APPLICATIONS OF HYDROLOGY IN MILITARY PLANNING AND OPERATIONS

MILITARY HYDROLOGY BULLETIN 1
JUNE 1957

A
CORPS OF ENGINEERS
RESEARCH AND DEVELOPMENT REPORT

PREPARED UNDER DIRECTION OF
CHIEF OF ENGINEERS

BY

MILITARY HYDROLOGY R&D BRANCH
U. S. ARMY ENGINEER DISTRICT, WASHINGTON

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PREPARED IN CONNECTION WITH
RESEARCH AND DEVELOPMENT PROJECT NO. 8-9710-003

FOR
ENGINEER RESEARCH & DEVELOP NT DIVISION OFFICE, CHIEF OF ENGINEERS

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PREFACE

This Bulletin is the first of a series of papers dealing with the various aspects of hydrology involved in military operations and with. the hydrologic techniques and methods of analysis which are considered most suitable for Army use. A number of these techniques were developed in the course of Research and Development Project No. 8-97-10-003, assigned to the Army Engineer District, Washington on 14 March 1951 by the Office, Chief of Engineers. Printing of this Bulletin was authorized by the Office, Chief of Engineers, on 9 May 1957.

Mr. A. L. Cochran of the Office, Chief of Engineers, formulated the objectives and scope of this bulletin. Messrs. H. H. Heim and C. L. R. Walke of the Military Hydrology Branch, Washington District, assembled the material and prepared the text of the bulletin, under the supervision of Mr. R. L. Irwin.

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SUMMARY

Recent military history provides a number of instances in which hydraulic warfare was used to create devastating floods, isolate troops, cut off supply lines, hinder river crossings, and disrupt military timetables. This Bulletin describes the principal hydrologic factors involved in these operations, outlines the types of data needed and procedures to be followed in order to accomplish the objectives, and makes certain recommendations concerning the need for collecting basic hydrologic intelligence, providing training in this field to military personnel, and establishing military hydrology units.

Chapter

INTRODUCTION

1. Purpose. The primary purpose of this pamphlet is to describe, by means of historical examples, how the science of hydrology may be employed to advantage in military planning and operations, and to out-line the types of information and procedures required in analyses of future operations of this category. In pursuance of this objective, the pamphlet also serves as a basic reference for the other Military Hydrology bulletins in this series which present detailed technical procedures used in the military applications of hydrology.

2. Scope. This pamphlet discusses the more important direct applications of hydrology in warfare. After providing historical illustrations of the uses in hydrology in military tactics and strategy, it summarizes the hydrologic factors involved and shows how hydrologic techniques and data must be established, analyzed, and developed before. they can be applied to military objectives.

3. Related References. A list of Military Hydrology Bulletins, Department of the Army Technical Bulletins relating td hydrology, and other references containing information on the history and the military applications of hydrology is presented in the REFERENCES at the end of this pamphlet.

4. Applications of Hydrology to War. Hydrology, the science which treats of water, its properties, phenomena, and distribution over the earth's surface, is of military importance in that it provides a method. whereby the characteristics and effects of flowing water can be predicted. Many instances of employment of water to form an obstacle are recorded in military history. The following examples of the application of hydrology in war illustrate its importance in military planning and operations, both in offense and defense:

a. The British bombing of the Moehne and Eder Dams, Germany, May 1943.

(1) This operation illustrates the strategic value of destroying water-control structures to hinder the enemy war effort. Moehne and Eder Dams are located in Western Germany, with Moehne Dam supplying both water and electric power to the heavily-populated, industrial Ruhr Valley. Eder Dam produces power, supplies water for the navigation of the Fulda and Weser Rivers and the important Mittelland Canal, and provides flood protection for the Eder, Fulda, and upper Weser Rivers.

(2) Moehne Dam, constructed of masonry, is approximately 2,100 feet long, 130 feet high, and 110 feet thick at the base, and formed a reservoir with a capacity of 109,000 acre-feet. The British Royal Air Force successfully attacked this dam on 17 May 1943, at a time when the reservoir was almost full. The resulting breach was large enough to release 94,000 acre-feet of water in the next 12 hours. This artificial-flood wave had a peak discharge at the dam of about 310,000 cubic feet per second, and was considerably larger than

the largest flood of record. More than 1,200 lives were lost in this flood, and the river valley was devastated for over 40 miles downstream. All bridges were washed out below the dam for over 30 miles, and two large powerplants were submerged by the water. Several important industrial towns, including Dortmund, were deprived of drinking water and electric power for several days, and remained without water for fire-fighting for several months. The large German "Todt" organization was mobilized to repair the damage to the Moehne and Ruhr Valleys after the flood.

.(3) On the same date, 17 May 1943, the British Royal Air Force attacked the Eder Dam, which is located east of the Ruhr Valley and Moehne Dam. Eder Dam was constructed of rubble masonry, and was the second largest dam in Germany. It was approximately 1,300 feet long, 150 feet high and 115 feet thick at the base. The reservoir had a storage capacity of 164,000 acre-feet. The artificial flood created by the breaching of Eder Dam had a peak discharge at the dam of about 300,000 cubic feet per second. It required over 36 hours to empty the reservoir of the 125,000 acre-feet of water in storage at the time of the breach. The damage caused by this flood was severe. The Eder, Fulda, and upper Weser River valleys were badly flooded. The navigation locks on the Fulda below the mouth of the Eder were either washed out or rendered inoperative by silt and debris. The effects on navigation were felt as far downstream as the Mittelland Canal. In addition, interruptions to navigation occurred in this canal long after the breaching of Eder Dam, since no water was available for release from the reservoir to maintain navigable depth.

b. The German flooding of the Liri, Garigliano, and Rapido Rivers, Italy, January-February, 1944.

(1) The Rapido River, flowing southward through Cassino, Italy, and the Liri River, flowing eastward, meet at a point about 10 miles south of Cassino to form the Garigliano River. Isoletta Dam was located on the Liri River about 20 miles above the confluence. '

(2) The British Army attempted to cross the Garigliano River when both tributaries, as well as Isoletta Dam, were in German hands. The Germans then released a flood wave from the dam which swept away the British assault boats caught in midstream. Further crossing attempts failed, on account of swift river currents resulting from German manipulation of Isoletta Dam. This failure was of critical importance, since it left open the flank of the American Army attacking Cassino, and the Rapido River sector of the battle front.

(3) Several weeks later, when units of the American Army began the crossing of the Rapido River above Cassino, the Germans dammed the river below the crossing, inducing a high river stage in the valley above the barrier. The flood plain became a quagmire, increasing supply difficulties and hindering the detection of land mines. The crossing was eventually secured, but only after a costly delay.

e. The German flooding of the Pontine Marshes, Italy, 1944.

(1) The Pontine Marshes extend along the Italian west coast for a distance of about 30 miles, just below the site of the Anzio Beachhead. These marshes had been drained and the land reclaimed for farm ins by the Italian Government. The fiat, formerly marshy land was ideal for artificial flooding and the creation of still water barriers. Consequently, after the Allied landings at Anzio in 1944, the Germans quickly reflooded the Pontine Marshes by destroying the drainage pumps to prevent more Allied landings and to contain the beachhead already established.

(2) Over 40 square miles of land were flooded by the Germans during the Anzio operation. As a result, the entire 30-mile reach of excel-lent landing beaches was rendered unusable for amphibious forces seeking to support the original beachhead. This flooding operation greatly assisted the Germans in containing the Anzio Beachhead for over two months with a relatively small defending force. The Allied Army eventually broke out of the beachhead, but only after sustaining severe casualties.

d. The German flooding of the Ay River, France, July 1944. This is another example of an artificial flooding operation used to augment the defense. Several similar operations were used by the Germans in Normandy in 1944. In this case, the American Army was advancing toward Saint Lo, an important German communication center in Normandy. The German left flank was anchored in the Ay River, which is a tidal body, normally easily fordable. The Germans, however, dammed a causeway crossing the river, creating a lake 6 feet deep and several miles wide, This inundation was of substantial aid to the German defense and made the Saint Lo breakthrough much more difficult for the American Army.

e. The British flooding of Walcheren Island, Netherlands, 1944, After the Germans lost the important port of Antwerp, Belgium, to the Allies in October 1944, they prevented its use by the Allies by holding Walcheren Island which controlled the sea approaches to the port. Amphi-bious assaults on Walcheren Island by British commando units were repelled by the defending Germans. The Royal Air Force then dropped six-ton bombs on the sea dikes protecting the island. The bombs created breaches in the dikes, which allowed the greater part of Walcheren Island to be flooded, including a large portion of the German defense installations. After this artificial-flooding operation, British assault forces captured Walcheren Island and eliminated the German threat to the port of Antwerp.

f, The German flooding of the Ill River, France, 1944-45,

(1) This artificial-flooding operation was used by the Germans in Alsace during the Battle of the Bulge in the winter of 1944-45. In this instance the Germans held a sector of the Rhine Fiver Valley called the "Colmar Pocket". Through this "pocket" ran the Ill River, a tributary of the Rhine. This section of the Ill River Valley was very wide and flat, and particularly suitable for artificial flooding. During peacetime, farmers on both sides irrigate their land by damming the river.

(2) The Germans obtained considerable assistance in holding this sector 'by flooding the Ill River Valley By damming the river, a ¯.taste 10 miles lens, 2 to 4 miles wide, and 3 to 5 feet deep was formed. This formidable barrier contributed greatly to holding

up the American Army's advance toward the Rhine, forcing 8 or 9 divisions to defend a sector of the Rhine Valley which might have been held with only 2 divisions, if the left bank of the Rhine, containing the "Colmar Pocket", had been cleared of the enemy. This water obstacle was finally overcome by the American Army, but only after special bridging and crossing preparations had been made.

g. The German flooding of the Roer River, Germany, 1944-45.

(1) In early December 1944 the U.S. Ninth Army had advanced to the west bank of the Roer River in western Germany. The U. S. First Army, which was attacking German forces in the Hurtgee Forest south of the Ninth Army, was planning to capture five dams on the headwaters of the Roer, above the Ninth Army position. The capture or demolition of these dams, especially the two largest, Urftal sperre and Schwammenaual, would eliminate the threat of artificial flood waves in the Ninth Army crossing of the Roer. It was estimated that artificial flood waves released from Urftalaperre and Sehwammenauet Dams could create an 18 foot rise in Roer River levels at some crossing sites, and increase river widths with a normal range of 60 to 200 feet by several thousand feet. In such an event, crossing and bridging operations would be prevented.

(2) When it became apparent that the strong stand made by the Germane in the Hurtgen Forest would prevent the capture of the Roar River dams as planned, aerial bombing attacks were undertaken. On 8 December 1944, a force of 200 aircraft dropped 797 tons of bombs on three Roer liver dams, including Urftalsperre and Schwemmenauel and on 11 December, 1,065 tons of bombs were dropped on Urftalsperre Dam alone, These bombing attacks, however, caused little damage and proe dueled no hydrologic effects of consequence. One end of Ueftaleperre Dam was cut, allowing a small amount of water to spill into Schwamme[e] nauei pool. Further attacks on the dams were postponed because of the battle of the Bulge on the Ardennes sector of the front. thus, even after the German offensive had been stopped in early February 1945 and the Allied armies had again assumed the offensive, the U. S. Ninth Army remained stopped at the Roer River because of natural flooding =editions and the continued danger of artificial flood waves from these dams. It is believed that the German Ardennes offensive would have been on a such smaller scale if the Ninth Army had been able to cross the Roer River in early December 1944, as originally planned.

(3) After several delays the U. S. First Army captured the Roar River dams, only to find that the Germans had demolished the outlet-control mechanism of Schwammenauel Dam so that it could net be closed. The resulting reservoir outflow produced a 5foot rise in river stages, with current velocities of 6 to 7 miles per hole:, and a large increase in river widths. As a result, the U. S. Ninth Army could not btidge or ford the Roer. Heavy rainfall during the succeeding weeks over the basin above Schwammenauel Dam resulted in high, reservoir inflow, and the reservoir emptied very slowly. The Ninth Army was finally able to cross the Roer on 23 February 1945 when stages had nearly returned to normal, after a delay of more than 3 weeks.

h. The Hwachon Dam operation, Three, April 1951.

(1) This example illustrates not only the utilization of artificial flooding in battle tactics, but also the defensive measures taken to counteract it. Hwachon Dam is located on the Pukhan River, Korea, about 20 river miles above the 38th Parallel. From its source the Pukhan River flows generally southward through Hwachon Reservoir and across the 38th Parallel to the South Korean town of Chunchon. In April 1951, the battle line was north of the 38th Parallel but south of Hwachon Dam, held by the North Koreans. United Nations forces constructed two floating bridges across the Pukhan about 15 miles apart, one just below the 38th Parallel and the other near Chunchon. The loss of either bridge would have seriously affected United Nations operations in this sector, since they were the only available crossings on the important Chunchon-Hwachon highway leading north.

(2) Hwachon Dam, one of the largest dams in Korea, is approximately 900 feet long and 275 feet high. The reservoir capacity is about 436,000 acre-feet. Intelligence reports to U. N. troops in the Pukhan valley below the dam indicated that if the North Koreans should open the spillway gates of the dam, enough water was in storage to cause a flood wave which would endanger the U. N. floating bridges. On 9 April 1951 the North Koreans opened about one-half of these gates. A U. N. fighter pilot observed the resulting artificial flood wave and reported it. The flood wave, however, reached the first floating bridge and damaged it to some extent before it could be cut loose, swung out of the current, and anchored. Similar action at the second bridge, taken before arrival of the flood crest, prevented serious damage.

(3) Since these bridges were known to be unreliable during floods, ferrying facilities were set up at both crossing sites. These ferries functioned in the absence of the bridges, so that transportation difficulties never became very serious. After this experience with an artificial flood, the U. S. Navy sent torpedo bombers to destroy some of the Hwachon Dam spillway crest gates. Several gates were destroyed, preventing the filling of the reservoir, and thus its use for flooding purposes, for a period of considerable duration.

i. "The Rhine River Flood Prediction Service", 1945.

(1) The importance of flood-warning systems in military planning and operations is brought out by the following example from World War "The Rhine River Flood Prediction Service", which was set up to assist the Allied Armies in crossing the Rhine, began operating on 1 January 1945 and continued until Germany surrendered. This crossing was one of the most important military operations conducted by the Allies after the Normandy landings in 1944. The German defense utilized every advantage of the Rhine as a barrier augmenting their "Westwall".

(2) The Flood Prediction Service provided engineers of the Allied Armies with short-range predictions of river stage as well as long-range forecasts of river-level trends. The Air Weather Service of the U. S. Army Air Force provided the collection service for the necessary meteorological data, as well as teletype and radio-communication facilities. River gages were installed at strategic locations by U. S. Army Engineers and were read three times daily.

Par. 4i(3)

Forecasting facilities were so organized that stage predictions could be made within two hours after the field data were received. Rivera stage predictions were issued twice daily, and 10-day forecasts were provided when requested, usually prior to initial crossing operations. Although the 10-day; predictions could not be made with a high degree
of accuracy, they succeeded in keeping staff personnel informed of potential floods during such periods.

(3) The Flood Prediction Service assisted military planning personnel not only in selecting the time and place for such operations over the Rhine as assault, bridging and ferrying, but also in providing measures for the protection of floating plant, ridges, and static installations. In addition to issuing forecasts of natural floc-1a, the Service was also prepared to predict artificial flood waves resulting from German destruction or regulation of seven dams on the upper Rhine, between Basel and lake Constance on the Swiss border. This threat. however, did not materialize. As a result of these flood predictions and analyses of river conditions, dozens of floating bridges were constructed across the Rhine in record time. River-stage and flood predictions made by the Service permitted all of the chine crossings to escape inundation, even though during the winter of 1944-45 certain reaches of the river had the highest stages in over 25 years. "The Rhine River Flood Prediction Service", the first hydrologic reporting network established by the U. S. Army, is credited with significant contribution to the success of the Allies in crossing the Rhine.

5. Categories of Hydraulic Warfare.

a. The applications of hydrology to warfare may be grouped in three major categories, as follows:T

(1) The strategic use of hydraulic installations in the interior zone of the enemy to damage his war effort.

(2) The tactical use and manipulation of hydraulic installations and water bodies on the battlefield.

(3) Methods of overcoming hydraulic obstacles used by the enemy.

b. The strategic use of hydraulic installations involves operations designed to hinder the war effort of the enemy by causing damaging artificial floods in his interior zone. Like the British bombing of the Moehne and Eder Dams described above, this type of operation is usually carried out by an air force. The Location, timing, and probable effects of the operation should be determined, however, by military engineering personnel.

c. The tactical use of hydraulic installations and water bodies is illustrated by the German flooding of the Garigliano and Ill Rivers, described in paragraph 4. It is employed to augment either the defense or the offense on toe battlefield, usually by subjecting troops or tactical installations to artificial inundation. The possibilities of utilizing hydraulic structures and water bodies to augment tactical operations are numerous and varied. Since such use is highly dependent on terrain characteristics and battle conditions, it often is not possible to make detailed plans very far in advance. Thus military engineering personnel on the field staff level will frequently be required to determine the optimum use of hydraulic installations to augment tactical operations.

d. "The Rhine River Flood Prediction Service", described in paragraph 4i, is a good example of the use of hydrologic data and methods as a means of determining how best to minimize the obstructive capabilities of a water barrier. Another example in this category was the U. S. Navy action to destroy the spillway gates on Hwachon Dam in Korea, in order to reduce the flood hazard. Hydraulic obstacles may best be overcome through advance studies of the potentiality and effects of flooding, and of proper defensive measures. As a means of reducing the effects of possible hydraulic warfare against the United States, studies should be made of all large hydraulic installations within its boundaries, as well as in any geographic area where our forces might be required to operate.

6. Hydrologic Studies as a Part of Advance Planning. a. The success of any operation in hydraulic warfare reflects to a high degree the extent to which hydrologic studies pertinent thereto were made in advance. This is especially true in the employment of hydraulic warfare in strategic and such large-scale tactical operations as the Rhine River crossing. The German government was quick to recognize the importance of hydrologic planning in military operations. Before World War II, it prepared comprehensive reports on the flow characteristics and artificial flooding potentialities of many important European rivers and waterways. These reports were at the disposal of German field staff officers at all times. The illustrations of hydraulic warfare given above show how effective their hydrologic planning became in World War II.

b. The time and effort required for the preparation of military hydrology studies depend upon: (1) the objective and scope of the study, (2) the availability of basic data, and (3) the degree of accuracy required. The preparation of a study on the hydraulic effects of such an operation as the breaching of a large dam might require many man-months. After military operations begin, there is seldom enough time or personnel to make such studies, nor can basic data be readily secured. Thus to be of significant value to military planning personnel, hydrologic studies must be made as far in advance of military operations as possible.

c. It is not possible to prepare in advance all the details of hydraulic warfare, especially those needed on the immediate field of battle. Consequently, field staff units will be required to determine the utilization and effects of local hydraulic installations. In order to make optimum use of such installations in military tactics, field staff officers should employ hydrology units consisting of personnel trained in hydrology and capable of making rapid evaluations of the hydraulic aspects of military field operations.

CHAPTER II

HYDROLOGIC PROBLEMS IN MILITARY PLANNING AND OPERATIONS

7. Types <u>of Problems.</u> In this section are described the more important applications of 'hydrologic principles to military situations, with discussion of the hydrologic factors involved. These problems are presented in the following order:

a. The selection of sites for static military installations.
b. The utilization of hydraulic installations for logistical purposes.
c. Artificial floods as weapons of warfare.
d. The selection of sites for river crossings.
e. The establishment and operation of flood prediction services.
f. The development of military equipment for use in water.

8. The Selection of <u>Sites for Static Military Installation</u>

a. The importance of hydrology in planning static installations is found in the selection of sites with adequate water supply, good drainage, and immunity from damaging floods. At one time during World War II, seven million military personnel were housed in the United States, with a mean daily water consumption of over 800 million gallons. Drainage conditions are of critical importance in the case of airfields. When static installations must be located near streams or in flood plains in order to facilitate construction or to be near transportation and communication facilities, or for tactical reasons, flood potentialities must be taken into consideration, and protective measures and plans must be established for emergency operation of the facilities. Before the hydrologic factors of water supply, drainage, and flood vulnerability involved in site selection can be considered, quantitative hydrologic data pertaining to the following subjects must be assembled and analyzed, as discussed below:

(1) The local climate
(2) Terrain and drainage characteristics
(3) Flood plain location and limits
(4) Precipitation-runoff relationships
(5) Flood characteristics

b. Climate is an influencing factor not only in selecting the location most suited to the activities of a particular military installation, but also in determining the effect of water supply, drainage, and flood vulnerability. Various types of climatological data, such as records of temperature, precipitation, and storm characteristics over a representative period of time must be assembled and analyzed to appraise these effects. A knowledge of the amount and kind of precipitation, its seasonal variation and areal distribution, and the frequency of drought and rainfall excess, is required. to evaluate the available water supply in the vicinity of the installation. Rainfall intensity and duration data are required in the design of drainage structures and conduits. If an installation is to be located in an area subject to inundation, storm patterns and precipitation volumes, as well as temperatures, are needed to establish rainfall-runoff relationships and to predict floods.

c. Terrain and drainage characteristics including the roughness and slope of the terrain, types of soil and vegetation, and the area, length, and drainage pattern of the streams in the watershed affecting the installations must be analyzed to determine their effect on the hydrologic problems at the site. The terrain and drainage characteristics of a watershed are generally determined by the analysis of topographic maps or aerial photographs. The scale and detail to be required of the maps or photographs depend on the importance of the installation, the size of the watershed affecting it, and the climatic variation within the area. If the installation is to be located adjacent to a large stream or in a flood plain, hydrographic surveys and stage-discharge measurements will also be required.

d. A flood plain may be defined as a wide, generally level section of land which is subject to overflow by an adjacent stream. An installation located in a flood plain may be vulnerable not only to natural floods, but also to artificial floods created by the destruction or regulation of upstream reservoirs, or by other methods of flow diversion. The flood vulnerability of such an installation may be appraised by a survey of the features and limits of the flood plain, an analysis of the effects of past floods, and an inspection of hydraulic structures and water barriers which could be used to cause flooding.

e. The relationship between the amount of precipitation falling on a watershed and the amount of runoff resulting therefore is important in forecasting both floods and water supply. This relationship varies in a watershed, the sources of variation being: (1) the character, intensity, and duration of the precipitation, (2) the air temperature,

(3) the characteristics, moisture content, and temperature of the soil,

(4) the type and extent of vegetation, and (5) the topography of the terrain. In order to compute the runoff resulting from a storm, or the water supply for a season, the records of stream-gauging and climatological stations in the watershed for a representative period of record must be obtained. The precipitation-runoff relationships for the area are obtained by an analysis of these records for several storms with consideration for the season of occurrence; From this information the hydrologist is able to make reasonably accurate flood and water-supply forecasts for the installation.

f. Information in flood characteristics, derived from the analysis of flood records at nearby river gages, is of value in choosing the site of the installation and in devising methods of flood protection. Frequency and duration curves may be developed to predict how often, for what period of time, and to what depth the installation will be flooded. Stage-relation curves may be used to predict the peak stage and the time of the flood peak at the installation on the basis of the corresponding peak at an upstream gage. Unit hydrographs which show the discharge distribution for specified intervals of time resulting from one inch of runoff from a storm of known duration, may be used to predict the entire flood hydrograph at the installation, if the total effective rainfall for producing runoff has been computed by one of several methods. All of these flood characteristics may be employed to compute the largest flood which might reasonably be expected to occur during the period of operation of the installation and against which protective measures should be taken. Among such measures may be listed levee construction and channel improvement.

9. The Utilization of Hydraulic Installations for Logistical Purposes.

The utilization of hydraulic installations for water supply, navigation, and the production of electric power an integral part of the complex operations of the services of supply of a modern army. The normal peacetime functions of all significant hydraulic developments in an area where military operations are planned should be studied before the start of the campaign. The records of operation and pertinent structural details of these developments, as well as the climatological and stream flow data upon which the operations were based, should be collected and analyzed in order that planning personnel may determine the logistical value and possible employment of each structure to aid the military effort.

10. Artificial Floods as Weapons of Warfare a. The term. "artificial flood", as used in this pamphlet, applies to any inundation brought about in whole or in part by breaching of dams or levees, manipulation of control structures, or temporary damming operations. Artificial flooding techniques fall into four general categories

(1) Major flood waves, created by the sudden breaching of a dam to release large quantities of impounded water.

(2) Detrimental streamflow variations, such as those accomplished by opening and closing the outlet works of water-control structures, producing sudden changes in discharges, velocities, depths, and widths of streams, and thereby increasing the difficulties of crossing operations and navigation,.

(3) Stillwater barriers, created by flooding land, using such means as breaching levees, diverting flow from canals, sand-bagging or otherwise inducing surcharge at dams, or constructing temporary dams.

(4) Drainage obstacles or mud flats, in which the water-content of the soil is increased to create muddy conditions impeding - military overland traffic, brought about by cutting off the natural drain-age of the land, destroying pumping facilities used to drain low or marshy land, or by inducing shallow inundation of flood plains, Mud flats may also be formed by draining reservoirs,

b. The successful execution of an artificial-flooding operation involves the advance determination of many hydrologic elements that are employed in the design and operation of a flood-control project in civil works. In many cases where artificial flooding is feasible, basic hydro-logic data needed in connection with the analysis of such projects as flood control, navigation, hydroelectric power, and water supply have already been established, In planning an artificial flooding operation, the following basic data may be assembled and analyzed far in advance of the actual operation:

(1) Precipitation and runoff records for the watershed involved.

(2) Data showing river-flow characteristics in the vicinity of the site of the artificial flood, including cross sections, profiles, channel capacities and current velocities at various discharges, and the daily and seasonal variations of streamflow,

c. If the artificial flood is to be produced by the destruction of a dam, or by the manipulation of its spillway gates and outlets, the following additional data frequently may be obtained from peace-time governmental reports and technical publications

(1) Data showing the physical dimensions of the dam and reservoir, and the reservoir capacity at various pool elevations.

(2) Normal operation records of the dam, including data on outlet and spillway capacities and the time required to fill and empty the reservoir under various conditions of initial pool elevation and inflow to the reservoir.

(3) The structural condition of the dam and outlet works, determining to a great extent the sizes of breaches therein which could be created by bombs or fixed demolition charges.

d. After the feasibility and the general plan of the proposed artificial flooding operation have been determined on the basis of the data listed above, specific plans must be formulated by military field personnel. These plans must be based on hydrologic conditions prevailing at the time and at the site of the operation, which are usually determined by field investigation. The following are among the factors to be determined by field personnel before initiating an artificial-flooding operation or taking preventive measures against one initiated by the enemy:

(1) The quantity of water available for flooding purposes, either in storage or in streamflow.

(2) The capacity of flood-protection and drainage works, including information on the location, height, construction features and material of levees and dikes, and on the location and capacity of drainage ditches, culverts, and storm sewers.

(3) The limits and trafficability of the flood plain, as determined by the location and elevation of roads, the slope of the terrain, and such soil characteristics as composition, water content, and vegetal cover.

(4) The discharge capacity and bank conditions of the stream near the site of the flooding operation, which determine its effect on depths and velocities.

(5) The stream velocity required to damage bridges or impair crossing operations in the vicinity.

(6) The magnitude and timing of artificial-flood releases, based on the distance and channel characteristics between the point of control and the site of the flooding, existing flow conditions, and the elements described above.

(7) The use of temporary dams to create stillwater barriers. The feasibility, location, and type of such structures are contingent upon the military situation at the time and upon the hydro-logic characteristics of the stream in question,

The Selection of Sites for River crossings. a. Another military problem in which hydrologic aspects are important is the selection of sites for river crossings. Most amphibious and tarrying operations are complex and require a large amount of advance planning. The selection of crossing points and determination of the rapidity with which traffic can cross a river depend upon adequate advance information concerning the physical and hydraulic characteristics of the river for the particular reach 'under consideration. The vulnerability of the site to artificial-flooding operations initiated by the enemy must also be considered.

b. A hydrologic investigation should be conducted on each large river to be crossed this investigation should produce information regarding:

(1) The widths, depths, and velocities for the reach of river having possible crossing sites,

(2) The daily and seasonal variations in stage, depth, discharge, and current velocity,

(3) Icing conditions,

(4) The magnitude, duration and frequency of floods,

(5) The condition of river banks and bottom,

(6) Navigable and fordable depth and velocity ranges,

(7) The condition of approaches to existing crossing points,

(5) The location, size, and current-velocity capacity of all bridges in the reach,

(9) The location, water depth and velocity at fords and ferries in the reach.

As many of these subjects as possible should be investigated well in advance of military operations, when basic data are more readily available.

12. Flood-Prediction Services. a, The establishment of a flood-prediction service, and a hydrologic intelligence reporting network to support it, will contribute greatly to the success of artificial-flooding and river-crossing operations, and will assist in the protection of static installations located on river banks or in flood plains. The size and coverage of a flood-prediction service depend on the importance of the installations co be protected or flooded, as the case may be, and on the climate, the drainage characteristics, and the area of the watershed from which floods may emanate.

b. Preparations for a large-scale reporting network should be made early in the planning stage of a military operation so that proper equipment and adequate personnel can be assigned to the service. Codes for the transmission of hydrologic data should also be prepared during the planning stage to order that the service function with a minimum loss of time between the collection and reporting of field data. Hydrologic investigations should be made of watersheds in which hydrologic data reporting networks are to be established to secure information on watershed characteristics so that the approximate location and number of precipitation and river gages can be determined

co The following problems are likely to be encountered in operating flood-prediction services, and are discussed below:

(1) The establishment of hydrologic intelligence reporting, networks,

(2) Liaison with other military components,

(3) Development of flood-prediction techniques.

de The success of a flood-prediction service depends to a large extent on the accuracy, timing, and general dependability of the hydrologic intelligence reporting network which must be established to supply the latest field data for flood prediction. Without accurate, timely reports of weather and streamflow conditions, a flood-prediction service can not make dependable forecasts. The approximate location of precipitation and streamflow gages and reporting stations can be determined by advance planning studies, but the exact location must be established in the field. The frequency of gage readings and reports must also be decided in, the field, and will depend on both tactical and climatic conditions at the time of operation. To operate a reporting network, a message center must be set up to receive and disseminate reports from the meteorologic and streamflow stations and to dispatch flood fore-casts to all units concerned.

e. In operating a flood-prediction service, it will be necessary to establish liaison with several military components to secure and transmit field data, and to disseminate streamflow and flood forecasts to all units affected by natural or artificial floods. It will nearly always be advantageous to establish liaison with the Air Force Weather Service to assist in securing current meteorological data and periodic precipitation reports needed to opera ate a hydrologic intelligence reporting network. Liaison with the Army Signal Corps will be required both to assist in the transmission of field data and to disseminate flood and streamflow fore. casts. Liaison should also be established with engineer intelligence units to secure hydrologic data from within enemy-held territory.

f. Personnel assigned the responsibility of predicting runoff and floods should be especially trained in flood-prediction techniques during the advance planning stages of a military operation However, each stream assigned for prediction service will present problems which are unique to its runoff characteristics and which can not be covered completely in advance training. Therefore, flood-prediction personnel will need to make special studies to develop precipitation-runoff relationships and to determine streamflow characteristics for each watershed and stream. Continuous studies of precipitation, runoff and flood characteristics must be conducted by these personnel, so that flood-prediction techniques can be modified to to continually improve the forecasts. "Dry ,runs" should be conducted occasionally to test equipment and communication facilities, and to familiarize personnel with their duties.

13. Ihe Development of Military Equipment.

Hydrologic factors are important to the design and development of bridges, amphibious vehicle, ferrying and assault craft and other military equipment for use in water. Conversely, the hydraulic characteristics of a stream will have an important bearing on the selection of the most suitable type of equipment for use. For example, the depth, width, bottom material and range of velocities at a given stream crossing will determine whether ferries, pent= or pile bridges are practical for specific operations. The criteria for development of apparatus must ensure that it is capable of operation over a wide range of hydraulic characteristics. Hence the development of military equipment for river crossings requires the collection and analysis of data concerning the flow characteristics, widths, and depths of many types of streams.

14. Conclusions

a. Hydrologic problems encountered in advance military planning must generally be solved by making hydrologic investigations leading to the determination of streamflow characteristics. A large proportion of hydrologic problems encountered in military operations must be solved by field investigations to obtain details not available in the planning stage. Since the advent of the atomic bomb, dams formerly believed impregnable to bombing attack may now become formidable weapons of war. A great deal of cognizance, therefore, should be given to the artificial-flooding capabilities of all large dams.

b. In view of the short time usually allowed military personnel to make hydrologic evaluations in the field, it is essential that manuals or handbooks of hydraulic warfare be prepared for their use. Rapid solution of hydrologic and hydraulic problems can be made only if basic data are systematically collected and indexed for quick reference. Military hydrology manuals, featuring short-cut methods and containing aids such as nomographs for determining runoff and streamflow relationships, should be available in all field staff headquarters. Manuals containing instructions for operating and servicing hydrographic equipment should also be available to military hydrology units operating in the field. Military personnel assigned to important positions connected with hydraulic warfare operations and flood prediction services should be given advance training to acquaint them with basic procedures used in making hydrologic investigations and with the uses and scope of military hydrology manuals.

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