Flood Control District of Maricopa County

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ARIZONA, U.S.A.

Final Report for the

Flood Warning Services Market Survey Study (FCD 89-75)

January 1992

JMM James M. Montgomery

Cover Photo: **Residential flooding in metropolitan Phoenix on August 14, 1990, near Alta Vista Road and 43rd Avenue.**
(Courtesy of the Flood Control District of Maricopa County)

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JMM James M. Montgomery
Consulting Engineers, Inc.

January 2, 1992

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ATTN: Mr. Thomas M. Donaldson
Hydrologist

SUBJECT: Final Report - Flood Warning Services Market Survey Study
(FCD 89-75)

Gentlemen:

James M. Montgomery, Consulting Engineers, Inc., (JMM) is pleased to present twenty-five (25) copies of the final report for the subject project.

The objectives of this project were to evaluate flood warning technology, identify the understanding of and perceived need for flood warning within Maricopa County, and develop flood warning alternatives for possible implementation by the District. An economic evaluation was also performed to identify the feasibility of improving flood warning services in Maricopa County. This report presents the study methodology and findings.

We are available to discuss any aspect of our report at your convenience. If you have any questions, please do not hesitate to call.

It has been a pleasure working with the District on this interesting project.

Very truly yours,

Laurie T. Miller, P.E.
Project Engineer

Fred K. Duren, Jr., P.E., P.G.
Project Manager

/jw

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Flood Warning Services Market Survey Study (FCD 89-75)

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FLOOD CONTROL DISTRICT OF
MARICOPA COUNTY

FLOOD WARNING SERVICES MARKET SURVEY STUDY

Prepared by

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January 1992

Final Report

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Executive Summary

EXECUTIVE SUMMARY

INTRODUCTION

This report describes a study undertaken for the Flood Control District of Maricopa County (District) by James M. Montgomery, Consulting Engineers, Inc. (JMM). On October 15, 1990, the District authorized JMM to perform a Flood Warning Services Market Survey Study. The purpose of the study was to survey and evaluate the need for and feasibility of improving flood warning services within Maricopa County.

BACKGROUND

The District operates flood control facilities in and around Maricopa County and participates in storm drainage projects which cross multiple jurisdictional boundaries. In conjunction with the role of operating flood control facilities during major flooding that occurred in 1978 and 1980, the District found itself in the very difficult situation of making decisions having little or no real-time data with which to perform. Consequently, the District began a scheduled program, over the next 10 years, of installing and operating a network of telemetered precipitation and stage gages for data collection. The resulting current system of telemetered gages transmit data to the District which in turn shares that information with the National Weather Service (NWS) for use in its responsibility of issuing flood warnings in Maricopa County.

Climatic conditions in central Arizona produce intense storms which can cause flash flooding, associated property damage, and serious injury or loss of life. As a result, the District is expanding the data collection system and improving flood warning services as a means of nonstructural flood control.

A constraint of current NWS activities is that the flood warnings issued cover large areas, such as large portions of the County and, in some cases, the whole County or even several counties. Further, the false alarm and unwarned event rates are relatively high. Local flood warning services would supplement the NWS operations by developing more location-specific information on flood threat and improving the accuracy of local flood warnings. This study addresses the need for and the feasibility of a local flood warning system in Maricopa County and makes recommendations of flood warning program alternatives.

EVALUATION OF FLOOD WARNING TECHNOLOGY

JMM evaluated a number of flood warning technologies for potential implementation in a flood warning program for Maricopa County. The types of technology include currently available components, such as precipitation and stage gages, and weather forecasting tools, such as radar, satellite, and lightning strike data.

Telemetered precipitation and stage gages provide useful real-time rainfall and runoff measurements of storm conditions as they occur. Weather forecasting tools aid in forecasting storm conditions before they occur but are limited in their abilities to provide quantitative forecasts at specific locations.

Improved future technology was also evaluated and includes Next-Generation Doppler Radar (NEXRAD), the planned new series of Geostationary Operational Environmental Satellites (GOES-NEXT), and other forecasting tools. The new technologies are under development and, when implemented, will provide more useful quantitative weather data. However, these federal programs are experiencing scheduling and budgetary difficulties. As a result, implementation by the federal government will probably be delayed for several years.

Development of a Geographic Information System (GIS) flood warning application was also investigated. The application would enhance flood warning capabilities, especially in the future when NEXRAD data become available. However, incorporating GIS into a flood warning program has not been routinely developed in other areas of the country. Therefore, inclusion of a flood warning application with the District's GIS would be a developmental effort given the state-of-the-art in this field.

MARKET SURVEY

To assess the communities' understanding of and needs for flood warning services, JMM prepared three separate questionnaires for distribution to 250 individuals from three categories of participants based in Maricopa County. The categories and number of participants include: 50 managers and administrators, 100 technical staff and users/implementors of flood warning services, and 100 homeowners.

The managerial group was composed of mayors, city council members, heads of agencies, and others in decision-making or policy-setting roles.

The technical group included city engineers, police and fire chiefs, public works directors, and others who would be involved in flood warning services within the County. Also part of the technical group were potential users of flood warning services such as utilities, transportation companies and the media.

The homeowners group was based on population density and on geographic representation throughout the County, with each community receiving at least one questionnaire. Participants were selected from membership lists of homeowners' associations where available and by consulting officials within the community for suggestions of homeowners to participate in the survey.

The results of the market survey indicate that there is strong interest in improved flood warning services, particularly in the homeowners' group. The survey also showed that there is a strong correlation between interest in improved flood warning services and the perception that the County is threatened by flooding. Desired flood warning system improvements indicated by the survey include additional precipitation and stage gages, more site-specific flood warnings, and longer lead time prior to a flooding event. There is also a high interest in generating maps to show expected inundation areas during flooding events.

As part of the marketing survey, the accuracy of the existing NWS flood warning services was reviewed. Verification information was obtained for Maricopa County from the NWS for flash flood and severe weather warnings for the past several years. For flash flood events in Maricopa County from 1986 through 1990, warnings were issued for only slightly more than one-half of the events that actually occurred (7 of 13 events). Additionally, there were 29 false alarms, where a warning was issued but no event occurred. In the severe weather category, flood warnings were issued for less than one-half of the actual events (35 of 77 events), and 50 false alarms occurred.

As a further indication of adequacy of existing NWS flood warning services, average lead time for the warned events for the five-year period was calculated. In the past five years, average lead time was approximately 40 minutes, with 10 of 42 verified events having a lead time of 10 minutes or less. In comparison, the market survey results indicate a need for one to two hours of warning before a flooding event.

Other selected findings of the market survey are listed below:

- The District was chosen second most frequently to NWS by the managerial and technical groups as best-suited to collect and analyze weather data.
- The District was selected most frequently by the managerial and technical groups as best-suited to collect and analyze rainfall and runoff data.
- The District was selected most frequently by the technical group as best-suited to act as decision-maker for issuing flood warnings, with NWS and Civil Defense ranking second and third, respectively. The managerial group selected NWS most frequently, with the District and Civil Defense ranking second and third, respectively.
- Top selections for best-suited to act as decision-maker for evacuating areas include the sheriff/police, as well as a mix of the District, Civil Defense and mayors.

FLOOD WARNING ALTERNATIVES

Based on the findings of the evaluation of flood warning technology, the market survey, and discussions with District personnel, JMM developed five alternative flood warning scenarios.

The District has stated that it does not wish to assume a flood warning role in which it warns the public directly. Rather, it would assume either an "active" role, defined as warning selected agencies when flood threats occur, or an "inactive" role, where other local agencies would contact the District. The local agencies would then be subsequently responsible for warning the public. In any case, the District would coordinate its flood warning efforts with the NWS, Civil Defense, and other agencies affected by flooding.

Each alternative is described briefly in the following paragraphs. They are presented generally in order of increasing lead time potential and sophistication. Lead time is defined here as the time between when a warning is issued and flooding begins to occur. It is the time available to the recipient to act on a flood warning.

Alternative 1 - Status Quo

Alternative 1 describes the District's current flood detection system which includes telemetered precipitation gages, stage gages and meteorological sensors, as well as color radar, light maps, and a voice synthesizer to automatically dial pre-selected telephone numbers and relay information. In keeping with the District's current operational procedures, flood warnings to local agencies would not routinely be issued in Alternative

1, but information would be disseminated to the NWS and Civil Defense to be used in issuing flood warnings.

Benefits of Alternative 1 include data collection for use in operation of District structures, calibration of hydrologic models, ground-truth activities, documentation for litigation, monitoring of dams, labor savings from reduced maintenance of flood control structures, increased knowledge of events during storms or flooding situations, and dissemination of information to the NWS and Civil Defense.

Alternative 2 - Flood Warning with Improved Flood Detection and Hydrologic Modeling

Alternative 2 would consist of flood warning services which rely on detection of precipitation and/or runoff for issuing flood warnings. The existing flood detection network would be substantially expanded by the addition of precipitation and stage gages and related equipment. Meteorological data would continue to be received as it is currently, for use in determining if a flood threat is indicated, but would be upgraded to mitigate current equipment constraints.

Alternative 2 would also include the addition of a hydrologic modeling component using the Corps' HEC-1 hydrologic modeling package. Existing hydrologic models developed under the District's Flood Insurance Study (FIS) and Area Drainage Master Study (ADMS) programs would be interfaced with real-time precipitation and runoff data.

In addition to the improved flood detection and hydrologic modeling component, a flood warning communications system would be added to disseminate flood warnings either by direct notices to local agencies from the District or where outside agencies must initiate contact with the District to obtain flood warnings.

The benefits of Alternative 2 would include those identified for Alternative 1, but warnings would be routinely issued directly or indirectly as previously defined. Because Alternative 2 would provide dissemination of warnings, direct benefits would be realized on a county-wide basis through damage reduction as a result of prior warning. Additionally, the expansion of the ALERT precipitation and stage gage network and inclusion of hydrologic modeling would further increase the accuracy of predicting flood threat and would enable the District to identify basin-specific flood potential. This information would improve the capabilities of the NWS and Civil Defense to issue flood warnings and make evacuation decisions.

Alternative 3 - Flood Warning with Improved Flood Detection and Meteorological Prediction

Alternative 3 would consist of the improved flood detection network described in Alternative 2 excluding hydrologic modeling, with the addition of a staff meteorologist or a meteorological service. Additional weather stations would be added to the system to aid the meteorologist in making more site-specific forecasts. As with Alternative 2, a flood warning communications system would be added to disseminate flood warnings.

The benefits of Alternative 3 would be similar to Alternative 2, with certain trade-offs. Alternative 3 would typically provide earlier indication of flood threat due to its meteorological prediction element but with less accuracy. Conversely, the hydrologic modeling component of Alternative 2 would typically provide greater accuracy on expected flooding conditions but with shorter lead time.

Alternative 4 - Flood Warning with Improved Flood Detection, Hydrologic Modeling, and Meteorological Prediction

Alternative 4 describes the combined elements of Alternatives 2 and 3. Alternative 4 includes an expanded flood detection network, hydrologic modeling, and meteorologic prediction. Quantitative Precipitation Forecasts (QPFs) developed by the meteorologist would be input into the hydrologic model at specified forecast points for analysis of potential flooding prior to the occurrence of rainfall.

In addition to the benefits described for Alternatives 2 and 3, the combination of improved flood detection, hydrologic modeling, and meteorological prediction would further increase the accuracy of the warnings, while substantially increasing lead time, and would improve the District's ability to identify basin-specific flood potential.

Alternative 5 - Flood Warning with Improved Flood Detection, Hydrologic Modeling, Meteorological Prediction, and GIS

Alternative 5 would consist of the elements outlined in Alternative 4 with the inclusion of GIS capabilities. Existing District GIS capabilities would be expanded to include flood warning. Additionally, information developed from hydrologic modeling would be input to the Corps' HEC-2 water surface profile program at specified points. The results of the hydraulic computations by HEC-2 would be input to GIS, and inundation maps would be subsequently generated.

In addition to the benefits identified for Alternative 4, the inclusion of GIS capabilities would allow generation of event-driven maps of expected inundation. Flood warning accuracy would be further increased, and the ability of providing site-specific forecasts would be significantly improved. Integration of flood warning components such as satellite and precipitation data could be accomplished, which would enhance flood warning capabilities.

ECONOMIC EVALUATION OF ALTERNATIVES

An economic evaluation of each flood warning alternative was performed by analyzing quantifiable benefits and costs. Overall benefits of a flood warning system include reduced contents flood damage, increased safety, and reduced rescue efforts, as well as reductions in travel delays and nonrecoverable business losses. Of these, only reduced contents flood damage could be quantified. Costs are primarily dependent on equipment and labor to operate a flood warning program.

Because the economic analysis conducted in this study addresses only the quantifiable benefits, other nonquantifiable benefits should be considered in determining whether or not to expand the flood warning system.

The results of the economic analysis indicated that the expected annual benefits from reduced contents flood damage in Maricopa County for flood warning systems providing approximately 30-minute and 2-hour lead times are as follows:

30-Minute Lead Time	=	$500,000/yr
2-Hour Lead Time	=	$2,600,000/yr

Although none of the alternatives can guarantee a specific lead time, it is believed that Alternative 2 would represent the low end of the benefit range with relatively short lead time, while Alternative 5 would enable average lead times at the upper end of the range. Benefits due to reduced contents flood damages are not associated with Alternative 1 because in this alternative flood warning information is not routinely issued to county citizens such that contents could be removed from flood hazard. However, as described earlier in this section, numerous non-quantifiable benefits are derived from Alternative 1. System costs were estimated to range from approximately $340,000/yr for Alternative 1 to $1,280,000/yr for Alternative 5.

EVALUATION OF ALTERNATIVES

Each of the alternatives was evaluated according to selected economic and non-economic criteria:

- Lead Time
- Accuracy
- Specificity
- Economic Ranking
- Ease of Development

Each of these evaluation criteria are discussed below.

Lead Time Factor

Lead time is considered the most important factor in evaluating alternatives because it determines the time available for preparation for a flooding event. Lead time is directly related to the direct benefits of a flood warning system resulting from reduced contents damage. It is also directly related to other important non-quantifiable benefits such as increased safety and reduced rescue efforts, and indirect benefits such as reductions in travel delays, and nonrecoverable business losses. It is inversely related to flood preparedness costs. Each of these factors was considered in ranking the benefit of long lead time. The individual factors are described in the following paragraphs.

Increased Safety. Increased safety resulting from improved flood warning services includes reduced loss of life and reduced injuries. Studies of past flooding events have shown that the factors most directly influencing threat to human lives are the lead time, size of the population at risk, and severity of the flooding event. Of these, lead time is the only factor which can be controlled by a flood warning system.

Reduced Rescue Efforts. Reduced rescue efforts result from individuals taking the appropriate actions in a flooding event when given advanced warning. Consequently, reduced rescue efforts are related to the amount of lead time provided by a flood warning.

Indirect Benefits. Indirect benefits resulting from improved flood warning services include reduced travel delays and nonrecoverable business losses. As with increased safety and reduced rescue efforts, indirect benefits are proportional to the lead time provided by a flood warning system.

Low Flood Preparedness Costs. Flood preparedness costs include actions taken to warn and evacuate floodplain residents, to direct traffic and maintain law and order, to carry out flood fighting efforts in order to reduce damages and increase safety, and to establish and organize emergency shelters. With increased lead time, there is additional time for flood preparedness activities. However, warnings that are more site-specific and more accurate would result in more efficient flood preparedness activities. It is noted that, in the absence of a flood warning system, flood preparedness costs would be replaced by higher flood fighting costs and rescue efforts.

Accuracy Factor

Accuracy of a flood warning system is measured by the relationship between warned flooding events, unwarned events, and false alarms. A highly accurate system would have a greater number of warned events compared to the number of unwarned events and false alarms. Alternatives which base warnings on observed rainfall and runoff data tend to be more accurate than those based on weather forecasting. Accuracy directly affects the credibility of a flood warning, which, in turn, affects the rate of response to a flood warning.

Specificity Factor

Specificity of a flood warning system indicates the ability to identify a specific area of coverage in which flooding is likely to occur. A highly specific system would provide warnings covering small areas. Specificity also affects the credibility of a flood warning and subsequent rate of response.

As with accuracy, the ranking scale of the specificity criterion ranges from 1 to 20, where 1 represents a less specific flood warning system covering broad, general areas, and 20 represents a highly specific system. The ranking scale for specificity was made equal to that for accuracy because it similarly affects the rate of response to a flood warning.

Economic Ranking Factor

The economic ranking factor represents the ratio of reduced flood damage due to implementation of a flood warning system to the flood warning program costs incurred by the District.

Ease of Development Factor

Ease of development represents the effort required to set up a flood warning program. A system which requires minimal effort to implement would rate a high ease of development ranking.

Overall Rank

The relative ranking of alternatives (1=most attractive, 5=least attractive) is as follows:

Rank	Alternative
1	Alternative 5 - Flood warning with improved flood detection, hydrologic modeling, meteorological prediction, and GIS
2	Alternative 4 - Flood warning with improved flood detection, hydrologic modeling, and meteorological prediction
3	Alternative 3 - Flood warning with improved flood detection and meteorological prediction
4	Alternative 2 - Flood warning with improved flood detection and hydrologic modeling
5	Alternative 1 - Status Quo

IMPLEMENTATION CONSIDERATIONS

Numerous agencies with operations in Maricopa County were contacted to identify related flood warning efforts and areas where data collected may be shared. It is concluded that many agencies could realize a mutual benefit by sharing data with the District. Some areas where data may be shared include:

- Hydrologic modeling
- Meteorological data
- Precipitation and runoff data
- Exchange of expertise on analysis of flood threat

Because of the semi-arid environment of Maricopa County, the use of a system for flood warning may be relatively infrequent. The development of alternative uses for the data obtained could potentially help reduce some of the system operating costs and could also serve to enhance the type of data collected.

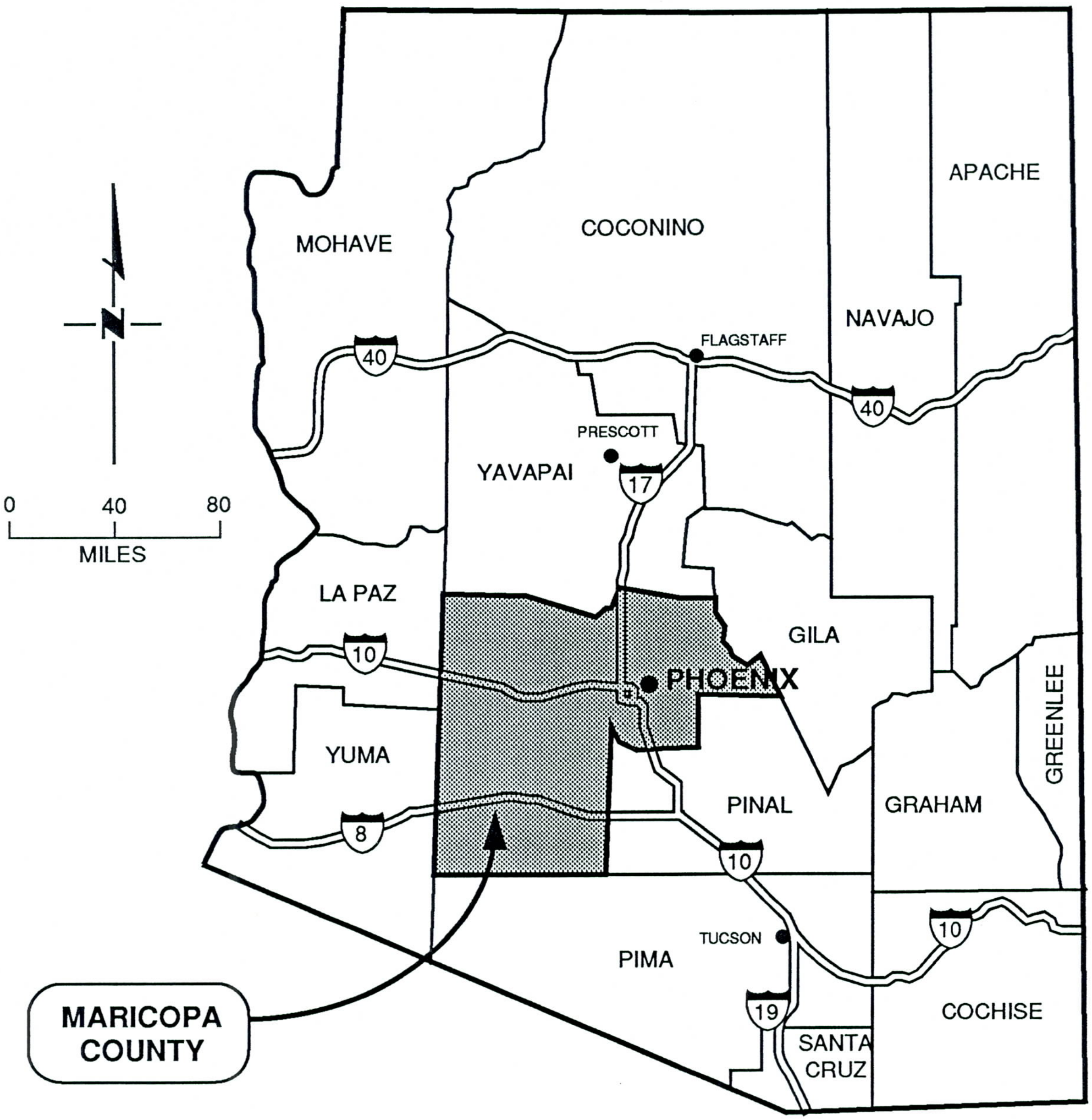
The general categories of alternative uses include the following:

- Data collection/dissemination to enhance local hydrologic science;
- Water conservation through the calculation of evapotranspiration rates;
- Assistance for NPDES stormwater permit compliance monitoring;
- Public information through telephone messaging, electronic bulletin boards, and/or map production;
- Fire prevention assistance; and
- Water production assistance.

RECOMMENDATIONS

Based on the findings of this study, it is recommended that Alternative 4, which includes an expanded flood detection network, hydrologic modeling, and meteorologic prediction, be implemented initially. After the program becomes operational, it is recommended that the GIS component be added to bring the program to that of Alternative 5.

Section 1



LOCATION MAP

FIGURE 1-1

- Benefit/Cost Analysis
- Implementation and Coordination
- Project Management

Evaluation of Flood Warning Technology. The evaluation of technology includes an assessment of existing and future flood warning technologies, other technologies applied to flood warning, and the appropriate communications media to support flood warning. Also, existing flood warning systems in the U.S. and operational systems in Maricopa County were reviewed.

Market Survey. The market survey element involved distribution of questionnaires to individuals based in Maricopa County. The participants included managers and administrators, technical staff and users or implementors of flood warning services, and homeowners. The questionnaires were collected and evaluated to assess the communities' understanding of and perceived need for improved flood warning services.

Benefit/Cost Analysis. The benefit/cost analysis includes an evaluation of economic feasibility of providing improved flood warning services for Maricopa County. Also, an evaluation of alternative uses of a flood warning system was performed.

Implementation and Coordination. The implementation and coordination includes a summary of coordination of flood warning efforts within the various governing agencies. Also included in this element are recommendations of flood warning alternatives based on data collected in the previous elements.

Project Management. Project management activities involved monthly progress meetings to provide updates on project status, as well as quality control activities.

PRIOR STUDIES

No formal studies have been performed on the District's flood warning program prior to this study. A literature review was performed as part of this project on similar studies performed for other local flood warning systems throughout the country, but none were discovered. Further, in discussions with operators of other locally funded and implemented flood warning programs, it was found that the systems were instigated as a result of a flood where lives had been lost. A benefit/cost analysis was not performed in any case; the decision to implement local flood warning services was made on loss of life considerations alone.

It is interesting to note that the Corps has implemented a number of flood warning projects, alone or as part of larger projects, as a means of nonstructural flood control. The Corps plans to continue pursuing flood warning as a recommended flood warning alternative (Kitch, 1991).

Section 2

SECTION 2

FLOOD WARNING TECHNOLOGY

INTRODUCTION

This section of the report describes the work conducted under the first element of the Scope of Work and includes the following subsections:

- Available Technology
- Improved Future Technology
- Geographic Information System Technology
- Existing Operational Systems
- Operational Systems in Maricopa County
- Appropriate Media to Support Flood Warning

A number of different types of technology and their applicability to flood warning in Maricopa County are identified in this section. The types of existing technology investigated include available technology, future technology, and other technology which could potentially be developed as a flood warning tool. The system evaluation of available technology addresses stage and precipitation gages, weather forecasting, hydrologic modeling, and thunderstorm detection systems such as radar, satellites, and lightning detection networks. Future technology evaluation includes new developments in radar and satellite technology, and weather forecasting tools. Geographic Information System (GIS) technology was also investigated for application to flood warning.

Six flood warning systems currently operational across the U.S. are also described in this section, as well as operational systems in Maricopa County. Lastly, this section includes a description of flood warning communications and dissemination equipment.

AVAILABLE TECHNOLOGY

Flood warning systems are generally composed of various combinations of stage gages, precipitation gages, weather forecasting, and hydrologic modeling. Also included are thunderstorm detection systems such as radar and satellite technology. The discussion that follows describes the currently available technology of each of these components as they relate to flood warning systems.

Stage Gages

Stage gage systems are able to provide information on flooding conditions as they occur. One special type of stage gage that has been utilized for flood warning is the Automated Local Evaluation in Real-Time (ALERT) stage gage. Information is transmitted to a base station where ALERT software receives and stores the data and also sounds an alarm automatically at the receiving site if a pre-set water level is exceeded.

Stage gages are comprised of several different types of systems used to measure streamflow. The various types of stage gages are subdivided into traditional and newer methods of water level measurement and direct flow measurement. Discussions of these are provided in the following paragraphs.

Traditional Methods of Water Level Measurements. The most commonly used system for gaging streamflow is an instrument that measures the height of water at a particular location along a stream. The stage, or height of the stream's water surface, is directly converted to a flow estimate using a height/flow relationship or rating curve. Rating relationships are typically developed at hydraulic control structures such as weirs and hydraulic drops, or at structures that affect the water surface profile such as a bridge. Often the stream section must be carefully gaged at several discharges in order to determine the rating relationship. Water level measurements may also be used for evaluating storage conditions in reservoirs and ponded areas.

General types of water stage gages that have traditionally been used are: float and wire-weight gages, which measure from a fixed point, and staff and crest gages, which read stage directly.

Float Gage. A float-type gage is most frequently used for water level measurement. This gage is constructed by fastening one end of a tape to a float resting on the water surface, and bringing the other end of the tape up and over a wheel and counterweighting it. A pointer is mounted by the wheel so that it rests against the tape. Readings are obtained from the tape at the pointer.

Wire-Weight Gage. Stage is determined from a wire-weight gage by manually lowering a weight attached to a wire to the water surface. The gage is read by means of a mechanical counter attached to the reel on which the wire is wound. These gages have the advantages of ease in installation and freedom from damage. Also, they can be installed to be readily accessible under all conditions of flow.

Staff Gage. Staff gages are an easily visible reference of water level for periodic observation where continuous records of water levels are not required. A staff gage is a graduated scale set in a stream by fastening it to a pier, wall or other structure. It is read by observing the level of the water surface in contact with it. One of the major problems of a staff gage is providing adequate protection from damage by boats, ice, or flood-transported debris, and locating the gage so that flow disturbances across the scale are at a minimum.

Crest Gage. A crest gage consists of a pipe set vertically with an open, screened bottom and a vented top. It contains a graduated wooden measuring stick. A small quantity of powdered cork in the pipe rises with the water level and adheres to the measuring rod, thus recording maximum water level. Crest gages are an inexpensive means of determining maximum stage when no observer is present. They are located at bridges, culverts, spillways, and are used to delineate the peak stage of a flood. These data are valuable in establishing flood profiles and in determining relationships for computing flood flows in streams.

Newer Methods of Water Level Measurements. Current stage indicator technology has made several recent advances. Shaft encoders, pressure transducers and ultrasonic transducers have been used with varying success in water level measurements.

Shaft Encoder. The shaft encoder is a field-located instrument for measuring water levels with higher resolution than those used for traditional methods of water level measurement. The shaft encoder consists of one moving part, a magnetic rotating rotor, that measures speed of rotation. A pulley, tape, float, and counterweight are attached to the shaft encoder which monitors the water level in the stilling well. The absence of gears and switches increases the reliability in rugged field conditions.

Pressure Transducer. Pressure transducers are water level sensors which measure pressure and can convert a pressure reading into water depth. As the water level rises, the change in head causes a corresponding pressure increase, which is recorded as a change in water level. They have been used for some special application sites where stilling wells are impractical. There are two general methods of installation for the pressure transducer. The first involves strapping the unit to a concrete block, and the second involves placing the unit in a pipe and suspending it by a cable. Pressure transducers may lack consistent performance over a long time period; however, performance problems can be mitigated with proper routine maintenance.

Ultrasonic Transducer. Ultrasonic transducers are water level sensors which measure distance by precisely timing a pulse of sound from a transducer to a reflecting surface and back to the transducer. Generally, it is attached at a weir. Ultrasonic transducers are available for operation in a non-vertical position and, thus, have application to sloping stream and reservoir banks. A sophisticated solid-state electronics module is utilized for signal processing.

Traditional Methods of Flow Measurement. Flow measurement can be performed indirectly in an open channel by stage gaging if the cross-sectional area of flow is known. The most common technique is current meter gaging, which measures stream velocity at several points in the flow by either wading the stream or taking measurements from a cableway. Flow is then computed from the velocity measurements and the cross-sectional area. Principal methods of flow measurement have historically been the rotating current meter and the dynamometer.

Rotating Current Meter. The rotating current meter is a mechanical device that measures stream velocity by converting a part of the stream momentum into angular momentum. Rotating current meters are oriented either vertically or horizontally to the direction of flow. Rotation about the vertical axle is accomplished by cups or vanes and about the horizontal axle by screw- or propellor-shaped blades. Rotating current meters are not suitable for very low velocities or conditions of extreme turbulence.

Dynamometer. The dynamometer is also a mechanical device which measures stream velocity. The momentum force of stream velocity is translated into either deflection or stress, which is measured and calibrated against velocity or discharge.

Newer Methods of Flow Measurement. Existing meter technology has made several advances that reduce the amount of time needed to gage a stream section and improve the accuracy of the measurements obtained. The latest instruments incorporate ultrasonic and electromagnetic sensors along with small computers that automate part of the data reduction.

Ultrasonic (Acoustic) Flow Measurement. Single-path acoustic flow measurement is currently performed with the aid of microprocessors. These gages take a sequence of measurements that are mathematically reduced to a single flow measurement. Use of acoustic flow measurements is hampered in streams with high concentration of suspended sediment.

Electromagnetic Flow Measurement. The electromagnetic flow meter relies on the principle that the flow of water through an electromagnetic field will induce a signal in a conductor (Faraday effect). This signal is measured and converted to flow in streams. Multiple electrical sensors can be installed across the channel bed and banks, which greatly increases the strength of the electrical signal to be measured.

Precipitation Gages

Precipitation gages are instruments that measure rainfall and are sometimes installed at the same location as stage gages. Precipitation gage systems are used to indicate impending flooding conditions. As with ALERT stage gages, ALERT precipitation gages report to the base computer where the ALERT software sounds an alarm at the receiving site if a pre-set amount or intensity of precipitation is reached.

Precipitation Measurement. There are three types of recording precipitation gages in general use: tipping bucket, weighing, and float.

Tipping Bucket Gages. Tipping bucket gages are used in ALERT systems and consist of a collector orifice that funnels rainfall into a tipping bucket mechanism. The mechanism consists of a pair of small containers designed so that when a certain amount of precipitation falls in one of the containers, it tips. Another container is brought into position to receive the next rainfall, empties into a storage container, and closes an electrical contact that makes a mark on a recorder chart. This process is repeated through the duration of rainfall. The tipping bucket is especially adapted to remote sites and has been used in operation by NWS since the early 1890's.

Weighing-Type Gages. Weighing-type gages in common use consist of a collecting bucket resting on a weighing platform and frame, which are suspended from a spring. Precipitation collected in the bucket increases the load on the spring, which lowers the platform frame. This deflection is proportional to the amount of precipitation collected.

Float-Type Gages. In float-type gages, precipitation is collected in a chamber containing a light float. Vertical movement of the float as the level of the water rises causes a movement of the pen on the chart.

Meteorological Sensors

Meteorological sensors take measurements of atmospheric conditions. Each sensor measures one particular meteorological parameter. Sensors grouped at the same station which measure a range of parameters are termed a weather station.

Weather Station. A basic weather station provides an array of sensors for the collection of meteorological data which includes measurement of precipitation. This sensor array typically includes a precipitation gage, air temperature probe, barometric pressure transducer, humidity probe, wind speed and direction probes, and solar radiation meter. Sensors can be added to the station to measure related environmental conditions such as soil temperature and moisture. A wide selection of sensors is available and varies with the range and accuracy needed for the measurement and the severity of the environmental conditions at the station.

In most cases, measurements are made by solid-state devices which require a minimum of maintenance and perform reliably in severe weather conditions. However, mechanical devices are still common for the measurement of rainfall, wind speed and wind direction. These mechanical devices provide reliable performance at a reasonable cost. For measurement of severe weather conditions such as hurricanes or tornadoes, solid-state devices are preferred since they are able to measure conditions outside the range of mechanical devices and can be more easily incorporated into platforms that can withstand the forces caused by severe weather.

Weather Forecasting

Weather forecasting, which provides one basis for flood forecasting, assesses thunderstorm threat, rainfall production, and storm tracking in an attempt to predict flooding conditions before they occur. There are two general types of flood forecasts: conventional flood forecasts and flood forecasts based on Quantitative Precipitation Forecasts (QPFs). The conventional flood forecast is based on observed rainfall and runoff, and, in flash flooding situations, may be issued just before the occurrence of a flood. Conventional forecasting is more accurate because it is based on rainfall and runoff that have already occurred. Accuracy in flood forecasting relates to the ability of the forecast to determine the time and magnitude of the flood. Unfortunately, the accuracy of the conventional flood forecast near the time of the flood is of little value if there is insufficient time to take action (Handar, Inc.).

The second type of flood forecast, based on the QPF, is a prediction of the quantity of precipitation based on meteorological guidance and is issued *before* the precipitation has occurred. The meteorological basis of estimating precipitation and runoff is satellite and radar data, observed precipitation patterns, hydrologic models, and guidance from the NWS National Meteorological Center in Suitland, Maryland. QPFs provide more lead time than conventional forecasts but are less accurate.

The sources of information on which weather forecasting is based fall into three broad categories: observational data, NWS forecast products, and value-added products and services. These categories are discussed below.

Observational Data. Observational data are the raw surface and upper air data used to create thunderstorm/rainfall predictions. The great majority of observations used by meteorologists to create forecasts are taken by NWS and form the backbone of weather forecasting.

Surface weather observations consist primarily of hourly observations taken by NWS, military, and Federal Aviation Administration (FAA) observers. Hourly observations of cloud cover, visibility, temperature, dew point, wind speed and direction, pressure, and other remarks are made. The hourly weather observations provide a general idea of local weather conditions. Hourly observations such as these are taken in many locations in Arizona, primarily at airports.

Hourly weather observations for the entire nation are summarized and available through the National Meteorological Center. Although the National Meteorological Center does not directly transmit this information to users, it is readily available from product vendors, which are described later in this section. While the National Meteorological Center provides it free to product vendors, re-packaging of it by the product vendors is done at a nominal fee.

Surface observations can be plotted collectively on a state, regional or national scale as surface charts, which indicate where weather features related to thunderstorm formation are located. Sequential surface charts can be used to assist in forecasting the movement of these features to future locations.

Upper air observations are made by NWS twice daily by launching instrumental balloons from more than 100 airports to collect a vertical profile or "snapshot" of the atmosphere's temperature, moisture, and wind structure. Upper air observations provide data used to plot constant pressure charts. The presence of upper air disturbances capable of triggering thunderstorms by lifting unstable air can be detected from the charts.

NWS Forecast Products. On the national level, NWS prepares products for use in flood warning at the National Meteorological Center; Heavy Precipitation Group; the National Environmental Satellite, Data, and Information Service (NESDIS); and the National Severe Storms Forecast Center (NSSFC). A complex array of products are prepared at these centers. To condense our discussion of these products, only those of direct value to Maricopa County are included; these descriptions are for product groups rather than individual products.

The National Meteorological Center produces both national and local forecast products. On the national level, 3-hour surface maps and 12-hour upper air analyses are produced, as well as constant pressure and atmospheric forecasts. These forecasts are numerical guidance tools for use by a forecaster and are readily available on the digital facsimile (DIFAX) line from NWS.

On the local level, the National Meteorological Center produces high/low temperature, dew point, wind speed and direction, pressure, cloud cover, and precipitation forecasts which are totally machine-generated. NWS forecasters use these numerical forecasts to produce their local public forecasting. These products are readily available on the Domestic Data Service.

The Heavy Precipitation Group produces several national products which can be useful to weather prediction. This agency prepares a line of forecast products on heavy precipitation accessible only to NWS forecasters on the Automated Field Operations and Services (AFOS) computer system and another line of forecast products accessible on the NOAA Weather Wire and Domestic Data Service. The latter products are areal outlines of portions of the country expected to receive over 0.50 inches of precipitation in 6, 12, 24-hour periods from general storms or thunderstorms. More detailed discussions and individual storm system predictions are made and could be acquired for a fee from the Domestic Data Service.

An analysis group in NESDIS produces precipitation estimates, specializing in satellite-generated rainfall estimates for the past 3-6 hours and QPFs for the next 3-6 hours. The scale of these forecasts covers a portion of a state. They are only available on the National Oceanic and Atmospheric Administration (NOAA) Weather Wire and Domestic Data Service.

The NSSFC produces thunderstorm outlooks, discussions, and watches of areas expected to experience severe thunderstorms and tornadoes. All products are available for a fee on Domestic Data Service and NOAA Weather Wire.

NWS prepares a range of local forecast products at the Phoenix office. These products include thunderstorm forecasts, special weather statements, urban flooding statements, flash flood watches and warnings, and severe thunderstorm watches and warnings. Local NWS operations are detailed in the subsection entitled "Operational Systems in Maricopa County" of this section.

Value-added Products and Services. Value-added services are services offered by others using NWS information. The services provide more site-specific (location-based) or mission-specific (use or weather threshold-based) forecasts. Value-added products are re-packaged NWS weather observation data and forecast products. Another form of the value-added element is an in-house meteorologist.

The most popular value-added element is provided by vendors of re-packaged NWS weather observations and forecast products. NWS places all of its publicly available observations and forecasts, both national and local, on the following national data lines:

- NOAA Weather Wire: All NWS local and state public forecasts, statements, watches, and warnings.
- FAA 604c Line: Aviation-oriented observations, forecasts, watches, and warnings.
- Domestic Data Service: NWS hourly surface and upper air observations, forecast discussions, alphanumeric guidance, long range outlooks, and NSSFC and Heavy Precipitation Group products.
- DIFAX: The National Meteorological Center sends graphical products, such as maps and charts of observed and forecast weather data, over a facsimile line.

These data are re-packaged by the private vendors and sent via satellite to a small earth station. The data lines are split into separate lines in the earth station. The NOAA Weather Wire transmits to a printer, while the Domestic Data Service transmits to an IBM-compatible PC with a data sorting software package (e.g., ALDEN Electronic's Weather Capture or Marta Systems' MS-TEXT) or runs continuously to a printer.

Vendors also obtain the NWS data and numerical forecasts and re-plot or re-tabulate the weather into other map scales or data groupings. These services offer a wide menu of NWS surface and upper air observations, numerical products, satellite data, and radar observations. Television stations are the primary customers of these vendors. Their databases are accessible by telephone modem or satellite delivery. Primary vendors include Weather Service International (WSI) Corporation; WeatherBank; Accu-Weather, Inc.; and Kavouras, Inc.

A more location-specific service is given to remote radar sites by Kavouras and Enterprise, Inc., which offer color remote radar receivers that convert radar displays to color monitors via telephone lines.

Similar services are offered for satellite visible and infrared pictures by vendors. The most basic pass-through systems, such as Northern Video Graphics' system, use an existing PC, interface card, and software to provide useful satellite video imaging. Satellite data acquisition systems can be acquired which give color image enhancement, graphic overlays, image editing, temperature readouts, histograms, zoom, looping, and mosaics of images.

Value-added services are provided by private forecasters. A private forecaster can supply site-specific, operation-specific, and basin-specific forecasts of thunderstorms and precipitation more refined than those offered by NWS.

An in-house meteorologist would provide site-specific services and operationally geared forecast support. The in-house meteorologist would be a focal point for participants in a local flood warning system.

Hydrologic Modeling

Hydrologic modeling can be performed to correlate precipitation to runoff. Once the relationship between rainfall and runoff is known for a particular basin, flooding can be predicted from precipitation. However, basin response to precipitation depends greatly on factors such as location of precipitation with respect to the basin, antecedent moisture condition at the time of the storm, and other physical factors. Further, parameters used to run hydrologic models must be calibrated in order to obtain reliable results.

Enhanced ALERT software includes the Sacramento Soil Moisture Accounting Model (Sacramento model); however, the model requires several parameters which must be based on historical data, much of which are not available for Maricopa County. Further, the model is not considered to be applicable to the physical conditions and flash flooding situations found in Maricopa County. Further discussion on the Sacramento model may be found in Section 5 of this report.

Enhanced ALERT software also has available the Corps of Engineers' (Corps) HEC1F computer program, which is an adaptation of the HEC-1 hydrologic modeling program and includes forecasting capabilities. A HEC1F model may be run in the ALERT operating system (QNX), or in the PC operating system (DOS) with an interface.

An interim alternative to a real-time/hydrologic model interface would be to model basin response to various hypothetical storms. Developing storms could be compared to the hypothetical storms to obtain estimates of expected flooding conditions. Additional information on integrating a hydrologic model with flood warning services may be found in the subsection entitled "Other Technologies."

Thunderstorm Detection Systems

The detection of the formation, approach and passage of thunderstorm systems can play a major role in detection of precipitation. The primary thunderstorm detection systems are based on radar, satellite, and lightning technology.

Radar. The primary thunderstorm detection tool for Maricopa County is the NWS 1974 Weather Surveillance Radar (WSR-74) located at Sky Harbor Airport in Phoenix. The District currently receives a real-time color picture of the Sky Harbor radar on a direct line through Kavouras. Video taping of the display by the District provides a form of animation to assist in storm tracking and motion estimation.

The radar displays location and intensity information and can be used to estimate storm motion and growth patterns. Constraints are a lack of precipitation mapping capability and a lack of radar output control by the District. An alternative to the use of the NWS radar is a composite radar, NOWrad, available from WSI. Advantages are the elimination of ground clutter and receipt of data from more than one radar site. A single-site conventional radar or a new Doppler radar from a commercial vendor, such as Enterprise or Kavouras could also be purchased.

Weather Satellite. NWS has used weather satellites to derive precipitation estimates since 1977. NESDIS has prepared satellite-derived precipitation estimates using an Interactive Flash Flood Analyzer since 1982. The Interactive Flash Flood Analyzer is used to prepare limited point precipitation estimates and 0-3 hour weather outlooks which can be prepared hourly and sent to NWS offices on the AFOS computer system. External users can access these products on the NWS Domestic Data Service and NOAA Weather Wire services from a large number of weather data brokers.

There have been major advances in the development of satellites, such as the Geostationary Operational Environmental Satellite (GOES), and satellite-derived precipitation estimate techniques.

GOES performs three separate functions: data collection, imaging, and sounding. The data collection system polls GOES gages and transmits precipitation accumulation data. The imager produces an image, or a "picture," of what is occurring in the atmosphere, including cloud top elevation and location. The sounder produces a profile of the temperature and moisture distributions in the atmosphere. The data utilized by the sounder include measurements of humidity, dew point, thermal gradients, and precipitable water. The existing system cannot operate both the imaging and the sounding systems together. The sounding functions are performed after the satellite has scanned during the data measurement period (Anderson, 1991).

The existing GOES system transmits satellite data at a standard frequency of 30 minutes. In severe weather conditions, GOES transmits data every 15 minutes, with the ability to transmit data at intervals of five minutes. Five-minute frequency, termed rapid interval scan, can occur for up to 2.5 hours in duration. The NSSFC dictates when the satellite system transmits on rapid interval scan. The 5-minute data are only provided to those with a downlink who can read the satellite directly.

The current satellite products are useful tools, especially in remote locations, in providing precipitation estimates. The 0-3 hour weather outlook product has also been useful at identifying potential regions of heavy rainfall which could experience flash flooding.

Lightning Detection Networks. A thunderstorm detection tool that is being developed is the lightning detection network. Lightning Location and Protection, Inc., (LLP) in Tucson has fully instrumented Arizona with a commercial lightning detection network which works in co-operation with the Bureau of Land Management network. The network was installed in 1977 to assist in early detection of wildfires caused by lightning. The network equipment was manufactured by LLP and is used to track severe thunderstorm activity.

In the LLP system, a position analyzer determines cloud-to-ground lightning location from the intersection of direction vectors and/or the ratio of the electric field strength from two or more direction finders. The position analyzer also handles outgoing communications, including a data line to NWS. LLP provides a PC workstation and communications equipment for external users to access these data in real-time for a fee.

Atmospheric Research Systems, Inc., (ARSI) has also installed a lightning detection network throughout the U.S. The ARSI system is based on time-of-arrival techniques to locate cloud-to-ground lightning strikes. When a ground strike occurs, an electromagnetic pulse is emitted and is detected by each of several listening stations. The listening stations record and transmit the time of detection to a central analyzer where the strike location is calculated. The direction, intensity, and movement can be tracked and displayed on a PC monitor.

Another product of lightning technology offered by ARSI is a flash warning system which measures the count and distance of lightning strikes from the point of measurement. As the strikes approach the point of measurement, accuracy improves. This application only measures the intensity of lightning as it approaches the point of measurement and does not track the direction and movement of the strikes. The build-up of electrical charge from cloud-to-ground can also be tracked and used to report the potential for a lightning strike, but only within a 5-mile radius of the tracking unit.

The application of lightning technology to predict precipitation has been investigated in other areas of the country. In general, the location of highest concentration of lightning activity during thunderstorms has indicated the highest intensity of rainfall. It is noted that future generations of GOES and low earth orbiting satellites will include lightning sensors (Goodman and Buechler, 1990).

IMPROVED FUTURE TECHNOLOGY

NWS announced plans early in the 1980's for a $3 billion modernization and restructuring program called the Advanced Weather Interactive Processing System for the 1990's (AWIPS). The primary new NWS technologies that are likely to impact flash flood warning systems are:

- NEXRAD Doppler radar
- GOES-NEXT satellite
- Vertical wind profilers
- Surface mesonets
- AWIPS workstations

The following discussion addresses each of these new technologies and describes their applicability to flood warning services.

Next-Generation Doppler Radar

Next-Generation Doppler radar (NEXRAD) is a new, highly computerized Doppler radar which will be implemented by NWS during the 1990's and will replace the existing WSR-74. The designation for NEXRAD radar is WSR-88D, or Weather Surveillance Radar-1988-Doppler. The main goal of NEXRAD is to provide timely and accurate warnings of impending severe weather. This purpose encompasses flood predictions, warnings of hazards to aviation, estimates of rainfall, detection of wind shear, and the protection of military operations and installations.

System and Equipment Description. NEXRAD is based on Doppler technology to detect and track hazardous weather conditions. Doppler weather radars detect potentially dangerous phenomena growing inside storms and significantly enhance the accuracy and timeliness of severe weather warnings. The Doppler system is designed to provide weather data on:

- Reflectivity (measure of precipitation volume, location, and distribution in the atmosphere);
- Velocity of the particles toward and away from the radar; and
- Velocity dispersion in the radar sample volume (spectrum width).

NEXRAD permits accurate determination of precipitation and ensures that a distant storm does not hide behind a severe local storm. There are three major components of the NEXRAD system, as follows (Alberty, 1990; Heiss, et. al., 1990):

Radar Data Acquisition. The radar data acquisition unit acquires and processes Doppler weather radar data such as mean radial velocity and reflectivity data. The unit is composed of an antenna, pedestal, radome, transmitter, receiver, and processor.

Radar Product Generator. The radar product generator processes most of the data and executes algorithms, or calculations performed to convert base Doppler data into meteorological and hydrological products. It also provides product storage, data archival, product distribution, and control and status monitoring of the data acquisition as well as its own functions. The unit is composed of the radar control processor and the meteorological analysis and product generation processor.

Principal User Processor. The principal user processor is the workstation of the NEXRAD system, consisting of a mini-computer, system console, two 19-inch color graphic monitors, color printer, graphics processor, and communications system. The graphic monitors display the meteorological products with background maps such as political boundaries, airways, highways, cities, and restricted areas. Meteorological overlays are also displayed, such as storm tracks, forecasts, and information on severe weather.

System Capabilities. NEXRAD can convert raw weather radar data into computer graphic displays of the overall weather picture and potential storm dynamics. False-color imagery shows relative differences in wind speed and direction. The various meteorological images are updated at 5-minute intervals. In addition, users can overlay geophysical conditions, magnify images, and display time lapses. Each Doppler radar site can accommodate up to eight displays.

The NEXRAD system automates the meteorological processing of the Doppler weather data using a series of sophisticated algorithms developed at government research centers. NEXRAD will be able to locate heavy rainfall centers, define storm movement, and derive rainfall estimates, all of which contribute to providing real-time, high resolution forecast guidance on severe weather and flash flooding.

Dr. Ron Alberty, Director of NEXRAD Operational Support Facility, has stated that NEXRAD will be a valuable tool for flash flood detection and that the flash flood algorithms were tested in the spring of 1991 with success (Alberty, 1991).

NEXRAD products to assist forecasters in flash flood detection and prediction include the following:

- Precipitation accumulations over the radar coverage area;
- Maximum accumulations within a flash flood guidance zone;
- Critical rainfall probability, a measure of the probability that the accumulation for a given area has or will exceed the critical amount of rainfall needed to cause flash flooding; and
- Maximum critical rainfall probability within a flash flood guidance zone.

The flash flood products are based on data for time periods up to the previous six hours, and are designed to provide QPFs on flash flood events up to one hour in the future.

NEXRAD precipitation processing sequences generate previous 1-hour, 3-hour, and storm total rainfall accumulation maps. However, accuracy is dependent on the availability of surface rain gages to ground-truth the algorithms. Ground-truthing is the process of correlating the quantity of precipitation measured in the air (as determined by radar) with that which is measured on the ground. Hail, storm freezing levels, rain gage reliability, and the vertical distance between the radar beam and the ground affect the accuracy of data.

NEXRAD Products. The NEXRAD system will provide information to:

- NWS
- FAA
- Air Weather Service and the Naval Oceanographic Command of the Department of Defense.

Each agency will apply the common information to its own needs. In general, NWS is responsible for public warnings, FAA for civil air routes and terminals, Air Weather Service for Air Force and Army operations and facilities, and Naval Oceanographic Command for naval and marine affairs. Within the continental U.S., the network will include 175 NEXRAD radars (Alberty, 1990).

External (i.e., non-NWS) users of NEXRAD will have access to a number of meteorological products. Some of these products are listed below:

• One-Hour Rainfall Accumulation:	1-hour total of surface rainfall accumulation updated every 5-6 minutes.
• Three-Hour Rainfall Accumulation:	3-hour total of surface rainfall accumulation updated every 5-6 minutes.
• Storm Total Rainfall Accumulation:	Total rainfall accumulation updated every 5-6 minutes, if storm duration is greater than three hours.
• Hourly Digital Precipitation:	Hourly amounts of precipitation over the radar scanning volume (primarily for use in computer modeling).
• Echo Tops:	Altitudes of the tops of the radar echoes.
• Velocity Azimuth Display Winds:	Vertical profile of horizontal wind speed and direction at a fixed range from the radar.

These products will be disseminated as part of a planned NEXRAD Information Dissemination Service which has selected WSI Corporation, Alden Electronics, and Kavouras as the three initial NEXRAD Information Dissemination Service vendors. These vendors will provide NEXRAD displays to external users in much the same way that Kavouras now disseminates color radar data to the District with Phoenix color radar information. The NWS, FAA, and Air Weather Service will also receive several additional products not available to external users.

Status of NEXRAD. The NEXRAD prototype was completed in August 1989. The probability of detection of severe thunderstorms was 91 percent compared with a national average of the current radars of 58 percent. The false alarm rate was 21 percent compared with a national average of 57 percent (Heiss, McGrew, and Sirmans, 1990).

As of this writing, NEXRAD is scheduled to be delivered in Phoenix in early 1994 and installed by mid-1994. However, some sources doubt the ability of NWS to meet its current schedule.

Areas for Potential Growth. Areas of potential NEXRAD system growth include the improvement of: algorithms used to convert radar data to forecasting products, the accuracy of precipitation estimates, cloud detection and wind profiling.

A potential shortcoming in the NEXRAD operational procedures is that the radar will not scan at elevation angles greater than 20 degrees, thus leaving an unexplored volume directly overhead. Although this volume is small compared to the remaining volume of radar coverage, it leaves open the possibility that severe phenomena may be unobserved for a few minutes while passing through the radar's cone of silence.

GOES-NEXT Satellite

In the 1990's, the first of a new series of GOES, termed GOES-NEXT or GOES-I, is scheduled to be launched that will improve existing satellite services and products. The following improvements are likely to be achieved by the GOES-NEXT products:

- Real-time transmittal of text and graphical satellite estimate products for rapid dissemination to NWS forecasters.
- More frequent precipitation estimates which can be linked to NEXRAD radar products to enhance flash flood statements.
- More easily updated atmospheric thermal stability and moisture fields which can be tracked to assist in thunderstorm prediction.
- Preparation of map backgrounds of rivers, river basins, counties, highways, terrain, and population which can be used with new geographical satellite products.

A primary function of GOES now and in the future is monitoring the approach of moist, unstable air from the Pacific Ocean and Mexico into Arizona. This information can be used with new vertical temperature and moisture soundings to compute changes in both atmospheric stability (i.e., thunderstorm potential) and rainfall production capabilities of the air mass and storms.

GOES-NEXT will have three operational modes which measure continuously: 30-minute mode, 15-minute mode, and 5-minute mode. The 5-minute mode is the warning mode which occurs during severe weather. All of these data will be available to NWS. During non-severe weather, NWS can specify the frequency of measurement. NESDIS plans to operate two GOES-NEXT satellites, one for the eastern portion of the country and one for the western portion. When there is severe weather on one-half of the country and not on the other, then one satellite can run on warning mode, and the other can run on standard mode.

As stated earlier, the existing GOES system cannot operate both the imaging and the sounding systems together. An improvement in GOES-NEXT is that it will simultaneously operate the satellite imaging and the sounding systems. Additionally, GOES-NEXT will have higher resolution in moisture measurement, as well as more rapid and specific area coverage (Anderson, 1991).

The construction of GOES-NEXT is currently undergoing scheduling, budgetary, and technical problems. GOES-NEXT is approximately 3-4 years behind schedule and $500 million over budget. In addition, there are technical problems with the instrumentation design. At the earliest, the first GOES-NEXT satellite, GOES-I, should be ready to launch into orbit in December 1992. There is a serious concern regarding the scheduling problems because the existing GOES in orbit, the GOES-7, is expected to lose capabilities in 1993. Therefore, if the delays in construction and technical problems of GOES-NEXT continue, for a period of time there may be no operating GOES to provide daily forecasting and weather data (Asker, 1991).

Vertical Wind Profilers

Wind profilers send vertical pulses into the atmosphere, at distances ranging from 1 km to 16.5 km above the earth's surface. The altitude of the atmospheric layer is determined based on the amount of time for the pulse to reach the layer. One advantage of the wind profilers is that a profile is obtained hourly, as opposed to the existing method, radio sounding profilers, which operate once every 12 hours.

The NWS is in the process of establishing a network of wind profilers in the midwest as part of the Stormscale Operational and Research Meteorology (STORM) project. One objective of STORM is to assess the effectiveness of wind profilers as a meteorological tool. Approximately 35 profilers are currently operating, with the majority located in Oklahoma and Kansas. The closest wind profiler to Maricopa County is in White Sands, New Mexico. Evaluation of the existing network of profilers will continue through 1992 or 1993.

Surface Mesometeorological Networks

Surface mesonets have been used as a forecasting tool to improve lead time and QPFs of urban flash flooding events. The design of a mesonet involves establishing a dense network of weather stations to provide an estimate of the spatial variation of measured parameters. Considerations in the design of a network include variation in terrain, storm characteristics, land use, and economic considerations (i.e., unit cost of a station, operation/maintenance, damage frequency, etc.).

Design criteria have been proposed for determining the density of the network on the basis of drainage area, thunderstorm frequency, and mean annual runoff for the purpose of conducting flood forecasts. A slight increase in the density of gages was recommended if daily (i.e., continuous simulation) forecasts of stream flow are required (Kohler, 1972).

AWIPS Workstations

There has been research performed on PC-based workstations which, when developed, would transform existing and new technology into useful graphical and forecast displays. These computerized workstations will integrate display capabilities from new and existing data sources, such as the ALERT system. Additionally, the workstation will process models such as precipitation algorithms derived from radar reflectivity data and automated surface gage data. The model results will then be graphically displayed for forecaster interpretation. The capabilities of the workstation can be used to enhance flood warning activities.

The Center for Analysis and Prediction of Storms is being formed at the University of Oklahoma to capitalize on the use of new technology in developing a science of storm-scale prediction. One important role will be to further develop effective workstation environments. Also, it will focus on the use of NEXRAD data in storm prediction and the use of NEXRAD data in mesoscale hydrologic models (Droegemeier, 1990).

GEOGRAPHIC INFORMATION SYSTEM TECHNOLOGY

Certain technologies in existence have recently found applications to flood warning services. One subtask of the Flood Warning Services Market Survey Study was to evaluate for the District possible incorporation of other technologies into a flood warning program.

The District requested JMM to focus on GIS capabilities as applied to flood warning. Therefore, the discussion which follows is limited to GIS technology. Use of hydrologic models is also discussed for future integration with GIS.

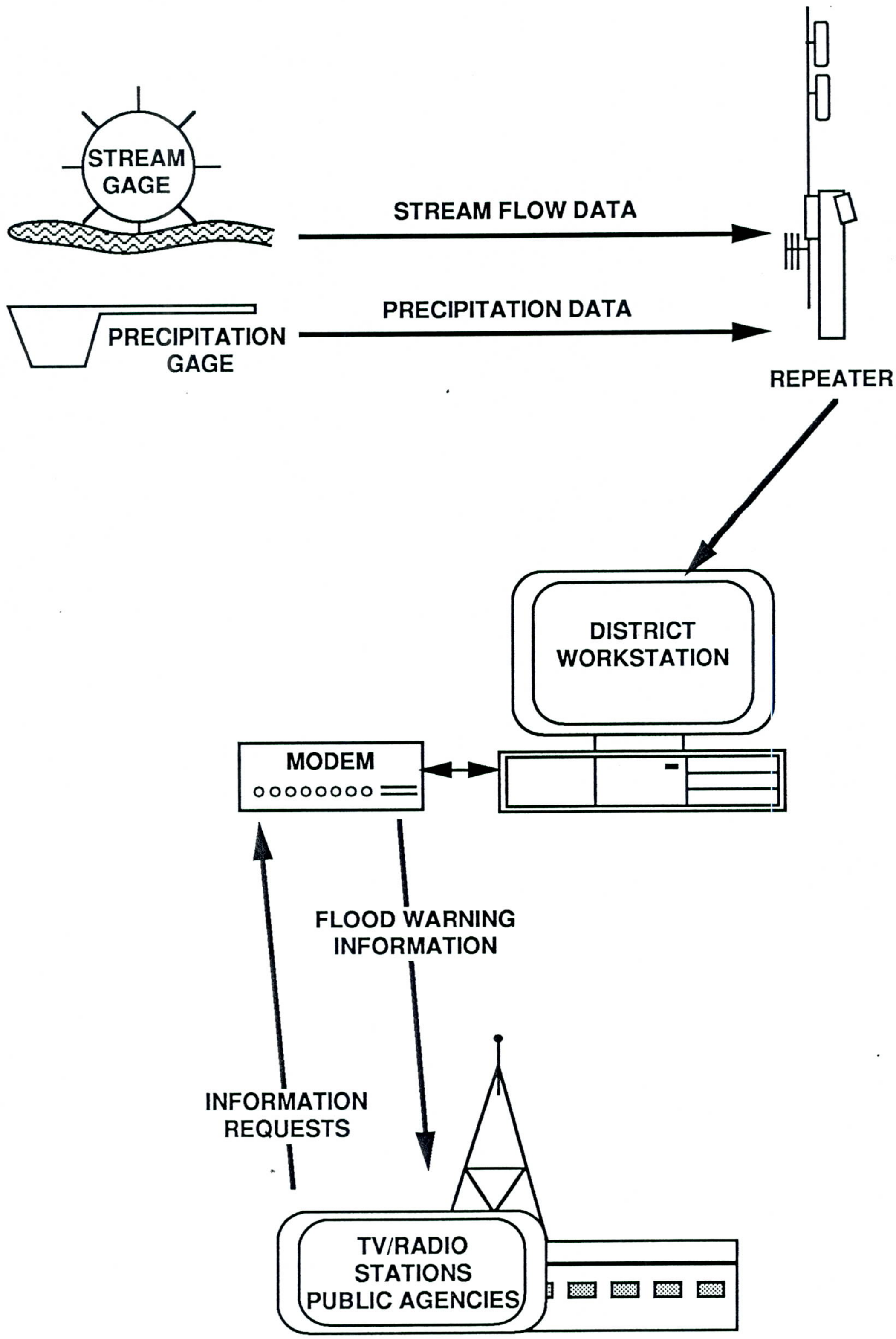
Conceptual Overview

The intent of a flood warning system is to limit damage caused by flooding. The system would be the focal point of an integrated approach to flood warning; a typical schematic is shown in Figure 2-1. Data would be gathered from the ALERT gages and correlated to help predict floods. System design would be based on an IBM-compatible PC or a Unix workstation using the following principals:

- Use of off-the-shelf hardware and software to minimize development.
- Phased implementation to allow the system to be useful as soon as it is installed and the base maps loaded. As more sophisticated functions are developed, they would be brought on-line for forecasters to use. Thus, the system will evolve from simple, user-directed forecasting to more sophisticated, automated forecasting.
- Menus, Help, Tutorials, and "Canned" programs would be employed to enable forecasters with limited computer knowledge to use the system.

The basic components of a GIS application would be:

- GIS, to manage the area base/street maps, terrain models, and display of forecast maps.
- Hydrologic modeling system to estimate the amount of runoff generated by actual or predicted precipitation.
- Hydraulic modeling system to estimate the limits of inundation caused by actual or predicted runoff.
- An AutoDial system that automatically calls the appropriate agencies in the case of a flood alert.
- A real-time monitor that would manage the real-time telemetry data. The system would ensure that data are processed properly as they arrive and any actions required are taken.



SCHEMATIC OF GIS APPLICATION

FIGURE 2-1

For a GIS application to be effective, it must be able to provide some basic information for forecasts. The functions that would provide the information are listed below, in increasing order of sophistication:

- Store historical data about previous floods, as a forecasting aid.
- Display the status of the stage and precipitation gages from the ALERT network
- Generate outlines of potential flood areas based on assumed flood depths.
- Produce lists of flooded roads and intersections.
- Model runoff in Maricopa County, to be used in flood prediction.

To perform these functions, the system would correlate data from a variety of sources and produce flood warning maps and tabular reports detailing information about the flood areas (Figure 2-2).

System Components

The most economical system would be based on off-the-shelf components. A starter system, based on an IBM-compatable PC or small Unix workstation, would include a computer, display, GIS software, relational database software (INGRES), printer, and a digitizer. Typical system components are described below.

Hardware Components. The major hardware components of a GIS are shown in Figure 2-3 and are described below:

Central Processing Unit (CPU) or Workstation. The CPU processes data for the system, and could also include an accelerator board to reduce the time required to process data.

Digitizer. A digitizer is used to enter maps and other graphical data into the system. Digitizer boards vary in size from 1 square foot to 20 square feet.

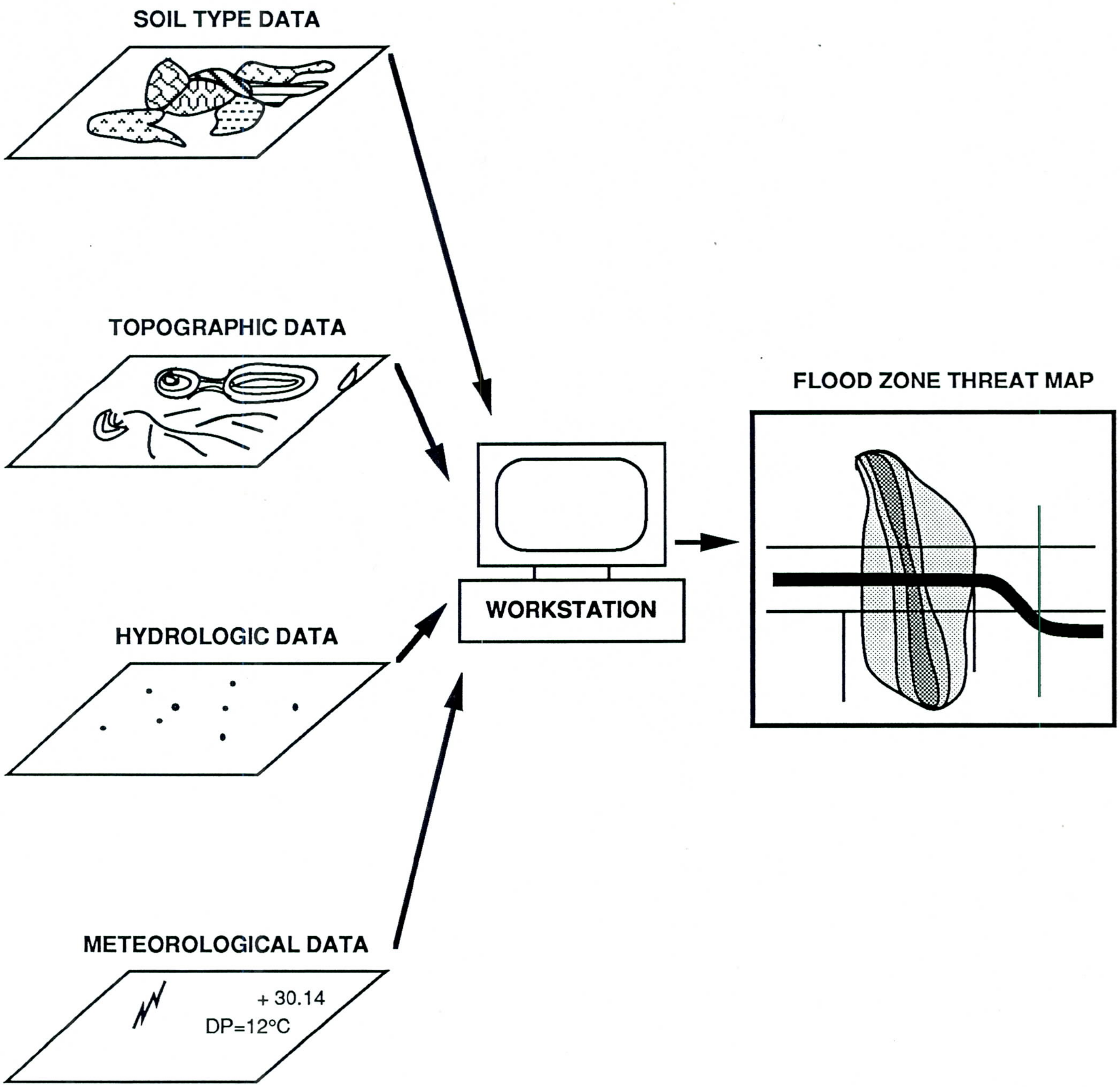
Color Camera. A color camera is used to photograph images from the system screen. The photographs could be used for reports, development work, and publicly distributed material.

Data Links. Data links to the system would be both dedicated and dial-up phone lines. The dedicated lines would carry telemetry data, while the dial-up lines (modems) would enable authorized agencies to get up-to-date flood warning information. The purpose of these links is to make acquisition and distribution of information as automatic as possible.

Optical Disk. An optical disk stores large amounts of historical and topographic data. Optical disks have removeable platters, like floppy disk drives, but can store 550 megabytes or more. In addition, they can be purchased in "jukebox" arrangements, which can automatically switch between multiple platters.

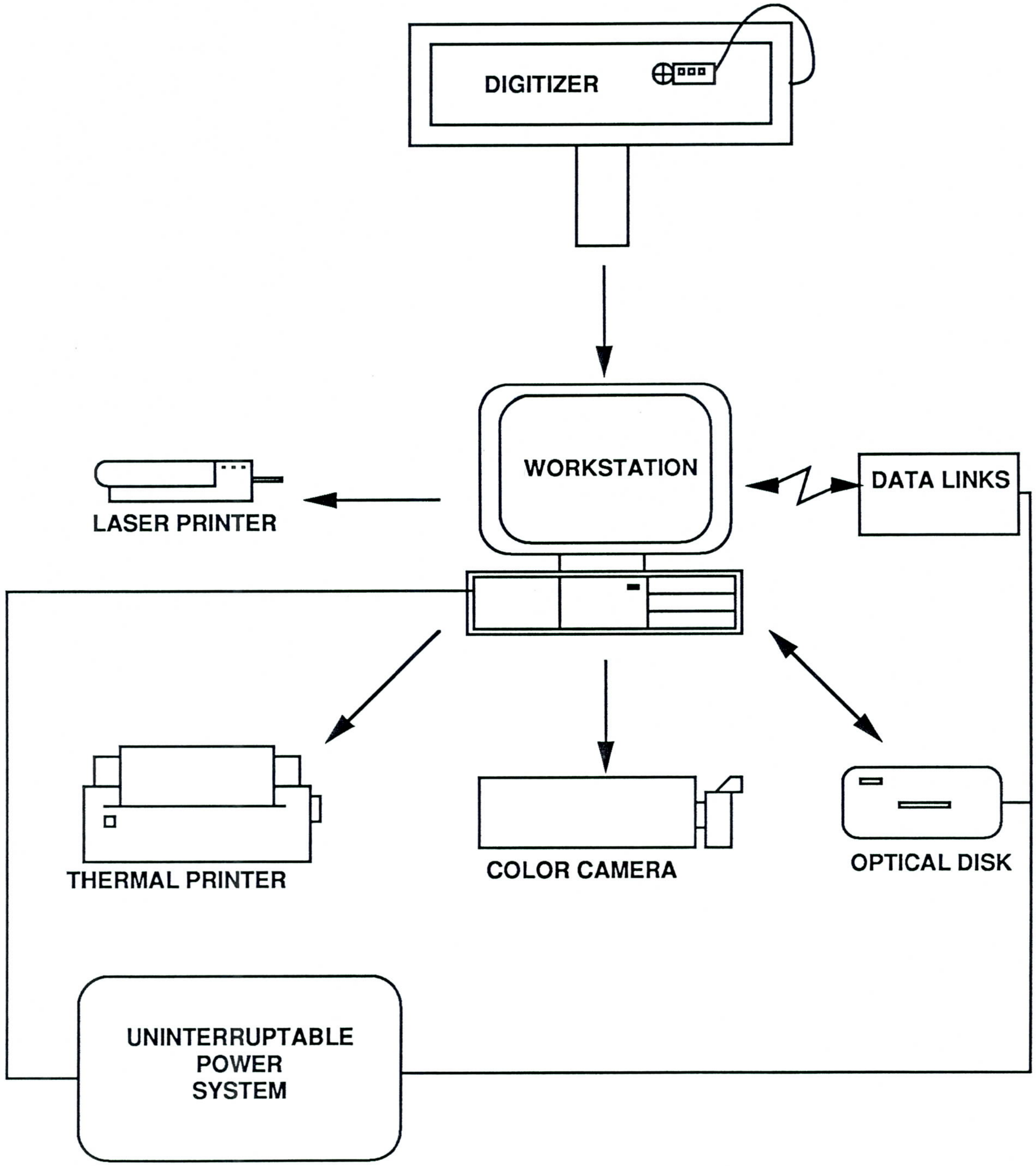
Color Thermal Plotter. Thermal plotters produce color maps inexpensively (A and B size drawings.) They are analogous to laser printers, except they are for graphics. The plots could be used for research and reports.

Laser Printer. A laser printer is used for producing both text and black and white graphics for reports.



INPUTS AND OUTPUTS OF GIS APPLICATION

FIGURE 2-2



HARDWARE COMPONENTS OF GIS APPLICATION

FIGURE 2-3

Uninterruptable Power System. These systems supply power in case of power outages, such as those caused by severe storms. They usually consist of a line monitor, batteries, and a generator. When the power fails, the batteries carry the system load until the generator can be brought on line.

GIS Functions. A GIS is a mapping system that has two components, a mapping/graphics display package, and an attribute database, which is a database of characteristics described by numbers or characters. The attribute database is usually relational (Figure 2-4). The mapping/graphics component manages the map information and symbology. The attribute database organizes the attributes (e.g., road number, parcel address, water quality record) associated with map elements (e.g., road, parcel outline, well location) into tables. The attributes are linked to the graphic elements, and this gives the system its power.

The GIS can locate objects by their type, proximity to other objects, or by their attributes. For example, an operator could first calculate the region a flood would cover and create a flood map. The operator could then overlay the predicted flood boundary on a street map and have the system print the combined map. Finally, a tabular report could be generated of all streets, intersections and business in the affected flood area.

A GIS requires a base map. This is the map in the system against which all other information is referenced. Figure 2-5 shows the layers of a typical GIS database.

The basic required GIS functions are listed below. The functions detailed are conceptual, and a GIS may actually accomplish the operations by using several lower-level primitives to create custom applications.

Data Translation. Data for the system may come from other GIS systems or from government agencies. The system should be able to read and write data files in a variety of formats, including AutoCad (DXF file), U. S. Geological Survey (USGS) Digital Quad map data (DLG-3 file), Intergraph (IGDS file), and ARC/INFO (DLG-3 or DXF files).

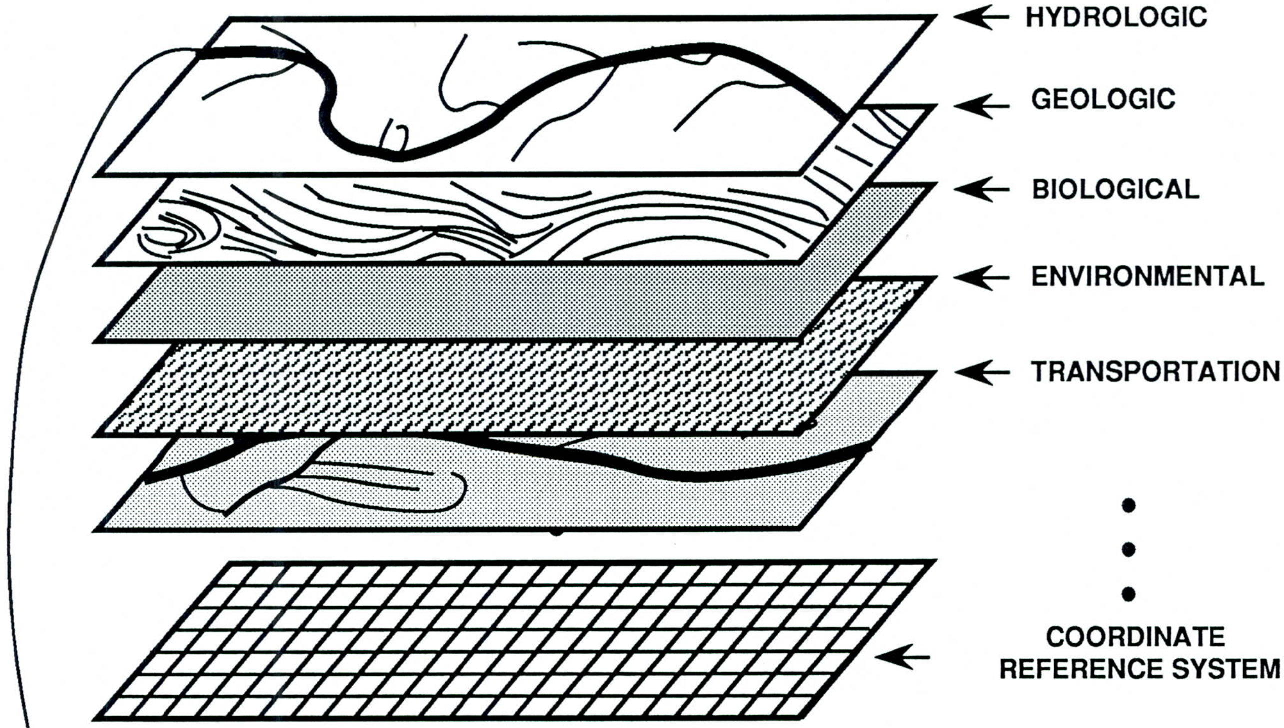
Map Registration. Maps of different projections, scales, and/or rotations would need to be linked to each other by common points in order to make the base map for the system.

Digital Terrain Model. The system would require a Digital Terrain Model (DTM) to model runoff. A DTM is a rectangular array of square cells that represents the height of the terrain at the center of each cell. These data can be obtained from the USGS or the Defense Mapping Agency, which generates digital terrain elevation data maps for the Department of Defense.

Data Driven Graphics. GIS is capable of changing the graphics used to display an object, based on a value stored in the database tables. For example, if the status of a stage gage changed from "Normal" to "Flood" condition, the symbol on the screen representing the gage would be changed from green to red.

Displayable Attributes. Attribute values, represented by text, change whenever the database value changes. For example, if the precipitation intensity is shown on the map as 1.2 in/hr, and the rate changes to 4.2 in/hr, the value on the screen would automatically change.

Graphics Capabilities. The system operators would need to be able to create and modify graphics.

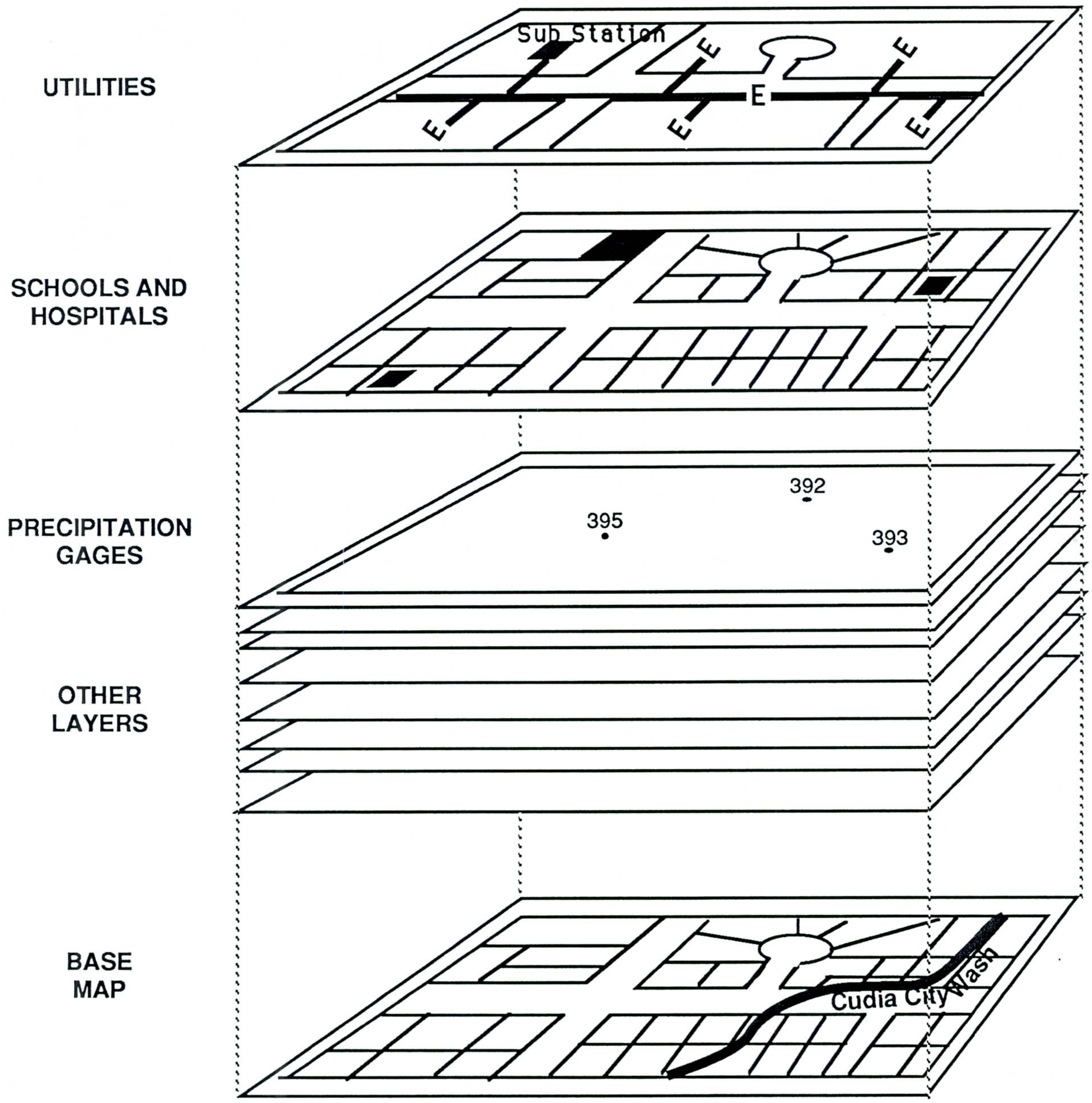


River Table

Name	Type	Annual Flow (ac-ft)	Sediment (oz/cf)	Water Quality
River A	Main	2,000,000	2.3	Very Good
River B	Feeder	1,600,000	3.4	Good
River C	Feeder	1,100,000	4.3	Fair
River D	Trib	200,000	5.8	Poor

EXAMPLE OF BASIC GIS COMPONENTS

FIGURE 2-4



TYPICAL GIS MAP DATABASE LAYERS

FIGURE 2-5

Cut and Fill. The cut and fill function was originally created for civil engineers to determine how much earth they need to cut or fill to complete a project. Here, it would be used to determine the outlines of floods. Given a height above a river bed bottom (i.e., water level), the system would determine all terrain nearby that is below the level and produce the outline of a predicted flood.

Custom Menus. The use of custom menus will enable the creation of a system that is usable by non-computer-literate operators.

Programmer's Tool Kit. The system should supply a programming interface to all of its routines to minimize the programming effort. In addition, it should allow the easy integration of user-written programs into the GIS.

Runoff Modeling System. A runoff modeling system would be used to predict the runoff or flood potential of the regions within Maricopa County. The runoff model would require:

- Surface soil type and soil permeability
- DTM and terrain slope
- Land use or imperviousness data
- Precipitation model
- Rainfall/Runoff algorithms (e.g., unit hydrograph method)

During rainfall events, GIS could be used to modify HEC-1 input parameters in a near real-time mode to account for changes in loss rate as a storm progresses. Further, the real-time precipitation data could be used to generate rainfall contours as a visual guide to forecasters as they monitor storm progress.

Data Integration. ALERT gage data would have to be integrated into GIS. The basic interface would be intermachine communication. One machine would be set up to gather the data and another machine to process the information. There are three types of intermachine communication: (1) interrupting, where the gathering machine sends the data to the processing machine and signals that there is new data, (2) polling, where the processing machine pulls the data from the gathering machine, and (3) sharing, where the gathering machine sends the data to the processing machine but doesn't signal that there are new data.

AutoDial System. The purpose of an autodial system would be to automatically warn preselected recipients of a flood alert. This would free the operator to monitor the storm's progress and evolution. This would also ensure that all required agencies are always notified.

Real-Time Control Program. GIS is generally not set up to operate in real-time; however, it could be programmed to operate in real-time. This program would run whenever the system is unattended. Whenever data arrives, it would start the necessary programs to process the data and then take the appropriate actions.

Implementation of GIS

Many of the problems associated with forecasting the precipitation potential of thunderstorms are currently being researched by academic and government institutions. In addition, some of the data that would be required in order to achieve maximum benefit, primarily NEXRAD data, may not be available for several years. However, if a GIS application were developed using a phased approach, it would be able to assist the District from very early in its development cycle. The phases and their function are described below:

Phase 1: Manual Forecasting Using Currently Available Data

- Historical flood data and cut and fill algorithms would aid in determining potential flood outlines.
- Ground data, combined with atmospheric data, are used by the forecaster to predict flooding conditions.
- When activated, the autodialer would call the required agencies, based on the current flood conditions.
- The system would be capable of supplying agencies and local TV stations electronically with flood outline maps and streets and intersections to avoid.

Phase 2: Storm Assessment and Runoff Modeling

- HEC-1 or other suitable models would be used to predict runoff.
- HEC-2 or other suitable models would be used to predict water surface elevations.
- Canned routines would be added to simplify the analysis procedure.

Phase 3: Semi-Automated Storm Warning

- The system would use the storm precipitation potential algorithms and the basin models to more accurately monitor storms (this is the system described in Phase 2). Automation of portions of the analysis would be implemented.

Large unknowns exist in developing a flood warning application with GIS. Two areas of concern are the interfacing of real-time and GIS hardware components, and the development of an unknown/unproven software interface between the ALERT data and GIS requirements. Because of these unknowns, incorporation of GIS in a flood warning program should be recognized and treated as a developmental project. Therefore, JMM recommends that a "technical data requirements and interfaces" analysis be performed to identify specific data needs. The pilot study should be performed with test data and interfaced prior to full-scale implementation of the phases outlined above.

EXISTING OPERATIONAL SYSTEMS

JMM contacted a number of sources to gather information on existing flood warning systems throughout the country and to identify flood warning perceptions. In general, JMM found that most systems had not been fully operational long enough to have tested the system with a major flooding event. Further, some systems only disseminate flood warnings internally. Of the systems investigated that did provide dissemination to outside parties, flood warnings were not issued to the general public. Rather, flood information was provided to local officials. Local officials then made the decision to act or not act on a flooding situation.

As a result of its investigations, JMM prepared a description of six operational systems which best fulfilled the following criteria:

- Climatic conditions similar to Maricopa County
- Similar in size to the Maricopa County drainage area
- Population base similar to metropolitan Phoenix
- Innovative flood warning activities
- Innovative alternatives uses for flood warning system
- Graphics capabilities.

The system descriptions are presented below. It is noted that the descriptions for the Los Angeles County and Pennsylvania Emergency Management Agency systems have been expanded as a result of JMM's field trips with the District staff on January 28, 1991, to Los Angeles County and on March 13, 1991, to Pennsylvania.

Ventura County Flood Control District, California

Detection. The Ventura County Flood Control District (VCFCD) relies on both weather forecasts and rainfall measurement to determine flood threat. The VCFCD acquires QPFs to determine flood threat from several sources including the Los Angeles NWS Forecast Office, a private weather service, and the Point Mugu Naval Station. These forecasts are used to establish the internal alert monitoring status of the VCFCD.

Once a flooding threat is indicated, an ALERT base station is monitored for precipitation information from 86 ALERT gages, including stage gages, precipitation gages, and combination gages, as well as 10 weather stations. These data are received via radio at the VCFCD office, the Los Angeles NWS Forecast Office, and Los Angeles County Flood Control District offices.

Decision-Making. Customized Enhanced ALERTNET software is used to assess the flooding threat which is keyed to individual basin responses. The VCFCD notifies the affected communities and the Navy when a set of pre-determined flooding criteria is reached. At this point, the local communities assume the decision-making role for their internal agencies' response to the flooding threat.

Dissemination and Evacuation. Once the local agencies respond to a flood threat, the VCFCD's role shifts to acting as a precipitation information source. The VCFCD detection network continues to be monitored by the communities through their own local computer/ALERT base station equipment. Community Emergency Management Centers are activated and evacuation decisions are made by local officials. Most evacuation warnings and messages are delivered door-to-door by community agency personnel.

Experience. A flood on March 1, 1983, tested the system with very favorable results, though some farmers were disappointed that early warnings couldn't have been issued to help save crops.

Comments. The system has very strong program management and multi-use. Strong program management includes effective utilization of funds to provide high benefits to the users and strong maintenance and education programs. Air pollution forecasting, fire weather monitoring, and water resource planning are examples of multiple uses.

Los Angeles County Public Works, California

Detection. The Los Angeles County Public Works Department (Public Works), which includes flood control, maintains a system of 51 precipitation and 29 stage gages, access to an extensive Corps gage system, forecast products of the NWS, and a private forecaster.

The drainage infrastructure within Los Angeles County is fairly complete and is considered to be adequate. The exception is the Los Angeles River, which is improved within the Los Angeles area except for one small section. The Corps believes that the Los Angeles River improvements are undersized and pose a potential flood threat. The ALERT gages are located mainly along the major drainageways. Repeaters transmit on several frequencies to an antenna on the roof of the Public Works building.

The Corps installed a separate Synergetics detection system as part of their operation of the Whittier Narrows Reservoir. It utilizes 2-way microwave and radio transmission and has been set up to transmit data to Public Works. Through a co-operative agreement with NWS, these data are translated into an ALERT-compatible display form and transmitted to the District via radio. The data is received as if it were ALERT, with approximately a 5-second delay. However, if the phone lines are down or the Corps' computer system is down, the data cannot be transmitted.

Weather forecasts are obtained from two sources. First, NWS provides the percent chance of rain for most of Southern California. The forecast is automatically sent to Public Works. Further, the local NWS provides 6-hour forecasts. A state-wide 24-hour forecast is provided as well as an extended three to five day forecast at 24-hour intervals. NWS automatically links by phone with the District's ALERT base station via modem to transfer the QPFs and weather forecasts. A daily weather forecast composed of these data is internally distributed within Public Works.

The second source is from a private forecaster. If rain is forecast, the private forecaster will provide 6-hour QPFs for 10 specific sites several times per day, as well as the expected maximum rainfall intensity.

Decision-Making. Once a flood threat is determined, Public Works produces a forecast of flooding threat which is relayed back to the NWS and local sheriff offices. The forecast is disseminated internally for inter-departmental usage.

Dissemination and Evacuation. Public Works has a Memorandum of Understanding with NWS which indicates that NWS accepts flood warning responsibilities. No dissemination by Public Works is made to the public nor is evacuation decision-making accomplished. Instead, the information is distributed throughout Public Works. The department has a Disaster Services Coordinator who primarily organizes earthquake drills. The county sheriff is the primary disaster mobilizer and is tied into Public Works operations. Public Works has a large "war room" with a 100-inch screen and channel selector to display various operations. The large screen displays what is currently running on the various computers used to monitor storm conditions.

Computer Operations. Computer equipment includes one 80286 PC which formerly was used for ALERT data and now receives data using NWS software. Two 80386 PC's are networked together with a voice synthesizer. Additionally, radar data is displayed, which is useful to identify when the storm has passed.

Useful graphic tools have been developed utilizing the software GTDraw. Graphics can be formatted for "pagedown" layers containing more specific information or can be set up similar to maps generated by International Hydrologic Service software.

Problems have been circumvented which occurred when trying to use a DOS environment to run real-time data. RUNDOS, a DOS emulator, is used to run DOS in a QNX environment. Graphics capabilities are used quite extensively, including generation of hydrographs.

Hydrologic modeling is performed with the river forecast model software from International Hydrologic Services, which is based on the Sacramento model. Historical data for 20 years was collected, and from that data, NWS selected the appropriate parameters required by the program to run. The model has not been tested for accuracy of rainfall/runoff estimation because of continued drought conditions.

Public Works also has some GIS capabilities. USGS maps were scanned into GIS and the ALERT data is hardwired into it. Methods are being developed to call up the Whittier Narrows Reservoir system and use color codes to display various types and levels of information. For example, water levels can be tracked throughout the system by using colors to indicate the level of concern.

Experience. The expanded network of gaged data has been very useful in operation of the reservoir system.

System Support and Funding. Three supervisory-level employees work full-time on the flood warning operations, each with two to four assistants for a total of nine to 15 people. However, they have other duties in addition to flood warning. Three people are usually required for tasks such as graphics development and calibration. Any field labor is provided by the Instrument Shop. Ten to 15 people take stage gage readings and develop rating curves. If more people are needed to run the system, they are taken from a "pool" of employees who rotate within Public Works.

Funding for flood control has been from a benefit assessment on all buildings according to size, land use and percent imperviousness. The method of assessment has been in use since 1970. The flood warning system is relatively low in cost compared to other functions of the flood control division of Public Works. The system was started in 1982-1983 with Sierra-Misco products; Handar equipment is now being installed except for precipitation-only gages which are still Sierra-Misco.

There is little growth foreseen in the future because of the mature flood control conditions in the area. NEXRAD will be installed in the future; Public Works would also consider purchasing their own radar. A staff meteorologist is not presently being considered.

Clark County Regional Flood Control District, Nevada

Detection. The Clark County Regional Flood Control District (CCRFCD) relies on a system of 29 precipitation gages, 10 weather stations, and 21 combined precipitation and stage gages. Additionally, 13 precipitation gages along the Colorado River are monitored by the Park Service. Two repeater stations transmit to NWS and to the CCRFCD offices where an audio alarm is sounded. If personnel are not present to receive the alarm, a dial-out modem begins calling personnel from a list of telephone numbers.

Dissemination and Evacuation. In the event of a flood threat, CCRFCD notifies the Clark County Emergency Management Office, as well as local emergency services in the affected area. The Clark County Public Works Department also maintains an active role in dissemination and evacuation. Personnel are informed of the location of flood threat and are dispatched immediately to the area.

Experience. For three separate storms which occurred on June 10, July 17, and August 17, 1990, the system performed very well. For example, the Public Works Department was notified of a flood threat on Flamingo Wash which passes under Caesar's Palace Casino in Las Vegas. The Casino was notified and evacuated, and vehicles were successfully removed from the parking lot. It is interesting to note that the Casino had been warned of flooding conditions on three separate prior flooding events, but had chosen not to evacuate. On all three occasions, flooding occurred and damage was sustained.

Comments. The 20 combined precipitation and stage gages monitored by USGS under a cooperative agreement are a unique feature. Theoretical stream rating curves of stage-discharge relationships have been developed by measuring velocities at various stages at known cross sections of the streams.

Urban Drainage and Flood Control District, Colorado

Background. The UDFCD serves the Denver metropolitan area and vicinity and encompasses six counties, including a portion of Boulder County. UDFCD operates a flash flood warning program during its flash flood season for participation by 6 counties and 43 municipalities. The area served covers an area of more than 1,800 square miles.

Detection. The Urban Drainage and Flood Control District (UDFCD) maintains a detection network of 101 rain gages, 56 stage gages and 4 weather stations. Flash flood and QPF forecasts are provided by a private forecaster and are issued from 3 to 6 hours prior to storm formation to agencies by phone, facsimile, and/or electronic bulletin board. The detection network serves primarily 8 specific basin warning plans: Boulder Creek, Ralston Creek, Lena Gulch, Bear Creek, Goldsmith/Harvard Gulches, Westerly Creek, Toll Gate Creeks, and Cherry Creek. The private forecaster uses radar, satellite, conventional weather data, an experimental mesonet, and proprietary forecast models to perform its roles.

Once a flash/urban flooding threat is detected, the ALERT gaging network and a NWS radar are used to monitor the location and intensity of thunderstorm systems. Mesonet surface weather data are fed into QPF models to determine storm rainfall threat. If no ALERT gages are available for a basin, the private forecaster makes rainfall estimates for use by local officials.

Decision-Making. While each basin warning plan and municipality uses its own warning procedure, several steps are followed by all groups. Internal alerts are made to areas threatened by a flooding potential and continue through the actual start of a flash flooding event. This information is used to activate a Situation Information Center which receives all ALERT real-time data. The Center is a focal point for local decision-makers from all affected city agencies through the mayor's office. The participation at the Center by agencies is determined by the severity of the flooding threat. Appropriate additional QPFs are issued to the Center which, along with ALERT data, are used to make decisions affecting the area threatened by the flood.

Dissemination and Evacuation. Heavy precipitation outlooks are issued twice daily by facsimile and electronic bulletin board to all agencies. Once a flash flood or urban flooding threat is determined, internal alerts are issued to a specific communications focal point. The evacuation decision is made by the municipality in which the affected basin is located. Evacuations are carried out by designated public agencies previously identified for the task.

Experience. Since 1979, more than 550 urban flooding and flash flooding events have been issued an internal alert and QPF. Of those, only six have been issued without lead-time of 30 minutes to 3 hours. This record has earned the program national model status for its successful integration of all program components.

Harris County Flood Control District, Texas

Detection. The Harris County Flood Control District (HCFCD) utilizes both predictive and monitoring components to gather information on flood threat. Weather forecasts are obtained from both the National Weather Service Forecast Office in Houston and Universal Weather Service to alert HCFCD personnel to increasing flooding potential due to general storm rainfall, tropical disturbances including hurricanes, and thunderstorm systems. HCFCD personnel are alerted when portions of the District are threatened by a flooding situation. Universal Weather Service is required to alert HCFCD personnel by beeper of situations which require additional monitoring.

Once a flooding situation has been identified, HCFCD personnel access the ALERT base station by telephone modem from home computers. The ALERT base station polls via a VHF radio output from more than 80 ALERT precipitation and stage gage stations and 3 complete weather stations. These rainfall data in the ALERT base station and input from the NWS and Universal Weather Service then form the basis for further decision-making.

Decision-Making. Once ALERT rainfall data and weather forecasts have been received, the HCFCD activates one of four alert phases for the affected area depending on the severity of the flooding threat. A combination of the forecasts and rainfall information help determine the severity of the flooding threat. ALERT data are also being input to a hydrologic model, but not on a real-time basis to date. Local decision-making aids are also employed to determine the effects of locally heavy rainfall, especially on roadways which are prone to frequent flooding from thunderstorms.

If a general street flooding, county-wide flooding or hurricane threat is indicated, 17 Emergency Management Centers are activated as appropriate. These centers are associated with incorporated local governments and assume an enhanced monitoring role. The centers act as a flood information source for local decision-makers from public agencies. Personnel at the centers make local evacuation decisions.

Dissemination and Evacuation. Local officials disseminate flooding and evacuation information to the public using local radio and television. A Public Information Emergency System radio provides site-specific information on the location and timing of flooding. Additional HCFCD phone lines are reserved for both the public and press to ask the HCFCD specific questions regarding the flooding situation. Local television coverage is encouraged from HCFCD offices during flooding events in an effort to keep the public informed. This intense public dissemination effort is considered a national model by peers.

Pennsylvania Emergency Management Agency (PEMA)

Detection. Pennsylvania Emergency Management Agency (PEMA) is responsible for state-level emergency response support and distribution of weather and flood information to county and city emergency agencies. The PEMA system relies on a combination of NWS forecasts, private hydro-meteorological forecasts and information packages, and an extensive precipitation monitoring system to assess and monitor the evolving flooding threat.

It should be noted that the system is quite extensive and monitors a variety of potential disasters such as flooding, hurricanes, and chemical or nuclear disasters. PEMA is meant to be a complete source for use by emergency managers of information and models needed to make decisions on the local level. Vast amounts of hydro-meteorological information are collected on a state-wide basis.

All counties in Pennsylvania actively participate in PEMA's emergency operations. Each is linked by two satellites to PEMA and its Emergency Information System (EIS). The EIS is software developed by Research Alternatives, Inc., which allows text and graphic information to be transmitted instantaneously among PEMA and the county emergency managers.

An extensive database has been built which covers the entire state. The database contains locations of roads, pipelines and pumps stations, precipitation gages, schools, hospitals, nuclear plants, and even the location and number of dairy cows, to name a few. Also part of the database is a description of every recorded flooding event in the history of Pennsylvania.

Of the 67 counties, 28 have access to the flood warning portion of PEMA's system. The 28 counties were selected as the most prone to major flooding. Flood warning activities are based on 198 precipitation gages located within the 28 counties. The NWS' PCIFLOWS software is used to monitor the gages. Flooding potential is monitored by a private meteorological service, which has access to all meteorological, hydrologic and hydraulic data available to PEMA.

Decision-Making. The PEMA system is a source of hydro-meteorological and hydrological information for use by the local officials charged with decision-making. As such, PEMA is not a decision-making source unless a local community's emergency manager wishes to confer with PEMA on weather, river and hydro-meteorological data. However, in the case of a statewide threat for flooding, PEMA will act as a central focal point for the dissemination of critical information.

Dissemination and Evacuation. PEMA is a very strong dissemination source through its EIS, but evacuation decisions are left to local managers. PEMA acts as a dissemination focal point for the distribution of NWS flash flood watches and warnings and NWS flash flooding statements and updates. The primary data access is through a computer workstation environment at the local emergency manager level.

Experience. On the local level, county emergency managers have reported successful use of the IFLOWS information. PEMA was asked how its system performed during the July 1990 Shadyside, Ohio flood where a number of people were killed. PEMA has stated that very little of its IFLOWS network was in the vicinity of the Shadyside, Ohio flooding. Its operations are well outside the area flooded, so its operations were not affected.

OPERATIONAL SYSTEMS IN MARICOPA COUNTY

Flood warning services in Maricopa County are presently the responsibility of NWS. This evaluation of the NWS system includes a description of NWS operations and products, an assessment of the success rate of flash flood and severe weather warnings issued by NWS, and an analysis of the effectiveness of NWS during a recent storm. Also discussed are flood warning activities of Arizona Department of Water Resources (ADWR), Maricopa County Department of Civil Defense (Civil Defense), and Salt River Project (SRP).

National Weather Service

NWS is involved in hydrologic, meteorological, agricultural, fire, and aviation weather service. Activities related to flooding are performed in both the hydrologic and meteorological sections. At present, the majority of the information utilized by NWS in issuing a flood watch or warning is from the Maricopa County ALERT gage network. Also used to identify flood watches and warnings are radar, satellite, and observer information.

Precipitation and Streamflow. The ALERT network is comprised of 119 precipitation gages and 44 stage gages operated by the District throughout Maricopa County. The gages transmit real-time data and automatically alarm NWS if 0.5 inches of rain or more occurs within a one-half hour time period at any precipitation gage.

In addition to the ALERT network, there are limited (approximately 10) GOES satellite gages installed by the USGS in Maricopa County. When no activity is present, every four hours these gages transmit 15-minute data for the preceding four to six hours duration. During active weather, data are transmitted every 15 minutes, thereby providing near real-time data.

A third type of precipitation measurement used by the NWS is the Phoenix Real-Time Instrumentation for Surface Meteorological Studies (PRISMS) weather station, which obtains real-time weather reports of the Phoenix area at 5-minute intervals. There are 14 PRISMS sites located in the Phoenix area with an additional two to be installed in August, 1991. The PRISMS sites are continuously monitoring meteorological sensors which measure temperature, humidity, air pressure, and wind velocity, in addition to precipitation.

NWS feels that although there are numerous precipitation gages in Maricopa County, the network could be greatly improved by increasing the number of stage gages. NWS recognizes that stage gage rating curves are limited in Maricopa County and that there are a number of ungaged watersheds. For improved analysis, NWS requires continuously updated runoff observations. Another constraint in the data received by NWS is that problems exist in networking data between counties.

Radar. The current NWS radar is the WSR-74. This radar system is an additional constraint in NWS flood warning services because the technology is outdated. The WSR-74 has the capability of identifying a storm's location and elevation, and how quickly the storm is moving, but cannot provide quantitative precipitation data.

SW Area Monsoon Project. In the summer of 1990, much information was collected through the SW Area Monsoon Project (SWAMP). SWAMP was sponsored by National Severe Storms Laboratory, Arizona State University, University of Arizona, SRP, CICESE, NWS, and the Aircraft Operations Center. Many agencies will be involved in reducing the data, which included daily documentation of the weather events and special observations, as well as rainfall and wind data. Preliminary results from the analysis of the data are expected in 1991; however, NWS believes that it will be 1992 before final results are available.

NWS Weather Statements. NWS meteorologists analyze the atmosphere and issue severe weather watches and warnings, including flash floods. Flash flooding often is predicted or occurs in conjunction with other severe weather such as high winds, tornadoes or hail. It is important to note that if flash flooding is associated with severe weather, it is recorded in the severe weather category and not the flash flood category.

Areal Extent of Flood Warnings. The extent of area covered by the watches and warnings is based on radar, satellite, and observer information to identify the extent of storm cells. A severe weather statement or watch covers a larger area than a warning. NWS attempts to be as site-specific as possible, but feels that more precipitation and stage gages and satellite imagery are needed to be able to better define the area in danger of flooding. In most cases, the extent of the area included in the severe weather or flash flood warnings issued by NWS is described by county or by portion of the county. Because Maricopa County is large (over 9,200 square miles), the effectiveness of a county-wide warning in reducing loss of life, injury, and property damage is diminished.

Success Rate of NWS Warnings. The success of NWS warnings can be measured by comparing historical records of events with records of warnings issued by the NWS. This comparison is termed a verification process and is performed by the NSSFC for over 200 local NWS offices on a monthly and year-to-date basis. Warning verification began at the NSSFC in 1979; in 1982, the NWS formulated a National Verification Plan that provided verification guidelines.

The verification of events is described by three categories:

- Verified Warning: A warning was issued prior to an event occurrence and the event actually occurred.
- Unverified Warning: A warning was issued but no event occurred.
- Unwarned Event: An event occurred without prior warning from NWS.

As previously stated, the NWS performs verification analyses of severe weather and flash flood warnings. To evaluate the effectiveness of local NWS warnings, flash flood and severe weather verification information for Maricopa County was obtained from NWS and NSSFC for a five-year period from 1986 through 1990. The following discussion provides the results of the evaluation.

It is noted that beginning in 1990, verification procedures for flash flooding were modified. The new guidelines state that if a flash flood event ends during a flash flood warning timeframe, then the warning is considered verified. For example, if a flash flood occurred from 2:00 p.m. to 4:00 p.m. and a flash flood warning were issued at 3:55 p.m., the warning would be categorized as verified, with zero lead time. Also, if the ending of a flash flood event is not specified, then the NSSFC verification computer program automatically assigns the duration of the event to be one hour. A summary is presented in Table 2-1 of all flash flood events that occurred and flash flood warnings issued in this 5-year period for Maricopa County based on the NWS "Flash Flood Verification Report for Phoenix, Arizona."

TABLE 2-1

FLASH FLOOD VERIFICATION SUMMARY
FOR MARICOPA COUNTY,
1986 THROUGH 1990

FLASH FLOOD EVENT					VERIFICATION		
Date	Time Warning Began (MST)	Time Warning Ended (MST)	Time Event Began (MST)	Lead Time (min)	Verified Warning	Unverified Warning	Unwarned Event
8/11/86	5:05 pm	6:00 pm	-	-		✓	
8/27/86	6:30 pm	9:00 pm	8:00 pm	90	✓		
8/28/86	8:50 pm	3:00 am	-	-		✓	
8/29/86	10:55 pm	12:00 am	-	-		✓	
10/11/86[a]	7:40 pm	9:00 pm	9:00 pm	80	✓		
10/11/86[a]	8:55 pm	10:30 pm	9:00 pm	5	✓		
	1986 Flash Flood Subtotal				**3**	**3**	**0**
7/31/87	6:10 pm	7:30 pm	-	-		✓	
8/10/87	6:10 pm	9:00 pm	-	-		✓	
9/22/87	5:53 pm	7:00 pm	-	-		✓	
10/24/87	5:18 pm	7:15 pm	6:00 pm	42	✓		
10/29/87	-	-	2:50 pm	-			✓
10/29/87	3:55 pm	5:00 pm	-	-		✓	
10/29/87	4:45 pm	7:00 pm	-	-		✓	
11/1/87	-	-	3:10 am	-			✓
11/1/87	-	-	5:10 am	-			✓
11/1/87	-	-	12:25 pm	-			✓
	1987 Flash Flood Subtotal				**1**	**5**	**4**
7/29/88	8:50 pm	10:45 pm	-	-		✓	
8/21/88	9:38 am	2:45 pm	-	-		✓	
8/21/88	-	-	5:00 pm	-			✓
8/23/88	6:09 pm	8:15 pm	-	-		✓	
8/23/88	9:45 pm	3:00 am	-	-		✓	
8/27/88	1:58 pm	3:30 pm	-	-		✓	
8/29/88	9:56 pm	6:00 am	-	-		✓	
	1988 Flash Flood Subtotal				**0**	**6**	**1**
8/15/89	10:03 pm	12:00 am	-	-		✓	
8/15/89	11:59 pm	1:00 am	-	-		✓	
8/16/89	12:43 am	2:45 am	-	-		✓	
	1989 Flash Flood Subtotal				**0**	**3**	**0**

TABLE 2-1 (continued)

FLASH FLOOD VERIFICATION SUMMARY FOR MARICOPA COUNTY, 1986 THROUGH 1990

FLASH FLOOD EVENT					VERIFICATION		
Date	Time Warning Began (MST)	Time Warning Ended (MST)	Time Event Began (MST)	Lead Time (min)	Verified Warning	Unverified Warning	Unwarned Event
7/13/90	8:03 pm	10:00 pm	-	-		✓	
7/21/90[b]	8:56 pm	10:15 pm	8:30 pm	0	✓		
7/24/90	-	-	2:00 am	-			✓
7/24/90	3:03 am	5:00 am	-	-		✓	
8/5/90	4:38 pm	7:15 pm	-	-		✓	
8/6/90	3:40 pm	5:30 pm	-	-		✓	
8/6/90	5:25 pm	6:40 pm	-	-		✓	
8/11/90	6:26 pm	7:30 pm	-	-		✓	
8/11/90	7:27 pm	8:30 pm	-	-		✓	
8/11/90	8:23 pm	9:30 pm	-	-		✓	
8/14/90	8:15 am	12:00 pm	-	-		✓	
8/14/90	12:00 pm	2:18 pm	-	-		✓	
8/14/90	2:18 pm	5:15 pm	-	-		✓	
8/15/90	4:33 am	8:30 am	-	-		✓	
9/14/90[a]	9:20 pm	11:15 pm	11:15 pm	115	✓		
9/14/90[a]	10:50 pm	12:00 am	11:15 pm	25	✓		
1990 Flash Flood Subtotal					3	12	1
5-YEAR FLASH FLOOD TOTAL					**7**	**29**	**6**

(a) More than one warning was issued with overlapping timeframes. Each warning was counted as verified because the event occurred during the overlap.

(b) Flash flooding began at 8:30 pm, but a flash flood warning was not issued until 8:56 pm. Prior to 1990, NWS would have considered the warning to be unverified. Due to changes in verification procedures implemented in 1990, this event was assumed to occur for a one-hour duration. Because the assumed duration of event lasted past the time of warning, the event was considered verified, with zero lead time.

The flash flood analysis indicated the following:

- 36 warnings were issued.
- Of the 36 warnings, 7 were verified, with an average lead time of 51 minutes.
- 6 unwarned events occurred.

Severe weather is specifically defined as tornadoes, hail greater than or equal to 3/4 inches in diameter, thunderstorm wind gusts greater than or equal to 50 knots, and thunderstorm wind damage, which may be accompanied by precipitation. If a tornado warning is in effect and *any* of the conditions describing severe weather occur during the warning timeframe, then the warning is considered verified. Table 2-2 presents a summary of all severe weather events that occurred and severe weather warnings that were issued in Maricopa County from 1986 through 1990 based on the NWS "Severe Local Storms Verification Report for Phoenix, Arizona."

The severe weather analysis indicated the following:

- 90 warnings were issued.
- Of the 90 warnings, 39 were verified, with an average lead time of 46 minutes.
- 42 unwarned events occurred.

Analysis of the September 3, 1990 Maricopa County Storm. The effectiveness of NWS weather announcements issued for severe weather and flooding events was investigated by comparing precipitation data for the September 3, 1990 storm with the NWS weather alert announcements for the storm. Data from five precipitation gages located in northwest Maricopa County indicated that the storm began at 5:00 p.m. and lasted approximately two hours. Table 2-3 presents a summary of the NWS weather announcements for the September 3, 1990 storm in Maricopa County based on the NWS "Significant Weather/Event Log" for September 3, 1990.

As shown in Table 2-3, the special weather statements and watches were issued over very large areas and were in effect for long periods of time while the warnings were issued over smaller areas and shorter timeframes.

The 4:45 p.m. to 6:45 p.m. severe thunderstorm warning was counted as three verified warnings because, based on the NWS/NSSFC verification analysis, three events occurred within the duration of the warning. The first was a tornado at 5:10 p.m., and the second and third were wind damage occurring at 6:00 p.m. The wind damage events occurred at different locations in the County. The lead times for the three events were 25 minutes, 75 minutes, and 75 minutes, respectively. Neither the tornado warning from 5:18 p.m. to 5:45 p.m. nor the severe thunderstorm warning from 6:15 p.m. to 6:45 p.m. was verified.

It is important to note that flash flooding did occur in Maricopa County after 5:00 p.m., but no flash flood warning had been issued for that time frame.

Future NWS Manpower Reduction. When NEXRAD is introduced in Arizona, the manpower at the Phoenix NWS office will be reduced from 13 to approximately 4. However, the overall number of NWS staff in Arizona will increase, as the NWS branch Weather Service Offices will have more people. NWS believes that its service will greatly improve with NEXRAD, especially in the area of flash flooding. However, a certification process exists where, before NWS can change its operations, users such as the District would have to agree that the NWS level of service provided by the new system would not be lowered.

TABLE 2-2

**SEVERE WEATHER VERIFICATION SUMMARY
FOR MARICOPA COUNTY,
1986 THROUGH 1990**

SEVERE WEATHER EVENT					VERIFICATION		
Date	Time Warning Began (MST)	Time Warning Ended (MST)	Time Event Began (MST)	Lead Time (min)	Verified Warning	Unverified Warning	Unwarned Event
3/11/86	5:35 pm	6:00 pm	-	-		✓	
3/12/86	6:10 pm	7:00 pm	-	-		✓	
4/1/86	8:45 am	9:30 am	-	-		✓	
5/31/86	4:00 pm	5:00 pm	-	-		✓	
5/31/86	-	-	5:30 pm	-			✓
5/31/86	6:00 pm	6:30 pm	-	-		✓	
6/1/86	-	-	5:00 pm	-			✓
6/25/86	-	-	7:00 pm	-			✓
7/2/86	-	-	7:07 pm	-			✓
7/3/86	3:45 pm	5:00 pm	4:30 pm	45	✓		
7/15/86	6:05 pm	7:00 pm	-	-		✓	
7/16/86	-	-	2:45 pm	-			✓
7/16/86	3:20 pm	6:00 pm	-	-		✓	
7/16/86	4:45 pm	7:00 pm	-	-		✓	
8/2/86	-	-	9:00 pm	-			✓
8/8/86	7:00 pm	8:00 pm	-	-		✓	
8/11/86	5:05 pm	6:00 pm	-	-		✓	
8/13/86	6:45 pm	8:00 pm	-	-		✓	
8/19/86	-	-	7:00 pm	-			✓
8/21/86	2:45 pm	4:00 pm	-	-		✓	
8/23/86	-	-	6:00 pm	-			✓
8/25/86	6:00 pm	7:30 pm	-	-		✓	
8/26/86	-	-	6:58 pm	-			✓
8/27/86	3:00 pm	4:00 pm	-	-		✓	
8/28/86	6:40 pm	8:00 pm	8:00 pm	80	✓		
8/28/86	8:50 pm	10:00 pm	-	-		✓	
8/29/86	-	-	9:30 pm	-			✓
8/29/86	10:55 pm	12:00 am	-	-		✓	
9/3/86	-	-	3:00 pm	-			✓
10/9/86	-	-	3:45 pm	-			✓
10/9/86	4:10 pm	6:00 pm	4:45 pm	35	✓		
10/10/86	2:30 pm	3:15 pm	-	-		✓	
10/10/86	-	-	11:55 am	-			✓
10/11/86	-	-	9:00 pm	-			✓
11/18/86	6:00 pm	7:30 pm	-	-		✓	
1986 Severe Weather Subtotal					**3**	**18**	**14**

TABLE 2-2 (continued)

SEVERE WEATHER VERIFICATION SUMMARY FOR MARICOPA COUNTY, 1986 THROUGH 1990

SEVERE WEATHER EVENT					VERIFICATION		
Date	Time Warning Began (MST)	Time Warning Ended (MST)	Time Event Began (MST)	Lead Time (min)	Verified Warning	Unverified Warning	Unwarned Event
5/10/87	4:37 pm	5:45 pm	-	-		✓	
5/14/87	3:45 pm	5:00 pm	-	-		✓	
7/14/87	-	-	9:00 pm	-			✓
7/26/87	-	-	6:00 pm	-			✓
7/27/87	8:30 pm	9:30 pm	-	-		✓	
7/31/87	-	-	6:00 pm	-			✓
7/31/87	6:10 pm	7:30 pm	6:15 pm	5	✓		
8/24/87	-	-	3:30 pm	-			✓
8/29/87	2:35 pm	3:30 pm	2:35 pm	0	✓		
8/29/87	3:34 pm	4:30 pm	-	-		✓	
9/22/87	4:20 pm	5:15 pm	-	-		✓	
9/22/87	5:13 pm	6:00 pm	5:45 pm	32	✓		
9/22/87	5:53 pm	7:00 pm	-	-		✓	
10/29/87	-	-	2:50 pm	-			✓
10/29/87	3:55 pm	5:00 pm	4:00 pm	5	✓		
10/29/87	3:55 pm	5:00 pm	4:52 pm	57	✓		
10/29/87	3:55 pm	5:00 pm	4:54 pm	59	✓		
10/29/87	3:55 pm	5:00 pm	5:00 pm	65	✓		
11/1/87	12:21 am	1:00 am	1:00 am	39	✓		
11/1/87	-	-	1:19 am	-			✓
11/1/87	-	-	2:00 am	-			✓
11/1/87	2:16 am	3:15 am	3:10 am	54	✓		
11/1/87	-	-	5:10 am	-			✓
	1987 Severe Weather Subtotal				**9**	**6**	**8**
4/16/88	11:32 am	12:30 pm	-	-		✓	
6/29/88	-	-	6:28 pm	-			✓
6/29/88	-	-	7:00 pm	-			✓
6/29/88	-	-	7:30 pm	-			✓
6/30/88	5:34 pm	7:30 pm	6:59 pm	85	✓		
6/30/88	7:16 pm	8:15 pm	7:45 pm	29	✓		
7/9/88	4:51 pm	6:00 pm	5:00 pm	9	✓		
7/10/88	4:59 pm	6:00 pm	5:00 pm	1	✓		
7/20/88	-	-	5:00 pm	-			✓
7/23/88	7:24 pm	8:15 pm	-	-		✓	
7/25/88	4:19 pm	6:15 pm	-	-		✓	
7/25/88	10:50 pm	11:45 pm	-	-		✓	
7/28/88	-	-	7:00 pm	-			✓

TABLE 2-2 (continued)

SEVERE WEATHER VERIFICATION SUMMARY
FOR MARICOPA COUNTY,
1986 THROUGH 1990

SEVERE WEATHER EVENT					VERIFICATION		
Date	Time Warning Began (MST)	Time Warning Ended (MST)	Time Event Began (MST)	Lead Time (min)	Verified Warning	Unverified Warning	Unwarned Event
7/29/88	5:08 pm	6:15 pm	-	-		✓	
7/29/88	6:18 pm	7:15 pm	-	-		✓	
7/29/88	8:50 pm	9:40 pm	9:00 pm	10	✓		
7/30/88	-	-	6:59 pm	-			✓
7/30/88	-	-	7:45 pm	-			✓
8/1/88	-	-	8:00 pm	-			✓
8/23/88	4:16 pm	5:15 pm	-	-		✓	
8/23/88	6:09 pm	7:15 pm	-	-		✓	
8/23/88	6:16 pm	7:15 pm	-	-		✓	
8/25/88	2:39 pm	3:45 pm	-	-		✓	
8/27/88	1:58 pm	3:30 pm	2:00 pm	2	✓		
8/27/88	-	-	7:30 pm	-			✓
10/13/88	9:05 am	10:00 am	-	-		✓	
10/14/88	-	-	8:58 am	-			✓
10/14/88	-	-	11:30 am	-			✓
1988 Severe Weather Subtotal					**6**	**11**	**11**
1/4/89	-	-	11:00 am	-			✓
7/10/89	-	-	3:45 pm	-			✓
7/21/89	6:57 pm	8:30 pm	7:30 pm	33	✓		
7/30/89	8:45 pm	9:45 pm	9:00 pm	15	✓		
7/31/89	-	-	6:00 pm	-			✓
8/6/89	6:50 pm	8:00 pm	7:45 pm	55	✓		
8/7/89	4:15 pm	7:20 pm	7:00 pm	165	✓		
8/15/89	10:03 pm	11:00 pm	-	-		✓	
8/15/89	11:59 pm	1:00 am	-	-		✓	
8/17/89	-	-	9:20 pm	-			✓
10/21/89	2:05 pm	3:30 pm	3:20 pm	75	✓		
1989 Severe Weather Subtotal					**5**	**2**	**4**
6/9/90	-	-	8:00 pm	-			✓
6/9/90	8:25 pm	9:30 pm	-	-		✓	
7/10/90	7:01 pm	9:00 pm	9:00 pm	119	✓		
7/13/90	8:03 pm	10:00 pm	-	-		✓	
7/21/90	-	-	7:25 pm	-			✓
7/23/90	11:16 pm	1:15 am	-	-		✓	
7/24/90	1:25 am	3:15 am	2:00 am	35	✓		
7/24/90	3:03 am	5:00 am	-	-		✓	

TABLE 2-2 (continued)

SEVERE WEATHER VERIFICATION SUMMARY FOR MARICOPA COUNTY, 1986 THROUGH 1990

SEVERE WEATHER EVENT					VERIFICATION		
Date	Time Warning Began (MST)	Time Warning Ended (MST)	Time Event Began (MST)	Lead Time (min)	Verified Warning	Unverified Warning	Unwarned Event
7/25/90[a]	12:33 am	2:30 am	1:00 am	27	✓		
7/25/90[a]	12:33 am	2:30 am	1:00 am	27	✓		
7/25/90	2:35 am	3:55 am	-	-		✓	
7/30/90	6:05 pm	8:00 am	7:42 pm	97	✓		
7/31/90	-	-	8:55 pm	-			✓
8/3/90	9:01 pm	11:00 pm	9:30 pm	29	✓		
8/3/90	9:01 pm	11:00 pm	10:30 pm	89	✓		
8/5/90	-	-	3:55 pm	-			✓
8/5/90	4:38 pm	6:45 pm	-	-		✓	
8/5/90	5:24 pm	7:15 pm	-	-		✓	
8/6/90	3:40 pm	5:30 pm	4:36 pm	54	✓		
8/6/90[b]	5:25 pm	7:15 pm	5:50 pm	25	✓		
8/6/90[b]	5:25 pm	6:40 pm	5:50 pm	25	✓		
8/6/90	9:30 pm	10:30 pm	-	-		✓	
8/6/90	9:30 pm	10:20 pm	-	-		✓	
8/11/90	6:26 pm	7:30 pm	-	-		✓	
8/11/90	7:27 pm	8:30 pm	8:08 pm	41	✓		
8/11/90	8:23 pm	9:30 pm	-	-		✓	
9/3/90	-	-	4:20 pm	-			✓
9/3/90	4:45 pm	6:45 pm	5:10 pm	25	✓		
9/3/90[a]	4:45 pm	6:45 pm	6:00 pm	75	✓		
9/3/90[a]	4:45 pm	6:45 pm	6:00 pm	75	✓		
9/3/90	5:18 pm	5:45 pm	-	-		✓	
9/3/90[c]	6:15 pm	6:45 pm	-	-		✓	
9/14/90	8:50 pm	10:45 pm	9:30 pm	40	✓		
9/14/90	8:50 pm	10:45 pm	9:50 pm	60	✓		
9/14/90	10:50 pm	12:45 am	-	-		✓	
1990 Severe Weather Subtotal					16	14	5
5-YEAR SEVERE WEATHER TOTAL					39	51	42

(a) Severe weather events occurred at the same time, but at different locations within Maricopa County.

(b) More than one warning was issued with overlapping timeframes. Each warning was counted as verified because the event occurred during the overlap.

(c) Due to a misclassification at the local NWS office of this warning, it was excluded from verification by NSSFC. JMM's review of the local NWS records indicate that the warning would have been classified as an unverified event.

TABLE 2-3

SUMMARY OF NWS WEATHER ANNOUNCEMENTS FOR THE SEPTEMBER 3, 1990 STORM FOR MARICOPA COUNTY

Time of Issue (MST)	Type/Description	Location	Timeframe
5:00 am	Special Weather Statement: Scattered heavy showers and thunderstorms.	Arizona	Afternoon & Evening
11:40 am	Special Weather Statement: Scattered showers and thunderstorms with very heavy rain and strong winds.	West Mohave County & developing elsewhere in Arizona	-
12:15 pm	Flash Flood Watch	Arizona	Until Midnight
1:48 pm	Severe Thunderstorm Watch	In Counties: Maricopa, Yuma, LaPaz, western & central Pima & Pinal, west half of Gila, and south Yavapai & Mohave	-
4:09 pm	Severe Thunderstorm Watch	Southwest Arizona	Until 8 pm
4:15 pm	Flash Flood Watch	Arizona	Until Midnight
4:45 pm	SEVERE THUNDERSTORM WARNING	South-central Arizona; North Maricopa County	Until 6:45 pm
5:18 pm	TORNADO WARNING	South-central Arizona; North-central Maricopa County	Until 5:45 pm
6:15 pm	SEVERE THUNDERSTORM WARNING	North Maricopa County	Until 6:45 pm
6:15 pm	Severe Thunderstorm Watch	Southwest Arizona	Until 8 pm
6:15 pm	Flash Flood Watch	Arizona	Until Midnight
7:48 pm	Severe Weather Statement: The severe thunderstorm watch is cancelled.	Southwest Arizona	As of 8 pm
9:16 pm	Flash Flood Statement: The flash flood watch is cancelled.	Arizona (except Mohave County)	As of 9 pm

Arizona Department of Water Resources

ADWR assists in the design, installation, and start-up of local flood warning systems, and provides ongoing technical expertise. This assistance is provided to communities with a high flood hazard, an interest in developing a flood warning system, resources to maintain the system, and the absence of an existing flood detection or monitoring system. Assistance is dependent on funds available to ADWR for flood warning.

ADWR has recently installed a local ALERT system in the Sedona/Oak Creek areas in Yavapai and Coconino Counties. A similar system is being developed for the Prescott area in Yavapai County. Also, work has recently begun to install a system in Clifton, Arizona.

ADWR's flood warning activities also include an intergovernmental agreement with NWS. Under the agreement, NWS provides space for ADWR personnel within its offices and ADWR provides technical hydrologic support during heavy storms. ADWR provides estimates of areas expected to reach a certain storm frequency and assists in monitoring storms on the watershed. ADWR also assists in taking telephone calls from observers during storms. After the occurrence of a flood, ADWR assists in viewing the affected areas and assessing the extent of any damage.

In addition to activities conducted at NWS, ADWR also monitors a weather radar display at its offices and is tied into the Sedona ALERT system.

Maricopa County Department of Civil Defense

Civil Defense is primarily a coordination agency during times of emergency. Its jurisdiction is in unincorporated Maricopa County, but also assists in coordination and/or notification when requested by a local, county, state, or federal agency, as well as school districts and the public.

Civil Defense is set up to disseminate emergency information and made evacuation decisions, but does not issue flood watches or warnings. All weather information is received by teletype from the NWS. Flood threat information is provided by the District to Civil Defense.

Civil Defense activates its Emergency Operations Center (EOC) during flooding situations that may involve evacuations in the County. Representatives from various agencies are called in to coordinate flood fighting efforts. If evacuation is required within incorporated areas, the local agency activates its EOC. When necessary, Civil Defense assists the local EOC.

If there is a flood threat, the Maricopa County Highway Department is alerted, and in flooding events, crews are dispatched to barricade roads. During river releases, Civil Defense is notified of changes in release rates. When releases occur, Civil Defense monitors the flow and informs the affected parties as necessary. Additionally, Civil Defense informs Luke and Williams Air Force Bases of river releases and potential flooding which could affect military operations.

Civil Defense recently purchased an EIS similar to that used by PEMA. The database contains information such as locations of schools, hospitals, and nursing homes. In the event of an emergency such as flooding, tables can be generated of contact persons and telephone numbers within a specified area.

Another use of the EIS is for monitoring hazardous materials. Civil Defense is responsible for tracking hazardous materials, and models aerial plumes based on temperature, relative humidity, and wind velocity.

Salt River Project

SRP monitors weather conditions to assist in its water and electrical service operations, but does not issue any type of weather watches or warnings. SRP receives weather data from NWS each morning and exchanges information as appropriate. SRP also receives a radar display from NWS and lightning detection information from Electric Power Research Institute.

SRP develops an afternoon forecast similar to NWS. By late afternoon, its in-house meteorologists develop more site-specific forecasts. Weather data are collected from the PRISMS weather stations and USGS stage gage data via GOES satellite, and are used in prediction models. SRP has a short-term (3-5 days) rainfall-runoff prediction model and a long-term (3-5 months) snowmelt prediction model. A third model uses real-time data for prediction of up to 72 hours in advance of a storm. It is noted that SRP operations are impacted more by volume of runoff from winter storms than by short-duration, high intensity summer storms which can produce flash flooding. Therefore, its focus on monitoring and modeling floods is for general winter storms.

In the event of a major threat from a spill approaching 10,000 cfs, SRP would activate its EOC, and would operate in cooperation with Civil Defense and other affected agencies. During lesser water releases, SRP follows standard notification procedures for alerting affected parties.

APPROPRIATE MEDIA TO SUPPORT FLOOD WARNING

Various forms of media available for data transmission, coordination and dissemination were investigated and are summarized below:

Data Transmission

Data transmission from remote gages is accomplished by telephone, radio and satellite. USGS has installed most of its stage gages on the national network with uplinks to the GOES satellite. For smaller networks, or where two-way communication is necessary, telephone or radio transmission provides the most practical mode of communication.

ALERT gages rely on one-way communication and are event-driven. The advantages of this type of communication are its simplicity and very low power consumption. However, data loss is possible, although the loss is usually not critical and the network can be designed to minimize the chance of loss.

One-way communication does not permit any command and control from a base station to a remote unit. To enable command and control, a two-way communication system must exist. In order to poll a remote unit, that unit must always be "alive" and as such its power requirements increase substantially compared to an event-driven system. Additional software is required to conduct data redundancy and error checking, both at the base station and at the remote unit.

One-way communication systems are limited to fairly simple sampling routines which are triggered by either a random event, or a set sampling interval (e.g., a set time or stage increment). To conduct more complex sampling requires either a more sophisticated program running on the remote unit, or input from a decision-maker at the base station. In order to communicate back to the remote unit, a two-way system must exist. Two-way communication allows for coordinated action at a group of remote stations, or for the command and control of instruments and facilities at a remote station. Gates can be opened, motors for sampling instruments turned on, etc., by the use of commands issued from a base station.

Data Storage and Retrieval Software

While the ALERT software has basic database capabilities, there are many database management systems available that provide features for the production of high quality reports and graphics generated from information in a database. It is typically necessary to include supplemental datasets in order to make full use of real-time hydromet data. Datasets such as rating curves and pertinent historic data on the site could be included in the database. Compatibility with other standard data formats is also desirable, such as formats developed by NWS and USGS, since it facilitates future data exchange. Database management software geared to existing NWS and USGS standards has been developed by EarthInfo Inc., and features the use of an optical disk for the storage of historic NWS and USGS data. EarthInfo also provides software products that allow third party users to construct databases in USGS format, and a programmer's toolkit of "C" language database management routines for development of special programs.

Generalized database management systems, such as DBase and RBase, could also be used to manage data from the gage network and to produce high quality data reports and graphics. The main purpose of this type of database management software would be to facilitate the distribution of data to interested parties in a standard printed and/or electronic format.

Data Dissemination

After it is determined that an area is threatened by flooding, the information must be transmitted from the prime flood warning agency to a pre-determined group of agencies or individuals. The discussion here of data dissemination by the District is limited to warning other agencies who would, in turn, warn the public within their jurisdiction.

One of the primary means of communication used in flood warning is the telephone. Voice transmission of a flash flood alert, watch, or warning can be an immediate and effective way of transferring information, especially if the information is to be transferred to only one party.

A constraint of voice communications can be the lack of accuracy in the transmission of the message from a dispatcher to additional people receiving the information. The message can be significantly altered by the time the message has been transferred over three times by voice. Even the use of message forms or number codes to infer the urgency of the message or its content is capable of being affected. Without a hard-copy transmission to support the voice communication, accuracy in the communication transmitted is almost always reduced. An additional constraint is a loss of reliability which can occur in telephone transmission systems when they become overloaded or damaged during a flash flooding or severe thunderstorm event.

Another useful form of telephone communication is the cellular phone. It allows ease of communication with contacts in the field. Additionally, if a communications base temporarily loses its normal telephone lines, cellular telephones may continue to operate.

However, because the use of cellular phones is limited to within the service area, they may not be used in some remote areas. In the future, this problem will be resolved by the implementation of a satellite-based mode of transmission, known as Iridium.

One of the most effective hard-copy transmission tools available to relay text and simple graphics is the facsimile machine. It has proven to be an effective means of transmitting the content and intent of a flash flood potential message or flood warning quickly to a number of points. An advantage of facsimile is its ability to be pre-programmed to transmit to a series of facsimile machines which can in turn branch the message to additional facsimile machines. It eliminates the problems of reliability in communicating the message, but does suffer from severe weather delays or system overloads as voice transmission does.

Amateur radio networks could be used to relay information between command centers instead of telephone voice transmission. This mode of operation would be effective when remote flash flooding problems exist. Ham radios have been linked to emergency communications operations through Civil Defense and NWS.

Another effective method of delivering information to users is an electronic bulletin board. The electronic bulletin board can be used to send messages computer-to-computer in an unattended mode. The electronic bulletin board can also stand alone to be polled by other computer users to access messages at their convenience. Unlike voice or facsimile messages which are imposed on the user, the electronic bulletin board is on demand to the user. However, the electronic bulletin board is accessed using a computer modem communicating over telephone lines and, therefore, experiences the same limitations as voice and facsimile transmissions.

Section 3

SECTION 3

MARKET SURVEY

INTRODUCTION

The objective of the Market Survey is to assess the communities' understanding of and needs for flood warning services. To achieve this objective, JMM prepared three separate questionnaires to be distributed to 250 individuals from three categories of participants based in Maricopa County. The categories include:

- Managers and administrators
- Technical personnel and users or implementors of flood warning services
- Homeowners

The proposed participants in the managerial and technical categories were reviewed by the District and approved on March 20, 1991. The managerial group is composed of 50 mayors, city council members, heads of agencies, and others in decision-making or policy-setting roles in each municipality within the County and within state and federal agencies with operations in Maricopa County.

The technical group is composed of 100 city engineers, police and fire chiefs, public works directors, and others within local, state or federal agencies who would most likely be involved in implementing flood warning services within Maricopa County. Also included in the technical group are potential users of flood warning services such as utility and transportation companies and the news media. Arizona Rock Products Association is also represented in this group because sand and gravel operations are typically located in floodways and are consequently greatly affected by flooding.

To include public participation in the market survey, a group of homeowners was developed. It is noted that the homeowners included in the market survey were not selected randomly; rather, selection of the 100 participants for the homeowners' group was based on population density and on geographic distribution throughout the County. Each community was assigned a number of participants according to its percentage of population within Maricopa County. Those communities with less than 1% of the population in Maricopa County were given one questionnaire. Although the smaller communities consequently received a higher representation in the survey than what would have been allocated based on population density, it was felt that each community should be included in the survey. Within each community, membership lists of homeowners' associations were obtained and participants were selected to achieve a balanced geographic representation. Where membership lists were not available, officials within the community were consulted for homeowners suggested to participate in the survey.

TEST SURVEY

As suggested by the District, JMM conducted a test survey prior to distribution of the 250 questionnaires. The purposes of the test survey were to determine if the questionnaires were properly formulated and whether the responses could be evaluated to give the needed information. On April 4, 1991, JMM distributed 25 test questionnaires, or 10% of the market survey, to individuals who were originally included in the market survey but who were later excluded because of over-representation of a particular area or agency.

The number of responses from the test survey are as follows:

Managerial:	3 of 5	(60%)
Technical:	7 of 10	(70%)
Homeowners:	6 of 10	(60%)
Total	**16 of 25**	**(64%)**

JMM evaluated the responses to the test survey and presented the results to the District on April 23, 1991. Based on the evaluation of the test survey, JMM made minor changes to the three questionnaires prior to distribution for the market survey. The final questionnaires are included in Appendix C.

MARKET SURVEY

On April 29, 1991, JMM mailed the 250 market survey questionnaires. The number of responses collected from each of the sampled agencies/municipalities prior to the cutoff date for analysis of May 24, 1991, are shown in Table 3-1, and summarized as follows:

Managerial:	17 of 50	(34%)
Technical:	53 of 100	(53%)
Homeowners:	51 of 100	(51%)
Total	**121 of 250**	**(48%)**

It is noted that the low response rate of some subgroups may have resulted in under-representation of those subgroups. For example, of the managerial questionnaires sent to local officials of the greater Phoenix area, only one responded. Therefore, the market survey results may not reflect the consensus of local managers in the Phoenix area. JMM discussed sending out reminder letters with the District to those who had not returned a questionnaire. It was agreed to forgo distributing reminder letters for the following reasons:

1. Although the response of 48% was lower than the 60% - 70% range which is considered to be a desirable level for a survey when reminder letters are distributed, it is apparent that the actual response rate was greater than 48%. The calculated 48% response does not take into consideration the fact that some responses were a joint effort of technical and managerial representatives within an organization. Therefore, the representation of the technical and managerial groups is actually higher than that indicated by the number of questionnaires returned.

2. Reminder letters would be ineffective for those participants who answered jointly and returned one questionnaire.

3. Distribution of reminder letters would have substantially delayed the project schedule because data analysis could not begin until all responses were collected.

Pre-Questionnaire Meetings

Seven pre-questionnaire interviews were conducted with selected agencies prior to collecting survey response. The objectives of the interviews were to introduce the project and questionnaire procedure to the agencies and collect any additional information not included in the questionnaires. Input from these agencies is summarized below.

TABLE 3-1

RESPONSES TO MARKET SURVEY QUESTIONNAIRES BY TARGET GROUP

Location/Agency	MANAGERIAL Number Distributed	MANAGERIAL Number Returned	MANAGERIAL Percent Response	TECHNICAL Number Distributed	TECHNICAL Number Returned	TECHNICAL Percent Response	HOMEOWNERS Number Distributed	HOMEOWNERS Number Returned	HOMEOWNERS Percent Response	ALL GROUPS Percent Response
Cities/Towns:										
Avondale, City of	1	0	0	3	2	67	1	0	0	40
Buckeye, Town of	1	1	100	3	2	67	1	1	100	80
Carefree, Town of	1	0	0	2	1	50	1	1	100	50
Cave Creek, Town of	1	0	0	1	0	0	1	1	100	33
Chandler, City of	1	0	0	3	2	67	4	3	75	63
El Mirage, City of	1	0	0	2	0	0	1	0	0	0
Fountain Hills, Town of	1	1	100	1	1	100	1	1	100	100
Gila Bend, Town of	1	0	0	1	1	100	1	0	0	33
Gilbert, Town of	1	1	100	3	1	33	1	1	100	60
Glendale, City of	2	0	0	4	2	50	7	4	57	46
Goodyear, City of	1	0	0	3	3	100	1	1	100	80
Guadalupe, Town of	1	0	0	2	0	0	1	0	0	0
Litchfield Park, City of	1	0	0	1	0	0	1	1	100	33
Mesa, City of	2	0	0	4	4	100	13	7	54	58
Paradise Valley, Town of	1	0	0	2	1	50	1	1	100	50
Peoria, City of	1	0	0	3	1	33	2	0	0	17
Phoenix, City of	2	0	0	5	2	40	43	18	42	40
Queen Creek, Town of	1	1	100	1	0	0	1	1	100	67
Scottsdale, City of	2	0	0	4	2	50	6	5	83	58
Sun City	0	n/a	n/a	0	n/a	n/a	1	1	100	100
Sun City West	0	n/a	n/a	0	n/a	n/a	1	0	0	0
Surprise, Town of	1	0	0	2	2	100	1	0	0	50
Tempe, City of	2	1	50	3	2	67	6	3	50	55
Tolleson, City of	1	0	0	2	1	50	1	0	0	25
Wickenburg, Town of	1	0	0	3	2	67	1	1	100	60
Youngtown, Town of	1	1	100	2	2	100	1	0	0	75

TABLE 3-1 (continued)

RESPONSES TO MARKET SURVEY QUESTIONNAIRES BY TARGET GROUP

Location/Agency	MANAGERIAL			TECHNICAL			HOMEOWNERS			ALL GROUPS
	Number Distributed	Number Returned	Percent Response	Number Distributed	Number Returned	Percent Response	Number Distributed	Number Returned	Percent Response	Percent Response
Maricopa County	5	3	60	5	2	40				50
State of Arizona	5	1	20	7	4	57				42
Federal	5	4	80	5	3	60				70
Water Districts	3	1	33	3	1	33				33
Utilities	0	n/a	n/a	3	2	67				67
Transportation	0	n/a	n/a	3	1	33				33
News Media	0	n/a	n/a	11	4	36				36
Miscellaneous	3	2	67	3	2	67				67
Total	**50**	**17**	**34**	**100**	**53**	**53**	**100**	**51**	**51**	**48**

City of Phoenix. The City's main flooding concern is local street flooding. The City is divided into four maintenance districts, so access to local flooding is not usually a problem. The City feels that improved flood warning services would be beneficial only if very site-specific forecasts could be made.

The City would be interested in obtaining real-time precipitation data. It would be helpful if the District communicated information on potential flooding while storms are occurring, such as the expected flooding at flood control structures along Cave Creek and Skunk Creek.

The City believes an alternative use of the District's existing precipitation and stage gage network could surface as a result of new Environmental Protection Agency (EPA) stormwater NPDES requirements.

City of Scottsdale. The City stated an interest in improving flood warning services, especially for north Scottsdale. The primary flooding concern is street flooding in the north area. When the City constructs infrastructure, such as improved roads, it has a duty to maintain them. However, public works crews are located in the southern end of Scottsdale and cannot reach the north areas in time to effectively barricade flooded roads. The City is aware of "electric arm" traffic barriers used in Texas and has not eliminated that option from consideration.

The completion of the Indian Bend Wash project has eliminated much of southern Scottsdale's flooding concerns. SRP releases water from the Arizona Canal into Indian Bend Wash during storms, filling the low flow channel to half capacity and closing wet crossings.

The City is currently preparing information to be used in the Federal Emergency Management Agency (FEMA) community rating system. The City feels there is a potential advantage for Scottsdale to implement flood warning services because it could receive a better rating.

Maps of probable road closures would be very useful to the City, as well as reconstruction of storms. The City perceived the District to be the primary information-gatherer.

Maricopa County Department of Civil Defense. The Maricopa County Department of Civil Defense (Civil Defense) relies entirely on NWS severe weather and flash flood watches and warnings, but contacts the District during conditions of potential emergencies. It is felt that the NWS forecasts are too broad. Further, the terminology used to describe affected areas is inconsistent. For example, what is described as eastern Maricopa County is different from one storm to the next. It was noted that lack of local geographical knowledge by forecasters new to the area may contribute to the problem.

Another constraint felt by Civil Defense is that NWS minimizes the number of agencies to directly notify. Currently, NWS notifies the County Sheriff who in turn contacts those on its call list. Civil Defense feels it is "low on the call list" and would like more direct and more timely information.

As previously stated, Civil Defense recently purchased an EIS, a type of system similar to that used by PEMA. The database contains information such as locations of schools, hospitals and nursing homes.

The principal use of the EIS is tracking hazardous materials, for which Civil Defense is responsible. A Civil Defense in-house computer program models aerial plumes based on temperature, relative humidity and wind velocity parameters. It was suggested that the District's existing precipitation and stage gage network could provide an alternative use in monitoring movement of hazardous materials. Gages could be modified to additionally measure temperature, relative humidity, and wind velocity for use in the computer model.

Lead time versus accuracy is a complex issue for Civil Defense because it is a "major alert" agency, and false alarms must be kept to a minimum. In the past, action has been taken based on forecasts from the NWS River Forecast Center in Salt Lake City where the forecasts were wrong. However, Civil Defense recognizes that time is also needed to mobilize.

Civil Defense is set up to disseminate emergency information but does not make evacuation decisions. It is believed that evacuation decisions should be made at the mayoral level. Civil Defense is very interested in participating in an active flood warning system. Civil Defense feels that the District could be the technical expert to provide Civil Defense with advice on flooding predictions or conditions. Civil Defense would like automatic notification of their on-duty or on-call officer when pre-established precipitation or runoff thresholds are reached.

Maricopa County Sheriff's Office. The Sheriff's Office has liaisons with most groups within Maricopa County. The NWS contacts the Sheriff's Office and the Arizona Department of Public Safety when a flood warning is issued. The Sheriff's Office carries out orders from the County Manager. In severe flooding conditions, the Corps of Engineers is notified by the Sheriff's Office.

U.S. Geological Survey. USGS is unique in that when a flood occurs, it is primarily interested in taking measurements rather than in avoiding the flood. USGS has data collection platforms at selected sites on the major water courses in Arizona, but not typically on smaller water courses on a county or local level. However, there are some ungaged bridge structures in the County at which USGS would like to obtain information. USGS has access to data from NWS, SRP, and the District, but access to District data is not automatic. USGS would like the capability of quick selective access to District data, but not necessarily automatic access.

USGS is interested primarily in the discharge rate and volume of runoff in major streams, whereas the District would also be interested in stage records on smaller streams. USGS' primary responsibility is in the operation of stage gage equipment and not flood warning. However, improved flood warning services would be of benefit to USGS for establishing runoff patterns. The more that is known about runoff patterns and high water areas, the better the stage gages can be maintained for better performance for the benefit of other agencies.

USGS takes current meter measurements at its stage gage sites during major flooding. USGS routinely acts on stage data and not precipitation data. USGS observes precipitation information but does not base decisions on it.

USGS believes that using the District's existing precipitation and stage gage network for alternative uses would be very important. For example, USGS currently monitors water quality, pH, temperature, and conductivity, among others and transmits the data by satellite.

Salt River Project. SRP feels that canal flooding problems north of the Salt River will shortly be mitigated upon the completion of the Arizona Canal Diversion Channel (ACDC). The ACDC, which is being constructed immediately north of the Arizona Canal from approximately 40th Street to Skunk Creek, is designed to eliminate canal flooding along this reach. However, flooding potential still exists east of 40th Street, particularly east of Indian Bend Wash where the first outlet for flow in the canal is provided. The main flooding exposure from the SRP canal system has historically been south of the Arizona Canal. During past floods, stormwater has been released from the canal, causing urban flooding.

SRP develops an afternoon forecast similar to NWS. By late afternoon, the in-house meteorologists develop more site-specific forecasts and exchange information with NWS as appropriate. The forecast information is only used in-house; SRP is concerned about the potential to issue information to the public which would conflict with NWS information, creating confusion.

SRP plans to install 16 weather stations by June 1991. All of the major washes are monitored by staff gages. SRP feels that sufficient precipitation and stage gage data for its needs are available within its service area, but much of the data are not useful because of integration problems. SRP's long-term goal is to tie the different real-time systems in their watershed together. It is not planned to make the information available to external groups, but SRP would be open to sharing the information under an inter-governmental agreement with co-funding. The usefulness of bringing District data into SRP's network would be evaluated.

SRP is satisfied with current forecasting of general winter storms. It is felt the forecasting, locating, and monitoring of summer storms need improvement. SRP is currently cooperating with NWS on research and development projects to improve forecasting. SRP feels the implementation of NEXRAD will improve the ability to locate storms. Monitoring would be improved if existing data collection systems were integrated and made available.

SRP also receives lightning detection information from a vendor through the State University of New York. SRP power operations are adversely affected by lightning and wind. Lightning prediction has not been pursued because it is felt that it is not applicable to conditions in Arizona.

An alternative use of the District's existing precipitation and stage gage network, of interest to SRP, would be wind measurement.

Arizona Rock Products Association. Substantial damage commonly exceeding $50,000 is sustained by sand and gravel operators from runoff during even minor storms. Runoff after a storm has passed further affects operations because it prevents crossing the river for reaching worksites.

Flooding on the Agua Fria is a serious concern for sand and gravel operators. It is felt that the water releases made at Waddell Dam are poorly regulated. When water is released, ingress and egress on Grand Avenue and on Bell Road is blocked. The only access is on a dirt road through the Town of Surprise, and the Town is sensitive to truck traffic. The lower section of the Agua Fria River is sensitive to flash flooding with respect to sand and gravel operations.

It is felt that two issues merit serious consideration. First, the impact on the Agua Fria from the ACDC is unknown and could adversely affect sand and gravel operations because of the channelized runoff from a large drainage area. Second, there is a concern that since the Hassayampa River is uncontrolled, recent increased development along the river will increase flood hazards. The Toyota Proving Grounds is planned for the area and will generate development.

It is believed that the District should assume an active role in flood warning services which should include coordination with operations of flood control structures. Flood warning activity in the County should be modeled after the existing phone notification system for the Salt River. However, although the phone notification system presently works well, it may become inadequate if more contacts are added to the call list. A long lead time is desired, and sacrificing accuracy to achieve that is acceptable to sand and gravel operators.

It was suggested that an alternative use of the flood detection system could be water quality data collection. It would be helpful to establish the ambient water quality which could be of benefit as supporting data on the environmental effects of sand and gravel operations.

MARKET SURVEY RESULTS

The remainder of this section describes the results of the market survey in detail. Several tables are provided to show breakdowns of the responses based on selected evaluation criteria. A summary discussion which presents generalized findings from the survey is also provided at the end of this section.

Upon receipt of the survey questionnaires, the responses were entered into a database program and evaluated according to specific criteria. Each question was first categorized into one or more of the evaluation criteria, as indicated in Table C-1 of Appendix C. Responses to each question were then evaluated individually for each of the three survey groups. Finally, the responses were averaged by category to estimate the total response level for each of the three survey groups. The results of the market survey by target group are presented in Table 3-2.

As shown in Table 3-2, the results of the market survey indicate that there is strong interest in improved flood warning services, particularly in the homeowners' group. To check the reliability of this response, selected related evaluation criteria were compared to measure consistency with the response for interest in improved services. These criteria included perceived flood threat and perceived accuracy and adequacy of existing flood warning services. For example, strong agreement that flooding is a threat in the County and that current services are inaccurate and inadequate would substantiate a high level of interest in improved services. Results of this comparison are shown in Figure 3-1.

As shown in the figure, there is a strong correlation between interest in improved flood warning services and the perception that the County is threatened by flooding. However, the response levels for perceived accuracy and adequacy do not show a similarly strong correlation with interest in improved flood warning services. Nevertheless, there are two reasons why the responses relative to adequacy and accuracy of the existing flood warning system are not necessarily contradictory to the response showing a high interest in improved flood warning services. First, the market survey only shows that there is not a consensus on the perceived accuracy/inaccuracy, or adequacy/inadequacy of existing flood warning services within the County. Second, the perception of adequacy and accuracy may be greater than actual experience indicates.

To investigate the reliability of responses addressing the accuracy and adequacy of existing flood warning services, a further comparison was made between the perception of accuracy and adequacy and the performance of the NWS for the past five years (1986-1990).

To measure accuracy of existing flood warning services, verification information was obtained for Maricopa County from the NWS for flash flood and severe weather warnings. Severe weather was included in the evaluation of NWS performance because flash floods are verified in the "severe weather" category if they are accompanied by high winds, hail, tornadoes, or other types of severe weather. The results of this comparison are presented in Table 3-3. For flash flood events in Maricopa County from 1986 through 1990, warnings were issued for only slightly more than one-half of the events that actually occurred (7 of 13 events). Additionally, there were 29 false alarms, where a warning was issued but no event occurred. For severe weather in Maricopa County from 1986 through 1990, warnings were issued for slightly less than one-half of the actual events (35 of 77 events), and 50 false alarms occurred. Therefore, it can be concluded that the perception of accuracy of existing services as determined

TABLE 3-2

RESULTS OF MARKET SURVEY BY EVALUATION CRITERIA AND TARGET GROUP

Evaluation Criteria	MANAGERIAL Total Group Response	TECHNICAL Total Group Response	HOMEOWNERS Total Group Response
	Based on 17 Responses	Based on 53 Responses	Based on 51 Responses
1. Perception of Severity of Flood Threat			
- Serious/moderately serious in urban Maricopa Co.	76%	74%	49%
- Minor problem/no problem in urban Maricopa Co.	24%	25%	45%
- Serious/moderately serious in rural Maricopa Co.	100%	85%	69%
- Minor problem/no problem in rural Maricopa Co.	0%	13%	27%
2. History of Flooding			
2.1 General			
• Have been flooded/affected by flooding	94%	75%	27%
2.2 Frequency			
• Average number of times flooded	-	5 times	4 times
2.3 Severity			
• Time affected for worst flood	-	2 weeks	4 days
• Time affected for average flood	-	4 days	-
2.4 Financial Impact			
• Impact of flooding on budget			
- Strong to moderate	47%	25%	-
- Little or no impact	47%	72%	-
• Average cost per flood	-	$23,000	$2,000
• Average cost for preparation for false alarms	-	<$500	$350
3. Accuracy of Current Flood Warning Services			
- Accurate	38%	60%	57%
- Inaccurate	42%	20%	37%
- Don't know/No opinion/Did not answer	20%	20%	6%

TABLE 3-2 (continued)

RESULTS OF MARKET SURVEY BY EVALUATION CRITERIA AND TARGET GROUP

Evaluation Criteria	MANAGERIAL Total Group Response	TECHNICAL Total Group Response	HOMEOWNERS Total Group Response
	Based on 17 Responses	Based on 53 Responses	Based on 51 Responses
4. Adequacy of Current Flood Warning Services			
- Adequate	46%	51%	48%
- Inadequate	33%	28%	34%
- Don't know/No opinion/Did not answer	21%	21%	18%
5. Lead Time for Flood Warning			
• Lead time vs. accuracy			
- More lead time, less accuracy	18%	19%	37%
- Less lead time, more accuracy	29%	34%	43%
- Don't know/no opinion/did not answer	53%	47%	20%
• Average desired lead time	1.5 hours	2 hours	1 hour
6. Interest in Improved Flood Warning Services			
- Interested	68%	70%	85%
7. Current Flood Warning Information Sources			
• During a heavy storm	NWS SRP Civil Defense District	NWS Civil Defense Sheriff/Police	TV Radio Sheriff/Police
• Triggers emergency plan	TV/Radio SRP Observed Flooding	NWS Observed Flooding TV/Radio	- - -
8. 24-Hour Staff Availability			
- Yes	-	81%	-

TABLE 3-2 (continued)

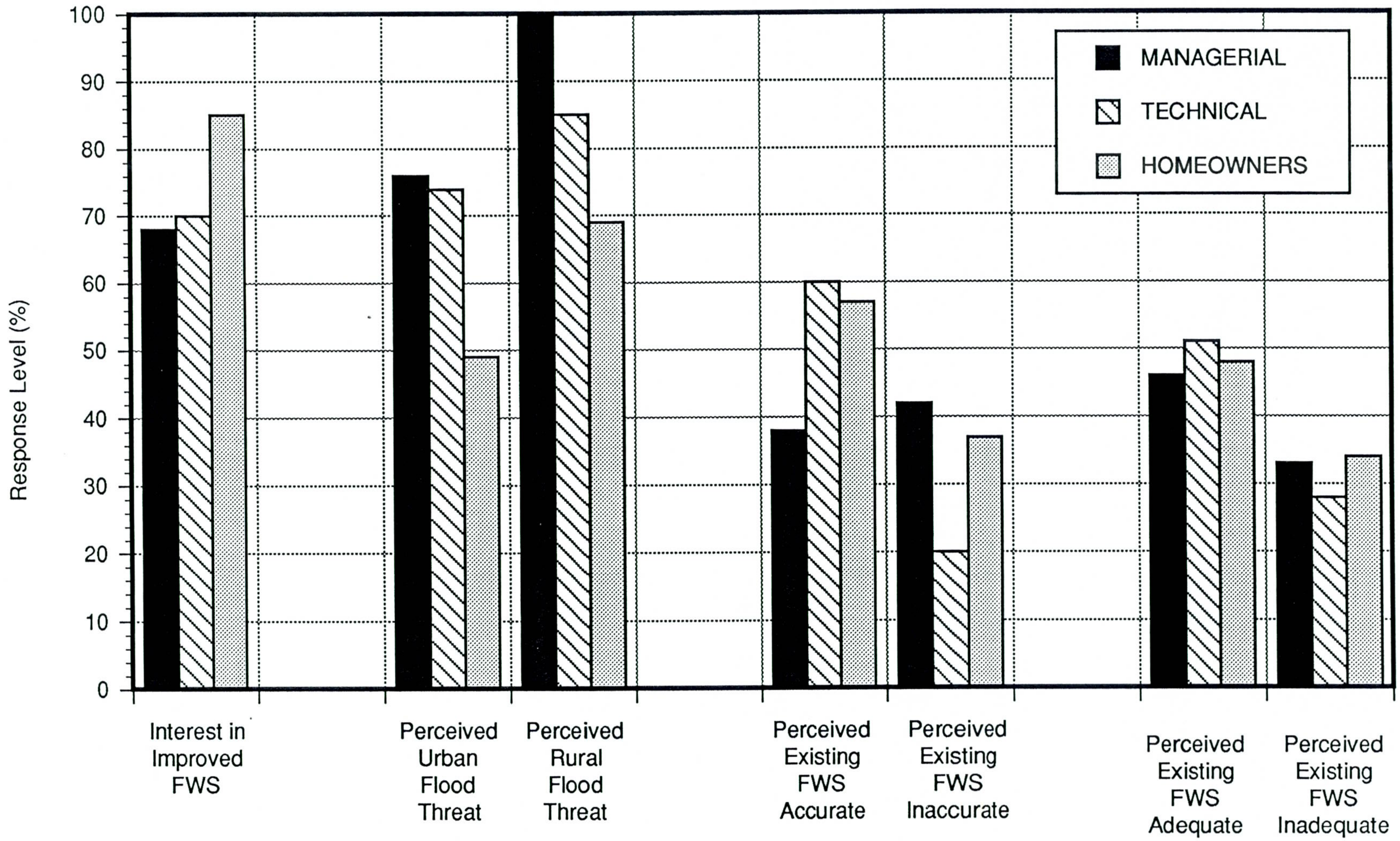
RESULTS OF MARKET SURVEY BY EVALUATION CRITERIA AND TARGET GROUP

Evaluation Criteria	MANAGERIAL Total Group Response	TECHNICAL Total Group Response	HOMEOWNERS Total Group Response
	Based on 17 Responses	Based on 53 Responses	Based on 51 Responses
9. Who Should Issue Flood Warnings			
• Most likely to obey if advised to evacuate	Sheriff/Police Fire Dept.	Sheriff/Police Fire Dept. Mayor	Police Car Bullhorn, Police In-Person Notification, Civil Def. TV/Radio Bulletin
• Best suited to collect and analyze weather data	NWS District SRP	NWS District SRP	- - -
• Best suited to collect and analyze rainfall and runoff data	District SRP NWS	District NWS SRP	- - -
• Best suited to act as the decision maker for issuing flood warnings	NWS District Civil Defense	District NWS Civil Defense	- - -
• Best suited to act as decision maker for evacuating areas	Sheriff/Police District Civil Defense Mayor	Sheriff/Police Mayor Civil Defense	Sheriff/Police Civil Defense District
10. Understanding of Flooding/Flood Warning			
- Adequate	71%	69%	71%
- Inadequate	20%	24%	20%

TABLE 3-2 (continued)

RESULTS OF MARKET SURVEY BY EVALUATION CRITERIA AND TARGET GROUP

Evaluation Criteria	MANAGERIAL Total Group Response Based on 17 Responses	TECHNICAL Total Group Response Based on 53 Responses	HOMEOWNERS Total Group Response Based on 51 Responses
11. Desired Form of Communication			
• Preferable mode of receiving information	-	Telephone FAX Cable TV PC Modem	-
12. Expectations of Flood Warning Services			
- High	84%	87%	75%
- Low	10%	9%	20%
13. Alternate Uses of Flood Warning Services	Precipitation, Flood Retarding Storages	Gauges, Volume of Runoff, Surface Water Quality, Rainfall Averages	-
14. Profile of Participants			
• Average time lived in Maricopa County	14 years	23 years	13 years
• Traverse flood-prone areas routinely	59%	66%	57%
• Aware of District prior to survey	94%	87%	69%
• Contacted District for flood information previously	59%	36%	-



INTEREST IN IMPROVED FLOOD WARNING SERVICES (Compared With Related Evaluation Criteria)

FIGURE 3-1

TABLE 3-3

NWS FLASH FLOOD AND SEVERE WEATHER WARNING VERIFICATION SUMMARY FOR MARICOPA COUNTY, 1986 THROUGH 1990

FLASH FLOOD VERIFICATION

Year	Warned Event (Warning Issued and Event Occurred)	Unwarned Event (No Warning Issued and Event Occurred)	False Alarm (Warning Issued but No Event Occurred)
1986	3	0	3
1987	1	4	5
1988	0	1	6
1989	0	0	3
1990	3	1	12
5-Year Total	**7**	**6**	**29**

SEVERE WEATHER VERIFICATION

Year	Warned Event (Warning Issued and Event Occurred)	Unwarned Event (No Warning Issued and Event Occurred)	False Alarm (Warning Issued but No Event Occurred)
1986	3	14	18
1987	9	8	6
1988	6	11	11
1989	5	4	2
1990	12	5	13
5-Year Total	**35**	**42**	**50**

from the market survey is higher than the actual accuracy of the NWS performance over the past five years.

As an indication of adequacy of existing flood warning services, average lead time for the warned events shown in Table 3-3 was calculated. In the past five years, average lead time was approximately 40 minutes, with 10 of 42 verified events having a lead time of 10 minutes or less. In comparison, the market survey results indicate a need for one to two hours of warning before a flooding event. Therefore, it can be further concluded that the perception of adequacy as determined from the market survey is higher than is warranted by the NWS performance over the past five years.

One factor which may have influenced the response on accuracy and adequacy questions was the 1990 SWAMP project, which was a study conducted through the NWS on summer weather activity. The presence of the SWAMP team greatly enhanced the performance of the local weather offices in 1990. Although the rate of false alarms was approximately the same in 1990 as the previous four years, the rate of unwarned events was significantly reduced.

Other selected findings of the market survey are listed below:

- The District was chosen second most frequently to NWS by the managerial and technical groups as best-suited to collect and analyze weather data.

- The District was selected most frequently by the managerial and technical groups as best-suited to collect and analyze rainfall and runoff data.

- The District was selected most frequently by the technical group as best-suited to act as decision-maker for issuing flood warnings, with NWS and Civil Defense ranking second and third, respectively. The managerial group selected NWS most frequently, with the District and Civil Defense ranking second and third, respectively.

- Top selections for best-suited to act as decision-maker for evacuating areas include the sheriff/police, as well as a mix of the District, Civil Defense and mayors.

- Most popular selection for desired mode of communication were the telephone, facsimile, cable TV, and PC modem.

- Generating maps to show expected areas of flooding was a strong interest of the three target groups.

- Suggested alternate uses of the District's existing data collection system include surface water quality measurement, calculation of runoff volume, and calculation of rainfall averages.

- The average desired lead time ranged from one to two hours among the three groups. It should be noted that sufficient lead time is a variable which is dependent on the type and location of storms and on the physical conditions and level of development of the areas affected. Optimal lead time is also influenced by accuracy considerations.

- There is no consensus that the respondents as a whole prefer less lead time with more accuracy or more lead time with less accuracy.

In addition to the three survey groups, response summaries were generated for various subgroups and are presented in Appendix D. The subgroups are defined below:

1. Those who have been flooded or affected by flooding in Maricopa County vs. those who have not been flooded or affected by flooding (Table D-1).

2. Local officials vs. county, state and federal officials vs. representatives of miscellaneous categories (Table D-2).

3. Metropolitan Phoenix (Phoenix, Scottsdale, Mesa, Tempe, Chandler, Glendale, and Peoria) vs. the remaining outlying communities (Table D-3).

Responses from individual cities within metropolitan Phoenix were not evaluated separately because in most cases the number of responses in the managerial and technical groups was two or less. Analysis of group response becomes statistically meaningless with such a small number of responses.

The results of each subgroup evaluation were compared to total group response to identify any substantial deviation of response as a whole. It was found that responses by subgroup were generally similar to the total group responses.

The subgroup responses which were found to differ substantially from total response trends are as follows:

- According to local officials in the managerial group, the impact of flooding on their organizations' budget is lower than that for the total managerial group;

- Expectations of managers in the outlying communities of the County are lower than that for the total managerial group;

- Homeowners who have been flooded in the past perceive the flood threat to be more serious in urban areas of the County than the total homeowners' group.

Within each subgroup, substantial deviations in response were noted:

- As expected, those in the technical group who have been affected by flooding indicated a higher impact of flooding on their organizations' budget than those who have not been affected by flooding.

- As expected, homeowners who have been flooded have a higher perception that flooding is a more serious threat to the County, lower perception of accuracy and adequacy of existing flood warning services, and higher expectations of flood warning services than those who have not been flooded.

- Homeowners outside metropolitan Phoenix perceive existing flood warning services to be less accurate than homeowners within metropolitan Phoenix.

- City and town managers perceive the existing services to be less accurate, but have a lower interest in improved services and lower expectations of flood warning services than managers at the county, state, and federal level.

- The technical group believes that flooding has a larger impact on budgets at the county, state and federal levels than on the local community level.

In summary, certain responses from the market survey and pre-questionnaire interviews indicated a strong need for improved flood warning services in Maricopa County. Comments received with the questionnaires have been reprinted in Appendix E. Comments shown were not modified, including punctuation and spelling, except where necessary to clarify the intent of the respondent.

Section 4

SECTION 4

FLOOD WARNING ALTERNATIVES

INTRODUCTION

As described in Section 2 of this report, there are a number of tools available with which a flood warning system could be formed. Selection of components to be considered in developing a flood warning program were based on the applicability to conditions in Maricopa County, on the District's needs, and on what features would best meet the needs and expectations as identified in the market survey. The desired components include the following:

- Additional precipitation and stage gages to provide better precipitation and runoff information.
- A weather forecasting element to increase lead time and provide more area-specific flood warnings.
- Incorporation of hydrologic modeling and floodplain mapping to predict expected areas of inundation during flooding events.
- Incorporation of GIS to generate maps of expected inundation, and tables of expected street closures, among other functions.

These components formed the basis of flood warning alternatives developed by JMM, as presented in this section. A description of each alternative is presented, as well as the comparative advantages and disadvantages. Benefits and costs for each system are quantified in Section 5, "Economic Analysis of Alternatives."

It is noted that the flood warning alternatives do not include future technology as described in Section 2 because they are not yet available and/or have not been sufficiently tested. It is believed that these technologies, particularly NEXRAD and GOES-NEXT, will provide very useful data in this decade. Therefore, it is recommended that the District monitor the progress of these technologies for future implementation in a flood warning program.

FLOOD WARNING ALTERNATIVES

The District has stated that it does not wish to assume a flood warning role in which it warns the public directly. Rather, it would assume either an "active" role, defined as warning selected agencies, or an "inactive" role, where other local agencies would contact the District. The local agencies would then be subsequently responsible for warning the public. In any case, the District would coordinate its flood warning efforts with the NWS, Civil Defense, and other agencies affected by flooding.

The alternatives are described in the following subsections generally in order of increasing sophistication and cost. It is estimated that Alternatives 2 through 5 could be expected to provide typical lead times in the 30-minute to 2-hour range, with Alternative 2 providing lead time at the low end and Alternative 5 providing lead time at the high end of the range. (Lead time is defined as the time from issuance of a flood warning [to the public] to the time flood damage begins to occur.) Alternative 1, the Status Quo alternative, is not associated with lead time because under present operations, warnings are not typically issued.

Alternative 1 - Status Quo

Alternative 1 describes the District's current flood detection system which includes telemetered precipitation and stage gages, computers, software, color radar displays, color monitor, VCR, and voice synthesizer. The District is presently converting its data transmission from UHF to VHF frequency and adding five new precipitation gages and spare parts, scheduled to be completed after January 1992. For discussion purposes, data transmission conversion and the additional gages will be treated as if the improvements have already been made.

The District also has a number of hydrologic and hydraulic computer models which have been developed under the District's Flood Insurance Study (FIS) and Area Drainage Master Study (ADMS) programs. These models could be incorporated into the flood warning program to aid in determining flood threat, as discussed subsequently in the remaining alternatives. These models have not been utilized for flood warning activities to date; therefore, they are not considered as a part of this status quo alternative.

In keeping with the District's current operational procedures, flood warnings would not routinely be issued in Alternative 1. However, information would continue to be disseminated to the NWS and Civil Defense for possible use in issuing flood warnings and making evacuation decisions.

Major components of Alternative 1 are as follows:

- Hardware
  - ALERT precipitation and stage gage network (124 precipitation and 44 stage gages, including 4 weather stations and 2 meteorological sensors)
  - ALERT base station
  - Personal computers
  - Printer
  - Plotter
  - Precipitation and streamflow indicator light maps
  - Radar monitor
  - VCR (records radar data)
  - Voice synthesizer

- Software
  - Enhanced ALERT software (Sierra-Misco)

- Meteorological Data
  - Kavouras radar data

Benefits of Alternative 1 include data collection for use in operation of District structures, calibration of hydrologic models, ground-truth activities, documentation for litigation, monitoring of dams, labor savings from reduced maintenance of flood control structures, increased knowledge of events during storms or flooding situations, and dissemination of information to the NWS and Civil Defense.

Alternative 2 - Flood Warning with Improved Flood Detection and Hydrologic Modeling

Alternative 2 would consist of flood warning services which rely primarily on detection of precipitation and/or runoff for issuing flood warnings. The existing flood detection network would be substantially expanded by the addition of precipitation and stage gages and related equipment. A discussion on the number of new precipitation and stage gages assumed to be added to the District's existing system is provided in Section 5 of this report. Additionally, meteorological data would continue to be received as it is currently, for use in determining if a flood threat is indicated, but would be upgraded. Composite radar data would be received, which would mitigate current equipment constraints such as ground clutter and noncoverage of areas impaired by physical features.

Alternative 2 would also include the addition of a hydrologic modeling component using the Corps' HEC-1 program. HEC1F could also be used, an adaptation of HEC-1 which was developed for use in real-time flood forecasting operations. For this alternative, integration of hydrologic models would be required, and the models would have to be interfaced with real-time precipitation and runoff data. It is assumed that hydrologic models developed under the District's Flood Insurance Study (FIS) and Area Drainage Master Study (ADMS) programs would be used. As additional hydrologic models become available through the FIS and ADMS programs, they would be added to the flood warning program. The advantages to this approach are:

1. The ADMS and FIS programs are being implemented generally in order of decreasing flood hazard. Therefore, the most critical flood hazard areas would be incorporated first for flood warning purposes.

2. In the early stages of developing the hydrologic modeling component, it is less difficult to incorporate existing models than to develop all new information.

3. It is more economical to utilize previously developed models.

Analysis of potential flooding conditions would be performed at specified "forecast points" within each drainage basin. A forecast point is defined as a critical point within a basin for which flooding conditions could be monitored to indicate flood threat downstream. At each forecast point, threshold and critical flood indicators would be identified based on potential flood risk. The indicators would then be used as a guide to the flood warning operator in making a decision whether or not to warn of flood hazards.

It is recognized that a hydrologic data management system could be necessary for storage and retrieval purposes. For this analysis, it is assumed that the Corps' Data Storage System (DSS) would be used to store and retrieve data such as precipitation input and outflow hydrographs. ALERT data would continue to be stored through the operations of the Enhanced ALERT software.

As previously indicated, the District also has hydraulic models (HEC-2) available for potential incorporation into the flood warning program. However, Alternative 2 is based on the improvement of the flood detection network and hydrologic modeling component only. Hydraulic modeling is included in Alternative 5, discussed later in this section.

In addition to the improved flood detection network and hydrologic modeling component, a flood warning communications system would be added to disseminate flood warnings either by direct notices to local agencies from the District or where outside agencies must initiate contact with the District to obtain flood warnings.

Major components of Alternative 2 are listed below. New or upgraded elements not currently part of the existing system are shown in italics.

- *Expanded ALERT precipitation and stage gage network*
- ALERT base station
- Personal computers
- Printer
- Plotter
- Precipitation and streamflow indicator light maps
- Radar monitor
- VCR (records radar data)
- Voice synthesizer

• Software
  - Enhanced ALERT software (Sierra-Misco) with HEC1F and interface
  - *DSS*

• Computer Operations
  - *Incorporate existing hydrologic models from the District's FIS and ADMS programs*
  - *Calibrate existing hydrologic models*
  - *Set threshold flooding indicators*

• Meteorological Data
  - *Upgraded radar data (composite radar)*

• Communications
  - *Electronic bulletin board*
  - *Facsimile/telephone*
  - *Telephone messaging*

The benefits of Alternative 2 would include those identified for Alternative 1, but warnings would be routinely issued directly or indirectly as previously defined. Because Alternative 2 would provide dissemination of warnings, direct benefits would be realized on a county-wide basis through damage reduction as a result of prior warning. Additionally, the expansion of the ALERT gage network and inclusion of hydrologic modeling would further increase the accuracy of predicting flood threat and would enable the District to identify basin-specific flood potential.

Alternative 3 - Flood Warning with Improved Flood Detection and Meteorological Prediction

Alternative 3 would consist of the improved flood detection network described in Alternative 2 and would also include a substantial upgrade of meteorological data. However, incorporation of existing hydrologic and hydraulic modeling would not be included in this scenario. Alternative 3 would include the addition of a staff meteorologist or a meteorological service. If a staff meteorologist were selected, additional hardware and software would be added to obtain meteorological products.

The meteorologist would produce QPFs for specified drainage basins. The forecasts would be based on surface weather observations and would be a basis of predicting flood threat. The QPFs would be compared to flooding data collected by the District during past rainfall events to determine if a flood threat is indicated.

As with Alternative 2, a flood warning communications system would be added to disseminate flood warnings either by direct notices from the District to other local agencies or where outside agencies must initiate contact with the District to obtain flood warnings. Also, additional weather stations would be added to the system to aid the meteorologist in making more site-specific forecasts. It is noted that additional hardware/software may be required by a staff meteorologist. However, it cannot be determined what, if any, requirements would be identified in the future. Therefore, additional hardware/software has not been included in the meteorological component of this alternative.

Major components of Alternative 3 are listed below. New or upgraded elements not currently part of the existing system are shown in italics.

- Hardware
  - *Expanded ALERT precipitation and stage gage network*
  - *Expanded weather station network*
  - ALERT base station
  - Personal computers
  - Printer
  - Plotter
  - Precipitation and streamflow indicator light maps
  - Radar monitor
  - VCR (records radar data)
  - Voice synthesizer

- Software
  - Enhanced ALERT software (Sierra-Misco)

- Meteorological Data
  - *District staff meteorologist*
  - *Upgraded vendor products (i.e., Kavouras, WSI, Alden)*
    or
  - *Private forecasting service*

- Communications
  - *Electronic bulletin board*
  - *Facsimile / telephone*
  - *Telephone messaging*

The benefits of Alternative 3 would be similar to Alternative 2, with certain trade-offs. Alternative 3 would typically provide greater lead time due to its meteorological prediction element, but with less accuracy. Conversely, the hydrologic modeling component of Alternative 2 would typically provide greater accuracy on expected flooding conditions, but with shorter lead time.

Alternative 4 - Flood Warning with Improved Flood Detection, Hydrologic Modeling, and Meteorological Prediction (Alternatives 2 and 3 Combined)

Alternative 4 describes the combined elements of Alternatives 2 and 3. Alternative 4 includes an expanded flood detection network, hydrologic modeling, and meteorological prediction. The QPFs developed by the meteorologist would be input to the HEC1F model at specified forecast points for analysis of potential flooding prior to the occurrence of rainfall.

Major components of Alternative 4 are listed below. New or upgraded elements not currently part of the existing system are shown in italics.

- Hardware
  - *Expanded ALERT precipitation and stage gage network*
  - *Expanded weather station network*
  - ALERT base station
  - Personal computers
  - Printer
  - Plotter
  - Precipitation and streamflow indicator light maps
  - Radar monitor
  - VCR (records radar data)
  - Voice synthesizer

- Software
  - Enhanced ALERT software (Sierra-Misco) with HEC1F and interface
  - *DSS*

- Computer Operations
  - *Incorporate existing hydrologic models from the District's FIS and ADMS programs*
  - *Calibrate existing hydrologic models*
  - *Set threshold flooding indicators*

- Meteorological Data
  - *District staff meteorologist*
  - *Upgraded vendor products (i.e., Kavouras, WSI, Alden)*
    or
  - *Private forecasting service*

- Communications
  - *Electronic bulletin board*
  - *Facsimile / telephone*
  - *Telephone messaging*

In addition to the benefits described for Alternatives 2 and 3, the combination of improved flood detection, hydrologic modeling, and meteorological prediction would further increase the accuracy of the warnings, while substantially increasing lead time, and would improve the District's ability to identify basin-specific flood potential.

Alternative 5 - Flood Warning with Improved Flood Detection, Hydrologic Modeling, Meteorological Prediction, and Geographic Information System

Alternative 5 would consist of the elements outlined in Alternative 4 with the inclusion of GIS capabilities. It is noted that, to date, the District has several fully operational workstations in use. It is currently developing a database which would be used to incorporate GIS into a flood warning system. Some of the necessary data which already have been input include conversion of floodplain data into GIS (i.e., topographic mapping, hydrologic parameters, and precipitation and stage gage data). The District is currently attempting to solve incompatibility problems between precipitation and runoff data and GIS.

Information developed from hydrologic modeling would be stored in the DSS program for immediate input to the Corps' HEC-2 water surface profile program, at specified forecast points. Existing hydraulic models developed as part of the District's FIS program would be incorporated to generate expected water surface elevations at specified forecast points. The results of the hydraulic computations by HEC-2 would then be input to GIS, and inundation maps would be subsequently generated using a digital terrain model. The limits of expected inundation could then be used to enhance road closure and emergency notification capabilities.

Major components of Alternative 5 are listed below. New or upgraded elements not currently part of the existing system are shown in italics.

- Hardware
  - *Expanded ALERT precipitation and stage gage network*
  - *Expanded weather station network*
  - ALERT base station
  - Personal computers
  - Printer
  - Plotter
  - Precipitation and streamflow indicator light maps
  - Radar monitor
  - VCR (records radar data)
  - Voice synthesizer
  - *UNIX Workstation* (related graphics equipment is already in place)

- Software
  - Enhanced ALERT software (Sierra-Misco) with HEC1F and interface
  - *DSS*
  - ARC/INFO

- Computer Operations
  - *Incorporate existing hydrologic models from the District's FIS and ADMS programs*
  - *Calibrate existing hydrologic models*
  - *Interface HEC-1 and HEC-2 output with GIS database*
  - *GIS training and development of custom programs*
  - *Convert existing record-keeping to GIS database*
  - *Set threshold flooding indicators*

- Meteorological Data
  - *District staff meteorologist*
  - *Upgraded vendor products (i.e., Kavouras, WSI, Alden)*
    or
  - *Private forecasting service*

- Communications
  - *Electronic bulletin board*
  - *Facsimile / telephone*
  - *Telephone messaging*

In addition to the benefits identified for Alternative 4, the inclusion of GIS capabilities would allow event-driven generation of maps of expected inundation. Flood warning accuracy would be further increased, and the ability of providing site-specific forecasts would be significantly improved. Integration of flood warning components such as satellite and precipitation data could be accomplished, which would enhance flood warning capabilities.

Section 5

SECTION 5

ECONOMIC ANALYSIS OF ALTERNATIVES

INTRODUCTION

Partial benefits and costs were estimated to indicate the economic status of each flood warning alternative. Benefits include reduced flood damages, increased safety and reduced rescue efforts, as well as indirect benefits. Benefits are dependent on lead time, accuracy, and site-specificity of flood warnings issued, while costs are primarily from equipment and labor to operate a flood warning program. The components which were included in this analysis are summarized in Table 5-1. There are a number of direct and indirect benefits and costs attributed to a flood warning system. Each component identified in the table is discussed in this section of this report.

It is important to note that it is not possible to quantify all benefits and costs associated with a flood warning system. Of the components identified in Table 5-1, reduced contents flood damage is the only benefit which is quantified and a dollar value of benefit estimated. It is recognized that other nonquantifiable benefits would substantially increase the overall benefit of a flood warning system.

To a lesser extent, indirect costs such as flood preparedness costs are also nonquantifiable. It is further recognized that nonquantifiable costs would increase the overall flood warning cost. However, it is felt that the impact of indirect costs on overall cost is much less than that of the indirect benefits on overall benefit.

Therefore, because the nonquantifiable benefits are very likely substantially greater than nonquantifiable costs, this evaluation cannot be considered a strict benefit/cost analysis. Instead, this analysis is intended to identify the general economic feasibility of alternatives.

As stated in Section 1 of this report, JMM's discussions with operators of locally funded and implemented flood warning systems throughout the country indicated that the systems were not installed as a result of economic justification of a benefit/cost analysis. Rather, flood warning services were initiated based solely on safety considerations. Thus, the economic analysis described in this section should not be considered the sole, or principal criterion for implementing a flood warning system in Maricopa County.

ESTIMATION OF BENEFITS OF A FLOOD WARNING SYSTEM

As described above, benefits of a flood warning system include both direct or quantifiable benefits and indirect benefits which are not quantifiable. Direct and indirect benefits evaluated in this study are described below.

Reduced Flood Damage

The primary element of calculating the annual direct benefits of a flood warning system is the amount of damage to property which could be avoided by removing movable property from flood threat. The removal of property would be in response to a warning in advance of an impending flood.

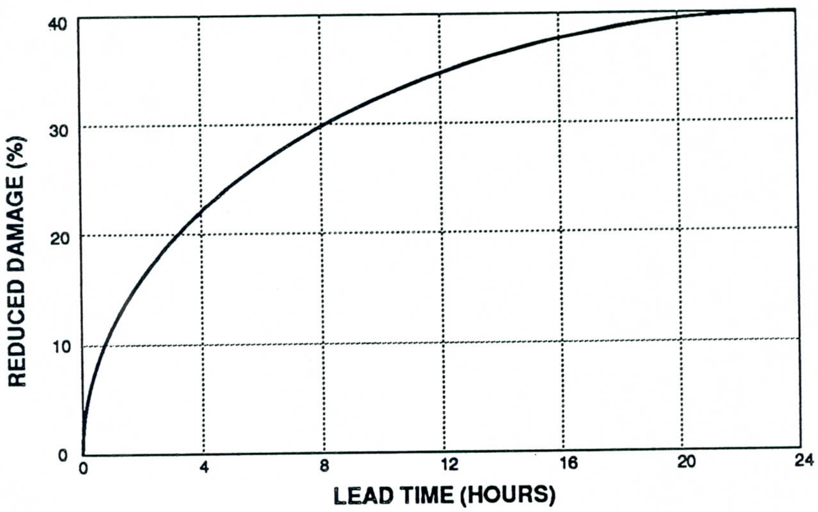
TABLE 5-1

SUMMARY OF COMPONENTS FOR ECONOMIC ANALYSIS

Component	Quantified with Dollar Value Estimated	Quantified but Dollar Value Not Estimated	Identified but Quantity and Dollar Value Not Estimated
Benefits			
• Reduced Flood Damages	✔		
- Residential			
- Commercial			
- Industrial			
- Public			
• Increased Safety		✔	
- Reduced Loss of Life			
- Reduced Injuries			
• Reduced Rescue Efforts			✔
- Police			
- Fire			
- Ambulance			
• Indirect Benefits			✔
- Reduced Travel Delays			
- Reduced Nonrecoverable Business Losses			
• Potential Benefits of Alternative Uses			✔
- Cost Savings of Multi-Use Data Collection			
Costs			
• Flood Warning Program Costs	✔		
- Equipment Costs			
- System Operations Labor Costs			
- Field Maintenance Labor Costs			
• Flood Preparedness Costs			✔
- Police			
- Fire			
- Ambulance			
- District			
- Civil Defense			
- Arizona Dept. of Transportation (ADOT)			
- Arizona Dept. of Water Resources (ADWR)			
• Potential Costs of Alternative Uses			✔
- Upgrade/Replace Gages			
- Record/Archive Data			
- Additional O&M			

For the purpose of estimating benefits of a flood warning system from reduced flood damage, only contents damage is typically considered. Contents are defined by the Corps to include furnishings, equipment, decorations, raw materials, materials in process, and completed products (Corps, 1990).

Reduced property damage is a function of lead time. The reduced damage and lead time relationship is based on the concept that providing advanced notification before a flood occurs gives individuals time to move or remove contents to reduce damages. In the early 1970s, Harold Day developed a hypothetical curve, termed the Day curve, which describes reduced damages as a function of lead time. The relationship assumes that an effective flood warning system is in place and that, given adequate warning, individuals will take appropriate actions to save property. Because both reduced damage and lead time are site-specific to the area of flooding, the Day curve is unique to each community. Therefore, a significant flooding analysis would be required to determine the shape of the Day curve. An example of a typical Day curve is shown below in Figure 5-1.



TYPICAL DAY CURVE

FIGURE 5-1

Day curves have not been developed for Maricopa County, and the actual data necessary to develop the curve are not readily available. As a result, JMM developed an alternative approach to estimate potential reductions in property damage. Two points of a "synthetic" Day curve for Maricopa County were established by JMM from work previously performed on estimating theoretical annual damage for a small area in Maricopa County. Expected annual contents flood damage was extrapolated to the remainder of the County with consideration for variations in value and density of development.

As described above, the approach for estimating reductions in property damage resulting from a flood warning system only addressed contents. It is recognized that individual flood-proofing efforts such as sandbagging could reduce both structural and contents property damage. However, neither the benefits nor costs of temporary flood-proofing were included in this analysis due to lack of data necessary to estimate the effect on damage reduction. If flood-proofing efforts as a result of flood warning were included in the analysis, the economic feasibility would be increased. Therefore, exclusion of this factor would result in a more conservative feasibility determination.

The approach developed by JMM for estimating the benefits of a flood warning system attributable to reduced flood damage is described in detail in the following paragraphs.

Annual Contents Flood Damage in Maricopa County. A review of available data from numerous local, county, state, and federal agencies, as well as from the private sector, has revealed that flood damage has not been recorded in the past, except for partial damage from a few major floods. Due to this lack of historical data, JMM developed an approach for estimating annual contents flood damage based on extrapolation of a detailed economic analysis completed in 1987 by the Corps on the Arizona Canal Diversion Channel, Reach 4 (Corps, 1987), referred to herein as the ACDC Reach 4 report. The ACDC Reach 4 study area as identified by the Corps to be the area protected by Reach 4 of the ACDC, is illustrated in Figure 5-2.

The ACDC Reach 4 report was used as the basis for calculating annual flood damage because the data were specific to Maricopa County and the report was completed recently, in 1987, with projections for 1991. Additionally, contents damage, the basis of estimating benefits of flood warning, was computed separately from structural damage.

Annual flood damage was estimated by the Corps in the ACDC Reach 4 report by integrating estimated damages from storm frequencies ranging from the 25-year flood to the 500-year flood. JMM applied the annual contents flood damage developed in the ACDC Reach 4 report for the ACDC Reach 4 study area to the remaining urban and rural areas of Maricopa County. Differences in average property values and density of development were taken into account in applying the ACDC Reach 4 annual contents damage to the remainder of the County. Annual contents damage was developed for the County by community and adjusted to include flood protection from the ACDC.

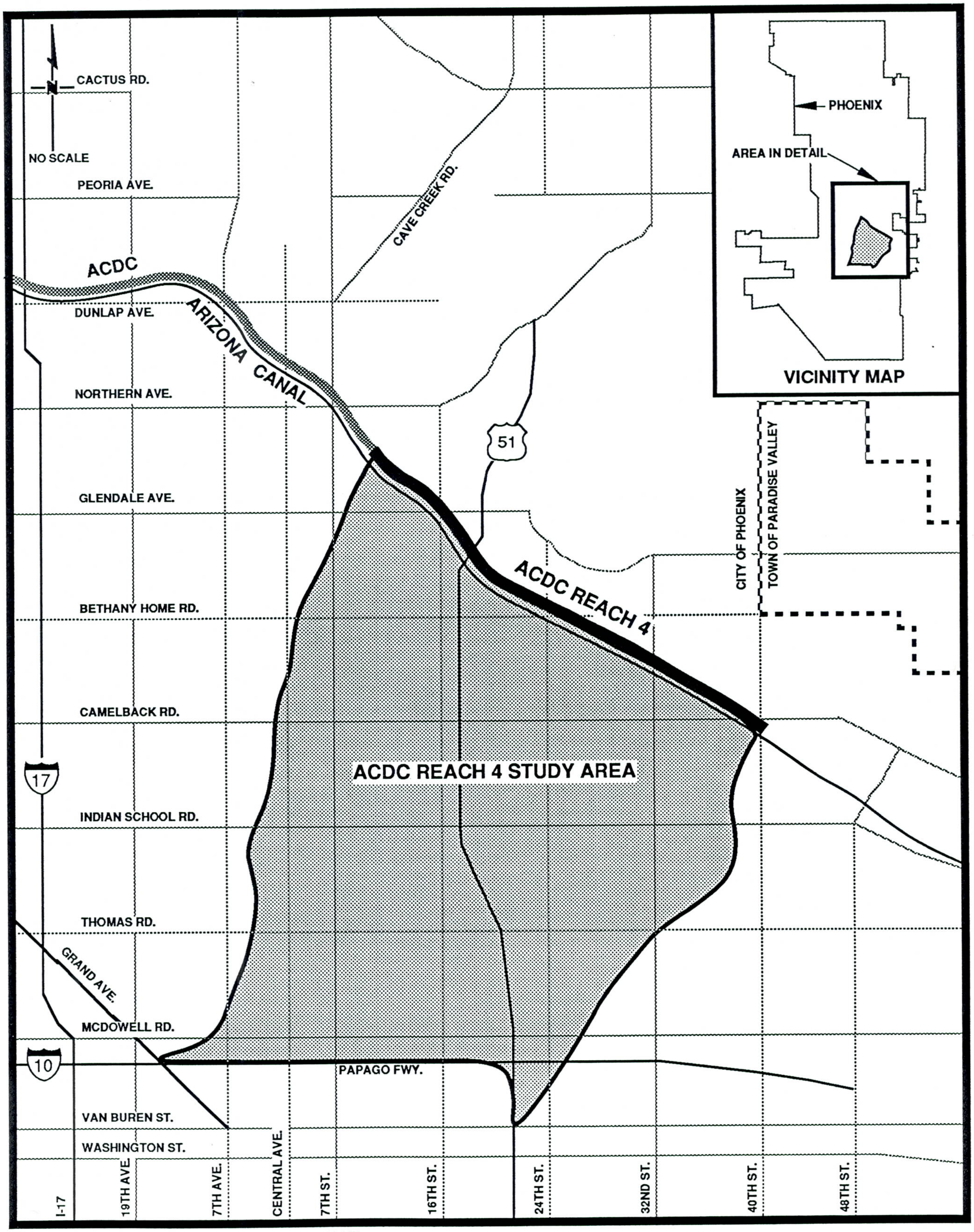
The approach used to estimate annual contents flood damage in Maricopa County includes the following assumptions:

- Assumptions on which the Corps' study is based, including the ratio of contents value to structural value for each land use classification, are also valid for the whole of Maricopa County.

- The distribution of the four land uses identified in the ACDC Reach 4 report (residential, commercial, industrial, and public) is approximately the same for the remainder of the County. It is noted that, according to the ACDC Reach 4 report, there was no flood threat to industrial property within the ACDC Reach 4 study area. Therefore, damage to industrial property for the remainder of the County is excluded, which could cause the annual contents flood damage to be underestimated in areas of heavy industrial use.

- The relative contents value throughout the County is the same as the ratio of real estate values between the ACDC Reach 4 study area and the remainder of the County. This assumption would cause underestimation of flood damages in some areas such as rural settings and overestimation in areas of prime real estate value.

- The level of flood control protection within the ACDC Reach 4 study area prior to construction of the project is roughly equivalent to the level of protection within



Based on the ACDC Reach 4 report (Corps, 1987)

LOCATION OF THE ACDC REACH 4 STUDY AREA

FIGURE 5-2

JMM

the whole of Maricopa County, less the area protected by the ACDC and upstream dams.

There has been some discussion on the validity of the assumption that the level of flood potential for the entire county is approximately the same as that for the ACDC Reach 4 study area. According to data collected by the District through its community rating system program, as of October 1990, only five percent of the acreage in Maricopa County is within the 100-year floodplain as defined by FEMA.

Notwithstanding this finding, it was decided to maintain the assumption for the following reasons:

1. The limits of the 100-year floodplain as defined by FEMA are for major floodways only. However, areas need not be located within the 100-year floodplain to experience localized flooding from heavy rainfall. For example, many areas outside the 100-year floodplain sustained extensive damage as a result of a storm which occurred on September 3, 1990, in the Phoenix metropolitan area. Another example is provided in the cover photograph, which shows an area within the County that experienced significant flooding even though it is outside the 100-year floodplain.

2. Damage calculations were made on an annual basis which took into consideration probability of occurrence for a range of flood frequencies.

3. Although comprehensive historical flood damage data are not available, the Corps did compare its calculated flood damage from the 100-year event in the ACDC report with a historical flood event of similar magnitude. The calculated damage compared favorably with records of actual damage sustained.

The methodology of estimating annual contents flood damage for the communities and unincorporated areas of Maricopa County is summarized in the following equation:

Equation 5-1:

$$\text{Annual Contents Flood Damage of Community (\$/yr)} = A \times B \times \frac{C}{D}$$

where A = ACDC Reach 4 Annual Contents Damage ($/sq mi/yr)
B = Area of Community (sq mi)
C = Community's Residential Property Value ($/sq mi)
D = ACDC Reach 4 Residential Property Value ($/sq mi)

The following paragraphs contain a description of the steps to compute the annual contents flood damage in Maricopa County based on the above equation.

<u>A = ACDC Reach 4 Annual Contents Damage.</u> Estimated annual contents flood damage data for the ACDC Reach 4 study area for 1991 were taken from the ACDC Reach 4 report (Corps, 1987). Total expected without-project annual flood damage, for contents only, is summarized in Table 5-2.

TABLE 5-2

ESTIMATED ANNUAL CONTENTS FLOOD DAMAGE FOR THE ACDC REACH 4 STUDY AREA

Land Use	Annual Contents Flood Damage ($ /yr)
Residential	1,135,000
Commercial	488,000
Industrial	0
Public	7,000
Total	**1,630,000**

It is noted that in the ACDC Reach 4 report, the annual flood damage for industrial land use was shown as $7,000/yr, and public land use as $0/yr. However, after further analysis and discussions with Corps personnel, it was determined that the industrial and public land use data had been reversed. The total annual flood damage of $1,630,000/yr from all land uses is not affected by this error.

The ACDC Reach 4 study area encompassed approximately 20 square miles. Therefore, the ACDC Reach 4 pre-project annual contents flood damage per square mile is:

$$\frac{\$1{,}630{,}000/\text{yr}}{20\ \text{sq mi}} = \$81{,}500/\text{sq mi/yr}$$

B = Area of Community. The area of community was determined from the 1991 Local Government Directory (League of Arizona Cities and Towns and Arizona Association of Counties, 1991). Urban areas are defined as incorporated Maricopa County, while rural areas are defined as unincorporated Maricopa County. However, data for Sun Lakes, Sun City, and Sun City West were treated as urban areas even though they are within unincorporated Maricopa County because the areas are characteristic of urban rather than rural development. Unincorporated Maricopa County includes the small portion of Apache Junction not in Pinal County, Komatke, Luke Air Force Base, as well as the remainder of the unincorporated areas in the County.

The total area of Maricopa County is 9,226 square miles. Of this, 1,400 square miles were computed as located within urban areas.

C = Residential Property Value by Community. Residential property values for each community were compared to that of the ACDC Reach 4 study area as the basis of extrapolating contents damage to the remainder of Maricopa County. The comparison was limited to residential property only because current data were not available for any other land use classification at the time of evaluation. Further, residential property was restricted to include only owner-occupied units of single-family homes, duplexes, and mobile homes/trailers. Multi-family homes of more than two units and rental properties is excluded because data were not available to determine the number of ground-level units. (On multi-level structures, only the contents on the ground floor would be considered threatened by flooding.)

Residential property value data from the 1990 census were collected from the Arizona Department of Economic Security (ADES) State Data Center (ADES, 1990). The data were used to estimate residential property value per square mile for each community as presented in Table 5-3. Background data used in developing the information in Table 5-3 are included in Appendix F.

D = ACDC Reach 4 Residential Property Value. Pertinent data for the 1990 census tracts in the ACDC Reach 4 study area were also collected from the ADES State Data Center (ADES, 1990). As with the data collected for individual communities, the data included only owner-occupied single family homes, duplexes, and mobile homes/trailers. Using the mean residential property value and total number of housing units within the ACDC Reach 4 study area, the total residential property value of the ACDC Reach 4 study area was estimated to be $1,829,000,000. Therefore, the residential property value per square mile for the ACDC Reach 4 study area is:

$$\$1{,}829{,}000{,}000 / 20 \text{ sq mi} = \$91{,}450{,}000/\text{sq mi}$$

Background data used to estimate residential property value in the ACDC Reach 4 study area are also included in Appendix F.

Annual Contents Flood Damage by Community. Annual contents flood damage for each community was estimated from Equation 5-1. An example of the procedure is presented below for the City of Scottsdale:

- ACDC Reach 4 annual contents damage = $81,500/sq mi/yr
- Area of Scottsdale = 185 sq mi (Table 5-3)
- Residential property value for Scottsdale = $27,041,000/sq mi (Table 5-3)
- Residential property value for ACDC Reach 4 = $91,450,000/sq mi

From Equation 5-1,

Estimated Annual Contents Flood Damage of Scottsdale =

$$\$81{,}500/\text{sq mi/yr} \times 185 \text{ sq mi} \times \frac{\$27{,}041{,}000/\text{sq mi}}{\$91{,}450{,}000/\text{sq mi}} = \$4{,}458{,}000/\text{yr}$$

The estimated annual contents flood damage by community in Maricopa County is summarized in Table 5-4. It should be noted that estimated damages were adjusted for Glendale, Peoria, and Phoenix due to additional flood protection from construction of the ACDC and upstream dams. Calculations for these adjustments may be found in Appendix G.

Estimate of Percent Contents Saved by a Flood Warning System. As previously stated, the primary quantifiable economic benefit of a flood warning system is the contents damage that could be avoided by removing property from flood threat in response to a warning. To estimate the damages which could be avoided, JMM developed a method to approximate savings as a percent of total contents flood damage.

In order to estimate the percent of damage which could be saved with prior warning, several parameters must be analyzed. First, a lead time must be assumed in order to estimate potential savings. Second, typical contents which would be damaged by flooding must be tabulated. Finally, typical contents which could be saved due to an assumed lead time must be developed. These three parameters are discussed below.

Lead Time. Lead times of 30 minutes and two hours were selected to represent the range that could reasonably be expected to be attained with a flood warning system for Maricopa

TABLE 5-3

RESIDENTIAL PROPERTY VALUES BY COMMUNITY

Community	Area (sq mi)	Estimated Total Value ($)	Estimated Unit Value ($/sq mi)
Urban			
Avondale	24	195,131,000	8,130,000
Buckeye	81	65,975,000	815,000
Carefree	9	209,708,000	23,301,000
Cave Creek	24	148,875,000	6,203,000
Chandler	46	1,953,151,000	42,460,000
El Mirage	11	39,852,000	3,623,000
Fountain Hills	17	484,119,000	28,478,000
Gila Bend	6	12,501,000	2,084,000
Gilbert	27	783,607,000	29,022,000
Glendale	53	2,754,038,000	51,963,000
Goodyear	134	62,682,000	468,000
Guadalupe	1	28,180,000	28,180,000
Litchfield Park	3	166,773,000	55,591,000
Mesa	122	5,370,371,000	44,019,000
Paradise Valley	16	1,634,401,000	102,150,000
Peoria	58	1,204,218,000	20,762,000
Phoenix	423	19,150,249,000	45,272,000
Queen Creek	11	61,696,000	5,609,000
Scottsdale	185	5,002,619,000	27,041,000
Sun City	14	1,469,066,000	104,933,000
Sun City West	10	955,403,000	95,540,000
Sun Lakes	3	362,238,000	120,746,000
Surprise	63	93,811,000	1,489,000
Tempe	39	2,751,011,000	70,539,000
Tolleson	6	45,517,000	7,586,000
Wickenburg	13	93,973,000	7,229,000
Youngtown	1	43,055,000	43,055,000
Urban Total	**1,400**	**45,142,000,000**	**32,000,000**
Rural			
Unincorp. Maricopa Co.*	7,826	2,723,797,000	348,000
Rural Total	**7,826**	**2,724,000,000**	**348,000**
Maricopa County			
Maricopa County Total	**9,226**	**47,866,000,000**	**5,000,000**

* Unincorporated Maricopa County includes Komatke, Luke Air Force Base, and a small portion of Apache Junction.

Data Sources: ADES, 1990; League of Arizona Cities and Towns and Arizona Association of Counties, 1991

TABLE 5-4

ESTIMATED ANNUAL CONTENTS FLOOD DAMAGE BY COMMUNITY

Community	Estimated Annual Contents Flood Damage ($/yr)[1]
Urban	
Avondale	174,000
Buckeye	59,000
Carefree	187,000
Cave Creek	133,000
Chandler	1,741,000
El Mirage	36,000
Fountain Hills	431,000
Gila Bend	11,000
Gilbert	698,000
Glendale[2]	2,120,000
Goodyear	56,000
Guadalupe	25,000
Litchfield Park	149,000
Mesa	4,786,000
Paradise Valley	1,457,000
Peoria[2]	953,000
Phoenix[2]	14,857,000
Queen Creek	55,000
Scottsdale	4,458,000
Sun City	1,309,000
Sun City West	851,000
Sun Lakes	323,000
Surprise	84,000
Tempe	2,452,000
Tolleson	41,000
Wickenburg	84,000
Youngtown	38,000
Urban Total	**38,000,000**
Rural	
Unincorp. Maricopa Co.[3]	2,427,000
Rural Total	**2,000,000**
Maricopa County Total	**40,000,000**

(1) Estimated annual contents flood damage is based on flood damage projections identified in the ACDC Reach 4 report with adjustments for relative property values and density of development.

(2) Damage estimates were reduced in Glendale, Peoria, and Phoenix due to construction of the ACDC and upstream dams (see Attachment C).

(3) Unincorporated Maricopa County includes Komatke, Luke Air Force Base, and a small portion of Apache Junction.

County. The time required to collect and evaluate the data on which a flood warning would be based is in addition to the lead time as defined previously.

Contents Saved in Response to a Flood Warning. For lead times of 30 minutes and two hours, JMM developed lists of contents which could reasonably be saved from the average residence. Table 5-5 summarizes these items, the estimated length of time to gather them, and their estimated replacement value. The value of the items was estimated to be $600 per residence unit for a 30-minute lead time and $2,900 per residence for a 2-hour lead time.

Typical Contents Damaged by Flooding. JMM developed a list of residential contents which would likely be damaged by flooding, as well as typical replacement or repair costs. Contents were based on the mean residential property value for the County ($97,000; see Table F-1) and an assumed house size of 1,800 square feet. Further, the average depth of inundation was assumed to be 1 foot (based on ACDC Reach 4 report).

As shown in Table 5-6, the cost to repair/replace the typical contents damaged by a flooding event in the mean residential property without response to flood threat is estimated to be $20,000.

Based on the estimates in Tables 5-5 and 5-6, the expected reductions in contents damages assuming 30-minute and 2-hour lead times were estimated as follows:

30-Minute Lead Time Content Savings = ($600 / $20,000) x 100% = 3%

2-Hour Lead Time Content Savings = ($2,900 / $20,000) x 100% = 15%

Adjustments for Constraints of a Local Flood Warning System. It is assumed that the percent savings of expected flood damage for residential property estimated above can be applied to all types of land uses. Therefore, the annual contents damages previously estimated for each community would be reduced by 3% and 15% for 30-minute and two-hour lead times, respectively. However, it is recognized that both the public response to a flood warning and the accuracy of a local flood warning system would be less than 100%. Therefore, calculation of reduced annual contents flood damage for each community was adjusted by the following equation:

Equation 5-2:

Reduced Contents Flood Damage of Community ($/yr) = E x F x G x H

where E = Annual Contents Flood Damage of Community ($/yr)
F = Percent Contents Savings from Response to a Flood Warning (3% or 15%)
G = Public Response to a Flood Warning (%)
H = Accuracy of the Local Flood Warning System (%)

The public response and accuracy factors are discussed in the following paragraphs.

G = Public Response to a Flood Warning. A review of published literature indicates no typical percentages of people expected to receive and heed a flood warning. Factors which would influence the rate of response include education and ethnic backgrounds (Perry and Mushkatel, 1986), the source of notification of impending flooding, the number of warnings received, the time of day of the warning, the perceived credibility of the agency issuing the warning, the degree of public education on flood warning, and the length of time since the most recent flood, among others.

TABLE 5-5

ASSUMED TYPICAL CONTENTS SAVED FOR 30-MINUTE AND 2-HOUR LEAD TIMES

Given a 30-minute lead time, the following is a chronology of the "typical" items which are assumed to be saved from the mean residential property:

Item	Time (min)	Value ($)
Planning/Wasted time	5	-
Telephone calls (family)	5	-
Children & pets	5	-
Photos	5	-
Clothes/toiletries	5	100
TV (2)	5	500
Totals for 30-minute lead time:	**30**	**600**

Given a 2-hour lead time, the following ADDITIONAL items are assumed to be saved from the mean residential property:

Item	Time (min)	Value ($)
VCR	5	200
Stereo	5	500
Camera	5	100
Books (2 shelves, 25 books ea)	15	500
Papers/memorabilia	10	-
Elevate items on beds/counters	50	1,000
Totals for next 1.5 hours:	**90**	**2,300**
Plus items saved in first 30 min.:	30	600
Totals for 2-hour lead time:	**120**	**2,900**

TABLE 5-6

TYPICAL CONTENTS DAMAGED BY FLOODING

Typical Contents Damaged	Estimated Repair Cost ($)	Estimated Replacement Cost ($)
Refrigerator	400	
Oven	100	
Dishwasher	200	
Washer	200	
Dryer	200	
Freezer	400	
Dry Goods		50
Food Spoilage		500
Recliner (2)		800
Carpeting/Linoleum @ 200 sy x $15/sy		3,000
Sofa, Love Seat, Chair		1,500
Coffee/End Tables (3)		400
Television(s)		500
Stereo		500
Bookcase		300
Kitchen Cabinets		2,500
Clothing		800
Bathroom Cabinets (2)		400
Beds (2 double, 2 single)		1,200
Desk		500
Dressers (4)		1,200
VCR		200
Camera		100
Books		800
Dining Table & Chairs		1,200
Albums, Cassettes, VCR Tapes		500
Draperies		500
Miscellaneous Personal Property		1,000
Subtotals	1,500	18,500
Total Repair/Replacement Cost		**20,000**

Assumptions: Mean residential property value = $97,000 (from 1990 Census data for Maricopa Co.)
Average size of residential unit = 1,800 sq ft (estimated by JMM)
Average depth of inundation = 1 ft (from ACDC Reach 4 Report)

According to the results of the market survey, the level of response which indicated an adequate understanding of flooding and flood warning was approximately 70 percent. This factor of 0.70 was taken to represent an assumed upper limit of response to a flood warning. However, as described above, there are numerous other factors which would lower the level of response. To account for these factors, the average level of response assumed for this analysis is reduced to 50 percent. It should be noted that public response to a flood warning could be expected to increase with time as the flood warning program gains experience and credibility.

H = Accuracy of a Flood Warning System. Several operators of active local flood warning systems were contacted regarding the percent accuracy of warned flooding events since implementation of a local flood warning system. The success rate ranged from 85 percent to 100 percent of events which occurred. A conservative factor of 85 percent, the lower end of the reported range of accuracy, is assumed as the average accuracy to account for reduction of benefits due to unwarned events.

Reduced Contents Flood Damage in Maricopa County. Using the results of Equation 5-1 (summarized for each community in Table 5-4), Equation 5-2 was used to calculate the estimated reduction of annual contents flood damage for each community. An example of the procedure is shown below for the City of Scottsdale:

- Annual Contents Flood Damage for Scottsdale = $4,458,000/yr (Table 5-4)
- Contents Saved from Response to a Flood Warning = 3% (30-minute lead time) or 15% (2-hour lead time)
- Public Response to a Flood Warning = 50%
- Accuracy of the Local Flood Warning System = 85%

Therefore, using Equation 5-2 for a 30-minute lead time, the savings would be:

= $4,458,000/yr x 3% x 50% x 85%

= $56,800/yr

A 2-hour lead time yields:

= $4,458,000 x 15% x 50% x 85%

= $284,200/yr

The reduced flood damages for 30-minute and 2-hour lead times by community in Maricopa County are listed in Table 5-7. The sum of the net annual reduced flood damages in Maricopa County for flood warning systems providing 30-minute and 2-hour lead times are as follows:

30-Minute Lead Time = **$500,000/yr** (approximately)

2-Hour Lead Time = **$2,600,000/yr** (approximately)

As described previously in this section, these values represent the only directly quantifiable economic benefits attributable to implementation of a flood warning system in Maricopa County. It is noted that benefits would be realized intermittently when flooding occurs, while flood warning program costs are continuously incurred.

TABLE 5-7

ESTIMATED ANNUAL REDUCED CONTENTS FLOOD DAMAGE BY COMMUNITY FOR 30-MINUTE AND 2-HOUR LEAD TIMES

Community	Estimated Annual Reduced Flood Damage 30-Minute Lead Time ($/yr)	Estimated Annual Reduced Flood Damage 2-Hour Lead Time ($/yr)
Urban		
Avondale	2,200	11,100
Buckeye	800	3,800
Carefree	2,400	11,900
Cave Creek	1,700	8,500
Chandler	22,200	111,000
El Mirage	500	2,300
Fountain Hills	5,500	27,500
Gila Bend	100	700
Gilbert	8,900	44,500
Glendale	27,000	135,200
Goodyear	700	3,600
Guadalupe	300	1,600
Litchfield Park	1,900	9,500
Mesa	61,000	305,100
Paradise Valley	18,600	92,900
Peoria	12,200	60,800
Phoenix	189,400	947,100
Queen Creek	700	3,500
Scottsdale	56,800	284,200
Sun City	16,700	83,400
Sun City West	10,900	54,300
Sun Lakes	4,100	20,600
Surprise	1,100	5,400
Tempe	31,300	156,300
Tolleson	500	2,600
Wickenburg	1,100	5,400
Youngtown	500	2,400
Urban Total	**479,000**	**2,395,000**
Rural		
Unincorp. Maricopa Co.*	30,900	154,700
Rural Total	**31,000**	**155,000**
Maricopa County Total	**500,000**	**2,600,000**

* Unincorporated Maricopa County includes Komatke, Luke Air Force Base, and a small portion of Apache Junction.

Increased Safety

Increased safety, including reduced loss of life and reduced injuries, is a major benefit resulting from the implementation of a flood warning system. However, it is difficult to estimate the number of lives that may be saved and accidents avoided due to a flood warning system. Additionally, there are no commonly accepted approaches to placing a dollar value on lives saved. It is believed by some that reduction in the risk to life is often sufficient justification alone for a flood warning system (Barrett and Davis, 1988).

A flood warning system can increase safety and reduce loss of life as follows:

- Institution of traffic controls, such as barricades, to prevent travel into hazardous areas and to facilitate evacuation;
- Evacuation of hazardous areas prior to flooding, thereby reducing risks to both evacuees and rescuers;
- Deployment of personnel and equipment to assure medical, fire, police, and other services are continued and available to all parts of the community;
- Provision of a basis for decisions affecting exposure to danger such as the opening and closing of schools, transportation of students, and release of employees from work;
- Provision of early alerts and assistance to invalids, those who are handicapped, and to other persons or organizations that require greater than average amount of time to evacuate; and
- Emergency management of gas and electric services to avoid fire, explosion, and other secondary problems (Shawcross, 1987).

Evaluation of Increased Safety from a Flood Warning System. Increased safety due to a flood warning system results in reduced threat to human lives. Approaches for estimating the threat to human lives posed by flooding have been developing since the early 1980s. Because of lack of procedures for predicting loss of life, one early approach assumed that a significant population at risk (PAR) from flooding translated into a significant loss of life. PAR is defined as all persons in the inundation area just prior to the flooding event. However, this approach is no longer considered valid because it is realized that more factors than PAR should be taken into consideration to estimate loss of life due to flooding (Brown and Graham, 1988).

Another approach is to estimate loss of life based on relationships between economic damages and fatalities from past flooding events. However, this approach does not account for the fact that economic losses are determined primarily by water depth and velocity, while the fatality rate is strongly affected by time considerations and other factors discussed in subsequent paragraphs.

For evaluation of increased safety resulting from a flood warning system, the following factors are considered:

- Identification of the variables influencing increased safety from flooding
- Analysis of historical data in Maricopa County

Variables Influencing Increased Safety from Flooding. Factors affecting threat to human lives due to flooding are as follows (Brown and Graham, 1988; Lee, et. al., 1987):

- Frequency and severity of flooding event
- Event detection and monitoring
- Decision process related to threat of event
- Whether or not a warning is issued
- Amount of lead time
- Size of PAR
- Response of PAR to warning
- Evacuation
- Impact of flood on persons remaining in the floodplain

Studies of past flooding events show that the factors which most directly influence threat to human lives are the size of PAR, amount of lead time prior to flooding, and severity of the flooding event (Brown and Graham, 1988; Lee, et. al., 1987). Other key factors include previous experience with flooding and population density of an area (Lee, et. al., 1986).

The U.S. Bureau of Reclamation (BuRec) has adopted procedures that estimate loss of life due to flooding based on the number of PAR, the amount of lead time, and adjustments due to local conditions. BuRec's analysis of historic cases shows that for cases with lead time greater than 90 minutes, PAR is a very good predictor of loss of life. However, for lead time less than 90 minutes, other factors such as the time of day, the occurrence of prior flooding, and the severity of flooding, have a greater influence on loss of life. BuRec's studies emphasize the importance of lead time. Improving lead time to 90 minutes or more reduces fatalities by over 90 percent. (Brown and Graham, 1988)

A study performed at the Oak Ridge National Laboratory for the Corps Institute for Water Resources also showed that PAR is a good predictor of loss of life for greater lead time and that loss of life is greatly reduced with longer lead time. The Oak Ridge Laboratory's study also showed that population density of an area has a strong influence on loss of life. In less populated areas, the warning process is not as efficient in disseminating the warnings because of lack of public officials and resources and because there is a larger area to cover. (Lee, et. al., 1986)

Analysis of Historical Data in Maricopa County. Information related to number of fatalities and injuries in Maricopa County as a result of flooding and/or severe weather has been collected from ADOT and NWS. The Corps was also contacted, but data on fatalities and injuries are collected only when a Corps flood control project is involved.

The ADOT data, shown in Table 5-8, include number of fatalities and injuries on any roadway in Maricopa County from 1973 through 1990. As shown in Table 5-8, approximately 1 fatality and 61 injuries per year occur due to traffic accidents on flooded roadways in Maricopa County.

The NWS data, shown in Table 5-9, included the number of fatalities and injuries in Maricopa County from severe weather and flooding events from 1959 through 1990. However, a limitation of the NWS data was that for major storms, fatality and injury counts for Maricopa County were combined with other portions of the State. Additionally, when flash flooding is associated with severe weather such as high winds, tornadoes or hail, the NWS records the event in the severe weather category. Consequently, the fatality and injury count due to flooding in Maricopa County is not readily apparent in the NWS data. Finally, the NWS only records information which is voluntarily submitted by other agencies or individuals, or from newspaper accounts. It does not perform a comprehensive

TABLE 5-8

ARIZONA DEPARTMENT OF TRANSPORTATION
TRAFFIC ACCIDENT REPORT FOR FLOODED ROADWAYS IN MARICOPA COUNTY, 1973 THROUGH 1990

Year	Number of Fatalities	Number of Injuries
1973	1	57
1974	1	53
1975	1	38
1976	1	36
1977	0	29
1978	7	109
1979	1	68
1980	1	47
1981	0	44
1982	1	80
1983	1	103
1984	1	136
1985	1	50
1986	1	52
1987	1	19
1988	0	61
1989	1	39
1990	0	79
18-Year Total	**20**	**1,100**
Yearly Average	**1**	**61**

TABLE 5-9

NATIONAL WEATHER SERVICE
STORM DATA AND UNUSUAL PHENOMENA IN MARICOPA COUNTY
AND OTHER AREAS, 1959 THROUGH 1990

	ALL SEVERE WEATHER EVENTS		FLOODING EVENTS ONLY	
Year	Number of Fatalities	Number of Injuries	Number of Fatalities	Number of Injuries
1959	8*	53*	0	0
1960	0	4	0	0
1961	1	2	0	0
1962	0	11	0	0
1963	1	0	0	0
1964	1*	5*	1*	4*
1965	0	2	0	0
1966	2	4	0	0
1967	0	2	0	0
1968	0	8	0	0
1969	0	5	0	0
1970	23*	4	23*	3
1971	7	66	0	0
1972	9*	10	8*	3
1973	0	0	0	0
1974	1	6	0	0
1975	0	6	0	6
1976	0	1	0	1
1977	1	0	0	0
1978	14*	20	14*	0
1979	0	23	0	0
1980	3*	3	3*	2
1981	0	2	0	2
1982	6*	14*	5*	14*
1983	22*	46	15*	43
1984	2	3	1	3
1985	0	18	0	6
1986	0	3	0	0
1987	0	4	0	0
1988	2	12	1	0
1989	0	3	0	0
1990	0	25*	0	0
32-Year Total	**103***	**365***	**71***	**87***
Yearly Average	**3***	**11***	**2***	**3***

* Includes areas in Arizona outside of Maricopa County.

analysis of injuries and deaths caused by flooding. Thus, it was felt that the ADOT data are more relevant to Maricopa County.

Based on the historical data on fatalities and injuries resulting from flooding and severe weather events in Maricopa County and on previous studies which have shown that increased warning time decreases the threat to human lives, it is concluded that increased safety would result from advance warning of a flood.

Reduced Rescue Efforts

Reduced police, fire, and ambulance rescue efforts would result from individuals taking the appropriate actions if given advanced warning of a flood. There would be less evacuation, care, and public assistance necessary. Additionally, there would be fewer accidents on the roadways, in homes, and at public and private facilities if a flood warning system provided warning of an impending flood.

Indirect Benefits

Indirect benefits resulting from the implementation of a flood warning system include reduced nonrecoverable business losses (i.e., losses which would not be insurable) and reduced travel delays.

Reduced Business Losses. Businesses most likely to experience non-recoverable losses include:

- Public utilities, including water supply, electricity, natural gas, and telephone;
- Businesses that deliver or process perishable items that may spoil;
- Businesses whose competitors are not affected by the flood; and
- Newspapers and radio and television stations. (Corps, 1988)

Advanced warning of flood threat can reduce business losses because precautions can be taken to properly shutdown facilities that would be affected by flooding or modify procedures to enable continued service in a flood event. If precautions are taken in preparation of a flood, businesses would have a faster and less expensive return to standard operations resulting in reduced down time, reduced unemployment, and smaller losses in sales (Shawcross, 1987).

It should be noted that if a business acts on a false alarm by preparing for a flood and/or closing because of a flood threat, then some business losses would occur due to the false alarm.

Reduced Travel Delays. Travel delays occur when flooding affects roads and bridges. In addition to the inconvenience associated with being delayed in traffic, there are also indirect costs that occur, such as vehicle operating costs and lost business time. A flood warning system can decrease travel delays if traffic management procedures, such as barricades, detours, and posted warnings, are employed, as well as early media notification of road closures. These methods would result in individuals choosing not to travel or to take alternate routes.

ESTIMATION OF COSTS OF A FLOOD WARNING SYSTEM

The primary costs attributed to a flood warning system are equipment costs and labor to operate and maintain the system. Program costs for each alternative were developed on an annual cost basis. To identify system costs, only costs which would be incurred over the period of analysis were considered. Existing equipment purchased in prior years was excluded because economic decisions are made on present and future costs and benefits only.

Assumptions which were used in the cost analysis, and subsequent results, are presented below.

Selection of Cost Analysis Parameters

Specific economic parameters were selected as a basis for calculating equivalent annual costs in 1991 dollars. The parameters include the useful life of equipment, period of analysis, discount rate, salvage value, and contingencies. These parameters are described in the following paragraphs.

Useful Life. The useful life of precipitation and stage gages and related hardware, as well as meteorological hardware, is established as 20 years. The useful life of computer hardware and ALERT software is five years.

Period of Analysis. The period of analysis is 15 years. This period is chosen because, based on information obtained on the District's existing flood detection network, the average date of installation of equipment was 1986. Therefore, the average remaining life of the flood detection network, with the exception of the computer hardware and software, is 15 years.

Discount Rate. The discount rate used to compute equivalent annual costs of present worth is 7.5%. This rate reflects discussions with District personnel on rates currently available to the District.

Salvage Value. Salvage value is assumed to be zero at the end of the useful life of equipment. However, for some of the alternatives, new equipment will be installed with a useful life which exceeds the period of analysis. For example, in Alternatives 2 through 5, additional precipitation gages are included, with a useful life of 20 years. Where equipment life exceeds the period of analysis, straight line depreciation methodology was used to calculate salvage value at the end of 15 years. The future salvage value was then annualized over 15 years and subtracted from the annualized costs.

Contingencies. An annual cost contingency factor of 20% of the total annual program cost for Alternatives 2 through 5 was included to cover costs unforeseeable in a feasibility level study. A contingency factor of 5% was included in costs identified for Alternative 1 to represent unspecified miscellaneous labor and equipment costs.

Alternative 1 Costs

The costs identified for Alternative 1, which is to maintain current flood warning activities, include periodic replacement of computer hardware and software over the period of analysis, as well as labor required to operate and maintain the system. Flood detection equipment costs are not identified because the existing equipment is expected to be operational through the period of analyses. Annual costs attributed to Alternative 1 are described below.

Computer Costs. As previously stated, the useful life of computer hardware and software is five years. The average date of installation of flood warning equipment is 1986; therefore, for this analysis, the existing computer system would be replaced every five years, beginning in 1991. Replacement costs for the existing computer system were developed for use in estimating total computer costs over the 15-year period.

System Operation Labor. Based on accounting information provided by the District from the past five years, it is estimated that current labor requirements for system operation are approximately $140,000 per year. System operation includes the efforts of a program manager and staff hydrologists and technicians to manage the flood warning program, monitor real-time data, and perform related operational tasks.

Field Maintenance Labor. Based on the same accounting information, it is estimated that current field installation and maintenance labor requirements are approximately $180,000 per year. Field maintenance includes routine replacement of batteries at gage sites, as well as replacement or repair of vandalized or otherwise inoperational equipment.

As shown in Table 5-10, it is estimated that annual costs for Alternative 1 are approximately $340,000. Costs for Alternative 1 are almost entirely labor costs to operate and maintain the existing system.

Alternative 2 Costs

In addition to costs identified for Alternative 1, costs were estimated for upgrading the flood detection system and radar data, as well as developing communications and hydrologic modeling elements. These components are described in the following paragraphs.

Expanded ALERT Precipitation and Stage Gage Network. The effectiveness of a flood warning system is directly dependent upon the timely availability of rainfall and runoff data. These data are in turn dependent upon the reliability of the network of gages to monitor and report these parameters. In the case of precipitation gages, the accuracy of the data improves with a more dense network (grid) of gages.

The District's existing network of precipitation gages for Maricopa County (124 stations, including five to be installed in the near future) is comprised of stations whose locations do not follow a uniform grid pattern. The existing network of stage gages in Maricopa County (44 stations) appears to be centered largely on New River, Cave Creek, and Hassayampa River. In order to prepare a preliminary estimate of the number of additional gages needed to improve the precipitation and stage gage network, precipitation characteristics were analyzed. A more detailed evaluation is recommended prior to establishing final sites for new gages.

Estimation of an appropriate number of precipitation gages required for a flood warning system is somewhat subjective. Each study area has unique qualities which affect the locations of precipitation gages. Qualities such as basin size, topography, storm type, level of development, accessibility, and land availability are all important factors in establishing a network of precipitation gages. In Maricopa County, a key factor in locating precipitation gages is the areal extent of the storm for which a flood warning system is designed. The following paragraphs briefly describe the types of storms which affect Maricopa County (Maricopa County, 1990).

Precipitation in Maricopa County is divided into two seasons, summer (June through October) and winter (December through March). Storm patterns are generally classified into three categories: general winter storms, general summer storms, and local storms.

TABLE 5-10

COST ESTIMATE FOR ALTERNATIVE 1
STATUS QUO

	Description	Quantity	Unit	Life (yr)	Unit Cost(1) ($)	1991 Cost(1) ($)	Annual Cost(2) ($/yr)
1.1	**Computer Costs**						
1.1.1	Computer Hardware						
	- COMPAQ DESKPRO 386/20e PC	1	ea	5	3,300	3,300	800
	- IBM PS/2, Model 60 PC	1	ea	5	3,500	3,500	900
	- Data General DASHER/286 PC	1	ea	5	2,000	2,000	500
	- Data General Lap Top Monitor	2	ea	5	2,500	5,000	1,200
	- IBM PROPRINTER 24 XL Printer	1	ea	5	700	700	200
	- Hewlett-Packard 7475A Plotter	1	ea	5	1,500	1,500	400
1.1.2	Computer Software						
	- Enhanced ALERT Software	1	ls	5	3,500	3,500	900
	Subtotal Computer Costs						4,900
1.2	**Meteorological Data**						
1.2.1	Meteorological Service	1	yr	-	-	-	800
1.3	**System Operation**						
1.3.1	Labor	1	yr	-	-	-	140,000
1.4	**Field Maintenance**						
1.4.1	Labor	1	yr	-	-	-	180,000
	Subtotal Alternative 1						326,000
	Annual Cost Contingencies (5%)						16,000
	Total						**340,000**

(1) Equipment and computer costs are Replacement Cost New
(2) Costs are annualized over 15 years at a discount rate of 7.5%

Note: The accuracy of the estimated costs is +50 percent to -30 percent of actual costs based upon a feasibility level of engineering detail or a "reconnaissance grade (order of magnitude estimate)" as defined by the American Association of Cost Engineers. Representative costs are in 1991 dollars and were based on data collected from the District, on JMM's experience with similar projects, and from vendors of flood detection equipment and related components. Data were also collected from discussions with operators of similar facilities.

General winter storms typically originate in the north Pacific Ocean, moving inland between October and May and covering relatively large areas. They produce light to moderate precipitation and affect large areas. These storms frequently last up to several days, may occur in a series, and can cover much of the state. General winter storms can be characterized by low intensity, long duration, and large areal extent.

General summers storms are remnants of tropical storms which originate in the Pacific Ocean north of the equator and south of Mexico during June through October. General summer storms are more localized than general winter storms.

Local storms are characterized by intense precipitation over relatively small areas. Scattered heavy downpours may occur over areas from a few square miles up to about 500 square miles during a time period up to six hours. Within the total area of larger storms is a region covering up to 20 square miles which is characterized by exceptionally heavy precipitation. This heavy precipitation often lasts less than one hour and is associated with thunder and lightning. Local storms typically occur during July through September and generally produce record peak flows for small watersheds, which can result in flash flooding.

Precipitation Gage Density. Because the local storms described previously tend to produce high peak runoff associated with flash flooding, these are the storms for which the grid of precipitation gages would be designed. A grid pattern which is too large (i.e., the gages are spread too far apart) may not detect such storms accurately. This is due to the possibility of the relatively compact intense "core" area passing between gages. As previously stated, this area of intense rainfall may cover an area up to 20 square miles. If it is assumed that this area of intense rainfall is circular in shape, it would have a diameter of approximately 5 miles. Based on this estimation, it is assumed that a 20-square-mile grid (4.5 mile by 4.5 mile square grid) could be used for precipitation gages in the urban portions of Maricopa County where information is most critical, due to the lack of flood warning lead time. As stated previously in this report, the estimated area of incorporated Maricopa County is 1,400 square miles. Therefore, approximately 70 gages would be required for the urban portions of the County. It is recognized that certain areas would require a greater density of gages, while other areas would require a less dense network.

In a discussion of depth-area-reduction factors, NOAA's Precipitation-Frequency Atlas (U.S. Department of Commerce, et. al., 1973) recommends a precipitation gage density of 1 per 100 square miles. If a precipitation gage density of one per 100 square miles is assumed for the 7,826 square miles of rural Maricopa County, 78 gages would be required. Again, some areas may require a greater or lesser density of gages.

Based on the above findings, a total of 148 precipitation gages (70 urban gages and 78 rural gages) are assumed to be required to improve the existing flood detection network. The County presently operates a network of 124 precipitation gages (including five to be installed in 1992), leaving a difference of 24 new gages. The assumed number of precipitation gages represents an increase of 20 percent over the existing system. It should be noted that the assumed number of gages have been developed for cost estimating purposes only in this feasibility-level study; the actual number and location of precipitation gages would be determined at the pre-design or design stage, when a detailed analysis of the study area would be performed.

Numerous publications regarding flood warning systems and precipitation gage requirements were obtained during the data collection phase of this project. Several references presented equations to estimate the number of precipitation gages required for flood warning systems (Jack Faucett Associates, 1990; Curtis and Schaake; Sierra-Misco, Inc., 1989). However, the gage recommendations were prepared for various areas of the country with different hydrologic and climatologic conditions than those found in Maricopa County. Further, urban and rural settings were not differentiated. Because of these differences, it was decided that the approaches recommended in these publications are of limited value in estimating gage requirements in Maricopa County.

It is noted that, given the small area of some storms, ALERT gages alone may not detect every storm at every point in time. Therefore, it is recommended that the District continue to monitor meteorological conditions in addition to its flood detection network.

Stage Gage Density. Estimating the number of required stage gages is less well-defined than estimating the number of precipitation gages. The placement of stage gages depends on the individual drainage basin characteristics (i.e., location of confluences, watershed configuration, areas of development, etc.). Therefore, no equations exist to estimate the number of required stage gages based on area.

For purposes of quantifying an upgrade of the stage gage network, it is assumed that, in general, stage gages would not be required in the upper portions of watersheds. Until runoff from minor tributaries have combined flows, a stage gage is not considered necessary. By comparison, precipitation gages in both the upper and lower watershed would provide valuable information regarding the precipitation differences within the watershed. Based on this assumption, it is concluded that one stage gage for every two precipitation gages would be adequate coverage. Therefore, 74 stage gages will be required, an increase of 30 stage gages. The recommended number of stage gages represents an increase of 68 percent over the existing system. As with precipitation gages, this estimate is made strictly for cost estimating purposes of this feasibility-level analysis; the actual number and location of gages would be determined at the pre-design or design stage.

Communications Equipment. Several components are included in the communications element of Alternative 2, including an electronic bulletin board, a facsimile, and a telephone messaging system.

Electronic Bulletin Board. It is recommended that the District maintain an electronic bulletin board so that authorized users could access up-to-date flooding information if desired. The electronic bulletin board would consist of a dedicated PC on which messages could be programmed. Public domain software is available at no cost. Alternatively, proprietary software is available for a fee which varies with the number of users that can be supported and program features.

Dedicated phone lines and modems would also be provided. It is assumed that the District would purchase three dedicated phone lines and modems for internal use; any additional phone lines which would be required for outside users could be funded by the user in lieu of a subscription fee.

Facsimile. A facsimile machine would be included in Alternative 2 to automatically dial multiple pre-selected numbers and transmit flooding information.

Telephone Messaging System. For users without computer access or facsimile capabilities, a telephone messaging system would be installed. It is assumed that the District would install two telephone lines and record flood information messages for outside parties.

Hydrologic Modeling. Several assumptions have been made in developing cost estimates to incorporate a hydrologic modeling component with flood warning. First, it is assumed that hydrologic modeling would be performed using HEC-1 or HEC1F, which includes forecasting capabilities. An alternative to HEC-1, the Sacramento model developed by NWS, is available from Sierra-Misco but is not considered to be applicable to Maricopa County for the following reasons:

1. The model requires several years of continuous flow data which would be available for few, if any, water courses in the County. No standard techniques have been developed to approximate parameters in the absence of historical data.

2. The model requires input of 18 separate parameters. The large number of variables makes calibration extremely difficult.

3. The program has difficulty with modeling infiltration of the upper soil zone due to the presence of Caliche, which is prevalent in Maricopa County (Brandon, 1991; Michaud, 1991; VanBlargan, 1991).

4. Most of the District's existing hydrologic models were developed using HEC-1.

5. HEC-1 is recommended in the Hydrologic Design Manual for Maricopa County, Arizona (District, 1990).

As stated in a previous discussion of alternatives, it is further assumed that the District would utilize existing hydrologic models developed in the ADMS and FIS programs and expand the system as additional analyses are completed. If the District chooses, additional hydrologic modeling could be performed for specific areas and incorporated into the flood warning program. However, costs for additional modeling are not included in this analysis.

Several tasks must be performed to develop a flood warning hydrologic analysis system based on existing hydrologic models. These tasks, which include model conversion, updates, and calibration are discussed below.

The work could be performed either in-house or by outside services. For this analysis, estimated costs were based on utilizing outside services because data were readily available to substantiate the costs. If the District performs the work in-house, it is recommended that a concentrated effort be made in developing the hydrologic component so that benefits can be realized at an early date.

Model Conversion and Updates. Models developed using a hydrologic program other than HEC-1 would have to be converted. Currently, at least two models covering more than 100 square miles would have to be converted. Additionally, models would have to be updated to include any significant areas which were developed after the initial development of the model.

Hydrologic modeling costs were obtained from the District's ADMS program. Based on the data provided by the District, as well as recent experience on similar projects, it was estimated that the average hydrologic modeling cost for the 11 models completed/in progress is approximately $800 per square mile. A factor of 25% of historic modeling costs is assumed to represent costs to convert, update, and incorporate the existing models. At $200 per square mile, the cost to convert, update and incorporate the ADMS and FIS hydrologic models, covering nearly 3,000 square miles, is approximately $600,000. Future incorporation of hydrologic modeling from ADMS' not yet performed is assumed to occur in five years over an area of approximately 1,500 square miles, at a cost of $300,000.

As part of the modifications to the hydrologic models, forecast points would be identified for each hydrologic model. It is estimated for the hydrologic modeling component that an average of four forecast points per model would be developed.

After the initial update of models, subsequent updates of models would be performed in-house as necessary to reflect additional development and drainage improvements.

Model Calibration. It is recommended that the hydrologic models be calibrated from available precipitation and runoff data to more accurately represent actual flooding conditions. However, it is recognized that available data may not allow proper calibration of many of the models. Therefore, it is assumed that 50% of the models would be calibrated.

Information was obtained from the District on the 34 existing ADMS and FIS models. It is assumed that calibration would be performed on 17 models in 1991 at $15,000 per model, or $260,000. Additional calibration for six future ADMS models would be performed as they are completed. Calibration would be performed within five years, at a cost of $90,000.

Data input and output of the hydrologic modeling component would be archived by the District as part of the system operation for Alternative 2. It is assumed that data would be archived using the Corps' data storage program, DSS. As stated previously, the DSS program would be used in the PC environment to store input and output hydrographs. Storage of ALERT precipitation and streamflow data would continue to be performed through the operations of the Enhanced ALERT software.

Upgraded Radar Data. The District currently receives NWS radar through Kavouras. As mentioned previously, there are several constraints of the existing product. First, the presence of ground clutter makes interpretation of data difficult. Second, physical features within the County (i.e., mountains) cause shadowing of the radar picture and results in noncoverage of radar in some key areas. Finally, the data are transmitted from the NWS through Kavouras without enhancements or features offered by other vendors.

To mitigate the constraints of the existing radar data, it is assumed that NOWrad, a composite radar offered by WSI, would replace the existing radar product. NOWrad has the advantages of removal of ground clutter, radar input from more than one site in the event that one radar site is down, and can provide coverage of the entire County. The upgraded system would have as a minimum a receiving unit software and monthly fee based on use. A satellite downlink could be obtained at an additional cost but is not included in this alternative.

System Operations Labor. It is estimated for Alternative 2 that labor requirements would increase to:

Program manager	-	1 @ 50%
Hydrologist	-	4 @ 100%
Computer Operator/Technician	-	1 @ 100%

The increase in system operations labor over existing allocations to the flood warning program would be used to monitor the expanded flood detection network and run the hydrologic modeling programs when a flood threat is indicated, as well as manage the input and output data, maintain the increased computer operations, and provide coordination with participating outside agencies. Further, as previously stated, the additional labor would be used to update existing models as necessary to reflect changes in development and flood control. Work on the updates would be performed when no flood situation is indicated within the County.

An average annual labor cost of $64,000 for the program manager and $45,000 for the remaining staff, equates to approximately $260,000 per year.

Field Maintenance Labor. It is estimated that the increase in gages and related equipment would result in increased labor for maintenance of 20% over that estimated for Alternative 1, for a total of $220,000 per year.

As shown in Table 5-11, annual costs for Alternative 2 are approximately $790,000. Costs are primarily due to development of the hydrologic modeling component and labor to operate and maintain the system.

Alternative 3 Costs

Costs for Alternative 3 would include those identified in Alternative 2, without the hydrologic modeling component. Further, a meteorological component would be included as described in the following paragraphs.

Meteorological Prediction. Meteorological prediction could be implemented in-house with a staff meteorologist or using outside services. In either case, it is assumed that, for cost-estimating purposes, 20 weather stations would be installed to provide additional information on atmospheric conditions. The actual number and placement of stations needed would be determined at the pre-design or design level of developing a flood warning program. It is noted that SRP operates and monitors a number of weather stations in the metropolitan Phoenix area. It may be possible to arrange the sharing of information collected by SRP to augment future District weather stations or eliminate the need for some of them.

In-House Meteorologist. If meteorological prediction were performed in-house by the District, a staff meteorologist would be needed. Because meteorological prediction would not be required year-round, the meteorologist could perform other related tasks such as public education, coordination of efforts with outside agencies, and operational tasks during non-flooding periods. Therefore, the labor cost for a staff meteorologist is shown at 50% in the meteorological component and 50% in the system operation labor.

For in-house meteorological prediction, the District may wish to consider utilizing an outside forecasting service initially to assist in the prediction program set-up. Additional costs for start-up assistance by a forecasting service are not included in the cost estimate for Alternative 3.

Meteorological data received by the District would be upgraded to better assist the meteorologist. Additional meteorological tools may also be useful to the staff meteorologist. However, costs are not included for additional tools because it cannot be determined at present what, if any, would be required by the meteorologist.

Private Forecasting Service. If a private forecasting service were used, the service would be required for approximately six months per year. The service would provide daily basin-specific QPFs with periodic updates. The private forecaster would also provide continuous meteorological support when indicated by potential severe weather.

TABLE 5-11

COST ESTIMATE FOR ALTERNATIVE 2
IMPROVED FLOOD DETECTION AND HYDROLOGIC MODELING

	Description	Quantity	Unit	Life (yr)	Unit Cost(1) ($)	1991 Cost(1) ($)	Annual Cost(2) ($/yr)
2.1	**Equipment Costs**						
2.1.1	Additional Precipitation Gages	24	ea	20	5,000	120,000	12,400
2.1.2	Additional Stage Gages	30	ea	20	5,000	150,000	15,600
2.1.3	Additional Repeaters	2	ea	20	6,000	12,000	1,200
2.1.4	EBB Hardware (computer and 3 modems)	1	ls	20	4,800	4,800	500
2.1.5	EBB Dedicated Phone Lines (3)	1	yr	-	-	-	1,700
2.1.6	FAX/Telephone Hardware and Hookup	1	ls	20	1,800	1,800	200
2.1.7	FAX/Telephone Maintenance and Fee	1	yr	-	-	-	1,600
2.1.8	Telephone Messaging (2 phone lines)	1	yr	-	-	-	1,400
	Subtotal Equipment Costs						34,600
2.2	**Computer Costs**						
2.2.1	Existing Computer Hardware	1	ls	5	16,000	16,000	4,000
2.2.2	Enhanced ALERT and Interface Software (HEC-1)	1	ls	5	4,750	4,750	1,200
2.2.3	DSS Software	1	ea	5	200	200	50
	Subtotal Computer Costs						5,300
2.3	**Hydrologic Modeling**						
2.3.1	Update/Convert/Incorporate Existing Models	1	ls	-	600,000	600,000	68,000
2.3.2	Convert/Incorporate Future Models (Year 5)	1	ls	-	300,000	300,000	23,700
2.3.3	Calibrate Existing Models	1	ls	-	260,000	260,000	29,500
2.3.4	Calibrate Future Models (Year 5)	1	ls	-	90,000	90,000	7,100
	Subtotal Hydrologic Modeling Costs						128,300
2.4	**Meteorological Data**						
2.4.1	Upgraded Radar Data						
	- Hardware	1	ls	15	18,000	18,000	2,000
	- Software	1	yr	-	-	-	3,500
	Subtotal Meteorological Costs						5,500
2.5	**System Operation**						
2.5.1	Labor	1	yr	-	-	-	260,000

TABLE 5-11 (continued)

COST ESTIMATE FOR ALTERNATIVE 2
IMPROVED FLOOD DETECTION AND HYDROLOGIC MODELING

	Description	Quantity	Unit	Life (yr)	Unit Cost(1) ($)	1991 Cost(1) ($)	Annual Cost(2) ($/yr)
2.6	**Field Maintenance**						
2.6.1	Labor	1	yr	-	-	-	220,000
	Subtotal Alternative 2						657,000
	Annual Cost Contingencies (20%)						131,000
	Total						**790,000**

(1) Equipment and computer costs are Replacement Cost New
(2) Costs are annualized over 15 years at a discount rate of 7.5%

Note: The accuracy of the estimated costs is +50 percent to -30 percent of actual costs based upon a feasibility level of engineering detail or a "reconnaissance grade (order of magnitude estimate)" as defined by the American Association of Cost Engineers. Representative costs are in 1991 dollars and were based on data collected from the District, on JMM's experience with similar projects, and from vendors of flood detection equipment and related components. Data were also collected from discussions with operators of similar facilities.

Costs for private forecasting services were found to vary widely, from approximately $1,000/month to $10,000/month. It appears that the variation in cost is due to the wide range of services provided. For this alternative, it is estimated that the type of meteorological support suitable for the District's needs would cost approximately $5,000/month.

As shown in Table 5-12, it is estimated that costs for an in-house meteorologist for 50% of the year, with additional hardware and software, are higher than that of an outside service. In calculating total program costs for Alternative 3, the costs for the more expensive option was used to represent the high end of the cost range.

System Operations Labor. It is estimated that the system operations labor requirements for Alternative 3 would be slightly higher than that for Alternative 1:

Program manager	-	1 @ 50%
Hydrologist	-	2 @ 100%
Meteorologist	-	1 @ 50%
Computer Operator/Technician	-	1 @ 75%

From previously defined average labor costs, $180,000 would be allocated to system operations labor. Again, 50% of the labor allocated for an in-house meteorologist is listed separately under the meteorological component.

Field Maintenance Labor. It is estimated that, due to the addition of 20 weather stations for Alternative 3, the required field maintenance would increase by 10% of that estimated in Alternative 2. Therefore, the total estimated field maintenance, including that for the expanded ALERT gage network, is $240,000 per year.

As shown in Table 5-12, annual costs to implement Alternative 3 are estimated to be approximately $620,000. The primary costs are attributable to labor to operate and maintain the system. Other significant costs include that for additional equipment and to provide meteorological prediction.

Alternative 4 Costs

The costs identified for Alternative 4 are a combination of those presented in Alternatives 2 and 3. System operations and maintenance labor are discussed below.

System Operations Labor. It was estimated that system operations labor requirements would increase to:

Program manager	-	1 @ 75%
Hydrologist	-	4 @ 100%
Meteorologist	-	1 @ 50%
Computer Operator/Technician	-	2 @ 75%

At previously defined average annual labor costs, this equates to $320,000 per year, including labor of $23,000 required for a staff meteorologist for one-half of a year. The increase in system operations labor would be for monitoring the expanded flood detection network and providing coordination with participating outside agencies.

Field Maintenance Labor. Field maintenance labor would be the same as that for Alternative 3, or $240,000 per year.

As shown in Table 5-13, it is estimated that $950,000 per year would be required to implement Alternative 4.

TABLE 5-12

COST ESTIMATE FOR ALTERNATIVE 3
IMPROVED FLOOD DETECTION AND METEOROLOGICAL PREDICTION

	Description	Quantity	Unit	Life (yr)	Unit Cost[1] ($)	1991 Cost[1] ($)	Annual Cost[2] ($/yr)
3.1	**Equipment Costs**						
3.1.1	Additional Precipitation Gages	24	ea	20	5,000	120,000	12,400
3.1.2	Additional Stage Gages	30	ea	20	5,000	150,000	15,600
3.1.3	Additional Repeaters	2	ea	20	6,000	12,000	1,200
3.1.4	Additional Weather Stations	20	ea	20	8,000	160,000	16,600
3.1.5	EBB Hardware (computer and 3 modems)	1	ls	20	4,800	4,800	500
3.1.6	EBB Dedicated Phone Lines (3)	1	yr	-	-	-	1,700
3.1.7	FAX/Telephone Hardware and Hookup	1	ls	20	1,800	1,800	200
3.1.8	FAX/Telephone Maintenance and Fee	1	yr	-	-	-	1,600
3.1.9	Telephone Messaging (2 phone lines)	1	yr	-	-	-	1,400
	Subtotal Equipment Costs						51,200
3.2	**Computer Costs**						
3.2.1	Existing Computer Hardware	1	ls	5	16,000	16,000	4,000
3.2.2	Enhanced ALERT Software	1	ls	5	3,500	3,500	900
	Subtotal Computer Costs						4,900
3.3	**Meteorological Data**						
3.3.1	Private Forecasting Service (A)	0.5	yr	-	-	-	30,000 (A)
	or						
3.3.2	In-House Forecasting (B)						
3.3.2a	Staff Meteorologist	0.5	yr	-	-	-	23,000
3.3.2b	Upgraded Vendor Products						
	- Hardware	1	ls	15	40,000	40,000	4,500
	- Software	1	yr	-	-	-	16,000
	Subtotal Meteorological Costs						43,500 (B)
3.4	**System Operation**						
3.4.1	Labor	1	yr	-	-	-	180,000

TABLE 5-12 (continued)

COST ESTIMATE FOR ALTERNATIVE 3
IMPROVED FLOOD DETECTION AND METEOROLOGICAL PREDICTION

	Description	Quantity	Unit	Life (yr)	Unit Cost(1) ($)	1991 Cost(1) ($)	Annual Cost(2) ($/yr)
3.5	**Field Maintenance**						
3.5.1	Labor	1	yr	-	-	-	240,000
	Subtotal Alternative 3						520,000
	Annual Cost Contingencies (20%)						104,000
	Total						**620,000**

(1) Equipment and computer costs are Replacement Cost New
(2) Costs are annualized over 15 years at a discount rate of 7.5%

Note: The accuracy of the estimated costs is +50 percent to -30 percent of actual costs based upon a feasibility level of engineering detail or a "reconnaissance grade (order of magnitude estimate)" as defined by the American Association of Cost Engineers. Representative costs are in 1991 dollars and were based on data collected from the District, on JMM's experience with similar projects, and from vendors of flood detection equipment and related components. Data were also collected from discussions with operators of similar facilities.

TABLE 5-13

COST ESTIMATE FOR ALTERNATIVE 4
IMPROVED FLOOD DETECTION, HYDROLOGIC MODELING,
AND METEOROLOGICAL PREDICTION

	Description	Quantity	Unit	Life (yr)	Unit Cost(1) ($)	1991 Cost(1) ($)	Annual Cost(2) ($/yr)	
4.1	**Equipment Costs**							
4.1.1	Additional Precipitation Gages	24	ea	20	5,000	120,000	12,400	
4.1.2	Additional Stage Gages	30	ea	20	5,000	150,000	15,600	
4.1.3	Additional Repeaters	2	ea	20	6,000	12,000	1,200	
4.1.4	Additional Weather Stations	20	ea	20	8,000	160,000	16,600	
4.1.5	EBB Hardware (computer and 3 modems)	1	ls	20	4,800	4,800	500	
4.1.6	EBB Dedicated Phone Lines (3)	1	yr	-	-	-	1,700	
4.1.7	FAX/Telephone Hardware and Hookup	1	ls	20	1,800	1,800	200	
4.1.8	FAX/Telephone Maintenance and Fee	1	yr	-	-	-	1,600	
4.1.9	Telephone Messaging (2 phone lines)	1	yr	-	-	-	1,400	
	Subtotal Equipment Costs						51,200	
4.2	**Computer Costs**							
4.2.1	Existing Computer Hardware	1	ls	5	16,000	16,000	4,000	
4.2.2	Enhanced ALERT and Interface Software (HEC-1)	1	ls	5	4,750	4,750	1,200	
4.2.3	DSS Software	1	ea	5	200	200	50	
	Subtotal Computer Costs						5,300	
4.3	**Hydrologic Modeling**							
4.3.1	Update/Convert/Incorporate Existing Models	1	ls	-	600,000	600,000	68,000	
4.3.2	Convert/Incorporate Future Models (Year 5)	1	ls	-	300,000	300,000	23,700	
4.3.3	Calibrate Existing Models	1	ls	-	260,000	260,000	29,500	
4.3.4	Calibrate Future Models (Year 5)	1	ls	-	90,000	90,000	7,100	
	Subtotal Hydrologic Modeling Costs						128,300	
4.4	**Meteorological Data**							
4.4.1	Private Forecasting Service (A)	0.5	yr	-	-	-	30,000	(A)
	or							
4.4.2	In-House Forecasting (B)							
4.4.2a	Staff Meteorologist	0.5	yr	-	-	-	23,000	
4.4.2b	Upgraded Vendor Products							
	- Hardware	1	ls	15	40,000	40,000	4,500	
	- Software	1	yr	-	-	-	16,000	
	Subtotal Meteorological Costs (B)						43,500	(B)

TABLE 5-13 (continued)

COST ESTIMATE FOR ALTERNATIVE 4
IMPROVED FLOOD DETECTION, HYDROLOGIC MODELING, AND METEOROLOGICAL PREDICTION

	Description	Quantity	Unit	Life (yr)	Unit Cost(1) ($)	1991 Cost(1) ($)	Annual Cost(2) ($/yr)
4.5	**System Operation**						
4.5.1	Labor	1	yr	-	-	-	320,000
4.6	**Field Maintenance**						
4.6.1	Labor	1	yr	-	-	-	240,000
	Subtotal Alternative 4						789,000
	Annual Cost Contingencies (20%)						158,000
	Total						**950,000**

(1) Equipment and computer costs are Replacement Cost New
(2) Costs are annualized over 15 years at a discount rate of 7.5%

Note: The accuracy of the estimated costs is +50 percent to -30 percent of actual costs based upon a feasibility level of engineering detail or a "reconnaissance grade (order of magnitude estimate)" as defined by the American Association of Cost Engineers. Representative costs are in 1991 dollars and were based on data collected from the District, on JMM's experience with similar projects, and from vendors of flood detection equipment and related components. Data were also collected from discussions with operators of similar facilities.

Alternative 5 Costs

Program costs for Alternative 5 would be the same as those shown for Alternative 4, with the addition of GIS-related activities. Costs to implement a GIS component are discussed in the following paragraphs.

Hydraulic Modeling. Output from HEC-1, generated from observed or forecast data, at the specified forecast points would be input to HEC-2 to generate a profile of water surface elevations. Existing HEC-2 models from the District's FIS program would be used to predict water surface elevations at specified forecast points. The HEC-2 output would then be input to GIS to generate inundation maps.

To estimate costs to incorporate HEC-2 modeling into the flood warning program, it is assumed that the existing HEC-2 models would be incorporated at 50% of the annual cost for the HEC-1 modeling component identified in Alternative 2. The models would be updated if necessary to reflect changes in development and flood control. Further, additional cross sections may need to be added at specified forecast points. Therefore, annual hydraulic modeling costs from outside services would be approximately $64,000. Incorporation of future models would be performed in-house by District personnel.

GIS Component. Discussions were held with District personnel regarding the status of the current GIS and the level of effort thought to be required to implement a flood warning application for the GIS program. Additional discussions were also held with JMM GIS specialists. A summary of the requirements for implementation of GIS is presented below:

- Purchase of one workstation, complete with full ARC/INFO package.
- Training for one operator, including expenses.
- Development of custom programs.
- Generation of rainfall contours from precipitation data.
- Development of INGRES database structure to convert from existing Data General System.
- Conversion of existing flood warning record-keeping to tabular database.

Due to the experimental nature of applying GIS to flood warning activities, implementation costs may be significant. It is assumed that, in addition to the District's internal start-up costs, outside services would be used for the first two years to develop the application at $400,000 per year. As previously stated, much of the data required to develop a flood warning application has already been input into the District's GIS. However, it is important to note that initial programming costs to develop data interfaces are usually high. The initial development cost of $400,000 for the first two years is intended primarily for programming rather than data input.

It is recommended that a pilot study be performed prior to full-scale development to identify specific data requirements and develop the required data interfaces. As previously stated, the GIS application should be treated as a developmental project given the state-of-the-art in this field. Costs to develop unknown/unproven applications are ill-defined and may be substantially different from that estimated.

After the GIS application is developed, a GIS consultant would be used as necessary to assist in periodic updates or program changes. It is estimated that outside services at $50,000 per year would be required for this periodic GIS assistance.

System Operations Labor. It is estimated that labor requirements to operate the flood warning components, identified in Alternative 5, include:

Program manager	-	1 @ 75%
Hydrologist	-	4 @ 100%
Meteorologist	-	1 @ 50%
Computer Operator/Technician	-	2 @ 100%
GIS Operator	-	1 @ 100%

At previously defined average annual labor costs, this equates to $390,000 per year. In addition to the flood warning duties in Alternative 4, the systems operations labor would operate the GIS workstation, manage input and output data, and incorporate hydraulic models as they become available through the District's FIS program.

Field Maintenance Labor. Field maintenance labor would remain the same as that for Alternative 4, or $240,000 per year.

As shown in Table 5-14, total annual program costs for Alternative 5 are estimated to be approximately $1,280,000. Primary costs are attributed to hydrologic modeling, incorporation of GIS, and labor to operate and maintain the system.

Flood Preparedness Costs

In addition to the flood warning program costs for each alternative, there are additional costs for flood preparedness. Flood preparedness costs generally include only the variable costs that would be incurred in preparation of a flood. Flood preparedness is defined here as actions taken by agencies upon receipt of and in response to a flood warning. The fixed costs of a flood warning system, such as equipment, operation and maintenance, and labor and administrative costs, are included as part of the flood warning program costs presented previously in this section.

Flood preparedness costs incurred prior to flooding as a result of a flood warning system include:

- Actions taken by the police and fire department, as well as ambulance and rescue units, to warn and evacuate floodplain occupants;

- Actions taken by the Arizona Department of Transportation (ADOT), and local police and fire departments to direct traffic and maintain law and order;

- Flood fighting efforts to reduce damages and increase safety, such as sandbagging and building closures;

- Establishing and organizing emergency shelters.

TABLE 5-14

COST ESTIMATE FOR ALTERNATIVE 5
IMPROVED FLOOD DETECTION, HYDROLOGIC MODELING, METEOROLOGICAL PREDICTION, AND GIS

	Description	Quantity	Unit	Life (yr)	Unit Cost(1) ($)	1991 Cost(1) ($)	Annual Cost(2) ($/yr)
5.1	**Equipment Costs**						
5.1.1	Additional Precipitation Gages	24	ea	20	5,000	120,000	12,400
5.1.2	Additional Stage Gages	30	ea	20	5,000	150,000	15,600
5.1.3	Additional Repeaters	2	ea	20	6,000	12,000	1,200
5.1.4	Additional Weather Stations	20	ea	20	8,000	160,000	16,600
5.1.5	EBB Hardware (computer and 3 modems)	1	ls	20	4,800	4,800	500
5.1.6	EBB Dedicated Phone Lines (3)	1	yr	-	-	-	1,700
5.1.7	FAX/Telephone Hardware and Hookup	1	ls	20	1,800	1,800	200
5.1.8	FAX/Telephone Maintenance and Fee	1	yr	-	-	-	1,600
5.1.9	Telephone Messaging (2 phone lines)	1	yr	-	-	-	1,400
	Subtotal Equipment Costs						51,200
5.2	**Computer Costs**						
5.2.1	Existing Computer Hardware	1	ls	5	16,000	16,000	4,000
5.2.2	Enhanced ALERT and Interface Software (HEC-1)	1	ls	5	4,750	4,750	1,200
5.2.3	DSS Software	1	ea	5	200	200	50
	Subtotal Computer Costs						5,300
5.3	**Hydrologic Modeling**						
5.3.1	Update/Convert/Incorporate Existing Models	1	ls	-	600,000	600,000	68,000
5.3.2	Convert/Incorporate Future Models (Year 5)	1	ls	-	300,000	300,000	23,700
5.3.3	Calibrate Existing Models	1	ls	-	260,000	260,000	29,500
5.3.4	Calibrate Future Models (Year 5)	1	ls	-	90,000	90,000	7,100
	Subtotal Hydrologic Modeling Costs						128,300
5.4	**Meteorological Data**						
5.4.1	Private Forecasting Service (A)	0.5	yr	-	-	-	30,000 (A)
	or						
5.4.2	In-House Forecasting (B)						
5.4.2a	Staff Meteorologist	0.5	yr	-	-	-	23,000
5.4.2b	Upgraded Vendor Products						
	- Hardware	1	ls	15	40,000	40,000	4,500
	- Software	1	yr	-	-	-	16,000
	Subtotal Meteorological Costs (B)						43,500 (B)

TABLE 5-14 (continued)

COST ESTIMATE FOR ALTERNATIVE 5
IMPROVED FLOOD DETECTION, HYDROLOGIC MODELING, METEOROLOGICAL PREDICTION, AND GIS

	Description	Quantity	Unit	Life (yr)	Unit Cost(1) ($)	1991 Cost(1) ($)	Annual Cost(2) ($/yr)
5.5	**GIS**						
5.5.1	GIS Workstation with ARC/INFO	1	ls	15	25,000	25,000	2,800
5.5.2	Develop GIS Application						
	- Year 1 ($400,000/yr)	1	yr	1	-	-	45,300
	- Year 2 ($400,000/yr)	1	yr	1	-	-	42,200
5.5.3	GIS Outside Services	1	yr	-	-	-	50,000
5.5.4	Hydraulic Modeling	1	yr	-	-	-	64,000
	Subtotal GIS Costs						204,300
5.6	**System Operation**						
5.6.1	Labor	1	yr	-	-	-	390,000
5.7	**Field Maintenance**						
5.7.1	Labor	1	yr	-	-	-	240,000
	Subtotal Alternative 5						1,063,000
	Annual Cost Contingencies (20%)						213,000
	Total						**1,280,000**

(1) Equipment and computer costs are Replacement Cost New
(2) Costs are annualized over 15 years at a discount rate of 7.5%

Note: The accuracy of the estimated costs is +50 percent to -30 percent of actual costs based upon a feasibility level of engineering detail or a "reconnaissance grade (order of magnitude estimate)" as defined by the American Association of Cost Engineers. Representative costs are in 1991 dollars and were based on data collected from the District, on JMM's experience with similar projects, and from vendors of flood detection equipment and related components. Data were also collected from discussions with operators of similar facilities.

ESTIMATION OF ECONOMIC FEASIBILITY

Previously in this section, directly quantifiable benefits of a flood warning system attributable to reduction in flood damage were estimated to be between $500,000 and $2,600,000 for lead times of 30 minutes and two hours, respectively. Although none of the alternatives can guarantee a specific lead time, it is felt that Alternative 2 would represent the low end of the range with relatively short lead time.

Alternative 3, which contains a meteorological prediction element, could be expected to provide lead times substantially greater than 30 minutes. However, it is unlikely that the decision to issue a flood warning would be made solely on meteorological predictions. Rather, the decision to issue a flood warning is likely to be delayed until supporting data are received. Therefore, the average expected lead time for Alternative 3 is selected to be 45 minutes. Assuming a straight line relationship of reduced flood damages as a function of lead time, Alternative 3 would realize an annual benefit of approximately $800,000 for reduced flood damages.

Expected lead time for Alternative 4 would increase with the combination of meteorological and hydrologic input. It is estimated that the higher level of confidence in data on potential flooding would result in an average lead time of 1.5 hours. Again, assuming a straight line relationship, the reduced flood damage benefits derived from Alternative 4 would be approximately $1,900,000.

Finally, with the implementation of GIS in Alternative 5 to enhance meteorological and hydrologic data, an average of 2 hours lead time could be expected. Annual benefits from reduced flood damages would be approximately $2,600,000.

Based on the estimate of direct benefits and costs presented previously, economic ranking factors for each alternative are calculated as follows:

Alternative	Reduced Flood Damage Benefits ($/yr)	Costs ($/yr)	Economic Ranking Factor
1	0	340,000	0
2	500,000	790,000	0.6
3	800,000	620,000	1.3
4	1,900,000	950,000	2.0
5	2,600,000	1,280,000	2.0

The economic ranking factors are calculated by dividing the reduced flood damage benefits by the corresponding costs.

It is emphasized that the benefits and costs shown above represent only the quantifiable components as described previously in this section. Further, it is not recommended that the economic ranking factors be used as the sole criterion for selection of a flood warning system. Other factors which should be considered are described in Section 6 of this report.

Section 6

SECTION 6

EVALUATION OF ALTERNATIVES

INTRODUCTION

In order to rank the five flood warning program alternatives, an evaluation matrix was developed which includes the major nonquantifiable benefits not addressed in the economic analysis as well as the quantifiable economic benefits described in Section 5. The matrix provides a numerical ranking for the five alternatives based on the following evaluation criteria:

- Lead Time
- Accuracy
- Specificity
- Economic Ranking
- Ease of Development

Each of these evaluation criteria are discussed in this section of the report.

RANKING CRITERIA

Each criterion used to evaluate the alternatives is associated with a ranking scale as presented in Table 6-1.

TABLE 6-1

RANKING CRITERIA FOR EVALUATION OF ALTERNATIVES

Ranking Criteria	Ranking Scale
Long Lead Time	1 to 30
High Accuracy	1 to 20
High Specificity	1 to 20
High Economic Ranking Factor	1 to 15
Ease of Development	1 to 10

The ranking scale for each criterion represents the selected relative importance of the criterion for evaluation of alternatives. Therefore, the more critical factors were given a higher weighting capacity than the lesser factors.

A discussion of the evaluation criteria and their ranking scales is presented below.

Lead Time Factor

Lead time is considered the most important factor in evaluating alternatives because it determines the time available for preparation for a flooding event and was therefore assigned the greatest ranking scale of 1 to 30. Lead time is related to the direct benefits of a flood warning system resulting from reduced contents damage. It is also directly related to other important non-quantifiable benefits such as increased safety, reduced rescue efforts, and indirect benefits. It is inversely related to flood preparedness costs. Each of these factors was considered in ranking the benefit of long lead time. The individual factors are described in the following paragraphs.

Increased Safety. Increased safety resulting from improved flood warning services includes reduced loss of life and reduced injuries. As discussed earlier, studies of past flooding events have shown that the factors most directly influencing threat to human lives are the lead time, size of the population at risk, and severity of the flooding event. Of these, lead time is the only factor which can be controlled by a flood warning system. Further, as previously discussed, flood warning programs have been developed as a result of safety considerations alone.

Reduced Rescue Efforts. Reduced rescue efforts result from individuals taking the appropriate actions in a flooding event when given advanced warning. Consequently, reduced rescue efforts are related to the amount of lead time provided by a flood warning. A system providing the greatest lead time would have the highest reduced rescue efforts ranking.

Indirect Benefits. Indirect benefits resulting from improved flood warning services include reduced travel delays and nonrecoverable business losses. As with increased safety and reduced rescue efforts, indirect benefits are proportional to the lead time provided by a flood warning system. Systems providing the greatest lead time would have the highest indirect benefits.

Low Flood Preparedness Costs. Flood preparedness costs include actions taken to warn and evacuate floodplain residents, to direct traffic and maintain law and order, to carry out flood fighting efforts in order to reduce damages and increase safety, and to establish and organize emergency shelters. With increased lead time, there is additional time for flood preparedness activities. Therefore, alternatives with greater lead time would typically result in higher flood preparedness costs. However, warnings that are more site-specific and more accurate would result in more efficient flood preparedness activities. Flood preparedness costs are not considered to be a priority evaluation criterion.

It is noted that, in the absence of a flood warning system, flood preparedness costs would be replaced by higher flood fighting costs and rescue efforts.

Accuracy Factor

Accuracy of a flood warning system is measured by the relationship between warned flooding events, unwarned events, and false alarms. A highly accurate system would have a greater number of warned events compared to the number of unwarned events and false alarms. Alternatives which base warnings on observed rainfall and runoff data tend to be more accurate than those based on weather forecasting.

The ranking scale of the accuracy evaluation criterion ranges from 1 to 20, where 1 represents a less accurate flood warning system and 20 represents a highly accurate system. Although lower than that for lead time, the ranking scale for accuracy is relatively high because it directly affects the credibility of a flood warning, which affects the rate of response to a flood warning.

Specificity Factor

Specificity of a flood warning system indicates the ability to identify a specific area of coverage in which flooding is likely to occur. A highly specific system would provide warnings covering small areas.

As with accuracy, the ranking scale of the specificity criterion ranges from 1 to 20, where 1 represents a less specific flood warning system covering broad, general areas, and 20 represents a highly specific system. The ranking scale for specificity was made equal to that for accuracy because it similarly affects the rate of response to a flood warning.

Economic Ranking Factor

The economic ranking factor represents the ratio of reduced flood damage due to implementation of a flood warning system to the flood warning program costs incurred by the District. In the evaluation matrix, a lower ranking scale of 1 to 15 is chosen because the economic ranking factors do not present a comprehensive representation of benefits and costs.

Ease of Development Factor

Ease of development represents the effort required to set up a flood warning program. A system with minimal changes or changes that are easy to implement would rate a high ease of development ranking. Ease of development was assigned the lowest ranking scale of 1 to 10 because it is considered to be a less important consideration with respect to the other factors.

RANKING OF ALTERNATIVES

The individual and cumulative rankings of each alternative are presented in Table 6-2. A discussion follows which describes the process of selecting individual ranking for each alternative.

Lead Time Rank

As previously stated, lead time is directly related to increased safety, as well as reduced rescue efforts, travel delays, and nonrecoverable business losses. Of lesser importance, it is inversely proportional to flood preparedness costs. Alternative 1 is assigned a lead time ranking of 1 (out of a possible 30) because warnings would not typically be issued, so lead time would not be relevant. Alternative 5 is assigned the highest ranking of 30 because it could be expected to provide a 2-hour lead time. Alternatives 2 through 4 are assigned proportional rankings based on the 30-minute and 1.5-hour expected lead times as established in Section 5.

Accuracy Rank

An accuracy rating of 1 (out of a possible 20) is assigned to Alternative 1. Alternative 1 is not associated with accuracy of warnings because warnings would not be routinely issued.

Alternative 2 would typically provide high accuracy on expected flooding conditions due to the expansion of the ALERT gage network and the inclusion of hydrologic modeling which would estimate runoff from observed rainfall at forecast points within hydrologic basins. Therefore, a rank of 15 is assigned to Alternative 2.

Compared to Alternative 2, Alternative 3 would generally be less accurate because it is based on meteorological forecasting rather than observed rainfall. QPFs are primarily based on satellite data, radar data, and observed meteorological patterns, and are typically issued before precipitation has occurred. Therefore, a lesser ranking of 8 is chosen for Alternative 3.

TABLE 6-2

EVALUATION MATRIX
FLOOD WARNING SYSTEM ALTERNATIVES

Alternatives	NUMERICAL RANKING					
	Long Lead Time (1 to 30)	High Accuracy (1 to 20)	High Specificity (1 to 20)	High Economic Ranking Factor (1 to 15)	Ease of Development (1 to 10)	TOTAL RANKING (Max of 95)
Alternative 1 Status Quo	1	1	1	1	10	14
Alternative 2 Flood Warning with Improved Flood Detection and Hydrologic Modeling	8	15	12	4	5	44
Alternative 3 Flood Warning with Improved Flood Detection and Meteorological Prediction	12	8	8	9	8	45
Alternative 4 Flood Warning with Improved Flood Detection, Hydrologic Modeling, and Meteorological Prediction	23	17	16	15	3	74
Alternative 5 Flood Warning with Improved Flood Detection, Hydrologic Modeling, Meteorological Prediction, and GIS	30	20	20	15	1	86

Alternative 4 includes the combined elements of an expanded flood detection network, hydrologic modeling, and meteorological prediction. Therefore, accuracy of the warnings is ranked 17, which is slightly better than that for Alternative 2.

Alternative 5 would typically be the most accurate because the addition of GIS would enable more precise development of flooding limits. It was assigned the highest rank of 20.

Specificity Rank

Alternative 1 is assigned a specificity rank of 1 (out of a possible 20) because warnings would not typically be issued, so specificity of warnings would not be relevant.

Alternative 2 would typically provide warnings with good specificity due to the expansion of the flood detection network and the basin-specific forecasts estimated from the hydrologic models. Therefore, a rank of 12 is assigned. The flood warnings issued in Alternative 3 would be less site-specific because it would be based on basin-wide precipitation forecasts, so it ranks lower at 8.

Alternative 4 would further improve the ability to provide site-specific warnings. In this scenario, QPFs would be input into the hydrologic models for specified basins and would provide improved identification of the flooding area of coverage. A relatively high rank of 16 is assigned to Alternative 4. Alternative 5 would typically be the most site-specific flood warning system because the addition of GIS would allow incorporation of runoff modeling to generate inundation maps. Therefore, it receives the highest rank of 20.

Economic Rank

Alternative 1 is assigned the lowest rank of 1 (out of a possible 15) because reduced contents damage benefits would not be realized as warnings are not issued. Therefore, the economic ranking factor is 0. Alternatives 4 and 5 are assigned the highest rank of 15 because they have the highest economic ranking factor. The rank of the remaining alternatives are proportional to their economic ranking factors as compared to Alternatives 1 and 5.

Ease of Development Rank

Alternative 1 rates the highest at 10 (out of a possible 10) since there would be no substantial modifications to the District's current operations.

Alternative 2 would be somewhat complicated to develop since incorporation of existing hydrologic models would be required and the models would have to be interfaced with real-time precipitation and runoff data. It is, therefore, assigned a rank of 5. Alternative 3 would be comparatively simpler to develop since it involves only expansion of the data collection network and the addition of a staff meteorologist or a forecasting consultant to produce QPFs. A rank of 8 is assigned to Alternative 3.

Alternative 4 would be slightly more difficult to develop than Alternative 2 because it involves incorporation of weather forecasting with hydrologic modeling efforts. It is assigned a low value of 3. Lastly, Alternative 5 would be considerably more difficult to implement since it includes all the development steps involved in Alternative 4, as well as interfacing GIS with runoff modeling. It receives the lowest rank of 1.

Overall Rank

As shown in Table 6-2, the overall ranking of Alternative 5 is highest at 86 out of a possible 95. The remaining alternatives 4, 3, 2, and 1 are ranked 74, 45, 44, and 14, respectively. This ranking system includes the criteria deemed to be most important for evaluating the alternative flood warning systems developed in this study. Based on the economic evaluation, Alternatives 2 through 5, are considered viable with the addition of non-quantifiable economic benefits. Notwithstanding the economic analysis, as mentioned earlier in this report, justification for implementation of a flood warning system has been made in the past solely on non-economic considerations.

Section 7

SECTION 7

IMPLEMENTATION CONSIDERATIONS

INTRODUCTION

JMM contacted numerous agencies with operations based in Maricopa County to fulfill two objectives. The first objective is to investigate related efforts and identify areas where data collected through a flood warning program may be shared. The second objective is to identify areas where alternative uses of flood warning equipment could be developed to maximize benefits of the program. The results of these investigations are summarized in this section.

AGENCY COORDINATION OF FLOOD WARNING EFFORTS

In an effort to enable coordination of flood warning activities, JMM contacted agencies who currently participate in flood warning activities or would be most likely to benefit and/or aid in disseminating flood warning information. Agencies which expressed interest in sharing data or coordinating flood warning efforts are listed below. Efforts which are currently being performed are noted with an asterisk (*).

- National Weather Service
  - -* collaborate on networking of data among counties
  - \- hydrologic modeling by the District
  - -* SWAMP data collected by NWS during the summer 1990

- Civil Defense
  - -* Emergency Information System could include flood warning data to be shared by Civil Defense and the District

- U.S. Geological Survey
  - -* USGS could provide access to its data within and outside of Maricopa County

- Arizona Department of Water Resources
  - \- data collection and archiving efforts
  - \- exchange of expertise on flood analyses

- Arizona Department of Transportation
  - \- use of freeway information signs to include flood warnings

- Arizona Division of Emergency Services
  - \- update Emergency Response and Preparedness Plans for Maricopa County to include flood warning improvements
  - \- coordinate training of state, county and city emergency management personnel

- Central Arizona Water Conservation District
  - -* exchange flood warning data collection equipment and maintenance
  - \- share data on soil moisture content

- Salt River Project
  - \- collaborate on converting flood warning data to a common format
  - -* exchange flood warning data

ALTERNATIVE USES OF A FLOOD WARNING SYSTEM

Because of the semi-arid environment of Maricopa County, the use of a system for flood warning system may be relatively infrequent. The development of alternative uses for the data obtained could potentially help reduce some of the system operating costs and could also serve to enhance the type of data collected. Alternative uses specific to Maricopa County are discussed below.

Potential Alternative Uses in Maricopa County

To evaluate potential alternative uses of the flood warning system, operators of other local flood warning systems were contacted by telephone. Various alternative uses and associated data collection requirements were obtained. Using the information obtained from existing flood warning operators, public and private agencies within Maricopa County were contacted to determine potential alternative uses for a local flood warning system. In developing the alternative uses, both existing services provided by the District and new services which would be developed as a result of a flood warning program were considered. The results of this investigation are summarized below.

The general categories of alternative uses include the following:

- Enhance data collection/dissemination to support local hydrologic science;
- Water conservation through the calculation of evapotranspiration rates;
- Enhance assistance for NPDES stormwater permit compliance monitoring;
- Enhance public information through telephone messaging, electronic bulletin boards, and/or map production;
- Enhance fire prevention assistance; and
- Water production assistance.

Each of these alternative uses are evaluated in the following subsections.

Data Collection. The orderly recording of weather and hydrologic data is fundamental to the ongoing development of hydrologic analyses, floodplain management, and stormwater management. Uses of data include a wide range of activity including the on-going evaluation of hydrologic methods. Since some of these methods may be included in the operation of a flood warning system, it is in the District's interest to maintain a historical database which can be used to routinely evaluate the performance of the system. Further, every hydrologic method has empirical parameters which must be calibrated from measured events. In Arizona, the existing database for calibration of hydrologic methods is relatively small.

In recent years, because of the advent of new technology for logging and communicating hydrologic/meteorological data, a number of specialized monitoring networks have been introduced in Arizona. These networks overlap parts of Maricopa County and could be used to develop a more complete hydrologic and meteorological database.

A cooperative effort among all providers of hydrologic and meteorological data to create a long-term database could benefit each participating agency and then create other users. Benefits could include:

- Elimination of overlapping sites and cooperative efforts on the use of common sites.

- Shared methods for data collection to facilitate the maintenance of existing systems and permit data produced by one system to be understood and used by another system.

- Development of a common format for exchanging data to permit the creation of a computer database and utilities for data storage and retrieval.

- Quality control checks to compare data and screen for errors and missing values.

- Download of data from the database to users at a cost sufficient to administer and maintain the database.

At this time, no state, county, or local agency maintains a comprehensive database of hydrologic and meteorological data based on the existing set of data collection networks in Arizona. The State Climatologist at Arizona State University maintains a limited database of stations in Arizona. The State Climatologist also participates in the PRISMS weather station program for SRP, but the PRISMS data have not been made part of the database.

At the state level, hydrologic and meteorological data collection efforts are presently conducted by a number of federal, state, county, and local agencies, as well as utility companies and universities. While a comprehensive database for Maricopa County would be useful, a statewide database would meet the needs of many more users and would probably have a better chance of funding its ongoing requirements.

The demand for a comprehensive hydrologic and meteorological database for Arizona appears to be significant. Discussions with the staff of the State Climatologist indicate that frequent requests are received for weather data from industry, primarily for permitting documentation for an air quality baseline. A similar market may also exist for water quantity and quality data. Beyond the industrial market, this type of data is often used by universities and research centers, as well as the agencies that gather the data.

Third-party vendors can provide software for the use of hydrologic and meteorological data in optical disk and floppy disk formats. Currently, USGS and NWS data are being distributed by a third-party vendor, EarthInfo Inc., which has developed a number of utility programs for analysis of these data sets. The value-added features of the EarthInfo products make it feasible to formulate a comprehensive database, based on a common data format, without writing extensive data storage and retrieval utilities.

Water Conservation. Using data obtained from weather stations, evapotranspiration rates can be determined for given areas to assist in water conservation efforts. Measurements of air and soil temperature, relative humidity, solar energy, and wind speed and direction have been used to calculate evapotranspiration rates. Knowing the rainfall amount from the preceding 24-hour period from individual rain gages and the evapotranspiration rates for various types of crops and turf, irrigation requirements have then been determined. For large municipal water users or for agricultural users, this type of service has helped optimize water use and ultimately has provided a cost savings to the end user. The evapotranspiration rate information could also be made available to the general public through maps produced by third party vendors for publication in local newspapers or for broadcast on local television stations.

Consumptive use of surface and ground water supplies in Maricopa County for irrigation of agricultural land and urban landscapes represents a major demand on the water supply. In much of the metropolitan Phoenix area, the local parks and recreation departments are the largest municipal water users due to irrigation of parks and golf courses. Optimizing water application would not only reduce costs but would also conserve water for future drinking water supplies. Similarly, as water costs have increased, large farming operations in Maricopa County have begun to use more sophisticated irrigation systems to reduce water waste and allow more crops to be grown for the amount of money expended. Therefore, the use of weather station information to calculate evapotranspiration rates appears to be a potentially significant alternative use for the flood warning system in Maricopa County.

In the City of Chandler, a computerized irrigation system is used to provide real-time control of irrigation operations. The watering schedule is based on an estimated evapotranspiration rate for the turf. Although the system has saved an estimated 17 million gallons in the first six months of operation, it is believed that the watering schedule could be improved if precipitation values were known for each zone of the irrigation system. The City of Chandler Parks Department is considering the addition of weather stations to improve the evapotranspiration estimate and to measure precipitation.

In the City of Phoenix, the Parks and Recreation Department uses a computer controlled system for its golf courses, based on evapotranspiration rates. The evapotranspiration rates are calculated from a weather station located on the golf course at Encanto Park, which is part of the University of Arizona's Az-Met project. Irrigation of parks is much less sophisticated, as no central control of the individual park irrigation systems exists and the systems are not setup to utilize consumptive use data.

The City of Phoenix Parks and Recreation Department would like to divide its parks into irrigation districts, each controlled by its own base station using local precipitation measurements and evapotranspiration estimates to optimize the watering system. The City would experience its most significant benefits during the high water use months of May through September. It was noted that water is used sparingly during the winter months as very few of the parks and only the tee boxes and greens of the golf courses are overseeded with winter grass.

One way for the District to incorporate the evapotranspiration rate function into its flood warning system may be through a cooperative effort with the Az-Met program. The Az-Met system is presently composed of 19 Campbell Scientific weather stations running an evapotranspiration calculation program prepared by Aqua Engineering. The State of Arizona has funded the installation of the gages, and the information is gathered by the faculty at the University of Arizona. The weather stations are located primarily in agricultural areas, with 7 stations located in Maricopa County. The system has been in operation since 1988, and information is disseminated to subscribers through an electronic bulletin board. Due to funding limitations, the Az-Met program currently has more demand than it can support. As a result, the District could propose assuming the operation of the system in Maricopa County, while maintaining the technical support of the university faculty. This type of arrangement would provide weather station information to the flood warning system, coupled with an established alternative use network.

NPDES Stormwater Permit Compliance Monitoring. As a result of federal legislation enacted on November 16, 1990, stormwater discharges from industrial activity and discharges from municipal separate storm sewer systems must meet discharge requirements outlined in individual National Pollutant Discharge Elimination System (NPDES) permits. The NPDES stormwater permit program will require monitoring and sampling of drainage systems for selected pollutants and heavy metals. Although none of the flood warning systems surveyed were presently being used for stormwater permit compliance activities, this option was being considered.

Cost of water quality monitoring stations are high, as are the costs of field visits to each station for wet weather data collection. A telemetered station can be a cost effective method of data collection, particularly in Maricopa County where periods of major runoff are infrequent and can be widely scattered.

For water quality monitoring, chemical analysis is performed in a laboratory using samples obtained either from a manual grab sample or by an automated sampler. The use of a telemetry system would serve to alert water quality data collection personnel that a runoff event was in progress. If manual sampling were used, then the data collection personnel could mobilize in time to sample more locations before the runoff subsided. If automated sampling were used, then the data collection personnel could be alerted to retrieve the sample before it deteriorated.

It is noted that the District is currently considering assuming the responsibility of sample collection for the municipalities in the Phoenix metropolitan area. The City of Phoenix has coordinated its purchase of automatic sampling equipment to ensure that the samplers will work with the District's telemetry network. Thus, development of this alternative use appears to be currently underway.

Public Information. Useful public information on hydrologic and meteorological conditions are presently available in Maricopa County. NWS weather data are disseminated via radio and television news reports and weather radio. Additionally, SRP reports on streamflow and reservoir levels within its jurisdiction via a telephone recording. Information on the District's flood warning system could be prepared for dissemination to the general public on a similar basis. The primary benefit of public information would be to create a greater understanding by the general public of climatic conditions and flood risk in Maricopa County.

More sophisticated public information products could be developed using the District's GIS software. Maps of streamflow and weather conditions could be developed and then made available for use by the television and print media as part of a news report. The maps could present county-wide information, such as the spatial distribution of cumulative rainfall.

Maps of hydrologic and meteorological conditions could also be used by universities to study the environment of Maricopa County and to better understand the severe weather and flooding conditions that can occur. This effort could be conducted with the assistance of a hydrologist from the District in cooperation with school districts and universities throughout the County.

Fire Prevention. Weather data such as temperature, dew point, and wind speed and direction have been used to assist fire fighting operations. Monitoring wind speed and direction has been especially critical in tracking toxic plumes released from fires or hazardous material spills.

Within the Phoenix metropolitan area, the potential for use of the flood warning system by local fire departments is not significant. The City of Phoenix Fire Department currently has its own base station which accesses the PRISMS weather stations. The information received meets current requirements for both fire fighting and hazardous material responses. Other communities, such as Mesa, utilize wind speed and direction information received from local airports (i.e., Falcon Field in Mesa) together with data obtained onsite from portable weather sensors located on response vehicles. The data obtained from the airport, coupled with the onsite data, are sufficient to meet Mesa's needs.

A flood warning system could possibly aid in assessing fire danger or fire potential in outlying areas of Maricopa County. The Rural Metro Corporation provides contract fire fighting services to some of the communities within the county, and is also under contract to provide fire fighting assistance to the U.S. Forest Service and the Bureau of Land Management. Its service area in Arizona covers approximately 25 percent of the state. Currently, it does not receive information relative to fire potential. Data such as humidity, barometric pressure, wind speed and wind direction, and temperature would be beneficial.

No estimate of the number of gages or monitoring locations required by Rural Metro can be established at this time. Further development of this alternative use would require determining the boundaries of the Rural Metro service area in Maricopa County and then evaluating potential instrument locations. If the needs of Rural Metro and the District are compatible, a cost sharing arrangement could then be established for equipment purchase and annual operation and maintenance costs.

Water Production. Several contacts were made with water utility/production departments in the Phoenix metropolitan area to investigate using the flood warning system as an aid in water production activities. Data which could be provided by a flood warning system were not considered critical or essential for operation of the water production facilities. In general, communities with surface water treatment plants assess the amount of water available in storage throughout their systems, together with the production capabilities of each plant and water availability from other sources such as ground water. An estimate of the next day's demand is made in part from the weather forecast and operational experience to determine what the water production amounts will be. It was noted that a direct correlation between rainfall and water consumption would be difficult to obtain, since a prediction of rain within a 2 to 3 day period can sometimes result in a drop in water demand, as people delay watering lawns, washing cars, etc. Thus, the water demand for a set of weather conditions on a given day could vary based on what the predicted weather might be.

Use of the flood warning system to provide advanced warning of high sediment/turbidity episodes in the SRP Canal system was also discussed. When turbidity levels in the canals rise due to stormwater runoff, the treatment plant operators work closely with SRP to bypass the poor quality water, thereby reducing treatment problems. Installation of stage gages on washes which convey runoff into the canals would provide some advance warning to the operators/SRP; however, this information was not considered critical. Also, the completion of the ACDC is expected to reduce the amount of sediment entering the Arizona Canal by intercepting runoff from major washes and storm sewers.

Summary of Alternative Use Potential

While flood warning is an important service, it is a relatively infrequent activity. Thus, the equipment and personnel dedicated to the operation of that system could be made available to perform other tasks during non-critical times. The advantage of this type of operation is that more refined climatic data are available to the public in usable formats. This should make the public more aware of the benefits of the flood warning system and of its operation by the District. The more refined information also promotes a better understanding of the diversity in the local environment and of climatic conditions associated with the desert southwest.

The potential user groups for each of the service categories described previously are diverse. The creation of a particular use may require a marketing effort to inform a user group about the availability and features of the service. A commitment to maintain the service, based on input from potential users, would also be required. In some cases, it may be reasonable to enter into agreements with third party vendors who would produce a value-added service for a user group utilizing data collected by the flood warning system.

The development of alternative uses for flood warning data could help to broaden the support and funding for the system. In principle, the exchange of data among the community of scientists and engineers involved in the study of hydrology and related fields is fundamental to the continued advancement of the respective disciplines. Should the District encourage a common database, it could provide some of the leadership necessary to focus the efforts of several other agencies.

The issues of water conservation and water quality represent two important issues that will be critical to the environment of Maricopa County for many years to come. While not directly within the mission of the District, the expertise of the District's staff regarding telemetered monitoring stations could benefit other agencies and individuals. Reimbursement for District services by other agencies whose mission directly addresses these issues could help offset the cost of maintaining the flood warning system.

Finally, the use of a flood warning system for evaluating fire danger/potential in nonurbanized areas should be investigated further. A cooperative effort between the District and Rural Metro Corporation could expand the amount of weather data available to the County at potentially minimal costs.

Clearly, development of alternative uses would not provide an economic justification to develop a flood warning program. However, development of alternative uses may help defray program costs and establish support for the program.

Section 8

SECTION 8

FINDINGS, CONCLUSIONS AND RECOMMENDATIONS

FINDINGS AND CONCLUSIONS

The results of this study indicate that there is strong interest in and a need for improving flood warning services within Maricopa County. Further, the market survey indicates that the District is well-suited for assuming a key role in improving flood warning services.

Based on the technology evaluation performed in this study, certain components were selected that best meet the needs of Maricopa County. Based on these findings, several system alternatives were developed for improving flood warning services as follows:

Alternative 1 - Status quo

Alternative 2 - Flood warning with improved flood detection and hydrologic modeling

Alternative 3 - Flood warning with improved flood detection and meteorological prediction

Alternative 4 - Flood warning with improved flood detection, hydrologic modeling, and meteorological prediction

Alternative 5 - Flood warning with improved flood detection, hydrologic modeling, meteorological prediction, and GIS

An economic analysis was performed of quantifiable benefits and costs of the five flood warning alternatives. The analysis indicates that the expected annual benefits, from reduced flood damages only, of implementing a flood warning system range from $500,000 to $2,600,000 if lead times of 30 minutes to two hours, respectively, are achieved. Equivalent annualized system costs are estimated for each of five flood warning alternatives and range from $340,000 for Alternative 1 to $1,280,000 for Alternative 5.

Based on the economic analysis and other important factors such as increased safety, accuracy and specificity of warnings, and other nonquantifiable benefits and costs, JMM ranked the alternatives for overall performance, with 1 being the most attractive and 5 the least attractive, as follows:

Rank	Alternative
1	Alternative 5
2	Alternative 4
3	Alternative 3
4	Alternative 2
5	Alternative 1

Additionally, it is concluded that there is potential to develop alternative uses of the flood warning program within the County. However, a marketing effort by the District would be required to develop a viable alternative use program.

RECOMMENDATIONS

Based on the results of the technology evaluation, market survey, and economic analysis, it is recommended that the components identified in Alternative 4 be developed initially to improve flood warning services. After the program becomes operational, it is recommended that the GIS component be implemented to bring the program to Alternative 5.

Either of Alternatives 2 or 3 could be implemented, but would result in reduced realization of benefits.

In order to develop the components of the recommended alternative, the following steps are necessary:

1. A preliminary system design on the selected alternative should be performed to include the following tasks:

   - Identify the number, location, and type of additional precipitation and stage gages and weather stations required to expand the flood detection network.

   - Identify which existing hydrologic studies require updates or modification.

   - If the meteorological component includes a staff meteorologist, identify specific hardware requirements to acquire useful meteorologic data. If the component includes an outside service, identify the specific meteorological requirements to be met by the service.

   - Identify specific requirements/constraints to incorporate GIS into the flood warning program.

   - Identify steps which must be taken to proceed with design and implementation of a flood warning system.

2. A task force should be formed to include representatives of the District, Civil Defense, emergency personnel, and other local officials. The objectives of the task force should include:

   - Determine the most effective way to disseminate warnings;

   - Identify the specific flood warning information needs of the various communities within the County; and

   - Develop means of coordination between agencies in the event of a flood warning.

3. A public education program should be developed to inform the general public on flooding and flood warning as they apply to the improved flood warning services.

4. Alternative uses of the flood warning program should be marketed within the County to maximize the potential benefits of improved flood warning services.

Appendix A

APPENDIX A

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Appendix B

APPENDIX B

LIST OF ACRONYMS/ABBREVIATIONS

ACDC	Arizona Canal Diversion Channel
ADES	Arizona Department of Economic Security
ADOT	Arizona Department of Transportation
ADWR	Arizona Department of Water Resources
AFOS	Automated Field Operations and Services
ALERT	Automated Local Evaluation in Real-Time
ARSI	Atmospheric Research Systems, Inc.
AWIPS	Advanced Weather Interactive Processing System for the 1990's
BuRec	U.S. Bureau of Reclamation
CCRFCD	Clark County Regional Flood Control District
CPU	Central Processing Unit
Civil Defense	Maricopa County Department of Civil Defense
Corps	U.S. Army Corps of Engineers
DIFAX	Digital Facsimile
DSS	Data Storage System
DTM	Digital Terrain Model
District	Flood Control District of Maricopa County
EIS	Emergency Information System
EOC	Emergency Operations Center
EPA	Environmental Protection Agency
FAA	Federal Aviation Administration
FEMA	Federal Emergency Management Agency
GIS	Geographic Information System
GOES	Geostationary Operational Environmental Satellites
GOES-NEXT	Next-Generation GOES
HCFCD	Harris County Flood Control District
JMM	James M. Montgomery, Consulting Engineers, Inc.
LLP	Lightning Location and Protection, Inc.
Mesonet	Mesometeorological Network
NESDIS	National Environmental Satellite, Data and Information Service
NEXRAD	Next-Generation Weather Radar
NOAA	National Oceanic and Atmospheric Administration
NPDES	National Pollutant Discharge Elimination System
NSSFC	National Severe Storms Forecast Center
NWS	National Weather Service
PAR	Population at Risk
PEMA	Pennsylvania Emergency Management Agency
PRISMS	Phoenix Real-Time Instrumentation for Surface Meteorological Studies
QPF	Quantitative Precipitation Forecast
SCADA	Supervisory Control And Data Acquisition
SRP	Salt River Project
SWAMP	SW Area Monsoon Project
STORM	Stormscale Operational and Research Meteorology
Sacramento Model	Sacramento Soil Moisture Accounting Model
UDFCD	Urban Drainage & Flood Control District
USGS	U.S. Geological Survey
VCFCD	Ventura County Flood Control District
WSI	Weather Service International
WSR-74	Weather Surveillance Radar-1974
WSR-88D	Weather Surveillance Radar-1988-Doppler

Appendix C

Managerial Questionnaire

Flood Control District of Maricopa County
Managerial Flood Warning Services Survey

INSTRUCTIONS: Please indicate your responses by marking the appropriate boxes or filling in the blanks provided.

1. **Flooding has been a problem in my area of jurisdiction.**

Strongly Agree	Agree	Slightly Agree	Slightly Disagree	Disagree	Strongly Disagree	No opinion/ Don't know
☐	☐	☐	☐	☐	☐	☐

2. **How severe a problem do you consider the flash flood threat to lives and property in the urban areas of Maricopa County?**

   ☐ Serious problem ☐ Minor problem
   ☐ Moderately serious problem ☐ Not a problem

3. **How severe a problem do you consider the flash flood threat to lives and property in the outlying areas of Maricopa County?**

   ☐ Serious problem ☐ Minor problem
   ☐ Moderately serious problem ☐ Not a problem

4. **Does your organization purchase flood insurance?**

   ☐ Yes ☐ No ☐ Don't know

5. **How significantly does flooding impact your organization/department's annual budget?**

   ☐ Strong impact ☐ Moderate impact ☐ Little or no impact

6. **What amount does your organization/department budget per year for implementation of an emergency plan for flooding?** *(Dollars or manhours--please specify)*

   ☐ Budget: ____________________ (Dollars or manhours)
   ☐ No plan ☐ Don't know

7. **How often does your organization/department receive complaints about the inadequacy of flood warning?**

   ☐ Very often ☐ Occasionally ☐ Never
   ☐ Often ☐ Infrequently ☐ Don't know

8. **Do you feel that public opinion would favor improved flood warning services?**

   ☐ Yes ☐ No ☐ Don't know

9. **Would your organization/department be in favor of allocating funds toward the development and maintenance of improved flood warning services?**

   ☐ Yes ☐ No ☐ Possibly

10. **The National Weather Service currently has the responsibility for issuing flash flood watches and warnings. In your opinion, is the information provided by the National Weather Service accurate (meaning that flooding events are predicted and do occur)?**

   ☐ Always ☐ 50% of the time ☐ Never
   ☐ Most of the time ☐ Occasionally ☐ No opinion

11. **Do the current flash flood watches and warnings provide enough time for your organization/department to prepare for a flooding event?**

- ❑ Always
- ❑ Most of the time
- ❑ 50% of the time
- ❑ Occasionally
- ❑ Never
- ❑ Don't know

12. **Do you think your organization/department receives adequate flash flood warnings from the National Weather Service?**

- ❑ Always
- ❑ Most of the time
- ❑ 50% of the time
- ❑ Occasionally
- ❑ Never
- ❑ Don't know

13. **Are the warnings too site-specific, not site-specific enough, or just right?**

- ❑ Too site-specific
- ❑ Just right
- ❑ Not site-specific enough
- ❑ No opinion

14. **Overall, do you feel that existing flood warning services provided by the National Weather Service:** *(Check all that apply)*

- ❑ Are reliable
- ❑ Aren't reliable
- ❑ Are timely
- ❑ Aren't timely
- ❑ Need improvement
- ❑ Don't need improvement
- ❑ No opinion

15. **Which type of flood warning service would be most helpful to your organization/department?**

- ❑ Longer warning time, but less accurate flood warnings (meaning there would be more time to prepare for a flood, but there would be more false alarms)
- ❑ Shorter warning time, but more accurate flood warnings (meaning there would be less time to prepare for a flood, but there would be less false alarms)
- ❑ Don't know

16. **What information triggers the implementation of an emergency operations plan for your organization/department?** *(Check all that apply.)*

- ❑ No plan
- ❑ TV or radio broadcasts
- ❑ Observation of local flooding
- ❑ SRP river flow information
- ❑ National Weather Service flash flood watch
- ❑ National Weather Service flash flood warning
- ❑ Maricopa County Civil Defense Notification
- ❑ Other *(please specify)* __________
- ❑ Don't know

17. **Is this information location-specific enough to effectively implement an emergency plan?**

- ❑ Yes
- ❑ No
- ❑ No plan
- ❑ Don't know

18. **Is this information sufficiently accurate to effectively implement an emergency plan?**

- ❑ Yes
- ❑ No
- ❑ No plan
- ❑ Don't know

19. **How much warning time for a flash flood would have the best impact on your operations? Consider typical percentages of false alarms which increase as warning time increases.**

- ❑ 0-10 minutes (less than 5% false alarm)
- ❑ 10-30 minutes (5% - 20% false alarm)
- ❑ 30-60 minutes (20% - 30% false alarm)
- ❑ 60-90 minutes (30% - 40% false alarm)
- ❑ More than 90 minutes (greater than 40% false alarm)
- ❑ Not applicable
- ❑ Don't know

20. Current National Weather Service flash flood watches and warnings cover broad areas such as the entire state, several counties or portions of one county. Would more site-specific information benefit your organization/department? *(If "No", or "Don't know", go to No. 22.)*

- ❑ Yes
- ❑ No
- ❑ Don't know

21. If so, which of the following more specific locations of flood threat would be of most benefit? *(Check one.)*

- ❑ Portions of Maricopa County (Central, North, etc.)
- ❑ Cities within Maricopa County (Wickenburg, Glendale, etc.)
- ❑ Portions of Cities (North Phoenix, East Mesa, etc.)
- ❑ Relative to highways or streets (north of I-10 and west of the Squaw Peak Parkway, etc.)
- ❑ Relative to waterways (Indian Bend Wash, Hassayampa River, etc.)
- ❑ Other *(please specify)* ______________________

22. During a heavy storm, who does your organization usually turn to for information? *Please check your top three choices.*

- ❑ Salt River Project
- ❑ Sheriff or police
- ❑ Fire department
- ❑ Weather Radio
- ❑ National Weather Service
- ❑ Flood Control District of Maricopa County
- ❑ Maricopa County Civil Defense
- ❑ Other *(please specify)* ______________________
- ❑ None of the above
- ❑ Don't know

23. During a heavy storm, who would you have your organization/department obey if you were advised to evacuate? *Please check your top three choices.*

- ❑ Sheriff or police
- ❑ Fire department
- ❑ Governor
- ❑ Mayor
- ❑ Flood Control District of Maricopa County
- ❑ Maricopa County Civil Defense
- ❑ Salt River Project
- ❑ Other *(please specify)* ______________________

24. Who do you feel is best-suited to collect and analyze weather data for use in flood warning services for Maricopa County? *Please check your top two choices.*

- ❑ National Weather Service
- ❑ Individual municipalities
- ❑ Salt River Project
- ❑ Flood Control District of Maricopa County
- ❑ Arizona Department of Water Resources
- ❑ Other *(please specify)* ______________________

25. Who do you feel is best-suited to collect and analyze rainfall and runoff data for use in flood warning services for Maricopa County? *Please check your top two choices.*

- ❑ National Weather Service
- ❑ Individual municipalities
- ❑ Salt River Project
- ❑ Flood Control District of Maricopa County
- ❑ Arizona Department of Water Resources
- ❑ Other *(please specify)* ______________________

26. Who do you feel should act as the decision-maker for issuing flood warnings in Maricopa County? *Please check your top three choices.*

- ❑ Local police or sheriff
- ❑ Governor
- ❑ National Weather Service
- ❑ Salt River Project
- ❑ Mayor of the municipality affected
- ❑ Flood Control District of Maricopa County
- ❑ Corps of Engineers
- ❑ Maricopa County Civil Defense
- ❑ Other *(please specify)* ______________________

27. **Who do you feel should act as the decision-maker for evacuating areas within Maricopa County during flooding or flood threat?** *Please check your top three choices.*

- ❑ Local police or sheriff
- ❑ Governor
- ❑ National Weather Service
- ❑ Salt River Project
- ❑ Mayor of the municipality affected
- ❑ Flood Control District of Maricopa County
- ❑ Corps of Engineers
- ❑ Maricopa County Civil Defense
- ❑ Other *(please specify)* ____________________

28. **Would forecasts of amount of expected rainfall be helpful to your organization/department?**

❑ Very helpful ❑ Helpful ❑ Marginally helpful ❑ Not helpful

29. **If maps could be generated and distributed before a storm occurs within Maricopa County showing the predicted extent of flooding , would they be helpful to your organization/department?**

❑ Very helpful ❑ Helpful ❑ Marginally helpful ❑ Not helpful

30. **Were you aware of the existence of the Flood Control District of Maricopa County before receiving this questionnaire?**

❑ Yes ❑ No

31. **Have you ever contacted the Flood Control District of Maricopa County for information on flooding?**

❑ Yes ❑ No

Please respond to the following questions 32 through 45 as a CITIZEN and not necessarily as a representative of your organization.

32. **On your everyday travel route, do you cross washes, rivers, or low spots that are prone to flooding?**

❑ Yes ❑ No

33. **How many years have you lived in Maricopa County?**

__________ years

Please indicate the extent to which you agree or disagree with the following statements.

	Strongly Agree	Agree	Slightly Agree	Slightly Disagree	Disagree	Strongly Disagree	No Opinion/ Don't know
34. A flash flood warning only applies to those adjacent to a river.	❑	❑	❑	❑	❑	❑	❑
35. I would reschedule an important appointment if a flash flood warning were in effect that day.	❑	❑	❑	❑	❑	❑	❑
36. I would alter my route of driving in response to a flash flood warning.	❑	❑	❑	❑	❑	❑	❑
37. I think current flood watches and warnings are not taken seriously because they are issued so frequently--and many times flooding doesn't occur.	❑	❑	❑	❑	❑	❑	❑

	Strongly Agree	Agree	Slightly Agree	Slightly Disagree	Disagree	Strongly Disagree	No Opinion/ Don't know
38. Because it doesn't rain much in Maricopa County, money spent on flood warning wouldn't be worth it.	❑	❑	❑	❑	❑	❑	❑
39. Improved flood warning services could lower flood insurance premiums.	❑	❑	❑	❑	❑	❑	❑
40. A flash flood warning system should provide estimates of amount of expected rainfall in specific areas such as individual cities.	❑	❑	❑	❑	❑	❑	❑
41. A flash flood warning system should be able to generate maps of expected areas of flooding.	❑	❑	❑	❑	❑	❑	❑
42. A flash flood warning system should be able to identify recommended street closures due to expected flooding.	❑	❑	❑	❑	❑	❑	❑
43. A flash flood warning system should be able to identify how high the water will get in specific areas during heavy rain.	❑	❑	❑	❑	❑	❑	❑
44. I think improved flood warning services would reduce damage to property from heavy rain and flooding.	❑	❑	❑	❑	❑	❑	❑
45. I feel that improved flood warning services would save lives or reduce serious injury due to heavy rain and flooding.	❑	❑	❑	❑	❑	❑	❑

46. The Flood Control District of Maricopa County currently operates a network of precipitation and stream gages throughout the County. Would your organization/department be interested in an upgraded system to collect other types of data? *(If so, please specify the types of data which would be useful.)*

❑ Yes ❑ No ❑ Possibly Type(s) of data ______________________

Your comments are welcome: ______________________

____

____

NAME: ______________________

TITLE: ______________________

AFFILIATION: ______________________

Thank you for taking the time to provide this information.
Please mail this questionnaire in the enclosed envelope as soon as possible.
No postage is necessary.

Technical/Users Questionnaire

Flood Control District of Maricopa County
Technical/Users Flood Warning Services Survey

INSTRUCTIONS: Please indicate your responses by marking the appropriate boxes or filling in the blanks provided.

1. **How severe a problem do you consider the flash flood threat to lives and property in the urban areas of Maricopa County?**

   - ❑ Serious problem
   - ❑ Moderately serious problem
   - ❑ Minor problem
   - ❑ Not a problem

2. **How severe a problem do you consider the flash flood threat to lives and property in the outlying areas of Maricopa County?**

   - ❑ Serious problem
   - ❑ Moderately serious problem
   - ❑ Minor problem
   - ❑ Not a problem

3. **How often does your organization/department receive complaints about the inadequacy of flood warning?**

   - ❑ Very often
   - ❑ Often
   - ❑ Occasionally
   - ❑ Infrequently
   - ❑ Never
   - ❑ Don't know

4. **Has heavy rain or flooding adversely affected your operations in the past?** *(If "No", go to No. 12)*

   - ❑ Yes
   - ❑ No

5. **If so, about how many times were your operations affected? Please specify also the time frame in the blank provided.**

   - ❑ 1-3 times in ___ years
   - ❑ 4-6 times in ___ years
   - ❑ 7-10 times in ___ years
   - ❑ 10-15 times in ___ years
   - ❑ More than 15 times in ___ years

6. **If so, for the WORST flood that your organization/department has experienced, how long were your operations affected? Include preparation for flood, duration of flood, and clean-up for any flood damages.**

   - ❑ Less than 1 day
   - ❑ 1-3 days
   - ❑ 4-7 days
   - ❑ 1-2 weeks
   - ❑ 2-4 weeks
   - ❑ Longer than 1 month

7. **If so, for an AVERAGE flooding event, how long were your operations affected? Include preparation for flood, duration of flood, and clean-up for any flood damages.**

   - ❑ Less than 1 day
   - ❑ 1-3 days
   - ❑ 4-7 days
   - ❑ 1-2 weeks
   - ❑ 2-4 weeks
   - ❑ Longer than 1 month

8. **Has your organization/department incurred property damage from flooding? Consider only property owned by your organization.** *(If "No" or "Don't know", go to No. 10)*

   - ❑ Yes
   - ❑ No
   - ❑ Don't know

9. **If so, what is the average cost per flooding event?**

   - ❑ Less than $1,000
   - ❑ $1,000-$5,000
   - ❑ $5,000-$10,000
   - ❑ $10,000-$25,000
   - ❑ $25,000-$50,000
   - ❑ More than $50,000

10. **Have your operations been adversely affected by flooding that occurred, but flash flood warnings <u>were not issued</u>?** *(If "No" or "Don't know", go to No. 12)*

❑ Yes ❑ No ❑ Don't know

11. **If so, how often?**

❑ 1-3 times ❑ 4-6 times ❑ More than 6 times

12. **Have your operations been adversely affected by flash flood warnings which were issued but flooding <u>did not occur</u>?** *(If "No" or "Don't know", go to No. 17)*

❑ Yes ❑ No ❑ Don't know

13. **If so, how often?**

❑ 1-3 times ❑ 4-6 times ❑ More than 6 times

14. **If so, to what extent were your operations affected?**

❑ Severely ❑ Substantially ❑ Moderately ❑ Mildly

15. **Has your organization/department incurred costs from preparation for a flooding event which was predicted but <u>did not occur</u>?** *(If "No" or "Don't know", go to No. 17)*

❑ Yes ❑ No ❑ Don't know

16. **If so, what is the average cost incurred for preparation for a flooding event that was predicted but <u>did not occur</u>?**

❑ Less than $500 ❑ $1,000-$2,500 ❑ $5,000-$10,000
❑ $500-$1,000 ❑ $2,500-$5,000 ❑ More than $10,000

17. **How significantly does flooding impact your organization/department's annual budget?**

❑ Strong impact ❑ Moderate impact ❑ Little or no impact

18. **What amount does your organization/department budget per year for implementation of an emergency plan for flooding?** *(Dollars or manhours--please specify)*

❑ Budget: ____________________ (Dollars or manhours)

❑ No plan ❑ Don't know

19. **Does your organization purchase flood insurance?**

❑ Yes ❑ No ❑ Don't know

20. **The National Weather Service currently issues flash flood watches and warnings. In your opinion, is the information accurate (meaning that flooding events are predicted and do occur)?**

❑ Always ❑ 50% of the time ❑ Never
❑ Most of the time ❑ Occasionally ❑ No opinion

21. **Are the warnings too site-specific, not site-specific enough, or just right?**

❑ Too site-specific ❑ Just right ❑ Not site-specific enough ❑ No opinion

22. **Overall, do you feel that existing flood warning services provided by the National Weather Service:** *(Check all that apply)*

- ❑ Are reliable
- ❑ Aren't reliable
- ❑ Are timely
- ❑ Aren't timely
- ❑ Need improvement
- ❑ Don't need improvement
- ❑ No opinion

23. **Which type of flood warning service would be most helpful to your organization/department?**

- ❑ Longer warning time, but less accurate flood warnings (meaning there would be more time to prepare for a flood, but there would be more false alarms)
- ❑ Shorter warning time, but more accurate flood warnings (meaning there would be less time to prepare for a flood, but there would be less false alarms)
- ❑ Don't know

24. **About how much lead time would your organization/department need to mobilize before flooding occurs?**

- ❑ No action is necessary
- ❑ Less than 1 hour
- ❑ 1-2 hours
- ❑ 3-4 hours
- ❑ 5-8 hours
- ❑ 9-12 hours
- ❑ 12-24 hours
- ❑ More than 24 hours
- ❑ Don't know

25. **Do the current flash flood watches and warnings provide enough time for your organization/department to prepare for a flooding event?**

- ❑ Always
- ❑ Most of the time
- ❑ 50% of the time
- ❑ Occasionally
- ❑ Never
- ❑ Don't know

26. **How much lead time would your organization/department need to remove movable property to higher ground if you were warned of a flood?**

- ❑ 0-15 minutes
- ❑ 15-30 minutes
- ❑ 30-60 minutes
- ❑ 1-2 hours
- ❑ More than 2 hours
- ❑ Not applicable
- ❑ Don't know

27. **How much lead time would your organization/department need to minimize operational difficulties if you were warned of a flood?**

- ❑ 0-15 minutes
- ❑ 15-30 minutes
- ❑ 30-60 minutes
- ❑ 1-2 hours
- ❑ More than 2 hours
- ❑ Not applicable
- ❑ Don't know

28. **How much lead time for a flash flood would have the best impact on your operations? Consider typical percentages of false alarms which increase as warning time increases.**

- ❑ 0-10 minutes (less than 5% false alarm)
- ❑ 10-30 minutes (5% - 20% false alarm)
- ❑ 30-60 minutes (20% - 30% false alarm)
- ❑ 60-90 minutes (30% - 40% false alarm)
- ❑ More than 90 minutes (greater than 40% false alarm)
- ❑ Not applicable
- ❑ Don't know

29. What information triggers the implementation of an emergency operations plan for your organization/department? *(Check all that apply.)*

- ❑ No plan
- ❑ TV or radio broadcasts
- ❑ Observation of local flooding
- ❑ SRP river flow information
- ❑ National Weather Service flash flood watch
- ❑ National Weather Service flash flood warning
- ❑ Other *(please specify)* ______________________
- ❑ Don't know

30. Is this information location-specific enough to implement an emergency plan?

❑ Yes ❑ No ❑ No plan ❑ Don't know

31. Is this information sufficiently accurate to implement an emergency plan?

❑ Yes ❑ No ❑ No plan ❑ Don't know

32. Current National Weather Service flash flood watches and warnings cover broad areas such as the entire state, several counties or portions of one county. Would more site-specific information benefit your organization/department? *(If "No" or "Don't know", go to No. 34)*

❑ Yes ❑ No ❑ Don't know

33. If so, which of the following more specific locations of flood threat.would be of most benefit? *(Check one)*

- ❑ Portions of Maricopa County (Central, North, etc.)
- ❑ Cities within Maricopa County (Wickenburg, Glendale, etc.)
- ❑ Portions of Cities (North Phoenix, East Mesa, etc.)
- ❑ Relative to highways or streets (north of I-10 and west of the Squaw Peak Parkway, etc.)
- ❑ Relative to waterways (Indian Bend Wash, Hassayampa River, etc.)
- ❑ Other *(please specify)* ______________________

34. Does your organization have staff available 24-hours/day to respond to storm or flooding notification?

❑ Yes ❑ No ❑ Don't know

35. Would forecasts of amount of expected rainfall be helpful to your organization/department?

❑ Very helpful ❑ Helpful ❑ Marginally helpful ❑ Not helpful

36. If maps could be generated and distributed before a storm occurs within Maricopa County showing the predicted extent of flooding, would they be helpful to your organization/department?

❑ Very helpful ❑ Helpful ❑ Marginally helpful ❑ Not helpful

37. During a heavy storm, who does your organization usually turn to for information? *Please check your top three choices.*

- ❑ Salt River Project
- ❑ Sheriff or police
- ❑ Fire department
- ❑ Weather Radio
- ❑ National Weather Service
- ❑ Flood Control District of Maricopa County
- ❑ Maricopa County Civil Defense
- ❑ Other *(please specify)* ______________________
- ❑ Not applicable
- ❑ Don't know

38. **During a heavy storm, who would your organization most likely obey if you were advised to evacuate?** *Please check your top three choices.*

- ❑ Sheriff or police
- ❑ Fire department
- ❑ Governor
- ❑ Mayor
- ❑ Flood Control District of Maricopa County
- ❑ Maricopa County Civil Defense
- ❑ Salt River Project
- ❑ Other *(please specify)* ____________________

39. **Who do you feel is best-suited to collect and analyze weather data for use in flood warning services for Maricopa County?** *Please check your top two choices.*

- ❑ National Weather Service
- ❑ Individual municipalities
- ❑ Salt River Project
- ❑ Flood Control District of Maricopa County
- ❑ Arizona Department of Water Resources
- ❑ Other *(please specify)* ____________________

40. **Who do you feel is best-suited to collect and analyze rainfall and runoff data for use in flood warning services for Maricopa County?** *Please check your top two choices.*

- ❑ National Weather Service
- ❑ Individual municipalities
- ❑ Salt River Project
- ❑ Flood Control District of Maricopa County
- ❑ Arizona Department of Water Resources
- ❑ Other *(please specify)* ____________________

41. **Who do you feel should act as the decision-maker for issuing flood warnings in Maricopa County?** *Please check your top three choices.*

- ❑ Local police or sheriff
- ❑ Governor
- ❑ National Weather Service
- ❑ Salt River Project
- ❑ Mayor of the municipality affected
- ❑ Flood Control District of Maricopa County
- ❑ Corps of Engineers
- ❑ Maricopa County Civil Defense
- ❑ Other *(please specify)* ____________________

42. **Who do you feel should act as the decision-maker for evacuating areas within Maricopa County during flooding or flood threat?** *Please check your top three choices.*

- ❑ Local police or sheriff
- ❑ Governor
- ❑ National Weather Service
- ❑ Salt River Project
- ❑ Mayor of the municipality affected
- ❑ Flood Control District of Maricopa County
- ❑ Corps of Engineers
- ❑ Maricopa County Civil Defense
- ❑ Other *(please specify)* ____________________

43. **Were you aware of the existence of the Flood Control District of Maricopa County before receiving this questionnaire?**

❑ Yes ❑ No

44. **Have you ever contacted the Flood Control District of Maricopa County for information on flooding?**

❑ Yes ❑ No

45. **If improved flooding information/forecasting were made available to your organization for Maricopa County, how would you prefer to receive the information?** *Please check your top three choices.*

- ❑ Telephone
- ❑ FAX
- ❑ PC modem
- ❑ Cable TV channel
- ❑ Ham radio
- ❑ Satellite
- ❑ Other *(please specify)* ____________
- ❑ Not interested in receiving information
- ❑ No opinion

Please indicate the extent to which you agree or disagree with the following statements.

	Strongly Agree	Agree	Slightly Agree	Slightly Disagree	Disagree	Strongly Disagree	No Opinion/ Don't Know
46. Flooding has been a problem in my area of jurisdiction.	❑	❑	❑	❑	❑	❑	❑
47. My organization receives adequate flash flood warnings from the National Weather Service.	❑	❑	❑	❑	❑	❑	❑
48. My organization does not take action based on National Weather Service flood watches and warnings because they are issued so frequently--and many times flooding doesn't occur.	❑	❑	❑	❑	❑	❑	❑

Please respond to the following questions 49 through 61 as a CITIZEN and not necessarily as a representative of your organization.

49. On your everyday travel route, do you cross washes, rivers, or low spots that are prone to flooding?

❑ Yes ❑ No

50. How many years have you lived in Maricopa County?

____________ years

Please indicate the extent to which you agree or disagree with the following statements.

	Strongly Agree	Agree	Slightly Agree	Slightly Disagree	Disagree	Strongly Disagree	No Opinion/ Don't Know
51. A flash flood warning only applies to those adjacent to a river.	❑	❑	❑	❑	❑	❑	❑
52. I would reschedule an important appointment if a flash flood warning were in effect that day.	❑	❑	❑	❑	❑	❑	❑
53. I would alter my route of driving in response to a flash flood warning.	❑	❑	❑	❑	❑	❑	❑
54. Because it doesn't rain much in Maricopa County, money spent on flood warning wouldn't be worth it.	❑	❑	❑	❑	❑	❑	❑
55. Improved flood warning services could lower flood insurance premiums.	❑	❑	❑	❑	❑	❑	❑
56. A flash flood warning system should provide estimates of amount of expected rainfall in specific areas such as individual cities.	❑	❑	❑	❑	❑	❑	❑
57. A flash flood warning system should be able to generate maps of expected areas of flooding	❑	❑	❑	❑	❑	❑	❑

	Strongly Agree	Agree	Slightly Agree	Slightly Disagree	Disagree	Strongly Disagree	No Opinion/ Don't Know
58. A flash flood warning system should be able to identify recommended street closures due to expected flooding.	❑	❑	❑	❑	❑	❑	❑
59. A flash flood warning system should be able to identify how high the water will get in specific areas, such as freeway underpasses, during heavy rain.	❑	❑	❑	❑	❑	❑	❑
60. I think improved flood warning services would reduce damage to property from heavy rain and flooding.	❑	❑	❑	❑	❑	❑	❑
61. I feel that improved flood warning services would save lives or reduce serious injury due to heavy rain and flooding.	❑	❑	❑	❑	❑	❑	❑

62. The Flood Control District of Maricopa County currently operates a network of precipitation and stream gages throughout the County. Would your organization/department be interested in an upgraded system to collect other types of data? *(If so, please specify the type(s) of data which would be useful.)*

❑ Yes ❑ No ❑ Possibly Type(s) of data ______________________________

Your comments are welcome: ____

____

____

____

NAME: ____
TITLE: ____
AFFILIATION: ____

Thank you for taking the time to provide this information.
Please mail this questionnaire in the enclosed envelope as soon as possible.
No postage is necessary.

Homeowners' Questionnaire

Flood Control District of Maricopa County
Informational Flood Warning Services Survey for Homeowners

INSTRUCTIONS: Please indicate your responses by marking the appropriate boxes or filling in the blanks provided.

1. **On your everyday travel route, do you cross washes, rivers, or low spots that are prone to flooding?**

- ☐ Yes
- ☐ No

2. **How severe a problem do you consider the flash flood threat to lives and property in the urban areas of Maricopa County?**

- ☐ Serious problem
- ☐ Moderately serious problem
- ☐ Minor problem
- ☐ Not a problem

3. **How severe a problem do you consider the flash flood threat to lives and property in the outlying areas of Maricopa County?**

- ☐ Serious problem
- ☐ Moderately serious problem
- ☐ Minor problem
- ☐ Not a problem

4. **How long have you lived in Maricopa County?**

- ☐ Less than 1 year
- ☐ 1-3 years
- ☐ 3-5 years
- ☐ 5-10 years
- ☐ 10-15 years
- ☐ More than 15 years

5. **How long have you lived at your current address?**

- ☐ Less than 1 year
- ☐ 1-3 years
- ☐ 3-5 years
- ☐ 5-10 years
- ☐ 10-15 years
- ☐ More than 15 years

6. **Have you been flooded in the past while living in Maricopa County? Include flooding at your house, your vehicle, and/or a business you own.** *(If "No", go to No. 12.)*

- ☐ Yes
- ☐ No

7. **If so, how many times have you been flooded while living in Maricopa County?**

- ☐ 1-3 times
- ☐ 4-6 times
- ☐ 7-10 times
- ☐ 10-15 times
- ☐ More than 15 times

8. **If so, what was the average damage cost per flood to your property and/or business?**

- ☐ Less than $100
- ☐ $100-$500
- ☐ $500-$1,000
- ☐ $1,000-$5,000
- ☐ $5,000-$10,000
- ☐ More than $10,000

9. **If so, for the WORST flood that you've experienced at your house, your business or while traveling in Maricopa County, how long were you affected? Include preparation for flood, duration of flood, and clean-up for any flood damages.**

- ☐ Less than 1 day
- ☐ 1-3 days
- ☐ 4-7 days
- ☐ 1-2 weeks
- ☐ 2-4 weeks
- ☐ Longer than 1 month

10. **Have you been inconvenienced by flooding that occurred, but flash flood warnings <u>were not issued</u>?**
(If "No", go to No. 12.)

❑ Yes ❑ No

11. **If so, how often?**

❑ 1-2 times ❑ 3-5 times ❑ More than 5 times

12. **Have you been inconvenienced by flash flood warnings which were issued but flooding <u>did not occur</u>?**
(If "No", go to No. 17.)

❑ Yes ❑ No

13. **If so, how often?**

❑ 1-2 times ❑ 3-5 times ❑ More than 5 times

14. **If so, to what extent were you inconvenienced?**

❑ Severely ❑ Moderately
❑ Substantially ❑ Mildly

15. **Have you spent money preparing for a flood that was predicted but <u>did not occur</u>?** *(If "No", go to No. 17.)*

❑ Yes ❑ No

16. **If so, what did it cost you to prepare for a flood that <u>did not occur</u>?**

❑ Less than $100 ❑ $200-$500 ❑ More than $1,000
❑ $100-$200 ❑ $500-$1,000

17. **How many people do you personally know <u>in Maricopa County</u> who have been flooded in the past?**

❑ 0 ❑ 4-6 ❑ More than 10
❑ 1-3 ❑ 7-10

18. **Do you carry flood insurance?**

❑ Yes ❑ No

19. **Do you feel that the current flash flood warnings are accurate, meaning that the floods are predicted and do occur?**

❑ Always ❑ 50% of the time ❑ Never
❑ Most of the time ❑ Occasionally ❑ No opinion

20. **Typically the National Weather Service issues flash flood watches and warnings which apply to whole counties or several counties. Do you think the warnings should be:**

❑ More specific and cover smaller areas ❑ Less specific and cover larger areas ❑ No opinion

21. **Do you feel that current flood forecasts give you enough advanced warning?**

❑ Yes ❑ No ❑ No opinion

22. **If you were asked to evacuate your home during a flood, what is the minimum amount of time you would need to get out safely without taking or protecting any valuables?**

- ❑ 0-15 minutes
- ❑ 15-30 minutes
- ❑ 30-60 minutes
- ❑ 60-90 minutes
- ❑ More than 90 minutes

23. **If you were asked to evacuate your home during a flood, what is the minimum amount of time you would need to remove valuables and get out safely?**

- ❑ 0-15 minutes
- ❑ 15-30 minutes
- ❑ 30-60 minutes
- ❑ 60-90 minutes
- ❑ More than 90 minutes

24. **Do the current flash flood watches and warnings provide sufficient time to prepare for a flooding event?**

- ❑ Always
- ❑ Most of the time
- ❑ 50% of the time
- ❑ Occasionally
- ❑ Never
- ❑ No opinion

25. **Which type of flash flood warning listed below would you choose?**

- ❑ More time to prepare for a flood, but less accurate flood warnings (meaning there would be more false alarms, but there is more time to prepare for a flood).
- ❑ Less time to prepare for a flood, but more accurate flood warnings (meaning the flood will most likely occur, but there is less time to prepare).
- ❑ No opinion

26. **During a heavy storm in your area, who would you most likely turn to for information?** *Please check your top three choices.*

- ❑ Salt River Project
- ❑ Sheriff or police
- ❑ Fire department
- ❑ TV announcements
- ❑ Radio announcements
- ❑ Flood Control District of Maricopa County
- ❑ Weather Radio
- ❑ Other *(please specify)*________________________________
- ❑ None of the above

27. **During a heavy storm, who do you think should be responsible for making the decision to evacuate areas in danger of flooding?** *Please check your top three choices.*

- ❑ Sheriff or police
- ❑ Fire department
- ❑ Mayor
- ❑ Governor
- ❑ Flood Control District of Maricopa County
- ❑ Maricopa County Civil Defense
- ❑ Salt River Project
- ❑ Other *(please specify)* ________________________________

28. **Who would you obey if you were told to evacuate your home due to flooding?** *(Check all that apply)*

- ❑ Phone call from police dept.
- ❑ Phone call from other agency *(please specify)*_________________________
- ❑ In-person notification from neighbor
- ❑ In-person notification from police dept.
- ❑ Warning siren
- ❑ Police car driving by with amplified announcement
- ❑ Maricopa County Civil Defense bulletins on the radio or TV
- ❑ In-person notification from other agency *(please specify)*_________________________

29. **Were you aware of the existence of the Flood Control District of Maricopa County before receiving this questionnaire?**

❑ Yes ❑ No

Please indicate the extent to which you agree or disagree with the following statements.

	Strongly Agree	Agree	Slightly Agree	Slightly Disagree	Disagree	Strongly Disagree	No Opinion/ Don't Know
30. A flash flood warning only applies to those adjacent to a river.	❑	❑	❑	❑	❑	❑	❑
31. It is safe to drive in flooded areas if I'm in a high-profile 4-wheel drive vehicle.	❑	❑	❑	❑	❑	❑	❑
32. I would reschedule an important appointment if a flash flood warning were in effect that day.	❑	❑	❑	❑	❑	❑	❑
33. I would alter my route of driving in response to a flash flood warning.	❑	❑	❑	❑	❑	❑	❑
34. It doesn't rain much in Maricopa County, so any money spent on flood warning wouldn't be worth it.	❑	❑	❑	❑	❑	❑	❑
35. Improved flood warning services could lower flood insurance premiums.	❑	❑	❑	❑	❑	❑	❑
36. I receive adequate flash flood warnings from the weather report.	❑	❑	❑	❑	❑	❑	❑
37. I tend to disregard flash flood watches/warnings from the National Weather Service because often they are issued but no flooding occurs.	❑	❑	❑	❑	❑	❑	❑
38. A flash flood warning system should provide estimates of amount of expected rainfall in the city where I live.	❑	❑	❑	❑	❑	❑	❑
39. A flash flood warning system should provide maps on TV of expected areas of flooding.	❑	❑	❑	❑	❑	❑	❑
40. A flash flood warning system should be able to identify recommended street closures due to expected flooding.	❑	❑	❑	❑	❑	❑	❑
41. A flash flood warning system should be able to identify how high the water will get in my house during heavy rain.	❑	❑	❑	❑	❑	❑	❑

	Strongly Agree	Agree	Slightly Agree	Slightly Disagree	Disagree	Strongly Disagree	No Opinion/ Don't Know
42. I think improved flood warning services would reduce damage to property from heavy raining and flooding.	❑	❑	❑	❑	❑	❑	❑
43. I feel that improved flood warning services would save lives or reduce serious injury due to heavy rain and flooding.	❑	❑	❑	❑	❑	❑	❑

Your comments are welcome: ______________________________

____

____

____

Optional

NAME: ______________________________
ADDRESS: ______________________________
____

Thank you for taking the time to provide this information.
Please mail this questionnaire in the enclosed envelope as soon as possible.
No postage is necessary.

Table C-1

Categorization of Market Survey Questions by Evaluation Criteria

TABLE C-1

CATEGORIZATION OF MARKET SURVEY QUESTIONS BY EVALUATION CRITERIA

	Evaluation Criteria	ASSOCIATED QUESTION NUMBERS: Managerial	Technical	Homeowners
1.	Perception of severity of flood threat	2,3	1,2	2,3
2.	History of flooding			
2.1	- General	1	4,46	6,17
2.2	- Frequency	-	5	4,7
2.3	- Severity	-	6,7,8	9
2.4	- Financial	4,5,6	9,15,16,17,18,19	8,15,16,18
3.	Accuracy of current flood warning services	10,14,18,37	10,11,12,13,14,15,20,22,31,48	10,11,12,13,14,19,37
4.	Adequacy of current flood warning services	7,11,12,13,14,17,20	3,21,22,25,30,32,47	20,21,24,36
5.	Desired lead time	15,19	23,24,26,27,28	22,23,25
6.	Interest in improved flood warning services	7,8,9,14,20,21,28,29,38	3,22,32,33,35,36,54	20,34
7.	Current flood warning information sources	16,22	29,37	26
8.	24-hour staff availability	-	34	-
9.	Who should issue flood warnings	23,24,25,26,27	38,39,40,41,42	27,28
10.	Understanding of flooding/flood warning	34,35,36,38,39,44,45	51,52,53,54,55,60,61	30,31,32,33,34,35,41,42,43
11.	Desired form of communication	-	45	-
12.	Expectations of flood warning services	40,41,42,43	56,57,58,59	38,39,40,41
13.	Alternate uses of flood warning services	46	62	-
14.	Profile of participants	30,31,32,33	43,44,49,50	1,4,29

Appendix D

JMM James M. Montgomery
Consulting Engineers Inc.

Have Been Flooded/Affected by Flooding vs.
Have Not Been Flooded/Affected by Flooding

TABLE D-1

RESULTS OF MARKET SURVEY BY RESPONDENTS' FLOODING EXPERIENCE

Evaluation Criteria	MANAGERIAL: Flooding is a Problem in Area of Jurisdiction	MANAGERIAL: Flooding is Not a Problem in Area of Jurisdiction	TECHNICAL: Operations Have Been Affected	TECHNICAL: Operations Have Not Been Affected	HOMEOWNERS: Have Been Flooded	HOMEOWNERS: Have Not Been Flooded
	Based on 16 Responses	Based on 1 Response	Based on 40 Responses	Based on 13 Responses	Based on 14 Responses	Based on 37 Responses
1. Perception of Severity of Flood Threat						
- Serious/moderately serious in urban Maricopa County	81%	0%	75%	69%	71%	41%
- Minor problem/no problem in urban Maricopa County	19%	100%	23%	31%	21%	54%
- Serious/moderately serious in rural Maricopa County	100%	100%	85%	85%	86%	62%
- Minor problem/no problem in rural Maricopa County	0%	0%	13%	15%	7%	35%
2. History of Flooding						
2.1 General						
• Have been flooded/affected by flooding	100%	0%	100%	0%	100%	0%
2.2 Frequency						
• Average number of times flooded	-	-	5 times	0 times	4 times	0 times
2.3 Severity						
• Time affected for worst flood	-	-	2 weeks	n/a	4 days	n/a
• Time affected for average flood	-	-	4 days	n/a	-	n/a
2.4 Financial Impact						
• Impact of flooding on budget						
- Strong to moderate	44%	100%	30%	8%	-	-
- Little or no impact	56%	0%	70%	92%	-	-
• Average cost per flood	-	-	$23,000	n/a	$2,000	n/a
• Average cost for preparation for false alarms	-	-	<$500	n/a	$350	n/a
3. Accuracy of Current Flood Warning Services						
- Accurate	40%	25%	57%	71%	46%	71%
- Inaccurate	43%	25%	24%	9%	46%	22%
- Don't know/No opinion/Did not answer	17%	50%	19%	20%	8%	7%
4. Adequacy of Current Flood Warning Services						
- Adequate	45%	57%	50%	53%	32%	54%
- Inadequate	35%	0%	31%	20%	50%	28%
- Don't know/No opinion/Did not answer	20%	43%	19%	27%	18%	18%
5. Lead Time for Flood Warning						
• Lead time vs. accuracy						
- More lead time, less accuracy	19%	0%	20%	15%	43%	35%
- Less lead time, more accuracy	31%	0%	33%	38%	43%	43%
- Don't know/no opinion/did not answer	50%	100%	48%	46%	14%	22%
• Average desired lead time	1.5 hours	Not Answered	2 hours	2 hours	1.5 hours	1 hour
6. Interest in Improved Flood Warning Services						
- Interested	70%	43%	74%	58%	93%	81%

TABLE D-1 (continued)

RESULTS OF MARKET SURVEY BY RESPONDENTS' FLOODING EXPERIENCE

Evaluation Criteria	MANAGERIAL: Flooding is a Problem in Area of Jurisdiction (Based on 16 Responses)	MANAGERIAL: Flooding is Not a Problem in Area of Jurisdiction (Based on 1 Response)	TECHNICAL: Operations Have Been Affected (Based on 40 Responses)	TECHNICAL: Operations Have Not Been Affected (Based on 13 Responses)	HOMEOWNERS: Have Been Flooded (Based on 14 Responses)	HOMEOWNERS: Have Not Been Flooded (Based on 37 Responses)
7. Current Flood Warning Information Sources						
• During a heavy storm	NWS SRP District Civil Defense	Sheriff/Police Fire Dept. NWS	NWS SRP Civil Defense	NWS Sheriff/Police Civil Defense	TV Radio Sheriff/Police	TV Radio Sheriff/Police Weather Radio
• Triggers emergency plan	TV/Radio SRP Observed Flooding Civil Defense	Observed Flooding	Observed Flooding NWS Flood Warning	NWS Flood Warning	-	-
8. 24-Hour Staff Availability						
- Yes	-	-	88%	62%	-	-
9. Who Should Issue Flood Warnings						
• Most likely to obey if advised to evacuate	Sheriff/Police Fire Dept. Civil Defense	Sheriff/Police Fire Dept. Governor	Sheriff/Police Fire Dept. Mayor	Sheriff/Police Fire Dept. Mayor	Police Car Bullhorn, Police In-Person Notification, Civil Def. TV/Radio Bulletin	Police In-Person Notification, Police Car Bullhorn, Civil Def. TV/Radio Bulletin
• Best suited to collect and analyze weather data	NWS District	SRP District	NWS District	NWS District	-	-
• Best suited to collect and analyze rainfall and runoff data	District SRP NWS	SRP District	District NWS	District NWS SRP	-	-
• Best suited to act as the decision maker for issuing flood warnings	NWS District	NWS Mayor Civil Defense	NWS District Civil Defense	District NWS Civil Defense	-	-
• Best suited to act as decision maker for evacuating areas	District Sheriff/Police Civil Defense Mayor	Sheriff/Police Mayor Civil Defense	Sheriff/Police Mayor Civil Defense	Civil Defense Sheriff/Police Mayor District	District Sheriff/Police Civil Defense	Sheriff/Police District Civil Defense Fire Dept.

TABLE D-1 (continued)

RESULTS OF MARKET SURVEY BY RESPONDENTS' FLOODING EXPERIENCE

Evaluation Criteria	MANAGERIAL: Flooding is a Problem in Area of Jurisdiction	MANAGERIAL: Flooding is Not a Problem in Area of Jurisdiction	TECHNICAL: Operations Have Been Affected	TECHNICAL: Operations Have Not Been Affected	HOMEOWNERS: Have Been Flooded	HOMEOWNERS: Have Not Been Flooded
	Based on 16 Responses	Based on 1 Response	Based on 40 Responses	Based on 13 Responses	Based on 14 Responses	Based on 37 Responses
10. Understanding of Flooding/Flood Warning						
- Adequate	72%	57%	69%	67%	77%	69%
- Inadequate	19%	29%	24%	24%	14%	22%
11. Desired Form of Communication						
• Preferable mode of receiving information	-	-	Telephone FAX PC Modem Cable TV	Telephone FAX Cable TV	-	-
12. Expectations of Flood Warning Services						
- High	83%	100%	88%	86%	89%	69%
- Low	11%	0%	8%	11%	9%	24%
13. Alternate Uses of Flood Warning Services	Precipitation, Flood Retarding Storages	Did Not Specify	Gages, Surface Water Quality	Volume of Runoff, Rainfall Averages	-	-
14. Profile of Participants						
• Average time lived in Maricopa County	15 years	8 years	24 years	19 years	14 years	13 years
• Traverse flood-prone areas routinely	63%	0%	65%	69%	79%	49%
• Aware of District prior to survey	94%	100%	85%	92%	86%	62%
• Contacted District for flood information previously	63%	0%	40%	23%	-	-

Local Communities vs. County, State and Federal Agencies vs. Others

TABLE D-2

RESULTS OF MARKET SURVEY BY COMMUNITY/AGENCY

Evaluation Criteria	MANAGERIAL			TECHNICAL		
	City/Town	County, State and Federal	Other	City/Town	County, State and Federal	Other
	Based on 6 Responses	Based on 8 Responses	Based on 3 Responses	Based on 34 Responses	Based on 9 Responses	Based on 10 Responses
1. Perception of Severity of Flood Threat						
- Serious/moderately serious in urban Maricopa County	67%	75%	100%	82%	67%	50%
- Minor problem/no problem in urban Maricopa County	33%	25%	0%	18%	22%	50%
- Serious/moderately serious in rural Maricopa County	100%	100%	100%	85%	89%	80%
- Minor problem/no problem in rural Maricopa County	0%	0%	0%	15%	0%	20%
2. History of Flooding						
2.1 General						
• Have been flooded/affected by flooding	83%	100%	100%	76%	67%	80%
2.2 Frequency						
• Average number of times flooded	-	-	-	4 times	7 times	8 times
2.3 Severity						
• Time affected for worst flood	-	-	-	1.5 weeks	2 weeks	2.5 weeks
• Time affected for average flood	-	-	-	4 days	5 days	5 days
2.4 Financial Impact						
• Impact of flooding on budget						
- Strong to moderate	33%	50%	67%	21%	44%	20%
- Little or no impact	67%	50%	33%	79%	56%	80%
• Average cost per flood	-	-	-	$16,000	$34,000	$32,000
• Average cost for preparation for false alarms	-	-	-	n/a	n/a	<$500
3. Accuracy of Current Flood Warning Services						
- Accurate	22%	45%	58%	62%	72%	49%
- Inaccurate	47%	37%	42%	15%	13%	35%
- Don't know/No opinion/Did not answer	31%	18%	0%	23%	15%	16%
4. Adequacy of Current Flood Warning Services						
- Adequate	47%	40%	57%	48%	57%	54%
- Inadequate	20%	39%	43%	27%	28%	32%
- Don't know/No opinion/Did not answer	33%	21%	0%	25%	15%	14%
5. Lead Time for Flood Warning						
• Lead time vs. accuracy						
- More lead time, less accuracy	17%	0%	67%	15%	22%	30%
- Less lead time, more accuracy	33%	25%	33%	35%	33%	30%
- Don't know/no opinion/did not answer	50%	75%	0%	50%	44%	40%
• Average desired lead time	1 hour	1.5 hours	1.5 hours	1.5 hours	2.5 hours	2.5 hours
6. Interest in Improved Flood Warning Services						
- Interested	53%	73%	86%	70%	70%	69%

TABLE D-2 (continued)

RESULTS OF MARKET SURVEY BY COMMUNITY/AGENCY

Evaluation Criteria	MANAGERIAL City/Town	MANAGERIAL County, State and Federal	MANAGERIAL Other	TECHNICAL City/Town	TECHNICAL County, State and Federal	TECHNICAL Other
	Based on 6 Responses	**Based on 8 Responses**	**Based on 3 Responses**	**Based on 34 Responses**	**Based on 9 Responses**	**Based on 10 Responses**
7. Current Flood Warning Information Sources						
• During a heavy storm	Sheriff/Police NWS Civil Defense	SRP NWS District	NWS Civil Defense	NWS Civil Defense Sheriff/Police	NWS District SRP	NWS SRP Weather Radio
• Triggers emergency plan	TV/Radio Civil Defense	Observed Flooding SRP TV/Radio	TV/Radio SRP NWS Flood Warning	NWS Flood Warning Observed Flooding TV/Radio	Observed Flooding NWS Flood Warning	NWS Flood Warning SRP NWS Flood Watch TV/Radio
8. 24-Hour Staff Availability						
- Yes	-	-	-	85%	56%	90%
9. Who Should Issue Flood Warnings						
• Most likely to obey if advised to evacuate	Sheriff/Police Fire Dept. Governor	Sheriff/Police Fire Dept. Mayor District	Civil Defense Sheriff/Police	Sheriff/Police Mayor Fire Dept.	Sheriff/Police Fire Dept. District	Sheriff/Police Fire Dept. SRP
• Best suited to collect and analyze weather data	NWS District	NWS District	NWS SRP	NWS District	District NWS	NWS SRP
• Best suited to collect and analyze rainfall and runoff data	District SRP	District SRP	NWS SRP	District NWS SRP	District NWS	NWS SRP
• Best suited to act as the decision maker for issuing flood warnings	Mayor District NWS Civil Defense	NWS District	NWS Civil Defense	District NWS Civil Defense	District NWS Civil Defense	NWS SRP District
• Best suited to act as decision maker for evacuating areas	Sheriff/Police Mayor District Civil Defense	District Civil Defense Sheriff/Police Mayor	Civil Defense	Mayor Sheriff/Police Civil Defense	District Civil Defense Sheriff/Police	Sheriff/Police District NWS Civil Defense

TABLE D-2 (continued)

RESULTS OF MARKET SURVEY BY COMMUNITY/AGENCY

Evaluation Criteria	MANAGERIAL			TECHNICAL		
	City/Town	County, State and Federal	Other	City/Town	County, State and Federal	Other
	Based on 6 Responses	Based on 8 Responses	Based on 3 Responses	Based on 34 Responses	Based on 9 Responses	Based on 10 Responses
10. Understanding of Flooding/Flood Warning						
- Adequate	59%	80%	71%	70%	73%	61%
- Inadequate	24%	14%	24%	23%	22%	27%
11. Desired Form of Communication						
• Preferable mode of receiving information	-	-	-	Telephone FAX Cable TV	Telephone FAX PC Modem	FAX Telephone
12. Expectations of Flood Warning Services						
- High	67%	94%	92%	88%	80%	92%
- Low	17%	6%	8%	7%	17%	7%
13. Alternate Uses of Flood Warning Services	Did Not Specify	Precipitation, Flood Retarding Storages	Did Not Specify	Gages, Rainfall Averages	Volume of Runoff, Surface Water Quality	Did Not Specify
14. Profile of Participants						
• Average time lived in Maricopa County	13years	16 years	11 years	23 years	16 years	26 years
• Traverse flood-prone areas routinely	50%	63%	67%	65%	78%	60%
• Aware of District prior to survey	83%	100%	100%	82%	100%	90%
• Contacted District for flood information previously	50%	75%	33%	26%	78%	30%

Metropolitan Communities vs.
Other Communities

TABLE D-3

RESULTS OF MARKET SURVEY BY METROPOLITAN/OTHER COMMUNITIES

Evaluation Criteria	MANAGERIAL Metropolitan	MANAGERIAL Other	TECHNICAL Metropolitan	TECHNICAL Other	HOMEOWNERS Metropolitan	HOMEOWNERS Other
	Based on 1 Response	Based on 5 Responses	Based on 15 Responses	Based on 19 Responses	Based on 40 Responses	Based on 11 Responses
1. Perception of Severity of Flood Threat						
- Serious/moderately serious in urban Maricopa County	100%	60%	80%	84%	45%	64%
- Minor problem/no problem in urban Maricopa County	0%	40%	20%	16%	48%	36%
- Serious/moderately serious in rural Maricopa County	100%	100%	80%	89%	70%	64%
- Minor problem/no problem in rural Maricopa County	0%	0%	20%	11%	25%	36%
2. History of Flooding						
2.1 General						
• Have been flooded/affected by flooding	100%	80%	87%	68%	28%	27%
2.2 Frequency						
• Average number of times flooded	-	-	3 times	4 times	3 times	4 times
2.3 Severity						
• Time affected for worst flood	-	-	2 weeks	1.5 weeks	3 days	1 week
• Time affected for average flood	-	-	5 days	2 days	-	-
2.4 Financial Impact						
• Impact of flooding on budget						
- Strong to moderate	0%	40%	20%	21%	-	-
- Little or no impact	100%	60%	80%	79%	-	-
• Average cost per flood	-	-	$20,000	$9,000	$1,000	$4,000
• Average cost for preparation for false alarms	-	-	n/a	n/a	n/a	$350
3. Accuracy of Current Flood Warning Services						
- Accurate	25%	21%	56%	62%	58%	52%
- Inaccurate	50%	48%	25%	10%	35%	46%
- Don't know/No opinion/Did not answer	25%	31%	19%	28%	7%	2%
4. Adequacy of Current Flood Warning Services						
- Adequate	57%	45%	53%	44%	52%	34%
- Inadequate	0%	25%	29%	26%	29%	55%
- Don't know/No opinion/Did not answer	43%	30%	18%	30%	19%	11%
5. Lead Time for Flood Warning						
• Lead time vs. accuracy						
- More lead time, less accuracy	0%	20%	13%	16%	38%	36%
- Less lead time, more accuracy	0%	40%	40%	32%	40%	55%
- Don't know/no opinion/did not answer	100%	40%	47%	52%	22%	9%
• Average desired lead time	1.5 hours	1 hour	2 hours	1.5 hours	1 hour	1 hour
6. Interest in Improved Flood Warning Services						
- Interested	28%	58%	73%	67%	83%	91%

TABLE D-3 (continued)

RESULTS OF MARKET SURVEY BY METROPOLITAN/OTHER COMMUNITIES

Evaluation Criteria	MANAGERIAL Metropolitan	MANAGERIAL Other	TECHNICAL Metropolitan	TECHNICAL Other	HOMEOWNERS Metropolitan	HOMEOWNERS Other
	Based on 1 Response	**Based on 5 Responses**	**Based on 15 Responses**	**Based on 19 Responses**	**Based on 40 Responses**	**Based on 11 Responses**
7. Current Flood Warning Information Sources						
• During a heavy storm	SRP Sheriff/Police Civil Defense	NWS Sheriff/Police Fire Dept. Weather Radio Civil Defense	NWS SRP Civil Defense	NWS Civil Defense Sheriff/Police	TV Radio Sheriff/Police Weather Radio	TV Radio Sheriff/Police
• Triggers emergency plan	SRP	TV/Radio Civil Defense	NWS Flood Warning Observed Flooding TV/Radio	Observed Flooding NWS Flood Warning TV/Radio	-	-
8. 24-Hour Staff Availability						
- Yes	-	-	93%	79%	-	-
9. Who Should Issue Flood Warnings						
• Most likely to obey if advised to evacuate	Sheriff/Police Governor District	Sheriff/Police Fire Dept. Governor	Sheriff/Police Fire Dept. Mayor	Sheriff/Police Mayor Civil Defense	Police Car Bullhorn, Police In-Person Notification, Civil Def. TV/Radio Bulletin	Police Car Bullhorn, Police In-Person Notification, Civil Def. TV/Radio Bulletin
• Best suited to collect and analyze weather data	NWS SRP District	NWS District	NWS District	NWS District	-	-
• Best suited to collect and analyze rainfall and runoff data	SRP District	District SRP NWS	District SRP	District NWS SRP	-	-
• Best suited to act as the decision maker for issuing flood warnings	Sheriff/Police Mayor District	NWS Mayor District Civil Defense	District NWS SRP	District NWS Civil Defense	-	-
• Best suited to act as decision maker for evacuating areas	Sheriff/Police Mayor District	Sheriff/Police Mayor Civil Defense District	Mayor Sheriff/Police Civil Defense	Sheriff/Police Mayor Civil Defense	District Sheriff/Police Civil Defense Fire Dept.	District Sheriff/Police Fire Dept. Civil Defense

TABLE D-3 (continued)

RESULTS OF MARKET SURVEY BY METROPOLITAN/OTHER COMMUNITIES

Evaluation Criteria	MANAGERIAL		TECHNICAL		HOMEOWNERS	
	Metropolitan	Other	Metropolitan	Other	Metropolitan	Other
	Based on 1 Response	Based on 5 Responses	Based on 15 Responses	Based on 19 Responses	Based on 40 Responses	Based on 11 Responses
10. Understanding of Flooding/Flood Warning						
- Adequate	71%	57%	64%	75%	70%	76%
- Inadequate	29%	23%	30%	17%	20%	21%
11. Desired Form of Communication						
• Preferable mode of receiving information	-	-	Telephone FAX PC Modem	Telephone FAX Cable TV	-	-
12. Expectations of Flood Warning Services						
- High	100%	60%	85%	89%	74%	77%
- Low	0%	20%	12%	4%	19%	21%
13. Alternate Uses of Flood Warning Services	Did Not Specify	Did Not Specify	Gages	Rainfall Averages	-	-
14. Profile of Participants						
• Average time lived in Maricopa County	19 years	11 years	18 years	27 years	14 years	10 years
• Traverse flood-prone areas routinely	0%	60%	33%	89%	53%	73%
• Aware of District prior to survey	100%	80%	80%	84%	70%	64%
• Contacted District for flood information previously	0%	60%	27%	26%	-	-

Appendix E

APPENDIX E

WRITTEN COMMENTS RECEIVED FROM MARKET SURVEY QUESTIONNAIRES

Comments received with the questionnaires are shown below. Comments were not modified, *including punctuation and spelling*, except where necessary to clarify the intent of the respondent. Clarifications are indicated in brackets [ ].

MANAGERIAL

- "Gilbert is very flat. Only minor flooding occurs. Recent flood control structures and basins have minimized our exposure."

- "As a federal organization [Soil Conservation Service], many of the questions don't directly apply."

- "Difficult for me to answer for a military installation [Luke Air Force Base] but tried to relate."

- "We [ADOT-Federal Highway Administration] are pleased to provide the enclosed response to your Managerial Flood Warning Services Survey. However, we feel a few comments may assist you in analyzing and properly recording our response.

  "The Federal Highway Administration is the Federal agency charged with administering the Federal-aid Highway Program. The primary focus of this program is on planning, designing, and constructing highway and street improvements (funding and oversight), with a secondary focus on maintenance and operations (oversight only). In discharging this mission, we work very closely with the State Highway agencies (in our specific case, the Arizona Department of Transportation), and, to a lesser extent, with local highway agencies.

  "We have a keen interest in flooding and flood control activities, primarily from the perspective of developing highway and street improvements which are able to withstand most flood events (1) without failure or significant damage, (2) without closure or loss of service, and (3) without causing or exacerbating damage to adjacent development. We also have an interest in these activities from the perspective of administering the Emergency Relief Program when significant damage to highway facilities occur. However, the scope of our programs and our activities do not require us to receive immediate flood watches, warnings, or forecasts. We have no capability or direct responsibility to act immediately prior or during flood events. Our primary responsibility is to rapidly assess damages after flooding has occurred, and to initiate, in cooperation with the State highway agency and appropriate elected officials, an Emergency Relief Program to provide for (fund) both emergency (often temporary) and permanent repair of highway facilities damaged by flooding.

  "We have responded to your survey from these perspectives."

TECHNICAL

- "Reference Flooding: [__________,] Town of Fountain Hills, works a lot with this type of problem, in his job duties with the street dept. He has much more first hand knowledge of flood control problems of our 18 square miles of the county than I do - I hope he received a questionnaire/survey."

- "I do not believe that another flash-flood agency is needed. Even the best forecasts by the national weather service can not predict storm behavior. Mapping potential flash flood areas has little benefit when dealing with the unpredictability of weather. It may even be counter productive in that those not in the mapped areas may get a false sense of security."
- "This kind of enhanced flood warning would be very valuable for the Valley as a whole. There would be certainly some value to our City [Tempe], although our protection limits much of the dangers to be controlled by these warnings."
- "Thank you for showing an interest to improve existing services."
- "Other parts of the ADEQ organization, such as those regulating wastewater treatment and disposal systems, public drinking water systems, solid waste disposal and hazardous waste disposal would answer this questionnaire differently."
- "Most flood hazard problems arise from (1) stupidity of individuals (2) the greed of land developers to build in flood hazard areas (3) behind the development curve to correct drainage problems after they have been created rather than initial designs/prevention."
- "When highways are closed due to flooding, they should be cleared & reopened promptly when flood has subsided - usually by 4 a.m."
- "We [Phoenix Transit System] provide public transportation, flooding prevents employees from being able to get to work, and forces us to reroute flooded areas."

HOMEOWNERS

- "Flood warnings for "downstream" area seems more appropriate than for foothills areas where I work and travel."
- "Flood <u>Prevention</u> would do even better! Building should be done so as to not change natural drainage paths & capacities."
- "The solution to this problem does not rest with flood warning. It rests with proper planning of the placement of housing & other improvements. If you build in or block a natural flood plain without provision for the water, it naturally follows you <u>will</u> be flooded."
- "If you want to put more effort into warnings, I feel it should go toward stopping people from driving across flooding washes. It may not stop them (mostly because they choose to be ignorant) but it wouldn't hurt to try."
- "Keeping the river channel and washes clean would help to eliminate future floodings. Also - allowing building of gravel pits, etc, in the channel is adding to the problem."
- "No amount of warning would save my house. Indian School Road needs to be lowered."
- "We have sufficient media & Public authority notification."
- "I am requesting a copy of the result - to the survey, to be sent to me at [__________]."

- "[Questions] 42 & 43 - I feel that less or no building of homes ect in normal flood areas would reduce damage. Flood control area should work more with city & builders & limit (stop) building in flood areas.

  "My husband threw this away & I retrieved & filled it out. His response might be different.

  "About 8-10 yrs ago a sand and gravel outfit began operation right nex to our property (east) & north. We called flood control because the high river bank that has held for 100 years or more was now gone. We feel a big river run could now be a threat to our land & home. We called flood control - answer you are probably right. Better get a good lawyer. This is 1 reason why I don't know who I would trust in time of an emergency."

- "We are not near a flood area in our home. [Question] #32 - Depends on where-when my appt is. I live in Mesa, work in N. Scottsdale (N. of Shea Blvd.)"

- "Flash flood watches/warnings issued over the radio/TV are much too generalized in locale to be taken seriously by the average citizen."

- "The Arizona Canal Diversion Channel is a big ugly concrete ditch. Please spare us more engineering marvels like this. To win public support in the 90's, you gotta do berms, dikes, retention & detention basins."

- "Although progress has been made to control flooding in the N.W. Phoenix area - warning systems are inadequate & vague; reliance on so called 'Civil Defense' unit would be fool hardy!!!"

- "Some of the information to be provided in the statements may not be available prior to flooding - such as height of water in house - this was considered in answering statements."

- "Even though there has been no flooding in my area, I tried to answer the questions to the best of my ability. My opinion is we should have more sewers for run-off and more diversionary canals, if and when funds are allocated to do so."

- "Freeway that are now being install around the citys, they cut out the rain water going south by southwest."

- "Even with adequate warning you can not change peoples I don't care attitude. Most would not listen. But it would be a benefit to those who do."

- "Its about time someone took the time to ask us. Thank you."

- "More attention, and money should be spent on improving the floor channels, and using them during non flood seasons for recreation & travel."

- "Introduction: I very much appreciate the opportunity to repspond to your questionnaire and the services provided by the Flood Control District. I am offering the following observations as a resident of Maricopa, County and the City of Scottsdale for the past 11 years. Thanks in advance for letting me share my thoughts and observations. Mr. Sagramoso, I would appreciate it if you discuss the results of your questionnaire and any of suggestions/writen rersponses on a cable or general televised format with the Board of Supervisors. In the event such a program is set up I would appreciate it if you would announce the date and time in local Valley newspapers as I bet others will have interest as well.

"1) **Drainage and Flood Control "Utility" System:** I have the perception that the Flood Control District is a Storm Drainage Utility. I realize that this is only a perception and in reality (I have checked) the Flood Control District operates on a subscription basis with the Cities in Maricopa, County. I reside in Scottsdale and I know that the City of Scottsdale sends a significant sum of money each year ($400,000) for this organization to co-ordinate our storm drainage system within the greater county system.

"My point here is that the Flood Control District should be set up as a "Utility" with payments made thru City/Town governments in their respective utility bills based on flood control needs within specific areas of each City/Town. Each City would (in this idea) operate as a franchise of the overall County Utility. Funds raised in each town (70% to 80%) would be spent on local flood control improvements. The remaining 20% to 30% of the funds generated would go to support the main overall County Utility and their co-ordination planning activities (including those areas that can not afford a professional staff). My percentages may be quite off but I trust the point is clear.

"My belief is that the City of Scottsdale gets very little value for the money sent to the existing system. I do not mean to imply a plot or subversion or anything sinister it's just the existing system does not give Scottsdale the value deserved based on mine and my fellow tax payers money spent! I believe that the folks involved in the present system a trying to make the system work as well as possible.

"The Indian Bend Wash is a magnificent example of what community involvement and strong local planning can accomplish for an effective storm drainage program and community amenity. I relaize the District had a role in the Indian Bend Wash but the Scottsdale Council, Zoning and Development Process had a lead role in the creation of this prize. The City of Scottsdale now has similar planning, design and construction needs for storm drainage in the area north of the CAP. This area will be a far more complicated project and likewise more expensive. I hope that some of the money we have paid and will pay astaxpayers will be used to manage the drainage issues in North Scottsdale.

"2) **Supervisors/County Manager/District General Manager:** Given the above 'Utility' as a reality someday, I believe that the Board of Supervisors that also serve as the District Board of Directors need to take a look at their organizational structure for a more streamlined approach.

"The County Highway Department, County Planning Department, County Information Services Organization all work under the direction of Roy Pederson as the County Manager. These organizations all manage information/systems that could be of direct service to such a Storm Drainage Utility. Mr Pederson's organization also has established working relationships with Cities and Towns that have responsibilities for local right of way (transportation/drainage) and "planning" activities in the area of land use.

"Dan Sagramoso's (MCFCD/GM) and his staff also have relationships with the same Cities and Towns organizations as Mr. Pedersons Organization. It seems to me that savings could be achieved if the organization forStorm Drainage and Flooding in Maricopa County worked within the budget of the County Manager w/driect working relationshiips with the other County offices which are the responsibility of Mr. Pederson.

"I realize there are some legal issues surrounding the funding that origionally established the District but if you share my sense that the present deployment of resources on this issue could be improved lets change the State Law enabling Act or whatever. I suspect the present system is getting close to being broke (what with Phoenix thinking of leaving the District) so it might be wise to 'fix it' soon.

"3) **North Scottsdale:** North Scottsdale has been designated in large measure a Flood Zone A classification. This designation in addition to the Scottsdale Enviromentally Senistive Lands Ordinance in effect assume that development may not take place until it is proven that the topography (scenic vistas), native vegitation and storm drainage are properly managed. Soon to some on to the scene for Scottsdale are EPA requirements for the "possible" treatment of storm drainage. I am not a radical enviromentalist but at the same time I do believe they have merit. I also relaize this "merit" has a price tag.

"My Community will continue to grow and prosper only if the City of Scottsdale has the tools to effectivly manage growth. This management includes a balance with the maintenance of the physical and financial environment. These tools include planning, design and construction of improvements that manage the path of storm drainage, quality of this water in concert with the planning development process in North Scottsdale.

"First, an information system is needed to magage these growth issues. The District can help here by allocating Scottsdale funds for these informations systems and planning activities in North Scottsdale. The private sector can then (in some instances) work with the City(s) in the installation of these improvements so the development may proceed in an appropriate fashion. This is not just a dream, it happened with the Scottsdale Indian Bend Wash. That same 'technology' can address this issue in North Scottsdale.

"Some of these information systems have already begun in Phoenix, Scottsdale, Mesa, Tempe, Salt River Project in the form of automated land base information systems. These are automated maps of the parcels and streets of these communities. The Flood Control District should reward the financial investments made by these communities (in addition to the investment in their District Subscriptions) by participating in the automated management of the topographic conditions that result in flooding issues. Your questionnaire spoke of a map for "early warning". These communities are building just such a map! This map can also be used to effectively evaluate and manage drainage and flooding options.

"In closing, I very much appreciate your having given me the opportunity to share my thoughts and those ideas you believe have merit for further consideration and improvement I thank you for listening."

- "Scottsdale Greenbelt has eliminated much flooding."
- "I am aware that the Flood Control District exists but I don't know what it does. I have heard flash flood warnings on the radio and TV, but I don't know if they actually occur."
- "The problem is most people don't use common sense. They think it won't happen to them. They think their 4-wheel 'HiRise' can go thru anything. Stop allowing builders to put homes etc. in flood plains (even 100 yr ones)."

Appendix F

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APPENDIX F

ESTIMATION OF RESIDENTIAL PROPERTY VALUE

ESTIMATION OF RESIDENTIAL PROPERTY VALUE BY COMMUNITY

Data from the 1990 census were collected for each community and included the total number of housing units, as well as the mean and total property values. The data is summarized by community in Table F-1.

ESTIMATION OF RESIDENTIAL PROPERTY VALUE IN THE ACDC REACH 4 STUDY AREA

Data from the 1990 census were collected by tract and included the tract number, the number of housing units, and the mean and total residential property values for each tract.

Some of the tracts were partially outside the ACDC Reach 4 study area. For these tracts, the percent development of each tract in the ACDC Reach 4 study area was estimated. The estimates were based on the Maricopa County 1990 Census Tract Map (Maricopa County, 1990), and on the Metropolitan Phoenix Street Atlas (Wide World of Maps, 1991) which indicated developed areas. The total number of housing units per tract within the ACDC Reach 4 area was estimated based on this percentage. The estimate of property value by tract is presented in Table F-2.

TABLE F-1

RESIDENTIAL PROPERTY VALUE BY COMMUNITY

Community	Number of Housing Units(1)	Mean Value ($)	Estimated Total Value ($)
Urban			
Avondale	2,939	66,394	195,131,000
Buckeye	1,122	58,801	65,975,000
Carefree	654	320,654	209,708,000
Cave Creek	925	160,945	148,875,000
Chandler	20,835	93,744	1,953,151,000
El Mirage	788	50,573	39,852,000
Fountain Hills	2,947	164,275	484,119,000
Gila Bend	295	42,375	12,501,000
Gilbert	6,421	122,038	783,607,000
Glendale	32,457	84,852	2,754,038,000
Goodyear	802	78,157	62,682,000
Guadalupe	728	38,709	28,180,000
Litchfield Park	1,021	163,342	166,773,000
Mesa	63,495	84,579	5,370,371,000
Paradise Valley	4,104	398,246	1,634,401,000
Peoria	14,726	81,775	1,204,218,000
Phoenix	212,020	90,323	19,150,249,000
Queen Creek	615	100,318	61,696,000
Scottsdale	34,145	146,511	5,002,619,000
Sun City	19,163	76,662	1,469,066,000
Sun City West	7,984	119,665	955,403,000
Sun Lakes	3,376	107,298	362,238,000
Surprise	1,664	56,377	93,811,000
Tempe	27,589	99,714	2,751,011,000
Tolleson	746	61,015	45,517,000
Wickenburg	1,303	72,120	93,973,000
Youngtown	888	48,485	43,055,000
Urban Total	**463,752**	**97,341**	**45,142,000,000**
Rural			
Unincorp. Maricopa Co.(2)	29,728	91,624	2,723,797,000
Rural Total	**29,728**	**91,624**	**2,724,000,000**
Maricopa County Total	**493,480**	**96,997**	**47,866,000,000**

(1) Only includes owner-occupied single family homes, duplexes, and mobile homes/trailers.
(2) Includes Komatke, Luke Air Force Base, and a small portion of Apache Junction.

Data Source: ADES, 1990

TABLE F-2

RESIDENTIAL PROPERTY VALUE IN ACDC REACH 4 STUDY AREA

1990 Census Tract No. (1)	Percent of Development by Tract in ACDC Reach 4 Area[(1)] (2)	Total Units[(2)] in Tract (3)	Total Units[(2)] in ACDC Reach 4 Area (4) = (2) x (3)	Mean Residential Property Value ($) (5)	Estimated Total Value for ACDC Reach 4 Area ($) (6) = (4) x (5)
1063	35	1,106	387	114,084	44,162,000
1064	50	755	378	136,744	51,621,000
1065	100	1,315	1,315	95,074	125,022,000
1066	40	953	381	217,959	83,086,000
1075	90	966	869	163,359	142,024,000
1076	100	1,229	1,229	95,786	117,721,000
1077	100	859	859	160,419	137,800,000
1078	50	654	327	330,390	108,038,000
1083	95	1,642	1,560	119,051	185,708,000
1084	100	912	912	94,944	86,589,000
1085	100	811	811	68,761	55,765,000
1086	100	644	644	55,064	35,461,000
1087	100	Indian School - No residential property			
1088	75	508	381	82,365	31,381,000
1105	90	257	231	93,113	21,537,000
1106	100	763	763	108,518	82,799,000
1107	100	1,097	1,097	64,160	70,384,000
1108	100	1,304	1,304	75,802	98,846,000
1109	60	994	596	87,735	52,325,000
1115	50	1,179	590	56,794	33,480,000
1116	100	1,073	1,073	55,353	59,394,000
1117	100	1,353	1,353	62,057	83,963,000
1118	90	853	768	115,015	88,297,000
1129	5	633	32	66,536	2,106,000
1130	60	109	65	112,385	7,350,000
1132	30	680	204	48,593	9,913,0000
1133	70	339	237	54,240	12,871,000
1135	5	629	31	53,200	1,673,000
Total					**1,829,000,000**

(1) Refers to percent development of tract that is included in the ACDC Reach 4 study area.
(2) Only includes owner-occupied single family homes, duplexes, and mobile homes/trailers.

Data Sources: ADES, 1990; Corps, 1987; Maricopa County, 1990; Wide World of Maps, 1991

Appendix G

APPENDIX G

ADJUSTMENTS TO ANNUAL CONTENTS FLOOD DAMAGE DUE TO EXISTING FLOOD CONTROL STRUCTURES

The annual contents flood damage amounts presented in the "Reduced Flood Damages" portion of the "Benefits of a Flood Warning System" subsection of Section 5 are based on an extrapolation and adjustment of the annual contents flood damage that occur in the ACDC Reach 4 study area *without* construction of Reach 4 of the ACDC. An adjustment to the annual contents flood damage is necessary to reflect additional flood protection from construction of Reaches 1, 2, 3, and 4 of the ACDC and upstream dams.

ADJUSTMENT DUE TO REACH 4 OF THE ACDC

In the Corps' ACDC Reach 4 report, annual flood damages were presented for conditions without and with construction of the ACDC in the Reach 4 inundation area. Therefore, based on these values, an adjustment can be made to the ACDC Reach 4 study area for construction of Reach 4 of the ACDC.

Expected annual contents flood damage without project and reduced damage with project in the ACDC Reach 4 study area were based on Tables 3-6 and 3-7 of the ACDC Reach 4 report as follows:

- Annual contents flood damage without project = $1,630,000/yr
- Annual contents flood damage PREVENTED with project = $1,328,000/yr

Therefore, the annual contents flood damage with project in the ACDC Reach 4 study area is $302,000/yr.

Using the equation for calculation of the annual contents flood damage, the annual contents damage for Phoenix excluding the ACDC Reach 4 study area is computed as follows:

- Unit ACDC Reach 4 annual contents damage without project = $81,500/sq mi/yr
- Area of Phoenix, less ACDC Reach 4 study area = 423 sq mi - 20 sq mi = 403 sq mi
- Unit residential property value per square mile in Phoenix, excluding the ACDC Reach 4 study area = $\frac{(\$19{,}150{,}249{,}000 - \$1{,}829{,}000{,}000)}{403 \text{ sq mi}}$ = $42,981,000/sq mi
- Unit residential property value per square mile in the ACDC Reach 4 study area = $91,000,000/sq mi

From Equation 5-1 in Section 5 of this report, the estimated annual contents damage in Phoenix, excluding the ACDC Reach 4 study area is:

$$\$81{,}500/\text{sq mi/yr} \times 403 \text{ sq mi} \times \frac{\$42{,}981{,}000/\text{sq mi}}{\$91{,}000{,}000/\text{sq mi}} = \$15{,}437{,}000/\text{yr}$$

As previously stated, the annual contents damage with project for the ACDC Reach 4 study area is $302,000/yr. Therefore, the estimated annual contents flood damage for Phoenix with an adjustment for Reach 4 of the ACDC is:

$$\$15{,}437{,}000/yr + \$302{,}000/yr = \$15{,}739{,}000/yr$$

ADJUSTMENT DUE TO REACHES 1 THROUGH 3 OF THE ACDC AND UPSTREAM DAMS

Economic data compiled by the Corps for Reaches 1 through 3 of the ACDC are not available. Therefore, to estimate the reduction in expected annual flood damages in areas protected by Reaches 1 through 3, the ratio of reduction in Reach 4 was used as follows:

$$\text{Reach 4 reduction ratio} = \frac{\$1{,}328{,}000/yr}{\$1{,}630{,}000/yr} = 0.8$$

The Cities of Glendale, Peoria, and Phoenix contain areas protected by the ACDC and upstream dams. The total area protected by the ACDC Reaches 1 through 3 includes 9 square miles in Glendale, 8 square miles in Peoria, and 30 square miles in Phoenix. These areas were estimated by JMM from inundation maps provided by the District of with-project and without-project scenarios. Table G-1 presents the calculation to determine the adjusted annual contents damage for the Cities of Glendale, Peoria, and Phoenix.

TABLE G-1

ADJUSTED ANNUAL CONTENTS FLOOD DAMAGE DUE TO CONSTRUCTION OF THE ACDC REACHES 1 THROUGH 3 AND UPSTREAM DAMS

City	Area Protected* (sq mi)	Total Area (sq mi)	Percent of Area Protected	Estimated Annual Contents Damage ($/yr)	Annual Contents Damage to be Adjusted ($/yr)	Annual Adjustment ($/yr)	Adjusted Annual Contents Damage ($/yr)
	(1)	(2)	(3)=(1)/(2)	(4)	(5)=(3)*(4)	(6)=(5)* 0.8	(7)=(4)-(6)
Glendale	9	53	17%	2,454,000	417,000	334,000	**2,120,000**
Peoria	8	58	14%	1,073,000	150,000	120,000	**953,000**
Phoenix	30	403*	7%	15,739,000	1,102,000	882,000	**14,857,000**

* The ACDC Reach 4 study area (20 square miles) has been subtracted from the area of Phoenix (423 square miles) because the area affected by Reach 4 of the ACDC has already been adjusted.

The last column of Table G-1 shows the annual contents flood damage for the Cities of Glendale, Peoria, and Phoenix with adjustments for flood protection from the ACDC. The adjusted damages are also shown in Table 5-4 of Section 5 of this report.