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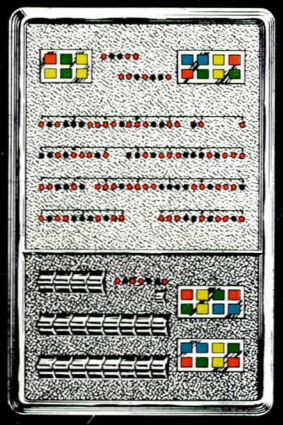
FLOOD PREDICTIONS



FLOOD ANALYSIS, CONTROL AND WATER CONSERVATION

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Mrs. Susan Brewer - Systems Modelling/Implementation Unit

Miss Trudy Misner - Engineering Writer

SECTION I - INTRODUCTION

Floods in deserts are such a contradiction at first glance that little thought is ever given to them except for idle curiosity. Swift flowing streams are rare and rivers of navigable depth almost unknown. To most residents of Phoenix and its surrounding countryside an inundation such as often occurs in the Ohio or Mississippi River basins is inconceivable. In fact, in this particular countryside there is such a sense of abject security that it is entirely possible for homes and businesses to be located within the boundaries of a known river channel.

However, a major flood in this area is not outside the realm of possibility. Further, without proper planning for prevention and protection this possibility can develop into probability. Realization of this fact led to the appointment of the Maricopa County Flood Control Agency composed of various other agencies and members including officers of the county itself, the City of Phoenix, and the Salt River Project. This agency was entrusted with investigating flood control, water conservation, and storm drainage for a specified area, together with recommendations for financing, constructing, and operating the major flood protection works for the benefit of the community.

As part of this overall program, the General Electric Company was commissioned to investigate the feasibility of using computers in the prediction of flood damage. Specifically, this information was to include how much rainfall would cause flood conditions, where (within the specified area) these conditions would occur, and to what extent.

In this particular instance, feasibility should be defined as embodying two factors: the capability of a task being accomplished or effected; and

the practicability of attempting the task. Viewing feasibility in the light of this definition, it is necessary to evaluate the nature of the specific problem and what is involved in the solution of the problem before its accomplishment or practicability can be introduced.

Obviously, one of the first factors to be considered is the science of hydrology. By definition, hydrology is a branch of physical geography that deals with the waters of the earth with special reference to properties, phenomena, and distribution. It treats specifically the occurrence of water on the earth, the description of the earth with respect to water, the physical effects of water on the earth, and the relation of water to life on the earth. In its scope and application this science involves:

1. The measurement, recording, and publication of basic data.
2. The analysis of the data to develop and expand the fundamental theories.
3. The application of these theories and data to practical problems.

In this feasibility study the physical effects of water on the earth and the particular items of measurement, analysis, and application become of prime importance. Another principal factor involves the physical or topographical aspects of the terrain; specifically, the meaningful mapping of the indicated area in relation to its hydrological aspects.

Both hydrology and map making are age-old sciences. Both date to practically the dawn of civilization. Both are founded on mans' curiosity about the world in which he lives and his attempts to control and use natural physical phenomena. Of such curiosity is science born.

As opposed to mathematics, for example, hydrology can be labeled an empirical science in that with its dealing with a multiplicity of variables, it must rely in large part on human judgement. This factor compounds the complexity of many problems and leads, not to an exact resolution, but one predicated on method.

SECTION II - PURPOSE OF THIS STUDY

The basic purpose of this study is to determine the feasibility of using computers to discover the mathematical relations between the earth's surface and the phenomena affecting this surface. It is evident that this basic purpose must be reduced to a more definite and specific object if it is to be significant. Therefore, defining the purpose more subjectively naturally leads to a determination of the effects of rainfall on a certain terrain, both under existing conditions and under conditions projected into the future. Further, this determination will be made using a mathematical model of the terrain.

Phoenix and its environs is one of the fastest growing communities in the Southwest. Pacing this tremendous growth in population has come a corresponding growth in real estate values and the structures and improvements needed to provide adequate services for this population. Churches, schools, stores, recreation facilities, transportation facilities, and many other material factors are being constructed. This building progression naturally changes both the physical and economic landscapes. Thus, what has been in the past a problem of mere academic interest, now becomes an eminently practical problem. When damage can be counted in dollars and cents, its importance becomes manifest.

Besides causing great property damage, floods take their toll in human lives not alone through the initial impact of a deluge, but through its many aftermaths. Polluted water, the cessation of transportation and communication facilities, power failures, fuel shortages, and many other catastrophies go hand in hand with major disasters. With no protection this situation

becomes critical. Even with some planning it can be relatively grave. And, with the best of planning and material protection, disasters still strike.

This then is the main goal of adequate flood control -- to protect life and property and to keep to a minimum the accompanying dangers. A secondary aspect is city planning itself. It is virtually impossible to plan a city sewer system or overall zoning, for example, without a clear picture of the forces affecting this area. In such a rapidly changing area, it is impossible to use simple interpolation or repetitive elements. It follows, therefore, that a planned approach is a necessity. After a suitable approach has been agreed upon, information is gathered, analyzed, and evaluated. Section III of this report discusses the approaches to this problem and later sections discuss the feasibility of using a computer to solve the problems.

SECTION III - APPROACHES TO THE PROBLEM

In order to study the effects of rainfall on a terrain, it is necessary to obtain adequate and workable knowledge of the physical make-up of the area, a precipitation record of the defined area including storm history, and runoff records of the area under consideration. In addition, the affected area must be critically defined. Boundaries must be set and the topography within these boundaries must be characterized. In a feasibility study such as this, these factors are inter-related and all must be taken into consideration to attain an effectual, comprehensive judgement.

Depending on the accuracy of these records (area, precipitation, and runoff), either singly or in combination, different approaches may be considered toward the solution of the stated problem. Each of these approaches must be analyzed and evaluated critically before a determination of the <u>most</u> feasible approach can be made. In arriving at this determination, maximum possible accuracy and dependability are criteria of no mean weight.

The area under consideration for the present study has a magnitude of approximately 1100 square miles and is indicated by the shaded area on the map designated as Fig. 1. Recent maps of sufficient accuracy for this area do not exist. Inasmuch as the lack of most any data may be bridged <u>except</u> the lack of knowledge regarding the physical area, one of the principal problems becomes an accurate mapping of this area relative to flood studies. The cost and time involved in mapping rapidly changing areas makes it imperative that some suggestion be provided as to various approaches to this problem.

Discussion of the recommended equipment and techniques are included in Section IV of this report.

FLOOD PROTECTION IMPROVEMENT COMMITTEE REPORT

EXHIBIT NO. 2

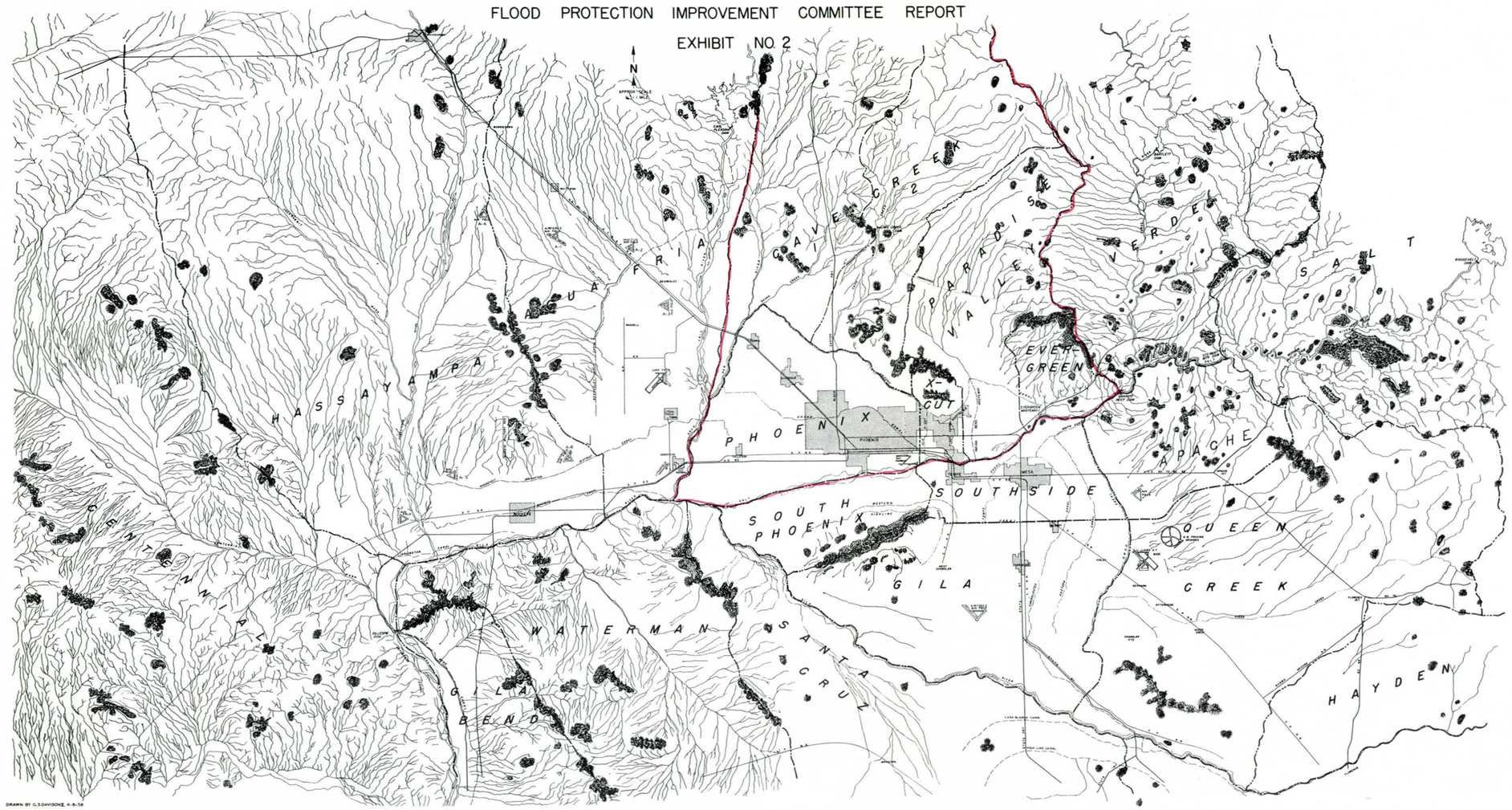


Fig. 1

Phoenix and its surrounding area have two continuous recording precipitation stations located at the United States Post Office and at Sky Harbor Air Terminal and seven non-recording precipitation stations located at Alhambra, Phoenix Indian School, Goulds Ranch, Camelback, Tempe, Tempe University of Arizona Citrus Experimental Station, and Mesa Experimental Farm. Fig. 2 shows that some of these fall directly within the study area and thereby give good records of the sub-areas under consideration. Some are located in surrounding areas which show sufficient similarity that they can be utilized in transposing precipitation data. Some sub-areas are completely devoid of records.

Discussion of study techniques with good records and for those with non-existent ones follow. Stations marked with an "X" on Fig. 3 show suggested locations for stream discharge recording gages.

The map shown as Fig. 4 shows the location of existing stream discharge recording gages. This same map shows the locations of recording precipitation stations and also non-recording precipitation stations. In the semi-arid area under examination the majority of the streams are dry a large percentage of the time. However, this does not lessen the importance for recording the time and magnitude of stream discharges and precipitation. Flash floods are dangerous. The advantage of enough stream discharge recording gages and adequate coverage by recording precipitation stations is evident. Therefore, the installation of additional discharge recording gages and recording precipitation stations is strongly recommended.

As has been stated previously, there is a wide range of available records. On one end of the scale is a well-documented basin; at the other end

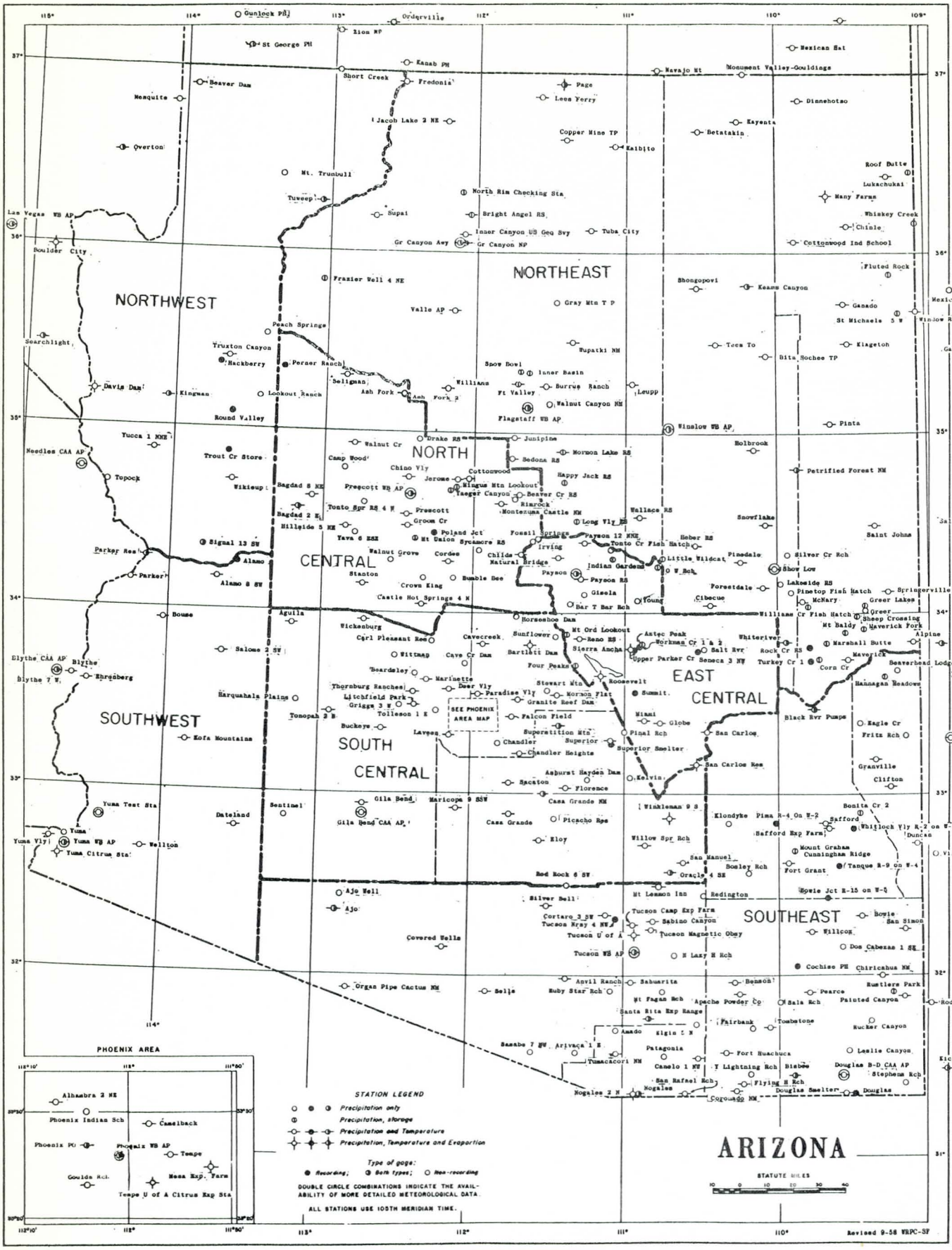

NORTHWEST
NORTHEAST
NORTH
CENTRAL
EAST CENTRAL
SOUTHWEST
SOUTH CENTRAL
SOUTHEAST
ARIZONA
PHOENIX AREA
SEE PHOENIX AREA MAP
STATION LEGEND
Precipitation only
Precipitation, storage
Precipitation and Temperature
Precipitation, Temperature and Evaporation
Type of gage:
Recording; Both types; Non-recording
DOUBLE CIRCLE COMBINATIONS INDICATE THE AVAILABILITY OF MORE DETAILED METEOROLOGICAL DATA.
ALL STATIONS USE 105TH MERIDIAN TIME.
STATUTE MILES
Revised 9-58 WRPC-SF

Fig. 2

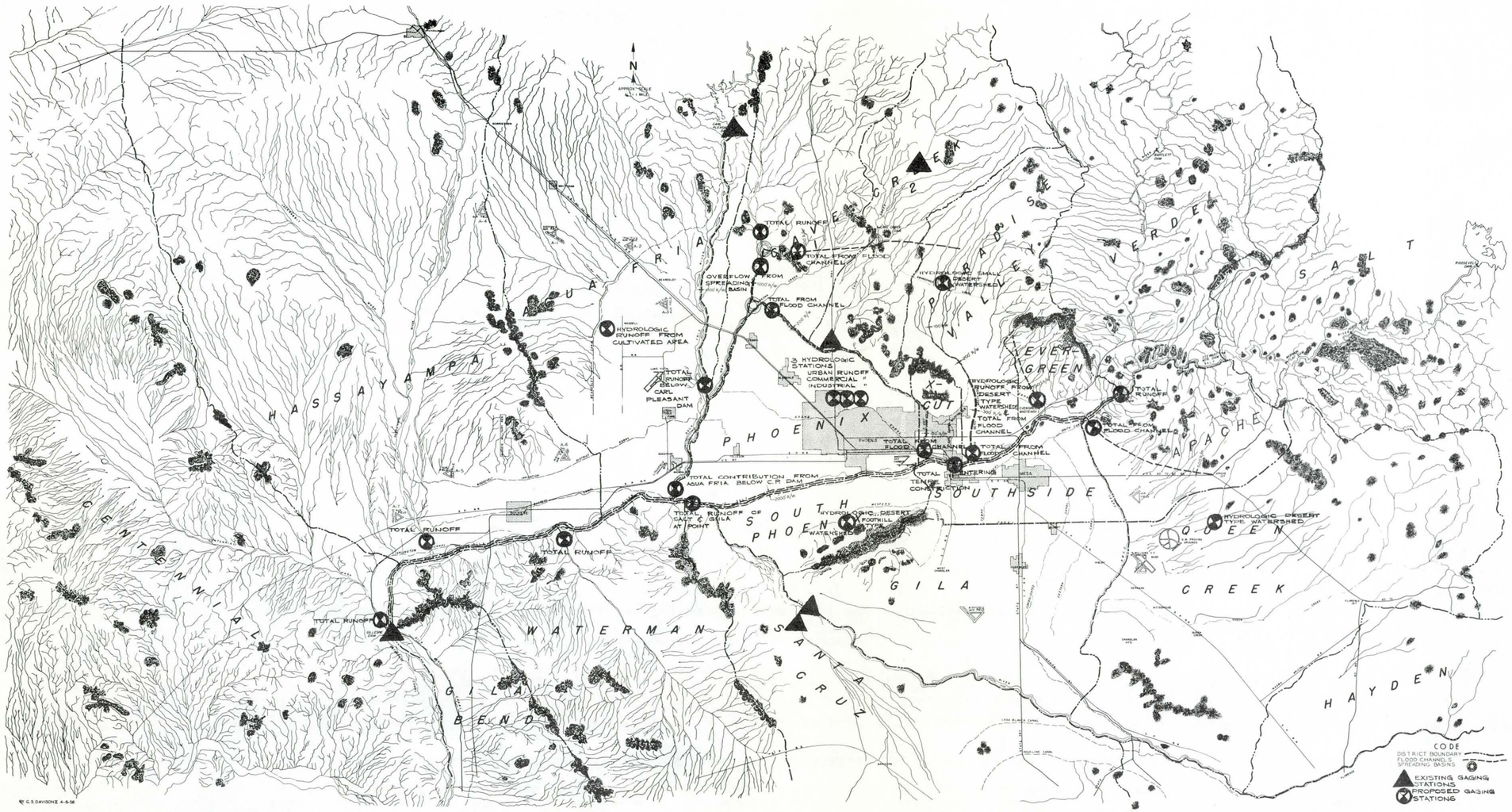
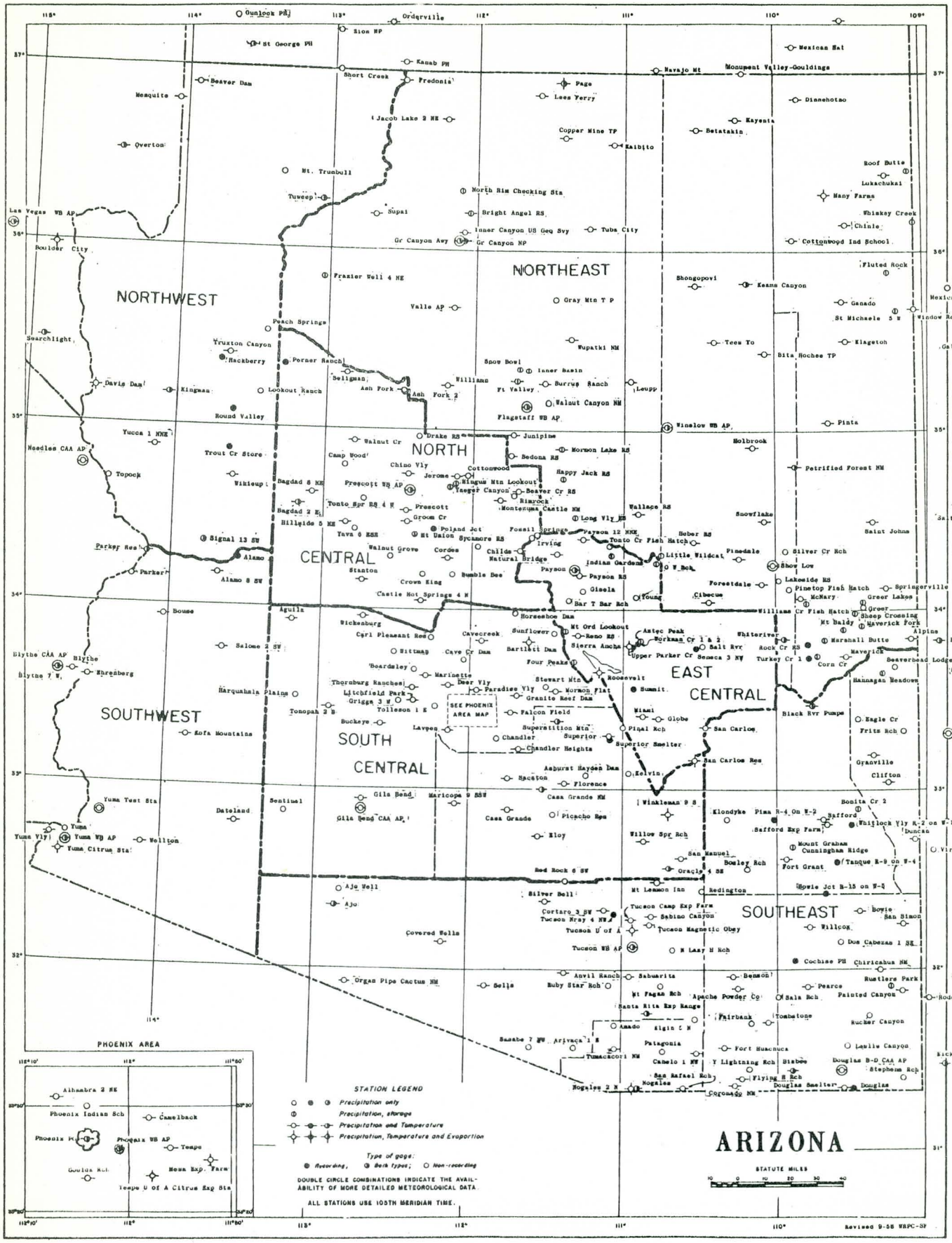

N
HASSAYAMPA
CENTENNIAL
WATERMAN
GILA BEND
SANTA CRUZ
GILA
CREEK
HAYDEN
PHOENIX
SOUTH PHOENIX
SOUTHSIDE
EVER-GREEN
APACHE
QUEEN
SALT
VERDE
PARADISE VALLEY
AGUA FRIA
TOTAL RUNOFF
TOTAL FROM FLOOD CHANNEL
OVERFLOW FROM SPREADING BASIN
HYDROLOGIC RUNOFF FROM CULTIVATED AREA
CARL PLEASANT DAM
HYDROLOGIC STATIONS URBAN RUNOFF COMMERCIAL " INDUSTRIAL "
X-CUT
HYDROLOGIC RUNOFF FROM DESERT TYPE WATERSHED & TOTAL FROM FLOOD CHANNEL
TOTAL FROM FLOOD CHANNEL
TOTAL CONTRIBUTION FROM AGUA FRIA BELOW C.P. DAM
TOTAL RUNOFF OF GILA & SALT RIVERS AT POINT
HYDROLOGIC DESERT FOOTHILL WATERSHED
HYDROLOGIC DESERT TYPE WATERSHED
TOTAL ENTERING CONSTRUCTION
CODE
DISTRICT BOUNDARY
FLOOD CHANNELS
SPREADING BASINS
EXISTING GAGING STATIONS
PROPOSED GAGING STATIONS

Fig. 3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DOUBLE CIRCLE COMBINATIONS INDICATE THE AVAILABILITY OF MORE DETAILED METEOROLOGICAL DATA.
ALL STATIONS USE 105TH MERIDIAN TIME.
STATUTE MILES
Revised 9-58 WBPC-SF

Fig. 4

of the scale is a basin with a complete absence of records. In between are basins where records are scanty, incomplete, or inadequate. The 1100 square mile area being examined breaks into sub-basins running the gamut of the above-described criteria. To establish feasibility it is necessary to examine each of the methods used to develop a basis for drawing an accurate picture taking all factors into consideration. In other words, a method to develop the unit hydrograph which will stand as the "representative" for the particular basin for which it was developed.

By definition, a unit hydrograph is the hydrograph of storm runoff at a given point that will result from an isolated event of rainfall excess occurring within a unit of time and spread in an average pattern over the contributing drainage area. In actual practice, the unit hydrograph represents exactly one inch of runoff from the contributing area. If this theory is sound, and for purposes of this report it is assumed to be sound, the hydrograph of runoff for any similar storm of the same duration will be established for the basin under consideration.

A well-documented basin is an ideal condition. Here, only meteorological and hydrological data are examined to the exclusion of detailed topographical data with the assumption being that all topographical factors are accounted for by the hydrograph shape. The method used to develop a unit hydrograph for this ideal condition encompasses an approach to a unit hydrograph assuming that all necessary rainfall and runoff data are available for the basin being studied. The following steps will result in this unit hydrograph.

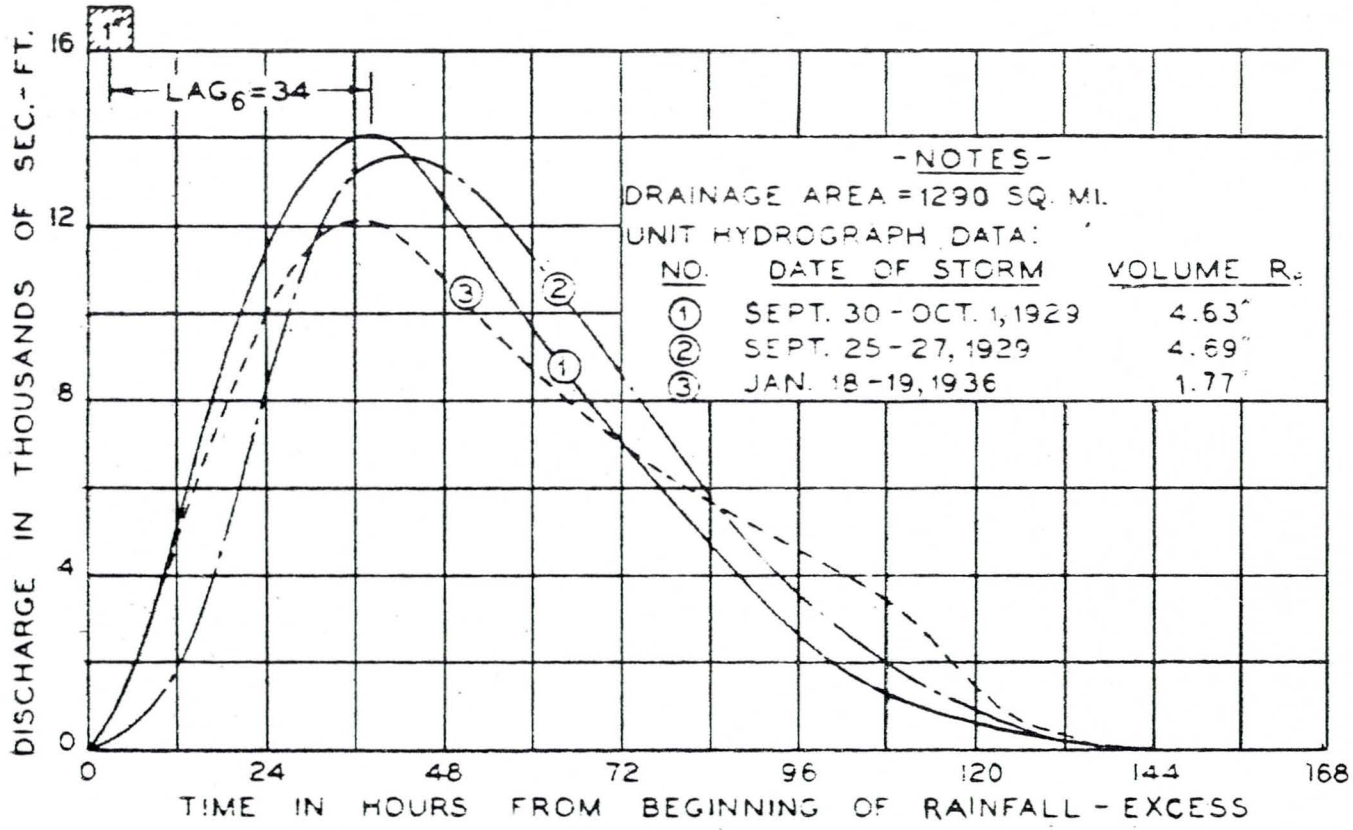
An existing stream discharge recording gage is selected in the study basin. This gage is the one located at the most desirable point for purposes

of study. Choosing the gage at the most desirable point will depend almost entirely on the considered judgement of a competent hydrologist. After the stream discharge gage has been selected, it is necessary for a choice to be made of floods with suitable characteristics. Here again, the judgement of the hydrologist is important in selecting floods of sufficient magnitude, having separable peaks resulting from periods of precipitation not too closely compounded, and from critical seasons of the year. Using published data from Geological Survey Water Supply Papers, hydrographs of selected floods are plotted. These plottings are corrected for any upstream storage which would affect the natural flow of the stream. The base flow is then subtracted from the hydrograph to arrive at the storm hydrograph.

The next step is to determine periods of excess rainfall to analyze the precipitation occurrence which caused the storm runoff. By definition, "rainfall excess" is that portion of the rainfall that enters the stream channel as storm runoff. The unit hydrographs are then isolated and compared, "misfits" discarded, and the remainder are averaged to arrive at the "representative" unit hydrograph for the basin under consideration.

The determination of lag time and volume of runoff represented by the area under the curve of the unit graph are the last steps to be taken. The lag time is the time, in hours, from the centroid of the rainfall to either the instant when one-half of the volume of runoff passed the gage, or to the peak of the unit graph. A typical unit hydrograph is shown in Fig. 5.

Some drainage basins are completely devoid of any rainfall or runoff records, and no other basin with substantially similar characteristics is known. In other words, this is a case of complete absence of both records



SIX HOUR UNIT HYDROGRAPHS, SALUDA RIVER
AT CHAPPELLS, S. C.

and usable data. For basins falling into this category it becomes necessary to construct a synthetic unit hydrograph.

In order successfully to build this unit hydrograph, a number of equations and definitions must be introduced. For purposes of this study these will include:

$$t_p = C_t \, (L \bar{L})^{0.3} \qquad \text{(lag)} \qquad (1)$$

$$t_r = \frac{t_p}{5.5} \qquad \text{(unit rainfall duration)} \qquad (2)$$

$$q_p = \frac{640 \, C_p \, A_d}{t_p} \qquad \text{(peak cfs/sq. mi.)} \qquad (3)$$

$$t = 3 + 3 \, \frac{(t_p)}{(24)} \qquad \text{(time base of unit hydrograph)} \qquad (4)$$

t_p = Lag time from midpoint of unit rainfall duration to peak of unit hydrograph, in hours.

t_r = Unit rainfall duration in hours.

q_p = Peak rate of discharge of unit hydrograph in cubic feet per second per square mile of drainage basin.

t = Time base in days of unit hydrograph.

L = Distance in miles from the gaging station to the upstream limits of the basin along the main drainage course.

$\bar{L}$ = Distance in miles from the gaging station to the center of gravity of the drainage basin along the main drainage course.

A_d = Drainage area in square miles.

C_t and

C_p = Empirical coefficients descriptive of the area.

It should be noted that the gaging stations referred to in these definitions are hypothetical points lying somewhere in the basin wherein no adequate data exists. Decision as to the choice of the location of these arbitrary stations lies solely in the considered judgement of a competent hydrologist. However, the hypothetical gaging station is usually based at the point of confluence or at a critical point below which great damage could occur in case of a flood.

To begin to build up a synthetic unit hydrograph the hydrologist will first derive the empirical coefficients C_t and C_p, if they are not already established, for the general area of the study. In deriving the coefficients, unit hydrographs from the same regional area should be utilized.

The empirical coefficients C_p and C_t which are representative of the particular study area are used in equations 1 through 4. The hydrologist then calculates q_p from the equation

$$q_p = \frac{640\ C_p\ A_d}{t_p} \qquad (5)$$

which gives the peak discharge in cfs/sq. mi. for the unit hydrograph of the basin under study. The q_p should then be substantiated using judgement and by checking with envelope curves. When the q_p has been substantiated, the lag, unit rainfall, and the time base of the unit hydrograph are computed from equations 1, 2, and 4. This results in the primary characteristics defining the unit hydrograph. Discharge in cfs can be determined by taking q_p times A_d for determining the unit hydrograph.

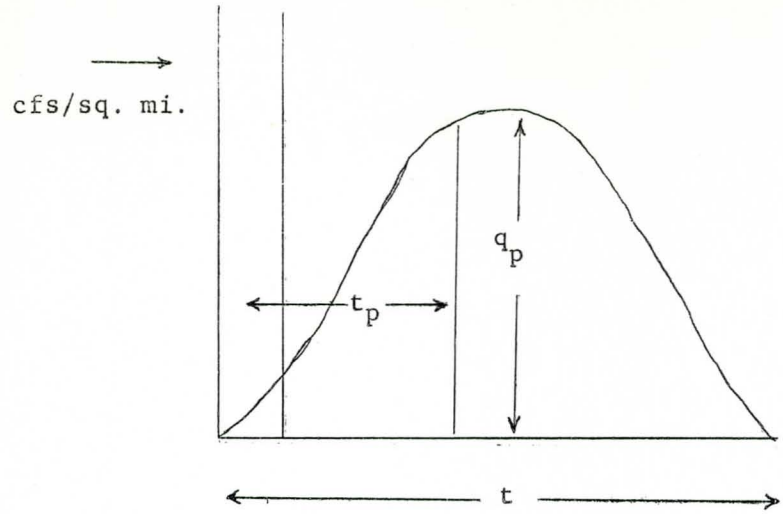


Fig. 6. Synthetic Unit Hydrograph

Reference has previously been made to those basins where records are scanty, incomplete, or inadequate, but where there are comparable basins with satisfactory records and with similar characteristics. Here, another method for developing a "representative" unit hydrograph can be utilized. If, for example, no information regarding a particular basin is available except its topographical and vegetative characteristics, it becomes necessary to build the unit hydrograph by transposing known data from a known basin exhibiting similar characteristics and preferably in the same general area.

The first step in the development of a unit graph based on such information is to explore existing hydrological records to find drainage basins with similar characteristics and which have adequate rainfall and runoff data available. After the hydrologist has selected similar basins, and the unit hydrographs for these basins have been determined, the unit graph for the unknown basin is constructed as follows:

Modify equation (1) to include the effect of basin slope S. Thus, equation (1) can be rewritten as:

$$t_p = C_t \frac{(L\,\bar{L})^n}{\sqrt{S}} \qquad (6)$$

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Then the observed lag for the similar basins are plotted on full logarithmic paper against their corresponding values of $\frac{L\,\bar{L}}{\sqrt{S}}$. These points will define a straight line as shown by

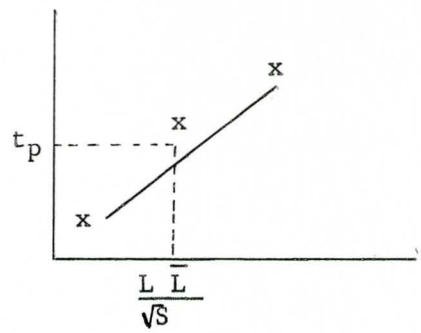

Fig. 7. Graphic Determination of
Lag Time for Transposed Unit Hydrograph

By evaluating $\frac{L\,\bar{L}}{\sqrt{S}}$ for the basin being studied, the t_p for the particular study basin can be read off the graph.

Next, the unit hydrographs of the similar basins are reduced to common ordinates and abscissas by expressing the discharge of each in cfs/sq. mi. and the time as a percentage of the respective basin lag.

Naturally, all the reduced unit graphs from the selected characteristic basins are available for immediate comparison. The comparison is then made as shown, the misfits discarded, and the remaining curves averaged to arrive at a representative curve upon which to base the unit hydrograph for the basin under study.

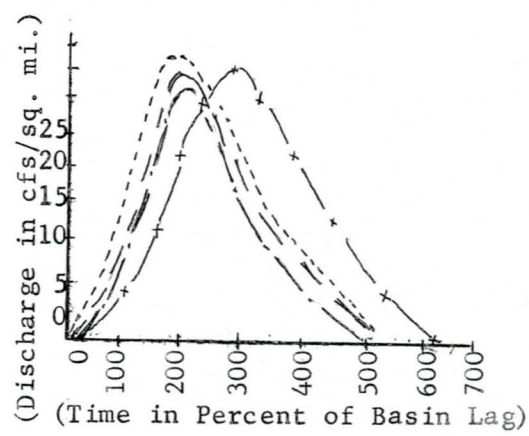

Fig. 8. Transposed Unit Hydrograph

The curve expressed in "cfs/sq. mi." and "time in percent of basin lag" can then be applied to the area of the study basin and the previously determined lag time to arrive at the transposed unit hydrograph.

This unit hydrograph can then be checked against envelope curves and other unit hydrographs to ascertain the logic of the result.

Thus, the hydrologist, by a deductive process, has constructed a unit graph which may be applied to the basin where only topographical and vegetative data were known originally.

In addition to hydrological records, which at their best cannot be designated as an entirely complete basis for operation, it is necessary -- as stated before -- that the area be critically defined. Inasmuch as hydrological and topographical data are inter-related entities in a study such as this, it becomes increasingly important that both be as accurate and complete as possible.

Speed is essential. Surveying, and subsequently mapping, by conventional methods is a time consuming process. Editing of completed maps adds another arduous task. Therefore, the feasibility of using photogrammetry for the mapping process should be thoroughly investigated.

The most expensive item in a photogrammetric survey is the establishment of control points. Of necessity, this must be done on the ground and its purpose is to establish control points for the aerial survey. Prior to or after these ground control points are established, the area is flown in strips with an overlap of approximately 60 percent in the line of flight and 20 percent laterally. Any one of the stereoscopic pairs of photographs becomes a model containing vertical control points (five desirable) and

horizontal control points, as determined by the preliminary ground survey. These models are processed and subsequently plotted.

Photogrammetry can be automated still further if desired. Use of a computer in this phase of the study will save considerable expense in that it will no longer be necessary physically to draft and edit the maps. For this purpose it is sufficient to feed numerical X, Y, and Z coordinates in a grid pattern into the computer and let the computer define the topography of the area. Utilizing present techniques, it is perfectly feasible to derive these coordinates directly from the stereoscopic pictures, without human interference or chance of error as far as misreadings or transposition of figures is concerned. Much narrower contours can be determined in the "computer map" than by manual plotting on paper. This added accuracy alone can result in a considerable saving both in time and money. For example, a 1000 foot per inch scale, which on paper would result in a 20 foot contour, will yield contours as narrow as five feet on a computer. All, or any part, of this "computer map" can, and will be displayed on a screen similar in appearance to a TV picture tube at the monitoring scientist's discretion.

The repetivity of arithmetic operations in a computer can be used to advantage in clarifying relations between variables. It follows, therefore, that the computer becomes increasingly valuable in all phases of this study as the realm of concrete measurements is left and progress made toward the more theoretical approaches. This coupled with the fact that most weather observations in most study areas tend to be spotty, gives added impetus to the attempt to computarize the complex hydrological standards.

It may now be pointed out that, with the increasing influx of humans as well as industry into the American Southwest, ravages of storms which previously held theoretical interest only, become crucial in terms of potential damage, human as well as material. Increasing density of recording networks will, of course, be helpful in recording damage once it has occurred. But, it is expedient to use modern tools to make more and more accurate predictions of this damage. In this effort it is necessary to make the best possible use of the existing information, spotty as it may be, and use the analytical ability of the human mind to transpose this information into meaningful conclusions.

SECTION IV - COMPUTER FEASIBILITY

The discussion in Section III - APPROACHES TO THE PROBLEM indicated that hydrology is an empirical science whose resolution is predicated on method. The tremendous number of variables, the unstable nature of these variables, and the lack of documentation are contributing factors to this inexactitude. Substantial support can be given the hydrologist in utilizing and developing his science by the use of electronic computers since vast amounts of information can be stored and processed with rapidity and consistency in these machines. This section of the report will discuss in detail the feasibility of using a computer in hydrological studies and make recommendation as to what specific equipment would prove of most value.

It is recommended that a digital electronic computer be used taking into consideration the following factors:

1. Only a digital computer has the necessary capacity required to store the quantity of information needed to perform hydrological systems studies.
2. The treatment of information must be consistent in that many passes over the same information must yield the same accurate results.
3. Any variation in the basic data must be identifiable with the results so that the accuracy of basic hydrologic data can be determined and verified.

In addition to the recommendation that a digital computer be used, certain qualifications must be met. A large computer is necessary expeditiously to handle the required storage. Rapid access to this storage is essential so that the monitoring hydrologist can recover data quickly in

order that pertinent information can be reviewed and modified with minimal delay. Therefore, a high-speed, rapid-access, commercially-available computer is recommended. This computer should be of sufficient size to meet the stringent storage requirements. As the program logic develops and becomes more sophisticated, it may be expected that special-purpose large-scale computers will be required. It is entirely possible that this future computer will be either developed specifically for hydrological analysis or it may be a modified, commercially-available, general-purpose machine.

At the present state of its development it is recognized that hydrology is a highly interpretative science. In using computers in hydrological analysis it will be highly desirable that the hydrologist follow, review, and improve the processing of information as definable to a computer. Digital computers process information with an exactness which requires complete problem definition and solution. In hydrology, certain areas of judgement cannot be represented with this exactitude of definition, thus making it mandatory that hydrologist-computer communications be pre-requisite to any utilization of these machines on a broad, systematic approach. IT IS EMPHASIZED THAT THE UTILIZATION OF LARGE-SCALE COMPUTERS IN HYDROLOGY WILL NOT REPLACE OR OBSOLETE HYDROLOGISTS. Basic, trivial, decisions can be computer processed. The judgement and experience of a hydrologist can not be computer processed. These facts give the hydrologists definite control over the results gained by using computers.

A review of information and the computer's treatment of this information must be readily accessible to the hydrologist. This accessibility can take the form of constructed electronic displays of computed, assumed, or

stored hydrographs. Contour and detail maps of the entire, or any part, of the gross area under investigation, or mathematics (and corresponding constants used in equations) may also be electronically displayed.

The monitoring hydrologist's task is to choose what information is necessary for the computer program, what information should be deleted, or what information modified. For example, within the limits of data availability he can inform the computer to process all the ready data for unit hydrograph development for any of the three methods of development. He can select the optimum design storm on which the area's hydrology studies can be based. He can outline forecasted area modifications to take into consideration increasing urbanization, review flooding possibilities, water conservation status, and flood protection requirements. The monitoring hydrologists can outline prospective flood protection projects directly to the computer and have an analysis immediately processed of their adequacy and their cost benefit ratios. It should be possible for hydrologists to modify constants and even equation forms used within the computer by a trial and error process, based on repeated program operations. Records of these trial constants and trial equations can be stored in the computer and reviewed periodically so that duplicating researches are obviated.

It can be concluded, therefore, that the developed computer program is not necessarily for analysis only, but can also be used to develop better methods of analysis, to forecast future required flood protection, to integrate these flood protection efforts with presently planned construction, and to establish whether areas are economically suited (protection-wise) to development.

A flexible computer program is considered to be most feasible at this present state of computer development. Initial efforts will be basically simple with a major emphasis on human judgement. The communication capabilities of hydrologist-computer and, conversely, computer-hydrologist must be at a high state of development. With present commercially-available equipment it is possible rapidly to display graphs, maps, and equations to the hydrologist. With other available equipment, the hydrologist can modify, delete, or extend information displayed to him. It is emphasized that first of all the computer displays will be within the hydrologist's currently used techniques. In fact, initially, the computer will process only recognized hydrology techniques and will be used primarily for production and not as a research tool in the development of new hydrological techniques.

It can be expected that the hydrologists directly associated with the program development and operation will, within a short period of time, suggest amplifications to the program. These hydrology-analysis changes may well include use of much data which is presently being overlooked by existing methods; e.g., topographical data. Apparently, hydrologists are not presently examining detailed contour information in their analyses. The actual effects of elevations or soil conditions (type, moisture content, cover, etc.) generally are not reviewed. Possibly much of this information is unavailable and probably, if it were available, human intelligence could not treat this amount of data rigorously. However, a computer can handle this amount of data quickly and effectively.

It is expected that computer running time will be less than one-half hour for a complete hydrological analysis of the 1100 square mile area most

critical to metropolitan Phoenix. This estimate includes the time delays necessary for the monitoring, interrogating, and modifying of the computer's analysis.

Photogrammetric scanners are presently being developed which will, with minimal costs, rapidly review aerial photographs and automatically record on computer cards or tape whatever information is desirable for computer processing of hydrology analysis. Use of these automatic scanners will materially expedite hydrological analysis in previously undocumented desert areas. The advantageous costs of topographical analysis will reduce the cost/benefit ratio and the processing of this information.

The application of computers to hydrological systems analysis is not restricted to the Phoenix area. It is expected that the same computer program which is applied to Phoenix's flood analysis, flood control, and water conservation problems can be applied to other regions and cities. Certainly program input parameters (e.g., optimum design floods, rainfall data, hydrographs, drainage basin sizes and shapes, contour and soil information, etc.) will be different, but the storage and computer processing of this information will be sufficiently similar (with competent monitoring by a hydrologist) for application of the same computer program and man-machine communication techniques as used in Phoenix. In other words, the use of the same anticipated scanning devices, same computer, and same program can be <u>general</u> and <u>generally applied</u>.

Computers in scientific endeavors can be applied with advantage either to situations where there is too much data for human assimilation and treatment or to situations where too little information about a complex process is available.

Hydrologists may well criticize the lack of available basic information. Equally, they may state that they do not know the relationship of this minimal amount of data (e.g., detailed rainfall and runoff samples) to other data which is available (e.g., rainfall and runoff data from similar hydrologic regions). Using computers, this relationship can be established. Again, for example, knowing the topographical characteristics, the existing drainage systems, and the rainfall records, it is possible to converge, by rapid iterations within the computer, to estimations of runoff at an unlimited number of positions, using as checks the known runoffs at a limited number of locations.

Summarizing, the advantages of this feasible application of computers to hydrology are:

1. Vast amounts of information can be stored.
2. With minimal data, it is possible to correlate and establish relationships with other data, extending the amount of information which can be applied to the hydrology effort.
3. Data changes (e.g., subdivision development or drainage system construction) of any magnitude can be easily entered in the computer's memory for future reference and treatment.
4. Large hydrological analyses can be accomplished quickly without presently existent study delays.
5. The basic analysis is done impersonally and will be accomplished with a minimum of human interpretation.
6. Those relationships between information and results which can be expressed mathematically will be processed accurately and quickly.

7. The presence of a hydrologist while the program operates permits certain decisions that are dependent on his overall experience and judgement to be readily entered as logic within the computer.

8. By recording, and having available, previous attempts to adjust constants, equation-variable relationships, and analysis techniques, repetitous researches in hydrology studies will be reduced and research will advance more rapidly to a science with exact resolutions.

SECTION V - SUMMARY AND CONCLUSION

It is fortunate that the advances in science and technology have so paralleled the rapid rise of an expanding economy that, as a consequence, newly valuable lands can be adequately protected. A great step forward will be made when the forces of nature, which so puzzle mankind, can be divided into their discrete elements and their interrelations clarified thereby affording the possibility of reasonable prediction.

The advent of computers and computer technology has taken the drudgery out of the numerous computations necessary, thus leaving the human brain free to explore the basic relations. Hydrology, photogrammetry, and computer analysis can be another alliance that will explore the now barely perceived relationships between nature's forces.

Being cognizant of these factors, and taking into consideration the material previously presented in this report, the following conclusions are drawn:

1. A tighter net of recording precipitation and runoff gaging stations is necessary to provide adequate data on which to base accurate predictions.

2. Additional contour records are necessary to augment hydrological data.

3. Computer programs should be prepared to digest the records thus produced.

4. Predictions programs should be prepared based on mathematical results yet to be discovered.

5. Follow-ups of prediction programs should be made, reprogramming when necessary to improve accuracy.

6. A computer program should be run combining all three types of hydrographs. Results of this run should be compared to allow the selection of the most pertinent type.

7. Because computer technology and photogrammetric sciences are sufficiently advanced to implement the above conclusions, it is recommended that these efforts be initiated immediately and the present investigations continued and extended.