you have extracted his card, you can find on that card such items as the observer's name, address, and telephone number, classification as a station, his reporting criteria, etc. This is important. If a river and rainfall station calls in and volunteers the rainfall or the river stage without any mention of the other elements, it is necessary to ask him for the other data. You cannot do this unless you know what data he is supposed to supply, for you cannot be expected to remember every detail of the reporting instructions for each observer. Therefore, if you refer to the card, you will not commit such an atrocity as forwarding a rainfall report for a river and rainfall station with no river stage given.

Observers frequently become confused as to reporting instructions, particularly as to rainfall reporting instructions. The observer at a rainfall station may persist in giving the rainfall amount since the last observation. He is not supposed to do this; he is supposed to give the rainfall amount since 7:00 AM and this applies regardless of the time of observation. A moment's reflection will show how necessary it is to hold this instruction inviolate. For example, an observer may report 1.32 of precipitation at 1:00 PM. This is the amount since 7:00 AM that morning. Let us suppose now that he reports 1.67 at 7:00 PM. If we do not know whether this amount is since 1:00 PM or since 7:00 AM, we are in a mess. In this particular case, which we have shown as an example, the observer keeps trying to report the amount since the previous observation and in each case, through the inquiries of the person receiving the call, the matter has been straightened out. Obviously, if a card shows an observer has considerable difficulty with this particular instruction, it becomes a matter of inquiring at each observation he reports as to whether it is in the correct form and amount until the observer has been trained to do it right.

This last example shows the use of Form E-14C as a training aid. Training of observers is a time-consuming and sometimes discouraging job, but it must be done. Train your observers when they phone in a report; ask them questions and make sure they get it right. Correspondence and visits to the observers are also very useful in training them. They all want to do a good job (or the ones you want to keep, do) and tactful help is usually appreciated.

Has the River Forecast Center asked for your reports to be submitted by 8:30 AM, 2:30 PM, 8:30 PM, etc.? Do you have a station that reports at 9:00 AM? If so, and he will not change his ways, you may have to get a new observer. Reporting times need not be exact, plus or minus one hour from the 7:00 AM criterion will not do much harm. But data that straggle in after the forecaster is well into his computations are not very helpful. Not all observers will be able to report at 1:00 PM and 7:00 PM, and practically none at 1:00 AM, unless they are insomniacs. Try to get as many reports at these hours as you can. If the forecast is organized into 12-hour unit hydrographs, 7:00 PM is the key extra report. If the forecaster uses 6-hour unit hydrographs, all are important. As far as the 1:00 AM reports are concerned, you can only ask the observer to make a report as late as he can during emergency situations when an obviously important flood is imminent.

These telephone report cards are very handy after the call has been received. They are large and substantial, almost impossible to lose, and can be routed physically from place to place until the necessary operations have been performed, such as forwarding them to the River Forecast Center, extracting data for a newspaper story, or supplying data to the Corps of Engineers. After these necessary operations have been performed, replacing the cards in their correct place in the file is simple and quick. These cards take very little time, possibly 15 seconds to extract the card from the file and 15 seconds to replace it. It might be added that many times observers' names and station names are somewhat confusing. You may have two Smiths, of you may have two stations with similar names, so that the name when scribbled hastily can be mistaken for another station. Use of the correct card, with verification of the observer's name and station, name insures that the report is located correctly.

As a bonus for the modest effort in filling out and using Form E-14C it can be noted that the making out of payrolls is a very simple matter when these cards are used, since a record of observations by stations is automatically available. Making out the payroll can be extremely time-consuming and subject to inaccuracies which cause friction with the observers, if the reports are scattered in some less accessible way.

Form WB E-14C should be used for stations whose reports are received occasionally, and one by one. If there are stations that report daily, and most River Districts have such stations, these stations should be, without any question, tabulated on a daily form. Space on this form should be allowed, however, for extra reports. If data are collected in groups from other organizations, such as power companies, then, of course, the use of a special form for such a collection by networks is indicated.

**CCED**

STATION Crop Corners, East Dakota OBSERVER James T. Smith
ADDRESS RFD #8, Kilowatt Jct., E.D. PHONE 812-904-2243

Rainfall
REPORTING CRITERIA
Rainfall: 0.50"
River:

RELAY TO:
RFC
USE

| DATE | TIME OF OBS. | AMOUNT | FORM | PREVIOUS 7a AMOUNT | WEATHER AT OBS. | SNOW DEPTH (NEW) | TOTAL SNOW DEPTH | WATER EQUIV. | STAGE (F.S.) | TENDENCY | PREVIOUS 7a STAGE | CREST STAGE | TIME OF CREST | CURRENT | MAX. | MIN. | REMARKS | RECEIVED BY | TIME | ~~PLOTTED~~ |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | PRECIPITATION 1 | 2 | 3 | 4 | 5 | 6 | 6A | 6B | RIVER 7 | 8 | 9 | 10 | 11 | TEMPERATURE | | | 12-13 | | | |
| 9/11 | 1p | 1.42 | R | .22 | R+ | | | | 4.5 | R | 2.3 | | | | | | Small creeks muddy | JS | 1^35 | ✓ |
| 11 | 7p | 1.73 ~~.01~~ | R | .22 | L- | | | | 7.2 | F | 2.3 | | | | | | | JS | 7^55 | ✓ |
| 12 | 7a | 1.74 ~~.01~~ | R | .22 | P.C. | | | | 6.2 | F | 4.5 | | | | | | | RS | 6^50 | ✓ |
| 16 | 2p | | | | | | | | 3.4 | | | | | | | | Telemark check | JS | — | — |
| | | | | | | | | | | | | | | | | | | | | |
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## HYDROLOGIC SERVICES

Lesson Six, Office Arrangements

References: NWS Manual, Chapters E-02,03, and your River District Manual

Objective: To discover ways in which you can most efficiently arrange the hydrologic material in your office. You should critically examine the layout in your particular River District Office and see whether there is some better organization of the material possible. All pertinent information that may become useful during flood periods should be arranged so that it is quickly accessible. This organization will help you to become well-acquainted with the streams in your district. It should be done well enough so that it could easily be used by any forecaster whether he is familiar with the streams or not.

Discussion: Record breaking floods occur somewhere in the United States every few months. People in every River District Office should remember that "it can happen here" and consequently be prepared for such an event. Preparation of the items mentioned in this lesson should be scheduled during periods of relative quiet. The pay-off comes when the streams are rising and the phones are ringing.

This lesson will suggest ways in which the material pertinent to river forecasting can best be organized in an office. Most offices have a wealth of information about the streams in their district which should be organized for the most efficient utilization during periods of operational stress. A properly designed and maintained river section pays big dividends in both accuracy and timeliness of forecasts and in the ease of orientation of employees recently assigned to hydrologic duties.

Work assignments:

1. Read pertinent parts of the references and the enclosed lesson material.

2. Outline the materials now used in your office for portraying distinctive river features.

3. Briefly describe physical layout of your RDO section.

4. If you find a need to improve 2 or 3, prepare a schedule for this improvement in cooperation with your MIC.

5. Answer the questions for this lesson.

HYDROLOGIC SERVICES

Hydrologic Services Lesson Six, Office Arrangements

I - Distinctive River Features

There is a lot of information about the rivers in a river district that should be at the finger tips of the river district officials. The RDO should prepare an Atlas of maps and charts that shows the many different aspects of the river which become vital information when floods are occurring. Many different scales of maps are probably necessary to show all the things that should be available in an Atlas. Most of them are available from Federal, State and local government agencies. Following is a partial list of the maps and charts that could be used to portray the distinctive river features in your area:

1. A map of the river district showing all the rain gages that report with different legends for the different types of rain gages and different types of reporting.

2. A map with the river gages and all the information printed beside gage locations that might be useful, such as flood stages, critical stages above the low-flow stages, and the highest flood of record that has occurred at each gage location.

3. Expanded scale maps for each municipal area subject to flooding in the district. These maps should show all the areas that are flooded at different stages. This will supplement the River Stage Data required on the new WS Form E-19.

4. Map showing areas subject to flash flooding. These should be correlated with radar overlays if they are available.

5. River profiles which show the height of dams on the streams, the height of inflowing tributaries and the slope of the river beds. Appendix B shows a profile prepared by TVA.

6. Drainage system schematics.Appendix A is a schematic prepared by the State of California.

7. A profile chart of past floods. An abridged example is shown in Appendix C. In some cases these profiles will show that a stage relation is not reliable because the slope from one point on the river to a lower point is extremely variable between floods. The charts are helpful, even in such cases as this, for obtaining first estimates of the forecast for downstream points.

No doubt you will be able to think of other maps which will be quite useful in your River District Office. USGS ratings and Corps of Engineers maps and plans are good source examples. It is most helpful to have this sort of rapid-access pictorial presentation of information that otherwise must be slowly dug out of a manual when time is of the essence.

For each gage in the river district, one should have complete information as to zero elevation of the gage, the height that all major floods have attained and some general information as to the areas flooded at these various heights. This is required on WS Form E-19 and its predecessor WB 531-4. An extra copy should be kept readily available.

Occasionally there will be a person in some agency who decides that it would be a good idea to change the zero elevation of a particular gage in order to clarify the readings. This is most likely if low-water flows have to be indicated by negative stage readings. The River District Official should try to dissuade any person that proposes such manipulations of the river gage. If he persists, you should advise your RFC and/or Regional Hydrologist.

Once established, the relative meaning of river stages at a particular gage becomes well-known to the many hundreds of users in the area. It is rarely desirable to change this gage datum, because one can never inform all the people who depend on the readings from the gage and forecasts of future readings on the gage. Thus there is considerable danger that a future reading or forecast will be misunderstood and loss of life and property could result.

Flood stages present a similar problem in that they are arbitrary levels, which should rarely be changed. A few users can relate their changing problems to established levels more simply than many users can be advised of changes.

When new gages must be installed because the old ones become irrelevant (e.g. when the few large dams replaced many smaller dams on the Ohio), they should be related to as many well-known landmarks as possible. The zero of the gage should be well below low-water stages.

Cross sections have been made at many points along the rivers especially at bridges and dams. These can be very useful information when installing a new gage, and the agencies involved will often cooperate to establish the zero elevation of a gage.

The River District Office library should include the regulation manual for all reservoirs in the district. It should also have late copies of the U.S. Geological Survey Water Supply Papers entitled,

"Surface W
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: Water Supply of the United States," that pertain to the rivers
listrict. They are now being published as state bulletins so
ne RDO's might need 2 or 3 publications to cover their area.
er Forecast Center library should be inspected when you visit
) determine what other publications can be useful for your
on.

e River District Official should be on the alert for new
nments upon the flood plain. Occasional flights over flooded
flood protection works, or levee systems can be very educa-
and should be managed when possible. Encroachments can
es be discouraged if the right type of data are available for
ation to the people concerned. If encroachment proceeds in
f possible consequences, this information should be relayed to
er Forecast Center and Regional Hydrologist. This is necessary
of the possible need for revision of flood stages or other new
a for forecasts being issued.

ere is also the problem of new or changing controls which may
forecast procedures. It is necessary for river district
ls to be on the alert for such changes and to report them to
ecast Centers. Among the many possible causes of a change in
are a new reservoir, a diversion canal, bypasses cut by the
r by man, and new bridges which may affect the cross sectional
a stream.

netimes there are dredging operations which may be extensive
to cause a change in the controls affecting your station. Large
usually scour an alluvial river bed early during the flood and
new silt late in the flood. This will cause changes that are
lt to define but the forecaster should be on the alert for
ions that the rating at a particular gage has changed after such
torms.

ch of the information discussed above is available on WS
.9 called, "Report on River Gage Stations." This was formerly
+, revised to make its completion less laborious. It is, of
essential that it be kept up-to-date and its accuracy verified.
acy that built a control will have a manual which should be
ed for pertinent and useful information.

ch information as is contained on page 8 of WS Form E-19
be copied and kept in a place easily accessible to the person
with the river. Appendix D shows this information for Warren,
vania. It is also a good practice to put the information
ed in E-19 in different form as has been discussed above. That
bits of information should be combined into maps, charts and
that show at a glance information that would ordinarily take

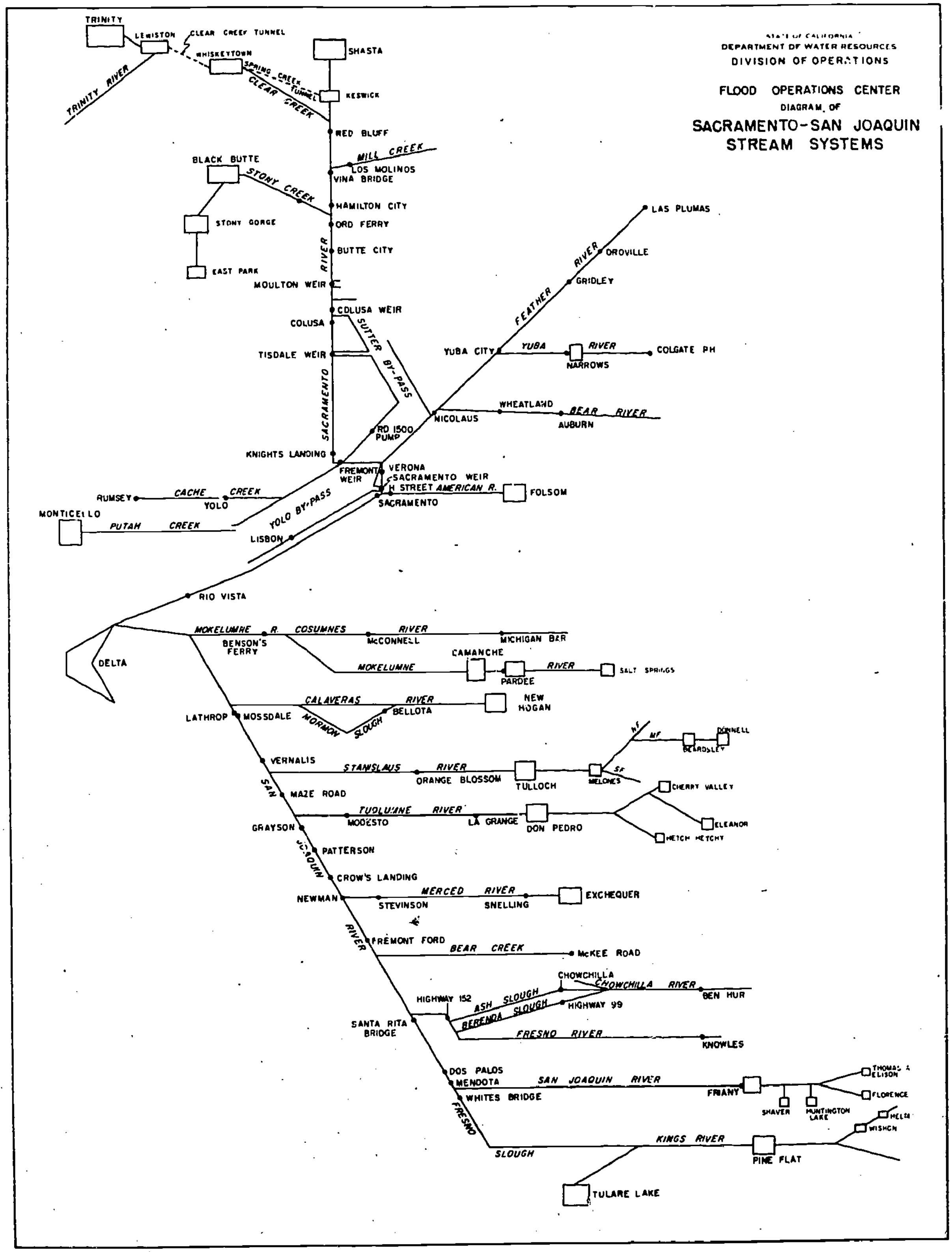
several minutes to dig out of a narrative report.

## II - Physical Layout

The space required for a River District Office operation naturally varies with the amount of river work to be accomplished. In some cases a whole desk and one or more file cabinets will be required to store all the material necessary. In other cases less than a full desk is needed for this function. In all cases a clear working area with convenient filing space should be allocated to the river district function and the following items should be kept there at all times:

1. The data handling aids and records indicated in lesson 5.
2. The Atlas mentioned in the previous section.
3. Telephone.
4. Files -
   a. as required by the operations manual.
   b. as desired in view of the factors mentioned in lesson 5.
5. Current hydrographs of pertinent river stages during all but low-flow periods.
6. A detailed schedule of hydrologic duties. An example of how this is done at St. Louis is shown in Appendix E.
7. The river district office manual as required by the operations manual.

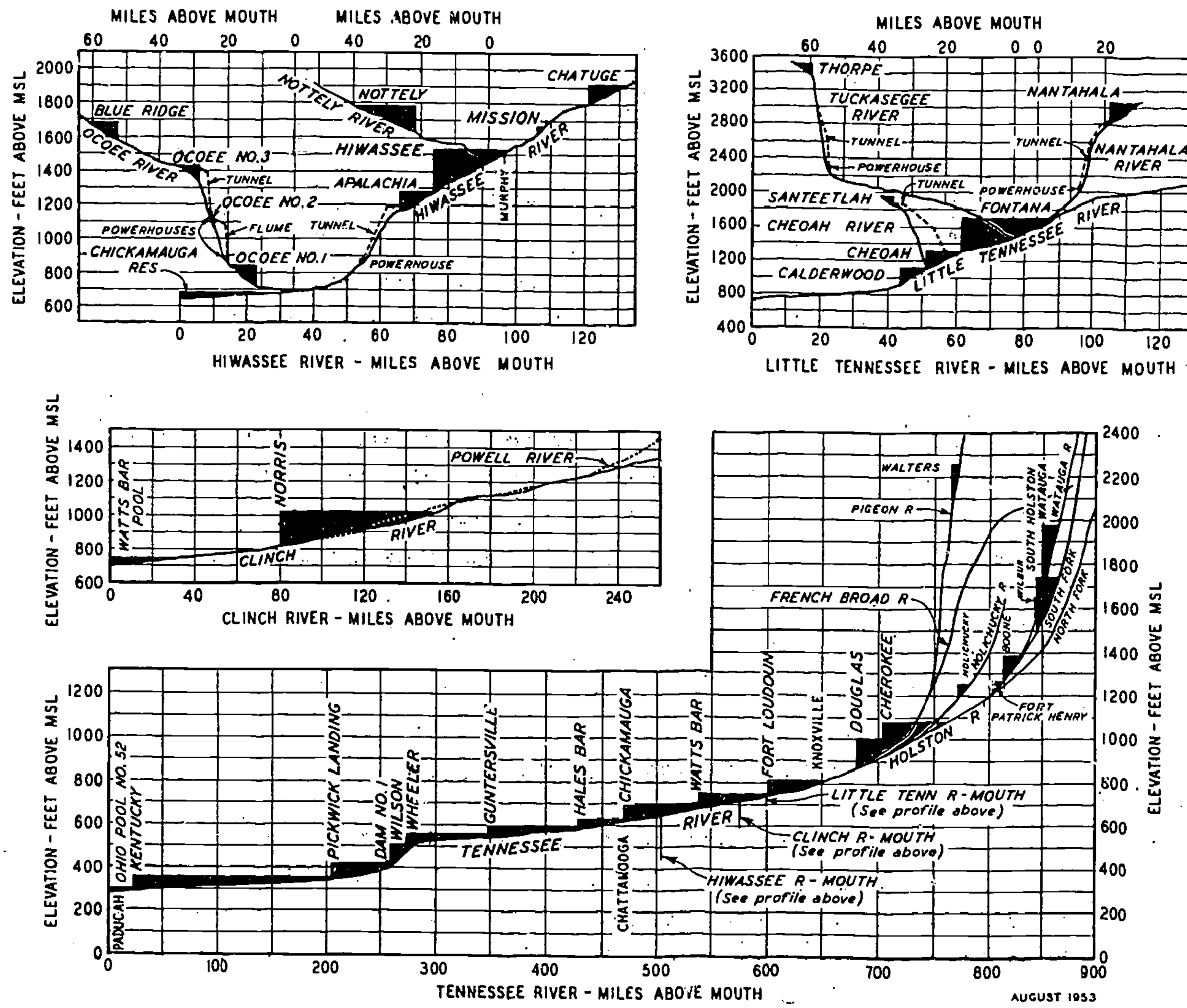
# APPENDIX A



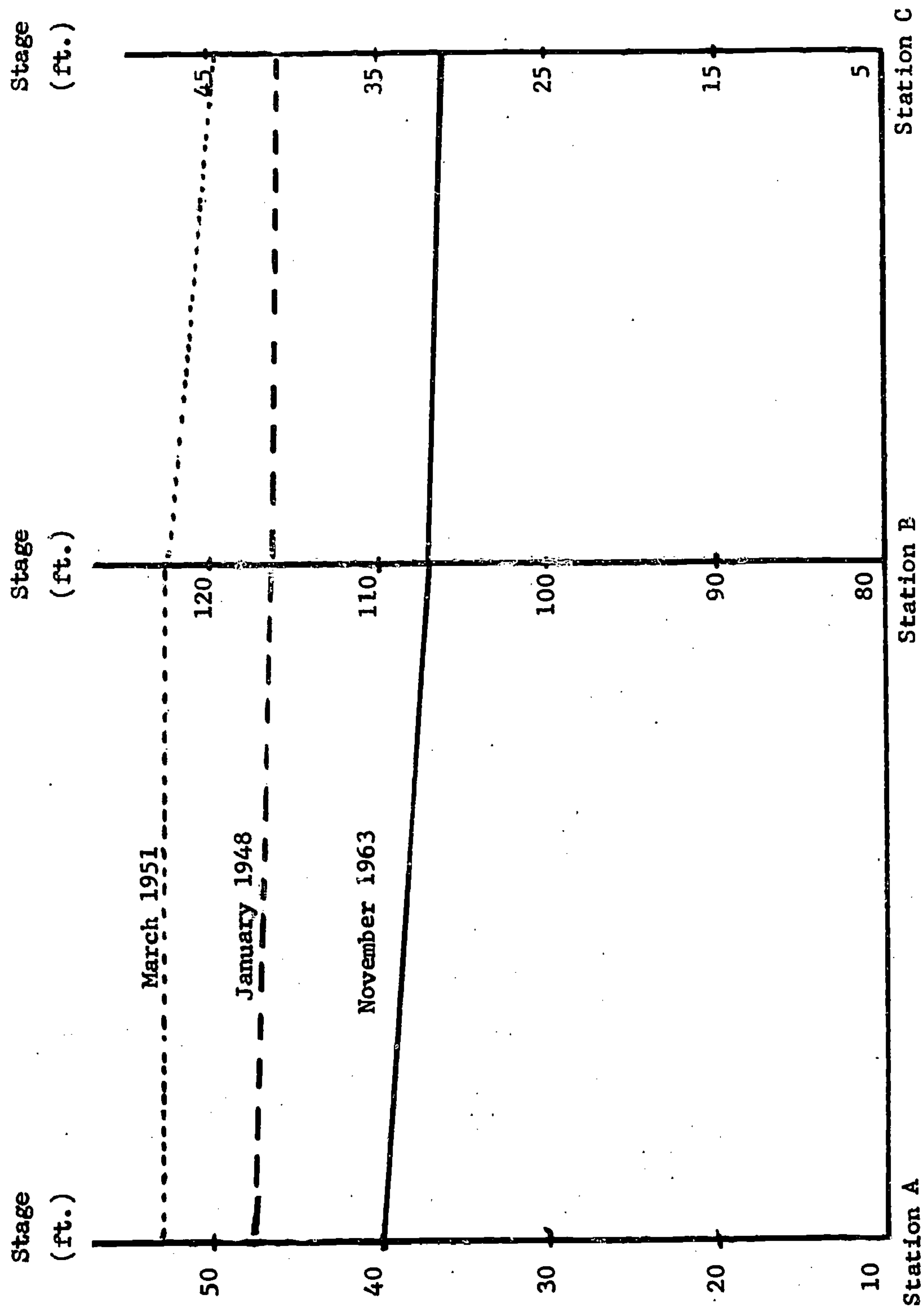
DEPARTMENT OF WATER RESOURCES
DIVISION OF OPERATIONS
FLOOD OPERATIONS CENTER
DIAGRAM OF
SACRAMENTO-SAN JOAQUIN
STREAM SYSTEMS
TRINITY
LEWISTON
CLEAR CREEK TUNNEL
WHISKEYTOWN
SPRING CREEK TUNNEL
CLEAR CREEK
TRINITY RIVER
SHASTA
KESWICK
RED BLUFF
MILL CREEK
LOS MOLINOS
VINA BRIDGE
BLACK BUTTE
STONY CREEK
STONY GORGE
EAST PARK
HAMILTON CITY
ORD FERRY
BUTTE CITY
MOULTON WEIR
COLUSA WEIR
COLUSA
TISDALE WEIR
SUTTER BY-PASS
SACRAMENTO RIVER
RD 1500 PUMP
KNIGHTS LANDING
LAS PLUMAS
OROVILLE
GRIDLEY
FEATHER RIVER
YUBA CITY
YUBA RIVER
NARROWS
COLGATE PH
WHEATLAND
BEAR RIVER
AUBURN
NICOLAUS
FREMONT WEIR
VERONA
SACRAMENTO WEIR
H STREET
AMERICAN R.
FOLSOM
SACRAMENTO
RUMSEY
CACHE CREEK
YOLO
MONTICELLO
PUTAH CREEK
YOLO BY-PASS
LISBON
RIO VISTA
DELTA
MOKELUMNE R.
COSUMNES RIVER
BENSON'S FERRY
McCONNELL
MICHIGAN BAR
CAMANCHE
MOKELUMNE RIVER
PARDEE
SALT SPRINGS
CALAVERAS RIVER
NEW HOGAN
LATHROP
MOSSDALE
MORMON SLOUGH
BELLOTA
DONNELL
BEARDSLEY
VERNALIS
STANISLAUS RIVER
ORANGE BLOSSOM
TULLOCH
MELONES
CHERRY VALLEY
MAZE ROAD
TUOLUMNE RIVER
MODESTO
LA GRANGE
DON PEDRO
ELEANOR
HETCH HETCHY
GRAYSON
PATTERSON
SAN JOAQUIN RIVER
CROW'S LANDING
NEWMAN
MERCED RIVER
STEVINSON
SNELLING
EXCHEQUER
FREMONT FORD
BEAR CREEK
McKEE ROAD
CHOWCHILLA
CHOWCHILLA RIVER
BEN HUR
HIGHWAY 152
ASH SLOUGH
BERENDA SLOUGH
HIGHWAY 99
SANTA RITA BRIDGE
FRESNO RIVER
KNOWLES
DOS PALOS
MENDOTA
SAN JOAQUIN RIVER
FRIANT
WHITES BRIDGE
SHAVER
HUNTINGTON LAKE
FLORENCE
WISHON
FRESNO SLOUGH
KINGS RIVER
PINE FLAT
TULARE LAKE

# APPENDIX B

## PROFILE OF THE TENNESSEE RIVER SYSTEM



## APPENDIX C




Crest Stages of Past Floods on Sample River

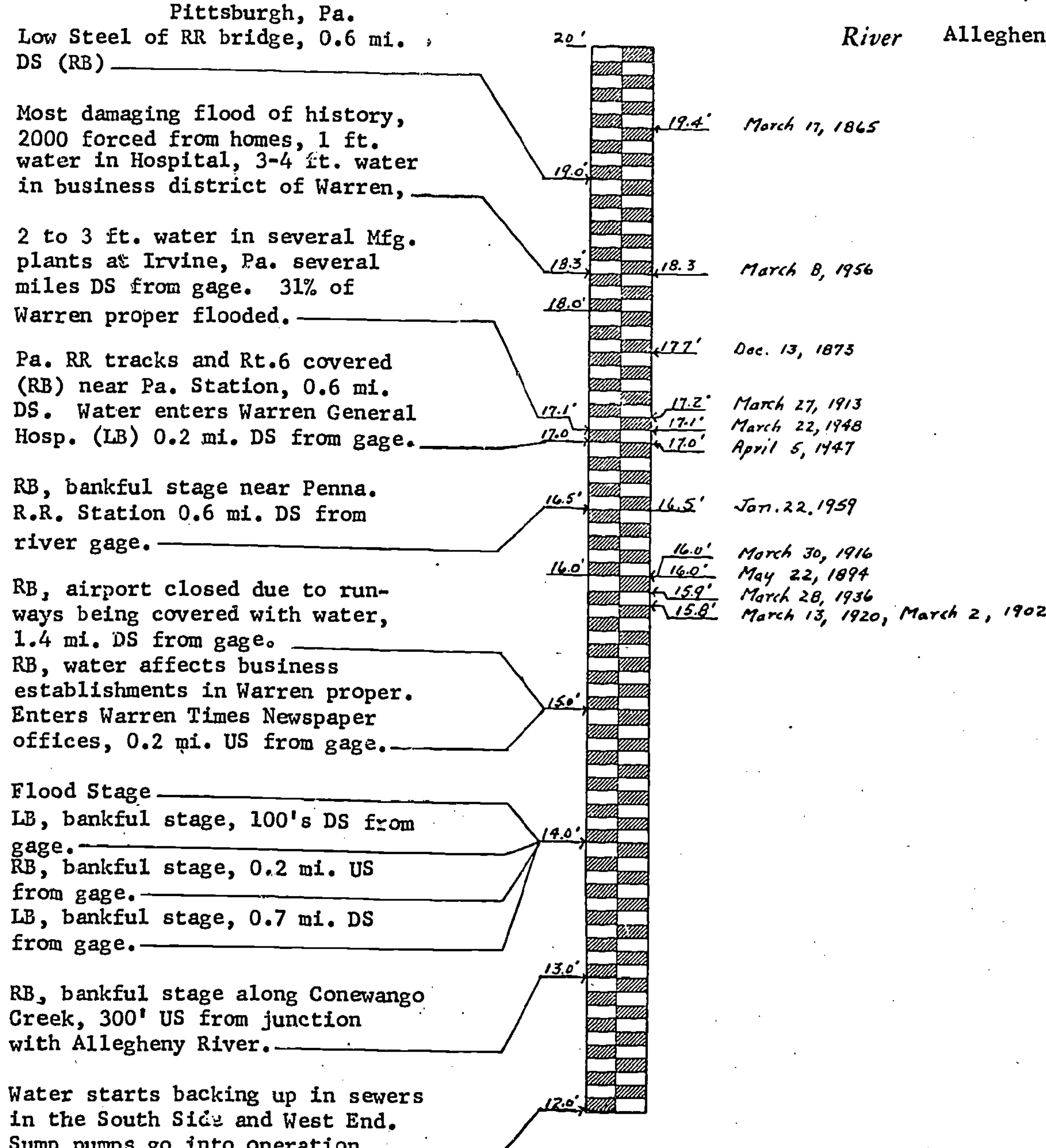
APPENDIX D

# RIVER STAGE DATA

*RIVER DISTRICT OFFICE*
Pittsburgh, Pa.

*Station* Warren, Pa.

*River* Allegheny




*REACH*

5 mile reach extending 1 mile upstream and 4 miles downstream from river gage.

Elevation Zero
1168.80'

Data Credits
USWB

WS Form E-19 Page 8

*Date* May 5, 1958

9. Gage elevations of areas subject to overflow.--Give elevation of both banks, mentioning any particularly low banks in the reach of the river served by this station. List a number of gage heights at which various significant areas are affected by overflow. Particular reference should be made to railroads, streets, roads, residence and business section, farmlands, etc. If possible, include a table showing relationship between stage and acres flooded, or between stage and flood damage.

| | Gage Height | |
|---|---|---|
| (A). | 12.0' | Water starts backing up in sewers in the South Side and West End. Sump pumps go into operation. |
| (B). | 12.8' | Crest of rise of April 4, 1956. No actual flooding in Warren proper. However, some cellars flooded in homes on South Side due to seepage. Water on some of runways of airport, 1.4 mi. DS from gage. |
| (C). | 13.0' | RB, bankfull stage along Conewango Creek, 300' US from junction with Allegheny River. |
| (D). | 14.0' | LB, bankfull stage, 100' DS from gage. |
| (E). | 14.0' | RB, bankfull stage, 0.2 mi. US from gage. |
| (F). | 14.0' | LB, bankfull stage, 0.7 mi. DS from gage. |
| (G). | 15.0' | RB, airport closed due to runways being covered with water, 1.4 mi. DS from gage. |
| (H). | 15.0' | RB, water affects business establishments in Warren proper. Enters Warren Times-Mirror newspaper office buildings, 0.1 mi. US from river gage. |
| | 16.0' | LB, Corral Inn affected 9.0 mi. DS (bankful stage) |
| (I). | 16.5' | RB, bankful stage near Penna. R.R. Station, 0.6 mi. DS from river gage. |
| (J). | 17.0' | RB, Penna. R.R. tracks and Route 6 covered with water near Penna. R.R. Station, 0.6 mi. DS from river gage. |
| | 17.1' | March 22, 1948 crest - 31% of all land area within Borough Limits flooded (496 acres). Yard, street and basement flooding extensive. Overbank flooding varied from 1 to 4.5'. |

Where flood protective works (levees, bypasses, etc.) are in existence in the reach of river served by this gage, they will be listed below with the design protection, or operation grade referred to the gage at this station.

17.1' (1) West End Area, 211 acres flooded in 1948 flood. Most downstream part of Warren, lying on the RB of a loop of the Allegheny River. The southern half of the West End contains the Warren municipal airport and hangar. Northern half contains several industrial plants and commercial establishments, number of residences, a school, a fire station, utilities, highways, and municipal and miscellaneous properties. Total estimated direct flood damages due to the 1948 flood was $203,500 for the West End area (excluding airport).

(2) South Side area, 86 acres flooded in 1948. South side area lies on the LB of a loop of the river and extends to the Penna. R.R. which crosses the loop. Area principally residential and contains a few neighborhood stores and the Warren General Hospital. Total estimated direct flood damages due to the 1948 flood was $113,000 for the South side area.

(3) Business Area, 27 acres flooded in 1943. Business area is contained in the angle formed by the RB of the Allegheny River and of Conewango Creek. Comprises the principal commercial area of Warren. Contains many fine homes, churches and schools.
Total estimated direct flood damages, 1948 flood, was $193,000 for the Business Area.

(4) East Side (of Conewango Creek), 107 acres flooded in 1948. Area along LB of Conewango Creek opposite the Business area. Principal flood damage on the East Side is to Beatty School, a large modern school building in the flood plain. Total estimated direct flood damages, 1948 flood, was $27,500 for the East Side Area.

(5) The Island Area, 21 acres, flooded in 1948. Commercial and industrial area of Warren extends to include the Island which is separated from the Business Area by a mill race extending from a dam on Conewango Creek, to the Allegheny River. Total estimated direct flood damages, 1948 flood, was $41,100 for the Island Area.

(6) East End Area - 44 acres flooded in 1948. East End of Warren extends along the RB of the Allegheny River down to Conewango Creek and comprises the principal industrial area of Warren. The flood zone lies riverward of the Penna. R.R. tracks. Flood damages in East End Area insignificant for 1948 flood. Therefore, 17.1' stage floods 496 acres and causes direct damages of about $578,100 (based on 1949 valuations).

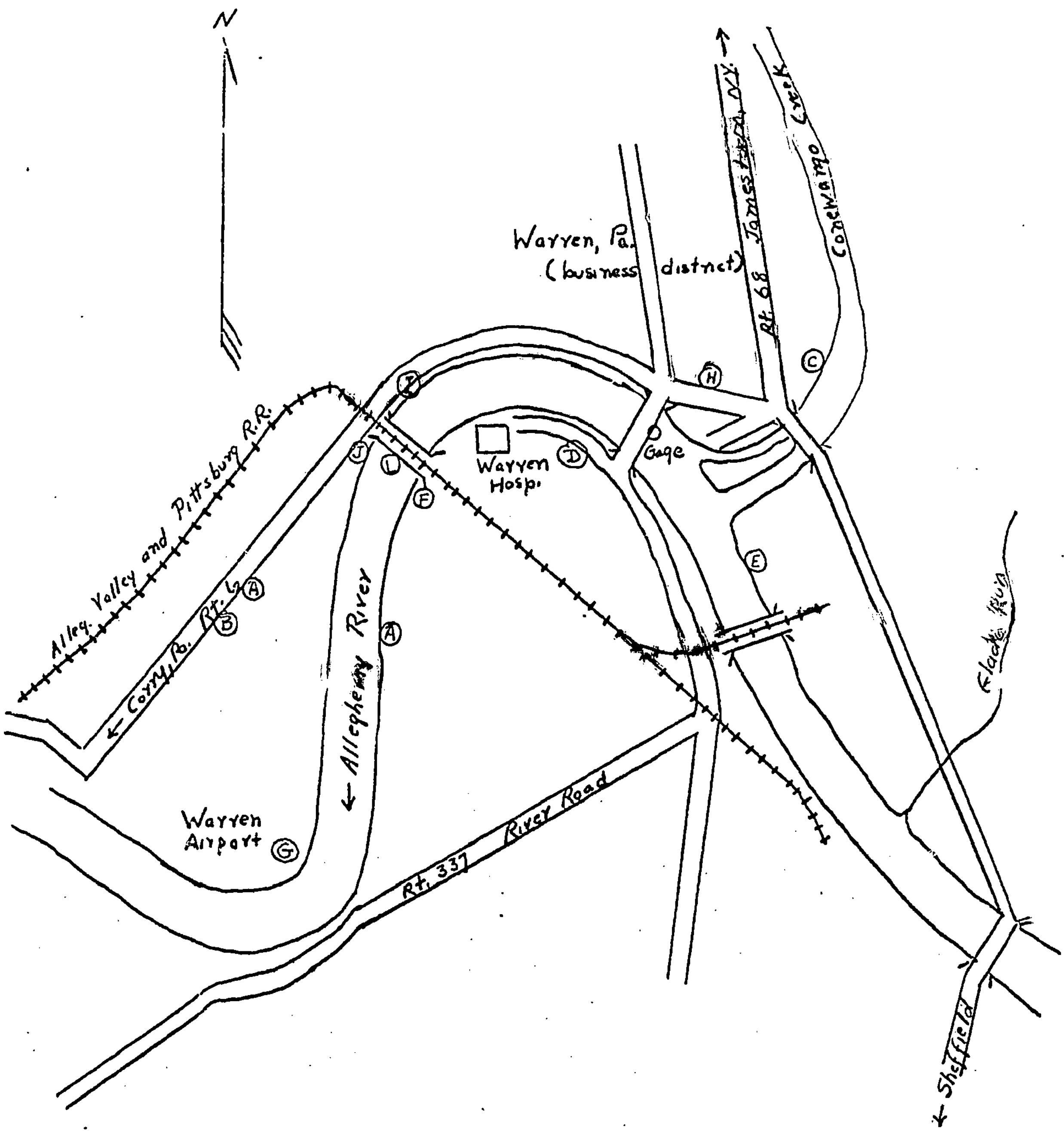
(continued)

(K). 17.1' From 2 to 3' of water in several manufacturing plants at Irvine, Pa. several miles DS from river gage.

18.3' March 8, 1956 crest - Considered the worst flood in Warren's history, the second highest of known record. Damages tremendous; about 2000 persons in Warren forced from their homes, (500 families), some patients in Warren General Hospital evacuated even though sandbagging around hospital was in effect. Water about 3' deep near the hospital, natural gas service interrupted, all key highways to town except one running north to the New York State line were cut by high water. About 1 foot of water entered 1st floor of Warren General Hospital; about 3 to 4' of water covered portions of the main business district in Warren.

(L). 19.0' RB, low steel of railroad bridge over Allegheny River near Penna. R.R. Station, 0.6 mi. DS from river gage.

NOTE: The letters (A), (B), (C), etc. shown alongside of gage heights refer to corresponding letters shown on sketch on Sheet page 61.


N
Warren, Pa.
(business district)
Rt. 68 Jamestown, N.Y.
Conewango Creek
Alleg. Valley and Pittsburg R.R.
Corry, Pa. Rt. 6
Allegheny River
Warren Hosp.
Gage
Warren Airport
Rt. 337 River Road
Glade Run
Sheffield

# APPENDIX E

## RIVER DUTIES

## DAILY WORK SCHEDULE

7:00 a.m. Call Telemark (MAin 1-4797) for signal - St. Louis River Stage and enter on Daily River Call Sheet. Obtain 2 a.m. and Yda 4 p.m. St. Louis river stages from observer and enter.

Call Grafton, Ill. telemark (618-786-3818) for signal Grafton river stage and enter on Daily River call sheet.

7:05 a.m.CST
8:05 am CDST Call Hannibal, Mo. (using Watts dial 137 for dial tone) phone number is 314-221-0341) They will give you 7 a.m. river stage and midnite river stage and precipitation amounts for both times.

7:10 a.m. Monday - or during periods when rivers are high and RFC requests BDT stages.

Obtain readings from BDT gages, using special telephone report (filed in River Desk with Daily River Call Sheets).

(a) In the past we have had difficulty in obtaining readings from Byrnesville and Eureka. The procedure to obtain readings from these stations is to call on a direct line, dialing phone number using area code. Using this method reading can be easily understood.

(b) In case of malfunction of any of these gages please report same to Keith or Frank immediately so that corrective action may be taken.

7:20 a.m. Begin preparing SR-1 (Transmission time is 7:40 CST; 8:40 CDST, send to FAA at 7:30 am CST, 8:30 am CDST.) Prepare river stages received in code on SR. Indicate rising (1) or falling (2) stationary (0) and total -- i.e., 25.2 Falling is 25221. Be sure to add the PM reading for the previous day for St. Louis and Chester -- show today stage first - follow with YDA PM reading. When Farmington or Lockwood call in a precip. report be sure to include this on SR-1, and if too late for SR-1 be sure to include on SF-2. When special precip reports are phoned to us be sure to include on SR as follows: OWMO 0088, etc.

| | |
|---|---|
| 7:30 a.m. | All telephone reports received from River and Rainfall Observers will be sent on RAWARC with the following routing: MKCR A STL M_____ (date-time). |
| | When precipitation reports are received from rainfall reporting stations be sure to include these in messages to MKCR. |
| | Readings from BDT gages will also be included in this message. |
| | Data received from Union Electric via radio and reports telephoned to us from Jerome, Mo. and Hazlegreen, Mo. will be routed as follows:<br>MKCR A STL M_____ (date-time) MKCE<br>ATTN MKCC PSU |
| | Missing data -- For those stations which report more than once a day, such as St. Louis and Chester, and data are missing for one of these periods, please note this in your message to MKCR..Example..STL 2 AM stg missing. |
| | Transmission to MKCR via RAWARC will be made every half hour after first transmission at 7;30 a.m. until all data that we receive have been relayed to them. |
| 7:40 a.m. | Disply ST. LOUIS RIVER STAGE...Also ST CHARLES RIVER STAGE when it is received---This goes on board in front. |
| 8:00 a.m. | Begin entering stages received on Daily River Call sheets to the River Stage Bulletin. Take precipitation amounts from Regional Temperature Bulletin and enter on River Stage Bulletin. |
| 8:15 a.m. | Data received from the Corps of Engineers via radio will also be transmitted to MKCR. |
| 8:30 am CDT<br>8:40 am CST | Send SR-1 to FAA.<br>Sent SR-2 to FAA. |
| 8:50 a.m. | Complete entries from SR-1 on River Stage Bulletin |
| 9:30 a.m. | RIVER STAGE BULLETIN - Send over all loops.<br>Use master tape from River desk drawer...Head it<br>NOAA-National Weather Service<br>Monday (day) June 30, 1966 (date) |
| | Radio and TV stations in the Bootheel and So. Illinois required Kentucky and Barkley stations on a daily basis. These are transmitted to us on RAWARC by Cairo and will be sent immediately at the end of the River Stage Bulletin. |

9:40 a.m. ENTER TODAY's STAGES ON RIVER FORECAST BULLETIN. When there is no flooding, St. Louis Hydrologist (Dennis Slaughter) will issue the River Forecasts for Dam 26 TW, St. Louis, Chester, Hermann and St. Charles -- (person covering "S" shift) will call the Corps of Engineers via Radio, around 10:45 a.m. for the 3-day forecast for Grafton. Forecasts for Cape Girardeau, Cairo and New Madrid will be issued by Cairo over RAWARC which we will enter on the River Forecast Bulletin. Stagex forecasts for Kansas City, Boonville and Jefferson City will be taken from the Reservoir releases issued by MKCR via RAWARC.

When the rivers go into flood, the forecasts will be made by MKCR and released over RAWARC by them.

9:45 a.m. When 3-day river forecasts for Cape Girardeau, Cairo, and New Madrid are received via RAWARC from CIRC, cut a tape with the following heading and message

NOAA National Weather Service
Date Time
3-Day River Forecasts

| | | | |
|---|---|---|---|
| Cape Girardeau Mo. | -- | --- | --- |
| Cairo, Illinois | -- | -- | -- |
| New Madrid Mo. | -- | -- | -- |

END SENT (time) ______

This tape will be sent over the Missouri and Illinois loops. It is important that this be done as soon as message from Cairo is received for radio and TV purposes.

10:00 am CDST Send SR-2 to FAA.

11:00 a.m. Union Electric will radio the 3-day Lakeside Pool Forecasts to us by this time and the extended flow forecast (four days in addition to the three already received earlier). This will be relayed via RAWARC with the following routing:

MKCR A STL M____ (date-time) MKCE
ATTN: MKCC PSU

11:00 am to 12:00 noon — Corps of Engineers will relay the data for Meredosia - Flow 7 a.m. and forecast and also Dam 22 Flow and forecast. This will be relayed to MKCR via RAWARC with usual routing. If these data have not been relayed to us by noon, call Corps of Engineers via radio for data.

By noon, Kansas City, if there is no flooding, will send via RAWARC the Reservoir Releases. To this message, insert after Mississippi River Grafton, Illinois, and Dam 26 TW Alton, Ill forecasts, continue running tape for rest of Reservoir releases, and at the end add the statement regarding the Pools at Clarksville, Winfield & Alton (this statement will be prepared by our Hydrologist (Dennis Slaughter) who will relay to person on "S" shift.

Any other statement that Kansas City releases, during periods of flooding, involving streams within our River District will also be added to this message. This tape will be sent over all loops with the exception of RAWARC.

Retain hard copy of Reservoir Releases as sent by us over the Memphis loop and attach with copy received from RAWARC to Daily River Forecast Sheet.

12:30 p.m. — During periods of flooding when news release is necessary, see the Hydrologist, Dennis Slaughter, Anne, or Mr. Brancato for information to be released.

1:15 p.m. — When additional telephone reports are received from rainfall or river observers, these will be sent to MKCR at this time.

Call areas to be alerted regarding flood warnings -- use information for FLOOD WARNINGS found in this manual.

Make a list of calls made regarding FLOOD WARNINGS with the following information:

Date - River in Flood - location called - time of call.

Attach this list to Daily River Forecast Sheet for that day. This information is necessary for report at end of the month.

# REMINDERS

DURING PERIODS OF HEAVY PRECIPITATION THE FOLLOWING PROCEDURE WILL BE FOLLOWED:

1. Precipitation amounts called in by Rainfall Observers will be entered opposite correct station in Special Precipitation Folder. This will be done at 7:00 a.m., 1 p.m., and 7 p.m. WHEN OBSERVER CALLS AT 7:00 PM be sure he gives you the total amount of precipitation that has accumulated since 7:00 a.m. Relay all of this information to MKCR via RAWARC and circle amount with blue pen.

2. As soon as possible, make a list of all stations and precipitation amounts reported and send message over RAWARC and all loops with the following heading:

   ALSYM A STL (date-time)
   NOAA NATIONAL WEATHER SERVICE ST LOUIS (Date)
   PRECIPITATION FOR 24 HOURS ENDING AT 7 A.M. (date)
   (Save message, attach to Daily Reporting Sheet.)

3. Plot all precipitation reports on map in red (maps are in folder in River Desk drawer). This should be accomplished by 8:45 a.m. Show map to forecaster for info for radio broadcast. After you have plotted precipitation map and you note that certain areas within the rainfall area have not called, then it is our responsibility to call them to find out if they have had any precipitation and the amount. When all of this has been accomplished, attach to daily report-sheet.

DURING PERIODS OF FLOODING OR RAPID RISES IN RIVERS:

Be sure dissemination of information is accomplished. (INSTRUCTIONS IN THIS MANUAL FOR FLOODING will give the points to be called for each stream in our River District when this situation arises.

Make sure all flood information involving rivers within our River District are included in the Reservoir Releases. If information is received from MKCR after Reservoir Releases has been sent, an additional message will have to be sent to all loops with the heading:
NOAA NATIONAL WEATHER SERVICE ST LOUIS (date & time)
ADDITIONAL RIVER FORECASTS

If in doubt as to whether a press release is necessary check with Anne, if she is here, Dennis Slaughter, or Mr. Brancato.

ON MONDAY

SEND COLLECT TELEGRAM GA 1-5000 to: PLATT'S OILGRAM 330 West 42nd St., New York, N.Y.

Degree Day ___________thru___________Total__________.
Seasonal Total__________, Month of__________Total__________.
Signed National Weather Service
St. Louis

We will receive schedule beginning Sept 1 thru May, which will be in front of Manual, pencil figures in opposite date for the message sent.

# HYDROLOGIC SERVICES

Lesson Seven, Forecasts

Reference: Chapters E-10, E-11, and E-13 Weather Service Operations Manual (also Chapter E-12 when available - meanwhile use paragraphs still effective in Chapter H03, Weather Service Manual), the attached statement, and "The Effects of Dams, Reservoirs, and Levees on River Forecasting" (Attached as Appendix A to this lesson).

Objective: To become familiar with the general regulations covering hydrologic forecasts and to learn some of the pitfalls inherent in river forecasting.

Discussion: Chapter H03 is being rewritten for inclusion in the Weather Service Manual of Operations Letters and should be published before all students have completed this lesson. The new chapters will be E-10, E-11, E-12. There will also be miscellaneous chapters on a glossary, hydrologic handbooks, and quality control for forecasts.

Many of the problems which a River District Office encounters while making hydrologic forecasts are unique to the area concerned. However, another group of problems has been encountered by almost everybody in the hydrologic program, and general solutions have been or will soon be written for these problems. These solutions should generally be used uniformly throughout the country. For example, in order to satisfy the requirements of the news media, the term "bulletin" is to be used in the heading when and only when the hydrologic product requires rapid transmission to save life and/or property.

Work Assignments:

1. Read the reference material.

2. Answer the questions for this lesson.

HYDROLOGIC SERVICES

Lesson Seven Statement - Forecasts

It should be recognized that some error is inherent in nearly all forecast procedures. It is necessary to use subjective judgment in the final phase of making an operational forecast. After the forecast is made you should consider how best to present it to the public so that they will derive the maximum benefit from your knowledge and judgment. A few important aids to producing good forecasts follow:

1. Plotting Hydrographs

An important factor in river forecasting is to keep the hydrographs up-to-date for each forecast point. Each new forecast hydrograph should be penciled in on the same sheet to see that it is reliable in the light of what has actually happened up to the time of issuance. This is even more important for the River District Office that disseminates the forecast than it is for the River Forecast Center that prepares the forecast.

2. Scheduled Priorities

A prearranged priority should be used in making the forecasts for several points. In general, flash flood and headwater forecast points should be handled first, since there will be more time for making the forecast and more time for action by the public at downstream points. If there is plenty of time to exploit the available data and make the best forecast, take the necessary time to do so.

3. Minimum Forecast Revision

Once a forecast is compared with the actual hydrograph of the river up to the forecast time, it is usually possible to determine, with a high degree of confidence, the probable maximum and probable minimum stage that will occur from the rain that has fallen. If the time of crest is several hours away, and especially if more rain is expected, it is best to issue a forecast that is conservative in view of the brackets thus obtained. Upward revision can still be made later, if necessary, in plenty of time for warning. This approach helps to avoid a situation in which a forecast may be lowered only to find a few hours later, it must be revised upward again. Such revisions are very confusing to the public and fail miserably to build confidence in our product. A good rule of thumb is to not revise a forecast if the revision is within the range of estimate.

4. Review and Analysis

After each significant runoff event, all forecast procedures involved should be reviewed. Make analyses of any deficiencies that may be discovered and amend the procedure if necessary. Such an amendment should be reviewed by your RFC before final adoption.

5. Practice Forecasts

Work through all the forecast procedures for points in your area at the beginning of the flood season. This will refresh your memory and bring skills back to peak efficiency before they are required.

6. Check River Conditions

Before the forecast is finally released, check the following items to see that recent events have not invalidated the forecast:

a. Have any flood protection works failed?
b. Has the release schedule from an upstream reservoir been changed?
c. Is there a downstream reservoir change or ice jam to cause backwater effect?

## HYDROLOGIC SERVICES

Lesson Eight - Dissemination

Reference: Weather Service Manual, Chapters E-30, E-31, E-32, old Chapter H-05, and the attached statement.

Objectives: To study the regulations for dissemination and to seek the most efficient manner in which this function can be accomplished.

Discussion: After the data are collected and analyzed and a forecast made and written into an intelligible form, there still remains the all-important final function of getting the word out to the people concerned. At a River District Office, the more important non-routine but significant river forecasts must often be distributed at very inconvenient times. In order to lessen the conflict between this and other important duties, procedures should be preplanned and streamlined to the greatest extent possible. Short warning lists are preferable if they are properly designed, so that recipients relay forecasts to other interested parties. This is but one of several points to be considered when setting up or reviewing dissemination service.

Work assignments:

1. Read the reference material.
2. Answer the questions for this lesson.

# HYDROLOGIC SERVICES

Lesson 8 - Statement on Dissemination

Dissemination is the final step of a complicated procedure in which river and rainfall reports are collected and relayed to the forecaster, the data analyzed, and a forecast made and finally disseminated through the River District Office to the general public and/or special users. In order to be of maximum value the forecast must be both timely and easily understood.

It is obvious that in order to satisfy the timeliness requirement, a forecast must be in the hands of the user in time so that he can take action to save life and property. As was discussed in lesson 7 and elsewhere, some forecasts can be issued days in advance. In flash-flood areas, at the other extreme, the user must be helped to make his own forecast because of the short time left for action after the rain occurs. In these areas, it is important to keep the user up-to-date on antecedent conditions and when appropriate, to advise him of the rainfall necessary to produce significant stages. Arrangements should be made for radar operators to call the user direct when heavy rain is observed in the headwater area involved and there is not sufficient time to issue warnings through the River District Office, or when the RDO is closed.

On rare occasions it may be desirable to utilize the Emergency Broadcast System. The procedure for arranging the use of this system should be worked out in advance with the local broadcast people. Step-by-step written instructions should be available for instant use.

Another factor to consider, when evaluating the timeliness of dissemination, is an attempt to meet press deadlines. Of course, many forecasts have to be issued when the need arises without consideration of this factor. However, the River District Official should be aware of deadlines for the various editions of his local newspaper, and particularly for radio and television news programs. Every attempt should be made to issue forthcoming forecasts and statements in time to meet these deadlines and thus assure the best use of mass media for dissemination.

In order for a forecast to be understood, it must be well-written. The statements should be as clear and concise as possible, and they should refer to any anticipated new forecast that will be issued later. Forecasts for different gages in the same town should be identified by the commonly used names of each of the gages involved.

Better understanding is also attained if one can instigate educational newspaper articles at the beginning of seasons with high flood potential. Subject material for such an article could well include a discussion of the forecast service, a list of all the points for which forecasts will be issued, a history of past floods and their crest stages, as well as the relation of various gage heights to areas subject to flooding. Such articles should be written when there is a change in the river regime or when any of the gages are moved.

Key users in outlying communities should have written notification of any changes in the regime or controls that will affect the forecast service in their area. An example of such a notice is shown in Appendix A. Dissemination procedures should also be reviewed after significant floods in a search for ways to improve the service.

Mass media of communications should be utilized to the fullest extent possible. This will reduce long warning lists which are somewhat self-defeating since their use decreases the timeliness of forecasts at the final phase. Frequent efforts should be made to initiate local teletype loops or to increase the coverage of those now in existence. Appendix B shows a brief example of an effort to find more customers for such a loop.

Another good device for improving dissemination is the making of arrangements to have other people relay warnings to a prescribed list of users. Appendix C shows an example of a flood-warning dissemination service performed by a Chamber of Commerce.

APPENDIX A

Mayor George Bugaile
New Eagle, Pa.

Dear Sir:

The community of New Eagle, Pa. located on the Monongahela River about 30 miles above Pittsburgh, Pa., is subject to flooding during periods of highwater. The most recent flooding occurred in March 1967 when New Eagle suffered heavy damage.

For the information of local officials, residents, and industry in New Eagle, the nearest river gage is Lock 4, Charleroi, located about 11 miles upstream from New Eagle. The upper pool gage was used as the reference gage during high water prior to the construction of the new high-lift dam at Charleroi. Crest forecasts were prepared and issued by the Pittsburgh Office of the Federal-State River Forecasting Service for the upper pool Lock 4 Charleroi gage. These forecasts were released to State Civil Defense officials for proper dissemination. Your community is located in Washington County and is under the jurisdiction of the Washington County Civil Defense Director.

With the expected completion of the new high-lift dam at Charleroi this summer and the discontinuance of the old Lock 4 installation, river forecasts will be made referenced to the lower pool gage of Lock 4, Charleroi. This will be a radical change from former conditions and perhaps will be confusing to your community for the first few floods. Flood stage will be established on the Lock 4 lower gage after the new river gages have been installed and we will notify you as to the critical stages based on this new gage.

Based on the existing Lock 4 Charleroi gage (upper pool gage) the March 7, 1967 crest was 35.6 and the March 16, 1967 crest was 23.5 (May 8, 1967 crest was 24.9). Other floods of record which affected your community were March 18, 1936 (34.3) and March 5, 1963 (33.8) - all referenced to Lock 4 upper pool gage.

Your community should contact the Washington County Civil Defense Director and establish an effective local flood warning and dissemination program. A map of your community should be prepared outlining the various areas flooded at certain river stages referenced to the existing Lock 4 Charleroi gage (upper pool gage). This map would be invaluable to your local disaster group and to the Civil Defense and Red Cross officials during times of severe flooding.

To expedite the flood warning program please contact your County Civil Defense Director, Mr. C. O. Bohner, 2198 N. Main St., Washington, Pa. 15301 and furnish him the name and telephone number of the person designated by you to be responsible for receiving flood information, such as the Police Chief, Fire Chief, or other person. Both day and night telephone number should be furnished as well as one or two alternate names and phone numbers to assure efficient service.

If this office can be of any assistance to you in setting up your program (especially in view of the new reference river gage), please advise and we will neet with you or your representative at your convenience.

Yours very truly,

Vernon T. Houghton, Jr.
Supervisory Hydrologist

APPENDIX B

NATIONAL OCEANIC AND ATMOSPHERIC ADMINISTRATION
UNITED STATES DEPARTMENT OF COMMERCE
NATIONAL WEATHER SERVICE

Pittsburgh, Pennsylvania

November 6, 1970

We believe you will be interested to learn that within the next few months we will be expanding the NOAA Weather Wire to a state-wide 24-hour-a-day service. We have long recognized that many news disseminators in cities distant from our offices desire more weather information than they presently receive to serve their public. The expanded NOAA Weather Wire Service makes it possible for all interested news disseminators to have the same level of timely and appropriate weather information.

The National Weather Service will pay for the long-line wire extension to the central telephone exchange in your city. The local line extension and teleprinter would be at your cost and all arrangements for completing the service into your office would be a business matter between you and your local telephone company. The telephone company long-lines representative in your city would be able to give you detailed cost information. The enclosure containx further information on service.

I hope to call on you in person to answer any questions you may have about the new NOAA Weather Wire. Because of the number of potential users to contact, it may be some time before I can make all the visits. In the meantime, please feel free to call me at 412-644-2882 if there is any further information you would like.

Paul F. Jacoby
Meteorologist in Charge

Encl:

# APPENDIX C

CHAMBER OF COMMERCE BUILDING
Pittsburgh, Pa.
Area Code 412-391-3400

January 13, 1971

TO: MEMBERS OF FLOOD WARNING SERVICE

FROM: CHAMBER OF COMMERCE OF GREATER PITTSBURGH

As a participant in the Chamber's Flood Warning Service, you are aware of the necessity of proper information concerning your personnel to be notified in case of an emergency.

To insure prompt service, we are enclosing four copies of our Flood Warning Data Form. Please complete the forms as soon as possible and return to James F. Egler, Manager-Urban Affairs Division, Chamber of Commerce of Greater Pittsburgh, Chamber of Commerce Building, Pittsburgh, Pennsylvania, 15219. Please keep one copy of the Flood Warning Data for your own files.

This information will enable us to continue this valuable service.

CHAMBER OF COMMERCE OF GREATER PITTSBURGH

FEDERAL-STATE FLOOD FORECASTING SERVICE

FLOOD WARNING DATA DATE: ________________

Firm Name ____________________________________________

Address ____________________________________________

Location of affected plants ____________________________________________

____________________________________________

____________________________________________

RESPONSIBLE PERSONS TO BE NOTIFIED IN CASE OF EMERGENCY:

Name ______________________ Title ______________________

Office Phone No. ______________________ Home Phone No. ______________________

Name (Second Alternate) ____________________________________________

Office Phone No. ______________________ Home Phone No. ______________________

Name (Third Alternate) ____________________________________________

Office Phone No. ______________________ Home Phone No. ______________________

All calls other than local will be made "Collect"

Critical stage at which warning is needed ______________________ Feet.

River gage used for above stage ____________________________________________

Stage at which actual flooding or damage occurs ______________________ Feet.

(Describe briefly the location of affected areas or property, and a general summary of the effect of various river stages to your firm. Use reverse side if necessary.)

# HYDROLOGIC SERVICES

## Lesson 9 - Administration

Reference : Weather Service Manual, Chapters H-01, H-02, Paragraphs H-0604 and H-0605, and Chapter H-07. (Substitute Weather Bureau Manual letters E-01 through E-09 and E-50 through E-59 when available).

Objectives: To become familiar with the rules and regulations under which the Hydrologic Services operate in the field.

Discussion: Much of the knowledge that is needed to run a River District Office is spelled out in the Weather Service Manual. The service has been expanding and the rules for running this service have been changing for several years and this trend is likely to continue. You should not only be familiar with the existing directives but plan to keep abreast of the changes as they occur. In some cases changes may be agreed upon and implemented before any formal directive is published. Such changes will be communicated to RDO's by memo, phone call, or personal visit.

Work assignments:

1. Read the reference material.
2. Answer the questions for this lesson.

# HYDROLOGIC SERVICES

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CHAPTER III

## HYDROLOGIC SERVICES

## HYDROLOGIC SERVICES

HYDROLOGIC SERVICES

WHO DOES WHAT

# CHAPTER I
# BACKGROUND AND HISTORY OF HYDROLOGY IN THE NATIONAL WEATHER SERVICE

## 1 Origins of the Weather Service

a. Introduction - Those who learn not from mistakes of the past must repeat them. History helps us not only to avoid past mistakes, but also to observe how success may have been achieved. History helps us understand the explanations and reasons for what we see today.

During the brief span of a few years, a situation may seem to be stable, but the perspective of history shows us that change is inevitable. We learn to accept change and adapt to it, and often to welcome it.

The thread of history shows trends and suggests future changes. Projecting the history of the Weather Service is like forecasting the weather and defining the climate. Beyond a short extrapolation we rely on other studies of past events to show the range and type of change that may be expected. Also, there is some security - and perhaps some inspiration - in ties with the past.

b. Early History - Dr. James Tilton, Surgeon General of the Army, initiated the first government collection of weather observations. During the War of 1812 he ordered his hospital surgeons to observe the weather and maintain climatic records.

In 1849, an extensive meteorological system was established by Professor Joseph Henry of the Smithsonian Institution. This was accomplished by supplying the telegraph companies with weather measuring instruments. In 1858 the Smithsonian began a practical application of meteorology by preparation of a daily exhibit of weather reports on a map of the United States. This application was terminated by the outbreak of the Civil War in 1861.

A Joint Congressional Resolution, HR 143, was introduced on February 2, 1870, authorizing and requiring the Secretary of War to provide for taking meteorological observations at Military Stations and other points in the United States and Territories of the United States, for giving notice on the Northern Lakes and on the Seacoasts by magnetic telegraph and Marine Signals, of approach and force of storms.

The Joint Resolution was passed by the House of Representatives and Senate, and signed by the President on February 9, 1870. The Weather Service was assigned to the War Department, Signal Service.

In 1884, Congress appointed a Joint Commission to review the scientific work of the Government. The report of the Commission, as issued in 1886, stated that the Weather Service did not belong in the work of the Military and that it should be considered as Civil Work because of its nature.

A number of Congressional bills were introduced but none was approved until the "Organic Act" of 1890. According to the provisions of this Act, the Weather Service was transferred from the Signal Corps to the Department of Agriculture. The transfer was effected on July 1, 1891.

## 2. Beginnings of Hydrology

a. Introduction - The management of water resources pre-dates the white man on this continent. Examples include pre-Columbian irrigation in the Southwest. In the white man's government, concern for water resources development began before attempts were made to forecast the weather. Early construction efforts are discussed in Chapter II, in sections relating to navigation, flood control and irrigation.

Early hydrologic work was unrelated to weather, and it was not until 1871 that the observing and reporting of river stages became a function of the Signal Service. This function was included in the authority, Oct. 1, 1890, of the Chief of the Weather Bureau, under the direction of the Secretary of Agriculture: ". . ; the gaging and reporting of rivers; . .".

b. Early Annual Reports - Excerpts selected from annual "Reports of the Chief of the Weather Bureau" testify to the resourceful and aggressive attack by our forebears on the problem of "reporting the rivers." The chronology and early perception of service needs are to be noted.

1891:

"Telegraphic reports of the stages of rivers at 26 places are received daily in the morning meteorological reports from Weather Bureau Stations.

"Predictions of stages for points on the rivers below the places are made from these reports, based on what has occurred in previous cases at points lower down, as shown by the records of river stages. The river and flood system includes the Mississippi River and its tributaries, the Savannah, and the Potomac.

"Special studies have been inaugurated with a view of determining more exact rules between the discharge and the stage of the rivers at various points, and thereby to make the flood forecasts of this service more accurate. A special study of weather types is also being pursued for the purpose of determining the meteorological conditions which are likely to be followed by extensive and heavy rainfalls over the drainage basins where floods are likely to occur. It is believed that in this way some improvements can be made, not only in the general forecast of rain, but also in the forecasts of probable extent and severity of floods.

"Important rises in the river are predicted three days ahead for Cincinnati, being based on the stages observed at Parkersburg, W. Va.;

Charleston, W. Va.; and Louisa, Ky. For Cairo, Ill., predictions of river stages are made six days in advance of their occurrence, and for Vicksburg, Miss., seven days in advance."

1897:

" The system of river and rainfall stations was revised at the end of the past year, such changes as were made going into effect on July 1, 1897. It was sought in this revision to secure a greater number of continuous records throughout the year. To do this without much increase of expense, some of the less important stations were closed.

" Beginning with the November 1896 issue of the Monthly Weather Review there has been included a monthly report on the conditions of the rivers of the United States, accompanied by a table of average and extreme gauge readings and range in the river stages at the various river stations. Since April 1, 1897 this has been supplemented by a hydrographic chart for selected stations on seven of the more important rivers.

" The river service is composed of 22 sections each with a central office receiving reports from a definite area and each making local forecasts for the river district under its supervision. In the case of impending great disaster, the Central Office at Washington dictates the important warnings for distribution by the section centers."

1899:

" The River and Flood Service did not develop any features of special interest during the year on account of the absence of great floods. Considerable improvement has been made in many of the river gages, and the service has been extended by the establishment of several new special river stations, particularly in the South Atlantic States, where the additional stations are being operated in cooperation with the U. S. Geological Survey.

" During the next two years, if sufficient funds are available for the purpose, it is proposed to prepare a comprehensive work on the entire navigable water regime, giving a complete history of all river stations, elevations above tide water, rate of flow of water, and data for flood forecasting.

" It is also proposed to measure the discharge of water at various places along the Ohio River. No work of this character has yet been undertaken, although its importance has long been recognized. Data of this character is also greatly desired by the U. S. Geological Survey, and the work will be prosecuted in cooperation with that branch of the public service."

To depart at this point from the presentation of these excerpts, it is instructive to view some of the lessons of history: It is not easy for a legislative body to divide technical work into mutually exclusive categories. Are rivers to be viewed as a flood hazard for the Weather Bureau to warn of, or as a resource for the U. S. G. S. to measure? Later it will be shown that rivers have many more aspects than Aesop's elephant displayed to the three blind men. Literally countless agencies are involved in one way or another with water resources. If their total job were to be divided on the basis of segments of a water-resource spectrum, there would be complications in separating other, though water-related, segments of the public service, such as construction of public works, agriculture, water supplies, and pollution abatement.

In the second year of the organized service (1892), recognition was given to the advantages of expressing river flow as discharge rather than stage in forecasting procedures involving flood routing. It would seem that the Weather Bureau in its early river forecasting activities had anticipated the need for data of this character and had expressed that need in its organic law, "*** the gaging and reporting of rivers." However, the report of 1899 indicates that the Geological Survey had meanwhile become interested in the water resources of the country, and the determination of stream discharge thenceforth became a responsibility of that agency.

The Act of March 3, 1879, creating the Geological Survey, did not define specifically its responsibilities in the water resources field. Annual appropriation acts, beginning with 1888, have authorized the use of appropriated funds for water resources investigations. Beginning with the fiscal year ending June 30, 1895, successive appropriation bills passed by Congress carried the following items:

> For gaging the streams and determining the water supply of the United States, and for the investigation of underground currents and artesian wells, and for the preparation of reports upon the best methods of utilizing the water resources.

Through subsequent years, the availability of river gaging stations and exhaustive stream discharge records of the Geological Survey have been important factors in the operation of the River and Flood Forecasting Service. The Survey operates its stream gaging program for the primary purpose of providing discharge records of the streams of the United States, while the river gages maintained by the Weather Bureau are operated primarily to provide a basis for the formulation of forecasts and a yardstick for announcing their expected severity.

In carrying out its main objective, the Geological Survey selects its river gaging stations so as to obtain accurate and comprehensive records of discharge, while the Weather Bureau in selecting its river stations must consider the need for forecast service, the availability of competent reporting observers, accessibility during high water, communication facilities, and the representation of drainage areas or damage sites having special significance for forecasting purposes. It is a long established policy that the Weather Bureau and the Geological Survey shall use same stations wherever possible. As a matter of fact, there is very little duplication of effort, in spite of some similarity in objectives. Each agency consults the other when new stations are established, and existing stations are consolidated whenever possible.

Another lesson of history is the ebb and flow of fiscal fortunes with the random occurrence of extreme events. Instead of recognizing floods and droughts as events that can occur at any time, and not waiting for disastrous reminders, there is a public tendency to follow the roof-mending practice which has been observed and reported by the Arkansas Traveler. The great floods of 1903 stimulated pressure to expand the River and Flood Service.

Continuing the excerpts:

1903:

"The work of the River and Flood Service, owing to the recent numerous and disastrous floods, has of necessity been a very prominent feature of the year. In no instance was the coming of a dangerous flood unheralded. The warnings were uniform, prompt, and timely, and in the main, remarkably accurate. The forecasts of the great floods of March, April, and June 1903 afford noteworthy examples of the efficiency the River and Flood Service has attained, and are later made the subject of more extended mention.

"The best recommendation that can be given work of this character is a demand for the broadening of its field of operations, and the extension of its benefits to localities not yet favored. Such demands have been constant and persistent, yet lack of the necessary funds has rendered it impossible to meet more than a small percentage of them. In several instances the limitations placed upon the work by lack of funds have seriously handicapped its efficiency and thereby caused loss of lives and property that might otherwise have been saved.

"The demands for the extension of the river and flood service are utterly beyond the ability of the Bureau to supply. A new service should be at once inaugurated on the Kansas and its tributaries, on the Delaware, and in other localities, and additional stations supplied to many of the already existing districts. The telegraph service should also be extended. The work of the Service should also be broadened so as to embrace other and very necessary coordinate branches.

"Another important field as yet imperfectly developed, but one of the first importance to the student of river regime, is that of the connection of rain and snowfall with the varying stages of the rivers. The winter snows in the mountains are often the controlling factors in our early spring floods, and numerous stations of observations must be provided. Of equal importance are reports of heavy rainfalls along the headwaters of the various streams. For this work a large number of special rainfall stations are necessary."

1910:

"The approaching completion of the irrigation projects in the Far West by the Reclamation Service imposed new responsibilities upon the Weather Bureau, namely, the obtaining of accurate snow measurements at the sources of water supply, the determination of the water equivalent of the accumulated snows of winter, and the gauging of the streams for the benefit of the water users. It has become a part of the duty of the River and Flood Division to determine as nearly as possible the amount of water that will be available each season for irrigating purposes. A sufficient supply of funds for the entire project has not yet been provided, but it has been proposed to conduct during the coming year at least one series of observations, probably in northern Utah."

1912:

"On June 30, river and rainfall observations were made at 483 regular Weather Bureau and special stations, of which 16 are cooperative stations. Rainfall observations were made at 93 special stations, of which 12 are cooperative stations.

"The river forecast schemes for the Ohio River and its tributaries were completed during the year and are now in use. Schemes for the interior rivers of the State of Ohio were also completed, and the scheme for the Savannah River is nearing completion."

1915:

"Instrumental Equipment: The experience of many years with respect to river gages may be stated thus;

1. Vertical staff gages are to be preferred when local conditions admit of their use.
2. Sloping gages of concrete construction, while expensive, are necessary in large streams like the Ohio and Mississippi, in the absence of bridges or docks.
3. Chain and weight gages, where they can be used, afford a simple and fairly accurate means of determining the level of the water. They should be frequently checked in order to secure accurate results.

"A first step in the accurate checking of the zeros of river gages has been taken in the appointment of an engineer to the service, with headquarters at St. Louis, Mo. It is estimated that at least two other engineers should be brought into the Service, so that eventually one each would be available for the Pacific Coast, the Mississippi Valley, and the Atlantic Coast States.

"The construction of a set of empirical rules for the forecasting of floods on the principal rivers of the United States was begun some years ago, and has been carried on continuously ever since. During the current year rules for the rivers of South Carolina have been completed and sent to the flood-forecasting center of that State for trial and such modification as may be found necessary.

"Forecasting rules have thus far been prepared for most of the principal rivers of the interior valleys."

1916:

"Sixty-two of the principal stations of the Bureau participate in the River and Flood work, and about 600 subordinate river-gaging and rainfall-reporting stations furnish the necessary hydrologic data for the respective watersheds. Flood warnings and all forecasts of river stages are issued by trained section officials and supervised in Washington, in the belief that constant supervision is necessary and helpful in maintaining the service at a high standard of efficiency."

1919:

"Owing to the unprecedented demand for engineers, it has not been possible to obtain from the outside persons having the necessary skill and experience to correct irregularities which invariably creep into the work of river-gaging stations. A return to the pre-war basis of having persons of engineering ability available at central points for service in keeping the system of river-gaging stations up to standard is urgently needed.

"The activities of the Bureau in determining the depth and density of the snow cover of high altitudes were restricted to the White Mountain region of Arizona, draining into the Roosevelt Reservoir, and to the headwaters of the Walker River of Nevada.

"Studies leading to the formulation of rules for forecasting floods almost wholly from the physical data of rainfall have been completed during the year for the Asheville, N. C. district."

Digressing again, we see the effects of the war, inflation following the war, and then the depression. Continuing the excerpts:

1922:

"The compilation of the histories of about 500 river stations has been brought to virtual completion and now serves to bring within a very small compass a large mass of valuable material that was unavailable and liable to loss.

"More river-gaging stations and much more intensive measurement of precipitation are needed. As it is, the service is virtually at a standstill so far as field extensions are concerned. One vital need is that of an engineer who can serve as a field man, inspecting stations, making repairs to equipment, and making surveys for the establishment of permanent benchmarks and other measurements of precision. These surveys are of highest importance in their relation to projects involving water supply for irrigation and power purposes."

1933:

"There have been demands for an expansion of the flood-warning service, but it has been impossible to meet them on account of lack of funds available for the river work. In fact, in June 1933 it became necessary to reduce the expenditures for this work by $12,562, which represents a reduction of almost 20 percent under the amount authorized for 1933, and the Bureau enters the fiscal year 1934 with a greatly changed organization for river work. In effecting the necessary reductions an effort has been made to trim the work where the least harm to the public interest will follow."

1934:

"On June 30 reports from 709 river gages were available. Of this number 626 were read by the Bureau and 83 were read by other agencies, principally the Engineer Corps of the Army. 98 are available only in times of threatened or actual floods; 482 are available daily throughout the year, and 129 are available daily in the months that may be said to constitute the flood season.

"In September 1933 the Public Works Administration gave the Bureau an allotment of $150,000 for replacing river gages with structures of a substantial and modern type. Work under this allotment has progressed actively, and on June 30 the following river gages had been erected:

| Type of Gage | Number Erected |
|---|---|
| Staff | 76 |
| Weighted Chain | 9 |
| Weighted Wire | 97 |
| Recording | 47 |
| Total | 229 |

1935:

"In the United States a flood caused by snow alone is rare, and the forecasting of floods caused by rain falling on a snow mantle cannot be reduced to a formula.

"Continuous records of river stages are being obtained from recording stations constructed in the last two years with funds alloted by the Public Works Administration. A similar advance in strengthening the method of measuring rainfall would not only make possible the refinement of flood forecasts in primary drainage basins, but would also be of inestimable value in agriculture, soil conservation, and all branches of hydraulic engineering.

"The needs of the flood forecaster alone seemed not to have had enough weight to bring about the installation of the required number of recording rain gages, but in the last few years other users of rainfall data have individually been making insistent demands and endeavoring to provide means for the establishment of a network of these gages."

1937:

"The great floods in the Eastern States in March 1936 and in the Ohio and lower Mississippi Valleys in January and February 1937 have forcefully brought to the foreground the necessity for establishing hydrologic districts throughout the whole of the country with the least possible delay.

"During the past year increased funds have made possible a beginning of a program to organize the United States into eight hydrologic districts. Within each district an intensive study of the relation of rainfall to run-off will be made, the results of which will be utilized in the development and improvement of river-stage forecasting methods. Two of these districts, one located in the Missouri Valley and the other in the upper Mississippi Valley, have been organized and good progress has been made in the work during the comparatively short time they have been in operation."

1938:

"Reorganization of the River and Flood Service, which is responsible for the prediction of flood and navigation stages in the rivers of the United States has progressed effectively in three directions; (1) Refinement of the observation and reporting system of effective rainfall in upstream basins of major drainage areas; (2) the analysis of rainfall and storm data for use by the Army in the design of flood control works; (3) expansion of the mountain-snowfall services in the West."

Another digression:

The Flood Control Act of 1938 authorized the Chief of Weather Bureau, with funds transferred by the Chief of Engineers, to establish, operate, and maintain precipitation observing stations and provide a flood warning service. Continuing the excerpts:

1939:

"Reorganization and expansion of the river and flood service, which is responsible for the prediction of flood and navigation stages in the rivers of the United States has continued to progress in its threefold program: (1) Refinement and expansion of the observation and reporting system of effective rainfall in upstream basins of major drainage areas; (2) hydrometeorological analysis of rainfall for use by the War Department and the Department of Agriculture in the design of flood control works; (3) expansion of the mountain-snowfall service in the West.

" The flood forecasts issued by the Weather Bureau are of proven economic value. In addition to minimizing or preventing the loss of human life by providing opportunity for evacuating threatened areas, the advance flood predictions enable manufacturers and warehousemen to remove perishable goods; such forecasts also provide essential warnings for the safeguarding of navigation and the construction and operation of emergency protective works.

" In order to maintain the flood-warning service at the greatest possible efficiency under existing appropriations, the River and Flood Division endeavors to extend its facilities into new areas and to improve forecasting methods through research. Research has progressed along two lines: (1) hydrometeorological studies conducted in cooperation with the Corps of Engineers of the Army and the conservancy agencies of the Department of Agriculture for the purpose of determining, by hydrometeorological methods involving air-mass analysis and transposition of storms, the maximum flood-producing characteristics of regions in which there are flood-control projects; (2) rainfall run-off studies conducted at the hydrologic regional centers of the River and Flood Division. These studies systematically attack the problem of determining river stages from rainfall data, which thus become the basis of flood-forecasting procedures in headwater and tributary basins. The older method of forecasting by gage relationships is not adequate for present-day needs, especially in headwater areas, where periods of concentration are short. It is in these headwater areas, however, that flash floods occur, often with destructive effects far out of proportion to the size of the streams involved."

3. Recent Developments in Hydrologic Services

Effective June 30, 1940, the Weather Bureau was transferred by Reorganization Plan IV of President Franklin Roosevelt, from Agriculture to Commerce. This action, of course, recognized the growing importance of weather forecasting to air commerce, and its purpose had nothing to do with water resources. The Plan recognized hydrologic functions, however, and provided that the Department of Agriculture continue snow surveys, and conduct research concerning: (a) relationships between weather and crops, (b) long-range weather forecasting, and (c) relationships between weather and soil erosion.

In the 1940's three significant developments occurred: One was increasing recognition by other agencies of the Weather Bureau as the single source of streamflow forecasts to be issued to the public: 2, establishment of water-supply forecasting on a systematic and objective basis; and 3, establishment of the first River Forecast Centers.

a. Official Forecasts - It seems axiomatic that a person or agency responsible for operating a facility should have authority to make or choose the forecasts necessary for decisions pertinent to that operation. Thus, the Corps of Engineers, for example, with responsibility for flood control operation of a reservoir, needs to know the expected inflow to the reservoir, and to the tributaries downstream. Also responsibility for sandbagging a threatened levee requires forecasts of stage, and the agency doing the sandbagging has a right to determine whether it is necessary.

If more than one agency makes public forecasts for the same event, the public gets confused, and then inevitably complains about waste of public funds in paying for duplicate efforts. To put the issue in a more positive vein, one agency should be given the authority to issue forecasts, and should be granted the facilities to do the best job for the money.

In 1948, statutes of the criminal code (18 U. S. C. 2074, June 25, 1948) specified that the Weather Bureau ". . . shall have charge of forecasting the weather, the issue of storm warnings, the display of weather and flood signals. . .". It is illegal for others to issue false forecasts, or alternative forecasts. It is not illegal, of course, to comment on a forecast, but there is only one source of an official forecast.

Where does this leave our reservoir operator, and levee maintenance man? He has two choices. One is to use the Weather Bureau forecast, and the other is to find another forecast or use his own if he wishes to make one, but he may not pass this other forecast along to the public as the official forecast. He may, and commonly does, disseminate the Weather Bureau forecast, as do the police and civil radio, and other channels of communication. He should make it clear, though, that the forecast given the public is the official Weather Bureau forecast.

Conversely, if a levee is threatened, and the public expresses concern, it is the responsibility of the Corps of Engineers, for example, to indicate what fate is expected of the levee. The Weather Bureau forecast, of course, is affected by levee failure, and the Bureau forecaster must make his own decision as to whether to assume failure or not, but he does not give this information to the public. This is the Corps' prerogative. Of course, such questions are the subject of inter-agency discussion and exchange of advice, at critical times.

In reservoir operation, particularly where multiple purposes have conflicting objectives, it is advantageous for an impartial agency to make the forecast. For example, flood-control operations require storage space rather than a full reservoir between floods, efficient hydroelectric power generation requires a full reservoir yet allows drawdown during periods of low inflow, and other interests prefer other types of control and regime. Similarly, downstream interests, and the reservoir operators, want assurance that flood damage with the reservoir will be no worse than before it was built. Thus, in addition to making forecasts of reservoir inflow, many places require "forecasts" of what the natural flow would have been. More will be said later about the role of forecasting in river management.

<u>b. Water Supply Forecasts</u> - The lag between accumulation and melting of winter precipitation provides the basis for forecasting, months in advance, the volume of water available for irrigation, hydro-electric power, municipal and industrial water supply, and many other purposes, particularly in the West. These forecasts are made at the beginning of each calendar month, January through May.

These forecasts not only serve reservoir operators and the general public, but also are an integral step in allocating daily increments of expected seasonal flow for flood warnings and other short-range forecasts.

<u>c. River Forecast Centers</u> - In 1946 River Forecast Centers were established at Cincinnati and at Kansas City, Missouri. Until this time river forecasts were made at widely dispersed River District Offices, incidental to other work, and with varying degrees of competence and interest. The River Forecast Centers are staffed by professional hydrologists who concentrate on river work. They have few public contacts, and are thus insulated from demands for special advices during busy periods. In addition to making routine and special forecasts, when time is available the people at these Centers work on improved procedures. The River Forecast Centers work closely with the River District Offices which assist in the gathering and transmittal of data, and in disseminating and at times modifying the forecasts. The working relationships, and other details of River Forecast operations, will be described in Part Three - Service Operations.

<u>d. Trend in Forecasting Skill</u> - In this discussion of historical trends, it seems appropriate to indicate the trend and status of river forecasting skill. To provide an example we may refer to a recent verification of river forecasts for a group of ten stations near Indianapolis, served by the Cincinnati River Forecast Center. This River Forecast Center was one of the first two to be established. While a great variety of forecasts are now being made, flood crests one day in advance serve as the best example for comparison. Standardization requires the omission of instances in which rain during the forecast interval was a complicating factor.

Forecast errors have been examined for each of three periods. One period is 1930 through 1946, prior to establishment of the River Forecast Center. During this period river forecasts were made somewhat subjectively, and incidental to weather forecasting. The second period is 1949 through 1958, and covers the first ten years' operation of the River Forecast Center after establishment of objective procedures. The third period, 1959 through May 1964, indicates the present status of forecasting skill.

The following table gives the average error of forecast crest stages in feet, the bias in feet, and the percent of forecasts which had errors greater than one foot.

| Period | Average Error (ft.) | Bias (ft.) | % Errors greater than one foot |
|---|---|---|---|
| 1930-1946 | 0.75 | +0.53 | 18 |
| 1949-1958 | 0.56 | -0.02 | 16 |
| 1959-1964 | 0.44 | +0.07 | 9 |

Forecasts for intervals longer than one day, and those with which unexpected rain occurs during the forecast interval, naturally have larger errors than appear in the foregoing table.

In addition to the increase in forecasting skill, the overall service has been improved by substantially increasing the number and types of forecasts. A modern forecast service includes not only floods, but the times that certain critical stages are reached, rates of flow, velocities, continuous flow forecasts, and water supply forecasts.

These ten forecast points constitute an admittedly small sample of the more than 2200 points for which forecasts are made, but we have reason to believe that they are representative.

4. Present Status of Hydrologic Services

a. Summary - The Weather Service provides the Nation's public river and flood forecast and warning service. About three-fourths of the area of the 48 conterminous states is now served by twelve River Forecast Centers, where specially trained hydrologists concentrate on river forecasting. Each River Forecast Center has differing responsibilities and organization. Usually, the area served by a River Forecast Center is divided into several river districts each with a network of river and rainfall reporting stations.

A weather service office in each river district is designated as a River District Office and, in addition to its usual duties, maintains the river and rainfall reporting network. Network observers transmit rainfall, river and other pertinent hydrologic data to a River District Office from whence it is relayed to the River Forecast Center. Additional data are received from cooperating agencies.

The River Forecast Center analyzes the data by objective procedures and prepares forecasts which are disseminated locally by River District Offices to the public and to special agencies. Modern computing methods for the preparation of forecasts are being established as rapidly as facilities become available. Forecasts are issued for more than 1800 points. For that portion of the country not yet served by River Forecast Centers, forecasts are made and issued primarily by the River District Offices for an additional 400 forecast points.

In addition to widely known forecasts of flood stage, there is a growing need for continuous flow forecasts. At a number of points forecasts of rate of flow, as well as stage, are made daily for the ensuing several days for water resources management such as navigation and pollution abatement.

Forecasts of volume of runoff from seasonally melting snow are made for about 400 points in the west and northeast where irrigation, municipal and industrial supplies, and hydro-electric operations require knowledge months in advance as to the volume of water expected for the coming season. The River Forecast Centers at Portland, Sacramento, Kansas City, and Hartford, plus a unit at Salt Lake City, make seasonal water supply forecasts each month during the late winter and spring.

In a number of headwater areas, mostly in the midwest, the lead time for flash floods is too short for communications and preparation of forecasts at a distant center. At these places, simple rainfall-runoff procedures, prepared by River Forecast Centers, are used by local authorities upon radar alerts from the River District Offices, and crest-stage warnings are prepared and issued locally.

In addition to streamflow forecasting, the Weather Service renders specialized hydrometeorological service, largely through transfer of funds, to cooperating agencies such as the Corps of Engineers for planning and design criteria. This service includes estimates of probable maximum rainfall and snowmelt, hurricane winds, storm rainfall intensity-frequency, and reservoir evaporation. Many of these studies formerly appeared in Hydrometeorological Reports, Technical Papers and Research Papers. They are now printed in Technical Memoranda and Technical Reports.

A mission-oriented research program in the Research and Development Laboratory of the Office of Hydrology, River Forecast Centers, and other field stations provides a basis for continuing improvement in forecasts and other service.

b. River Forecasting

(1) Services

The best-known of these services is the forecasting of floods. This is the most dramatic and perhaps the most beneficial of the river forecasting services. By beneficial we mean the saving of lives, and of property damage that would occur but for the forecasts. During a flood or threat of flood, people work around the clock, get special observations, and issue frequent advisories and warnings. During a long and severe flood, special professional help from other offices may be detailed to a flood area, from a region not under emergency, to relieve people who may have been on duty for long hard hours.

The essence of any forecasting service is continual surveillance. Worse than a poor forecast, or even a late forecast, would be for a forecaster to be unaware of an event he should be forecasting. Not only must the river forecaster maintain daily watch on the rivers and on weather that affects river flow, but many riverside activities require daily forecasts, whether the river is going up or down or not changing. Thus forecasts are made each weekday morning and on other mornings when appropriate. They are required for daily reservoir operations, regulation of power, water supply, navigation, riverside industries, and construction and maintenance in and along a river.

Extended forecasts of low-water stages or flow are made for navigation, planning of special reservoir releases to maintain required minimum flow, for water supply, and for coordination of storage or releases of pollutants.

Forecasts of seasonal and water-year runoff have been discussed earlier. These forecasts are necessary for forecasts in which daily increments of the expencted season's volume of flow are distributed according to expected snow melting conditions and storm rainfall. In Columbia Basin, 30-day outlooks are prepared in cooperation with the Corps of Engineers. These outlooks are necessary for planning reservoir regulation. Forecasts of the seasonal peak flow at key points are made months in advance.

Forecasts are made of natural flow in regulated streams as a guide to control operations and evaluation of their effectiveness.

Forecasts of river-ice formation and dissipation are made for shipping and riverside industry.

In areas where tide and storm surges in estuaries are important, the effects of wind as well as of runoff are considered in making forecasts of stage in low-lying areas.

The alertness which characterizes continuous surveillance has made it possible to issue special warnings when accidental spills of harmful chemicals in rivers have threatened the quality of municipal water supply.

(2) Operations

Operations will be described in more detail in later Parts of the Course. Briefly, they consist of data gathering by River District Offices and collection centers, transmittal to a River Forecast Center, preparation of the forecast, transmittal of the forecast from the River Forecast Center to the River District Office, and dissemination to the public through news media and teletype loops, to other agencies, and to downstream River Forecast Centers.

River District officials are knowledgeable and commonly discuss the forecasts with the River Forecast Centers before they are issued. On some occasions it is quickly evident to River District officials that serious flooding is imminent, and they issue warnings promptly on the basis of scattered reports. A few hours later, after more data have been received, and forecasts prepared by the River Forecast Center, the warnings are refined and expressed in quantitative terms. Figs. 1 and 2 show the flow of data and of forecasts, and the cooperation between the River District Office and River Forecast Center.

The typical River Forecast Center works exclusively on river forecasting. It is staffed by highly trained hydrologists and equipped with a computer. It has limited public contacts. The work is the analysis of meteorological and hydrologic data, preparation of forecasts, improvement of procedures, and changing of procedures to meet conditions of changing river regime.

The typical River District Office performs many services, of which the river work is only one. Its river work consists of maintaining a network of observing stations, collecting and relaying data to an RFC, and disseminating the river forecasts. The River District Office has many public contacts.

Several River District Offices, each covering a tributary drainage area of about 10,000 to 100,000 sq. mi., generally work with one River Forecast Center. In addition to this typical working relationship there are others. Operations are tailored to meet local needs and circumstances. As indicated earlier, part of the country is not covered by River Forecast Centers. Several River District Offices thus perform the functions of River Forecast Centers. In new England, and in other places, the River Forecast Center performs functions of a River District Office. Figure 3 is a map which shows the location and area responsibilities of stations in the river forecasting system.

(3) Reduction of flood damages by forecasts

Flood damages are prevented or reduced by actions and measures taken as a result of advance warnings. They include evacuation of people and goods, flood fighting by temporary means, such as barriers of sandbags or boards, or packing machinery in grease; and rescheduling of operations or rerouting of transport. Table 1 indicates the relative susceptibility of flood loss, in certain economic areas, to reduction by emergency measures.

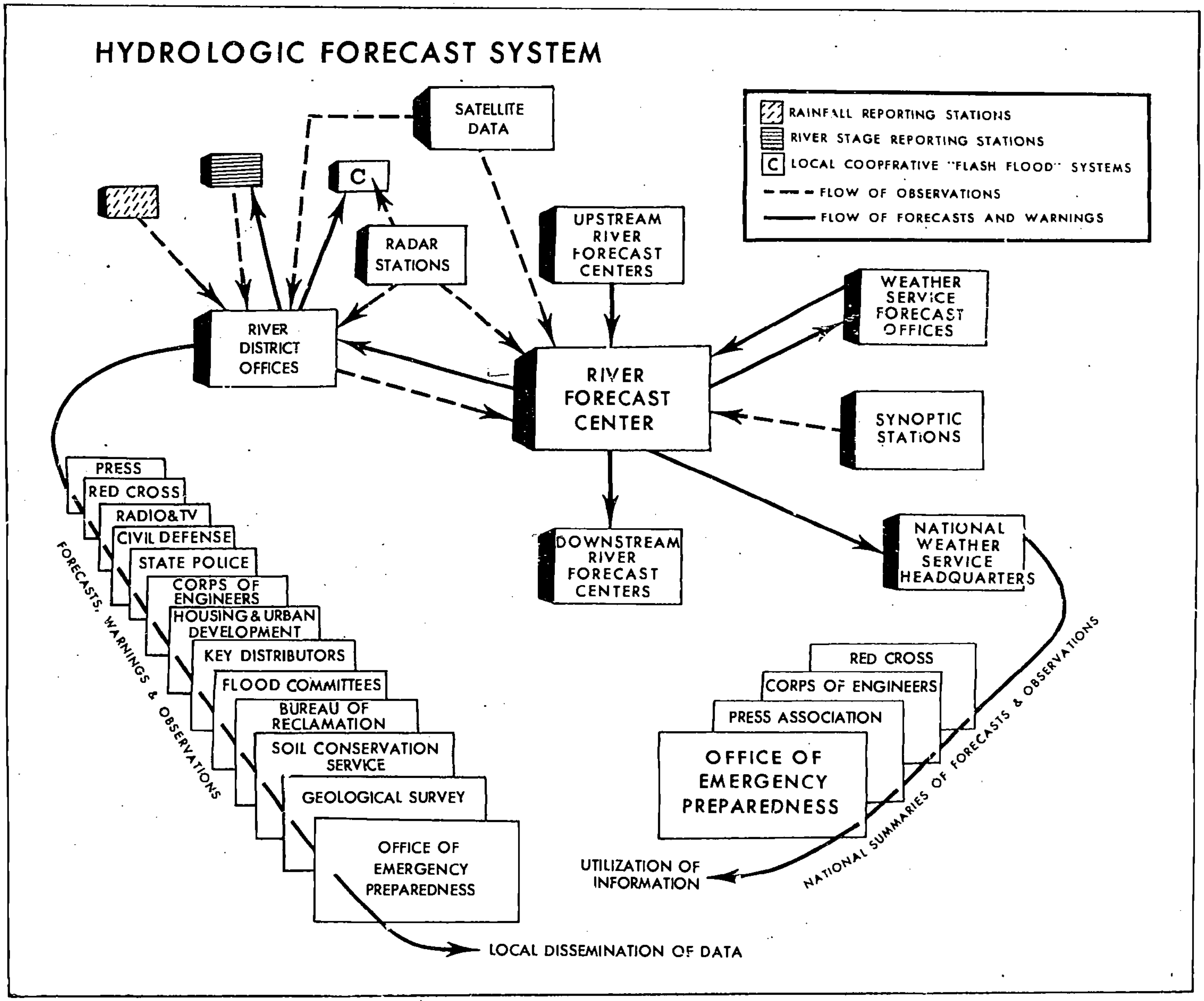



FIGURE 1. Flow of information in river forecasting.

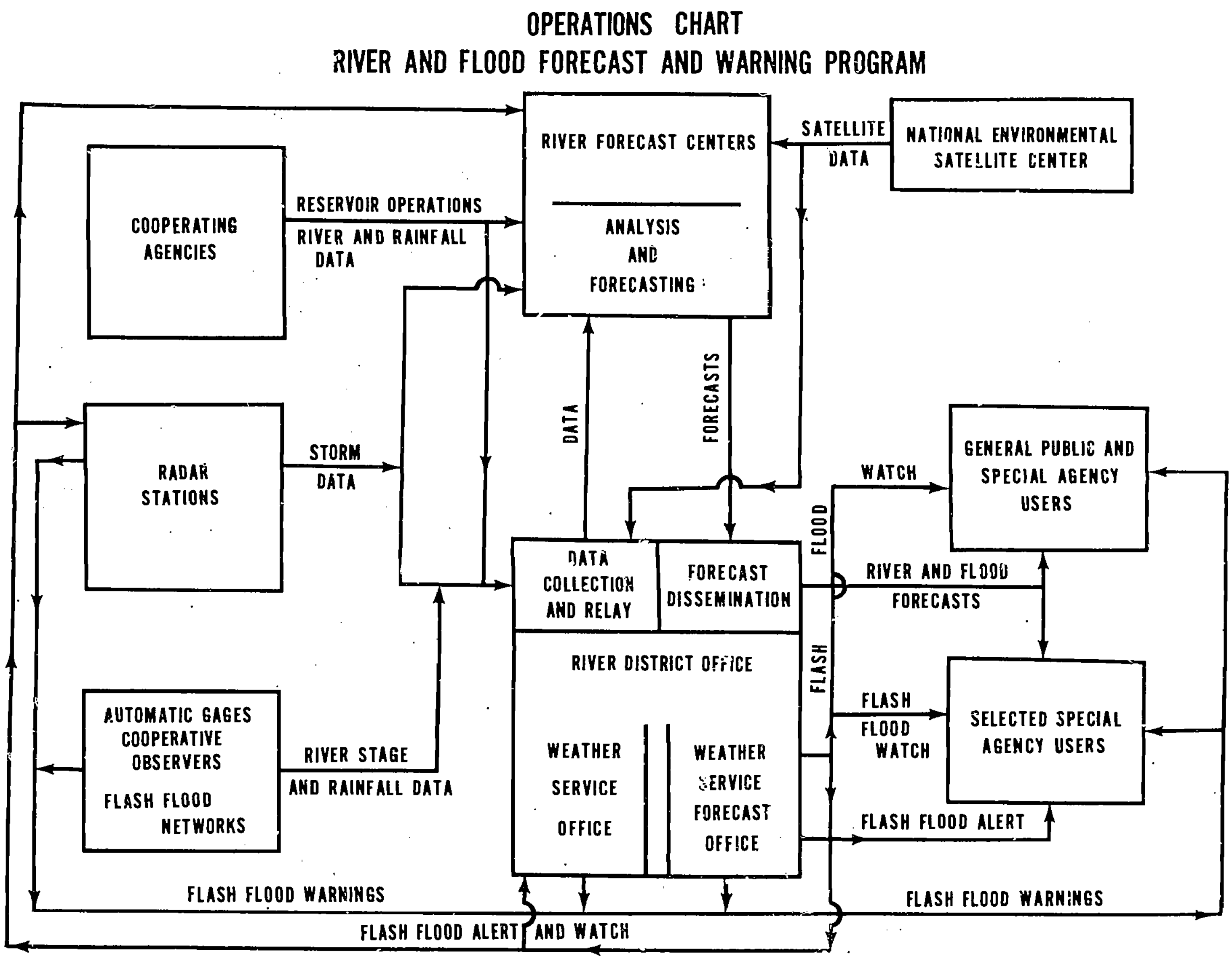



FIGURE 2. River and flood forecast operations chart.


RIVER AND FLOOD FORECAST SERVICE
U.S. DEPARTMENT OF COMMERCE
LEGEND
GULF OF MEXICO
PACIFIC OCEAN
PORTLAND
SACRAMENTO
SALT LAKE CITY
KANSAS CITY
TULSA
FORT WORTH
CINCINNATI
ATLANTA
LOWER MISSISSIPPI
LAKE SUPERIOR
LAKE HURON
LAKE MICHIGAN
ALASKA
ANCHORAGE
HAWAII

FIGURE 3

Since 1903 the WeatherService has atte annual flood damage and savings figures. They are the o... - this type regularly published and have the merit of continuity, national coverage, and consistency in manner of collection. However, they are deficient in coverage of agricultural damages, indirect losses, and headwater and isolated flash flood areas. For the 15 year period 1951-65, these figures show annual flood damages to be approximately 450 million dollars and average annual savings resulting from forecasts to be 57 million dollars, in terms of 1971 values. In other words, the annual savings due to flood forecasts and warnings are more than 10 percent of the annual damages. Since the total budget of the Weather Bureau for hydrologic services is now approximately 4 million dollars, the benefit to cost-ratio is approximately 15 to 1.

Since these figures for flood damage and savings represent long-term averages for only a portion of the people and organizations effected, values for the country as a whole can be expected to be much larger. Also, due to expansion of population and increased use of flood plains, current losses are much greater. The report on "Insurance and Other Programs for Financial Assistance to Flood Victims" by the Senate Committee on Banking and Currency, (p. 27) states that the upward trend in flood damages can be calculated as about 5-1/2 percent annually. Hoyt and Langbein, in Water Facts for the Nation's Future (1955), state: "Assuming the Corps of Engineers' 'downstream' estimate and the Department of Agriculture's 'upstream' estimates are mutually exclusive, in part, we may conclude that the average annual flood damages in the United States exceed one billion dollars." The Comprehensive Report of the Arkansas-White-Red Basins Interagency Committee (1955) estimates annual flood damages to be over one billion dollars of which an estimated five percent is to movable property, which can be saved on the basis of flood warnings issued sufficiently in advance of each flood. Benefits resulting from the forecasting service to the operation of flood control projects or to the flood proofing of stationary property were not evaluated. House Document 465, 89th Congress, A Unified National Program for Managing Flood Losses, states categorically that current losses from flood amount to more than one billion dollars per year.

It is clear that the generally accepted value for flood losses is one billion dollars annually. Using the extremely conservative figure of 5 percent of average annual damages, savings due to flood forecasts and warnings would amount to more than $50 million annually yielding a benefit-to-cost ratio of more than 17:1.

These benefits may be even greater for sections of the country which experience rather frequent flooding and whose inhabitants have been organized to react promptly and properly to flood warnings.

The Pittsburgh River District has compiled rather complete figures for the period 1947-66, showing average annual flood damages of 5 million dollars and an average annual saving, due to flood forecasts and warnings, of 5 million dollars within its area of responsibility. Savings have averaged almost 100 percent of damages during this period and yield an average annual benefit-to-cost ratio of 100 to 1.

Carnegie Institute of Technology conducted a comprehensive study of flood damage in Meadville, Pennsylvania, a community of 16,000. This community was selected because it contains a representative sampling of

TABLE 1. Reduction of flood losses by actions based on river forecasting. (From G. F. White, "Human Adustment to Floods," University of Chicago Press, 1945)

| Class of loss* | Degree to which loss may be reduced by emergency-measures based on timely and accurate flood-forecasts: Large | Medium | Small or none | Emergency-measures |
|---|---|---|---|---|
| **Agricultural** | | | | |
| 1. Crops | | | | |
| a. Unharvested mature crops | - | x | - | Re-scheduling - 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 | Re-scheduling - Delay in planting |
| 2. Stored crops | x | - | - | Removal |
| 3. Orchard | - | - | x | - |
| 4. Farm timber | - | - | x | - |
| 5. Livestock & livestock products | x | - | - | Removal |
| 6. Residence - see "Urban Residential" | | | | |
| 7. Furnishings | x | - | - | Removal |
| 8. Personal belongings | x | - | - | Removal |
| 9. Other farm buildings | - | - | x | - |
| 10. Farm machinery & equipment | x | - | - | Removal, Protection |
| 11. Automobiles, trucks, wagons, boats | x | - | - | Removal |
| 12. Fences, roads & outdoor improvements | - | - | x | - |
| 13. Drainage & irrigation works | - | - | x | - |
| 14. Land | - | - | x | - |
| 15. Non-farm income | - | - | x | - |
| 16. Evacuation & re-occupation | - | - | x | Re-scheduling |
| **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 | - | - | Removal |
| 4. Garage & other buildings | - | - | x | - |
| 5. Automobiles, wagons, trucks | x | - | - | Removal |
| 6. Grounds & outdoor improvements | - | - | x | - |
| 7. Loss of property income | - | - | x | - |
| 8. Evacuation & reoccupation | - | - | x | - |
| **Retail & 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 | - | - | Removal |
| 7. Grounds & improvements | - | - | x | - |
| 8. Business interruption | | | | |
| a. Production of goods & services | - | x | - | Re-scheduling |
| b. Productive equipment & supplies | - | x | - | Protection, removal, re-scheduling |
| c. Excess cost of delayed sales | - | - | x | - |
| 9. Evacuation & reoccupation | - | - | x | - |
| **Manufacturing** | | | | |
| 1. Buildings - see "Urban Residential" | | | | |
| 2. Office furnishings & records | x | - | - | Removal |
| 3. Plant machinery | - | x | - | Removal, protection |
| 4. Stock of raw materials or finished goods | x | - | - | Removal, protection |
| 5. Minor buildings | - | - | x | - |
| 6. Automobiles, wagons, trucks. etc | x | - | - | Removal |
| 7. Grounds & improvements | - | - | x | - |
| 8. Business interruption | | | | |
| a. Production of goods | - | x | - | |
| b. Productive equipment & supplies | - | x | - | |
| c. Excess cost of delayed production | - | - | x | |
| 9. Evacuation & reoccupation | - | - | x | |

| Class of loss* | Degree to which loss may be reduced by emergency-measures based on timely and accurate flood-forecasts: Large | Medium | Small or none | Emergency-measures |
|---|---|---|---|---|
| **Public Buildings & Grounds** | | | | |
| 1. Building - see "Urban Residential" | | | | |
| 2. Furnishings | x | - | - | Removal |
| 3. Equipment | - | x | - | Removal, protection |
| 4. Stocks of supplies | x | - | - | Removal |
| 5. Public records, books or other valuables | x | - | - | Removal |
| 6. Minor buildings | - | - | x | - |
| 7. Grounds | - | - | x | |
| 8. Automobiles, wagons, trucks, etc | x | - | - | Removal |
| 9. Evacuation or reoccupation | - | - | x | |
| **Public Services** | | | | |
| 1. Indoor equipment, housing & grounds | - | x | - | Protection |
| 2. Outdoor stationary equipment | - | x | - | Protection |
| 3. Outdoor mobile equipment | x | - | - | Removal |
| 4. Underground facilities | - | x | - | - |
| 5. Lines, mains, tracks, poles, etc | - | - | x | - |
| 6. Emergency service | x | - | - | Re-scheduling |
| 7. Evacuation & reoccupation | - | - | x | Re-scheduling |
| **Railroads** | | | | |
| 1. Minor buildings | - | - | x | - |
| 2. Outdoor stationary equipment | - | x | - | Protection |
| 3. Roadway | - | - | x | - |
| 4. Rolling stock | x | - | - | Removal |
| 5. Goods in transit | x | - | - | Re-scheduling, removal |
| 6. Emergency service | - | x | - | Re-scheduling |
| 7. Evacuation & reoccupation | - | - | x | Re-scheduling |
| **City Streets & Highways** | | | | |
| 1. Roadway | - | - | x | - |
| 2. Cost of re-routing traffic | - | x | - | Re-scheduling |
| 3. Cost of fighting flood | - | x | - | Re-scheduling |
| 4. Clean-up | - | - | x | - |
| **Bridges** | | | | |
| 1. Piers & abutments | - | x | - | Protection |
| 2. Superstructure | - | x | - | Protection |
| 3. Approaches | - | - | x | - |
| 4. Utilities | - | - | x | - |
| **Miscellaneous river structures - Dams, revetments, levees, etc** | - | - | x | - |
| **Relief Expenditures** | | | | |
| 1. Evacuation & rescue work | - | x | - | Re-scheduling |
| 2. Emergency supplies | - | x | - | " |
| 3. Administration on rescue camps | - | x | - | " |
| 4. Care of sick & injured | - | x | - | " |
| 5. Policing | - | x | - | " |
| 6. Flood-fighting | - | x | - | " |
| 7. Clean-up (public) | - | - | x | - |
| **Public Health** | | | | |
| 1. Sickness & injury | - | x | - | Re-scheduling |
| 2. Emergency public health activities | - | x | - | " |
| 3. Loss of life | - | x | - | Removal, reduction in rescue work, improved public health work. |

* Classification from National Resources Committee, Report of the Subcommittee on Flood Damage Data, March 15, 1939, mimeographed.

residential dwellings, service structures, and light and heavy industries; and because it has been subjected to a number of serious floods in recent years so that a wealth of flood damage d a was available for study. The results of the study indicated a redu of 27 percent in flood damages that could be attributed to flood f recas and warnings, an average annual saving of $180,000 over a per 8 years, and a benefit-to-cost ratio considerably in excess of 30:1.

The report of the Rock Island District of the Corps of Engineers for the record flood of April-May 1965 on the Mississippi River shows, that for its area of responsibility alone, flood damages amounted to 37 million dollars and savings due to flood warnings were 154 million dollars or more than 400 percent of damages.

For the flood of March 5-9, 1967, in the Pittsburg River District, damages totaled 6.8 million dollars and savings from forecasts totaled 6.1 million dollars, or 90 percent of damages.

In essence, the annual benefits derived from the proper utilization of adequate flood warnings, while impressive, are probably underestimated. Moreover, with increased utilization of flood plain areas these benefits will increase substantially.

(4) River forecasts as guide to reservoir operation

There is a notion, less widespread than it used to be, that once the rivers are "controlled," that is when all the dams and levees are built, there will be no more floods, and no need to forecast the rivers. This notion is not valid, and the following discussion will explain why. Operation of a multi-purpose reservoir is complex, and the operation of a system of reservoirs is especially complex. Even the flood-control aspect alone of this operation is far from simple.

It would be possible to operate a reservoir without forecasting inflow. In this case, space for flood control storage would continually have to be available, and could never be encroached upon for other purposes. During and after a flood, releases would have to be made as rapidly as downstream conditions allow, in order to reserve the flood-control space for the next flood.

With effective forecasts of inflow, it would be possible to use more of the reservoir capacity for purposes other than flood control. Between floods, this space could be occupied by water to be released as needed for water supply, power generation, and many other purposes. When a flood is imminent, water could be released in advance of inflow of the flood to the reservoir, thereby providing sufficient space in time to contain the flood.

Allowable rates of release depend on downstream conditions, which include inflow to the main stem for tributaries immediately downstream from the reservoir. If a major tributary is pouring flood water into the river downstream from a reservoir, this might be a poor time to release water from the reservoir. Thus efficient reservoir operation depends on forecasts both of inflow to the reservoir, and inflow from downstream tributaries. How efficient is reservoir operation made by forecasting?

A study made by Rutter, reported in the 1951 ASCE Transactions, shows that for three floods in TVA, the difference between no forecasts and perfect forecasts amounted to a factor of two in the reservoir size. In other words, twice as much storage space is required for flood reduction, with no forecasts, as would be required if we had perfect knowledge of future streamflow.

(5) River Forecasts for Water Management

Operation of reservoirs and other structures, such as flood gates in levees, in the event or anticipation of floods, is only part of water management. Operation of power plants, irrigation works, and water supply systems requi[illegible] owledge of future river flow even in the absence of f[illegible] be decided when to open or close gates, and how much, and which reservoirs to draw upon. Load must be shifted between steam-power and water-power plants of a system so as to use them in the best combination. Drafts on storage can be made only with due regard to contents on hand, and in prospect.

Forecasts of seasonal and water-year water supply are made at monthly intervals, January 1 through May 1.

The hydroelectric power producer will determine from such forecasts his probable need for thermal generation. In low-flow years he will carry base load or part of the base load with thermal generation and use hydroelectric power for its most effective purpose -- which is peak load. In years of abundant water, he may use streamflow in excess of storage capacity to carry base load 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. Similarly shippers spot their freight cars, and processing plants plan their operations on the basis of expected water.

The water supply operator, who is dependent on a combination of groundwater and surface water for his water supply, will use such forecasts to determine how much surface water he can use, and regulate his groundwater pumping accordingly. In many areas of potential groundwater overdraft, a substantial conservation of groundwater may be effected in this way. Certainly, there is no point in withdrawing groundwater 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 one to ten 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. 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.

The role of river forecasting for abatement of flood damages is well known. The point is to be made that forecasting is not merely one of several alternatives -- structural and other -- to be considered in the management of water resources. River forecasting is a necessary accompaniment of any and all operational alternatives: flood-proofing, flood-plain zoning, evacuation, reservoir operation, scheduling the release of pollutants, water supply operations; ad infinitum. A water management program which realistically employs river forecasting will have greater economy and efficiency than one which ignores forecasting, or which implicitly assumes that forecasts will be perfect.

(6) <u>Self-help Community Flash-Flood Warning Systems</u>

Hundreds of communities are subject to flooding which cannot adequately be served by the usual flood warning system. These communities are located in the headwaters of fast-rising streams where the flood crest occurs only a few minutes or hours after the occurrence of intense storms. Under these circumstances, it is not possible to collect observations, transmit them to a forecast office, prepare the forecast, and relay the warning to the threatened area in advance of flooding. A solution has been to establish cooperative community Flash Flood Warning Systems. The community establishes a network of rainfall and river observing stations and a warning representative is appointed to collect the reports, prepare a forecast based on a procedure developed by the River Forecast Center, and issue the warning. Whenever possible the warning representative is provided with advance warning of potentially heavy rainfall, either predicted or detected by radar surveillance. The local River District Office monitors the community plan, and the River Forecast Center provides the forecasting procedure. About 100 communities are currently served by these Flash Flood Warning Systems.

(7) <u>Quantitative Forecasting of Precipitation</u>

The greatest advance in river forecasting in recent years has been the use of precipitation data. Thirty years ago most flood forecasts were based on reported upstream river stages. Forecasts were not possible for small basins and could be issued only after the flood had begun to crest in the headwaters of large basins. New forecasting tools 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.

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

Urban drainage is usually accomplished by storm sewers, which are commonly designed for storms which would be equalled or exceeded no oftener than an average of once in ten years. When storms of greater severity occur, the resultant runoff may exceed the capacity of the sewer system, and flooding may occur. Radar and quantitative forecasting of precipitation make it possible to warn of such flooding.

c. Hydrometeorological Analysis for Planning and Design

(1) Archival Function of Environmental Data Service of NOAA

The climatic and climatological functions that until recently were vested in the old Weather Bureau are now expanded to include additional environment data, and these functions now rest with the Environmental Data Service of NOAA. As indicated in the discussion earlier of the 1938 Flood Control Act, and its amendments, the Corps of Engineers receives and transfers substantial sums of money annually to NOAA for the taking, processing and custody of precipitation data. Our FC (Flood Control) network is part of this cooperation, as many of us know.

In addition to precipitation data, the elements generally regarded as necessary for hydrometeorological work, and which are also observed and processed in NOAA, are short-wave radiation, sunshine, cloudiness, solar radiation, air temperature, snowfall depth, snow cover depth and water equivalent, humidity, pan evaporation including pan water temperature, surface wind, and barometric pressure. These elements are used in forecasting streamflow, and for other hydrometeorological purposes which will be discussed shortly. It is important for field people to know of the availability of these data, and how they are tabulated and made available to the public. The tabulations and summaries of these data include observations made by cooperating agencies. It is in the public interest for these data to be available in a central place.

These data are recorded on punch cards which are machine processed for publication and subjected or made available for high-speed electronic analysis for various purposes at NOAA's National Climatic Center at Asheville, N. C., which also acts as the national depository for all data made available to it.

From these data - organized, analysed and interpreted - come answers to questions of planners and designers: How much rain or snow fell in a particular storm, and how was it distributed in time and area? How often does a storm of this magnitude and intensity occur? How big is the maximum storm of record? How much bigger could a storm be? What effects do season, mountains, and other circumstances have on large storms, and on the sequence of storms? These questions apply not only to storm rainfall, but also to snow melt, evaporation, and other hydrologic processes, and involve analysis of observed elements such as radiation, humidity, wind, and temperature.

(2) Precipitation as the Basic Source of Water Supply

Attention can be focused on any part of the hydrologic cycle, and any phase preceding this part can be regarded as the source of water. Many foresters and agronomists regard water as coming primarily from the soil, where it supports vegetation, runs off into streams, and replenishes ground water and wells. Many city dwellers regard streams and deep ground water as the source of water. In fact the scare articles we read about water shortage compare tabulations of streamflow with tabulations of water use.

The oceans are the main repository of water, and supply most of the water vapor which is precipitated as rain or snow. This process is a world-wide desalting system—a tremendous solar still whose absorption area is the entire surface of the seas and whose heat source is the sun. The water so evaporated rises and is then condensed by cooling as it rises to lower pressures and lower temperatures in the atmosphere.

Average annual precipitation over the conterminous 48 states averages thirty inches, ranging from about 200 inches in parts of the mountainous northwest to about five inches in parts of the arid southwest. At some points in these 48 states it has rained more than 35 inches in one day, more than 12 inches in an hour, and more than one inch in one minute. At some places and times there may be no rain for weeks or months. Obviously, for planning the management of water resources, it is important to know more than averages, because variations in precipitation are basic to the entire water supply system, and to problems of managing it.

(3) Frequencies and Extremes of Storm Rainfall

In addition to averages, data on extreme values are 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 over-design and under-design 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. Weather Bureau Technical Paper No. 40, "Rainfall Frequency Atlas of the United States," is the best source of information on rainfall duration-area-intensity-frequency regimes.

Since 1939 the Weather Service 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 for which only rainfall records are available. What is required is a simultaneous rainfall and streamflow record for, say, ten 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 4 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

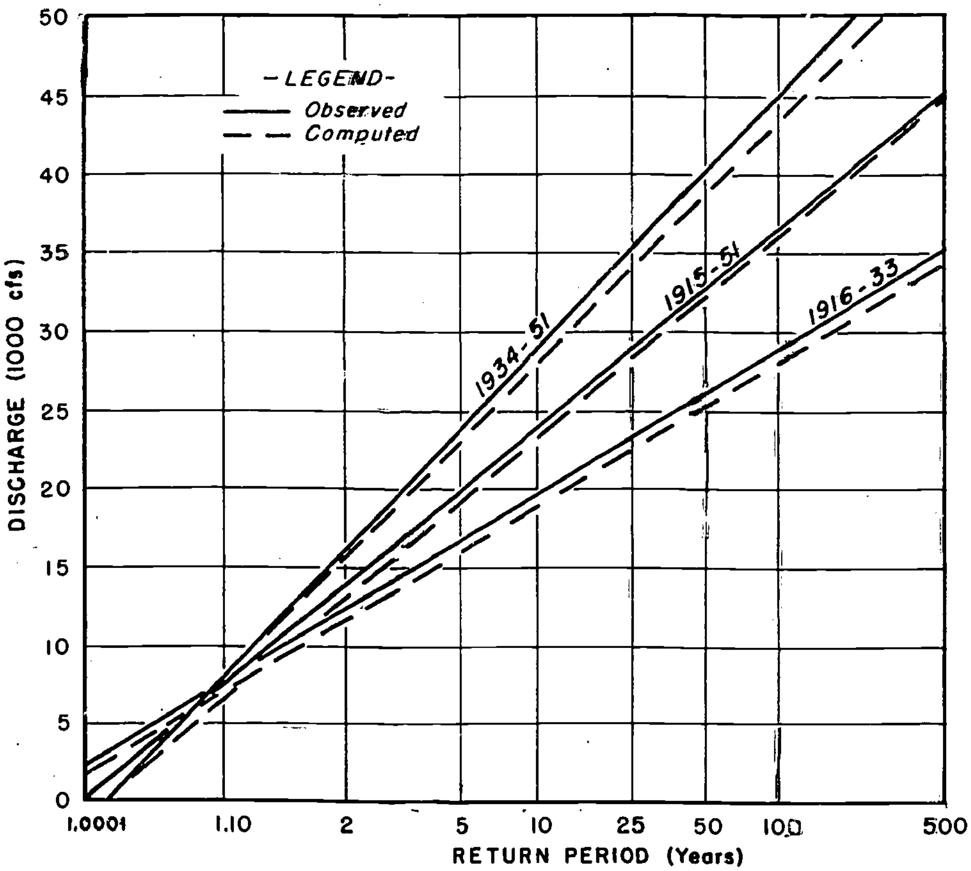



FIGURE 4. Comparison of computed and observed frequency curves for the periods 1915-51, 1916-33, 1934-51, Hocking River, Athens, O.

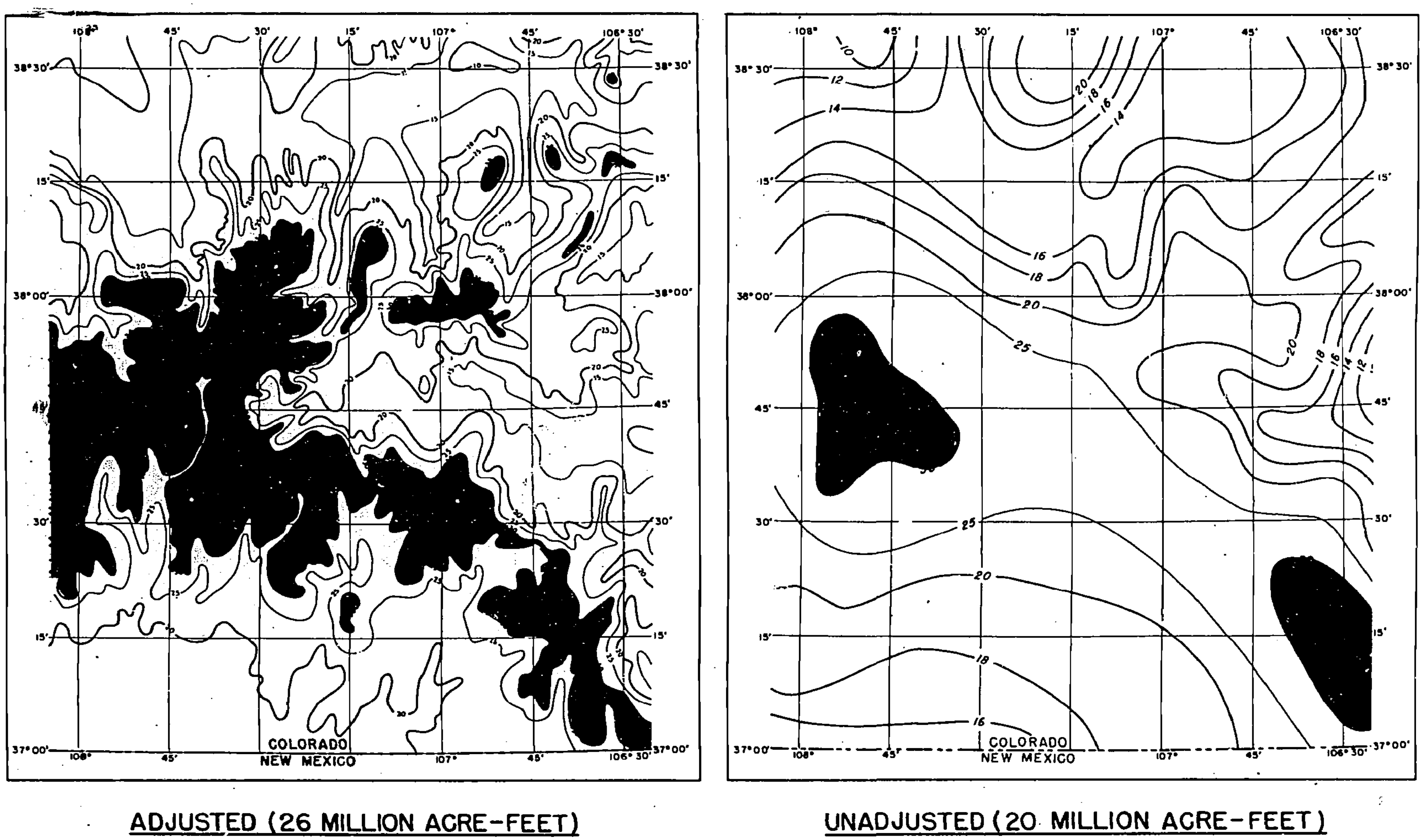



FIGURE 5. Physiographically adjusted precipitation map.

what happened with controls. It is, in fact, a technique necessary for 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, or other cultural changes, on streamflow.

(4) Physiographic Adjustment of Average Precipitation

Even the most common of the values available -- the average precipitation, 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 may often be inadequate -- made 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.

Mutual adjustments may also be made with average runoff and average evapotranspiration. Figure 5 compares mean annual precipitation maps for Western Colorado. One shows the precipitation 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 six million acre-feet greater than was previously known.

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. In planning network expansion, the analytic, synthetic and interpretative techniques will provide the guide to efficient location of new stations.

(5) Importance of Evaporation in Water Resources Management

Of the 30 inches of precipitation that normally falls each year on the conterminous 48 states, about 21.5 inches return to the atmosphere by evaporation and transpiration, which together are called evapotranspiration. This average value of evapotranspiration ranges widely from place to place, from year to year, and is distributed non-uniformly during the year, being greatest during hot sunny weather and in hot sunny regions. There are about 400 evaporation pans in the Weather Service network.

Evapotranspiration is a critical item in river forecasting because the combination of antecedent 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 NOAA maintains a national observational and research program in evaporation.

The data are, of couse, 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," supplies the most reliable estimates to date.

Current evaporation investigations aim at a daily accounting of the water gain and loss in a river basin. The immediate purpose is to develop an improved soil moisture index to increase the accuracy of river forecasts. 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.

# CHAPTER II
# WATER MANAGEMENT PROGRAMS

## 1. Navigation

a. Introduction - Federal enterprise in the management of water resources stems from the famous "Commerce Clause" of the Constitution: Article 1, Section 8, item 3, which gives the Federal Government authority

"To regulate commerce with foreign nations, and among the several states and with the Indian Tribes."

In those days most commerce was water-borne. Canals and rivers predominated over trails and corduroy roads.

It is easy to trace the early evolution of flood control as an adjunct of navigation. Floods were hazards to navigation.

The next step, to generation of hydro-electric power and use of water for irrigation, was an easy one. Having stored the water to control floods, and for releases to maintain sufficient depth for barges, why not get energy or other use from the water instead of wasting it?

b. Early History - The first major project - The Erie Canal, built by the State of New York - proved so profitable that the waning years of the 18th century, and the early years of the 19th, saw the construction of a remarkable network of canals by private enterprise and by the States. The age of canal building overlapped the earlier years of the steamboat period, during which river transportation, particularly on the Mississippi and Ohio Rivers, reached a stage of development not to be equaled until modern times. Between 1811 and the Civil War the steamboat, or packet, revolutionized river transportation. By 1860 steamboat arrivals at New Orleans averaged 10 per day, and the cargoes which they delivered that year were valued at an amount equal to a half billion of 1960 dollars.

For about a half century following the Civil War, waterway transportation seemed about to expire altogether as the railroads became undisputed rulers of the transportation field. Yet it was during this period that great advances in science and engineering made possible improvements in marine engines, and the adaptation of the propeller to shallow-draft vessels.

In the early days of this country, there were fewer kinds of engineers than there are now. Civil engineering was distinguished from military engineering. But military engineers did what we now call civil engineering, because they were the only federal group with engineering construction capability.

Works of improvement for navigation have been a responsibility of the Corps of Army Engineers since the first federal improvement of rivers and harbors was undertaken in the United States in 1824. Since 1824 about $5 1/2 billion have been appropriated for construction, operation, and maintenance of navigation works by the Corps of Engineers.

c. Modern Network - The present system of inland waterways, excluding the Great Lakes, comprises over 20,000 miles of commercially used waterways. In calendar year 1968, a total of 179 billion ton-miles of commercial traffic moved on the system. Technological improvements in equipment for river navigation in recent years have greatly increased the ability of the inland waterways to carry traffic, and there is every indication that the growth in use will continue.

The total waterway traffic in 1968 was 6 times the 1946 figure. This is equivalent to adding to the national transportation system about 2,600 miles of railroad carrying nearly 3 million ton-miles of freight per mile of road annually. This means that the increase in the use of the waterways is comparable to the addition of a transcontinental railroad to the Nation's transportation system each year.

The present commercial system has a composition as follows:

| Depth range (feet) | Standard depth for range (feet) | Miles | Percent |
|---|---|---|---|
| Under 6 | ---- | 4,181 | 21 |
| 6 to 9 | 6 | 2,936 | 14 |
| 9 to 12 | 9 | 6,397 | 32 |
| 12 to 14 | 12 | 4,018 | 20 |
| Over 14 | ---- | 2,621 | 13 |
| Total | ---- | 20,153 | 100 |

In addition to the Federal expenditures, considerable amounts have been spent by States, cities, and other non-Federal entities to bring the Federal waterways system into existence.

Of the extensive system of waterways provided by non-Federal projects, only 525 miles carry commercial traffic today.

d. Types of Navigation Systems - There are three basic methods of providing and managing inland waterways.

(1) Run-of-the-River - Barge operators and other users travel in the flowing river, with or without provision of upstream storage to insure high enough stage or sufficient depth during periods of low natural runoff.

(2) Slack-Water - Locks and dams provide slack water or pools, which provide adequate depths, and whose cross-section is relatively great so that velocities are usually not excessive. The water required for operating the locks is much less than that required for maintaining high stages in run-of-the-river navigation.

(3) Canalization - Instead of damming the entire river, a canal with locks adjoins the river. Water from the river is conveyed into the canal to fill the pools from lock to lock and to provide water for locking. Canalization may cut off bends in the river, and avoids excessively high velocities from occasional floods. Excavation for canalization is relatively expensive.

The trend favors slack-water navigation, with dams whose purposes include hydro-electric generation.

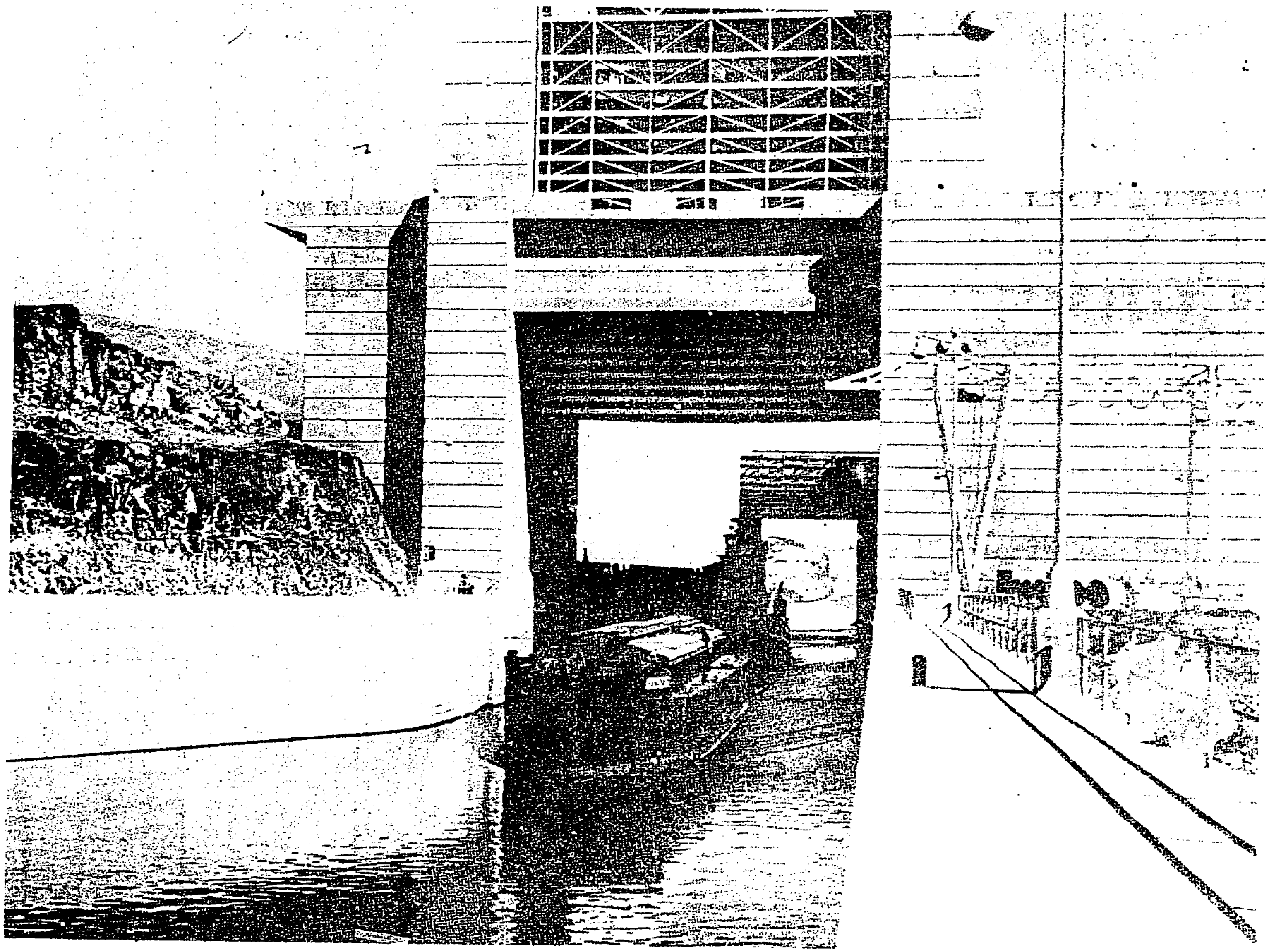


FIGURE 6. Wheat barges in John Day Lock, Columbia River, Oregon (Courtesy Corps of Engineers).

e. Water Needs for Navigation - Rates of flow required for efficient utilization of the major inland waterways are shown in Table 2, taken from the Senate Select Committee on National Water Resources, Print no. 11, 1960.

f. Local Cooperation in Federal Projects - As Federal navigational programs became prevalent, arrangements evolved for local cooperation. Under current legislative and administrative policies non-Federal interests are required to:

1. Provide all lands, easements, and rights-of-way necessary for the construction and operation of any Federal waterway, including "spoil" areas for the disposal of excavated material.
2. Hold and save the United States free from claims for damages which may result from construction of the waterway.
3. Accomplish, without expense to the United States, alterations of sewer, water supply, drainage, and other facilities affected by the waterway, and arrange for non-Federal assumption of any increased maintenance resulting from such alterations.
4. Assume a share of the cost of altering railroad and public highway bridges in accord with the Bridge Alteration Act of June 21, 1940, as amended by the Act of July 16, 1952.
5. Provide and maintain at local expense adequate public terminal and transfer facilities which shall be open to all on equal terms.
6. Make a suitable cash contribution toward the first cost of the waterway when deemed warranted and appropriate.

The total of the non-Federal contributions which have been made under the policy outlined above is not known. It is evident, however, that the value of lands, easements and rights-of-way, and the cost of providing public terminals are both sizable contributions.

In addition to the public terminals mentioned above, private investments have been made in terminal and transfer facilities by individual industries using the inland waterways.

g. Recreational Boating - Recreational boating is an important, and rapidly growing, use of existing waterways, including those of less than 6 feet depth. The manufacture of boats, marine engines and related equipment for recreational use has become a major industry. During 1970 the sale of these items amounted to almost $3.5 billion. Although it is generally agreed that outdoor recreation is reflected in real economic benefits, a monetary value has not yet been placed upon this use of the Federal waterways. It seems probable, however, that eventually this source of benefit will be recognized and taken into account in the planning of waterways. The Congress has, in fact, already recognized the importance of recreation on the waterways by authorizing the construction of small-boat harbors, and even some waterways, primarily for the use of recreationists.

h. Role of Forecasting - The role of river forecasting in waterways management and use is rather direct and obvious. This is particularly true of run-of-the-river navigation, where velocities in excess of about 6 knots are usually difficult and where stages less than about 9 feet are usually deficient. With a system of locks and dams, heavy

TABLE 2 - Flows required for efficient navigation on inland waterways of the United States and estimates of flows which will be required in 1980 and 2000

| Waterways | Critical flow[a] in cubic feet per second 1959 | 1980 | 2000 | Comments |
|---|---|---|---|---|
| New England, existing waterways: all | 0 | 0 | 0 | All waterways are in tidal reaches. |
| Middle Atlantic, existing waterways: | | | | |
| Great Lakes to Hudson River and Champlain Canals | 2,000 | 2,000 | 2,000 | Available flow 13,000 c.f.s. |
| Delaware | b | b | b | If depth increased to 45 feet minimum flow will have to be increased by 2,900 c.f.s. to repel salinity. |
| South Atlantic: | | | | |
| Existing waterways: | | | | |
| Cape Fear River above Wilmington, N.C. | 50 | 100 | c | |
| Savannah River below Augusta, Ga. | 5,000 | 5,800 | c | |
| Altamaha River below junction of Ocmulgee and Iconee Rivers. | 1,000 | 5,000 | c | |
| Okeechobee Waterway | 50 | 50 | c | |
| Apalachicola below Jim Woodruff lock and dam | 9,300 | 9,300 | c | |
| Alabama River below Selma, Ala. | 3,000 | 3,000 | c | |
| Warrior system | 540 | 540 | c | |
| Possible future waterways: | | | | |
| Santee-Congaree | ....... | 5,200 | c | Project might be found feasible if river developed for power. |
| Ocmulgee River below Macon, Ga. | ....... | 300 | c | |
| Cross-Florida Barge Canal | ....... | 700 | c | Authorized project. |
| Chattahoochee River below Atlanta, Ga. | ....... | 300 | c | |
| Flint River below Albany, Ga. | ....... | 200 | c | |
| Coosa River | ....... | 300 | c | Do. |

TABLE 2 (Continued)

| Waterways | Critical flow [a] in cubic feet per second 1959 | 1980 | 2000 | Comments |
|---|---|---|---|---|
| South Atlantic: (continued) | | | | |
| Tennessee-Tombigbee | ....... | 1,246 | c | Authorized project (1,246 c.f.s. would be diverted from the Tennessee River.) |
| Arkansas-White-Red: | | | | |
| Existing waterways: | | | | |
| White River (to mile 168.7) | 6,500 | 10,000 | 10,000 | |
| Cuachita-Black | 100 | 100 | 100 | |
| Waterways under construction: | | | | |
| Verdigris River (at Catoosa, Okla.) | ....... | 115 | 115 | Provision of 9-foot waterway as part of multiple-purpose development of the Arkansas River. |
| Arkansas (at Webber Falls) | ....... | 300 | 300 | Do. |
| Arkansas (at Short Mountain) | ....... | 530 | 530 | Do. |
| Arkansas (at Dardanelle) | ....... | 505 | 505 | Do. |
| Arkansas (Dardanelle to mouth) | ....... | 1,000 | 1,000 | Do. |
| Possible future waterways: Overton-Red Waterway | ....... | 300 | ....... | Authorized project. |
| Gulf-Southwest: | | | | |
| Waterways under construction: Guadalupe to Victoria | ....... | 0-1,800 | 0-1,800 | For periodic flushing. |
| Possible future waterways: | | | | |
| Trinity River (below Dallas) | ....... | 400 | 800 | Authorized project. |
| Trinity River (above Dallas) | ....... | 150 | 325 | Do. |
| Missouri River Basin, existing waterways: | | | | |
| Missouri at Sioux City [d] | ....... | 30,000 | 30,000 | Could be reduced to 25,000 by dredging. |
| Missouri at Omaha [d] | 28,000 | 28,000 | 28,000 | |
| Missouri at Nebraska City [d] | 31,000 | 31,000 | 31,000 | |
| Missouri at Kansas City [d] | 35,000 | 32,500 | 32,500 | Could be reduced to 27,500 by dredging. |
| Missouri at mouth [d] | ....... | 35,000 | 35,000 | |

TABLE 2 (Continued)

| Waterways | Critical flow [a] in cubic feet per second | | | Comments |
|---|---|---|---|---|
| | 1959 | 1980 | 2000 | |
| Upper Mississippi Basin: | | | | |
| Existing waterways: | | | | |
| Main stem, pools 1-10 | 375 | 750 | 940 | Not required in winter. |
| Main stem, pools 11-22 | 2,000 | 2,000 | 2,000 | Do. |
| Main stem, pools 24-26 | 70,000 | 25,000 | 25,000 | Required all year. |
| Main stem, Missouri to Ohio | 54,000 | 75,000 | 75,000 | Do. |
| Minnesota | 0 | 0 | 0 | Mississippi backwater. |
| St. Croix | 0 | 0 | 0 | Do. |
| Illinois Waterway | [e]720 | [ef]1,826 | [ef]1,826 | |
| Fox River | 300 | 300 | 300 | Not required in winter. |
| Possible future waterways: | | | | |
| Kaskaskia River | 0 | 200 | 300 | |
| Big Muddy River | 0 | 200 | 400 | |
| Tittabawassee River | 0 | 200 | 200 | |
| Ohio River Basin: | | | | |
| Existing waterways: | | | | |
| Ohio River (main stem) | c | c | c | River canalized. |
| Allegheny River | 100 | 140 | 150 | |
| Monongahela River | 340 | 440 | 670 | |
| Kanawha River | 300 | 400 | 400 | |
| Kentucky River | 100 | 150 | 200 | |
| Green River | 150 | 250 | 400 | |
| Cumberland River | 100 | 150 | 250 | |
| *Possible waterways:* | | | | |
| *Big Sandy River (main stem)* | *0* | *329* | *329* | |
| *Big Sandy River (Levisa Fork)* | *0* | *176* | *176* | |
| *Lake Erie-Ohio River Canal* | *0* | 430 | 430 | |
| Lower Mississippi River: | | | | |
| Existing waterways: | | | | |
| *Main stem at Cairo* | 100,000 | 120,000 | 120,000 | |

TABLE 2 (Continued)

| Waterways | Critical flow[a] in cubic feet per second 1959 | 1980 | 2000 | Comments |
|---|---|---|---|---|
| Lower Mississippi River: (continued) | | | | |
| Existing waterways: | | | | |
| Main stem below Arkansas | 140,000 | 150,000 | 150,000 | |
| Ouachita-Black | 100 | 150 | 150 | |
| Possible future waterways: | | | | |
| Yazoo below Greenwood | ....... | 100 | 100 | |
| Columbia River Basin: | | | | |
| Existing waterways: | | | | |
| Main stem at Bonneville | 40,000 | 40,000 | 40,000 | |
| Main stem at The Dalles | [g]700 | [g]1,500 | [g]2,500 | |
| Willamette, mouth to Salem | 6,000 | 6,000 | 6,000 | |
| Willamette, Salem to Corvallis | 5,000 | 5,000 | 5,000 | |
| Snake, mouth to Ice Harbor | 300 | 1,000 | 2,000 | |
| Waterways under construction: | | | | |
| Main stem John Day to McNary | 110,000 | 1,500 | 2,500 | |
| Snake, Ice Harbor to Lewiston | ....... | 1,000 | 2,000 | |
| Possible future waterways: | | | | |
| Main stem head McNary Pool to Rock Island | ....... | 36,000 | ....... | Under study. |
| Snake, Lewiston to mile 174 | ....... | 500 | 1,000 | Do. |
| Snake, mile 174 to mile 188 | ....... | 500 | 1,000 | |
| Snake, mile 188 to mile 232 | ....... | 350 | 700 | |
| North Pacific Coast, Possible future waterways: | | | | |
| Skagit, mouth to Concrete | ....... | 10,000 | 10,000 | |
| Central Valley, existing waterways: | | | | |
| Sacramento | 5,000 | 5,000 | 5,000 | Shallow draft. |
| San Joaquin above Mossdale | 100 | 100 | 100 | Do. |

Footnotes for Table 2.

a. Rate below which streamflow cannot drop without reducing the efficiency of navigation.

b. Anticipated flows will meet the needs of navigation.

c. Estimates not available.

d. Flows required from April through November, assuming continuation of open river navigation. Canalization now being studied. If Missouri canalized these flows would be greatly reduced.

e. Average annual flow required at Lockport, Ill. Includes 250 c.f.s. to prevent reversal of flow into Lake Michigan when storm runoff occurs. Excludes 120 c.f.s. of present industrial usage which bypasses Lockport lock.

f. Requirements for recommended duplicate lock system.

g. These values of critical flow are academic. The minimum record flow at the Dalles is 35,000 c.f.s.; and present day (1966) controlled minimum is about 80,000 c.f.s.

inflow to the system may make it similar to run-of-the-river at flood times.

Canalized systems are subject to local inflow and river flooding at times. Where flows are controlled by large reservoir storage, forecasts are necessary for proper operation of the reservoir. Examples of reservoir operation problems are given in Part One - Fundamentals of Hydrology.

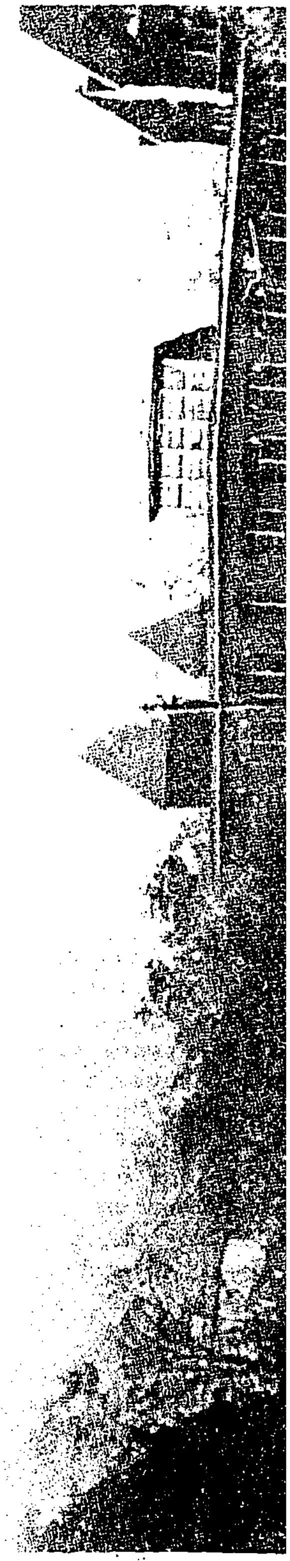
Traffic heading north from the lower Mississippi uses forecasts of stages two or three weeks in advance. These forecasts enable barge operators to load their barges to maximum safe draft.

## 2. Flood Control and Prevention

a. Introduction - The term "flood control" means different things to different people. To people in the Corps of Engineers, and to people working closely with them, the term means storage dams and levees. To people who misunderstand the limitations of physical structures it means "no more floods." To some writers on water resources planning the term means any measures intended to reduce flood damage. Possibly to avoid confusion between the programs of the Corps of Engineers and the Soil Conservation Service, the SCS uses the term "Flood Prevention."

The term "Flood Prevention" cannot be taken literally any more than "Flood Control," and people must understand that for any project, the degree of protection is determined by the nature of the project or program, and not by its label. The following discussion of "flood control" is taken largely from Print no. 15 of the Senate Select Committee on Water Resources, which was prepared by the Corps of Engineers, and much of it naturally describes the work from the Corps point of view. Description of the procedure for assistance in the SCS program is taken from U. S. Department of Agriculture brochures.

b. Early History and Legislative Background - For more than a century after the establishment of the United States, its Constitution was interpreted as prohibiting the undertaking of "internal improvements" by the Federal Government, with the single exception that Federal responsibility for the improvement of waterways was considered lawful under the "commerce" clause of the Constitution. But even that authority was not generally acknowledged until 1824, when the famous opinion of Chief Justice John Marshall established that "The power of Congress * * * comprehends navigation within the limits of every State of the Union * * *." In that same year the Congress appropriated $75,000 to remove certain sandbars and "sawyers, planters, and snags" from the Ohio and Mississippi Rivers as an aid to navigation. This task was assigned the Corps of Engineers. Thereafter for a period of 78 years, harbors and waterways were the only "internal improvements" which the Congress formally acknowledged to be a Federal responsibility. Then in 1902 it authorized the first Federal reclamation projects and, even though at the time it was intended to confine such projects to the public domain, this helped weaken the resistance to internal improvements. It was not until 1917 that Congress agreed that Federal funds could be used for flood-control projects as such. In that year, as a result of destructive Mississippi floods in 1912, 1913, and 1916, Congress



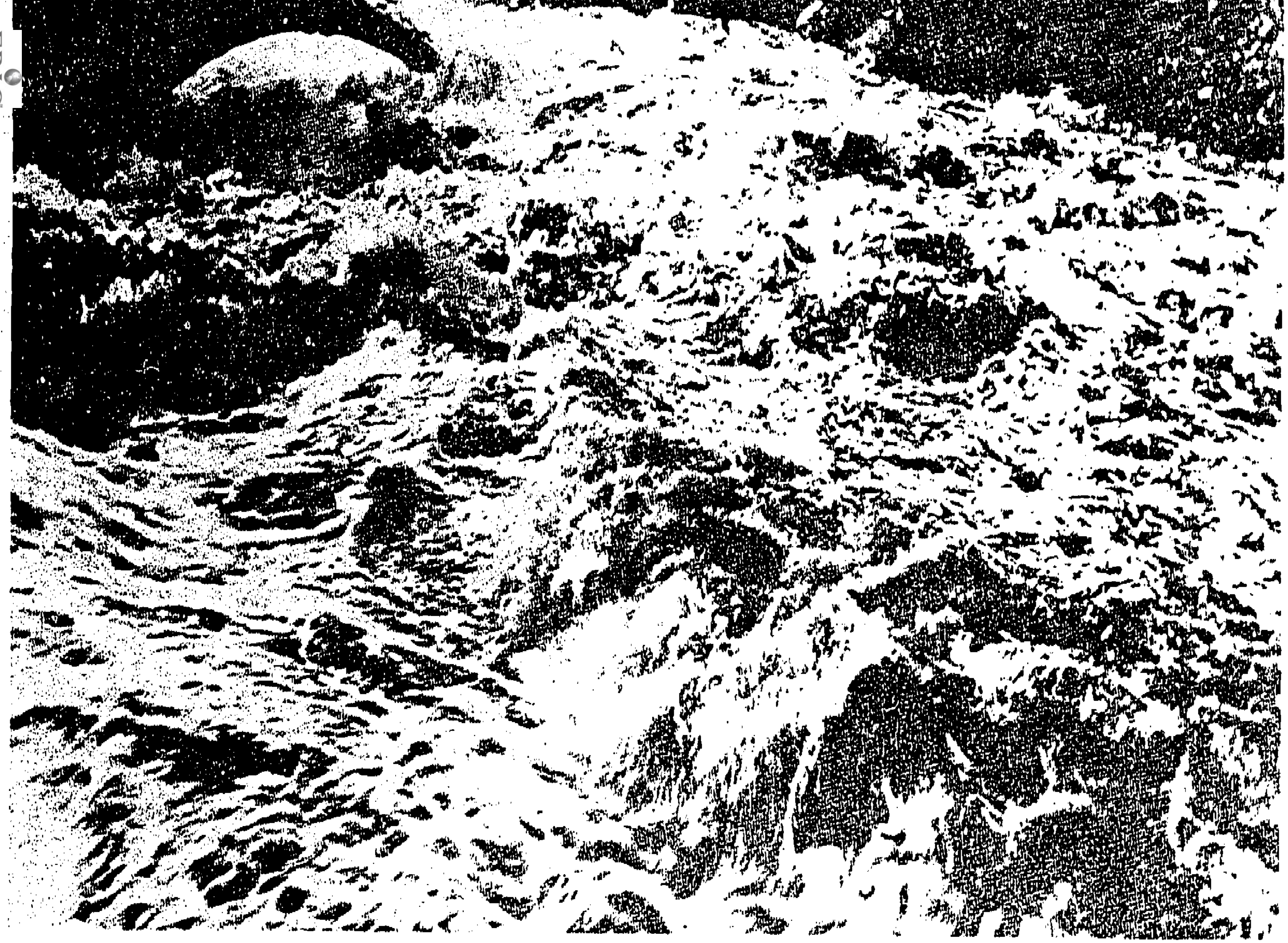


FIGURE 7. Hurricane flood, Ware, Mass., Sept. 1938 (Courtesy American Red Cross).

authorized flood-control work on both the Mississippi and Sacramento Rivers. From that time forward the constitutionality of internal improvements for dealing with flood problems was no longer questioned. It was evidently established that floods were a hazard to navigation and should be controlled.

The battle to widen the responsibilities of the Federal Government to encompass internal improvements other than navigation works, revolved almost entirely around the Nation's greatest flood problem: the propensity of the lower Mississippi River to overflow the vast and rich alluvial plain which it had created.

Congress, in 1874, appropriated funds for relief work and created a commission to study the problem. The report of this Commission, which became known as the Warren Commission, greatly strengthened the advocates of Federal action, and led directly to the establishment of the Mississippi River Commission in 1879.

Between 1879 and 1917 Federal funds were made available for some flood-control work by the Mississippi River Commission, but throughout this period the Congress insisted that navigation be the stated purpose of these appropriations. As a result of all these developments the Congress was by 1916 conditioned to accept responsibility for the Mississippi flood problem. The great flood of that year precipitated action, and early in 1917 the first clear-cut flood-control legislation was enacted into law.

It was not until the Act of May 15, 1928, authorized the "Jadwin Plan" that the Congress went far enough to really bring the "Father of Waters" under control. This act dealing with flood control in the alluvial valley of the Mississippi was amended and broadened by legislation in subsequent years which gradually extended the degree of Federal participation.

Although in 1917, and again in 1928, the Congress agreed to assume a high degree of responsibility for the Mississippi and Sacramento, these were considered special problems, and it was not until 1936 that a general flood-control policy was adopted by law.

c. 1936 Flood Control Act - Developments outside the Federal sphere were also helping to lay the groundwork for the Flood Control Act of 1936. Communities subject to serious flood damage attempted from time to time to solve their own problems; but, in the main, they did not get much beyond the stage of making investigations and plans, thus strengthening the conviction that eventually the Federal Government would have to take a hand. A notable exception was the work of the Miami Conservancy District which was established under the laws of Ohio in 1913. This entity planned and constructed a series of reservoirs for the protection of Dayton, Ohio, and other communities in the valley of the Miami River.

Of great importance in establishing the mood which led to acceptance of the Flood Control Act of 1936, was the great depression of the early thirties. The effect of this economic catastrophe was to create an urgent need for work relief projects, as well as to place the cities and States in such bad financial condition that they considered it impossible for them to undertake such projects. Consequently, many flood-control projects were undertaken by the Federal Government under the work-relief programs.

In 1936 the Senate Committee on Commerce gave intensive and long continued consideration to the formulation of a national policy on flood control. Its work was reflected in section 1 of the Act of June 22, 1936, which set the policy for the first general flood-control legislation in the Nation's history. This act did not, however, come into being without travail. There was a great legislative battle over the share of the cost to be assumed by beneficiaries. Also, efforts were made, without success, to broaden the bill to establish a reviewing and coordinating agency at the Presidential level. One effort to broaden the legislation did succeed. The Secretary of Agriculture was authorized to prepare plans for the reduction of floods by means of forest improvement, soil conservation, and other land-treatment measures.

The 1936 Act in its final form --

(1) Established a national policy on flood control;

(2) Authorized the construction of some 250 projects, and the appropriation of $310 million to initiate construction, as well as the use of work relief funds, and

(3) Authorized numerous examinations and surveys, and the appropriation of $10 million to initiate these investigations.

Of greatest importance for the purposes of this report is the national policy established by the Act of 1936. The principal elements of this policy were --

(4) The Federal Government would cooperate with "States, their political subdivisions and localities thereof" in flood-control projects (this policy marked the final destruction, after almost 150 years of controversy, of the argument that the Federal Government had no authority to undertake "internal improvements.").

(5) A two-pronged attack would be made on the flood problem; the Corps of Engineers would develop engineering plans, and the Department of Agriculture land treatment plans, for the reduction of flood damage.

(6) To qualify as a Federal project under the act, the benefits attributable to a project would have to exceed the costs.

(7) Projects would be recommended in survey reports but could not be constructed until specifically authorized by law.

(8) Non-Federal interests would provide lands, easements, and rights-of-way; would protect the Federal Government from damage claims; and would operate and maintain the flood control works provided by the Federal Government.

d. <u>Subsequent Flood Control Acts</u> - The 1936 Act was amended and supplemented by the Flood Control Acts of 1937, 1938, 1939, 1940, 1941, 1944, 1946, 1948, 1950, 1954, 1958, and 1960. As the Acts of 1938, 1944, 1958, and 1960 were important from the standpoint of basic policy, each of them requires some discussion. All of the Federal Flood Control Acts also authorized appropriations for the construction of projects, and for surveys and other studies.

(1) <u>The Act of 1938</u>

The Act of June 28, 1938, made a major change in the cost-sharing policy of the 1936 Act. It provided for Federal assumption of the entire cost of both reservoir and channel improvement projects. This relieved the local interests of the cost of lands, easements, and rights-of-way, except for levee projects.

The 1938 Act also authorized the Chief of Engineers to evacuate areas subject to flood in lieu of protecting them by levees or floodwalls; provided for the installation of penstocks in dams; and authorized the use of flood-control funds to collect rainfall data.

Of particular interest to WeatherService people is the provision of the 1938 Flood Control Act, authorizing 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 non-recording precipitation stations, known as the Hydro-climatic 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 work improvement authorized 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."

(2) The Act of 1944

The Act of December 22, 1944, greatly extended the national policy laid down by the 1936 Act. Of particular importance was the expression of congressional intent that projects were to be considered "on a basis of comprehensive and coordinated development," a great stride away from the single-purpose concept and toward the concept of comprehensive programs for the development, use and conservation of the resources of major river basins. Other important policies expressed in this Act may be summarized as follows:

(a) Waters arising in States lying wholly or partly west of the 98th meridian may not be used for navigation if such use would conflict with beneficial consumptive use (this provision has been repeated in subsequent acts);

(b) Major drainage improvements may be treated as flood-control projects;

(c) The Secretary of the Army shall prescribe regulations governing the operation of flood-control storage constructed wholly, or in part, with Federal funds, regardless of the agency responsible for construction;

(d) Power generated at Corps of Engineers projects shall be marketed by the Secretary of Interior;

(e) The rights and interests of States in water shall be recognized by the Federal agencies;

(f) The sale of "surplus" water is authorized;

(g) The States and the Secretary of the Interior shall be given an opportunity to review Corps reports and to cooperate;

(h) The public shall have free access to reservoirs under the control of the Department of the Army, and the Chief of Engineers is authorized to construct and operate public park and recreational facilities, and to permit others to do so.

(3) The Act of 1958

Title III of the Act (July 3, 1958) authorized the inclusion, in Corps of Engineers and Bureau of Reclamation reservoirs, of reservoir capacity to impound water for municipal and industrial use, provided an appropriate non-Federal entity should be willing to bear the cost allocable to this capacity.

(4) The Act of 1960

Section 206 of this Act recognizes the increasing use and development taking place in the flood plains of the United States and the need for regulations of such use by States and municipalities as a basis for avoiding future flood hazards. It authorizes the Secretary of the Army, through the Chief of Engineers, when requested by a State or a responsible local governmental agency, to compile and disseminate information on floods and flood damages, including identification of areas subject to inundation, and to provide engineering advice to local interests for their use in planning to ameliorate the flood hazard. These Corps of Engineers' "Flood Plain Information Reports" are much more detailed than the U.S. G. S. Flood Plain Maps which are described below.

Another feature of this Act is that it establishes a minimum requirement for local cost sharing for a number of local flood protection projects. It provides for specific projects that local interests assume at least 20 percent of the cost allocable to flood control. It did not, however, make this a general provision of law.

e. U. S. G. S. Flood Plain Maps

The U. S. Geological Survey has similar authority to assist communities to assess their flood hazards, by preparing maps of historical flooded areas, and indicating the incidence of floods of various magnitudes.

As an illustration of how flood information can be presented on a map, and to develop techniques, the U. S. Geological Survey made pilot studies in several areas and published the results as map reports. These were published as Hydrologic Investigations Atlases, as have been all such Survey reports. These reports, usually on one sheet, show on a topographic map base the area inundated by a flood. In addition there is shown a histogram of floods, a flood-frequency curve, flood profiles, photograph of area during flood, and a short text. The variety of conditions covered include:

(1) A large, single area covered by a specific flood.
(2) Several separate areas on flat terrain covered by a specific flood.
(3) Flooded area shown on a photomosaic.
(4) Areas in a city covered by floods of selected frequency.
(5) Foothill and tidewater inundation.
(6) Inundation by ocean tides.

State and local interest in flood inundation problems is evidenced by the fact that 13 states and local agencies and the Commonwealth of Puerto Rico have contributed funds for cooperative projects with the Survey.

Projects of the type described here are conducted by district offices of the Surface Water Branch, Water Resources Division, of the Geological Survey. Consultative service is provided by the Washington office staff. District offices are located in almost every state, usually at the State Capital.

USGS cooperation with States and local agencies is financed on a 50:50 basis, not only for this flood-plain mapping, but also for the bulk of its stream-gaging program.

f. The Watershed Protection and Flood Prevention Acts

(1) Background - The basic purpose of the Watershed Protection and Flood Prevention Act of 1954, commonly referred to as Public Law 566, and subsequent acts amending and supplementing the 1954 Act, was to enable the Department of Agriculture to utilize engineering works for the control of headwater floods.

The Flood Control Act of 1936 authorized the Secretary of Agriculture to propose land treatment projects for the reduction of floods on the same river basins for which engineering plans were prepared by the Corps of Engineers. However, the studies made under this authority soon indicated that the effect of land treatment measures on floods large enough to cause substantial flood damage would be relatively small. These studies also showed that, in the aggregate, considerable flood damage is suffered on the narrow flood plains adjoining the many miles of headwater valley.

The Department of Agriculture considered that any substantial reduction in these damages would require the construction of reservoirs or other engineering works, or both. Moreover, it appeared that since the Corps of Engineers was under constant pressure from the Congress, and the interests involved, to give priority to the more serious flood problems of the major rivers and their principal tributaries, the need for engineering measures in headwater valleys would not be met for many years under existing laws, policies, and appropriation limitations. This led to the introduction of the bill which subsequently became Public Law 566. This act authorized the Secretary of Agriculture to assist local organizations to prepare and carry out plans for the reduction of flood damages along streams draining less than 250,000 acres (nearly 400 square miles).

These plans may encompass both engineering works and land treatment measures. But since adequate legislative authority, established programs, and large appropriations are available for any land treatment work needed within the watersheds for which Public Law 566 projects are planned, the authorities of that act are used almost entirely for the planning and construction of small headwater reservoirs and other engineering works. Not more than 5,000 acre-feet of flood control capacity may be provided for flood control purposes in a single Public Law 566 reservoir.

(2) Procedure for Obtaining Protection

(a) General - As originally enacted, Public Law 566 required local interests to provide lands, easements, and rights-of-way and to assume such share of the cost of flood control works as the Secretary of Agriculture should find appropriate. In 1956, the act was amended for the stated purpose of bringing the cost-sharing provisions into consonance with those of the flood control acts under which the entire cost of construction of Federal local flood control works are borne by the Federal Government, but under which non-Federal interests provide lands, easements, and rights-of-way. The same amendatory act considerably broadened the scope of Public Law 566, permitting the Department of Agriculture to construct, at the request of local organizations, engineering works for drainage, irrigation, recreation, fish and wildlife enhancement, municipal and industrial water supply, and other purposes. However, it is only for the "flood prevention" component of Public Law 566 projects that the Federal Government bears the full cost of construction.

The Watershed Protection and Flood Prevention Act authorizes the Secretary of Agriculture to give technical and financial help to local organizations in planning and carrying out watershed projects. The watershed projects are for flood prevention, agricultural water management, recreation, municipal and industrial water supply, and fish and wildlife development. The program is administered by the Soil Conservation Service.

(b) The Application -

Preparing the Application. Any legally qualified local organization may submit an application. The application includes (a) size and location of the watershed, (b) description of the problem, (c) extent of damages, (d) details about the work needed, (e) source of funds, and (f) information about the organization. Standard application forms are available at local SCS offices. The local organization sends the application to the agency designated by the Governor of the State and a copy to the SCS State Office.

Field Examination. Technical specialists of the SCS, Forest Service, Fish and Wildlife Service, and other interested agencies both Federal and State, may examine the watershed.

State Action. If the State agency disapproves the application, it notifies the local organization. If it approves, it sends the application to the SCS State Conservationist. He sends it to Washington for review by the SCS Administrator.

Planning Authorization. Based on planning priorities recommended by the State agency, the SCS State Conservationist makes preliminary investigations, reconfirms the local organization's desire to go ahead with preparing a work plan, and recommends to the SCS Administrator that planning help be authorized. The State Conservationist notifies the local organization when planning help is authorized.

(c) Work Plan -

Detailed Field Studies. The SCS, Forest Service, Fish and Wildlife Service, and other interested Federal and State agencies assist the local organization by making detailed field studies to determine what can be done, the cost, and the benefits. Benefits must exceed costs.

Work-Plan Preparation. The local organization prepares a work plan with SCS assistance. The plan describes the benefits, the proposed measures, how they will be financed, and when they will be installed. Both the local organization and the SCS sign the watershed work plan agreement.

Work-Plan Approval. If funds are available, the SCS State

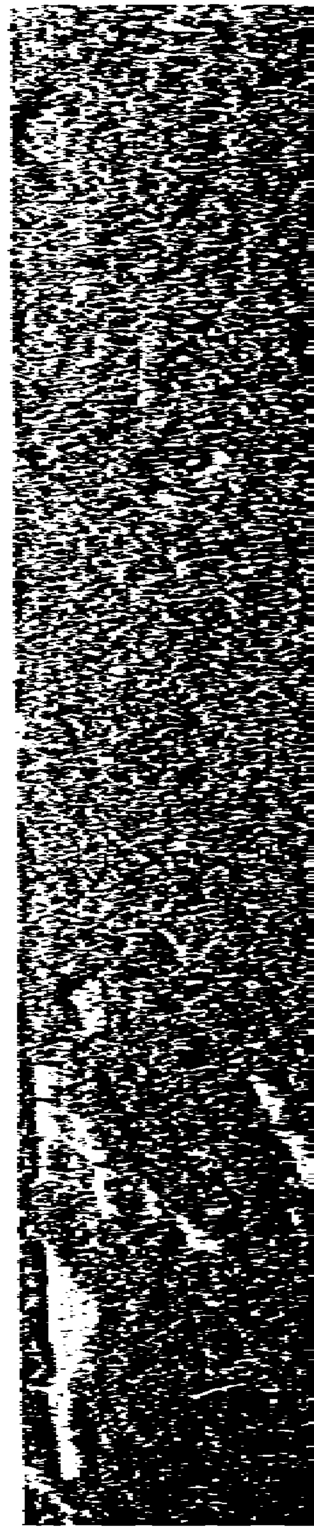


FIGURE 8. Flood prevention structure, Tennessee (Courtesy USDA - Soil Conservation Service).

Conservationist can authorize the operations to begin at once provided:

(1) The estimated Federal contribution to construction costs does not exceed $250,000; and

(2) The work plan does not contain any single structure having a total capacity of more than 2,500 acre-feet. (An acre-foot is the amount of water which would cover an acre to a depth of one foot, or a lot 70 ft. by 100 ft. to a depth of slightly more than 6 ft.)

If the estimated Federal contribution to construction costs exceeds $250,000, or if the work plan contains a single structure having a total capacity of more than 2,500 acre-feet, the procedure is:

(1) Other interested Federal agencies review the plan within 30 days.

(2) The plan is sent to the Director of the Office of Management and and Budget, who transmits it to the Congress.

(3) Committees of the U. S. Senate and House of Representatives approve the plan before further Federal assistance is made available.

Making Funds Available. The SCS Administrator allocates funds for watershed projects from money appropriated each year by Congress.

Cost Sharing. For flood prevention, the Federal Government pays for all engineering and construction costs. For irrigation and drainage and for public recreation and fish and wildlife development, it pays for all engineering service and up to 50 percent of the construction.

In certain circumstances, it pays up to 50 percent of the cost of the land rights and of the minimum basic facilities for public recreation or for public fish and wildlife development. All other costs -- including all costs for industrial and municipal water supply -- must be paid by the local organization.

Land Rights. The local organization must obtain all land and land rights needed for a watershed project.

Loans and Advances. To help a local organization pay its share of the project cost, the Federal Government, through the Farmers Home Administration, can make loans. The loans can be for periods of up to 50 years at the Federal long-term borrowing rate, with a limit of $5 million for one project. The Federal Government can also advance money to preserve sites for future construction, once the work plan has been approved. This money must be repaid with interest before construction. Also, the Federal Government can make money available for the extra cost of developing water-supply storage for future municipal or industrial use. No interest is charged and no repayment of the principal is required until water is first used -- except that interest can be deferred for only 10 years after completion of the storage facilities.

(d) Operation -

Land Treatment. The local organization is responsible for needed soil and water conservation treatment. It must be applied before or during work on the structures. SCS technicians and others can provide additional technical assistance to accomplish this during the time specified in the work plan.

Engineering Work. Engineers make field surveys and prepare designs and specifications for construction. The local organization has the option of employing its own engineers or of requesting SCS to provide them.

Project Agreements. The SCS and the local organization enter into an agreement covering each potential contract for the construction of works of improvement. This agreement is the basis for obligating Federal Funds.

Construction. The local organization is responsible for issuing bids and lets the contracts for construction. Contractors build the structures and other works of improvement.

Operation and Maintenance. Once works of improvement are installed, the local organization is responsible for operation and maintenance. The local organization must sign a written operation and maintenance agreement before Federal funds are made available for any construction.

g. Multiple Purpose Aspects of Flood Control Projects - When the first general flood control legislation was enacted in 1936, the Congress made it very clear, in hearings, committee reports, and debate, that the Federal Government would participate in only those projects for protecting cities and other urban areas against great, or catastrophic, floods. When specific projects were being selected for authorization by the act, the Senate Committee on Commerce repeatedly rejected projects for the protection of agricultural areas on the ground that these were equivalent to "reclamation projects." Many projects of this kind, however, were subsequently included in the bill finally enacted. As the years went by the Congress began to take a broader view of flood control, and successive flood control acts reflected this by authorizing protection of urban areas not subject to catastrophic damage, then protection of the larger agricultural valleys, and finally of even small agricultural areas.

In 1936, also, the Congress tended to think in terms of single-purpose flood control projects. But it was not long before it became clear that reservoirs for the storage of floodwaters could be used for other purposes, and particularly the generation of electric power. By the time the 1944 Act was under consideration, the important concept of comprehensive and coordinated development of the resources of the Nation's major river basins was already understood and accepted by many Members of Congress. As the years went by, the Federal program being carried out pursuant to the flood control acts became progressively broader in scope. At the present time these acts, although they are still referred to as "flood control acts," constitute the main body of Federal law dealing with the development, utilization, and conservation of the Nation's water resources.

Under these acts power is generated and marketed, major outlets are provided to facilitate drainage of land, storage for irrigation water is made available, water is provided for municipal and industrial use as well as for the abatement of pollution and for navigation improvements, recreational facilities are provided, measures for the enhancement of fish and wildlife are carried out, and plans for the comprehensive development, use, and conservation of the water and land resources of major regions are made and put into effect. In short, flood control law has become the legislative basis for the broadest

FIGURE 9. Newly installed Tainter gates, Carlyle Reservoir, Kankakee River, Illinois (Courtesy Corps of Engineers).

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Chicago, November 1958.

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ma years, the National Weather Service has recorded the best

TABLE 3. Flood disasters in the United States causing more than 100 deaths.

| Year | Stream or place | Lives Lost | Cause[1] |
|---|---|---|---|
| 1874 | Tributary of Connecticut River | 143 | Failure of small dam. |
| 1889 | Johnstown, Pa. | 2,100 | Do. |
| 1893 | South Atlantic coast | 2,000 | Hurricane. |
| 1900 | Galveston, Tex | 6,000+ | Do. |
| 1903 | Kansas, lower Missouri, and upper Mississippi Rivers | 100+ | |
| 1903 | Heppner, Oreg | 247 | Cloudburst on 20 square miles. |
| 1913 | Miami, Muskingum, and Ohio Rivers | 467 | |
| 1913 | West Texas Rivers | 177 | |
| 1921 | Upper Arkansas River | 120 | |
| 1926 | Lake Okeechobee, Fla | 350 | Hurricane. |
| 1927 | Vermont | 120 | |
| 1927 | Lower Mississippi River | 313 | |
| 1928 | San Francisquito Valley, Calif | 350 | Failure water supply dam. |
| 1928 | Lake Okeechobee, Fla | 2,400 | Hurricane. |
| 1935 | Republican and Kansas Rivers | 110 | |
| 1935 | Florida Keys | 400 | Hurricane. |
| 1936 | Northeastern United States | 107 | General storm plus snowmelt. |
| 1937 | Ohio River | 137 | |
| 1938 | New England | 500+ | Hurricane. |
| 1955 | Northeastern United States | 187 | Do. |
| 1957 | Gulf Coast, La. and Tex | 430 | Do. |
| 1969 | James River Basin in Virginia | 153 | |

[1] Where cause is not listed the flood was caused by excessive rainfall and runoff.

TABLE 4. Flood disasters in the United States resulting in damage exceeding $100,000,000.

| Year | Stream or place | Damage (millions) Contemporary dollars | Damage (millions) 1971 dollars | Cause[1] |
|---|---|---|---|---|
| 1889 | Johnstown, Pa................. | 20 | 110 | Failure small dam. |
| 1900 | Galveston, Tex................ | 25 | 137 | Hurricane. |
| 1903 | Kansas, lower Missouri, and upper Mississippi Rivers..... | 40 | 192 | |
| 1913 | Miami, Muskingum, and Ohio Rivers..................... | 150 | 672 | |
| 1926 | Lake Okeechobee............. | 70 | 186 | Hurricane. |
| 1927 | Lower Mississippi River...... | 284 | 775 | |
| 1936 | Northeastern United States... | 270 | 870 | General storm plus snowmelt. |
| 1937 | Ohio River.................. | 418 | 1,298 | |
| 1938 | San Gabriel, Santa Ana, and other southern California rivers..................... | 79 | 250 | |
| 1943 | Central States.............. | 172 | 408 | |
| 1944 | ....do..................... | 82 | 190 | |
| 1947 | Missouri and middle Mississippi....................... | 235 | 437 | |
| 1947 | Central and southern Florida. | 60 | 111 | |
| 1948 | Columbia River.............. | 102 | 178 | |
| 1951 | Kansas River................ | 935 | 1,494 | |
| 1952 | Red River of North and upper Mississippi................. | 198 | 312 | |
| 1955 | Northeastern United States... | 714 | 1,089 | |
| 1955 | California and Oregon........ | 172 | 263 | |
| 1957 | Southwestern United States.. | 125 | 178 | |
| 1959 | Ohio Basin.................. | 114 | 156 | |
| 1963 | Ohio Basin.................. | 98 | 127 | |
| 1964 | West Coast.................. | 416 | 535 | |
| 1964 | Ohio & Tributaries.......... | 82 | 105 | |
| 1965 | Colorado.................... | 415 | 524 | |
| 1965 | Midwest..................... | 181 | 229 | Snowmelt plus rain. |
| 1967 | Gulf Coast in Texas......... | 98 | 117 | Hurricane Beulah. |
| 1967 | Tanana and Chena Rivers, Alaska...................... | 99 | 118 | |
| 1968 | Northern New Jersey......... | 167 | 191 | |
| 1969 | California.................. | 399 | 433 | |
| 1969 | Upper Midwest............... | 151 | 164 | Snowmelt. |
| 1969 | James River Basin, Virginia. | 116 | 121 | |

[1] Where cause is not listed the flood was caused by excessive rainfall and runoff.

information that has been made available to it by county agents, city officials, and others. Admittedly, this record has covered only part of the flood damage suffered in the Nation. The Corps of Engineers has made numerous determinations of flood damage within reaches of streams which would be affected by contemplated Corps projects, or within the scope of authorized surveys. These, of course, were not intended to be complete inventories of nation-wide flood damages. Recently the Soil Conservation Service has made estimates of flood damages in many headwater valleys, usually along streams draining less than 250,000 acres. Here again, however, damage estimates have been made in connection with studies of specific projects, and cover in detail only a small percentage of all headwater flood plains.

Thus it is not possible to present any complete inventory of past flood damages in the United States.

It has been estimated that flood damages, despite programs and projects for abatement of such damage, now average about a billion dollars per year. This estimate includes agricultural damage as well as urban damage. Agricultural damage occurs generally on smaller streams than urban damage does, and is more a result of frequent overflowing than of rare events of larger magnitude.

It has been estimated that the flood plains of the conterminous 48 states total about 100,000,000 acres, or about 5% of the land area. This portion of the land area is important out of proportion to its size, because of the benefits of occupying it. Its uses include water-level transportation routes such as railways and highways, water-using industries, access to water supply for municipalities, access to waterways, and alluvial farm land.

i. <u>Non-Structural Alternatives</u>

(1) <u>Introduction</u> - In recent years, recognition has been given to alternate methods of abating flood damages. Structures are still the predominant method, but in most instances a combination of methods has been found to be most helpful. The following paragraphs describe some of the alternative methods for reducing or avoiding flood damage.

Human occupancy and use of flood plains can be had only by accepting flood damages or by attempting to reduce or prevent them. Thus, finding the best solution for any particular flood problem is basically a matter of considering a number of alternatives. If it is found that any feasible method of reducing flood damage would cost more than the reduction achieved, the alternatives are to allow those who suffer the damages to continue to absorb them, or to spread the losses by such means as disaster relief. If it is decided that measures for reduction of flood damage are essential, a choice may be made between (1) abandonment or evacuation of flood plains, (2) regulation of flood plain use to accommodate it to the flood hazard, and (3) provision of works and measures for flood protection or control. In some cases a combination of these alternatives may offer the best solution.

(2) <u>Flood relief</u> - Where flood damages have been relatively minor they are usually permitted to continue. Ordinarily, this is not a conscious decision, but in some instances the choice has been arrived at by an investigation which showed that the cost of abating flood damage

would exceed the value of the reduction in damage. Regardless of the way in which this alternative is selected, however, it has become a universal practice in the United States to lessen the impact of flood catastrophes by flood relief. The effect of this is to distribute, by use of public funds and private contributions, the cost of a part -- although usually a small part -- of the damage to those not directly affected by the flood waters.

(3) Flood Plain Abandonment and Evacuation - Where flood damages become unbearably high, something is ultimately done to lessen them. One way of accomplishing this is simply to abandon use of the flood plain. Such abandonment may be complete or partial as, for example, when cropland is permitted to revert to pasture or woods. Abandonment has, in fact, been the usual solution for the frequently overflowed flood plains which border creeks and small rivers in agricultural areas. In many instances this is a very practical and economical solution. It has often been pointed out that failure to use flood plains of minor streams means that a potential source of production is not being used. But, obviously, no real loss will result from this until that potential production is needed and can be developed at less cost than other means of production available at the time.

Abandonment of larger flood plains to avoid flood loss is not generally feasible. The cost to the Nation of the necessary adjustments would be very high, and the production is usually so great that it could not be absorbed by existing surplus capacity. Nevertheless, sizeable agricultural areas on flood plains have been abandoned, and the practicability of this as an answer to some flood problems was recognized by Congress in the Flood Control Act of 1938, which authorized "evacuation" of flood plain lands as an alternative to protecting them.

Even less feasible, from the economic standpoint, than the abandonment of large agricultural flood plains is the abandonment of urban areas. In a few instances this alternative has been used, but economic studies show that, in general, where large investments have been made in developing a flood plain it will cost less to protect those investments than to abandon them.

A measure for ameliorating flood damage much more commonly resorted to is the temporary abandonment, or evacuation, of flood plain areas. This is the usual procedure in many of the larger river valleys when it is known that a great flood is imminent. People move to higher ground, taking such of their belongings as they find it possible to move, and do whatever is possible to minimize damage to the properties which cannot be moved. To make this measure more effective, and particularly to insure that it may be used without loss of life, flood warning systems are obviously necessary. Such systems are essential if reliance is to be placed upon evacuation of flood plain lands as a means of reducing the damage done by great floods. Also essential are carefully prepared evacuation plans which can be placed in operation promptly.

More information on streamflow forecasting is available in Print no. 25, of the Senate Select Committee on National Water Resources. Committee Print 25 describes the hydrologic and hydrometeorological work of the Weather Bureau, and may be regarded as an appendix to the material described herein.

(4) Regulation of Flood Plain Use - A measure which is receiving

progressively greater attention as the Nation's flood plains are more intensively developed, is "regulation of flood plain use." This requires the use of the legislative and police powers of the States, and their subdivisions, to so control the development of flood plains that excessive damage will not be suffered when great floods occur. High hazard areas are frequently set aside, or "zoned," for such uses as stream-front parks. In some instances, buildings are permitted in such zones if they are "flood-proofed" by raising the lowest floor above flood stage or by providing for quick closure of all openings during floods.

As the Nation develops it will find it necessary to use flood plain lands more and more intensively. Flood plain regulation will, therefore, become increasingly important. In fact, it should currently be given a great deal more attention that it has received in the past.

j. Structural Alternatives

(1) Confinement of Floods - One of the most used measures for reducing flood damages is the construction of levees, or dikes, to keep the flood-waters from spreading over the entire flood plain. It is by this means that vast areas of the original flood plain of the great Mississippi River have been protected from overflow. Levees are also frequently used for the protection of cities. In some instances flood-walls of reinforced concrete are used instead of levees because of the high value lands in urban areas. Confinement of floods is one of the oldest and most effective means of reducing flood damages. In some places levees have so constricted the river channel that for a given rate of flood flow the new stage is higher than the old, and may threaten the levee itself.

(2) Decreasing Flood Runoff - Early in the present century considerable publicity was given the hypothesis that the removal of forests and cultivation of the land had greatly increased the magnitude and frequency of floods. This led to the conclusion by many that floods could be prevented, or much reduced in magnitude, by reforestation or by the use of "soil conservation" practices. The concept which gave rise to this belief was that such measures -- usually referred to collectively as "land treatment" measures -- would increase the rate at which precipitation would infiltrate into the soil, and would also increase the capacity of the soil mantle to retain infiltrated water.

Research during the past three or more decades has shown that land treatment measures do indeed increase the infiltration capacity, and also, to a limited extent, the storage capacity of the soil mantle. But is has also revealed that these effects are small when compared to the intensities and volumes of storms that produce the larger floods on major rivers. Hence, it is now generally conceded by all who understand the natural processes by which floods are created that land treatment alone is not a feasible measure for reducing large floods.

Land treatment measures, however, are of great value in themselves for they conserve the soil and improve its productivity. They also have a considerable effect upon the total amount of water which infiltrates into the soil during the year, as even a small increase in the infiltration occuring during each storm may aggregate several inches of water during the course of a year. Moreover, the effect of such a small increase in infiltration may substantially reduce the peak stages of small floods on minor streams.

(3) Increasing Channel Capacity - A much used means of reducing flood stages, and hence flood overflow, is the enlargement of channels. This is usually accomplished by excavating to increase the depth or width (or both) of the natural channel. Channel capacity may also be increased by reducing the resistance which the channel offers to flow. This is accomplished by removing "snags" and other obstructions, providing a more uniform cross section, and eliminating unnecessary bends. When large values are at stake, the resistance to flow may be reduced by providing a smooth channel lining. This measure is exemplified by the concrete channels which carry floodflows through Los Angeles and its suburbs. Such channel linings also serve to protect the channel against erosion by the high-velocity flows which a reduction in resistance to flow often induces.

Another means of increasing channel capacity is the provision of an alternative channel which comes into play only during great floods. This measure is exemplified by the "floodways" provided at certain points in the Mississippi Valley and in the Sacramento River Valley in California. These floodways do not come into action until a "fuse plug" levee is broken, or gates are opened, as certain flood stages are reached. Increased channel capacity has the disadvantage of sediment with low flows; and because of negligent maintenance, the stream may soon revert to its earlier limited capacity. Rating curves may change rapidly after a few small floods following an "improvement." Also many times segments of straightened channels are discontinuous, and at the lower end of a segment flooding may actually be induced because of timing, and greater delivering capacity to the existing channel.

(4) Storage of Floodwaters - The principal means of reducing flood stages is by storing floodwater in reservoirs and releasing it at rates as nearly as possible within the safe capacity of downstream channels. Such storage, with uncontrolled outlets, may be very temporary, and releases may often exceed downstream carrying capacity. In reservoirs with controlled outlets the stored water may be held longer and released more slowly, depending on need for the water, downstream stages, and the prospect of additional heavy inflow to the reservoir.

Reservoirs as a means of flood control are perhaps of greatest importance from the standpoint of comprehensive river basin development. The same reservoirs which reduce flood flows may often be used to provide water supply, generate power, reduce stream pollution, and provide opportunities for public recreation and for preservation of fish and wildlife. In brief, reservoirs constitute a basic facility for multiple-purpose river development.

(5) Degree of Protection - Determination of the degree of flood protection to be provided by flood control works is an important and difficult procedure. It is obvious that the degree of protection should vary with the hazard involved. Thus, a levee to protect agricultural land may be quite satisfactory if it is designed to provide the degree of protection which economic analysis shows will result in the greatest excess of benefits over costs, even though the degree of protection may be relatively low -- say against a flood of 10-year frequency. On the

other hand, an urban area where loss of life may result from failure, or an industrial area where heavy property damage is involved, must be given a very high degree of security not only from the greatest floods of record but from the even greater floods which storm and flood studies indicate may occur.

Different degrees of protection are acceptable for different types of works. For example, if the capacity of a flood channel is exceeded, the water merely spreads out slowly across the flood plain, whereas if a levee or floodwall fails by overtopping, the resulting rush of floodwater into a protected area would cause great destruction and probably loss of life.

Determination of a proper degree of protection is most critical where there is a possibility that, as a result of flood protection, areas which are now agricultural, or lightly developed, will develop intensely for urban and industrial purposes. If the degree of protection originally provided is too low, a false sense of security is induced, unwarranted development is encouraged, and when the great flood comes inevitably, the stage will be set for a disaster. Consequently, determination of the proper degree of protection to be provided is an important decision to be reached in providing for a solution of a flood problem.

The degree of protection at many reservoirs is designed for high benefit areas such as downstream cities, then after the reservoir is built, the operating manual is issued which may not correspond to the design criteria. The reason for this is political pressures arising from many sources (usually agricultural interests downstream from the reservoir) who object to minor flooding, or in many instances to long-period bankful conditions, which was necessary in the design to evacuate the flood control storage as soon as possible. Consequently, the longer the time the flood control zone is occupied, the less the degree of protection provided for the high benefit areas. This problem is almost impossible to resolve.

k. Coastal Flood Protection - The provision of measures for reduction of damage from coastal flooding presents a separate and difficult problem.

On most exposed reaches of shoreline subject to hurricane flooding there may be no practicable way of providing protection. Barriers in such cases may seriously interfere with the natural beauty and recreational value of beach areas. In a limited number of cases, the building up of beaches and sand dunes may afford a reasonable solution. In most cases, however, on exposed reaches of shoreline, the principal reliance for reduction of damage from hurricane floods will probably have to rest with adequate warning service, proper building codes, evacuation plans and routes, and with the zoning of more hazardous areas.

l. Procedure for Corps of Engineers' Projects - Consideration of a flood problem begins with the request for a survey by local people concerned. When such a survey is authorized by Congress it is accomplished by the Corps of Engineers as soon as funds are appropriated for that purpose. During the course of the survey the views of local interests are sought by means of public hearings, and coordination with States and other Federal agencies is effected at field level by the district engineer charged with conduct of the study. There is no statutory size limitation on projects of the Corps of Engineers.

When completed the report passes through successive stages of review by the division engineer, Board of Engineers for Rivers and Harbors, and Office, Chief of Engineers. Comments of the Governors of States and heads of the various Federal agencies are secured. These along with the recommendation of the Chief of Engineers are furnished by the Secretary of the Army to the Office of Management and Budget (OMB) for review. The report then goes to Congress with the statement from the OMB as to conformity with the program of the President.

Reports on flood control projects received by the Congress are usually considered by the Public Works Committees at intervals of from 2 to 4 years for inclusion in flood control legislation. Public hearings are held by these committees at which testimony by local interests and by the Corps of Engineers and other Federal agencies is heard. When legislation including a specific project is enacted into law, that project becomes a part of the authorized program and eligible for appropriations for design and construction.

Since a single "omnibus" flood control act may authorize a large number of projects, some years may elapse before it is possible for the Congress to appropriate funds to start the work. When funds become available the project is designed and built by the Corps of Engineers, usually by contract with private construction firms. When local flood protection projects are completed they are turned over to local interests for maintenance and operation in accordance with instructions provided by the Department of the Army. Reservoirs for flood control or for multiple-purposes are maintained and operated by the Corps of Engineers.

m. Forecasting - Most of us are probably as familiar with flood forecasting as we are with any aspect of water resources, and techniques of forecasting will be discussed in later parts of this course. At this point, however, it is significant to state that forecasting is a necessary adjunct of every other measure for achieving relief from flood damages.

Examples of the need for forecasting include the following: With structural "control," forecasts of inflow into the system are necessary for operation of the system and for planning releases. With ungated structures, forecasts of outflow are equally and obviously necessary for protection of downstream interests. For planning storage releases, forecasts of inflow from tributaries between the storage site and downstream damage sites are necessary.

With levee systems, forecasts are necessary for areas downstream from the levee, for maintenance and protection of the levee, and for warnings of possible levee overtopping. Forecasts are necessary for internal drainage back of the levee, both of the internal area itself, and of stages of the river into which the local runoff is to be pumped.

For flood-plain zoning, forecasts are necessary to warn of need for evacuation of areas zoned for intermittent use. Where reliance is placed on flood-proofing of structures in zones subject to flooding, warnings are obviously necessary. Even if a zone is to be abandoned to a floodway, its boundary is, in practice, influenced by floods and their forecasts. Construction of a large number of farm ponds, or larger reservoirs with uncontrolled outlets, may affect the rainfall-runoff relations used in making forecasts.

### 3. Irrigation

a. Introduction - The problems of water resources are essentially too much water or too little water; water in the wrong place, at the wrong time, polluted water or not enough at the right time.

The major consumptive use of water is for the growing of vegetation. In addition to the water which naturally falls on farm land, water is taken from wells, surface storage, and streams to augment the natural supply. This is known, of course, as irrigation.

Irrigation may be divided into two major categories. One is seasonal irrigation in parts of the 17 western states where growing-season rainfall is normally deficient for agriculture. The other kind of irrigation is known as supplemental irrigation, applied where there is normally enough rain, but at times when additional water is necessary for successful crop production.

The Bureau of Reclamation is the major agency engaged in development of seasonal irrigation, and the Soil Conservation Service is the major agency for supplemental irrigation. For convenience in presenting the background information from the points of view of these two agencies, the following discussion refers to them separately. The following information on seasonal irrigation is summarized mostly from Committee Print no. 14 of the Senate Committee on National Water Resources.

b. Seasonal Irrigation

(1) History - Irrigation has been practiced in North America for many centuries. The canal-building Hohokam Indians of the Southwest had developed an advanced culture by the year 1400 A. D. Some of the large irrigation works in use for irrigation of the Salt River Valley in Arizona follow the alinement of these old canals.

Spanish explorers and colonizers in the Southwest brought from Europe a knowledge of irrigation based on Arabic experience and established simple irrigation facilities by the year 1600. For the ensuing two and a quarter centuries the only significant permanent agriculture in the arid West by the white man was that surrounding the Spanish missions and settlements.

In 1847 the Mormon settlers of Utah established the first successful modern irrigation farming operation. By 1850 they had placed 16,000 acres under irrigation, and by 1890 their irrigated area had grown to 263,500 acres. Their cooperative principles of irrigation worked out through the experience of trial and error are basic to present processes governing irrigation in the West.

With the decline of fur trading and placer mining, the trappers and miners found it necessary to enter other activity. Some of them took up ranching in the mountain areas, but they soon found that irrigation was necessary to insure a winter feed supply for their livestock herds. In addition, there was a constant flow of westward-bound settlers. Thus, starting about 1870, irrigation expansion began at a relatively constant

FIGURE 10. Irrigating a bean field (Courtesy Bureau of Reclamation).

rate.

The centers of population at the Indian irrigated areas, Spanish settlements, Mormon villages, and scattered ranches were the way stations of the West during the early days. Today, these old crossroads are the major towns and cities of that area. By 1900 the Western States had slightly over 7 million acres under irrigation. By 1950 the irrigated area had reached 25 million acres, and by 1958 it comprised about 30.5 million acres.

The first irrigation developments depended entirely on the simple diversion of natural streamflow. As development proceeded it became evident that further expansion required additional water or more elaborate means of transporting available riverflows to irrigable land. Construction of storage and large-scale pumping plants, which comprised the obvious solution was relatively expensive and beyond the means of most groups of water users. In response to this need, the Federal Government entered the irrigation field and has been responsible for the construction of substantial storage and pumping facilities. These, in turn, have provided the basis for the continued expansion of irrigation.

Federal assistance in irrigation took several forms, including the Desert Land Acts of 1877 and 1891. The first act of major significance was the Carey Act of 1894 which was designed to encourage irrigation development on public land and provided for land grants to the States for resale to individuals. More than a million acres of land were reclaimed under the provisions of this act.

Difficulties arose, however, from the limited financial resources of States and individual promoters and from the absence of sufficient safeguards against inadequate engineering and hydrologic studies. In a number of instances, poorly founded or speculative ventures had resulted in a breakdown of public confidence in large-scale irrigation proposals and resulted in a recognition of the need for responsible sponsorship of investigations, construction, and settlement practices. The Reclamation Act of 1902 overcame many of these shortcomings, and it has since provided an important basis for the continued development and economic growth of the 17 western States. In addition to providing many facilities by Federal financing and construction on a reimbursable basis, it has established the technical pattern and knowhow that has permitted expansion of private development.

(2) Present Status - Today about one-fifth of all irrigated lands in the West receive a full or partial water supply from facilities constructed by the Bureau of Reclamation. About one-fifth of the farms in the West are partially or wholly irrigated. Acreage and production of the major crops for these farms, as of 1960, is given in Table 5.

Present irrigated farming ranges from extensive use for hay and pasture to very intensive use for citrus fruits, dates, avocados, and many kinds of vegetable. Double cropping is practiced in the Southwest, largely in the production of vegetables.

Irrigated farms provide feed for farm livestock and a feed base for sheep and cattle which are pastured during the summer on range and forest land. There are about 10 million cattle and calves and 6.5 million sheep on irrigated farms at the beginning of each year. About one-third of these animals are raised entirely on irrigated farms, and

TABLE 5. Acreage and production of major crops, as of 1960.

| Item | Acres: Number | Acres: Percent | Units | Production | Average yield per acre |
|---|---|---|---|---|---|
| Corn | 2,282,000 | 7.5 | Bushels | 157,642,000 | 69 |
| Oats | 620,000 | 2.0 | ....do | 29,304,000 | 47 |
| Barley | 1,775,000 | 5.8 | ....do | 80,725,000 | 45 |
| Grain sorghums | 2,300,000 | 7.5 | ....do | 123,140,000 | 54 |
| Mixed grain | 6,000 | ... | ....do | 205,000 | 34 |
| Forage | 375,000 | 1.2 | Tons | 5,598,000 | 15 |
| Hay | 11,400,000 | 37.5 | ....do | 30,111,000 | 2.6 |
| Pasture | 400,000 | 1.5 | Animal units * | 3,143,000 | 6.8 |
| Wheat | 1,615,000 | 5.3 | Bushels | 58,028,000 | 36 |
| Rye | 20,000 | .1 | ....do | 373,000 | 19 |
| Rice | 820,000 | 2.7 | Hundredweight | 28,283,000 | 34 |
| Potatoes | 710,000 | 2.3 | ....do | 123,950,000 | 175 |
| Sugar beets | 675,000 | 2.2 | Tons | 10,959,000 | 16.2 |
| Sweet potatoes | 16,000 | .1 | Hundredweight | 1,352,000 | 85 |
| Dry beans | 820,000 | 2.7 | Pounds | 1,331,107,000 | 1,623 |
| Soybeans | 16,000 | .1 | Bushels | 273,000 | 17 |
| Cotton | 2,875,000 | 9.4 | Bales | 4,849,000 | 1.69 |
| Flaxseed | 40,000 | .1 | Bushels | 1,233,000 | 31 |
| Peanuts | 50,000 | .2 | ....do | 2,123,000 | 42 |
| Fruit | 1,930,000 | 6.3 | Dollars | 1,080,800,000 | 560 |
| Vegetable | 1,350,000 | 4.4 | ....do | 459,000,000 | 340 |
| Other | 345,000 | 1.1 | ....do | 48,300,000 | 140 |
| Total | 30,500,000 | 100.0 | ---------- | ---------- | ---------- |

* An animal unit is equivalent to one cow per month. Smaller animals are assigned fractions of this, so as to give a common measure.

the remainder are pastured on range and forest land. It is estimated that some 200 million acres of rangeland are associated with irrigated land in this manner.

In areas like the Great Plains which are subject to recurrent drought, farm operators have found that irrigation takes much of the risk out of livestock production. A small irrigated acreage on each farm will provide a dependable feed supply and will permit the addition of livestock production as a complement to grain farming.

Early irrigation developments consisted of simple diversion structures and canals, but the possibilities for this type of irrigation were soon limited by the amount of easily divertible natural riverflow available during the irrigation season. Irrigation from storage and from more elaborate pumping installations was then undertaken, followed in recent years by the rapid development of ground water. Reservoir storage normally is used to regulate natural flows, and on a normal project the irrigation water supply is an admixture of natural flows and stored water.

On the average, at least 10 acre-feet of storage are required for each acre of land irrigated from storage. The average annual diversion requirement is about 4 acre-feet per acre, so that much of the irrigation reservoir capacity involves holdover storage for service in years when streamflow is insufficient to refill the reservoirs.

Of the 190 million acre feet of reservoir capacity in which irrigation is a major function, 110 million acre feet are used for irrigation itself, power uses more than 100 million, and flood control uses nearly 40 million. This joint use of the same space for different functions at different times provides efficient use of storage capacity, in which the sum of the parts is greater than the total at any one time.

c. Supplemental Irrigation - Just as the region of seasonal irrigation is usually regarded as the 17 western states of the conterminous 48 states, supplemental irrigation is usually associated with the other 31 states, sometimes referred to as the humid region. This discussion of supplemental, or humid-region, irrigation is taken largely from such sources as the USDA Yearbook of 1955, "Water."

In most of the humid area, annual rainfall generally is enough to support sustained production of crops and pasture. Short dry periods are common, however. Supplemental irrigation is used primarily to make up for poor distribution of rainfall during the growing season.

Supplemental irrigation safeguards against droughts, increases yields, permits production of products of higher quality, provides earlier maturity, and maintains grazing capacities of pasture, especially in late summer and fall. Response from other improved practices, such as application of fertilizer, is also better with supplemental irrigation.

Rice fields in Louisiana and Arkansas are flooded, some irrigation of vegetables in Florida and North Carolina is subsurface, and most of the irrigation of citrus fruits is by the furrow method. Crops that require ground saturation or actual flooding, such as rice and cranberries, have long been irrigated in humid areas. The feasibility of irrigating other crops, such as vegetables and small fruits, has been recognized by eastern and southern growers for many years. But only in recent years have farmers generally come to realize the full potentialities of supplemental irrigation. In a number of eastern and southern states, the area irrigated has been doubling every ten years.

Among the factors that have encouraged supplemental irrigation in the humid areas are drought periods; improved irrigation equipment, particularly portable, lightweight pipe and sprinklers; better information on moisture requirements of crops and pastures; and relatively high farm incomes, which have favored investment in irrigation systems.

When prices received by farmers are high, irrigation has a better chance of providing a profit. Increased income derived from irrigation of a high-valued crop, such as vegetables, sometimes has enabled farmers to pay for irrigation equipment after 2 or 3 years of operation. With higher incomes farmers are more willing to use savings or to borrow money to make the substantial investments that irrigation systems require. Although weather, soil, and the kinds of crops grown affect the need for irrigation, the feasibility of supplemental irrigation as a regular farming practice is conditioned by the availability of an adequate supply of good water.

Serious shortages of water in growing seasons often occur in many sections of the humid areas. Only a few farms have streams, ponds, or wells sufficiently reliable to supply irrigation when it is most needed. This does not mean that the streams do not carry enough water during the year. It means that at the time of greatest supply, demand is usually at its lowest point. When supply is at its lowest point, or nonexistent, the demand for irrigation may be greatest. Seasonal shortages are among the major factors that affect the feasibility of supplemental irrigation.

Farm reservoirs, if they are large enough to meet peak irrigation needs and are properly located, offer a means of solving the problem of variable water supply. Water from wells is often used for irrigation. Where the water table is high, instead of using a well, a small pond may be made merely by digging out a hollow, with no outlet, and pumping from it. Where the rate of yield from wells is too low to supply water at a fast rate, accumulated flow from the well may be stored in a pond, and pumped out or allowed to flow out at intermittent high rates. The well continually replenishes the supply.

Sprinkler irrigation is the predominant method of applying irrigation water in the east. Except for alluvial lands, soil and topography are such that flooding, surface ditches, and furrow irrigation usually are considered not feasible. Sprinkling does not require land which is naturally level, or artificially made level, as for irrigation by ditches and furrows. Less water is wasted by runoff or infiltration in excess of what is needed, and there is less tendency for the irrigation water to leach out salts and induce pollution problems downstream. The relatively small size of the farms in the East and South justify the use of pipe and sprinkler systems which could not economically be used in the great expanses of the West.

American farmers first used sprinkler irrigation about 1900. In 1955 more than 2 million acres were irrigated with sprinklers.

Lightweight aluminum pipe with quick couplers came into widespread use after 1945. It cut labor costs of the earlier portable systems and demonstrated that sprinkler irrigation could be adapted to most sites and crops in the United States. The advantages of sprinkler irrigation, properly installed and operated, are indicated in the following several paragraphs.

Erosion can be controlled. Safe irrigation is possible on land too steep for the efficient use of other methods. If soil erosion is a hazard, sprinkler irrigation is well adapted for use in conjunction with mulching, terracing, and stripcropping.

Uniform application is possible on all kinds of soil. On sandy soils that have high intake rates, sprinkler irrigation distributes water better than other methods do. Water can be saved, more land can be irrigated, and drainage problems may be reduced.

The amount of water can be controlled to meet the needs of the crop. Light applications of water can be made to seedings or young plants.

Land preparation is not required. Soils too shallow to be leveled properly for other methods can be irrigated safely with sprinklers. On deeper soils the costs of land leveling can be eliminated or greatly reduced.

More land is available for cropping. Field ditches, corrugations, and dikes are not needed. It also lessens the weed problem, reduces wear on farm machinery, and simplifies tillage. Surface runoff of irrigation water can be eliminated.

Small streams of irrigation water can be used efficiently. Many small farms that have a continuous-flow water supply often have insufficient water to irrigate efficiently with surface methods.

The time and amount of application of fertilizers can be controlled to meet the needs of the plants. Water-soluble pesticides and fertilizers can be applied through the sprinklers.

Labor costs are reduced, notably on soils having high rates of intake and on land that is steep or rolling. Irrigation can be fitted into other farming operations as incidental work that is done once or twice a day.

Crop damage from frosts can be reduced by the use of specially designed sprinkler systems.

Disadvantages of sprinkler irrigation include the following. Wind may distort sprinkler patterns and cause an uneven distribution of water. When the spray is blown about, parts of the field may get too much water and others too little.

Tight soils, which have slow intake rates, cannot be irrigated efficiently in hot, windy climates. When water is applied at the low rates required for such soils, the percentage of loss by evaporation and wind drift is increased greatly. Costs of labor or installation may be higher on fields that remain muddy for some time after irrigation has been completed.

Climatic data and hydrologic data are essential for planning irrigation. Natural precipitation may furnish a large part of the moisture required by crops in humid areas. Peak water-use rates are much lower on the relatively cool coastal plains and in the high intermountain areas than in the hotter and drier interior valleys. Wind conditions in some places require special attention. Sprinkler spacing, nozzle sizes, nozzle pressures, and lateral layouts may need to be adjusted to provide adequate water distribution. Under adverse conditions, special wind nozzles sometimes are required. Climate also affects the minimum rate at which water should be applied. Application rates as low as 0.10 inch an hour may be satisfactory in cool, humid areas where the wind velocity is low. They are much too low for hot, arid, and windy interior valleys, because most of the water would be lost by evaporation and wind drift. Field crops in the hot, dry, southern areas may require minimum application rates approaching 0.5 inch an hour.

d. Forecasting for Irrigation - Obviously, forecasting has several applications to irrigation. One is the forecast of seasonal water supply, particularly in the West, where such a forecast is particularly important, and where it is naturally possible because of the lag between the accumulation of mountain precipitation and its runoff several months later. Another application of forecasting is of volume of streamflow where water is withdrawn or stored for supplemental irrigation. Usually, when supplemental irrigation is contemplated, there has been a dry period, and streams may naturally be low. Thus a forecast of low flows may be critical. This is particularly true where there are competing needs for water. An advantage here, as in other instances of the Weather Service making the forecast, is the fact that the NWS is impartial about the uses to be made of the water. An agency responsible for use of water, or for reservation of reservoir storage space for flood control, would have a possible conflict of interest in forecasting the supply.

Another application of forecasts to supplemental irrigation is the quantitative forecast of precipitation. If a reliable forecast of rain is made, the cost and labor of moving pipe and other equipment can be saved, and not only is water also saved, but possible damage from over-irrigating can be avoided. Similarly, if a farmer hesitates to irrigate after several dry days, because of the possibility of rain, a valid forecast of continuing dry weather helps him make his decision.

In scheduling sprinkling, the effects of wind and temperature, particularly near freezing, are important, and are appreciated by many weather forecasters.

## 4. Agricultural Drainage

Drainage of agricultural land is logically associated with irrigation for several reasons. One is that in many places, irrigation itself causes a drainage problem. Another reason is that drainage is an alternative to irrigation as a method for increasing crop yields.

The following information on land drainage is taken largely from the 1955 Yearbook of Agriculture, "Water."

a. History - American farmers since the early days of settlement have drained land.

In 1763 the Dismal Swamp area of Virginia and North Carolina was surveyed by George Washington and others with a view to land reclamation and inland water transportation. The Dismal Swamp Canal Company was chartered in 1787 by the two States. The canal was opened 7 years later.

It is still a means of transportation and helps to prevent floods.

In 1835 John Johnson of Seneca County, N. Y., brought over from Scotland patterns from which clay tile was molded by hand and laid on his farm. This was the beginning of modern tile drainage in the United States.

Settlement of the Ohio and Mississippi Valleys was just starting. Much of this land, though very fertile, could not be cultivated until it was drained, and malaria was prevalent in large areas. Here the use of tile spread rapidly; 1,140 tile factories, mainly in Illinois, Indiana and Ohio, were in operation by 1880. More than 30,000 miles of tile were laid in Indiana by 1882.

Farmers learned that the success of many tile systems depended on large outlet ditches. The construction of such ditches increased rapidly as the North Central States were settled. The Ohio Society of Engineers and Surveyors reported in 1884 that in Ohio, 20,000 miles of public ditches had been constructed, benefiting 11 million acres of land and improving the health of the citizens.

Drainage has added an estimated 25 million to 30 million acres to the tillable area in the North Central States and has increased production on about 37 million acres more.

THE SWAMP LAND ACTS of 1849 and 1850 were the first important Federal legislation relating to land drainage. They were the result of more than 20 years of discussion in the Congress of appropriate procedures for initiating reclamation of the wet lands of the public domain. For more than 75 years they were almost the only statement of Federal drainage policy. Under the acts, vast acreages of swamp and overflowed lands were transferred to the States on condition that funds from their sale be used to build the drains and levees necessary to reclaim them.

Under the Swamp Land Acts of 1849, 1850, and 1860, approximately 64 million acres of swamp and overflow land in 15 States were conveyed to the respective States to facilitate reclamation of the land for agricultural use. No important reservations were attached to this transfer, and the States were free to dispose of the land as they saw fit. In that way the Federal Government relinquished control of most of the potential drainage work in the public domain.

It has become common practice to dismiss as failures the drainage and flood-control projects started under the Swamp Land Acts. It is true that for the most part the States did not immediately develop the land as anticipated. But that is not the whole story.

Over the lower Mississippi Valley States, where administration and use of swampland funds was a major political, economic, and social issue for more than 30 years, reclamation carried out under the Swamp Land Acts permanently affected the agricultural economy. Experiences in flood control and drainage engineering, gained in trying to meet the provisions of the grants, formed the basis for the elaborate drainage projects later undertaken by local districts and by the States and the Federal Government for control of floods in the lower Mississippi Valley. Likewise most of the legal and administrative concepts and machinery set up under the Swamp Land Acts became a permanent part of flood-control and drainage practices.

According to the wording of the Swamp Land Acts, the reclamation included both flood control and drainage. But State and Federal legislators alike underrated the complexity and cost of flood control and drainage in the lower Mississippi Valley. Receipts from the sale of swamplands were a pittance compared to the amount required to control floods and improve drainage. Historically the Swamp Land Acts are significant chiefly because of the vast transfer of lands made under them -- first from the Federal Government to the States, soon thereafter by State governments to the counties and the levee boards, and later to private citizens and corporations.

Disastrous floods occurred frequently from 1850 through 1900. Loss of life and property led to increased expenditures for flood-control work each year. Flood-control improvements in time grew to an impressive size. With their increasing enlargement, waves of optimism found expression in the development of new land. By 1900 or so, it appeared that public reclamation work should include land drainage besides levee building. Soon the landscape of much of the Delta region was altered through drainage activities initiated and financed through creation of local drainage districts under State laws.

b. Modern Status - Drainage is a land improvement and cultural practice on about 2 million farms. The agricultural census of 1950 reported nearly 103 million acres of land in organized district and county drainage enterprises in 40 States. More than 900 million dollars, or an average of about 9 dollars an acre, has been expended on public drainage improvements on the 103 million acres, which is larger than the combined areas of Ohio, Indiana, and Illinois. More than 155,000 miles of outlet ditches, 56,000 miles of main outlet tile drains, and 7,800 miles of levees have been constructed.

Nearly every state has some drainage, but the predominant areas are Louisiana and Texas Gulf Coast, Southern Florida, the Delaware-Maryland-Virginia peninsula, much of the corn belt and southern Michigan, much of Minnesota, eastern Dakotas, the Mississippi lowlands from the Ohio River to the mouth, and irrigated areas of the West, particularly the Sacramento-San Joaquin Valley.

In general, drainage is more economical than irrigation, but on most small farms these two practices are not available alternatives.

c. Relation of Drainage to Forecasting - Drainage outlets may be inundated during periods of high water. Drastic changes in extent of areas drained have some effect on the timing and amount of runoff, and influence the forecasting relations and procedure. Return flow to streams from seasonal irrigation in the West has important effects on seasonal water supply forecasts, just as diversions for irrigation have.

In planning or designing a drainage system, important use is made of climatic data, as well as hydrologic data.

## 5. Storm Drainage

a. Discussion - Storm drainage is really small-scale flood control. Control is achieved by conducting the storm runoff through conduits or other specially prepared channels. Storm drainage is a problem mostly in urban areas, though about 20% of the cost of modern highways and airfields is for storm drainage. The concentration of people living and working in urban areas, and the high values of urban land, warrant the extreme degree to which storm flows are controlled or managed.

More than half the people of the United States live in less than 1% of its area. They occupy cities having an aggregate area of approximately 30,000 square miles. In this vast area, forests and fields have given way to lawns and gardens, a million miles of sewers and streets, and millions of buildings. Rain and snow fall on this area, with little heed of its congestion and of man's status and activities.

Removal of rain and snow from big cities is necessary for normal conduct of the nation's business and for safety. Proper disposal of storm rainfall reduces the frequency and intensity of flooding, and permits more intensive use of the land. Reduction in flooding saves physical damage, the cost of cleaning up after flooding, interruption of business, impairment of health, and loss of life. Prompt removal of snow and ice permits normal transportation, allows movement of emergency and service vehicles at all times, and reduces risk of property damage and loss of life.

Little brooks have been replaced by a vast network of storm sewers. The cost of rerouting, paving and covering the entire network of headwaters streams of an urban area ranges from a third of a million dollars per square mile for a dispersed city like Los Angeles to three million dollars per square mile for a more compact city such as Chicago. The average investment in storm sewers is about a million dollars per square mile.

An urban snow program consists of sanding, salting, and plowing snow from major thoroughfares, and of removing the snow from congested portions of downtown areas. In Washington, D. C., the annual cost is a quarter million dollars per year or more, depending on the severity of the weather. Most large cities have more snow than Washington. The average annual cost of snow removal is estimated to be about $10,000 per square mile of total city area.

A typical city of a million, occupying an area of 100 square miles has an investment of $100,000,000 in 1500 miles of storm sewer, and pays $1,000,000 per year for snow removal.

The required size of storm sewers is estimated on the basis of frequency, such as the rainstorm which would be equalled or exceeded on the average of once in ten years. This magnitude of storm is known as a ten-year storm. The portion of the ten-year storm which runs off into a sewer is estimated by considering such factors as area of pavement, type of soil, and area and nature of the vegetative cover. The estimated peak rate of runoff is usually about half the average rate of rainfall for the critical duration, known as the time of concentration. The time of concentration is the time required for runoff to travel from the most remote part of the drainage area to the point at which runoff is estimated. For an area of a hundred acres the design flow is generally a few hundred cubic feet per second, and may require a conduit about six feet in diameter. It would be virtually impracticable and certainly uneconomical to design for the maximum possible rain, which in many places would be more than ten inches in an hour.

b. Relationship to Hydrologic Program - Storm drainage relates to the NWS hydrologic program in several ways. One is the analysis of rainfall data to provide

FIGURE 11. Modern filtration plant (Courtesy U.S. Study Commission, Southeast River Basins).

estimates of rainfall-intensity frequency relations. Another facet is flash-flood warnings, which have been discussed earlier. A third facet is the application of current data by the city authorities for operating decisions, such as snow clearance.

Application of rainfall intensity-frequency data to planning and design of storm drain systems for cities is one of the biggest hydrologic jobs there is. Widely accepted projections of population growth and urban development indicate that by the year 2000 the urban population of the U. S. will exceed 200,000,000, and that the urban area will be 60,000 square miles, twice what it is in the 1960's. Providing storm drainage for the 30,000 square miles of new urban area to be developed in this next generation is as big a job as providing all the storm drainage facilities now in operation.

Urbanization, including artificial drainage and increased paved area, is believed by many to influence the relation between rainfall and runoff. Cities may influence precipitation itself by the effects of urbanization on temperature and the production of condensation nuclei.

It is convenient to discuss snow clearance in the general subject of urban hydrology. The criteria for snow clearance usually are rather simple. Typically, when two inches of snow has fallen, and more is expected, the plows and trucks go out. But three inches of light fluffy snow might cause less trouble than a delay in recognizing an inch of heavy wet snow. Snow may accumulate rapidly in parts of a large city while gentle rain is falling in the location where snow-clearance decisions are made. In addition to helping with operating decisions, a good record of times and amounts of snow, with observations of water equivalent as well as depth, would provide opportunities to establish more rational operational criteria.

The time may be fast approaching when Weather Service hydrologic forecasts will be demanded at places other than River District Offices. People living in many cities now benefit from local flash-flood warning systems. Runoff from little streams passing through cities may occasionally cause floods too large to be confined in sewers, and thus endanger areas not properly zoned or otherwise protected from flooding. Runoff from these tributary streams concentrates too rapidly for data to be sent to River Forecast Centers, and for forecasts to be prepared and disseminated in time for adequate warning. The time is too short. An increasing number of locally managed systems, established and assisted by experienced hydrologists, and alerted by the NWS radar, do a very economical and effective job of local flood warning.

### 6. Municipal and Industrial Water Supply

a. Introduction - Municipal and industrial water supply is closely related to problems of water quality and pollution abatement. These several subjects will be discussed together in the next two sections. Industrial use of water is almost entirely nonconsumptive. Water is used for cooling, conveying materials, and washing. The incorporation of water into manufactured products is almost trivial - even in a bottling works.

b. Examples of Forecasts - Where water comes from wells, there is usually little relation between streamflow forecasting and water supply, except that high water may flood and pollute some wells.

Where the municipal or industrial supply comes from surface water, there are several important relations between streamflow and the water supply. Where water is taken from a large lake, the only problem of importance is usually possible pollution - such as sewage entering the lake and mixing with the water supply. There are two solutions, one is extensive treatment of the sewage, and the other is to withdraw the water a great distance from where the sewage enters the lake.

Where water is taken from a small lake, whose level may fluctuate, or from a river, two important relations occur. One, if the river flow or flow into the lake is low, the rate of supply may be inadequate for the needs of the city's system. Two, if the supply is low, the lake level or stream stage may be low, and the intake can be left high and dry - literally. For both of these situations, forecasts of flow and stage are important.

In addition to these rather routine forecasts, others can be very helpful. A dramatic example occurred a few years ago, in which cans of cyanide rolled from a truck into a creek, which in turn was tributary to the Ohio river which supplies water to a nearby large city. The danger of panic from this threat of poisoning was averted by knowledge of two kinds. First, it was forecast that it would take two days for the poisoned water to reach the city's intake, and second, by the time it got there it would be mixed with high flows in the main river and be too dilute to cause any harm.

More recently another example was reported. In a Pennsylvania coal-mining region, there is a tendency at times of declining low flows for concentration of acid from mine wastes to become excessive, and as the streams subside this material is left deposited on the stream banks. When a rise occurs, this accumulated material is picked up and carried downstream where it could enter water supply intakes, and require purification. Instead, by virtue of forecasts of rises, intakes are kept closed until this slug of polluted water has passed. Most cities have about a day's supply or more of water in their storage systems.

Other examples could be cited. It is important to be familiar with local water supply systems and river characteristics, to learn the problems of people who work in this field, and to discover pertinent relationships and opportunities in each locality.

### 7. Pollution Abatement

a. Introduction - A slogan of public health officials is that "dilution is not the solution to pollution." By this they mean that more stress should be placed on treatment of industrial and municipal wastes before they enter the receiving stream. In addition to dilution, a moving stream assimilates the wastes by aeration coming from turbulence and contact with the air. When the stream is low, or ice-covered, the aeration process is diminished.

Much of the following information on water supply, water quality and pollution abatement has been digested from Prints no. 7, 9 and 24 of the Senate Select Committee on National Water Resources, prepared in 1960 by the Public Health Service of the Department of Health,

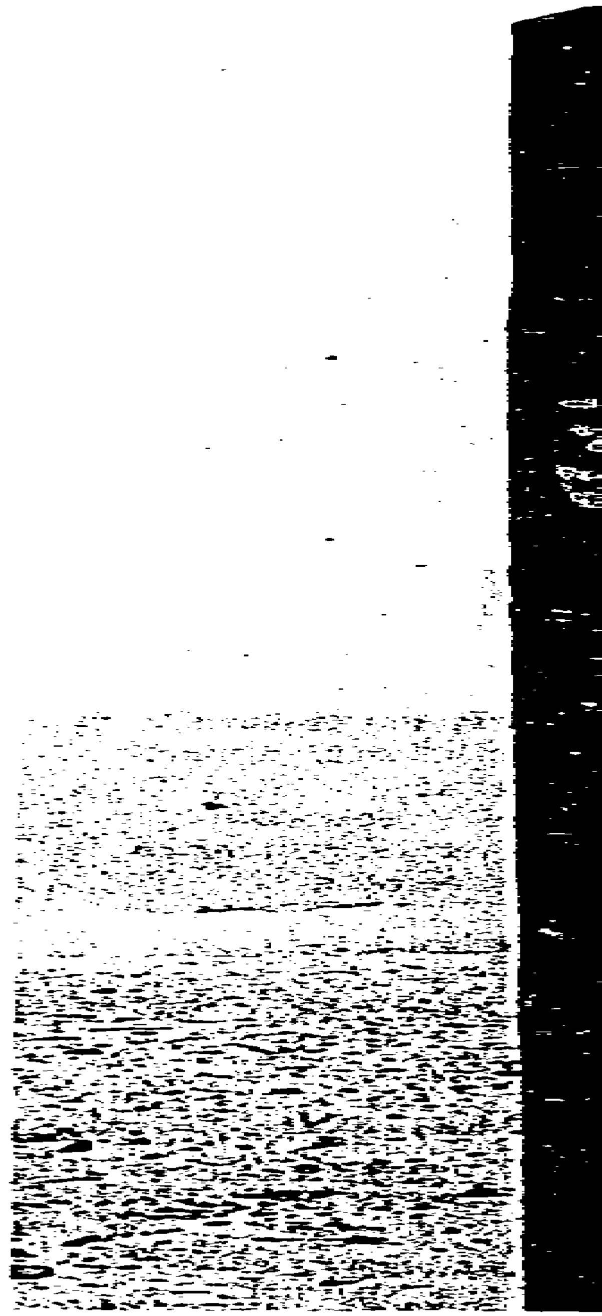

FIGURE 12. Poll


ed water, Hammond, Ind.(Courtesy U.S. Dept. of the Interior, Water Pollution Control Administration).

Education and Welfare.

b. Water Use - On a national basis, municipal water use at the present time averages about 150 gallons per person per day, but this use varies, region by region, from 100 gallons per person per day to as much as 250 gallons. A recent analysis of the 600 community water supplies covered, which serve 84,000,000 persons, indicates that 41 percent of this average daily per capita requirement is attributable to domestic use, 18 percent to commercial, 24 percent to industrial, and 17 percent to public use.

Pronounced regional and local differences in the per capita daily requirement result from differences in climate, size of city, industrialization, and other factors. For example, in 6 States having annual rainfall of less than 15 inches, the median per capita consumption was 210 gallons per day, while in 11 States with rainfall exceeding 45 inches, consumption was 119 gallons per day. As might be expected, urban areas in arid regions, such as Grand Junction, Spokane, and Salt Lake City, show a greater per capita requirement than do cities in the more humid areas. This is only a generality, however, and some of the larger metropolitan areas in the humid regions, such as Chicago, New York, and Philadelphia, also exhibit high consumption rates, but for other reasons, such as greater industrialization.

There is a tendency for areas having higher temperatures to show higher per capita use, probably because of increased air conditioning and lawn watering.

Water is used for many purposes, and, in the process, is often polluted by both organic and mineral substances to such a degree that it is no longer fit for other uses such as municipal water supplies, some industrial processes, irrigation, fish and wildlife, or recreation. In most instances, such polluted water can be cleaned up sufficiently for reuse for these purposes, but sometimes the pollution is of such a nature that it cannot be purified except at exorbitant expense, and must be discarded. Thus, where municipalities run out of water, it will usually not be because of a lack of water, but because the water available is unfit for use. The problem is not one of quantity, but of quality. In many areas of the country, this situation is becoming critical.

c. Institutional Factors - Problems affecting the provision of water in urban areas often stem from difficulties in the field of political structure or organization. These occur at two levels of government. At the State level, the problem results from the conflicting demands in adjacent States for water from rivers flowing across State lines. As an example, the city of New York is limited by Supreme Court action in the amount of water it can divert for its own use from the New York State portion of the Delaware River Basin, as a means of protecting the needs and claims of the downriver States of Pennsylvania, New Jersey, and Delaware. As demands in these lower States increase in the future, this problem will increase, and New York may, at some future time, be required to give up some of the water it is now withdrawing from the Delaware, and to substitute water from the nearby Hudson River.

Another similar situation involves the proposals of the city of

Chicago to increase diversions from Lake Michigan, a proposal which is opposed by other lake States as well as Canada. While these proposals presently involve water for dilution of sewage effluents, the whole controversy involves problems of water supply from Lake Michigan, and may ultimately have to include consideration of the waters withdrawn for this purpose also.

These problems are largely legal in nature, but require full consideration of all technical possibilities, including possible results which may be achieved from needed research into new methods of disposing of wastes. A breakthrough in the development of new methods of treating and handling sewage and other wastes could have a profound effect upon the amount of water available for municipal and other uses.

In other areas of the country, interstate problems of water use which affect municipal supplies arise out of conflicts over the nature of proposed plans for the development and use of interstate streams. What is needed in most situations is a river-basin planning mechanism which can effectively coordinate such planning in order to assure optimum utilization of the river's resources on an equitable basis.

In many large and older cities there are combined storm and sanitary sewer systems. Even where they are not combined, accumulations of filth and debris between rainy periods lead to pollution of storm runoff. Efforts are being made to separate storm and sanitary systems, and to reduce the concentrations of pollutants in urban areas, but the expense will be great and many institutional factors are involved.

The national water pollution problem is a complex one, involving many facets. Water is withdrawn for use over and over again for many purposes as it flows to the sea. Most of this water is taken for granted and is used freely for all purposes, including the disposal of waste materials. Because of this indiscriminate use, water is becoming badly polluted. The expanding need for water, therefore, emphasizes the necessity of preserving its quality.

d. Sources of Pollution - Water pollution may be defined as the adding to water of any substances, or the changing of water's physical characteristics in any way which interferes with its use for any legitimate purpose. Thus, the addition of toxic chemicals in harmful concentrations or the presence of compounds that aggravate taste and odor problems in potable water supplies must be considered pollution. An increase in nutritive substances resulting in excessive troublesome aquatic growth is pollution. Increased water temperature in streams is detrimental to aquatic environment and to the reuse of water by industry for cooling purposes. Erosion of soil from land areas and resuspension from the stream bottom may result in or add to a polluted stream condition. The introduction of pathogenic organisms and a host of noxious substances by sewage is pollution.

Water polluting substances may be classified according to eight general categories: (1) Sewage and other oxygen demanding wastes, (2) infectious agents, (3) plant nutrients, (4) organic chemical exotics, (5) other mineral and chemical substances, (6) sediments, (7) radioactive substances, and (8) heat. Water polluting substances are discussed under these various category headings in the following sections.

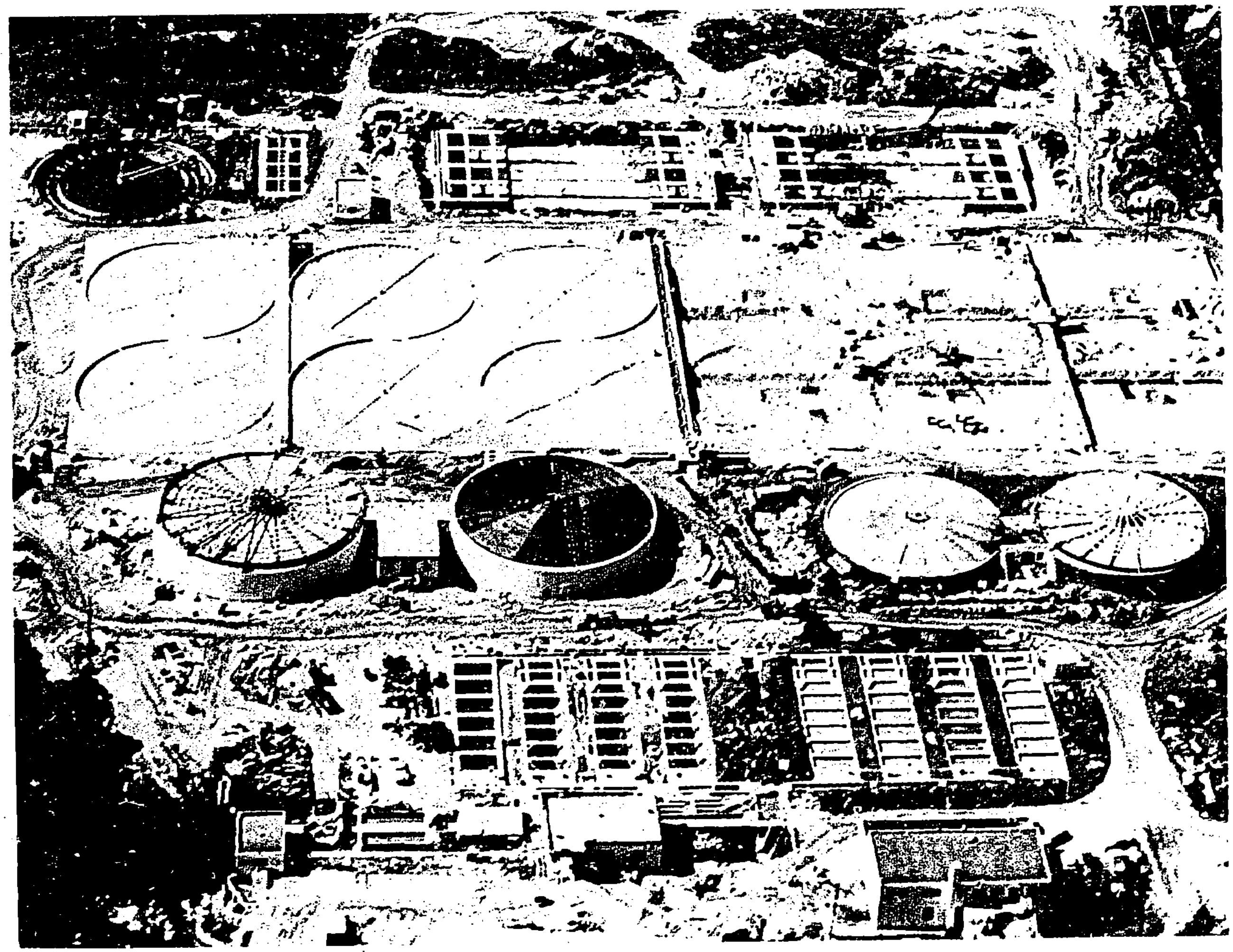

FIGURE 13. Waste treatment facility (Courtesy U.S. Study Commission, Southeast River Basins).

(1) Sewage and Other Oxygen-Demanding Wastes

This category covers the traditional putrescible organic substances which come mainly from domestic sewage and from such industries as food processing plants. These wastes are so named because, under normal conditions they are reduced to stable compounds through the action of so-called aerobic bacteria, which require oxygen in their life processes. This oxygen is taken from the dissolved oxygen normally found in water under natural conditions, and this type of pollution is measured in terms of the amount of oxygen required. The oxygen requirement is called the biochemical oxygen demand, usually abbreviated to BOD.

The amount of oxygen which can be dissolved in water depends largely on the temperature of the water. The amount ranges from more than ten parts per million for temperature less than 60°F. to eight parts per million for temperature of 80°F.

When the oxygen demands of organic pollution reduce the dissolved oxygen in a stream below about four or five parts in a million parts of water, only rough fish life can normally exist. When the oxygen in a stream is reduced to zero by these demands, a different type of bacterial action occurs, as nonoxygen demanding, or anaerobic, bacteria take over the job of reducing the organic pollutants to inert materials. This latter situation produces what is called a septic condition, and the receiving waters take on the familiar dark, evil-appearing, foul-smelling condition which is characteristic of grossly polluted water.

Municipal sewage includes those wastes from domestic, commercial, public, and industrial establishments discharging through municipal sewer systems. Perhaps 80 percent (by number, rather than by volume or value of products) of the industrial establishments in the United States are connected to such systems, and it is estimated that approximately one-third of the organic wastes created by municipalities are industrial in origin.

Analysis of average municipal sewage indicates that 0.17 pound of oxygen is needed to stabilize the daily sewage and related wastes of one person. By using this figure to measure the demand for oxygen by industrial wastes, these wastes can also be expressed in terms of "population equivalents." This unit is therefore useful in measuring or estimating the totals of present and future oxygen-demanding pollution loads from both municipal and industrial sources. It does not apply to other pollution materials, however, such as common salt, cyanide, detergents, synthetic organic chemicals, and other materials that are not easily broken down by chemical and biological action. The unit is useful, nevertheless, in expressing pollution loads placed on water resources because many stream quality criteria are based upon the concentration of dissolved oxygen remaining in water after receiving sewage.

Several factors will tend in the future to increase the strength and volume of municipal sewage. The increasing use of garbage grinders will be one important factor. Sewage strength is likely also to increase because a greater percentage of industrial wastes will reach municipal systems. This will occur through the engulfing of the "industrial parks" and "industrial campuses" that are being located in the outer rings of metropolitan areas. Many of these now have their own treatment units as well as water supplies. Inducement for discharging industrial wastes into the municipal system will become strong, as industrially owned treatment facilities reach obsolescence and greater volumes of domestic sewage become available for diluting these industrial wastes. However, more municipalities will undoubtedly demand pretreatment of those industrial wastes that may tend to corrode or erode sewers, pumps, and treatment facilities or are incompatible with or interfere with their treatment processes. Such pretreatment will also protect against poisonous or other industrial substances that may upset or interfere with sewage treatment processes. As more municipalities impose tax or other surcharges for treatment of high volume or high strength industrial wastes, however, the industrial load on municipal treatment facilities may ultimately decrease somewhat because of pretreatment and other factors.

(2) Infectious Agents

These are disease-causing organisms which are carried into streams, lakes, and ground water sources by wastes from municipalities, sanatoria, and certain kinds of industries, such as tanning and slaughtering plants, which contain human and animal wastes. These organisms can cause diseases such as typhoid fever, or various virus infections and intestinal disorders in persons ingesting them either directly by drinking the untreated water, or indirectly through recreational and similar activities.

It has been demonstrated that effective treatment followed by disinfection will, in addition to reducing the oxygen demands of sewage effluents, also markedly reduce the number of disease organisms in these effluents but the resulting effluents may still contain a portion of each kind of the micro-organisms which were present in the raw sewage. The concentration of these surviving disease producers and their persistence in the receiving streams are dependent upon numerous factors, such as the amount of exposure to sunlight, the degree of dilution and the physical and chemical characteristics of the receiving waters. Under winter conditions the relative concentrations of these bacteria in large rivers receiving sewage will be reduced approximately 90 percent after 2 days flow and 95 percent after 4 days flow. Under summer conditions the reductions may be greater. Organisms causing enteric disorders have been repeatedly isolated from river waters throughout the United States, as well as other areas of the world. Tuberculosis bacteria have been detected in streams as far as 3.5 miles downstream from the point of discharge of sanitoria wastes.

Although the transmission of the infectious diseases by treated water is apparently infrequent, the presence of infectious disease agents in polluted surface waters represents a potential danger to participants in aquatic sports and to other users of the raw waters. Disinfection of treatment plant effluents and other wastes before discharge into public water bodies, by means of chlorine or other substances, substantially reduces this danger.

(3) Plant Nutrients

Plant nutrients are mineral substances in solution which are used as food by aquatic plant life, such as the algae and water weeds normally found in streams and lakes. Nitrogen and phosphorus are the two elements principally involved. These occur to some extent in streams under natural conditions but are introduced in much larger quantities by discharge of municipal sewage and some industrial wastes. These substances are also leached or washed from farmlands in increasing quantities as agricultural use of chemical fertilizers expands.

Nutrients having their origin in sewage are stable mineral compounds remaining in solution after the oxygen demanding organic wastes are removed by treatment. They are a serious problem because they are not removed by ordinary sewage treatment processes. Desalting, the only practicable treatment process available other than direct consumption and removal by aquatic plants, is far too expensive for general application today.

These nutrients in solution are fertilizers, and stimulate intensive and extensive growths of water plants, which when they die and decay, cause secondary oxygen-demanding pollution in the receiving waters, accompanied by disagreeable tastes and odors. These tastes and odors detract from reuse of the water for municipal purposes unless expensive additional treatment is provided to remove them. Our concern over these substances stems therefore from a need to maintain a balanced aquatic environment which will permit maximum beneficial use of available water resources.

Not the least of the nutrient problems of the future is the possibility of toxic reactions developing in water supply sources resulting from the high density growth, death, and decay of certain types of algae. A poison generated in some algae accumulations, which resembles strychnine, has on occasions killed ducks, sheep, dogs, and cattle that have consumed such water.

On the positive side, green plant life converts these residual waste products of civilization eventually into dissolved oxygen. It is possible therefore, that, in the future, the nutrient balance in streams and lakes will be carefully controlled by water pollution control agencies to promote the controlled manufacture of dissolved oxygen. In this manner the streams may be better able to successfully assimilate the treated sewage and industrial wastes. It is more likely however, that criteria for the plant nutrient content of treated wastes will eventually be established as a basis for maintaining stream-water quality. This in turn may lead to the purposeful growth of algae in treatment plant effluent "polishing ponds." Here oxygen would be manufactured by algae and in the process, the plant nutrients would be removed from solution. The algae might, in turn, be harvested and converted to animal and possibly human food products.

(4) <u>Organic Chemical Exotics</u>

A water pollution problem of great concern, which will increase manyfold in significance in the future, is caused by discharges of certain synthetic organic chemicals in our water bodies. These chemicals include such substances as the detergents used in household washing and laundering and the new insecticides, pesticides, and weed killers which are now receiving increasingly widespread usage in agriculture.

Detergents are carried into water bodies with domestic and industrial sewage. The insecticides, pesticides, and herbicides may be washed off vegetation and land surfaces by rain or irrigation water, or may be applied directly to these waters for control of pests or rough fish.

Other persistent substances are discharged with some industrial wastes. None of these substances are removed from water either by sewage treatment plants or water purification plants to a satisfactory extent.

These organic chemicals are relatively new, and their effects upon human beings, animals, and fish and wildlife are as yet little understood. The greatly expanded use of organic insecticides since the advent of DDT in 1944 has created new problems in water pollution. There now are more than 100 synthetic organic insecticides on the market and these are available in thousands of different formulations.

Fish and Wildlife Service and Public Health Service experiments with various insecticides as toxicants to fish and small game indicate that there may be insidious consequences from prolonged exposure to small quantities of insecticides in small mammals and birds. Observations on quail indicated that a large percent of the eggs were infertile and chicks were often weak, resulting in a decimation of the population. Where the insecticides were introduced through the water environment, they seemed even more destructive to small game population, fish, snakes, and frogs.

Most pollutants can be traced to a point source in a stream. Insecticides, however, may have their source in an entire watershed. Moreover, pollutants of this type are not amenable to accepted means of treatment. Analysis of samples taken in connection with several Public Health Service investigations and the national water quality basic data program has shown the presence of insecticides in our major rivers. As the use of these chemicals increases, health authorities are showing an increasing concern over possible long-term ingestion of these materials.

(5) Other Mineral and Chemical Substances

A large number of other mineral and chemical wastes results from various mining and industrial processes, or come from certain sources found in nature. They include a wide variety of substances such as common salt, metals, and metal compounds in solution or as very fine particles, acids, and a wide array of manufactured chemicals. Their effects upon human and animal life as well as upon various industrial and agricultural processes are equally varied and often not yet known or understood. Some have serious toxic effects. For convenience in discussing them, these various substances are subdivided into salt, acids, and other industrial chemicals.

Pollution from common salt dissolved from natural deposits occurs to some degree in many areas but is a serious problem primarily in certain river basins of the Southwestern United States. This is especially true of the Arkansas and Red River Basin areas of Texas, Oklahoma, and Kansas.

One source of salt pollution in this area is brine discharged with oil as it is pumped from the ground. A program for the reinjection of these brines into the underground strata is becoming effective, however. The big problem in the area is the salt discharged from seeps and solution areas.

Salt used for urban snow melting is a growing source of pollution.

While acids are contained in many industrial wastes, the principal extensive source of acid as a water pollutant is drainage from coal mines.

Sulfuric acid is formed at exposed surfaces in coal mines where sulfur-bearing minerals, water, and air come into contact. Water flowing through mines or pumped to the surface carries acid to the receiving steams. Acid mine drainage problems are generally confined to the more humid coal regions east of the Mississippi River. More than 90 percent of all acid mine drainage occurs in the Ohio River Basin. In addition there are serious acid mine drainage problems in the upper watersheds of the Potomac, Delaware, and Susquehanna Rivers and some of the tributaries of the Mississippi River in Illinois.

This acid damages water quality by rendering streams acid and increases hardness and mineral content, thereby making expensive and difficult the treatment of the water for municipal and industrial purposes. Treatment for municipal use may include the deliberate addition of lime which neutralizes the acid, but increases the "hardness" of the water. Acid waters corrode all manner of concrete and steel structures and plumbing systems. In addition, recreational values are reduced and biological stream self-purification processes are altered. Aquatic life may, in the more serious situations, be destroyed.

Some improvement has been achieved by augmenting normal low streamflows with releases of neutral or alkaline waters from reservoirs. Nevertheless, the number of miles of major streams and their tributaries still affected runs into the thousands.

Return flows from irrigation, passing through alkaline soil, have increased the salinity of the Colorado River to such a degree that its quality as well as its quantity is an important factor to Mexican users in its lower reaches, and the subject of serious international discussions.

(6) Sediments

Sediments are primarily soils and mineral particles washed from the land by storms and floodwaters. While sediments are not normally a primary concern of water pollution control agencies, they nevertheless have important bearings on water quality problems. Aside from filling stream channels and reservoirs, they make necessary expensive additional treatment processes for municipal and industrial water supplies and contribute to the problems involved in the assimilation of oxygen-demanding organic pollutants by streams and lakes. Sediments cause erosion of power turbines, pumping equipment, and other structures, reduce fish and shellfish population by blanketing fish nests, spawn, and food supplies, reduce the light received by green aquatic plants in the process of maintaining dissolved oxygen in water, and plug water filters.

As more dams, both large and small, are constructed on the various rivers and tributaries, more and more sediment, both natural and man induced, will be trapped and settled out. The continuing program of soil conservation practices will reduce sediment loads in many areas. Thus, whereas earlier water treatment problems were concerned with high turbidity, short filter runs, and variable chemical quality, future treatment will, as sediments are reduced, center more and more on such problems as tastes and odors caused by algae growths induced by sunlight penetrating the clarified waters. On streams such as the "Big Muddy" Missouri River, which are already being clarified, algae problems are beginning to show up. Such problems may well be more complex in their solution than those produced by sediments, which, on the positive side of the ledger, did at least serve to drag down a portion of the organic pollution contained in sewage and industrial wastes, thus aiding in stream self-purification.

As detention and impoundment reservoirs are constructed, the ultimate effect upon water quality will be that of a changing environment in which water will be clearer, extremes of high and low streamflow reduced in range, and water velocities will be more uniform Each of these factors will profoundly affect the interplay of physical, chemical, and biological factors involved in the assimilation by these water bodies of the wastes from city, industry, and farm. These factors will need to be evaluated.

(7) Radioactive Substances

Radioactive substances which are possible sources of water pollution are produced from several sources. Waste products from mining and refining radioactive minerals such as uranium or thorium may wash or be discharged into streams. Waste products from the use of refined radioactive substances in power reactors or for industrial, medical, or other research purposes, can, if allowed to escape, also produce dangerous concentrations in the receiving streams. Radiation has serious harmful effects upon all human and animal life, and concentrations of these substances in water bodies must therefore not be allowed to rise above those relatively minute maximum amounts which are considered safe. The three major factors which determine the importance of any specific radioactive waste are: (a) the quantity of material involved, (b) the duration of the waste discharge, and (c) the degree of hazard associated with the specific radioisotopes involved.

(8) Heat as a Pollutant

Tremendous quantities of water are withdrawn daily from streams and lakes for cooling purposes by stream-electric powerplants, steel mills, petroleum refineries, and various other industrial plants. After use, these waters are usually returned to the river or lake from which they are withdrawn. Substantial amounts of heat are thus transferred to these water bodies. Since the amount of oxygen which water can hold in solution diminishes with increasing temperature, the introduction of heat in any substantial quantities into such water bodies has the net effect of introducing additional pollution, because the ability of these water bodies to assimilate oxygen-demanding pollution, or to support fish life, is thereby reduced.

Heat also has a direct detrimental effect upon fish and other aquatic life because it changes their physical environment. Some fish can stand only a very few degrees of increase in temperature, and a substantial increase in temperature can result in the virtual elimination of all aquatic life.

The problem of heat pollution will prevail whether the powerplant be the conventional fossil fuel burning plant or the newer nuclear energy powered plant, because cooling water is used for condensing spent steam in either case.

In certain heavily populated and industrialized areas, such an increase in heat pollution of rivers and lakes could have a profound effect upon the pollution assimilating capacity of these water bodies, as well as upon their ability to meet satisfactorily the ever increasing demands for recreational facilities and fishing opportunities. Careful planning of the location of plants requiring cooling water will be necessary to minimize this heat pollution danger, and it may well be necessary to require recirculation, or spray pond, cooling tower, or air cooling methods as a means of reducing the amount of cooling water used in those instances where heat pollution would seriously interfere with these other uses of water.

Another effect of heat which results in the depletion of oxygen in stored water reservoirs and some natural lakes is caused by excessive summer temperatures, which heat up the surface layers of the lakes. Under these conditions, these water bodies tend to stratify, with cool water remaining undisturbed and uncirculated in the deeper portions of the lake. Decomposing vegetation depletes the dissolved oxygen in these lower strata, and fishlife then leaves the area. When such waters are discharged through the lower gates of reservoirs, the oxygen-deficient water may have a detrimental effect on the receiving stream, both with respect to its aquatic life and its ability to assimilate oxygen demanding pollution introduced downstream.

Stratified lakes tend to recover their oxygen content with the return of cold weather, but may suffer a serious detrimental effect during summer months. Withdrawal of water from higher level gates during the hot months can correct this difficulty if such gates are provided for in the design and construction of the dam in the first place.

e. Industrial Wastes -

Industrial wastes include all of the eight categories of pollutants previously discussed. Of particular significance, however, is the fact that adequate criteria for evaluating some of them have not yet been developed. Until recently, oxygen demanders have generally been looked upon as the gage of water pollution, but this class of pollutants is only one of the types of pollutants contained in industrial waste discharges. Chemical, mineral, and stable organic compounds (largely found in industrial wastes) are now coming to be of equal or greater significance in water pollution.

The biological processes for stabilizing oxygen-demanding organic pollutants are well enough understood to permit empirical design of treatment facilities which can stabilize up to about 90 percent of these wastes, although it must be recognized that even this degree of treatment is inadequate in some situations. The treatment of this type of pollution is, therefore, in general no longer dependent upon the discovery of applicable techniques, although we still could use more economically designed plants. Elimination of most of this type of pollution can now be achieved at any time that the public believes that the resulting benefits in terms of providing suitable water for other purposes is sufficiently important to warrant the necessary action. The costs involved, while substantial, are not unreasonable.

The same situation is not necessarily true of pollution from the chemical and mineral substances being produced by industry. A broad group of these waste products remains relatively stable or is reduced in nature so slowly as to be classified as virtually stable. These pollutants are legion and their numbers are increasing with our technological developments. They include chemical wastes, petrochemicals, salt brines, acids, silt, sludges, and radioactive materials. Many of these substances are toxic. Many of them were not known a few years ago, and neither the methods of removing them from water nor their effects upon people of various processes are yet understood. In addition, about 400 new chemical substances are created each year by industrial research. Through ever-increasing use, many of these are finding their way into our water sources, and the problems posed are, to say the least, puzzling. Thus, pollution associated with industrial development takes on a special significance.

## 8. Water Quality and Future Needs

a. Introduction - By 1980, total withdrawals of water for all purposes, from surface and underground sources in the United States, might equal half the 1,200 billion gallons per day of these sources and by year 2000, such withdrawals could amount to as much as the total supply. As pointed out, however, such huge demands are not necessarily a cause for alarm, since water can be used over and over again as it flows to the sea. The mere adding up of all uses is, therefore, not a valid measure of the amount of water that must be supplied.

While water demands are increasing sharply with no letup in sight, it is abundantly clear that water needs can be met by using the available supply over and over again. This has already happened in some of the more heavily populated and industrialized area of the country. Thus, it has been estimated that during periods of low flows the water of the Ohio River is reused almost four times before it reaches the Mississippi. In the future, the waters of many of our major rivers may have to be reused many more times than this.

The alarming thing about this situation is not the total amount of water required, but the fact that water, in the process of being used, becomes polluted, and may be rendered unfit for further use for some purposes, unless means can be found to cleanse it. This situation is further complicated by past preferences based on public health considerations and by the popular feeling that water once soiled must be thrown away; present municipal water supply practices are, wherever possible, based on this point of view. There is, of course, usually no more logical reason for throwing away dirty water than for throwing away a dirty shirt. Both dirty shirts and dirty water can be laundered and reused. For both shirts and water, however, it is essential that those substances which cannot be removed by cleaning, such as stains or certain persistent chemicals, be kept away from them in the first place.

Fishing and water-oriented recreational pursuits also require relatively clean streams and lakes, and demands for these facilities will increase greatly as population continues to expand and living standards and leisure time increase. However, because streams and lakes must, for many years in the future, continue to function as residual waste carriers, the management of water resources presents a problem of the first magnitude, because we are rapidly running out of clean water. Adequate treatment of wastes before discharge into water courses is becoming imperative.

Past water conservation and development projects were concerned almost entirely with water volumes. Dams and related structures were constructed to store water for power, irrigation and flood control, and aqueducts and diversion structures were constructed to transport water from areas of surplus to areas of need. Such projects, which have done much to increase the volume of available water, will continue to be needed for the provision of water to the limit of our economically capturable and transportable water resources.

If water of satisfactory quality and adequate quantity for future requirements is to be provided, answers must be found to a number of questions, including the following: (1) What are the actual quality requirements for the various water uses? (2) To what extent should the Nation's streams function as waste carriers? (3) What are the valid economic factors in managing water quality? (4) What water quality priorities are needed to resolve the differences between the conflicting and competing water uses, and how shall they be established? (5) Who gets water of what quality, how much does he get, and how much can he be reasonably expected to pay for it? (6) Who should manage water quality and how? (7) To what degree will our present waste treatment processes, primarily aimed at treating municipal sewage only, provide water quality protection involving other pollutants? (8) What are the solid facts regarding the present effects of pollution on water quality, and what are future trends?

b. Requirements for Various Purposes - In order to better understand what is involved in water quality management, it is essential to understand the water quantity and quality requirements for the various purposes which water serves. These purposes include municipal water supply, industrial supply, irrigation, fish and wildlife, recreation, and navigation.

(1) Municipal Water Supply.

Because of the anticipated tremendous population increase in the next three decades, and the fact that by that time most people in the United States will be living in metropolitan areas, we may, by the year 2000 require as much as 85 to 90 billion gallons of water per day for municipal purposes. This is five times 1960 requirements. Most of this water must come from rivers and lakes which must also serve other purposes. Very little of this municipal water will actually be permanently removed from the streams of the country. Most of it will, after use for household, commercial, and industrial or public cleaning and waste disposal purposes, or for industrial processing, be returned to the rivers or lakes, generally with various polluting substances added. Some of this water will, however, be used for watering gardens, lawns, and public parks, and much of this will not return to the watercourses. Some will be diverted to other streams.

Cities usually have only a single system of pipes for water distribution. Provision of dual supply systems would, of course, permit use of less highly treated water for most general purposes, with highly treated water restricted to consumptive uses such as drinking and cooking. Public health officials have always strongly objected to such dual systems, with their inherent danger to the public health which would result from cross connections or misuse. Consequently, all municipally supplied water must be of drinking water quality. This means, therefore, that the water source itself must be of such quality that after treatment, the water will be both safe and acceptable in taste and appearance for human consumption. Since too many of the polluting substances now reaching public water supply sources are not removable by existing economical treatment methods, greatly intensified programs for the careful control of pollution are required to insure preservation or improvement in the quality of water sources serving municipal systems.

(2) Industrial Supply

(a) Use of Water in Indust y

The growth of industry in the United States in recent decades has been phenomenal and this growth is expected to continue. Industry may require 80 percent and more of the expected increase in total future water requirements and may account for 65 percent or more of all fresh water used in 1980 and 2000. This is not only because of rapidly rising production but because many new industrial processes need more water than the old ones.

There are few communities today that do not have at least one industrial plant and are seeking more. The location of industry is guided by many considerations, but among them a satisfactory water supply is important.

Industries are moving into the Southwest and other water-short regions where advantages other than water availability are overriding, but where water must, nevertheless, be provided, often by diverting it from irrigation use.

Large quantities of water are withdrawn for industrial use directly from rivers, lakes, and ground-water aquifers. Much of this water is used for cooling, and must at least be of suitable temperature for this purpose. While it need not meet potability standards, it must be free of corrosive chemicals or those which would leave scale or other heavy deposits in the cooling apparatus. It should also be sufficiently free of organic compounds and aquatic life to require only simple chlorination to prevent growth of slimes and algae in the cooling equipment.

Substantial amounts of water are used directly in industry processing. This water must be of such quality that it will not have detrimental effects on the final products. These uses range from food processing, requiring water treated to potability standards, to pulp and paper mills and complex chemical plants, requiring varying degrees of purity and cleanliness. Many of the substances now reaching our water sources can be harmful to some industrial products, and water supplies suitable for industrial purposes are becoming harder to find.

(b) Water Conservation in Industry

Although the total water resources in the United States are not decreasing, industry tends to concentrate in well-defined areas, thus adding to the problem of providing adequate supplies in areas where shortages are already being felt. In all likelihood, the tendency toward concentration of industry and industrial water demand will continue. In some cases industry has been stimulated to conserve water as a result of actual shortages, and, in other instances, the plant's past practice of flushing away its unwanted wastes has met with stringent legal restrictions. It has been shown that under restraint to eliminate pollution there may be as much as 90-percent reduction in the quantity of water used in some industries.

Through skillful design and operation of their water facilities, industries have found that they can conserve their supplies by increased utilization of existing supplies, by thorough water surveys, recharging of ground-water supplies, reconditioning their waste water, and forming industry-municipality conservation teams.

Five basic techniques of water conservation in industry are: (1) conservation of fresh water by substitution of other sources; (2) reduction in water use and waste of water; (3) recycling; (4) multiple reuse; and (5) reconditioning of water and wastes.

(3) Irrigation -

Irrigation will require the next largest segment of increased water needs, after industrial requirements, and may account for about 30 percent of total fresh water use in 1980 and 2000. Continuation of the trend toward supplemental irrigation in the East would drastically increase these figures and have far-reaching effects on other water uses, both with respect to quantity and quality.

Principal quality problems affecting use of water for agriculture are those resulting from excess quantities of detrimental chemicals such as common salt and alkalis. Boron, derived from washing compounds, is also toxic to plants, even in very low concentrations. In some Western States, programs for the control of salt and alkaline substances are required. Control of chemicals such as insecticides and herbicides, which may get into water intended for irrigation use, is also important. In certain local areas where sewage effluents could become an important source of agricultural water, better control of infectious agents in these effluents would also be required, particularly where the crops grown are intended to be consumed raw.

Use of water for irrigation is largely a consumptive use, which means that a substantial part of the water so used is evaporated, or transpired, and is no longer available for other uses further downstream. What is returned to water-courses is often laden with salts, insecticides and other chemicals.

(4) Fish and Wildlife and Recreation

Fish and wildlife preservation and propagation, and recreation, are non-withdrawal uses of water of emerging significance. Both activities require high-quality water, paralleling that for public water supplies. The demand for clean water for swimming, boating, sport fishing, water skiing, and other water-related sports has grown tremendously in recent years and will continue to do so. In a number of States the recreation and sport fishing industries are the largest source of income, and in a growing number of other States are an important source of income.

There were in 1947 a total of 1,800,000 outboard motors and 2,400,000 pleasure boats in use on our rivers, lakes, and coastal waters. By 1970 these figures had grown to 7,215,000 and 8,814,000, respectively. The sale of boats in this country is growing at a more rapid rate than was ever achieved in the sale of automobiles. In 1968, more than two billion dollars were spent on fresh water fishing alone and 28,787,000 fishing licenses were taken out. Water-oriented recreation and sport fishing together add up to an important segment of total national economic activity, contributing importantly to total income.

If, as predicted, the number of working hours and the length of the work week continue to decrease with improved business and industrial techniques, personal income and living standards will continue to improve, and more and more Americans will have both more leisure time and more income with which to enjoy outdoor recreational pursuits. Since, in addition to fishing, a very substantial part of outdoor recreation is water oriented, these activities will require substantial increases in the amounts of clean, esthetically attractive streams, lakes, and coastal areas dedicated to these purposes.

Water quality requirements for sport fishing and for recreation are of the highest order. Sport fish require water which contains at least five parts per million of dissolved oxygen. Chemical substances such as some insecticides and certain other chemicals are definitely toxic to fish and must be kept below critical concentrations. Polluted water is unattractive for boating, water skiing, swimming, or even picnicking, and is also a health hazard in connection with such uses. The polluting of waters which are used for fishing or recreation may thus result in the total destruction of these water bodies for these purposes. The problem is not only economic but carries esthetic, health and social implications as well.

One other increasingly important aspect of pollution in recreational water stems from the recreational use itself. As more and more pleasure boats are used, their waste discharges constitute a source of pollution which is becoming increasingly serious and requires regulation or control.

Recreation and fishing are water uses which compete with other uses for the same water. Suitable flow regulation, together with adequate abatement or control of pollution, is therefore required as part of a comprehensive water quality management program having as its objective the equitable use of water for all purposes.

(5) Navigation

Except for possible health hazard to the people involved, water pollution normally has little effect upon navigation facilities and operations. There is, however, a direct relationship between navigation requirements on a river and water quality management for pollution control purposes. Where the run of the stream is insufficient, navigation on inland rivers is achieved either by releasing stored water at times of low flow, in order to maintain the proper depth of water in the channel, or by constructing a series of dams and locks in a river to provide slack water navigation. Where navigation is provided by the first method, the river will often also provide a considerable volume of water for the dilution or transportation of treated wastes. Where navigation is achieved by means of a series of low dams and locks, the actual flow of the river may be quite low during dry-weather periods. In the latter case, the transportation of wastes and their dilution will be adversely affected. These possible situations must be considered in preparing comprehensive plans for water quality management of a river basin.

Some forms of pollution, such as acids or acid-forming wastes, also have a direct effect upon navigation equipment as, for example, the corrosion of concrete structures and steel hulls and lock gates. Other wastes may foul the bottoms of boats or clog their cooling systems. Accumulations of sludge and silt deposits also clog navigation channels, as in the case of the Chicago Drainage Canal. Where waterway traffic is heavy, wastes from the boats can also become a problem. Where the waters traversed are also the sources of water supply for the vessels themselves, pollution can be a source of danger to the vessels' occupants.

c. Limitations of Streams as Waste Carriers -

(1) Nature of the Problem

Through the years, a basic concept in the design of sewage and industrial waste treatment works has been to take full advantage of the self-purifying capacities of streams by discharging waste into them. The degree of treatment provided was tailored to the diluting capacity of the stream and to its oxygen resources, and the stream was often called on to do much or most of the job of treatment. We were dealing then, of course, with wastes largely amenable to biological stabilization and of known behavior. Within the limits of the flexibility of available processes, sufficient treatment was provided to prevent nuisance conditions, maintain fish and other aquatic life, and protect downstream water supplies.

Now, we are in a period of rapid population and industrial growth that is expected to continue. Municipal and industrial waste outlets are becoming more numerous and are carrying much greater volume of stronger wastes of growing complexity. Merging cities bring sewer outlets closer to water supply intakes. The task of collecting, treating, and disposing of municipal wastes alone is already taxing the administrative and financial resources of our public agencies. Furthermore, the diluting capacity and oxygen resources in the streams are no longer adequate for assimilating waste effluents in a growing number of places. The problem presented by tomorrow's supercities is even more staggering.

In some river basins there may not be enough water available for every desired use or purpose, and choices must be made. Under these circumstances it may be desirable or even necessary to prepare plans for alternative possible combinations of basin development as a guide in allocating water to various purposes.

The preparation of such basin development plans is a procedure in which, starting in the headwaters and working downstream, various assumptions as to possible uses, withdrawals, and discharges are used as the basis for working out possible combinations of development. At every stage in this procedure, water quality plays an important part, and the determination of possible pollution loads and of facilities needed for their abatement and control are an essential part of the overall plan. Because both the nature of wastes and the methods of treating them are expected to change radically in the future, these plans must remain flexible and susceptible of continual modification as changes warrant. The plan, itself, should, nevertheless, be in sufficient detail to guide future development.

Water supply and pollution trends show that one of the most pressing problems in water quality management is the need to develop new treatment processes which will remove more of the contaminants from municipal wastes than we are able to do by present methods. Present treatment methods now remove only 75 to 90 percent, each, of the suspended solids and the biochemical oxygen demand (BOD) in domestic sewage. Little of the total nitrogen and phosphorous is removed; their availability for stream fertilization and algae growth is actually increased. Because of these deficiencies in present treatment methods, large quantities of water must be available to dilute and transport the residual wastes after treatment of sewage, and when it is not available, serious pollution problems result.

Unless new methods of treatment are discovered, the volume, strength, and complexity of future municipal wastes can only result in the discharge of larger and larger amounts of impurities into badly needed water resources. As an illustration, Chicago, with modern treatment facilities, pours into the Illinois Waterway waste waters which have pollution effects equivalent to the discharge of sewage from about 1 million persons and contain solids - natural and synthetic, organic and mineral -- amounting to about 1,800 tons per day.

The Chicago situation is a classic example of the profound economic, social, technical, and legal difficulties inherent in the growing metropolitan sewage disposal problems already with us and certain to increase in number. Conventional sewage treatment methods of today have not solved the problem, so the courts and the Congress have been petitioned to solve it by providing more diluting water. In the case of Chicago, permission has been requested to divert additional water from Lake Michigan into the Chicago Drainage Canal.

The ultimate solution for all such cases, however, will require us to increase our knowledge of how to remove much more of the contaminants from metropolitan wastes, particularly those which remain in solution following existing so-called complete treatment. To do this, we must develop new treatment processes, probably based on entirely new concepts and principles, that will convert waste waters to fresh water. This will require a major coordinated research program which must utilize the best minds in the country and be able to attract physicists, physical chemists, hydrologists, economists, and devotees of other disciplines whose skills have not, up to now, been fully utilized in water pollution research.

(2) <u>Needs for Research</u>

The physical, chemical, and biological processes pertinent to many pollutants are too poorly understood to serve as guides to management. There is almost a complete lack of knowledge of the role of viruses in water pollution because we have not been able to develop techniques for isolating and identifying them in dilute solutions, although we know they are there. Even the fate and importance of pathogenic bacteria in streams are inadequately understood. Our epidemiological and toxicological techniques for measuring and tracing the effects of water pollutants are as yet poorly developed. The effects of the pesticides, insecticides, and older detergents are little understood, and their general removal from municipal water sources, if present, is practically impossible with present methods. Not enough is known about the behavior of radioactive wastes in water, or the effects on humans from using water contaminated by such wastes.

Many other problems that have been with us for years still remain to be solved. Among these are pollution from land drainage, silt from erosion, acid mine drainage, natural salt deposits, mineralization from irrigation practices, and cumulative concentration of chemicals in streams caused by repeated reuse of water by municipalities and industries.

The backlog of unsolved water pollution problems and the new problems that are developing make it abundantly plain that a major research effort is urgently needed.

d. Water Quality and River Forecasting -

In several regions, daily forecasts of river flow are used by municipal and other water-supply officials for scheduling withdrawals of water at times of acceptable quality. Similarly, forecasts of flow are being used by industries for withholding or treating wastes so as to limit releases to maintain acceptable water quality. In the Ohio River system, the NWS is participating in a Federal-State-industry cooperative program for managing water quality. The Cincinnati River Forecast Center issues three-day forecasts of Ohio River flow to the Eight-State Ohio River Valley Water Sanitation Commission (ORSANCO), whose regulations provide for lagoon storage of chloride and other wastes. Releases from these lagoons are coordinated with expected high flows.

The growing population, and industrial and agricultural output, with inevitable by-products which affect water quality, have led to a new appreciation of the importance of clean streams. Modern technology employs a combination of methods and degrees of waste treatment, and wastes are released to streams at irregular rates, which vary with time of day, week and season. These releases are superimposed upon fluctuations in flow of the river itself. Management of water quality in this very complex system clearly requires forecasts of river flow.

9. Use of Water for Electric Generation

a. General Discussion - Water is used in two major kinds of electric power generation. One is known as hydroelectric, in which the force of falling water drives a hydraulic turbine connected to a generator and converts the energy of the water to electrical energy. The other use is for condenser cooling. In this use, the generator is usually driven by a steam turbine. The steam is provided by a boiler or other source of heat, usually from the burning of fossil fuel, such as gas, oil or coal. For the steam turbine to operate efficiently, the exhaust steam must be condensed by cooling. The need for cooling is somewhat similar to that of an automobile engine.

Condensation may be accomplished in small p nts by air-fin cooling. In larger plants water cooling is necessary. In some plants, the cooling water is recirculated, being cooled itself in cooling ponds or cooling towers, where heat is removed partly by evaporation. Heat of vaporization is so great that relatively little water is lost from cooling towers and ponds. The largest plants, however, (and by far the largest portion of the world's electricity is generated in these plants), do not recircul e the cooling water. A portion of the river is run through the plant.

In each type of water use, the amount of water lost to the stream system is trivial, but this use of water is important for other reasons which will be discussed in the following sections.

b. <u>Uses of Electricity and its Water Requirements</u> - Table No. 6 and much of the related narrative are taken from the Senate Select Committee Print no. 10, "Electric power in relation to the nation's water requirements." Table No. 6 gives recent and projected electric energy requirements of the United States for various uses as indicated in the table.

It should be noted that the figures in the table do not include Alaska or Hawaii. At the end of 1968, Alaska had 366,000 kilowatts of generating capacity of which 68,000 kilowatts were hydro-electric. Hawaii had an installed capacity of 978,000 kilowatts of which only 19,000 kilowatts were hydro-electric. Alaska has a total undeveloped hydroelectric power potential of about 33 million kilowatts. Hawaii's undeveloped hydroelectric resources are small and are estimated at 35,000 kilowatts.

To produce the amount of energy indicated in Table No. 6 for the year 1980, the following amounts of water are expected to be required:

Steam generation, 1,720 billion kilowatt hours (bkw),
Water requirements for condenser cooling, 290 million acre feet,
Hydro-electric generation, 280 billion kilowatt hours (bkw),
Hydro-electric water requirements, 1,700 million acre feet.

Water requirements of hydroelectric plants are substantially greater than for steam-electric plants, but the use is not of a consumptive nature. The composition of the water is not changed, there is no pollution involved, and there is little effect, if any, on the temperature. In steam-electric plants the temperature of the water used in the condenser is raised significantly.

Of the total generation (1,720 bkw of steam, plus 280 bkw of hydro), for the year 1980, about 1100 billion kilowatt hours will be what is called base energy, and the remaining 900 billion kilowatt hours will be peak energy. If use of electric energy is plotted on a time scale, the graph will show peaks, as the electric load varies from hour to hour and day to day. Industrial use is highest during the usual daily and weekly working hours. Domestic use is highest at different times in different parts of the country depending on use of electricity for heating, lighting and air conditioning.

A major use of hydroelectric generation is for peaking. The reason is simply that the water can be turned on and off very quickly. But in steam generation, to meet a peak, the fires must be kept banked in preparation for a sudden load, and this requires wasteful use of fuel. A steam plant cannot start [illegible] cold beginning to full operation in less than several hours.

Steam generation is often cheaper for base energy than hydroelectric is. The reason is that interest on the large investment for a hydroelectric plant (dam, relocations, spillway, land inundated by the reservoir, etc.) is large compared with the cost of the fuel used in the steam plant. When nuclear energy becomes more widely used, there will in all likelihood still be a need for hydroelectric generation for peaking. A remotely possible exception would be a technical or scientific breakthrough in which nuclear energy could quickly, efficiently, and

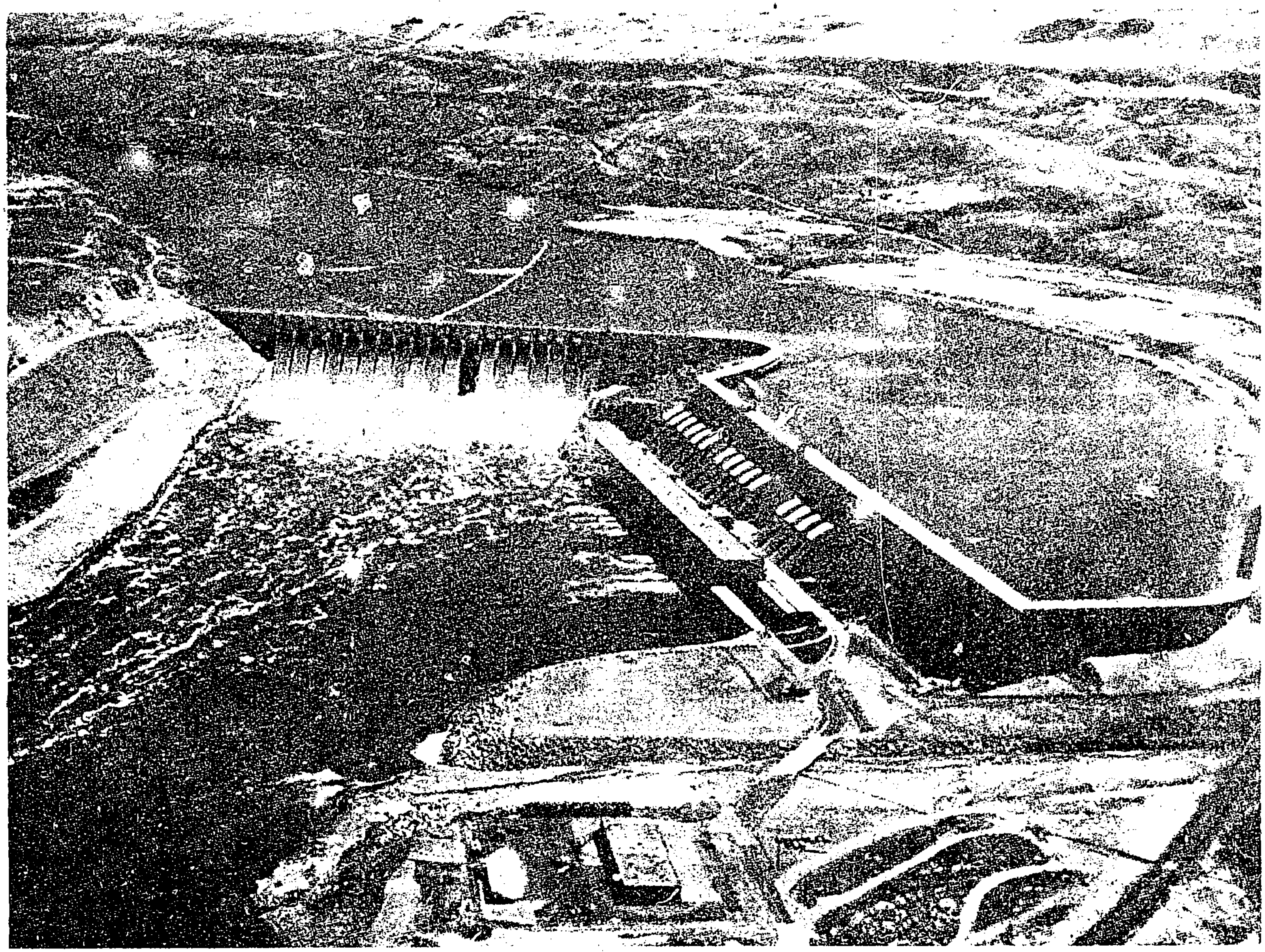

FIGURE 14. Hydroelectric plant, Chief Joseph Dam, Columbia River, Washington (Courtesy Corps of Engineers).

directly be converted to electrical energy, without going through an intermediate phase requiring the generation of heat.

c. Characteristics of Hydro-Electric Power

(1) General

Hydroelectric power potential is created by the flow of water between different elevations. (The difference in elevation is termed the "head.") The energy of the water is used to turn a waterwheel and is converted into electricity by a generator driven by the waterwheel. The capacity of an actual or potential hydropower installation is measured in kilowatts, and the energy produced, or producible, in kilowatt-hours.

An outstanding characteristic of the demand for electricity in a typical electric power system is its periodic variation. Daily, weekly, and seasonally, the demand rises to peaks which may be considerably greater than the average level. The ratio of the average load, or demand for kilowatts, over a designated period to the peakload occurring in that period is termed the "load factor." The significance of this relationship is that generating capacity must be sufficient to take care of the peakload, which may be five times the average load.

The ratio of the average load on the plant, for the period of time considered, to the aggregate rating of all the generating equipment installed in the plant is known as the "plant factor." The higher the average use of the plant capacity during a given period, the higher is the plant factor for that period.

Against these universal characteristics related to the demand for electricity and the plants which supply it are production characteristics peculiar to hydropower. The flow of the stream being utilized for hydropower commonly varies over both long and short periods, reflecting rainfall and runoff patterns. In the ideal stream these fluctuations would correspond precisely to the desired variations in the output of its hydroplants.

Differences between short-period fluctuations in streamflow and desired variations in plant output can be overcome through the use of a small reservoir to provide pondage for the plant. Long-term regulation of flow can be provided through storage reservoirs. Unless a plant has storage it is termed a "run-of-river" plant, either with or without pondage. Under any of these conditions, however, both flow and head can normally be expected to vary.

There is at any site a minimum flow below which the stream can normally be expected not to fall. The power capability that this flow and the available head represent is termed the "continuous power" or "prime power" that can or could be produced at that site. The principal function of a storage reservoir for power purposes is usually to increase the minimum flow, hence the continuous or prime power level.

The use of waterpower for electricity generation is further complicated if such use is part of a multipurpose development. If the stored water is also used for irrigation or maintenance of a navigation channel only part of it may be available for power, and the continuous power level that can be assigned to the associated hydro power facilities is thereby lowered. Similarly, the use of a reservoir for flood control may be incompatible with maximum power development, for a reservoir must

TABLE 6. Electric energy requirements of the United States (1958 preliminary actual; 1980 and 2000 estimated.)

| | 1958 | 1980 | 2000 |
|---|---|---|---|
| Electric energy requirements (million kilo-watt-hours): | | | |
| Utility requirements: | | | |
| Farm, excluding irrigation and drainage pumping....... | 23,000 | 46,000 | 77,000 |
| Irrigation and drainage pumping........................ | 8,000 | 19,000 | 29,000 |
| Nonfarm, residential.................................. | 144,000 | 507,000 | 1,192,000 |
| Commercial........................................... | 102,000 | 307,000 | 671,000 |
| Industrial........................................... | 284,000 | 871,000 | 1,751,000 |
| Street and highway lighting........................... | 6,000 | 15,000 | 30,000 |
| Electrified transportation............................ | 4,000 | 5,000 | 6,000 |
| Other deliveries to ultimate consumers................ | 19,000 | 43,000 | 79,000 |
| Losses and unaccounted for............................ | 64,000 | 203,000 | 429,000 |
| Total | 654,000 | 2,016,000 | 4,264,000 |
| Nonutility generation less deliveries to electric utilities........................................ | 78,000 | 148,000 | 203,000 |
| Total energy requirements | 732,000 | 2,164,000 | 4,467,000 |
| Population (thousands).................................. | 174,000 | 273,000 | 426,000 |
| Annual energy requirements per capita (kilo-watt-hours)...... | 4,200 | 8,000 | 11,000 |

be kept low in periods when floods may occur if it is to fulfull its flood control function. This reduces the head available for power generation and may limit the amounts of water that can be stored for later use in power generation when natural streamflows are low. (Thus irrigation and navigation may also be in some degree incompatible with flood control.)

The problems encountered in selecting multiple-purpose project sites and designing the projects are much more complex than for single-purpose power projects, and it is sometimes difficult to reconcile the various uses to the best advantage of overall needs. Provision for flood control requires that a reservoir contain more storage space and that the powerplant operate at lower head than would be desirable for power generation alone. Releases of water for navigation do not coincide with releases normally necessary for power generation. Water required for irrigation is usually not available for power generation, and at some multiple-purpose projects power is actually consumed in the process of pumping the water into irrigation canals, thus taking away from the power that would be available if the project were a single-purpose power development.

It can be stated as a general rule that projects are operated so that power production does not seriously interfere with use of the water for other purposes. Water needs for municipal water supply, navigation, irrigation, flood control, fish preservation, and other purposes usually have priority over requirements for the generation of power.

(2) Water Use

There is no consumptive use of water in the actual generation of electrical energy at hydroelectric plants. There is, however, some net evaporation in the reservoirs of storage-dam hydroplants. The amount of this net evaporation is the amount of water lost through evaporation from the water surface minus the transpiration loss of the trees and vegetation removed for the construction of the reservoir.

Evaporation is substantial under arid and semiarid conditions and, therefore, must be considered in evaluating a project. According to a recent study by the U. S. Department of the Interior, if reservoirs with capacity beyond an additional 10 to 15 million acre-feet are constructed in the upper Colorado River Basin, evaporation loss will thereafter offset the hydrologic benefit of the regulation so achieved. it has been estimated that 11.5 million acre-feet (3,750 billion gallons) of water are evaporated annually from existing water surfaces in 11 Western States.

Characteristics of Steam-Electric Generation

(1) General

With respect to water use at steam-electric plants, the figures shown in Table No. 7 apply to total water requirements. A small amount of the to[illegible] represented by boiler feed water and some of this is lost, but the amount is insignificant. Some utility companies make use of storage ponds from which water is taken for condensing purposes and returned for reuse after it has been permitted to cool. There is, of course, evaporation from such ponds. Other utility systems do not have an adequate supply of condensing water and must utilize cooling towers. This also involves evaporation loss. However, total water loss at steam-electric stations is comparatively unimportant, but total water use is very significant.

The amount of water required by steam-electric generating stations is a very important factor in determining the location of plants. In any closed cycle steamplant -- and all utility plants are of this type -- condenser water must be used to obtain satisfactory efficiencies. It would not be economical or technically feasible to provide enough turbine blading to extract so much of the heat from the steam that it would be discharged to the boiler feed lines as condensed water without the use of a condenser. If the steam were not condensed or used for other purposes such as process heat for nearby factories, it would have to be wasted by discharge to the atmosphere. The more water that is used for condensing purposes, the greater is the efficiency; but economics determines the amount. The cost of providing additional condensing water must be balanced against the savings resulting from the increased efficiencies which can be obtained.

An ample supply of condenser water is an asset to efficient operation, but thermal plants are often built where water supplies are very limited. In general it is not expected that there will be a physical lack of water in the country for condensing purposes because water requirements can be reduced, although at the cost of reduced efficiency, and also cooling towers can be utilized. Use of cooling towers increases the total cost but results in reduced fuel costs. The ideal situation would be to have an unlimited supply of cool water which would flow by natural gravity through the condenser. With conditions less favorable than this, plant design and operation can be altered to fit the available water supply.

The estimates of steam-electric capacity needed in the future, as given earlier, are not broken down by type of fuel. The three conventional fuels being used at the present time are coal, oil, and gas. Coal accounts for about 65 to 70 percent of the present generation in electric utility plants. Gas accounts for close to a quarter of the total, and oil less than 10 percent. Nuclear power is now coming into the picture, and the 1958 figures on installed generating capacity include about 110,000 kilowatts in nuclear plants. Both technical considerations and economics will control the rate of development of nuclear power.

(2) Nuclear Power

At this stage of development, it is hazardous to attempt to estimate how fast nuclear-power production will expand. But from the standpoint of water needs, the requirements of nuclear plants should not be greatly different from those of steam-electric plants if the same thermal efficiencies are assumed. Nuclear plants are not yet as efficient, however, as conventional plants. In this connection, it should be pointed out that one of the factors which will reduce the future requirements of water at steam-electric plants is the increasing efficiency of these plants. The most modern high-pressure, high-temperature steam-electric plants require considerably less water per kilowatt-hour than the older plants. There is a limit, however, to how much improvement can be made in thermal plant efficiencies.

(3) Water Use

Water is used in thermal plants mainly for condensing the steam. All other uses are so small as to be insignificant. Only a very small proportion of this cooling water, that portion evaporated in cooling towers or ponds, is actually a consumptive use.

Cooling water requirements of thermal powerplants may be broken down into the following categories of installati n in which:

(a) the cooling water is withdrawn from, and returned to, a natural river;

(b) cooling water is withdrawn from, and returned to, a natural lake;

(c) the cooling water is withdrawn from, partially consumed (by evaporation or windage loss) and returned to an artificial reservoir or pond constructed for cooling purposes

(d) cooling water is partially cons by evaporation or windage loss in cooling towers; and

(e) salty or brackish cooling water is withdrawn from, and returned to, coastal waters and estuaries.

In the above cases, all of the water entering the condenser is discharged unchanged except for an increase in temperature.

Water requirements of the above thermal capacity are affected by the cooling water methods used. These are:

"Once through," where water is taken from a stream, lake or the ocean, passed through the condenser, and returned to the source.

"Cooling ponds," where the water is taken from the pond, and after passing through the condenser is returned to the pond.

"Cooling towers," where the process is similar to the cooling pond, except that the water is cooled in a tower after passing through the condenser.

The volume of water circulated and consumed is shown in Table No. 7 for 1959 and as projected for 1970 and 1980.

In many cases, the cooling water passed through one generating station will again be passed through one or more stations located downstream on the same river. Thus, the sum of total intake by several plants on the same river may lead to erroneous conclusions and in some cases lead to flow quantities much greater than the total flow of the river.

The consumptive use of water imposed by a thermal plant, not its total intake, is usually the important consideration. The increase of river temperature may be a factor in the overall analysis of the water resource problem. Where cooling towers are employed a quantitative determination of water consumption can be made within reasonable limits. In such cases the total rejected heat from the turbine is dissipated by

TABLE 7.

Total water circulated through condensers

(Billion gallons a ually)

| Year | River | Lakes | Brackish and sea water | Cooling towers | Artificial reservoirs or ponds | Total |
|---|---|---|---|---|---|---|
| 1959.................... | 12,428 | 3,254 | 7,820 | 2,755 | 556 | 26,813 |
| 1970.................... | 23,842 | 8,168 | 16,455 | 6,635 | 2,185 | 57,285 |
| 1980.................... | 42,754 | 15,260 | 28,015 | 15,487 | 4,893 | 106,409 |
| | Consumptive use of water | | | | | |
| 1959.................... | (1) | (1) | (1) | 42 | 10 | ....... |
| 1970.................... | (1) | (1) | (1) | 111 | 39 | ....... |
| 1980.................... | (1) | (1) | (1) | 248 | 89 | ....... |

(1) Less than 1 percent.

evaporation of a portion of the total water circulated. It is, therefore, necessary to determine the makeup requirements and provide source and pumping quantities when the proje : is designed. The theory and practice is well established for this type of cooling.

Where thermal plants obtain cooling water from coastal and estuary sources, the total intake and consumptive water quantities are not involved in the problems concerned with fresh water.

The thermal plant cooling water withdrawn from, and returned to, the Great Lakes is estimated at 5,868 billion gallons for 1970 and about 10,922 billion gallons for 1980. These amounts can also be eliminated from any overall national studies because the consumptive uses represented by these intake quantities will be insignificant compared to the natural evaporation of these large bodies of water. A similar line of reasoning could be applied to other large lakes whose water is used for thermal plant cooling.

For the total United States the cooling water withdrawn from rivers expressed as a percentage of total withdrawals for cooling purposes is 46 percent in 1959, 42 percent in 1970 and 40 percent in 1980.

Considering total withdrawal, exclusive of those from coastal waters and the Great Lakes, the quantity of water from all other sources estimated for 1959 is 16,413 billion gallons. Even if the consumptive use of plants from these other sources were as high as three-fourths of 1 percent the quantity of water consumed would only be 123 billion gallons, or only 3.3 percent of the natural evaporation from the water surfaces of the 11 Western States.

In 1950, 100 megawatt turbines were typical. They rejected about 4,600 B.t.u./kw-hr. to the cooling water. Some recently installed units rejected only 3,480 B.t.u./kw-hr to the cooling water.

Technical progress has resulted in the introduction of pumped storage projects in the United States. Here, waterflow is reversed for added reservoir storage -- when electricity demand is low -- and subsequently released through the turbines when demand is high.

The economical feature of pumped storage is that pumping uses cheap, off-peak power, and generation occurs during peak times when power cost is at a premium. While efficiencies of pumping and power generation are high there is no attempt to overcome the limitations of perpetual motion.

e. Hydropower for [illegible]ng purposes

Hydropower ne[illegible]sarily will represent a relatively small share of the Nation's total electricity generation, and the bulk of the massive future demands will be met by thermal generation. Regional exceptions, especially the Pacific Northwest and Alaska, will remain for some time, however.

In almost every instance, technological developments may be interpreted as having a favorable effect upon the development and management of multiple-purpose water facilities and multiple use of water in the United States.

In spite of the vast expansion of steampower generating facilities now anticipated, steam plants are not expected to displace hydroelectric plants, because of the much enhanced value of waterpower for peaking purposes on systems within reach of both types of generation.

Hydropower, unlike fuel-produced power and atomic power, is a renewable resource and once developed continues to produce without depletion of available resource reserves. Furthermore, as already noted, hydroelectric power can serve an important and useful place in regional power economics by carrying the variable demands of peak loads.

f. Role of Forecasting

Forecasting of streamflow for hydroelectric generation, and for cooling water, is not so much forecasting of stages, as rates of flow. People who operate electric generating plants want forecasts of the hydrograph as far in advance as possible. They are interested in peaks and in low flows. Where forecasts of any skill at all can be made more than a few days in advance, they are useful. Seasonal Water Supply Forecasts are an example of this.

Releases of water from hydroelectric generation, of course, affect the flow of streams; and it is necessary to obtain reports of releases and of scheduled releases from cooperating power plants.

## 10. Recreational Uses of Water Resources

a. Introduction

It has been estimated that something like 70% of the millions of annual "user days" of recreation are water oriented: swimming, boating, skiing, and just enjoying the esthetic aspects of a water scene. Water is essential to camping and hiking. The subject of fishing will be discussed separately, later, partly from an ecological and partly from recreational and other points of view.

Since World War II, the demands for outdoor recreation have greatly accelerated and much of this recreation activity is concerned with the use and enjoyment of our water resources. All indications point toward a continuing increase of these demands.

The total volume of withdrawal water needed to supply recreation area visitors, although very important, is relatively minor in comparison with water needs for agriculture, industry, and other uses. The quantity of surface water needed for recreation is great and the need is steadily becoming more and more critical. Fortunately, surface water used for recreation can also serve other needs.

Unfortunately, however, it is practically impossible to evaluate recreational water needs by either volume or surface acres. For example, the water surface needs for such recreation activities as boating, swimming, or scenic enjoyment are much too variable to use as a basis for planning. Criteria for density of use, such as number of users per acre, have not been established.

Until very recently, recreation has been a stepchild in water resources planning. Planners of programs for outdoor recreation have made recommendations for use of water resources. The following paragraphs summarize some of these recommendations, which are given in more detail in Committee Print no. 17, of the Senate Select Committee on National Water Resources. Shortly after this Committee Print was prepared, the Bureau of Outdoor Recreation was established in the Department of Interior (1962). This agency has responsibility to promote the coordination and development of effective programs relating to outdoor recreation,

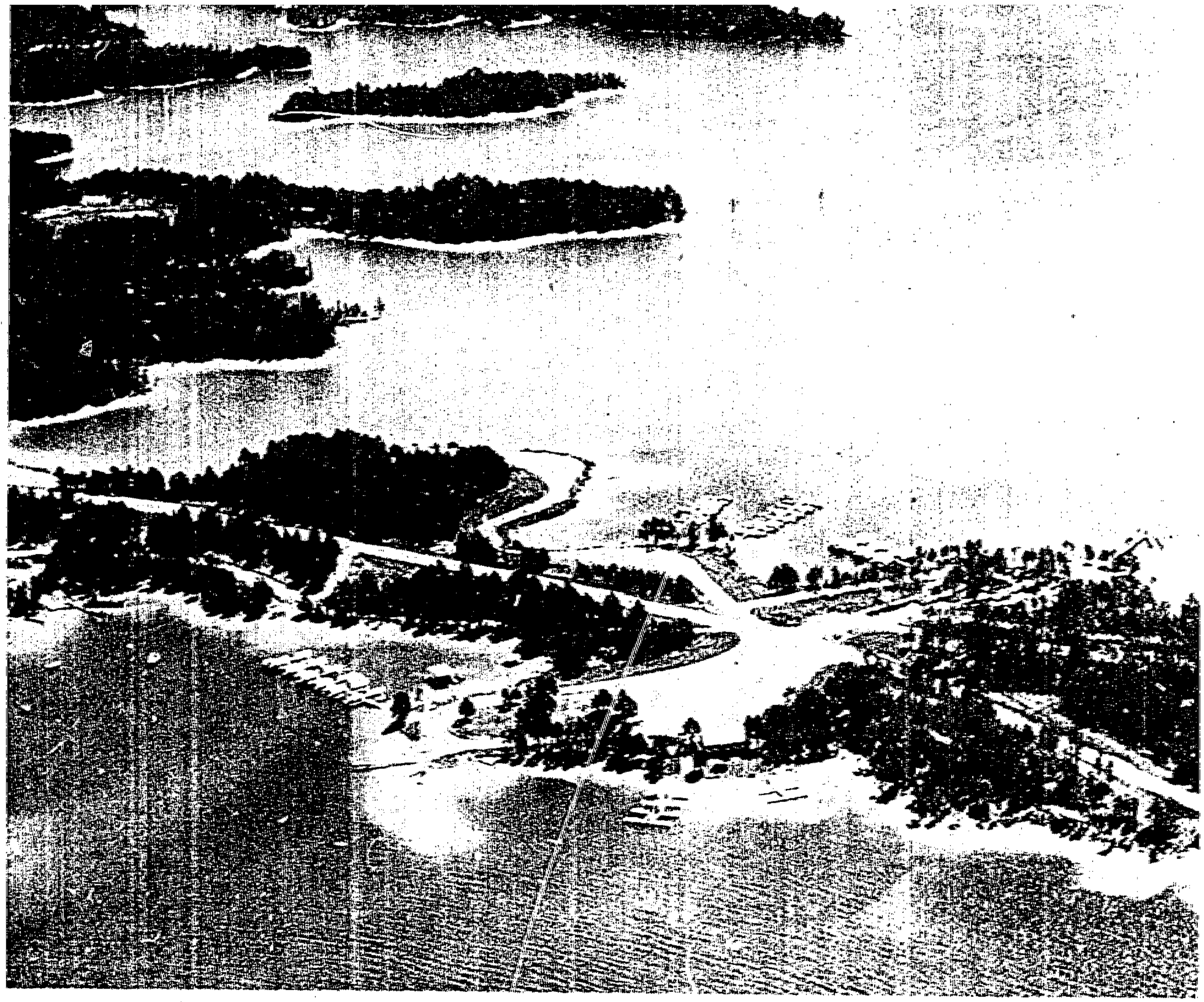

FIGURE 15. Recreational opportunities, Lake Lanier, Georgia (Courtesy U.S. Study Commission, Southeast River Basins).

cooperating with federal and other agencies.

Recreationists recommend the preservation of certain free-flowing streams in their natural state, because their natural esthetic, scenic, scientific, and recreational values are outstanding, and do not want these streams to be included in water development or control programs. They recommend that pollution abatement programs be intensified, and that recreation be included as a major use in any multiple-purpose reservoir developed for public use.

b. Examples of Use of Water Bodies for Recreation

Recreation is coming to be recognized as an appropriate use of domestic water supply reservoirs and watersheds. Such reservoirs constitute an important potential water recreation resource. At present there is great variation in the extent of recreation use permitted of these areas. Studies have indicated that in many instances safe water supplies can be maintained where appropriate recreation use, including swimming and boating, under proper control, is made of the reservoir and watershed.

Significant developments relative to some of the major water recreation activities are as follows:

(1) Swimming

During the period 1950 to 1959, the number of residential swimming pools increased from 3,600 to 175,000 -- an increase of nearly 4,800 percent.

In 1955, 359 city and county bathing beaches had an attendance of almost 70 million and 1,100 swimming pools had an attendance of over 36 million -- nearly 50 percent higher than reported in 1950.

State agencies reported that, in 1955, attendance at 181 State beaches was close to 18 million and attendance at 26 swimming pools was over 1 million.

Swimming is primarily a day-use activity with over 80 percent of total participation taking place on weekend days.

(2) Boating

The January 1958 issue of Outboard Boating stated that America's pleasure boat fleet has nearly tripled in the last 10 years and there is "now" 1 pleasure boat in use for every 24 Americans.

More than 44 million of our citizens now take part in recreation boating annually (1970) and they use nearly 9 million boats. This contrasts with the 15,000 pleasure craft in use on all U. S. waterways in 1904.

Boating is also primarily a day-use activity. However, some of the larger boats are used for weekend and vacation cruises.

(3) Water skiing

Since World War II water skiing has grown to the point where 6 million Americans in 1959 engaged in this popular water sport.

(4) Recreation use of reservoirs

In the 3 years from 1955 to 1958, the number of recreation visits rose 50 percent at reservoirs constructed by the Bureau of Reclamation, the Corps of Engineers, and the Tennessee Valley Authority. Total use in 1955 was estimated at 100,000,000 visitor-days and by 1965 the corresponding figure was more than 250,000,000.

Annual attendance at civil works projects of the Corps of Engineers, 1950-65:

| | |
|---|---|
| 1950 | 16,000,000 |
| 1955 | 62,522,000 |
| 1958 | 94,793,000 |
| 1962 | 127,000,000 |
| 1965 | 168,600,000 |

Estimated person-day visits to TVA reservoirs 1947-65:

| | |
|---|---|
| 1947 | 7,338,755 |
| 1955 | 27,779,977 |
| 1958 | 36,600,408 |
| 1965 | 49,410,500 |

(5) Withdrawal of Water for Recreational Needs

Certain criteria have been established for various withdrawal uses of water in our parks and recreation areas. Generally speaking these can be broken down under the following headings:

1. Drinking and sanitary use.
2. Stock and wildlife watering.
3. Irrigation of lawns, campgrounds, and some rangelands.
4. Storage for fire protection and for regulation of distribution of small flows to meet peak daily or hourly demands.

The quantitative water needs for these purposes are not yet available as national averages or for the individual water resources regions. However, the 1957 average for the 23 national parks, monuments, and recreation areas in the Lower Colorado River was 155 gallons per visitor-day.

It is not entirely facetious to suggest care to avoid double counting of water use, as increasing numbers of people spend larger portions of each year at recreational sites where they use water instead of at home.

c. Coordination of Recreational Needs With Other Water Uses

As indicated earlier, one of the most important aspects of recreational use of water is its quality. Other aspects are less obvious. Sharp rises from releases of water for hydroelectric power generation are a hazard immediately downstream from many reservoirs. High velocities in rivers are dangerous for swimming, and canoeing.

Changes in stage of a reservoir adversely affect recreation, particularly with respect to access from shore facilities. Not only may the drawdown be a source of unsightly mud flats, but access points left high and dry make it expensive and difficult to use the reservoir.

Until the last few years, recreation was regarded by many puritanical resource developers as unworthy of evaluation as a legitimate purpose. The recreationist, who could hardly be fenced out of attractive places, was regarded as a nuisance and a free-loader. Any compromise between operation of a reservoir for hydroelectric generation or other economic purpose and recreation meant that the users of electricity or other products were subsidizing the lazy or improvident recreationists.

Now, instead of complaining about the power loss stemming from joint use of a multiple-purpose reservoir, arrangements are sometimes made to delay seasonal drawdown until after the Labor Day termination of the recreational season.

d. Forecasting of Streamflow for Recreationists

Forecasts of inflow to a reservoir, and of river velocities and stages, are probably most important. Other forecasts, and possibilities of forecasts, include low flows or shoaling for recreational boaters, and period of flow exceeding certain rates over spectacular falls. For example the seasonal water supply forecast of flow of streams in some of the Western Parks could easily be related to the time of year and duration of attractive water falls - months in advance.

The distinction between a hydrologic and a weather forecast is not important to a recreationist. The time has come when he can visit or call any NWS office and expect to find out if the river is muddy, what the prospects are of wind for sailing, storms for camping or picnicking, stream stages for boating or for fording during hikes - in general, all of his environmental factors.

At some stations these generalized forecasts of recreational weather are taped for listed or unlisted telephone announcements. Boats operating in Chesapeake Bay may obtain special Bay and Weather Advisories by radioing the marine operation at Wilmington, Delaware, and asking for the "Boat to Forecaster Service."

11. Fish and Wildlife

a. Introduction - The fish and wildlife people are less unanimous in their objectives than most groups involved in water resources management. They, like the recreationists, have been somewhat underprivileged in the past. It has been difficult to assign monetary benefits to water management favoring fish and wildlife. One of the most troublesome aspects is the problem of objectives. One objective is service to hunters and fishermen. Another objective is preservation of an ecological balance. A third objective is opening the great outdoors for enjoyment of nature lovers. The term "conservation" means all things to all people, including preservation and utilization and everything between.

Thus in addition to the usual inter-function competition for water and space and related facilities, the fish and wildlife function has complex intra-function problems of coordination and meeting diverse needs.

The principle agencies managing fish and wildlife resources are the Department of Interior, with its Bureaus of Sport Fisheries and Wildlife and the Department of Commerce with its newly organized National Marine Fisheries Service. The following paragraphs are taken mostly from their contribution to the Senate Select Committee, Print no. 18.

b. National Marine Fisheries Service - The fishing industry of the United States is a significant part of our economy. The commercial fisheries of the Nation provide employment, both direct and indirect, for about half a million people. Fish taken in the commercial catch are tremendous sources of raw materials for food, the manufacture of drugs, for other industrial uses, and as ingredients in mixed feeds for livestock and poultry. Fish which enter into commercial channels create wages and profits for the whole chain of commerical distribution from canner to wholesaler to the neighborhood supermarket.

In 1954 the U. S. commercial fishing industry produced nearly 5 billion pounds of basic product, valued at $356 million. Of these amounts, somewhat more than 61 percent of the volume (2.9 billion pounds) and 58 percent of the value ($208 million) were accounted for by aquatic species which are dependent on fresh water during part or all of their lifetime. Retail value amounts to about 2 1/2 times the basic amount, or about $500 million of product each year from fresh-water-dependent species.

In addition to the strictly fresh-water species, there are important anadromous fishes, such as salmon and striped bass, which ascend the streams from the ocean to spawn. There are others which live in the brackish waters of estuaries along the seashore and still others, such as shrimp and menhaden, which spend the crucial period of their young lives in the nearly freshwater heads of estuaries. The existence of these species depends upon the vital supply of fresh water to their environment.

The 1954 commercial catch of fresh-water-dependent species was composed of the following:

(In thousands)

| Species | Landed weight | Value to Fisherman |
|---|---|---|
| | Pounds | |
| Fresh water...................... | 218,153 | $20,999 |
| Anadromous...................... | 397,956 | 47,902 |
| Estuarine dependent.............. | 2,304,289 | 139,379 |

To this supply from commercial sources must be added the substantial sport-caught volume which is now estimated by the Sport Fishing Institute to exceed 1 billion pounds annually. Of this, about three-fourths are composed of fresh-water species.

U. S. commercial production of fresh-water-dependent species in 1954 represented a substantial proportion -- about 6 percent -- of the world production of all fishery products.

c. Sport Fisheries and Wildlife - A nationwide survey made for calendar year 1955 showed that one out of every three households in the United States included one or more fishermen or hunters. One in every five persons, 12 years of age or more, fished or hunted during that year; this amounted to 25 million people in that age category. One in every four men fished, and one in every five hunted. Approximately $3 billion were spent by fishermen and hunters in 1955 in pursuit of their sports. This amount is about the same as that spent in 1955 by all of the households in the United States for residential electricity. Fishermen and hunters spent 567 million man-days and traveled 10.4 billion miles by automobile on fishing and hunting trips.

d. Congressional Recognition - The Congress itself recognized the growing importance of fish and wildlife resources to the Nation and the necessity of expanded programs for their conservation by passage of the Fish and Wildlife Act of August 8, 1956 (70 Stat. 1119). In the opening lines of this statute --

The congress hereby declares that the fish, shellfish, and wildlife resources of the Nation make a material contribution to our national economy and food supply, as well as a material contribution to the health, recreation, and well-being of our citizens; that such resources are a living, renewable form of national wealth that is capable of being maintained and greatly increased with proper management, but equally capable of destruction if neglected or unwisely exploited ***.

e. Administration of Fish and Wildlife Conservation - The Fish and Wildlife Act of 1956 greatly raised the stature of fish and wildlife conservation activities in the Federal Government. The activity began with the establishment of the Bureau of Fisheries in the Department of Commerce in 1871 and was followed by the establishment of the Bureau of Biological Survey in the Department of Agriculture in 1885. The two agencies were combined to form the Fish and Wildlife Service in the Department of the Interior in 1940.

The Fish and Wildlife Act of 1956 established within the Department of the Interior the position of Assistant Secretary for Fish and Wildlife and the U. S. Fish and Wildlife Service, headed by a Commissioner. Within the service were two separate bureaus, as called for by the act; one was the Bureau of Commercial Fisheries and the other was the Bureau of Sport Fisheries and Wildlife. Under the law, the Bureau of Commercial Fisheries was responsible for Federal programs relating primarily to commercial fisheries, including whales, seals, and sea lions. The Bureau of Sport Fisheries and Wildlife was responsible for Federal functions, including research, relating primarily to migratory birds, game management, wildlife refuges, and sport fisheries in both fresh and salt waters. Under the Presidential Reorganization Plan No. 4 of 1970, the Bureau of Commercial Fisheries and the marine functions of the Bureau of Sport Fisheries and Wildlife were placed in the newly created National Oceanic and Atmospheric Administration in the Department of Commerce.

Many of the sites for new industries are along the shores of rivers where there is a dependable water supply and, in many cases, access to low-cost water transportation. Hundreds of these sites were riverside marshes and wetlands utilized by waterfowl and other wildlife and as fish nursery areas prior to being converted into factories. Waste from industry and from the larger urban complexes, which is passed into the rivers in increasing quantity, pollutes streams and bays and destroys or detracts from their usefulness as fish and wildlife habitat.

f. Effects of Water Resources Programs - The huge water resources program of the Federal Government has an altogether vital effect on fish and wildlife resources. Meandering rivers which have offered outstanding opportunities for fishing and as resting areas for waterfowl are many times converted into straight, swift-flowing, denuded water courses of little value to fish and wildlife. This has happened particularly in some parts of the lower Mississippi River Basin.

Dams may block the passage of fish that live most of their lives in the sea and run into fresh water high in the headwaters of the rivers to spawn and reproduce their kind. If this happens, the life cycle is broken and the run of fish may be destroyed. This has happened to the Atlantic salmon runs in most rivers in New England.

The estuaries of our Gulf and Atlantic coasts are essential production areas for shrimp, oysters, and other shellfish and are nursery grounds for marine fin fishes which support both commercial and sport fisheries. In addition, these estuaries and associated marsh and wetlands are essential parts of the waterfowl habitat of the Nation. In recent years, particularly, many estuaries of the Nation have been subject to dredging and spoil deposition in a manner which has damaged important fish and wildlife resources.

Each section of coastline has specific problems in connection with its estuarine areas. Among these are: filling of marshland areas in New England, domestic and industrial pollution in the Middle Atlantic, pesticide pollution in the South Atlantic, leveeing and similar development in the eastern Gulf of Mexico, water supply shortage in the western gulf, and pulpmill pollution in the Northwest.

The Wildlife Coordination Act of March 10, 1934, amended in 1946 and 1958, contains important authorizations for both Federal and State fish and game agencies for investigation and participation in planning, development, and operation of water resource projects. It is perhaps most significant in its provision of authority for Federal construction agencies to incorporate fish and wildlife conservation and enhancement features into project planning.

Basically, the act provides for a study by the Fish and Wildlife Service and the affected State fish and game agencies of all Federal construction projects, and those requiring a Federal license or permit, involving the use and control of water. The purpose of the study is (1) to determine the effects of the project on fish and wildlife resources, and (2) to formulate measures for incorporation in project construction and operation plans designed to eliminate or mitigate adverse effects on those resources and to take advantage of project-occasioned opportunities to develop and enhance fish and game.

The act provides authority for Federal construction agencies to modify their plans for project construction and operation to accommodate these measures, and to acquire additional project lands for fish and wildlife conservation purposes.

These activities are carried on in connection with projects licensed by the Federal Power Commission. Similar activities are carried on by the Fish and Wildlife Service pursuant to the Watershed Protection and Flood Prevention Act. Section 4 of the Act provides that the Secretary of Agriculture may pay from Federal funds part of the cost of incorporating fish and wildlife facilities in these locally sponsored projects.

The legislative authorization for many projects of the Corps of Engineers and the Bureau of Reclamation includes specific provisions for fish and wildlife conservation.

g. Dam and Reservoir Construction - The construction of dams and reservoirs normally has many and diverse effects on fish and wildlife resources. These effects are dependent upon many factors, including the region of the country in which a reservoir is constructed, the climate, the topography, the size of the reservoir, its depth, the fluctuation pattern, the flow remaining in the stream below the dam, the type of vegetation and topography inundated, and the purposes for which the reservoir is to be operated. These and other factors influence and dictate the effects upon fish and wildlife resources.

Dam and reservoir construction has adversely affected anadromous fish species through blocking their passage to and from the spawning grounds; decreasing the flow with resulting loss of living space, buildup of contaminants, and interference with migration; increasing the silt load of the rivers; physically damaging vital living and spawning areas; upsetting required oxygen and temperature conditions; and damaging the vegetative food base for the species. Anadromous fish are conducted past dams, by fish ladders and elevators, to their spawning areas. Also fish hatcheries are used to stock streams blocked by dams.

Reservoirs commonly inundate wildlife habitat, thus either destroying animals themselves or forcing them into adjacent habitat which commonly is already supporting wildlife to the extent of its capabilities. Insufficient releases of water from dams to the streams below at certain times of year result, in many cases, in fishery losses. Reservoirs inundate important spawning areas for fishes, especially anadromous species, and in other cases reservoirs in northern latitudes may not have sufficient depth to permit year-round fish life. Fish eggs may be stranded by reservoir drawdown during critical seasons. Stream temperatures below dams in many cases are altered due to the temperature of water released from the reservoirs, thus destroying valuable existing fisheries.

h. Channelization - The channelization of rivers and streams and the construction of new channels through land or marsh areas are of great concern to the fish and wildlife interests.

There are numerous projects throughout the country which involve the deepening and straightening of streams in order to reduce flooding, increase the rapidity of runoff, lower the water table on adjacent lands, and improve navigation. Such projects often destroy valuable fish habitat by dredging in the project area, increasing siltation in downstream areas, and decreasing or eliminating overflow on adjacent lands or areas which are used as spawning and nursery areas by fishes. Estuarine dredging is particularly destructive when it destroys or alters an existing ecological balance.

Channelization projects may also harm wildlife resources by destruction of fur animal habitat, drainage or filling of adjacent marshland, and the destruction of tree and shrub cover along the stream.

i. Water Quality - Pollution in streams can be seriously detrimental to fish and wildlife resources through direct toxic effects and the reduction of the dissolved oxygen supply. Municipal and industrial wastes often have a strong deoxygenation effect on streams. There is, in many cases, insufficient oxygen remaining in the water to permit the survival of fish. Pollution of the Great Lakes and other lakes and reservoirs from domestic and industrial sources is becoming a serious problem.

Water quality is definitely impaired by industrial and domestic pollution in certain areas adjacent to densely populated and highly industrialized centers of the Midwest, such as southern Lake Michigan, and Lake Erie.

We are learning that some of the toxic substances found in industrial wastes and in chemicals applied to crops, orchards, marshes, et cetera, are cumulative in effect and difficult to remove.

Increased and stabilized streamflows would alleviate many quality problems. Excessive discharge of fresh waters during periods of flood has long been a problem in estuarine areas. The sudden entrance of many times the normal flow of water, usually silt laden, can and does have a catastrophic effect on marine organisms that cannot escape or survive the rapid change in water character. Upstream flood detention reservoirs that store these surplus waters and release them gradually are generally beneficial to the estuarine habitats. Conversely, retention of too much fresh water on a watershed may result in intrusion of highly saline water farther into the heads of estuaries so that valuable brackish water species, such as oysters, may be destroyed by favoring their parasites and predators.

A problem closely related to pollution is that of siltation, which not only has adverse effects upon aquatic life but also may shorten the life of reservoirs, many of which will become completely filled if precautions are not taken. Farm pond and reservoir studies have shown that turbidity may reduce the production of desirable fish species by as much as 80 percent through restriction of food supplies, reproduction, and growth. Turbidity is objectionable esthetically and implies upstream land practices which permit erosion.

The principal programs of the Fish and Wildlife Service in pollution control and abatement are in the research field and in bringing to the attention of water-project construction agencies the need of fish and wildlife resources in relation to the needs for pollution control.

j. Irrigation - Irrigation projects, without considering reservoirs which usually make them possible, may be of substantial benefit to fish and wildlife resources. Reports of the Fish and Wildlife Service may recommend (1) ponding areas along irrigation canals for the benefit of both wildlife and fish, (2) fencing of large concrete-lined canals to prevent deer from entering the canals and drowning or being unable to escape, (3) constructing dirt-covered bridges for migrating deer to cross concrete-lined canals, (4) fencing specific canal and drain areas to provide protected habitat for wildlife, (5) planting food and cover plants for wildlife in some small areas otherwise unused in the irrigation system, (6) participation by fish and game agencies in organized weed and insect control planning to minimize wildlife losses that may result from the use of toxic herbicides and insecticides, and (7) provision for free public access to Federal lands for fishing and hunting purposes.

k. Leveeing - Projects for the control of floods employ levees, in many cases, as primary features. Levees may be damaging to fish and wildlife resources in that they prevent the periodic overflow of areas adjacent to rivers which are important for fish spawning and nursery areas and for waterfowl.

The Fish and Wildlife Service may recommend that certain lands within levee projects be acquired and made available for fish and wildlife management. The introduction of water into specified areas, and management of such areas through the use of water-control structures, can provide valuable fish and wildlife habitat. In other cases, the Service may recommend that sumps resulting from the project be managed for fish and wildlife purposes. Sometimes the Service recommends realinement of proposed levees so that certain areas can be preserved in their natural state. In many cases, the Service recommends that desirable wildlife food plants be established on the levees. These plants also serve to prevent erosion of the levee banks.

l. Drainage - Wetlands of the United States are disappearing at a rapid rate because of drainage programs. This matter is of great concern to the Bureau of Sport Fisheries and Wildlife since such lands provide vital habitat for many species of wildlife. Various species of fur animals and upland game make heavy use of wetland areas. Specific types of wetlands provide the best remaining habitat for big game animals in some sections of the country. Waterfowl, moreover, are dependent upon wetlands for their very survival.

Since the early 1950's, the Bureau of Sport Fisheries and Wildlife has carried on a program designed to stimulate preservation of wetlands, especially wetlands valuable as waterfowl habitat.

The program has included close study of the programs of other Federal agencies whose activities affect wetlands, and a continuing liaison with such agencies at appropriate levels. Studies have shown that elimination of Federal assistance for drainage in some areas would save most of the habitat now being drained. There is, of course, no suggestion of restricting the rights of private landowners to drain their own lands without governmental assistance.

m. Small Watershed Projects - The Fish and Wildlife Service studies the watershed work plans and proposes measures for the prevention of losses, and improvement of fish and wildlife resources. These studies are made in accordance with section 12 of the Watershed Protection and Flood Prevention Act, noted earlier. The act includes an amendment adopted in 1958 providing for Federal sharing in the cost of small watershed projects on account of fish and wildlife benefits.

Recommendations made by the Service may include storage capacity in reservoirs for fish and wildlife development, modification of reservoir structures, marsh development, and improvement of stream channels by herbaceous, tree, or shrub plantings and fencing.

n. Highway Construction - The construction of new highways has tremendous potential for damage to fish and wildlife resources of our Nation. At the same time highway programs offer many splendid opportunities for improvement of these resources.

Some of the types of damage done to fish and wildlife by highway construction are: (1) improper installation of road culverts so that they form an impediment to the passage of migratory fish; (2) the imposition of superhighways across productive waterfowl marshes; (3) the destruction of fish habitat in streams through dredging and filling and subsequent siltation; (4) the widening of stream channels, thus permitting warmer and shallower water which is undersirable for fish; (5) the rerouting of stream channels through barren, dredged cuts which may be impassable for migratory fish; and (6) providing outlets for drainage of valuable wetlands.

On the other hand, when highway construction agencies are aware of the damages to fish and wildlife caused by some of the methods they use, they may be able to change construction procedures so as to preserve fish and wildlife habitat without unduly interfering with the road construction. Properly installed road culverts usually do not impede passage of migratory fish; highways sometimes can be routed around important waterfowl marshes; the extent of destruction of stream channels by construction equipment often can be reduced; and stream channels often can be maintained with sufficient depth and other characteristics so as to preserve fish habitat.

Working relationships have been established between the Fish and Wildlife Service and the Bureau of Public Roads to further the cooperative efforts. Field personnel of these agencies, as well as personnel of State fish and game departments and State highway departments, are encouraged and assisted in taking advantage of opportunities for creation and preservation of fish and wildlife habitat in connection with Federal-aid highway planning and construction.

o. Saline Barriers - The construction of saline barriers to prevent salt water intrusion into streams and agricultural lands is a new type of water-development proposal which is now undergoing study by the Fish and Wildlife Service.

Low-lying lands and streams along coastal areas are subject to intrusion of saline waters from the oceans. As flows of the streams are reduced and water tables lowered due to increased use of water for municipal, industrial, agricultural, and other purposes, ocean waters may penetrate further inland. This causes damage to agricultural lands and deterioration of water quality for the above purposes. Fish and wildlife habitat also may undergo substantial changes.

In order to prevent the undesirable effects of salt water intrusion in certain areas, several Federal agencies and States are studying corrective measures which might be undertaken. One of the most promising measures under study is the contruction of dams across the streams affected to prevent intrusion of saline waters during periods of low streamflows. Such dams often would require ship locks and sometimes additional facilities for the passage of migratory fish.

A policy is desired by many conservationists to reserve some of the streams in the Nation in their natural state because of their outstanding character from a fish and wildlife and outdoor recreation standpoint. In these cases, there is little which can be done in the way of modifications in project construction and operation plans to preserve the natural values which make these areas outstanding.

It is recognized that the number of such areas reserved from water resources development will have to be few, in the light of the increasing need for water development. Nevertheless, there should be recognition in the water policies of the Nation that there are some areas which contribute to public benefit most by being left unaltered--in their natural state. In some cases, it can be demonstrated that the natural characteristics are more valuable to the public than the benefits which would be created by the development of a water resources project, with the attendant loss of the natural values.

p. Forecasting - Fish and Wildlife programs are partly for the fish and wildlife, and partly for fishermen and hunters. In either view, forecasts are necessary.

Fish and wildlife, of course, do not receive warnings of floods or low water, but conservationists who manage the natural resources need to know what the river will do so that they can plan and schedule their operations.

Hunters and fishermen need warnings of impending floods, and are aided by forecasts of low water and other stages.

Forecasts that help abate pollution, help preserve fish and wildlife.

## 12. Other Water Resource Programs

a. Introduction - The foregoing Sections summarize the major water management programs on a functional basis. This Section describes in less detail the water-related programs of several agencies not cited in the earlier Sections.

Most of the agencies whose work is discussed in this Section have programs in which water may be a relatively minor factor, in which the water aspects are only distantly related to water management or to the field program of the NWS, or which are essentially regional.

There is no implication of the work of any agency or program as being more or less important than that of any other. Failure to cite any agency or program which should be included here is inadvertant rather than intentional.

Pertinent summaries of Agency activities are given in the annual "U. S. Government Organization Manual," and the "Handbook of Federal Aids to Communities," both available from the Government Printing Office. The "Federal Aids to Communities" was prepared by the Economic Development Administration of the Department of Commerce.

b. Commerce - In addition to the Environmental Data Service and the National Weather Service in NOAA, there are several other water - interested agencies.

(1) The Census Bureau has no construction or management program regarding water resources, but does include in its normal work the measurement and reporting of areas of water. It also conducts major censuses, as follows: population and housing, years ending in 0; agriculture, years ending in 4 and 9; drainage and irrigation, years ending in 9; governments, years ending in 2 and 7; and manufactures, mineral industries, business, and transportation, years ending in 3 and 8.

(2) The Bureau of Domestic Commerce is concerned with use of water, and publishes reports on current trends and projections of water use.

(3) The Bureau of Standards tests current meters, and does considerable hydraulic research. It publishes a catalog, "Hydraulic Research in the United States," which describes much of the research being done in the field of water resources.

(4) The Small Business Administration assists small businesses and other victims of floods and other disasters, by making loans for

repair or replacement of their homes, businesses, and other property. The agency also makes loans to small businesses which may have suffered indirect economic losses from such disasters

(6) The Economic Development Administration renders financial aid in the form of grants and loans for public works, including water and sewer systems.

(6) The National Ocean Survey of NOAA prepares nautical and aeronautical charts, conducts precise geodetic, oceanographic, and marine geophysical surveys, monitors the earth's geophysical fields and seismic activity, predicts tides and currents, and issues tsunami warnings to the Pacific Ocean area. It also prepares and publishes navigational charts and related materials for the Great Lakes, and conducts investigations of the physical aspects of the lake waters.

(7) The Maritime Administration provides technical assistance which includes advice on port development.

(8) The National Marine Fisheries Service seeks to discover, describe, develop, and conserve the living resources of the global sea, especially as these affect the American economy and diet. It conducts biological research on economically important species, analyzes economic aspects of fisheries operations and rates, develops methods for improving catches, and cooperates with the U.S. Department of State in international fisheries affairs. With the U.S. Coast Guard, it conducts enforcement and surveillance operations on the high seas and in territorial waters. It also studies game fish behavior and resources, seeks to describe the ecological relationships between game fish and other marine and estuarine organisms, and investigates the effects on game fish of thermal and chemical pollution.

c. Food and Drug Administration, in Department of Health, Education and Welfare -- High water caused by floods often inundates local water supplies, and the flood waters may contaminate the water. To avoid pollution of water to be used in bottling soft drinks and other purposes, several River District Offices include the Food and Drug Administration in their list of agencies to be warned of impending floods.

d. Department of Housing and Urban Development - This important new agency is concerned not only with housing, but with the community environment It provides financial aid and technical assistance for programs of many kinds, including urban storm drainage, water and sewer, urban land use, flash floods, effects of urbanization, and related problems.

e. Department of Defense - In addition to the Civil Works function of the Corps of Engineers, both that agency and the Navy Bureau of Yards and Docks are interested in designing and operating shore installations such as cantonments, airfields, and training areas where streamflow forecasting and estimates of flood frequencies are important.

The function of civil defense was established originally, as we know, for protection of civilians in the event of war. Between wars there were problems of apathy toward an organization that usually had little to do, and that hopefully would never have to function. At the same time, there was a job that could be done with an organization of this type, which had public contacts, communications, and a public-service orientation: protection of people and assistance to them in any emergency - not merely a military emergency. As a result the responsibilities of the civil defense function have been broadened, and many of us know its very important role in disseminating flood warnings, and helping in other ways with flood emergencies. These responsibilities are now in the Office of Civil Defense, which is in the Department of Defense.

f. Department of Interior -

(1) The Office of Saline Water performs functions vested in the Secretary of the Interior by the Act of July 3, 1952, as amended by the Act of September 22, 1961. The act authorized $75 million for fiscal years 1962 - 1967 inclusive, for research and development of practical means for the economical production, from sea or other saline water, of water suitable for agricultural, industrial, municipal, and other beneficial consumptive uses.

The program is conducted by means of research grants to, and contracts made with, chemists, physicists, engineers, educational institutions, scientific organizations, and industrial or engineering firms, to conduct research and technical development work.

(2) The Geological Survey as is well known to all hydrologists, is the major stream-gaging agency. Also, that agency supplies topographic and other maps, and is the major source of information on ground water. In broad terms, the Geological Survey determines the source, quantity, quality, distribution, movement, and availability of both surface and ground waters. This work includes investigations of floods and droughts, their magnitude, frequency, and relation to climatic and physiographic factors; the evaluation of available waters in river basins and ground-water provinces, including water requirements for industrial, domestic, and agricultural purposes; determination of the chemical and physical quality of water resources and the relation of water quality and suspended sediment load to various parts of the hydrologic cycle; special hydrologic studies of the interrelations between climate, topography, vegetation, soils and the water supply; research to improve the scientific basis of investigations and techniques; scientific and technical assistance in hydrologic fields to other Federal agencies. The results of these investigations appear in several series of Geological Survey publications.

(3) The Bureau of Land Management performs functions concerned with the identification, classification, use, and disposal of public lands and the development, conservation, protection, and utilization of the natural resources on public lands and the mineral resources on certain acquired lands.

The Bureau carries out a coordinated program for the conservation, development, and utilization of water in order to preserve and protect the soil and water resources. The program is a combination of land treatment and structural practices having a planned pattern in support of multiple-use management. It is designed to regulate surface water runoff for control of accelerated erosion and to stabilize the soil resources implementing resource use.

The management of watershed, recreational, or other resources is integrated with forest and range management for the greatest total public benefit. The Bureau has varied program responsibilities for outdoor recreation and wildlife values of the public lands. It also develops transportation plans and plans for design and construction of access roads to public lands, and provides engineering standards covering design and construction of soil moisture and range improvement projects, buildings, and facilities.

(4) The Bureau of Outdoor Recreation was created April 2, 1962. It performs the functions prescribed under the Act of May 28, 1963, to promote the coordination and development of effective programs relating to outdoor recreation. The Bureau assists the Secretary of the Interior in carrying out these responsibilities and reports to the Secretary through the Assistant Secretary for Public Land Management.

The Bureau is responsible for preparing and maintaining a continuing inventory and evaluation of the outdoor recreation needs and resources of the United States; preparing a system for classification of outdoor recreation resources; formulating and maintaining a comprehensive nationwide outdoor recreation plan; promoting coordination of Federal plans and activities relating to outdoor recreation; cooperating with and providing technical assistance to States, political subdivisions, and private interests; encouraging interstate and regional cooperation; sponsoring, engaging in, and assisting with research relating to outdoor recreation; and cooperating with and providing technical assistance to Federal departments and agencies.

(5) The National Park Service is concerned with preservation, conservation and use of natural resources, including water. In addition to supplying water to visitors to the National Parks and other areas under jurisdiction of the Park Service, that agency has a protection program which consists of preventing fires, stream pollution, and injury to natural, historic or prehistoric features, and restricts uses that are incompatible with the conservation policy of the Service.

(6) The Office of Water Resources Research (OWRR) was created by Public Law 88-379, known as the Water Resources Act of 1964.

OWRR has two major programs. Title I of the Act provides for grants of federal funds to the Land Grant Universities of the 50 States and Puerto Rico to conduct research and training in water resources. There are thus 51 Water Resources Research Centers or Institutes, financed by substantial federal and matching funds, and working on a broad coordinated program of water-oriented projects, which are approved after review by the OWRR.

Title II provides for additional research by grants, contracts, matching or other arrangements with additional institutions, including States, private firms, foundations, educational institutions, and local agencies. Projects under Title II must first be approved by the Congress. Federal agencies assist other institutions in their planning of worthwhile research projects.

Title III of the Act requires the Secretary of the Interior to obtain the continuing advice and cooperation of Government agencies at all levels and of private institutions and individuals to avoid unnecessary duplication of research. It also provides that the Secretary shall make generally available information and reports on projects completed, in progress, or planned. Nothing in the Act is to be construed to give the Secretary of Interior authority over water resources research conducted by other Federal agencies, nor control or direction of education at any college or university.

The OWRR publishes an annual "Water Resources Research Catalog" which gives the titles, objectives, description of work, locations, names of project leaders, and names of supporting institutions of hundreds of water resources research projects. All water-oriented research projects are reported to the Science Information Exchange of the Smithsonian Institution, which prepares the Catalog under contract to OWRR.

The OWRR is also organizing a Water Resources Scientific Information System which will ultimately serve as a focal point for the water resources technical information activities of many Federal agencies.

(7) Power Administrations include Bonneville in the Columbia River Basin, Southeastern Power Administration and Southwestern Power Administration. These agencies market the hydroelectric power generated at federal dams in their respective areas. Close cooperation with the Corps of Engineers and other agencies is necessary, in order to coordinate the functions of flood control, navigation and power generation.

g. Department of Agriculture

(1) The Agricultural Stabilization and Conservation Service has functions which include conservation assistance, carried out through sharing with individual farmers the cost of installing needed soil-, water-, woodland-, and wildlife-conserving practices through the Agricultural Conservation Program, and emergency disaster relief, through direct assistance to farmers and ranchers.

An Agricultural Conservation Program as authorized by the Soil Conservation and Domestic Allotment Act of 1936, provides for the Government sharing with farmers and ranchers the cost of carrying out approved soil-building and soil-and-water-conserving practices, including related wildlife-conserving practices which farmers would not perform to the needed extent if they had to bear the whole cost. Conservation measures for which cost-sharing is offered include those primarily for (1) establishment of permanent protective cover, (2) improvement and protection of established vegetative cover, (3) conservation and disposal of water, (4) establishment of temporary vegetative cover, (5) temporary protection of soil from wind and water erosion, and (6) benefits to wildlife.

(2) The Farmers Home Administration makes loans for water systems and changes in land use. These loans enable groups of farmers and rural residents to develop community water supply systems, drain farmland, and carry out soil conservation measures; also to shift land into recreation, grazing, and forestry uses.

(3) The Forest Service is concerned not only with forested land, but also with certain range lands. All land, of course, is part of one watershed or another.

National forests are managed under the twin conservation policies of multiple use and sustained yield. Technical methods of forestry are applied to the growing and harvesting of timber. Livestock grazing is scientifically regulated to obtain range conservation along with use of the annual growth of forage. Watersheds are managed for the regulation of streamflow, reduction of flood danger and soil erosion, and the protection of sources of water for power, irrigation, navigation, and municipal and domestic supply. Provision is made for popular outdoor recreation. Scientific management is applied to the development and maintenance of wildlife resources. The Forest Service operates many field experimental areas, research stations, and watersheds.

(4) The Soil Conservation Service (SCS) has several major water-oriented functions which have been discussed earlier, but for convenience a resume of its pertinent activities is given here.

The improvement of specific watersheds is planned and executed throughout the country by cooperative efforts of the Soil Conservation Service, Forest Service, and local watershed and soil conservation districts. The problems to be corrected include flood damage to crops and pastures, roads, bridges, and minor fixed improvements; sediment damage to flood plain lands; active interference with farming operations by overbank flows; and disruption of traffic caused by flooding of roads.

The works of improvement planned to combat these problems include such measures as installation of floodwater retarding structures, improvement of stream channels, tree planting and timber stand improvement, fire control, roadbank and gully stabilization, and land treatment measures such as crop rotation, pasture planting, waterway development, pond construction, terracing, drainage, contour strip cropping, and wildlife-area planting.

The soil and water conservation program is carried on through technical help to locally organized and operated soil conservation districts; local sponsors of watershed protection projects, resource conservation and development projects, and rural-area development projects; and consultive assistance to other individuals and groups.

SCS has the responsibility for the watershed activities and river basin surveys and investigations of the Department of Agriculture. Under the Watershed Protection and Flood Prevention Act, local sponsoring organizations are given technical and financial help for land treatment and structural measures for flood prevention, fish and wildlife development, recreation, and agricultural and municipal water supply in watersheds up to 250,000 acres in size.

Under authority of the Flood Control Act of 1944, SCS plans and applies flood prevention measures and practices in 11 major watersheds comprising approximately 30 million acres. Detailed plans are prepared and applied to tributary watersheds.

River basin surveys are undertaken at the request of cooperating State or Federal agencies. These surveys provide a basis for coordinated resource development of river basin areas.

SCS has departmental leadership for establishing public recreation areas in watershed projects and for assistance to landowners and operators in developing income-producing recreation enterprises on private land.

SCS gives assistance to local sponsoring groups in planning resource conservation and development projects. In these projects landowners, communities, and Government agencies work together to solve land and water resource problems and improve the economic well-being of an area. Ten areas in the United States are now receiving this assistance.

SCS makes and coordinates snow surveys for forecasting water supply for irrigation in the Western States.

(5) The Economics Research Service makes studies of economic utilization of land and water resources, impact of urban and industrial expansion, land tenure problems, legal-economic aspects of land and water use, and relationship of resource utilization and tenure to income and values. River basin and watershed investigations are conducted relating to the formulation of comprehensive river basin plans

and programs, watershed planning, development and management programs, and resource conservation projects.

(6) The Agricultural Research Service engages in a broad spectrum of activities, an important one being investigations to improve methods of soil and water management. ARS manages many experimental watersheds where studies are made of land, water, and vegetation relationships.

(7) The Rural Electrification Administration (REA) is a preferred customer of federally-financed hydro-electric plants, and is interested in all major water resource developments.

REA also makes loans for plumbing, electrification of farmsteads, and for generation and transmission of electricity.

h. Environmental Protection Agency

This agency was formed by the Presidential Reorganization Act of 1970 and has assumed the functions of the old National Air Pollution Authority, Solid Waste Office, and Federal Water Quality Administration (formerly Federal Water Pollution Control Administration). In-so-far as water resources is concerned it administers a national program to enhance the quality and value of the nation's water resources and to otherwise assure the fulfillment of a national policy for the prevention, control and abatement of water pollution.

i. Executive Office of the President

(1) The Office of Management and Budget reviews and advises on proposed legislation and other plans, including, of course the development and management of water resources.

(2) The Office of Emergency Preparedness offers financial assistance for alleviation of damage from major disasters, such as floods and droughts.

(3) The Farm Credit Administration secures loans to farmers and their cooperatives for a variety of things, including certain water development facilities.

j. Authorities, Special Commissions, and Corporations

Several Commissions and inter-agency committees are active in water resource development.

(1) The Delaware River Basin Commission is responsible for the development and approval of a comprehensive plan and for programming, scheduling, and controlling projects and activities, within the Delaware River Basin. Its objectives are to provide effective flood damage reduction; conservation and development of ground and surface water supplies for municipal, industrial, and agricultural uses; development of recreational facilities in relation to reservoirs, lakes, and streams; propagation of fish and game; promotion of related forestry, soil conservation, and watershed projects; protection and aid to fisheries dependent upon water resources; development of hydroelectric power potentialities; improved navigation; control of the movement of salt water; abatement and control of stream pollution; and regulation of stream flows to attain these goals.

It is important for NWS officials to be familiar with regional or River Basin agencies of this type. No effort will be made to include a description of all of them here, but each office should maintain a record of the agencies, federal, state, inter-state, and local, that work with water resources. This record should include their organization, purposes and activities.

(2) The Interstate Commerce Commission regulates water carriers, and is given extensive authority with respect to transportation by common and contract carriers by water, to inquire into and report on management of the business of such carriers and of persons controlling, controlled by, or under a common control with water carriers. The Commission is to keep itself informed as to the manner and method in which these activities are conducted. It may obtain from the carriers and persons controlling them such information as it deems necessary, and establish from time to time just and reasonable classification of carriers required in the administration of the act. It has authority to issue such general and special rules and regulations and to issue such orders as may be necessary.

(3) The Saint Lawrence Seaway Development Corporation as its name implies is responsible, in cooperation with Canadian authorities, for the operation of the Saint Lawrence Seaway.

(4) The Tennessee Valley Authority is well-known. Because of its regional nature, and comprehensive program, management of water resources in its domain does not require or involve a great deal of Federal inter-agency cooperation. The Authority makes river and flood forecasts in the Tennessee Valley, and cooperates closely with Weather Service hydrologists and meteorologists in several geographical and subject areas.

(5) The Federal Power Commission regulates the interstate aspects of energy such as electric power, issues licenses for construction and operation of non-federal power plants on federal land or on navigable waters, and reviews plans for federal hydroelectric generation.

(6) International Commissions are agencies for United States Cooperation with Canada and Mexico in the management of water resources of joint interest on international rivers, such as the Columbia, Colorado, and Rio Grande.

(7) The newly formed Appalachian Regional Commission is engaged in many activities to help that region, and many of its functions pertain to improved water supply and sanitation, and development of water resources. Grants are made for sewage treatment facilities, restoration of mining areas, soil conservation, and water resource surveys.

# CHAPTER III
# IS THERE REALLY A WATER SHORTAGE?

Having considered the demands made on a limited supply of water, by a great variety of users, and considering the frequent reports of drought, many people may wonder if we are really running short of water.

To the New Yorker in 1965, whose dirty car was a mark of civic cooperation, there was indeed a water shortage. In the Midwest, parts of California, and New Orleans, where people experienced severe floods that same year, "water shortage" was hardly a decent topic of conversation. Water has its ups and downs, but on the average there is as much as there ever was, and as much as there ever will be. The problem is fitting use and management to a limited resource faced with rapidly increasing demands.

## 1. Increasing the Availability of Water

One of the oldest and best-known methods of water management is the storage of excessive flows in a reservoir, with controlled release during times of deficient natural flow. Much of the cost of a reservoir is for the land permanently inundated by the water, and for distribution of the water to places of use. Relocations of railroads, highways, and buildings add to the cost.

Another well-known method is drilling a well. Well water is naturally filtered, and ordinarily requires less treatment than river water, but most wells have limited capacity. Excessive pumping may reduce the supply, and near the ocean may draw salty water into the system.

Early in this century many people believed that the planting of trees would increase the transpiration of moisture into the atmosphere, and thus increase the local rainfall. It was argued that rain falls plentifully where there are forests. More logically, trees grow where there is water. Modern meteorological measurements have shown that most of the evaporation and transpiration occur during cloudless dry periods, and that evaporation from ocean surfaces is the source of most of the moisture for continental rainfall.

In the past 30 years foresters and agriculturists have demonstrated on small watersheds that improved vegetative cover reduces wasteful flood runoff, and tends to hold water in the soil where it percolates slowly to maintain streamflow between rainy periods. This effect has not been demonstrated on a large scale, partly because of the difficulty of making much improvement of vegetation over a large area and because of groundwater phenomena which do not occur on small watersheds. In parts of the West there is a campaign to destroy nonproductive vegetation which lines streams and canals, because this vegetation draws water from the streams and transpires it into the air.

Evaporation loss from small reservoirs has been reduced by covering the water surface with a thin film of a harmless chemical which is impermeable to water. It is difficult and costly to maintain such a film against the wind and waves of a large reservoir. Efforts are being made to reduce the loss of water vapor from plants. As part of their natural growth process, plants normally use hundreds of times the amount of water which becomes part of the plant.

Runoff from snow may be controlled by selective cutting of timber so as to trap and hold blowing snow, and in non-forested areas by dusting the snow surface with dark powder to increase the absorption of the sun's heat and thus increase melting at desired times. If the dust layer is too thick, it will insulate the snow instead of helping it melt. A wind shift might not only distribute the dust non-uniformly, but might cover a city instead of a barren prairie. Dusting might have to be repeated after new falls of snow.

Cloud-seeding has been a controversial topic for 20 years. Cloud-seeding requires clouds, and other favorable conditions. Whether a rainstorm may be ascribed to seeding or to natural causes is hard to prove. One man's rain may dampen another man's picnic, or hay, or his wife's laundry. If seeding makes rain fall at one place instead of another, by design or by miscalculation, unhappy people at either place may sue the rainmaker. Cloud-seeding has shown considerable promise in some regions, and its legal and physical ramifications are being studied in great detail.

In the past five years much has been heard about desalting sea water at seaside places such as Kuwait, Guantanamo, and Key West. Its practicability has been demonstrated on a large scale, but the process is costly. By using waste heat from nuclear power plants the cost can be shared. Desalting ocean water still costs more than cleaning up and reusing the water in municipal sewage.

Ice frozen from sea water contains very little salt. Thus it has been suggested that icebergs be towed to coastal cities where the melt water can be skimmed off the heavier sea water and used in the cities. Practical problems include hazards to shipping and suitable docking facilities.

Some readers may recall the old domestic cistern, which stored rain-water from the house roof. Such a source of water is important on some islands such as Bermuda. The idea is being applied to areas of an acre or more in parts of the West, where plastic sheets cover the soil. Rain falling on these areas runs off and may be stored, instead of soaking into the soil.

Recent Science Fairs have exhibited models of plastic domes, in which water from the air is condensed. On a practical scale the expense would be great, because hundreds of cubic feet of new moist air must be circulated to produce each pound of water.

There has been serious talk of really large scale inter-basin diversion; bringing some of the water from Columbia River to southern California, and to parts of Arizona and Nevada. There has even been talk of bringing water from the Arctic to these dry areas, perhaps by a sea level canal.

In Israel some success has been reported in growing crops on land underlain by salt water. Loose rocky material a short distance under the surface changes its temperature diurnally. Fresh water vapor from the underlying salty water condenses on these rocks when they cool, is conducted up into the soil by capillary and vapor movement, and is used by the plant roots.

Increasing emphasis is being given to dew as a source of water. Some thought is being given to moving or locating heavy users of water to places where there is plenty of water, instead of moving water to regions of salubrious climate and other advantages, but lacking water.

The New Yorker with his unscrubbed car was practicing conservation as a last resort. In most of the country, conservation of water until lately has not had the emphasis given to conservation of other resources, such as forests, soil, and petroleum.

The problem of matching needs for water to availability of water does not have a pat answer. Assessment of need for water is greatly complicated by problems of definition and measurement. How does one distinguish between wasteful use and real need? How does one count the use of water which passes unchanged through a turbine wheel, or falls on a farmer's field prior to other use? How does one count water which is used unnumbered times between Pittsburgh and New Orleans? Posing of these questions does not resolve the inevitable problem of increasing use of a limited resource.

Each community and water-using region must consider the pros and cons of each alternative available to it, distinguishing between political and technical issues. Treatment and reuse of water used locally will often be the most economical alternative, and will require education to overcome esthetic and other inhibitions.

## 2. Reuse and Conservation of Water

### a. General Considerations

The purpose of this section is to state in broad terms the present methods of reuse and conservation of water by domestic, industrial, and agricultural users; to outline the problems encountered in attempting effectively to reuse waste waters; and to indicate the prospects of more extensive conservation of water supplies and utilization of waste waters.

About half the people in the U. S. are now using water which has already been used at least once for domestic sewage and industrial waste disposal.

Population is concentrating in urbanized centers which discharge treated sewage into streams serving downstream communities. Further concentration of population in these urban centers will tend to increase the percentage of reuse of these receiving waters for municipal purposes.

The domestic water demands are about 7 percent of the total demands of water for all purposes. However, the transmission and distribution of this water are frequently accomplished concomitantly with water supplied to commercial and industrial establishments in urban areas. Thus, water fit for human consumption frequently is the governing criterion in the reclamation and use of waste waters even though much of the water serves purposes for which a water of lower quality would be satisfactory.

Industry now uses nearly one-half of the water supplied for public and private use. By 1975, industry may require as much as two-thirds of such water.

Approximately one-half of all of the water used by industry is required for process cooling water and boiler feed purposes. Only 2 percent of all of the water used by industry is actually consumed, with the greater portion returned to a water course, and hence not actually lost. Only 1 percent of municipal waste waters is presently used by industry prior to return of these waters to natural streams.

Agriculture, which is second to industry in amount of usage, now requires more than 40% of the total water withdrawals.

Unlike industry, however, water use in agriculture is largely cosumptive. That is, the greater portion of the water used, sometimes as much as 80 percent, is lost by transpiration and evaporation. The smaller remaining portion is returned to streams via surface runoff or percolation through the soil.

Only small amounts of waste waters are reused by agriculture, although historically, one of the oldest methods of sewage disposal was land irrigation. Because of hygienic problems connected with the use of sewage effluent for agricultural purposes, sewage irrigated crops grown in the United States are used primarily for animal feed.

b. Natural Water Reuse

Every community consumes water and produces domestic and industrial wastes. Where communities border large rivers or bodies of fresh water, they take water from these convenient sources and generally return domestic sewage and industrial wastes to the same waters. Thus along a river, successive communities from headwaters to the mouth may reuse water which has already been used by communities upstream.

Although sewage treatment may remove considerable amounts of polluting substances from waste waters, depending on the nature and efficiency of the treatment, varying amounts of pollutants will, nevertheless, be returned to the receiving waters. The receiving waters, whether streams, lakes, seas or oceans, have the capacity for self-purification by natural processes. These natural processes act more slowly than similar processes utilized in sewage treatment plants, but they accomplish the same purpose and ultimately result in the purification of the receiving waters.

The most complete and efficient types of sewage treatment utilized today do not of themselves produce water of a quality that is potable. The self-purification processes of the water into which the treated sewage effluents are discharged are essential to raise the quality of the water. In addition, further purification is necessary when the river water is withdrawn for use as a potable supply. Depending upon the degree of pollution of the water source, water purification processes including storage, disinfection, coagulation, sedimentation, and filtration are necessary to provide a safe potable water supply.

One important problem that has developed in connection with the growth of urban areas and the concentration of industry around these areas **is the increasing concentration of complex chemicals** from commercial and industrial operations. These chemical pollutants create a nuisance because of the inability of existing treatment processes to remove them effectively. They can cause unpleasant tastes and odors as well as highly alkaline or acid conditions, and some of them may prove to be harmful to humans.

Among the new sewage and waste treatment processes being considered as supplemental means for obtaining higher quality of treated effluents are: Waste stabilization in oxidation ponds; microstraining (filtration to remove finely divided solids from the treated effluent); and coagulation followed by sand filtration. In addition, new combinations of conventional biological treatment processes will be used to obtain better effluents.

c. Industrial Supply

Of the water used by industry, 90% is taken from surface supplies. Of that amount 80% is from fresh water and 20% from saline sources. This point is significant because it shows that industry is using vast amounts of fresh surface water and that ground water and saline water are at present a minor part of its supply.

Approximately one-half of the total industrial water supply in the Nation is used for cooling. When used for cooling on a "once through" basis and returned to the source, the water is usually changed but little. One deleterious effect of warming the water is that the higher temperatures may increase the rate of depletion of oxygen in the receiving streams. They may also promote the growth of blue-green algae which produce tastes and odors.

d. Wastes from Industry

In some areas in the United States, industrial pollution of surface supplies renders them unusable for industrial as well as domestic supply. Although most industrial wastes are amenable to the same treatment processes as domestic sewage, certain substances such as grease and oil, hot liquids, gasoline and flammable solids, acids, and poisonous chemicals cannot be eliminated by ordinary sewage treatment processes.

The problem of increasing discharge of complex chemicals from industrial and commercial processes into surface waters and treatment facilities has been recognized by a number of regulatory agencies. For example, the Ohio River Valley Water Sanitation Commission recently reported that 61 of 100 municipal sewage treatment plants were experiencing difficulty in treating industrial wastes. The deleterious effect of acid mine wastes in the Susquehanna, Potomac, and other rivers has been a matter of concern for many years.

Since the volumes and strengths of wastes from industrial processes are extremely variable, the costs and sizes of facilities for treating these wastes vary greatly between industries. Whereas the smaller industries rely heavily upon existing municipal waste treatment facilities, the larger ones more frequently treat their own liquid wastes.

(1) Recovery of Byproducts

Industry can and does reclaim from its wastes byproducts which are of economic value. This practice should be followed whenever the return will pay part of the cost of waste treatment.

(2) Control of Industrial Wastes

A number of successful approaches have been adopted to control industrial wastes. In nearly all instances, cooperation between regulatory agencies and the specific industry concerned is essential. The following methods or combinations of methods may be utilized in industrial pollution abatement: (1) the industry may provide its own waste-treatment facilities to remove the undesirable waste products before returning the effluent to the receiving waters; (2) the industry may provide sufficient pretreatment to permit discharge of the wastes to a municipal treatment plant; (3) the industry may contribute to the construction of additional municipal plant facilities in order that it be capable of handling the particular industrial wastes.

Pretreatment is essential where industrial wastes contain solids which may damage the sewerage system and pumping facilities. Pretreatment is also essential for highly alkaline or acid wastes. These wastes not only affect the efficiency of sewage treatment, but can, as in the case of acid mine or pickling wastes, render the receiving waters undesirable for further industrial or domestic use.

e. Effect of Irrigation on Surface Water Supplies

Agriculture is a major user of both surface and ground water supplies for irrigation. Irrigation, in turn, is a source of stream pollution. Although the practice of irrigation was developed in the arid regions, irrigation farming is increasing in the humid areas of the United States because of its demonstrated efficacy in increasing crop yields. The use of surface waters for irrigation, unlike industrial and domestic use, is largely consumptive; that is, about 80 percent of the water is lost to transpiration and evaporation.

(1) Salt Concentration Increase

When water is used for irrigation, the dissolved salts from the soil are carried off with the drainage waters. Where the irrigation drainage flows back into surface waters, the salt concentration may be greatly increased.

(2) Pesticide Concentration Increase

An additional pollution problem arising from irrigation practices is the potential effect on river quality of spent irrigation water containing agricultural insecticides and herbicides.

The effect of the growing practice of irrigation throughout the United States must be evaluated in terms of its impact on surface water quality. More extensive research should be undertaken on the quantitative as well as qualitative effect of addition of salts and other chemicals on surface waters, with particular reference to the potability of water.

f. Methods of Controlling Pollution of Surface Sources

No national standards or regulations have been developed in the United States for the control of discharge of wastes into surface waters. However, water quality standards have been given thorough study by national technical organizations and agencies of the Federal Government. In some instances, interstate compacts have been drawn to establish standards of required treatment of polluted waters to render them usable for various purposes.

Because of the variability of conditions which cause pollution and the variation in the effect of pollution on receiving waters, there has been in the United States a substantial body of opinion holding that pollution should not be controlled by applying rigid standards on a national statewide or regional basis. Rather, the solution of each problem should depend upon the water uses involved and the economics of abatement in each case. According to this philosophy, there should be a gain in values commensurate with the costs of control. On the other hand, there is a desire by others, particularly those charged with regulation of pollution on a local and State level, to develop uniform standards of waste water quality control. The principal argument in favor of this approach to the problem is that it is easier to obtain action when everybody is required to expend approximately the same amount of money on control measures regardless of local benefits to be gained.

### 3. Reuse of Wastes

a. Discussion

Treated sewage effluents are frequently as good as, and sometimes of better quality than, other raw water supplies.

The use of sewage effluents for industrial purposes in the United States is being accomplished in all areas where economics dictate its use. From an economic viewpoint, reclaimed municipal and industrial wastes have more value to industry than to any other prospective user. Municipal waste waters, though considerably degraded, are adequate for cooling and boiler feed waters. It is estimated that 50 percent of all industrial water is required for these uses. Because of the great difference in sewage effluent qualities, the requirements for industrial use and needed treatment for such use are highly variable.

b. Agricultural Water Supply

The oldest method of sewage treatment is disposal on land. Land disposal of collected sewage was early recognized in Western Europe as an effective means of purifying sewage. Many European cities today, such as Bremen and Paris still operate disposal farms where sewage is spread on the ground with little or no pretreatment. In America, municipal sewage effluents are utilized for irrigation only in areas which have low annual rainfall.

The terms "land disposal" or "land treatment" are used when disposal of sewage is the primary purpose of the operation and agricultural utilization is a secondary purpose. Sewage farming, on the other hand, refers to the practice of irrigating with treated sewage for the primary purpose of producing crops and animals.

In the United States, no sewage, regardless of the degree of treatment, is utilized in the irrigation of crops which are usually eaten raw. Even when the agricultural product is cooked before consumption, it is better practice not to apply sewage irrigation for a period of from 20 to 45 days before harvesting. A number of sewage-borne organisms have been shown to be present on vegetables and fruits after ripening and marketing when sewage effluents are used for irrigation. Therefore, sanitary standards in the United States do not allow the use of raw sewage for truck farming.

c. Use of Sludge for Fertilizer

Sludge, the precipitated solids from sewage treatment, is being used for manufacture of commercial fertilizer, and (after additional treatment) in some places is applied directly to the soil, where it has been found to be as effective as commercial fertilizer.

### 4. Underground Storage of Water

a. Discussion

Because of its relatively constant temperature, its uniform and frequently satisfactory quality, its local availability, and its comparative cheapness, ground water is an important source of water supply throughout the world. Ground water supplies are taken from three principal sources: (1) the glacial, alluvial, or windblown deposits of granular materials such as sand, gravel, and sandstone; (2) from the solution passages, caverns, or fractures of rock; and (3) from combinations of these consolidated and unconsolidated geological formations.

Water reaches these formations, called aquifers, by downward percolation of rain and other surface waters. Ground water exists in natural underground reservoirs, which, in parts of this country, are being drawn on at a faster rate than they can be replenished. Municipal and private ground water supplies, though smaller in daily delivery, are much more numerous than surface water supplies.

Ground water supplies about 20 percent of the total demand for water and about 30 percent of the demand for public supplies in the United States. Thus, it is an important resource upon which a large segment of the population depends.

In many areas, excessive withdrawal has resulted in lowering of the water table, and in much greater costs of using the ground water. Ground-water users have been obliged to drill deeper into the earth to find new supplies as the ground-water levels have fallen, and in addition have had to purchase more expensive well equipment. Finally, they are faced with a higher operating cost to lift the water to the surface.

b. Ground-water Recharge

**Because of the rapidly falling ground-water levels in many areas, much attention has been centered on the use of ground-water recharge for restoring ground water supplies. Reclaimable waters potentially useful for artificial recharge are flood waters, industrial wastes, and domestic sewage. These waters can be discharged into ground water either by spreading on the ground surface or by pumping underground.**

Advantages to be gained from ground-water recharge are numerous. Ground water supplies can be replenished where overdrafts have endangered municipal water supplies; the quality of the liquid applied can be improved as a result of the filtering effect of the soil and aquifers through which the liquid flows; the water is less subject to contamination by poisonous materials or radioactivity in the event of war; loss of the ground water from sea water intrusion can be stopped; there is less evaporation loss than from surface storage; and excess surface waters from floods can be utilized to replenish ground-water reservoirs.

Methods of accomplishing artificial ground water recharge are (1) surface spreading and (2) injection by means of wells. The surface spreading method of recharge is used when pervious materials exist between the ground surface and the aquifer, and sufficient land area is available on which to carry out this operation.

(1) Surface Spreading

Artificial recharge of ground water reservoirs by spreading techniques has been successfully carried on in Europe and the United States for many years.

Surface spreading is accomplished by directing the water into charging ditches or basins or by flooding suitable areas above the ground water basin. Water from streams, rivers and lakes, or cooling waters from industrial operations or treated sewage effluents are introduced into the spreading area. These waters leach into the ground to increase the natural ground-water supplies.

Storm sewers in some cities direct the water to basins from which substantial amounts percolate to the aquifer. The plan not only saves water but also reduces storm drain costs.

(2) Recharge Wells

Recharge wells are generally used only where spreading cannot be employed. The use of wells to recharge with surface waters has been only moderately successful because where the water is poor in quality, clogging of the areas adjacent to the well casings soon renders the wells inoperative. However, there are some notable examples of successful recharge of ground water supplies by wells. As techniques are improved it is likely that their use will increase.

(3) Recharge with Sewage Effluents

Studies have shown that highly treated sewage can safely be applied to the ground water by spreading.

Experiments in one locality demonstrated that there was no significant bacterial contamination below a depth of 7 to 10 feet and there was no significant contamination of ground water. These experiments also showed that an organic mat of increasing ability to filter out bacteria forms at the soil surface and substantially reduces bacteria in the infiltrating waters. In some coastal areas, ground water recharge serves the dual purpose of preventing salt water intrusion and adding to the ground water supply.

c. Improved Control of Artesian Flows

Numerous instances exist of improper development of artesian aquifers which have resulted in the release and consequent waste of huge amounts of usable water. Waste of valuable ground water has also resulted from the inadequate plugging of flowing wells. In addition, the release of and loss of fresh water has brought to the surface even greater amounts of saline water, with the attendant problems of pollution from high concentrations of salts.

Control of this problem can be achieved through the enactment of legislation which will make it mandatory for the driller of a well to develop new wells and plug old ones in a manner which will afford a positive means of preventing overflow. Similar legislation has proved satisfactory in controlling brine production in abandoned oil wells. Since many of the water-producting wells are of small diameter and of unknown origin, it may be necessary for the States involved to assume control of these wells and to provide personnel and funds to cap them.

d. Underground Waste Disposal

In discussing the problem of artificial ground water recharge, cognizance must be taken of the growing problem of pollution and consequent impairment of ground water supplies. Length of travel of bacteria in some types of underground strata is comparatively limited. On the other hand, recent studies have shown that chemicals may travel underground for great distances. Thus, with regard to pollution of underground sources, chemical contamination is more significant than bacterial pollution. The deleterious effect of disposal of industrial and commercial wastes into the ground is beginning to receive close scrutiny because of the dangers implicit in the continuation of this practice.

Since so much of the industrial operations are near urban and suburban areas where high water demands exist, it is likely that pollution from industrial wastes will have an important effect on local ground and surface water supplies. With the expansion of industry and the consequent increase in the demand for water, the volume of waste waters to be disposed of will increase. Since there is a growing resistance to the discharge of industrial pollutants into streams, the use of ground disposal of wastes by industry may increase.

Increasing concern has been evidenced regarding the pollution of ground waters by detergents from manufacturing processes and individual homes. Sources of ground water pollution from detergents include septic tank tile fields, cesspools, oxidation ponds, and holding ponds for industrial wastes. Where the surface active agents in detergents reach a concentration of 1.5 parts per million, frothing and unpleasant tastes may result.

## 5. Ground Water - Needs and Management

### a. Discussion

The available evidence does not indicate any basis for assuming that the replenishable supply of ground water for the entire Nation is declining, but rather that ground water is being taken from storage in specific areas at rates greater than the natural replenishment. One of the important conclusions to be drawn from a study of ground water resources is that there is inadequate information.

In the High Plains of Texas (the Lubbock and Plainview area) is a situation which is regarded by many as a legally interpreted exception to the principle of ground water replenishment. In this particular arid area, which is almost a mesa, recharge is entirely local, and the only practical way to maintain a sustained yield would be to drastically reduce the pumping. This is not being done; the water is being mined, just as petroleum is. It is unlikely, in the present economic regime, that pumping will be reduced. The Internal Revenue Service has permitted depletion allowances for farmers, just as for pumping oil, which is regarded as a non-renewable resource. In legal terms, considering the unlikelihood of pumping being reduced to less than the meagre natural replenishment from rainfall on the area, the depletion is permanent. In terms of the longer-range geologic time scale, and ultimate possibilities, the depletion is not permanent; nor is it irreversible in any physical sense.

An intimate relation exists between ground water and surface water. Both resources are related to infiltration and soil moisture. Ground water in most areas is a related part of the hydrologic cycle of surface water. For example, the dry weather flow of streams is sustained almost entirely by discharge of water from the ground.

Three important aspects of ground water management must be emphasized at all levels of government. They are: (1) controlled withdrawals, (2) improved artificial and natural recharge, (3) improvements or supplementation of existing ground water sources by importation of water.

(1) Controlled Withdrawals

Where rapid exploitation of ground water has resulted in lowered ground water levels and contamination of the source by intrusion of sea water and other deleterious substances, programs of conservation can be established which control withdrawals both as to amount and location.

(2) Improved Recharge

Artificial and natural recharge offers great promise for the maintenance and restoration of ground water reservoirs. Not only must the practice of artificial recharge from surface waters and waste waters be more fully developed, but the concurrent responsibility of municipalities and industries to maintain the quality of the ground water and surface sources by eliminating the introduction of degrading substances into the ground water reservoirs must be recognized.

(3) Importation

A third method of utilizing ground water reservoirs is to store within them water imported from other sources. As was shown earlier, the practices which have developed for ground water replenishment,where intermittent usage is possible, may be adopted with advantage in areas which are facing ground water shortage.

Artificial recharge, heavy pumping, and other changes in the relation of ground water to surface water may affect the hydrologic regime in some areas, so that river forecasting procedures may have to be revised.

b. Location and Evaluation of Ground Water Supplies

With the increasing need for development of new underground supplies and evaluation of the capacities and life of existing supplies, the use of geophysical principles offers many promising possibilities. A brief review is given here of the methods now available for subsurface exploration of water.

(1) Electrical Resistivity Method

The technique which appears best suited to the problems of ground water exploration involves the measurement of the electrical resistivity of sub-surface strata. Variations in resistivity depend upon the type of rock or other materials in the underground formation, the degree of saturation with ground water, and the mineral content of the water present in the formation. Coarse water-bearing materials offer greater resistance to electrical currents than do fine ground materials such as clay. With experience and knowledge gained from research of the typical resistivity of soils under known conditions, it is possible to interpret resistivity records in terms of geologic structures, rock type and porosity, water content and water quality.

With resistivity surveys, successful water wells have been drilled in the Middle East in 75 to 90 percent of well drillings made as a result of these tests. Resistivity surveys are being made in the United States in an increasing number of explorations. They have been used to locate ground water levels, to obtain relative salinities and to outline the boundaries of promising aquifers. Of a large number of test drills made after resistivity surveys were completed, the correctness of the resistivity data was confirmed in 92 percent of the cases reported.

(2) Seismic Refraction and Reflection

The seismic method, which is losing popularity because of the success with the electric resistivity method, is an excellent means of determining depth of rock. It involves the detonation of a small charge and the recording of the travel time from the resulting direct and reflected sound or shock waves to reach instruments located at known distances from the explosion. Since the speed of the waves depends upon the type of materials through which it passes, it is valuable in the location of subsurface formations. Although wave motion is higher in moist than in dry formations, the actual presence of ground water is difficult to determine since the velocities from saturated and unsaturated zones frequently overlap and are difficult to interpret with accuracy. This method has been used extensively in New England to locate ground-water supplies.

(3) Electric Well Logging

This method was originally used by petroleum and gas companies in prospecting for new supplies of oil and gas. It has now been adopted for use in exploration for underground water resources. It consists of the measurement of electrical resistance and potential by means of electrodes attached to a drill cable in the course of drilling a well. It is possible to correlate the measurements of electrical resistance and voltage as the drilled hole passes through various strata with the presence of water-bearing formations. Other instruments can be used in the drilled hole to measure gamma ray and neutron radiation, temperatures, and velocity and direction of waterflow within the well.

Logging has been found useful for determination of types of underground formations, for locating aquifers, ground-water contaminants, stray earth currents which may produce electrolysis and corrosion, and for correlating underground formations between wells. The use of electric logging is limited to drill holes which do not require metal casing.

Determination of depth and thickness of various strata, and their accompanying acquifer characteristics, is made by a combination of well logs and seismic or resistivity methods, in which the logs give vertical scale and the other data help interpolate horizontally. Highway excavations and other deep cuts into the ground or rock also help occasionally in determining geological formations.

# CHAPTER IV
# COORDINATED WATER RESOURCES DEVELOPMENT

## 1. Historical and Legislative Background

Now, having described the major and minor areas of water resources activities, many involving inter-agency cooperation, it is appropriate to discuss efforts to coordinate this vast effort on a national basis.

Quoting from the President:

"* * * Works designed to control our waterways have thus far usually been undertaken for a single purpose, such as the improvement of navigation, the development of power, the irrigation of arid lands, the protection of lowlands from floods, or to supply water for domestic and manufacturing purposes. While the rights of the people to these and similar uses of water must be respected, the time has come for merging local projects and uses of the inland waters in a comprehensive plan designed for the benefit of the entire country. Such a plan should consider and include all the uses to which streams may be put, and should bring together and coordinate the points of view of all users of water. The task involved in the full and orderly development and control of the river systems of the United States is a great one, yet it is certainly not too great for us to approach. The results which it seems to promise are even greater."

This quotation was from President Roosevelt; Theodore Roosevelt; in 1907. Six decades later, ways are still being sought for formulating comprehensive coordinated and cooperative plans for development. Federal water resources development is costing tax-payers about two billion dollars annually, much of it for flood control, yet flood damages increase annually.

Scores of federal agencies are involved in water resource management, and citizens may well ask why are so many agencies involved, how are their activities coordinated, and how did this situation ever get started?

To begin with, the situation got started with the famous "Commerce Clause" of our constitution, as cited and discussed earlier.

Inherent in the commerce clause is the need for flood control. Originally, flood control by Federal agencies was not so much to protect riparian property owners as it was to make navigation possible and safe. A system of locks and dams smoothed out the flow of rivers such as the Mississippi and Ohio, holding back flood waters, and releasing the water at times of low natural flow so that barges would not run aground.

Pres. Theo. Roosevelt's plan for a Waterways Commission was finally enacted into law in 1917, and the authorization included this language:

" * * * to bring into coordination and cooperation the engineering, scientific, and constructive services, bureaus, boards, and commissions of the several governmental departments of the United States and commissions created by Congress that relate to study, development, or control of waterways and water resources and subjects related thereto, or to the development and regulation of inter-state and foreign commerce, with a view to uniting such services in investigating, with respect to all watersheds in the United States, questions relating to the development, improvement, regulation, and control of navigation as a part of interstate and foreign commerce, including therein the related questions of irrigation, drainage, forestry, arid and swampland reclamation, clarification of streams, regulation of flow, control of floods, utilization of waterpower, prevention of soil erosion and water, storage, and conservation of water for agricultural, industrial, municipal, and domestic uses, cooperation of railways and waterways, and promotion of terminal and transfer facilities, to secure the necessary data, and to formulate and report to Congress, as early as practicable, a comprehensive plan or plans for the development of waterways and water resources of the United States for the purposes of navigation and for every useful purpose, and recommendations for the modification or discontinuance of any project herein or heretofore adopted."

It is evident that the Congressional leaders were aware of many facets of water management. Consideration of these facts should make it clear why there is no single water resources department. Water is related to so many activities that if every agency involved with water management were put in one department, very little of the non-military segment of government would be excluded. In such a department the problems of coordination among the water-oriented and other responsibilities would be very nearly at cabinet level.

Though the Waterways Commission was authorized, its members were never appointed, and it never functioned. Its authorization was repealed in 1920. World War I may have prevented this Commission from being activated.

It is noteworthy that ideas for reorganizing water-oriented functions of the Executive Branch of the federal government have been numerous and frequent, and many ideas we think of as recent have been in the mill for decades. In 1921 a Joint Committee on Reorganization was created, with duties as follows.

"It shall be the duty of the Joint Committee on Reorganization to make a survey of the administrative services of the Government for the purpose of securing all pertinent facts concerning their powers and duties, their distribution among the several executive departments, and their overlapping and duplication of authority; also to determine what redistribution of activities should be made among the several services, with a view to the proper correlation of the same, and what departmental regrouping of services should be made, so that each executive department shall embrace only services having close working relation with each other and ministering directly to the primary purpose of which the same are maintained and operated, to the end that there shall be achieved the largest possible measure of efficiency and economy in the conduct of Government business."

Its recommendations in 1924 included the following:

I. The coordination of the Military and Naval Establishments under a single Cabinet officer, as the Department of National Defense.

II. The transfer of all nonmilitary functions from the War and Navy Departments to civilian departments -- chiefly Interior and Commerce.

III. The elimination of all nonfiscal functions from the Treasury Department.

IV. The establishment of one new department -- The Department of Education and Welfare.

V. The change of the name of the Post Office Department to Department of Communications.

VI. The attachment to the several departments of all independent establishments except those which perform quasi-judicial functions or act as service agencies for all departments.

The foregoing declarations of needs to reorganize had little result, as we know.

By 1932 the country was well into the depression. One of Hoover's last acts as President was a recommendation to consolidate public works:

"I have established a Division of Public Works in the Department of the Interior and designated that the title of one of the present Assistant Secretaries shall be changed to "Assistant Secretary of the Interior for Public Works," under whose direction I have grouped the following organizations and functions:

1. The Bureau of Reclamation, now in the Department of the Interior.
2. The Geological Survey, now in the Department of the Interior.
3. The Office of the Supervising Architect, which is transferred from the Treasury Department to the Department of the Interior.
4. The nonmilitary activities (except the "Survey of northern and northwestern lakes" and the "Supervisor of New York Harbor") administered under the direction or supervision of the Chief of Engineers, U. S. Army, including rivers and harbors and flood control work, and the duties, powers, and functions of the Mississippi River Commission, the California Debris Commission, the Joint Board of Engineers for the St. Lawrence River Waterway, the Board of Engineers for River and Harbors, and the Interoceanic Canal Board, which are transferred from the War Department to the Department of the Interior, and the said commissions and boards shall serve in an advisory capacity to the Secretary of the Interior."

President Hoover's justification said, in part:

"The river and harbor and flood control work now performed by the Office of the Chief of Engineers and the various commissions and boards reporting or responsible to the Chief of Engineers is primarily nonmilitary in character. It is related to national defense in only the most indirect manner and then largely because it pertains to the general transportation capacity and economic strength of the country in time of war. It was originally placed under the control of the War Department because at the time river and harbor improvements were first undertaken by the U. S. Government, the War Department was the only Government establishment which possessed a group of engineers of sufficient size and training to prosecute the work satisfactorily.

"The prosecution of river and harbor improvements and flood control work under the Corps of Engineers has necessarily resulted in the expansion of the officer personnel of that Corps beyond the point to which it would normally have grown if its field of operations had been confined to strictly military activities. It is proposed that the services of engineer officers should continue to be available by detail in the performance of this work.

"This river and harbor improvement and flood control work is similar to and should be grouped with other public works and construction activities. It is recommended, therefore, that these activities now performed under the direction and supervision of the Office of the Chief of Engineers, War Department, be transferred to the Department of the Interior where they will be closely coordinated with other Federal public works functions."

Sentiment in the Congress was that reorganization by a lame duck would be unfair to his successor; so for this reason and others, Pres. Hoover's reorganization plan was disapproved, and in March 1933 the executive orders were repealed. Prior to repeal, a house committee had this to say of the reorganization plan:

"There is no present economy in what is proposed by the President. What is proposed is merely a rearrangement of present activities. The orders do not even purport to require discontinuance or even curtailment of existing activities so as to reduce present costs. True, they suggest that subordinates may work out and, with the approval of the President, adopt changes that it is hoped will permit economies -- but when? And what assurance has Congress that subordinates will ever so function? They seldom do. It was the clear purpose of the economy law that claimed avenues to economy in operation should be made to appear, that they might be considered in determining whether proposed action should be approved or denied.

"One thing is certain -- the changes provided for in the Executive orders will cause present loss and expense -- and this just at a time when rigid economy is essential -- yes, imperative. It is to be observed that there are a large number of changes proposed -- a shifting of present activities from one place to another, and so forth. To be even reasonably effective or to permit of any benefit there will likely be necessary an extensive and costly moving program with attendant loss of time, rearrangement of space not only to accommodate moved agencies but to accommodate existing agencies thereto, with possibly need for further expense to rent additional or more convenient space. This would likely involve a present expenditure of no small amount, and the attendant loss of time by officers and employees -- with retard of official business -- would be difficult to measure but would prove very real."

It may be recalled that in 1933 a great program of public works was established, and much of it was water-oriented. From then until 1936 several emergency agencies were performing a great variety of public works, with a major objective of providing employment and income. The water-oriented work included everything from small gully-control check dams and stream-straightening works to large concrete dams.

TVA was created in May 1933.

In 1935 the SCS was established, and in 1936 the Congress passed the important "Flood Control Act of 1936."

Following the depression and the second world war, a series of Commissions has had important influence on the policies of water resources management in the federal government, though many of their recommendations have not been adopted. These Commissions include those listed below:

The Commission on Reorganization of the Executive Branch of the Government, established in 1947 (First Hoover Commission).

President's Water Resources Policy Commission, established in 1950 (Cooke Commission).

Subcommittee to Study Civil Works, established in 1951 (Jones

Subcommittee).

Commission on Organization of the Executive Branch of the Government, established in 1953 (Second Hoover Commission).

Presidential Advisory Committee on Water Resources Policy, established in 1954.

2. Present Methods for Achieving Coordination

Coordination of water resource activities is now achieved by formal and informal inter-agency cooperation, and by River Basin Commissions and similar agencies.

a. Inter-Agency Committees

There are two prominent committees in the field of water resources planning: The Committee on Water Resources Research (COWRR) of the Federal Council for Science and Technology, and the Water Resources Council (WRC) which in 1966 succeeded the Inter-Agency Committee of Water Resources (ICWR). ICWR had earlier replaced the Federal Inter-Agency River Basin Committee in 1954.

Commerce is represented on COWRR and is an associate member of WRC.

(1) Committee on Water Resources Research

(a) Introduction

The Federal Council for Science and Technology was established by Executive Order 10807 of March 13, 1959, to promote closer cooperation among Federal agencies, to facilitate resolution of common problems and to improve planning and management in science and technology, and to advise and assist the President regarding Federal programs affecting more than one agency. Council membership includes the Chairman, designated by the President, and officers of policy rank from eight departments and agencies. Designated representatives of three other departments and agencies attend meetings as observers.

Program planning and coordination are effected through Council committees on Oceanography, Atmospheric Sciences, Materials Research and Development, High Energy Physics, Natural Resources, Water Resources Research, Behavioral Sciences, Patent Policy, Long Range Planning, International Programs, Science Information, Scientific and Technical Personnel, and a standing committee concerned with research administration. The Council Secretariat is provided by the office of Science and Technology.

(b) Functions

On December 20, 1962, the Federal Council for Science and Technology approved creation of the Committee on Water Resources Research to coordinate Federal Activities in water resources research and development.

The report "Federal Water Resources Research Activities: dated February 11, 1963, which was approved by the Federal Council for Science and Technology, generally defines the Committee's function as:

. . . to identify technical needs and priorities in various research and related data categories;

. . . review the adequacy of the over-all program in water resources research in relation to needs;

. . . recommend programs and measures to meet these needs;

. . . advise on desirable allocations of effort among the agencies;

. . . review and make recommendations concerning the manpower and facilities of the program;

. . . recommend management policies and procedures to improve the quality and vigor of the research effort; and

. . . generally facilitate interagency communication and coordination at management levels.

(c) Operations

Appropriate provision is made for involving in the Committee deliberations both technical personnel and personnel conversant with water resources operational problems and needs requiring research. The Committee is assisted as needed by technical panels having competence in the various research categories. It coordinates its efforts with other committees and is cognizant of other research programs within the Federal Government as well as state and private agencies that may affect water resources.

(2) Water Resources Council

This Council was formed in 1965 under Title I of Public Law 89-80, known as the "Water Resources Planning Act." The Council is composed of the Secretaries of Interior; Agriculture; Army; Health, Education and Welfare; Transportation; and the Chairman of the Federal Power Commission. Heads or representatives of other Federal agencies, such as Commerce and the newly formed Department of Housing and Urban Development, are invited to participate when matters affecting their responsibilities are considered by the Council. Commerce became an associate member during February 1967.

The Council maintains a continuing study of the adequacy of water requirements and of the relation of regional and agency plans and programs, and makes recommendations to the President regarding Federal policies and programs.

Title II of the Water Resources Planning Act authorizes the President to establish River Basin Commissions, with Council and State cooperation. Each such Commission coordinates Federal, State, interstate, local and non-governmental plans for the development of water and related land resources in its area; prepares and maintains a comprehensive, coordinated joint plan; recommends long-range schedules of priorities for collection and analysis of basic data, and for investigation, planning, and construction of projects; and makes pertinent studies.

River Basin Commissions are composed of Agency, State and other representatives. Agency representatives are chosen on the basis of the Agency having a substantial interest in the work to be undertaken by the Commission. The Commissions' duties correspond to those of the Council. Presently authorized commissions are:

Great Lakes Basin Commission
New England River Basins Commission
Ohio River Basin Commission
Pacific Northwest River Basins Commission
Souris-Red-Rainy River Basins Commission
Susquehanna River Basin Commission

Title III of the Act provides for financial assistance to the States for comprehensive planning grant authorizations, with D. C., Puerto Rico, and Virgin Islands being regarded as States.

Title IV indicates the limitations on the funds that may be appropriated, after authorization, for Titles I, II and III.

A mechanism of the Council is the Interdepartmental Staff Committee, whose meetings in Washington are attended by Weather Service representatives.

b. Regional and Local Organizations

(1) Planning Commissions

Among the more important efforts to accomplish comprehensive, cooperative inter-agency planning of water resources development were the New England-New York Inter-Agency Committee and the Arkansas-White-Red Basins Inter-Agency Committee. They were created in 1950 and functioned until about 1956. These Committees were not particularly successful in achieving inter-agency agreement on a coordinated plan, or on how to plan. They were successful, however, in demonstrating recognition of the need to cooperate, and in actually working together in real situations. Much was learned about devising a mechanism for cooperative planning, and much has been written about the Arkansas-White-Red experience.

More recent experiments in cooperative planning were the United States Study Commissions for Texas and for the Southeast River Basins, both starting in 1959 and lasting about three years. Much has been written, and is being written about these two Commissions. In each of these four planning efforts, there was some degree of State participation.

It has been generally conceded that these two Study Commissions made substantial progress. New River Basin Commissions, under the auspices of the Water Resources Council, will continue the effort to devise and improve methods for cooperative resource planning.

It is not easy for powerful, nearly autonomous agencies, brought together in a competitive arena, to agree on how to plan. Some of the outstanding problems and areas of disagreement are definitions, evaluation of regional and national benefits of various programs and practices, interest rates, consideration of uncertainties, adequate consideration of alternatives, appropriate degree of detail, how far to carry a plan in the direction of an approved design, evaluation of intangibles, benefit-cost analyses, design standards and criteria, and how to divide the work and share the costs when the plan is to be carried out.

The National Weather Service participated in all four of the planning efforts cited above, and made substantial contributions, mostly in helping define the climate and hydrologic environment of the pertinent regions.

(2) Local Organizations

It is important for a field office, whether it participates directly or not, to be familiar with local committees, River Improvement Associations, various kinds of Districts, etc.

U. S. DEPARTMENT OF COMMERCE
ENVIRONMENTAL SCIENCE SERVICES ADMINISTRATION
WEATHER BUREAU

Weather Bureau Technical Memorandum ER-16

Second Edition

# THE EFFECTS OF DAMS, RESERVOIRS AND LEVEES ON RIVER FORECASTING

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EASTERN REGION HEADQUARTERS
SCIENTIFIC SERVICES DIVISION
TECHNICAL MEMORANDUM NO. 16

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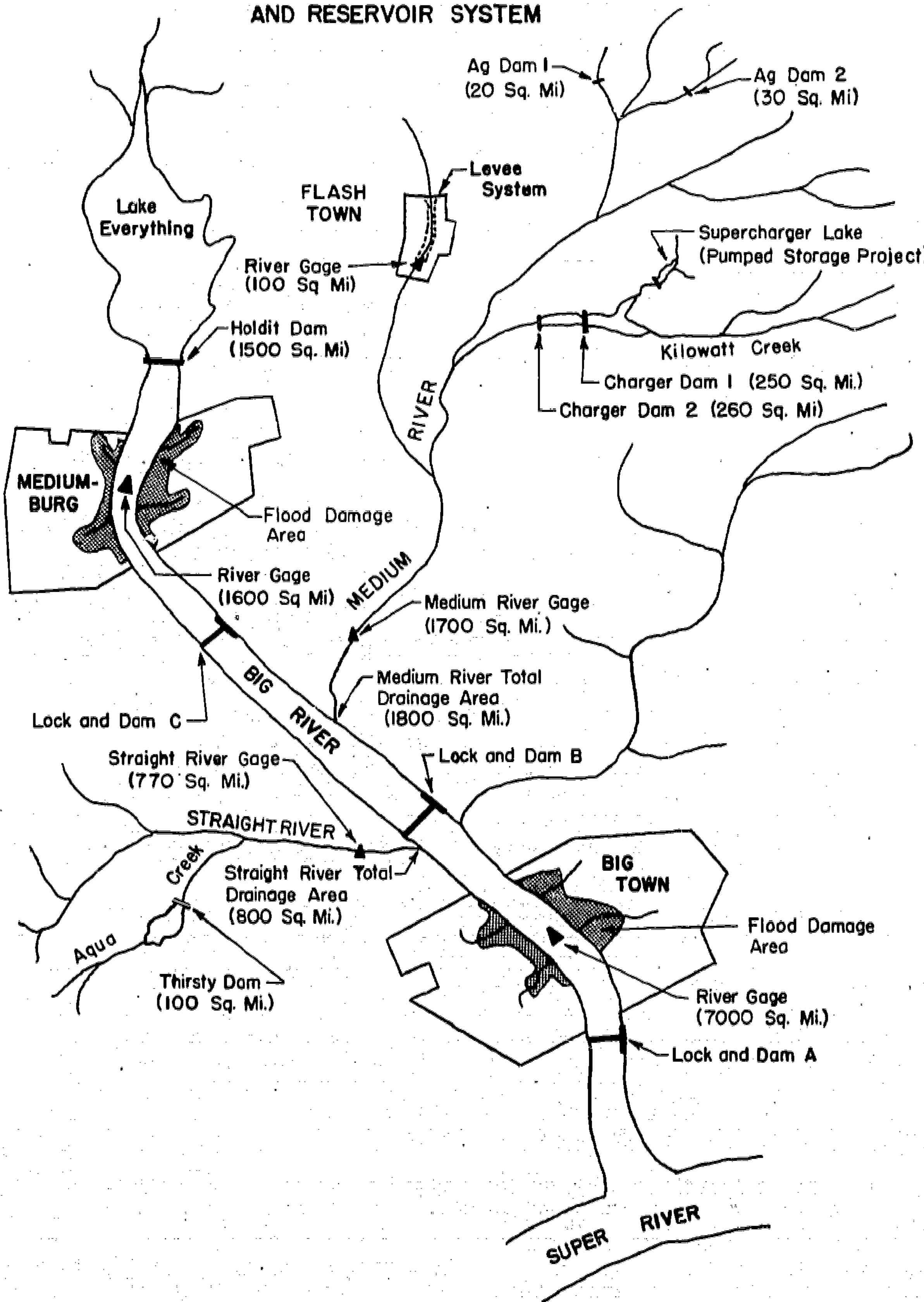
CONTENTS

# INTRODUCTION

Technical Memorandum Number 16 was written primarily for inclusion in the U. S. Weather Bureau Hydrologic Public Service Course. This memorandum discusses the effect of man-made controls on river flows and river forecasting. The river system portrayed with its various types of controls and forecast problems is entirely hypothetical. Most of the problems that are incurred when man disturbs natural drainages are thus demonstrated in a single river system.

Fig I-I DIAGRAM OF "BIG RIVER" HYPOTHETICAL RIVER BASIN AND RESERVOIR SYSTEM



1-1. River Conditions Prior to Reservoir Development.

The Big River System, tributary to Super River was originally a "normal" stream from the hydrologic prediction standpoint. Forecast points included Mediumburg, Flash Town, Medium River Gage, Straight River Gage and Big Town. The river basin area had recurring problems including the following: (1) Urban flooding which could be related to the Mediumburg and Big Town gages; (2) Flooding of farm lands which could be related to these gages as well as the Medium River and Straight River Gages; (3) Flash flooding in Flash Town; (4) Soil erosion in the upper reaches of Medium River and siltation in the lower reaches; (5) an increasing pollution problem particularly severe during protracted dry periods and during the period from late summer through early winter; (6) Lack of adequate rail and highway transportation facilities at Mediumburg slowing down industrial expansion; (7) Fish kills caused by low dissolved oxygen content of the water and concentration of lethal pollutants during extended drought periods; (8) Lack of water-based recreational areas; and (9) Insufficient electric power, particularly to cover peak loads.

For all of these problems the basin had one outstanding virtue to the river forecaster. It was relatively easy to predict the flow and resulting stages at the forecast points. There were problems such as rainfall-runoff relations varying over the basin, the need for differing unitgraphs varying with expected flow volumes, variable streamflow routings, shifting rating curves including backwater effects at some of the gaging stations, etc. While these problems kept the hydrologist on his toes, over a period of time and with experience with floods of varying magnitudes, an excellent set of forecast procedures was developed. However in response to the river-oriented problems in the basin, the reservoir system illustrated in Figure 1-1 gradually evolved. Let us look at some of the things these reservoirs did, some of the things they didn't do, and, most important to the purpose of this course, the effect on the natural streamflow and changes required to carry on an effective river forecasting service.

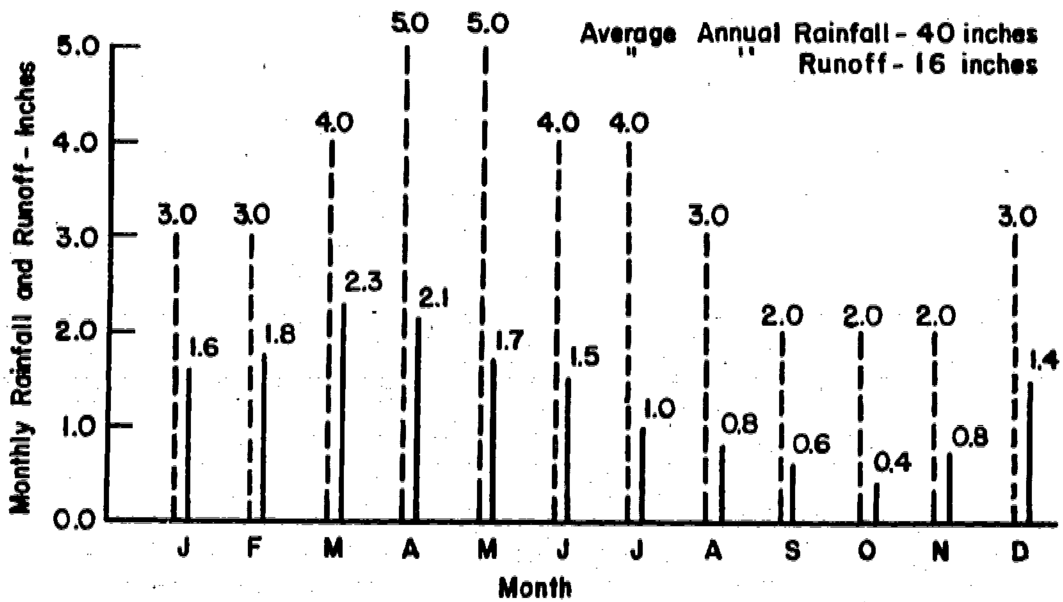
1-2. Lake Everything

This reservoir behind Holdit Dam is used to illustrate the multipurpose reservoir which is becoming more common as the result of an overall look at proper use of our water resources, rather than looking at single-purpose use of a dam site. As we will see, some of the beneficial uses of a reservoir are almost diametrically opposed to each other from a physical standpoint. The resulting compromise, while desirable from the standpoint of utilization of available water resources, does present difficult problems to the river forecaster.

a. Available water: The average annual rainfall in the 1500 square mile area above Holdit Dam is 40 inches. Let us assume that the average annual runoff from this basin is 16 inches depth over the basin. Let us further assume that the presence of the reservoir has no effect on the amount of water available at the damsite. This is not strictly correct, because evaporation from the lake surface will be higher than that of the natural terrain prior to the presence of the lake. This would make slightly less water available when the reservoir is in operation, but for purposes of illustration we will ignore this refinement. The distribution of these average values is illustrated in Figure 1-2.

Fig 1-2 MEAN MONTHLY DISTRIBUTION OF AVERAGE RAINFALL (¦) AND RUNOFF (|)

Big River Basin Above Holdit Dam




Before proceeding further, let us define units and relate them to each other.

<u>Cubic foot per second</u> (cfs) - A volume of flow past a point of one cubic foot in one second.

<u>Second foot day</u> (SFD) - A flow of 1 cfs for a period of one day. (Also commonly referred to as day second foot or DSF.)

<u>One SFD = 86,400 cu. ft.</u> $\left(\frac{1\ ft^3}{sec} \times \frac{60\ sec}{min} \times \frac{60\ min}{hr} \times 24\ hr = 86{,}400\ ft^3\right)$

<u>1 Cubic Ft. = 7.48 Gallons</u>. Therefore <u>1 SFD = 646,000 Gallons</u>.

<u>1 inch of water (or runoff) over an area of one square mile</u> = $2{,}323{,}200\ ft^3$ = 26.9 SFD or 17.38 million gallons.

For the 1,500 square miles of drainage area above Holdit Dam

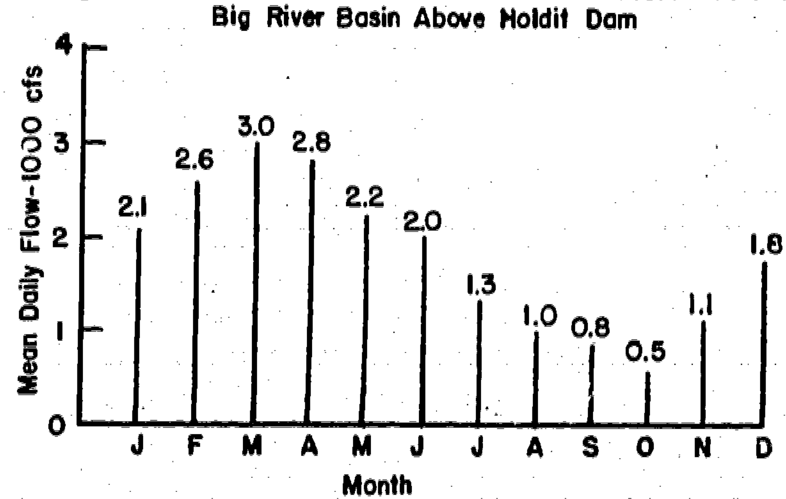
26.9 X 1,500 = 40,350, so

1 inch of Runoff = 40,350 SFD or about 26.07 Billion gallons.

Another term commonly used, particularly in the West, is Acre Foot (AF). This is defined as the volume necessary to cover one acre to a depth of one foot. 1 AF = 43,560 $ft^3$ $\frac{43,560}{86,400}$ = .504. 1 Acre Foot = 0.504 SFD or roughly 1/2 SFD. This gives a standard of comparison if you see this term used with reference to reservoir storage or volume needed for irrigation purposes, etc.

Sixteen inches of runoff over a drainage area of 1,500 square miles represents a volume of 645,600 Second Foot Days (SFD) or 417.06 billion gallons of water. This is nearly sufficient for example to supply the total municipal and industrial water supply needs of New York City. This is a plentiful supply of water. If it were uniformly distributed throughout the year, it would represent a mean continuing flow of about 1769 cubic ft/second (cfs) at the Holdit Dam Site. The problem, of course, is that the flow isn't uniform. First let us look at another table. Figure 1-3 shows the mean daily discharge for calendar-month periods assuming that each of these months had exactly the average runoff for that month. In these and in subsequent tables figures are rounded, but the picture should be clear.

Fig I-3 MEAN DAILY FLOW DURING EACH MONTH
Big River Basin Above Holdit Dam

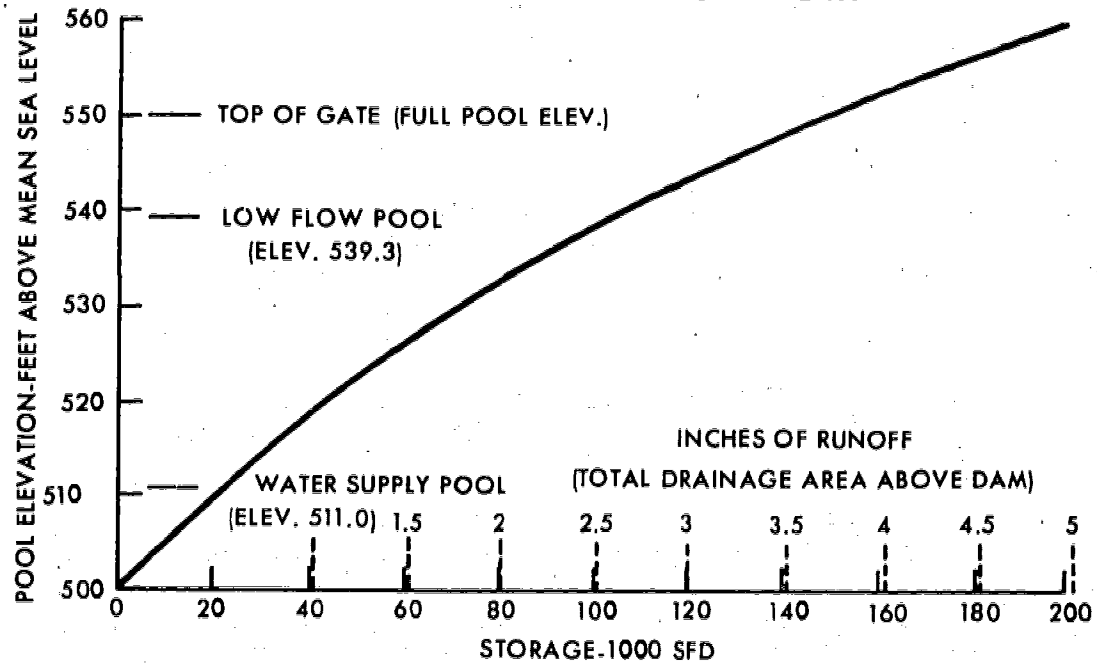



This graph gives average variation in the flow throughout the year. Even if "average" runoff conditions occurred, the mean daily discharge would vary from about 3000 cfs in March to 500 cfs in October instead of a nice smooth flow of about 1800 cfs throughout the year. Now let us look at more interesting values than the mean. Without getting far out of the realm of reason a wet year may have 2.5 times the runoff of a mean year, while a dry year might have only 40% of the mean runoff. This would bring the mean daily flow for a wet year to 2.5 X 1769 cfs, or about 4422 cfs and for a dry year to about 708 cfs. The monthly variation would be more extreme. For example during a wet March the runoff volume could conceivably be 10 inches representing a mean daily flow of about 12,900 cfs, and a prolonged dry period even in a relatively humid basin such as this could produce a mean daily flow of 100 cfs or less for a given month. The instantaneous peak discharge for a basin of this size could easily be 100,000 cfs. The reason for a reservoir is thus obvious - to smooth out the variations in the natural river flow. The obvious intent is to eliminate the effects of a devastating flood on the one hand and of prolonged low flow on the other hand, whether the variation be considered on an instantaneous, daily, weekly, monthly or annual basis. Now let's see just what the reservoir can and can't do to overcome this undesirable fluctuation.

b. Available storage. One of the facts of life often overlooked by the general public and unfortunately some journalists is the fact that storage for a reservoir project is not an unlimited resource. There is always an upper limit on available storage. This limit may be determined by natural topographic characteristics of the reservoir site or it may be imposed by economic practicalities, but it is always present. If the terrain is relatively flat, it is not practical to flood a large portion of the valley which would likely be excellent farmland. On the other hand if the valley terrain is narrow and rugged on both banks of the stream, then cities, railroads, highway road beds, etc. tend to follow the valley floor. Thus the economic benefits of the reservoir do not justify all the resettlement involved in the construction of a completely adequate reservoir. Let us say that a careful topographic survey and economic study have disclosed that a total storage of 200,000 SFD or approximately 396,000 Acre Feet is available between elevations 500 ft MSL (bed of river) and 560 ft MSL (maximum allowable height of reservoir). The relation between elevation and storage for a reservoir is often depicted graphically as in Figure 1-4.

The dam will likely be designed to allow some 10 ft of reservoir elevation above the top of gates to allow for the probable maximum flood, but the reservoir is invariably operated to prevent water flowing over the gates and the elevation 550 ft is thus considered the "Full Pool Level". Thus for operational purposes the available storage is 148,000 SFD. Since one inch of runoff over the 1500 square mile drainage area is 40,350 SFD of volume, we have an available storage of some 3.67 inches of runoff up to the full pool level. This is a large reservoir for this size drainage basin. Now let us look at the purpose for which the storage will be used and see how the available storage is to be distributed for the different reservoir functions.

FIG. 1-4 ELEVATION-STORAGE CURVE
LAKE EVERYTHING RESERVOIR




c. Allocation of storage. As indicated earlier the reservoir will serve several purposes. Let's look at some of the potential uses and resulting decisions necessary in future operations. For subsequent considerations keep the following simple formula in mind, change in storage = inflow minus outflow or $\Delta S = I-O$. This is a basic consideration which can be manipulated many ways, but not overlooked.

1. Flood Control. A single-purpose flood control operation would be to keep the reservoir bone dry except in times when surface runoff is occurring. The gates would then be closed until the runoff period was over. The reservoir would then be emptied at a rate which would not be harmful further downstream and we would return to a bone dry reservoir until the next runoff period. If this were possible we would have flood control storage of 3.67 inches available nearly all the time. This would be sufficient for all but the most extreme floods. Another possibility would be to release at a limited rate during the flood to increase available storage for the maximum flood period. For example if a continuous flow of 10,000 cfs were released for one week this would make available an additional 70,000 SFD of flood control storage available or 1.74 inches of runoff. This would make a total available storage plus controlled flow of 5.41 inches *if* a release of 10,000 cfs were allowable. This would be an excellent flood control reservoir which would effectively eliminate all but the most severe floods and could be operated to reduce those. Of course runoff events

do not always space themselves conveniently to allow for emptying the reservoir between times, among other possible factors to consider, but let us now look at the reduction in flood control benefits necessitated by other proposed uses of the reservoir.

2. Water Supply. For this single-purpose the reservoir would be kept as full as runoff conditions permitted. This would reduce pumping costs to withdraw water from the reservoirs. It would also effectively eliminate virtually all flood control benefits of the reservoir. To build a reservoir this large solely for water supply purposes would be unrealistic economically, so a decision is required as to how much storage to allocate for this purpose. Let us make some simplifying assumptions for purposes of illustration. First assume the water supply will be used for Middleburg and environs with a total population of 700,000 people. At present the average per capita consumption of water for all purposes nationwide is about 150 gallons per day. This includes home, industrial, agricultural and all other uses. For an industrialized city, such as Middleburg, the average consumption might approximate 250 gallons per day. Let us assume this consumption, to avoid further complication, and assume uniform distribution throughout the year. After a study of past flow records, it was decided to design for possible serious drought conditions indicating a minimum average daily inflow for six months of 150 cfs. This would be a total volume of inflow for 6 months of about 27,400 SFD or equivalent volume of about 0.68 inches of runoff. With the assumed consumption rates for 700,000 people, of 250 gallons per capita per day, the consumption for 6 months would be about 31.9 billion gallons or about 1.23 inches of runoff. If we accept this as the design criterion, we will have to allot the difference between consumption and inflow (1.23 inches - 0.68 inches Runoff) of 0.55 inches of storage or about 22,200 SFD for water supply storage.

What does this mean? It means that the water in storage would never deliberately be drawn down to less than 22,200 SFD of storage to provide for an assured water supply for users. This would be poor planning in that no increase of average consumption or no population growth rate has been considered. Also such factors as evaporation and seepage losses have not been considered. As pointed out this is an idealized example. Let us look back to Figure 1-4. A storage of 22,200 SFD would represent a pool elevation of about 511.0 ft. So we will call 511.0 ft the Water Supply Pool Elevation. We have now reduced our storage available for flood control from the original 3.67 inches to 3.12 inches.

3. Low flow augmentation. One of the major benefits anticipated from the Lake Everything Reservoir is the assurance of reliable flow downstream from the dam. This is beneficial in many respects; it alleviates pollution problems, it enhances development of fish and other aquatic life and vegetation, it allows for reliable river navigation further downstream and offers potential for recreational facilities by eliminating the unsightly mud flats formerly in evidence during low flow periods, making small boat travel feasible, etc. It also enhances

property values along the streams. After some study a flow of 450 cfs is determined as the desirable minimum flow and is established as the minimum release through the outlet works at Holdit Dam.

Using the same design criterion as for water supply needs, let us assume the natural low flow conditions without the dam would be for an average flow at the damsite of 150 cfs for 6 months. Actual flow conditions might vary during this period say between 500 cfs and 50 cfs, but the average must be considered to determine necessary volume. When the reservoir is designed, we cannot consider this volume of flow in determining how much volume is needed to provide the 450 cfs daily flow for low flow augmentation. Why not? Simply because this volume has already been reserved for water supply purposes. We must assume that the water needed to augment flow is in addition to that needed for water supply. An average daily release of 450 cfs for this 6 month period represents a total volume of about 82,000 SFD of storage to be reserved (allocated is the usual term) to augment low flow. This would be about 2.04 inches of runoff over the basin. Since 0.55 inches (22,200 SFD) of storage have already been allocated for water supply, this low flow augmentation storage would be on top of that amount making a total requirement of dedicated (reserve) storage of 2.59 inches (104,200 SFD) for these 2 purposes. Going again to Figure 1-4 this would represent a pool elevation of about 539.3 ft. This reduces our flood control storage from the original 3.67 inches to 1.08 inches. The elevation of 539.3 ft we will identify as the Low Flow Pool Elevation, and if the design assumptions are accepted, we will never deliberately draw the pool down below that level.

4. Other possible storage conditions. In some reservoirs it might be deemed advisable to provide additional storage above the water supply and low flow requirements to assure a sizeable lake for recreational and aesthetic purposes. If this were done it would necessarily further deplete the flood control storage available. Let us assume that Lake Everything will have adequate water available stored for water supply and flow augmentation use to satisfy most (never all) avid conservationists and recreationists and leave it as Lake "Nearly" Everything to avoid further complication.

Another possible use for the reservoir storage would be for irrigation. This feature of a reservoir is diametrically opposed to flood control. Perfect flood control would require no storage whatsoever during the maximum runoff season while for irrigation purposes every possible drop should be retained behind the reservoir to release to the parched crops in the hot dry summer. While some supplementary irrigation is desirable in even such a moist climate as Florida, the Big River Basin is a climatic area where storage for irrigation purposes would normally not be seriously considered and we will not include irrigation storage in our hypothetical reservoir design.

Storage of water for generation of hydroelectric power is another possibility which might be considered. For efficient power generation the difference in elevation between the pool behind the dam and the river level below the dam (this elevation difference is called the "head") should be kept as large as possible. In other words the lake should be as full as possible for power purposes while for flood control it should be as empty as possible. Since power can be marketed and sold for a profit the question of whether to sacrifice some flood control storage for power generation is often not an easy question to resolve. A compromise often results which provides neither the best possible power dam or flood control dam, but keeps the most tax payers happy. In the case of Lake Everything we will assume that the economics in favor of flood control storage win out and not include power as a consideration. In addition to making it easier for a reservoir operator or a river forecaster to sleep nights, this assumption avoids a further complication in preparing the example for this course. We will have more on a hydroelectric dam when we come to the Charger Dam System on Kilowatt Creek.

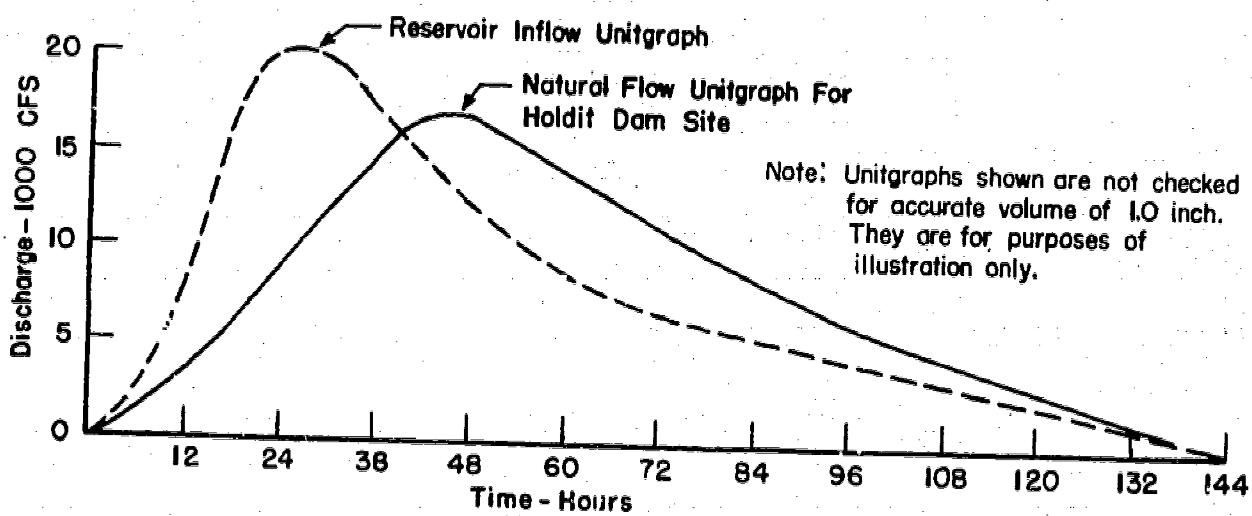
d. Change in forecasting procedures occasioned by Lake Everything Reservoir.

1. The first change would be in the unit hydrograph or unitgraph which was valid for natural flow conditions. As defined earlier in the course, basically the unitgraph is the flow at a gaging point resulting from one inch of runoff occurring in a particular time period over the drainage area above that gaging point. This is a basic tool used in river forecasting. For one thing the rain falling directly on the water surface of the lake would instantly show up as reservoir inflow. Also at the farthest reaches of the lake, flow would enter the reservoir and almost immediately show up as increased storage and therefore a higher elevation at the dam. Under natural conditions the dampening effect of valley storage in the river channel would delay this flow at the damsite. The effect of this "lost valley storage" can be illustrated by a simple experiment in the home. Water poured in the upper end of an empty bath tub slowly flows toward the drain. If the tub already has water in it the same inflow will produce a rapid rise at the opposite end. Figure 1-5 shows the hypothetical 12 hour unitgraph for 1 inch of runoff before and after the completion of the reservoir.

Note that the volume would be the same, but the unitgraph peak would be earlier and somewhat higher. This would not necessarily be true of any dam but would depend on basin shape, slopes, storage characteristics of the reservoir, etc. In a drainage area of this size it would be quite common. In any event, some change will occur, due simply to the reservoir being there. This is extremely difficult to evaluate theoretically and it is usually necessary to experience a few river rises after the reservoir stores water until a completely reliable inflow unitgraph can be developed.

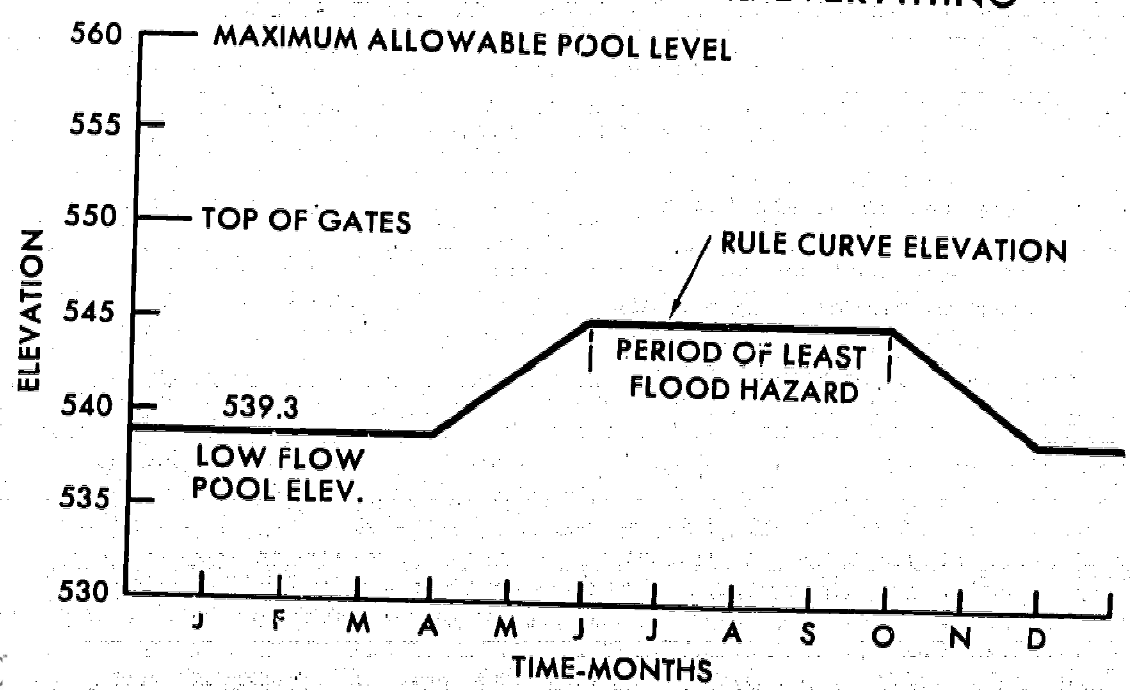
2. The next factor which must be considered in forecasting is the manner in which the reservoir is operated during a particular runoff period. This can have almost infinite variation in a reservoir such as this one with limited flood control storage. At the time the reservoir is designed, an optimal level varying during the year is developed, and

Fig I-5 12 HOUR UNIT HYDROGRAPHS FOR HOLDIT DAM SITE




the reservoir is kept as near this level as feasible depending on streamflow conditions. This operational criterion is known as a rule curve. A hypothetical rule curve is shown in Figure 1-6 for Lake Everything.

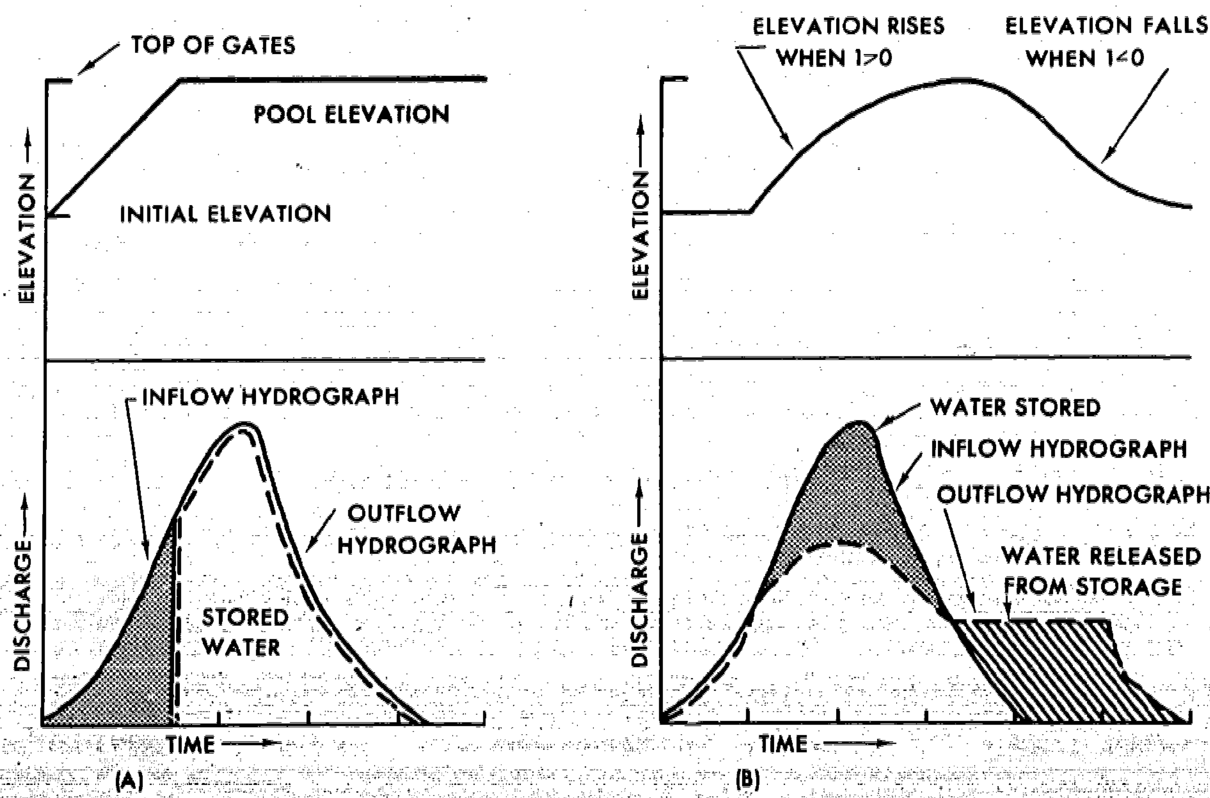
FIG. 1-6 RULE CURVE-LAKE EVERYTHING



In this rule curve, during the period December 1 through March 31, when flood hazard is greatest, the pool level is kept at the Low Flow Pool Elevation of 539.3 ft to allow the maximum 1.08 inches of runoff of flood control storage. On April 1 the pool level is allowed to rise to a maximum of 545 ft from June 1 through September 30 since the flood threat would be diminished and it is necessary to store as much water as possible for the season when outflow would normally be greater than inflow. On October 1 the pool level is dropped gradually to the 539.3 ft level. This rule curve is only a guide to be strived for. Flow conditions seldom permit the level to be exactly what the rule curve states. However if the pool filled during February, for example, releases would be scheduled to bring the level down to 539.3 as rapidly as possible to make the flood control storage available again. Likewise if the elevation were at 535 ft in August, all available runoff above the 450 cfs minimum release would be stored to bring the pool back up to the 545 ft rule curve elevation.

Suppose that runoff occurs in excess of the storage available. There are several possible ways of handling this depending on the operating criteria set up when the reservoir is designed. Figure 1-7 shows two ways of operating. In both of these operations the inflow runoff is identical and is greater than the available storage up to the top of the gates. The initial elevation is the same in both cases. In (a) the reservoir is allowed to store water until the top of gates is reached.

FIG. 1-7 RESERVOIR OPERATION-LAKE EVERYTHING



At this point the outflow must be made equal to the inflow or the water will flow over the gates anyway with possible damage to the gate structures. This is a fairly typical operation for a small reservoir intended for water supply or power generation, and any flood control storage achieved is a matter of chance. Whether the flood crest was different from the natural flood crest would depend on the changes in flow characteristics produced by the presence of the reservoir, plus the timing of the event. If the reservoir filled after the inflow peak, the flood crest might be reduced substantially. If it filled prior to the crest there would be no change in the natural flow hydrograph.

In (b) a more typical operation for a reservoir such as Lake Everything is shown. In this operation a maximum safe release is allowed consistent with preventing complications downstream. As long as the inflow exceeds this release, the pool will rise ($\Delta S=I-O$). The release is continued after the inflow drops off until the reservoir returns to its initial level which allows storage for further runoff.

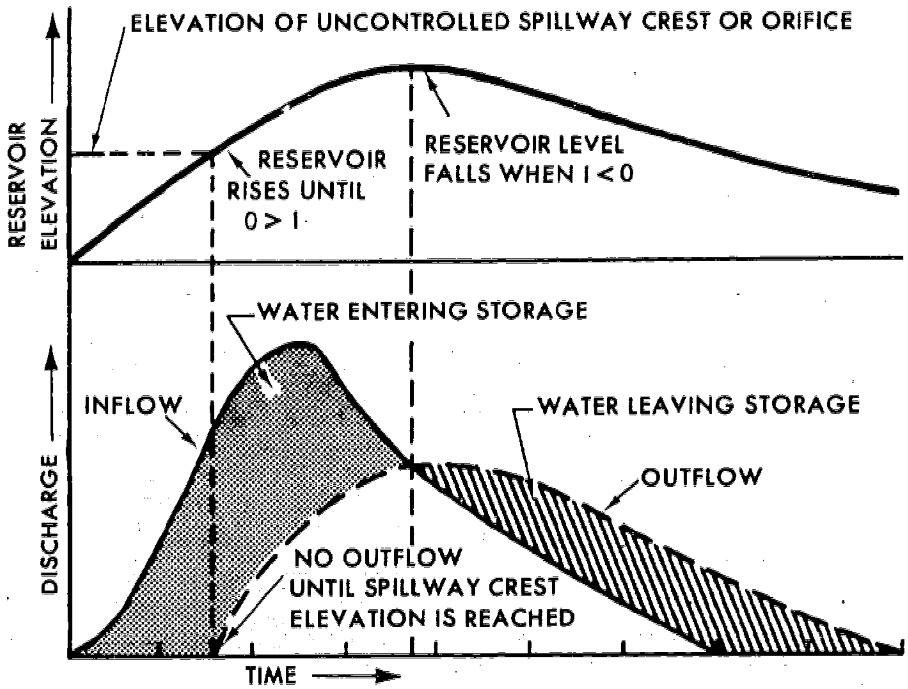
At this point, we will not go into the complexities involved with balancing out the effect of this flow on the downstream areas. There are many ways of operating the reservoir for flood control. We have shown that the forecasting problem has changed considerably and become more complex as a result of Holdit Dam. The operators of large dams need forecasts of inflow in order to make the most intelligent use of their ability to control outflow. Forecasts of flows from any tributaries that may enter Big River between the dam and Mediumburg are also important so that releases added to these flows will not cause floods at Mediumburg. On the other hand, the forecaster must keep abreast of release changes by the dam operator which will affect downstream stages. The interplay between forecasts and operational decisions can become quite complex during large storms. Let us now look briefly at the changes occasioned by some of the other engineering works in the basin. Before doing this, one very important factor should be pointed out. The reservoir cannot store any of the runoff occurring downstream from the dam.

## 1-3. Medium River.

a. Ag Dams. Medium River is the largest tributary of Big River and has several problems and interesting structures. Let us look first at Ag Dam 1 and Ag Dam 2. These dams are intended to reduce sedimentation and offer some measure of flood control to farm land downstream. Their effect on the flow at the Medium River Gage will be small and almost non-existent at the Big Town gage as we shall see.

These 2 dams are typical of small dams in that there is no control mechanism in the outlet works. The water is allowed to fill the pool until it reaches a level where the water discharges through an orifice or an opening in the crest of the dam. This outflow opening is designed so the outflow will be less than the inflow. An example of the change in hydrograph resulting from the presence of these dams is shown in Figure 1-8.

FIG. 1-8 TYPICAL OPERATION OF 'AG' DAM

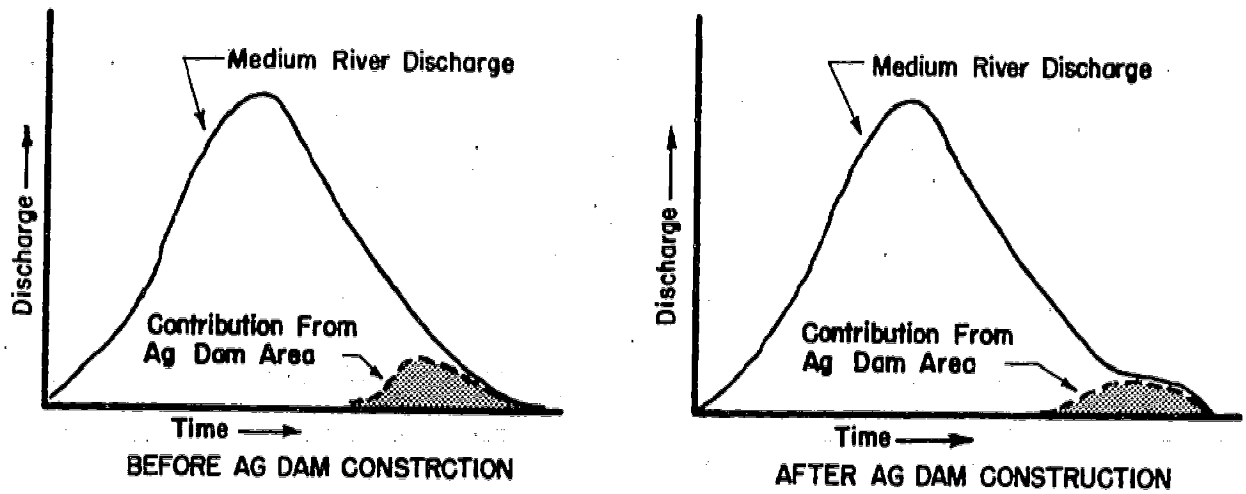



This type of reservoir can be extremely effective in reducing sedimentation, erosion and flooding for a short distance below the dam. The flood control effect diminishes rapidly as you go downstream due to the small size of the drainage area above the gage and correspondingly small volumes of water involved. In this instance the drainage area above the Medium River gage is 1800 square miles and above the two Ag Dams is only 50 square miles or less than 3% of the entire Medium River Gage drainage. Also since the dams are in the extreme headwaters, the contribution from this area above the dams arrived at the Medium River gage well after the flood crest. Figure 1-9 illustrates this minimal effect for a flood with uniform runoff above Medium River gage.

In some actual basins there is a sufficient number of this type of dam to present a significant forecast problem. Although the drainage areas of many are typically much smaller than the examples used here their summation can be critical. This is especially true since the forecaster rarely has definite knowledge of the timing of uncontrolled spill.

b. Flash Town. It should be evident that all of the reservoirs constructed on the Big River System have exactly no effect on the flash flood problem at Flash Town. Whatever problem existed prior to reservoir construction would still exist after completion of the system. The flash flood problem is a highly localized phenomenon and any structural attempts to solve the problem would have to be made in the immediate vicinity and

Fig I-9 EFFECT OF AG DAMS ON FLOW AT MEDIUM RIVER GAGE

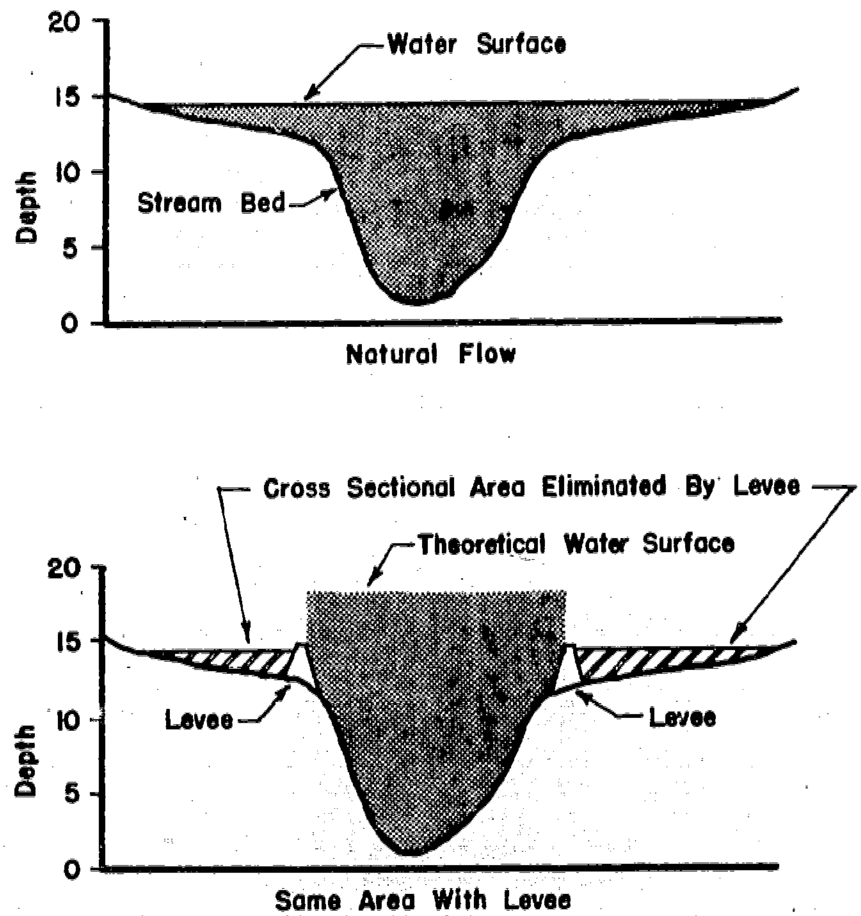



upstream from Flash Town. Let us assume that the possibility of a flood control dam upstream from Flash Town was investigated and found economically unfeasible. Another possibility is the improvement of the channel to prevent backup from natural channel characteristics. In some areas natural factors such as sand bar formations, heavy vegetation, bends in the river, etc. have slowed the flow and caused a partial damming effect which can be cleared out. Another possibility is a levee or flood wall system to prevent the water from reaching potential damage areas. Or a combination of these latter two possibilities may be employed.

In most instances the improvement of the channel is only a partial solution. Frequent overflow in low areas is often cut down drastically, but for a major flood the reduction in stage may be very slight. The river has a tendency to return to its natural conditions unless continuing dredging and vegetation control is employed. A further problem is to prevent encroachment by building and other commercial activity in the flood plain resulting from a sense of false security occasioned by the channel work. Unless flood plain zoning accompanies this work the end result may be a more serious flood problem than previously experienced.

The levee system is often an economical means of providing flood relief. Unless carefully designed and carefully maintained, however, this method can become dangerous. Some privately constructed levees may be built with the crest of the levee at the height or only slightly above the maximum flood height of record. If building proceeds behind this levee, a serious problem may result. For one thing there is no assurance that a greater flood won't occur at any time, overtopping the levee nor that the levee will not fail in a lesser flood. Another factor which may not be considered or properly evaluated is the fact that the elevation of the water surface will usually be higher for the same discharge because of the constriction of the river channel. Figure 1-10 illustrates this principle.

Fig I-10 EFFECT OF RIVER CONSTRICTION




The discharge is the product of cross sectional area of the stream and velocity of flow, or expressed mathematically Q=AV. If the discharge and velocity are reasonably constant the cross sectional area of the water will also remain constant. If the natural area is restricted the result is an increase in elevation of the water surface in order to occupy the same area. Of course, the theoretical water surface illustrated would not occur. The water would simply overtop the levee unless it could be protected by emergency sandbagging protection. This factor should be obvious but locations exist where a flow of 30% of the flood of record would overtop the levee system. In practice the velocity would be increased and the same flow could be passed through a smaller cross sectional area. Also the channel bed may scour out due to the higher velocity of flow. This would result in a different cross sectional area and conceivably even lower stages for the same flow than before levee construction. These factors would not ordinarily compensate for the diminishing of cross sectional area and an increase in elevation occasioned by the levee construction is quite common. All this should be considered in proper design of a levee system. Other factors must also be considered such as the effect on accelerated flow downstream from the levee.

Let us assume that the Flash Town levee system is properly designed with a crest elevation deemed advisable by a hydrometeorological study. Two other factors will still likely be involved which continue the need for river forecasts and alerts based on expected rainfall.

1. Runoff from the local drainage on the landward side of the levee will usually be passed through the levee system under normal conditions to prevent ponding or stagnation of water in this area. These outlets through the levee may close automatically when the river elevation gets high enough or it may be necessary to manually close these off to prevent flood water flowing through. A warning may be necessary for timely closure of these outlets. Also pumps may be required to pump out the storm runoff behind the levees into the river. If these pumps are not provided, the "interior" drainage problems may become nearly as serious as the flood problem, particularly from health hazard. These pumps are often used infrequently and must be checked out to be sure they are ready to meet any flood threat. In some cases the pumps are so large that emergency measures are required to provide sufficient power for their operation.

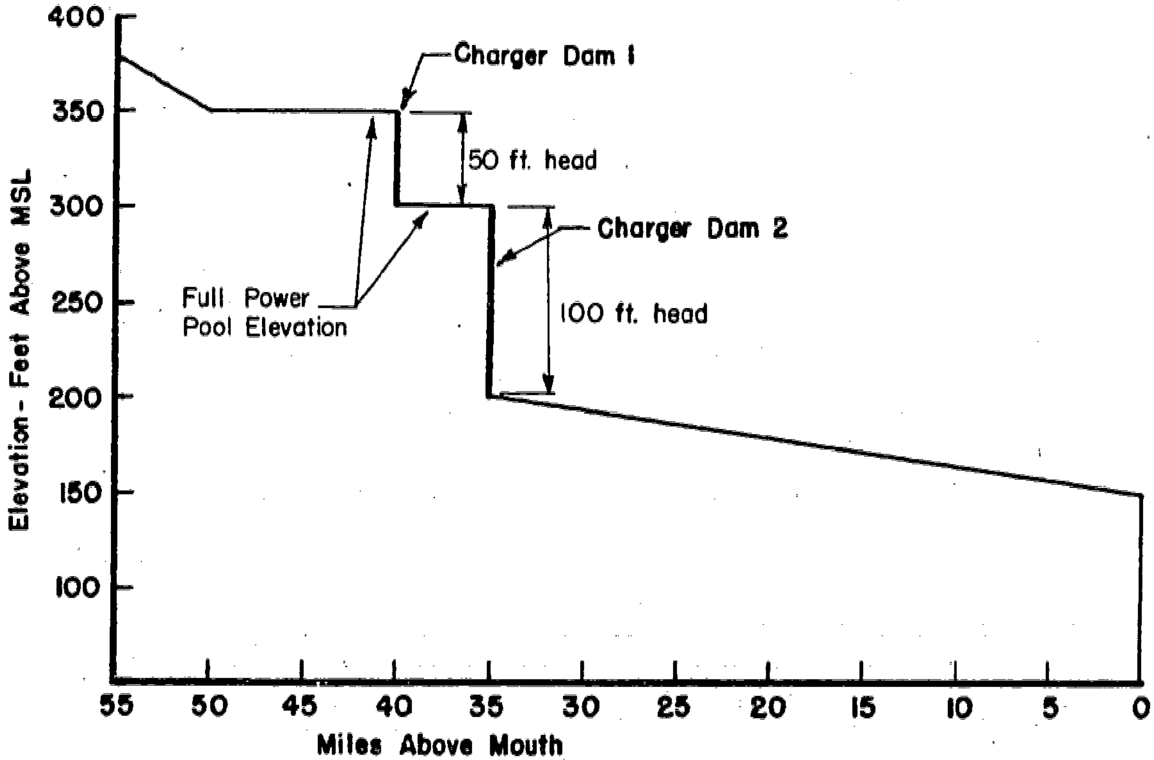
2. Often it is not economically practical to modify bridges and highways to pass over the levee system. Crossing openings are ordinarily left in the levees with elevations well below the levee crest. Gates or stop logs must be put in place in advance of a flood or the river will flow through these openings when the water elevation gets high enough.

Both of the factors listed here require timely warnings whether the levee system is on a major river or "Flash Creek". The difference is in the time intervals available for taking protective action. For a major river system several days may be available. For Flash Creek the crest may occur from 3 to 6 hours after the end of short heavy rain or serious flooding may occur even during longer periods of rain. The levee system has thus required changes in the forecast procedure due to the change in channel conditions. It has not eliminated the need for warnings. If anything flood plain encroachment has probably occurred since the levees were built and the flood problem is potentially more serious.

c. Charger Dam and Supercharger Lake. We now come to the hydroelectric operations which were conveniently skipped in describing Lake Everything. Figure 1-11 represents a cross section of Kilowatt Creek from the mouth to a point upstream of Charger Dam 1.

This figure shows one obvious reason why these dams were built where they were. Note that from mile 50 to mile 35 the natural river falls from an elevation of 350 ft to 200 ft, a fall of 150 ft in 15 miles or an average of 10 ft per mile. From mile 35 to the mouth the slope is a more gentle 50 ft in 35 mile or an average of about 1.43 ft per mile. If the water

Fig I-II PROFILE OF KILOWATT CREEK
TRIBUTARY TO MEDIUM RIVER
BIG RIVER SYSTEM




in the steep slope area can be stored and converted to electrical energy by running through turbines this represents money in the bank. Other factors are of course considered, such as needs for power, distance of transmission lines required from source to user, topography and geology of the proposed reservoir area, value of inundated property, cost of moving roads, bridges, railroads, etc.

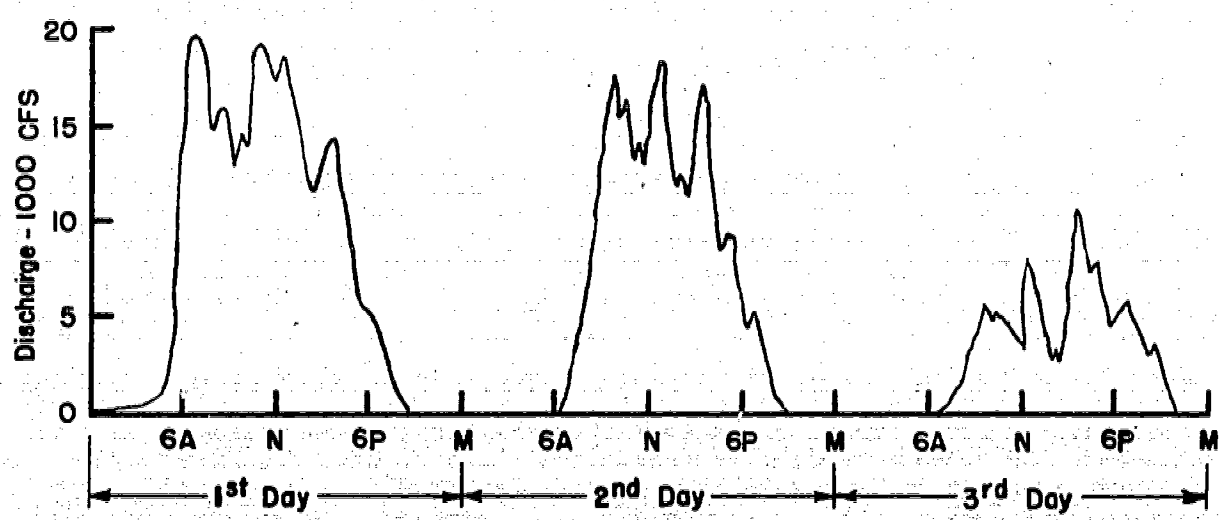
In any event after a favorable survey the dams were constructed. The next question is why 2 dams? The answer is to keep a nearly constant lake elevation in the lower lake by allowing the upstream reservoir to rise and fall with the vagaries of nature. Since the "head" available at Charger Dam 2 is greater than at Charger Dam 1, it is economical to keep the maximum possible head at Dam 2 by releasing from Dam 1 if necessary to keep Dam 2 filled.

The amount of power which can be generated is a function of 4 factors, the head, the volume of water released, the capacity of the turbines and the efficiency of the turbines. Determining the location of the dams, turbine capacity at each, size of gates to provide for passing flow in excess of lake and turbine capacity, etc. is a complicated matter in itself which we won't go into for this course.

The big advantage of hydroelectric power is that it is instantly available to meet varying load requirements. In contrast to a thermal plant where several hours may be required to build up steam pressure to drive the turbines, hydro power can be increased or decreased rapidly by operation of valves which can be remotely controlled by electric servo-mechanisms. Usually, particularly in the East, the amount of hydro power in a total electrical generation system is a small part of the total power generated. It is, however, a very important part, since it can rapidly be regulated up or down to meet varying demands. Since peak requirements vary with many factors difficult to predict in advance, it is not economical to build up steam pressure sufficient to generate a peak load requirement which may not be needed. These peak needs which may be of short duration can be met by fluctuating the available hydro power instead. In many modern balanced power systems the hydro power is seldom more than 5% or 10% of the total capacity, but its importance is great because of its flexibility.

Unfortunately for the river forecaster, this flexibility complicates his problem since the rapid change in release through the turbines results in a very ragged hydrograph of flow below the dam which can only be approximated for forecast purposes. Figure 1-12 shows a typical outflow hydrograph downstream from Charger Dam #2 for a 3 day period. This illustrates quite vividly why a river forecaster begs for data other than a once daily stage reading for a station below a power dam. While a mean daily outflow or total daily generation (which can be converted to mean daily discharge) doesn't give the total picture, it at least helps in the hydrologic "bookkeeping" for downstream forecasting.

Fig 1-12 HYDROGRAPH OF OUTFLOW FROM CHARGER DAM NO. 2



For forecast purposes, the storage in Charger Dam 2 will usually be negligible since it is kept nearly full at all times, but it is necessary to keep track of storage available in Charger Dam 1 since when or whether it fills during a rise has an important effect on the forecast hydrograph below the dam.

Several facts of life in the normal operation of a hydro reservoir must be kept in mind by the forecaster. A few of these are as follows:

1. If a reservoir has a sizeable volume of storage, the Agency (Private or Federal) distributing the power to users will usually try to commit the sale of power in advance. Unless forced by unusual circumstances the operators will not deviate too much from the mean daily volume of flow committed in advance although hourly fluctuations are great. This type of committed power is called prime power and sells at a price several times that of power delivered during a period of excess flow which was not anticipated.

2. Peak demands for power come during working hours and this is when hydro power sells for a premium due to the flexibility mentioned earlier. For this reason the hydro plant is usually completely or nearly completely shut down during night time hours and weekends and the system utilizes thermoelectric generating systems in order to save the valuable hydro power for daylight peak load demands. During a prolonged high flow period, the hydro plant will be operated at night rather than "waste" the water through flood gates but the price received per kilowatt is only a fraction of that during daylight hours.

3. Power demand is almost invariably reduced during weekends and holidays, so a pronounced 5 day cycle of greater outflow through the turbines is predictable below the dam. If the turbine is operated during these off times because of high flow, the excess power over that scheduled in advance is known as "dump" power and brings a lower price than the "prime" power.

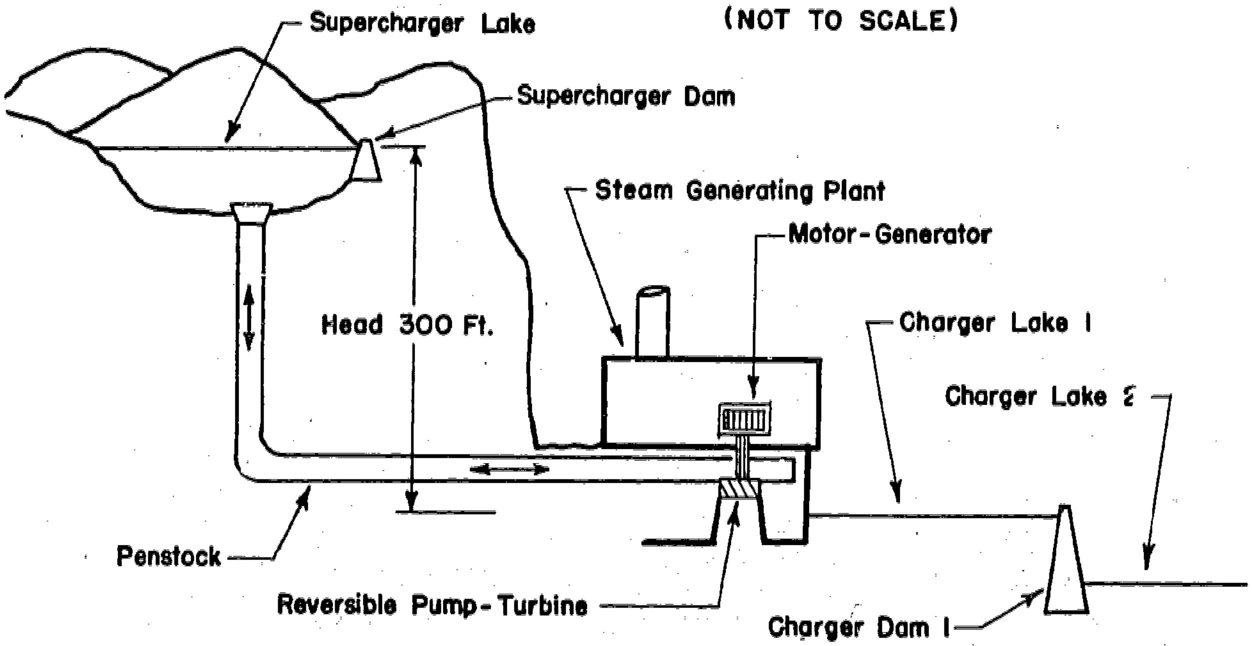
4. The operators invariably try to arrive at the end of a runoff period with a full reservoir. If they release through the turbines in advance of anticipated runoff which doesn't occur they will lose money. Since the release was of dump power they receive little for this and a lower head left in the reservoir represents potential energy lost which could have been converted to money in the bank during prime power periods. If the forecast was right and had been used to operate, money could be saved since they might have to waste water through the flood gates if the reservoir fills and the inflow is greater than the turbine capacity.

5. Dumping in advance may effectively reduce a flood peak, but it is difficult to convince an operator to take a chance unless he has great faith in the river forecaster, (or his own estimate agrees with that of the forecaster).

This course does not intend to go into sufficient detail to point out various operations which might result in operation of a hydro dam. Since the outflow must be forecast in order to predict the downstream flow, a knowledge of hydro operations plus a number of calculations to successfully consider these factors is necessary. As in most predictions of the vagaries of nature, particularly where man has considerable regulation, experience not easily programmed on a digital computer is invaluable.

Fig I-13 DIAGRAMMATIC SKETCH OF SUPERCHARGER LAKE POWER FACILITY

(NOT TO SCALE)




Supercharger Lake. As mentioned, the bulk of power in a sizeable electric generating system is usually produced by driving turbines by steam pressure. The steam may be produced by burning coal, oil or natural gas or by nuclear reaction. In the Supercharger Lake system a happy combination of hydro and steam generated power is utilized. This is known as pumped storage and is becoming an increasingly popular means of generating electricity when topographic conditions are right. A lake is not required, a sizeable river will serve as well, but we will use the water stored in Charger Lake 1 for illustrative purposes.

Supercharger Lake is created by damming a small creek on a plateau some 300 ft above Charger Lake 1. The lake does not have to be large. Since a high head exists, the volume of flow does not have to be large to generate substantial amounts of electricity.

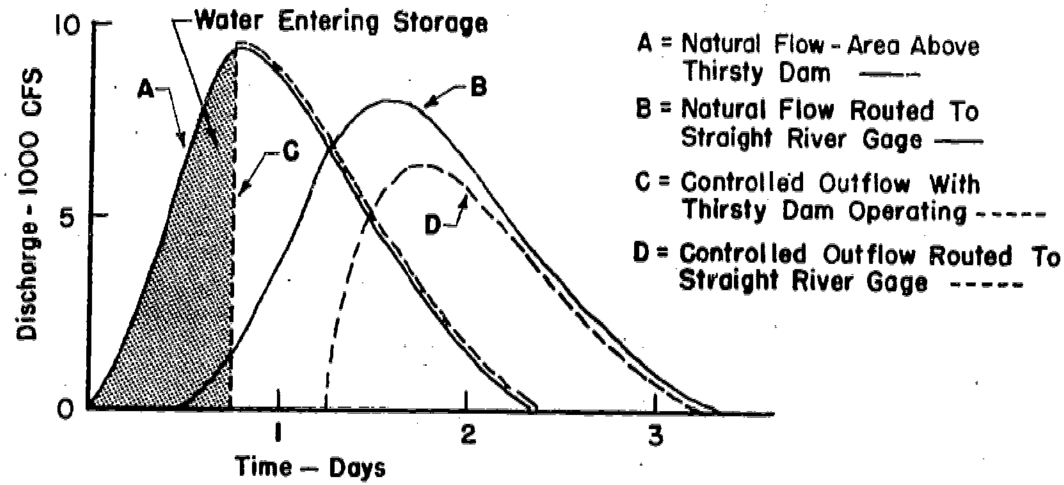
Anyone who has fired a boiler knows that it takes more fuel (and time) to build up a good head of steam than to maintain it for a few hours. A head of steam is built up at the steam plant to meet power requirements during the peak load daylight hours. Rather than banking the fires during minimum load requirements at night, the steam power generator is continued at a high level. The power is used to drive a pump which pumps water up into Supercharger Lake during this off peak time. In daylight prime power generating hours, the reversible pump-generator is reversed. Water is released through the turbine to generate hydro-power which is added to the total system power. Obviously more power is required to pump the water up to Supercharger Lake than is generated by returning the water through the turbine. The secret, of course, is that "dump" or cheap power is used to pump the water and "prime" expensive power is generated representing a net financial gain. Furthermore almost no water is lost in the process.

Of course a weather forecaster likes to have a storm system pass his forecast area and keep moving. Likewise the river forecaster likes for water to pass on downstream and eventually to the ocean. This pumped storage water keeps coming back necessitating extra bookkeeping to keep track of the total basin flow. Obviously power plant operators are more interested in making a profit than in keeping down the frustration level of the river forecaster.

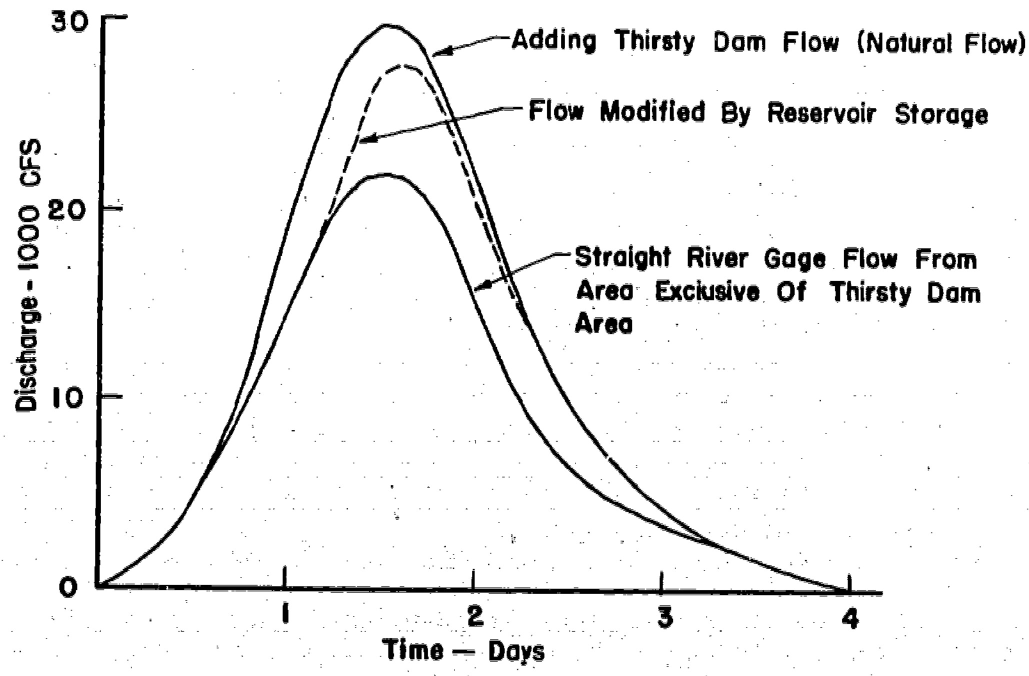
<u>1-4. Thirsty Dam</u>. Since forecasts are made for the Straight River gage, it is necessary to account for the effect of the Thirsty Dam water supply system on Aqua Creek. The drainage area of the Straight River gage is only 770 square miles so a significant volume will either be contributed or stored from the 100 square mile area above Thirsty Dam. This can be accomplished by one unitgraph for the 770 square mile total area to be used if Thirsty Dam is full and another for the 670 square mile area below Thirsty Dam to be used when Thirsty Dam is empty. Another possible way is to break the area into two separate areas for unitgraph analysis. The inflow into Thirsty Lake would then be computed and once the lake is full, the ordinates of both unitgraphs would be added to make the forecast for the Straight River gage. The latter is a somewhat more complicated, but also more accurate procedure. In a water supply dam, it is usually a safe assumption that the reservoir will not be allowed to spill until it is brim full. This is often not very efficient from a flood control standpoint, since it would be preferable to spill early during a flood and store water during the peak flow conditions. It does make the forecasting easier if this practice is followed, so we will assume that Thirsty Dam is a normal water supply reservoir in this respect. Figure 1-14 illustrates a potential before and after effect from Thirsty Dam.

Figure 1-14a shows the effect of the Dam after the water from this area travels through the valley storage between the dam and the Straight River gage. In this case it is assumed there is no difference between the natural inflow and the inflow when the reservoir is in existence. This is a simplifying assumption for purposes of illustration. It is also

# Fig I-14 EFFECT OF THIRSTY DAM STORAGE




(a) EFFECT OF DAM ON FLOW ARRIVING AT STRAIGHT RIVER GAGE

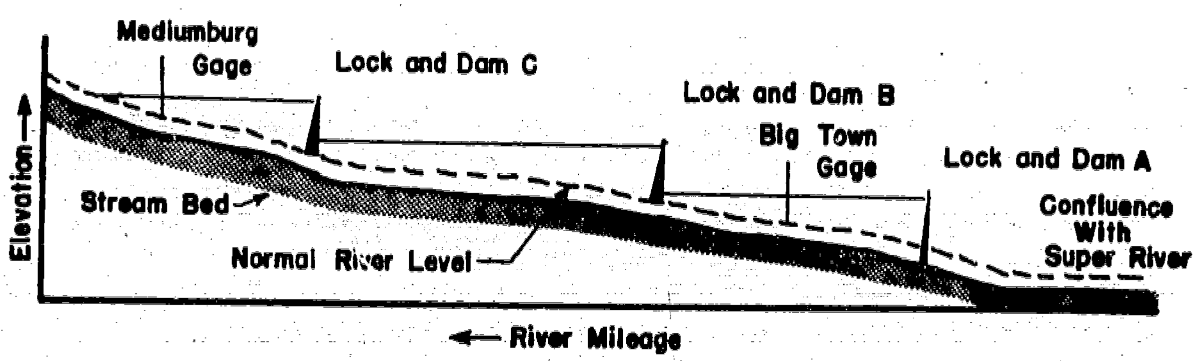



(b) EFFECT OF DAM ON TOTAL STRAIGHT RIVER GAGE FLOW assumed no outflow from the dam occurs until 18 hours after the beginning of the storm and then outflow equals inflow, again a reasonable simplifying assumption. Curve B represents the flow arriving at Straight River Gage from the area behind the dam during natural conditions and Curve D during controlled conditions.

Figure 1-14b illustrates the natural flow from the area exclusive of the dam drainage and then adds on the natural flow from above Thirsty Dam and the controlled flow. Since the area exclusive of the dam drainage is nearly 7 times as large, the volume would be about 7 times as great if runoff were uniform over the whole drainage. Obviously we have distorted the illustration by having proportionally more flow from the Thirsty Dam drainage area. Even with this distortion the effect of Thirsty Dam in this hypothetical case is relatively minor, but it does have to be considered if an accurate forecast is to be made from the Straight River Gage.

1-5. Locks and Dams A, B, and C. We will give somewhat short shrift to these navigation locks and dams. The obvious purpose of the dams was to create a navigable channel throughout the river from the mouth to the Mediumburg area. Prior to the lock and dam construction there were shoals in the river in some stretches which prevented reliable navigation.

Fig 1-15 RIVER PROFILE OF BIG RIVER




The providing of water by the navigation dams allowed for a reliable year round navigation. Depending on the design and operation of the gates at these dams, there would be some changes in the channel hydraulics which would have to be evaluated. In this example there should be adequate water available for low flow augmentation from Lake Everything to insure reliable navigation channels during low flow conditions. In some rivers this is not the case and flow must be estimated as much as 2 weeks in advance to determine how full the barges can be loaded for their long trip.

There are other problems which may be occasioned by the locks and dams. Often dock and warehouse facilities are built below maximum flood levels to minimize costs in loading and unloading. Also low lying industry may develop close to these dock facilities which would increase the hazard of flood losses. The rating curves at both the Mediumburg and Big Town Gages would be affected by backwater from the lakes formed. This necessitates changing these rating curves (graphs of river stage vs stream discharge) and making discharge measurements very difficult due to the flat slopes of the water surface. Ice may form more readily in these lakes due to the decrease in water velocity. Ice may also form jams at the dams and be more of a hazard due to the increased number of boats and possible damage to the gates and lock mechanisms. Pollution may become more of a problem in low flow conditions, since the water would not be free flowing as in the past.

We won't go into details on any of these factors, but it can be seen that these locks and dams do change natural flow conditions and result in a number of additional factors which must be evaluated by the river forecaster.

CONCLUSION. The vagaries of nature are always difficult to understand and to predict. When the human element is added the problem invariably becomes more complex. This technical memorandum in a few pages obviously could not go into great detail on the effects of man made regulation of river flow. Also the idealization may be considered as an over simplification by some. The author has tried to keep the examples within the realm of reality and to illustrate basic principles in the process. Some people feel that in the not too distant future all streams will be "controlled" and the river forecaster will be another occupational casualty of improved technology. It is hoped this paper demonstrates that the problems are just different for the river forecaster. The need for forecasts is still present and in fact these forecasts are even more necessary and are more difficult than under natural conditions.