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An intelligent tutor for flood forecasting

Cyril Mehta
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An intelligent tutor for flood forecasting

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San Jose State University, 1992

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AN INTELLIGENT TUTOR FOR
FLOOD FORECASTING

A Thesis

Presented to

The Faculty of the Department of Meteorology
San Jose State University

In Partial Fulfillment
of the Requirements for the Degree
Master of Science

By

Cyril Mehta

May, 1992

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ABSTRACT

AN INTELLIGENT TUTOR FOR FLOOD FORECASTING

by Cyril Mehta

Flood forecasting is a complex problem for scientists and, potentially, a life-and-death concern for the general public. To address the task of teaching students the hydro-meteorological aspects involved in northern California flood prediction, an artificial-intelligence (AI) based tutoring program is described. Emphasis is placed on collecting and codifying knowledge deemed important in understanding the forecasting process. An interactive FORTRAN program gives a pupil access to the knowledge and to a set of exercises that tests the pupil's understanding. The program captures hydrological and meteorological knowledge related to flood forecasting in a single location, but the FORTRAN language's constraints limit the system's current level of intelligence. Potential ways to expand the program and enhance it with more AI characteristics are recommended.

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CHAPTER 1

INTRODUCTION

Flood forecasting is a complex problem for scientists and, potentially, a life-and-death concern for the general public. Understanding of the critical meteorological and hydrological processes involved has increased markedly in the past half-century as computers have emerged. Concurrent with progress on the scientific side, however, has come a growing human toll. From 1980 to 1986, floods killed over 1000 Americans, making them the deadliest severe-weather events (Wright 1989). As previously undeveloped areas become populated, water flow is inevitably altered, thus enhancing the potential for devastating floods. Clearly, weather forecasters need to comprehend fully the hydrological phenomena that influence where and when floods occur (Georgakakos 1986a).

A tool that could stimulate awareness of the hydro-meteorological nature of floods is the intelligent tutor, an outgrowth of artificial-intelligence (AI) research. The heart of AI is to study human intelligence and, as closely as possible, to represent it in computerized form. Practical applications of AI have included expert systems, programs that attempt to mimic the knowledge and the reasoning strategies employed by human experts in specific fields of study. By definition, such systems have advantages over

traditional, procedure-based programs because they must accommodate some form of qualitative as well as quantitative knowledge, uncertainty in data and in cause-and-effect relationships, and "flexibility" in reaching a solution to a problem. For example, a procedure-based program for determining the acidity of a liquid may be able to categorize it as a weak or strong acid or base using the measured concentration of hydrogen or hydroxyl ions. An expert system which contains the rule-of-thumb knowledge of a chemist could classify the same liquid based on the shade of color found on red or blue litmus paper after a drop of the liquid has been placed on the paper. Because of their benefits, the techniques learned in expert-system construction have been extended to the development of advisory and tutoring programs. Such programs have become popular in fields like law, medicine, economics, and geology since they assemble a broad range of knowledge in a single location and are easily accessible to both experts and novices.

The problem to be addressed in this project is the teaching of flood forecasting in northern California to interested students. An AI-based tutoring program is proposed as a solution. The short-term objectives are 1) to acquire expert knowledge, case histories, and basic concepts and codify them in an important component of an expert system, the knowledge base; 2) to incorporate the knowledge base in an interactive FORTRAN program; and 3) to provide

a blueprint for expanding the program and enhancing it with more AI characteristics. The longer-term goals would be 1) to design and implement a more "intelligent" tutoring program which features graphical displays and presents real-time flood-forecasting situations and 2) to help students understand the hydrometeorological character of flood events.

This thesis is arranged in the following way: Chapter 2 provides background, including a brief history of northern California floods, the meteorological and hydrological aspects of and current techniques and research in flood forecasting, and AI applications to meteorology, hydrology, and tutoring programs; Chapter 3 discusses the construction and implementation of the flood-forecasting tutoring program; Chapter 4 details possible future expansion of and refinements to the program; Chapter 5 presents conclusions from and implications of this project; and the Appendix lists the tutoring program's code.

CHAPTER 2

BACKGROUND

a. Northern California Floods

Floods regularly punctuate the meteorological history of northern California. A unique combination of natural and man-made conditions induces frequent, varied, and potentially dangerous flood events. Under such conditions, flood forecasting is both a challenging and an essential task.

During California's wet season, which runs from October to April, two semi-permanent pressure systems control the weather. These are the Pacific high and the Aleutian low (Figures 1 and 2). "Cold" storms originate over the Gulf of Alaska, north of the high, and are noted for the wide-spread, low-elevation, and sometimes heavy snow that they bring. "Warm" storms are supported by troughs that draw subtropical air from the central Pacific and bring excessive rainfall. A storm of either type, or one having some combination of both of their characteristics, is usually responsible for the most serious northern California flood events.

Many researchers have documented the causes and effects of California's floods. The widespread damage that occurred after the heavy rains of December 1955 illustrated the multi-faceted character that floods in California can display. According to Cole and Scanlon (1955) and Cayan and Namias (1982), a strong blocking high-pressure area over

Figure 1. Schematic diagram showing the surface pattern leading to "cold" winter storms over California (From California Department of Water Resources 1980).

Figure 2. Schematic diagram showing the surface pattern leading to "warm" winter storms over California (From California Department of Water Resources 1980).

the Bering Sea produced a split in the normal winter jet stream (Figure 3). One branch carried cold air from the north, and the other sent subtropical air streaming in from the southwest. The convergence of the two air masses brought extensive rain and snow to California (California Department of Water Resources 1980). Warm air preceding the storms hastened the melting of snow already on the Sierra Nevada mountains and contributed to the excessive runoff that caused widespread river flooding in the Sacramento and San Joaquin Valleys. Prolonged moderate-to-heavy rainfall saturated the ground over the northern two-thirds of the state, and combined with short but intense rain bursts, especially over mountainous terrain, to produce flash, river, and urban flooding along the coast, in the San Francisco Bay area, and in the Central Valley.

Other floods that had a similar meteorological background to the one in 1955-1956 took place in December 1964 and January 1965, January 1982, and February 1986 (California Department of Water Resources 1965; Cayan and Namias 1982; Hirschboeck 1987). Studies of these and other incidents over the past 35 years have increasingly acknowledged the need to account for hydrological concepts. The effects of reservoir and dam operations, construction along hillsides and in flood-prone areas, agricultural activities, erosion, and soil moisture are all essential factors in understanding and predicting floods.

Figure 3. Schematic diagram showing the surface pattern characteristic of the catastrophic floods of 1955, 1964, 1982, and 1986. Note the blocking high off the Alaskan coast that splits the jet stream.

b. Flood Forecasting

The development of increasingly powerful, widely available, and "user-friendly" computer technology has strongly influenced flood-forecasting techniques. Numerical models, satellite and radar imagery, and automated rain and stream gauges have allowed realistic flood scenarios to be tested, verified, and refined quickly and easily. Additionally, more prompt and accurate forecasts of potential flood events have become possible, though problems such as irregular data collection and limitations on model accuracy remain.

(1) Meteorological Aspects

Numerical atmospheric models often provide the first indications that flooding may occur in northern California. As discussed by Hirschboeck (1987), the most extreme and damaging floods in the United States occur in the West and evolve from anomalies in large-scale atmospheric circulation patterns. One such perturbation, blocking, causes a split in the wintertime jet stream over the north-central Pacific Ocean and a merger of polar and subtropical air masses over the Pacific coast (Figure 3). Strong blocks preceded the catastrophic floods of 1955, 1964, 1982, and 1986. Forecasters can detect abnormalities from model results provided by the National Meteorological Center (NMC) in Washington, D.C. (Shuman 1989). Models like the limited-area fine mesh model (LFM) and the nested grid model (NGM)

provide guidance for predicting temperature, pressure, wind, precipitation, and other patterns.

An integral part of the flood-forecasting procedure is the prediction of the amount and duration of precipitation over a given point or area of interest. Corfidi and Comba (1989) detailed the NMC's role, starting with the 12-, 24-, 36-, and 48-hour surface weather prognoses issued twice daily. Based on the NGM and the LFM, but manually modified for the longer forecast times as more complete model data arrives, these outlooks draw attention to the general location and timing of rainfall. For more precise data, local forecasters and hydrologists consult the NMC's Quantitative Precipitation Forecast (QPF) products. Two consecutive 6-hour forecasts are released four times a day, 24-hour QPFs are issued three times daily, and 15-, 21-, and 24-hour excessive rainfall predictions are also made each day. All rely on the surface weather forecast and satellite, radar, upper-air, and surface reports, with the 6-hour QPFs serving as updates for the 24-hour prediction. The QPF data is displayed on isohyetal (rainfall-contour) maps, and all except the 6-hour depictions are accompanied by a forecaster's written discussion of supporting reasoning. Excessive-rainfall outlooks are distributed to areas where total precipitation could exceed two inches (in the western United States) or 6-hour rainfall may be greater than a locally defined flash-flood threshold.

Northern California forecasters supplement the NMC's QPFs with local information. Trapp (1990) stated that the National Weather Service Forecast Office (NWSFO) in Redwood City combines the NMC's guidance data with the expertise of the office's forecasters, climatic history, and radar data to make four consecutive 6-hour QPFs twice a day for 17 circular areas of 30-mile radius. Also, since 1988, the Automated Local Evaluation in Real-Time (ALERT) gauging system has provided hourly rainfall data that update the QPFs.

Depending on the flood situation, some meteorological data require careful monitoring. Snowfall and temperature forecasts can warn of excessive spring runoff into rivers; satellite, radar, and surface observations indicate where persistent rainfall or thunderstorms may induce flash flooding (Fleming and Spayd 1986); and moist low-level flow in mountainous areas has been observed as a crucial precursor to bursts of heavy precipitation (Maddox et al. 1980).

(2) Hydrological Aspects

Heavy precipitation does not lead automatically to flooding. Whether or not a flood occurs also depends on how water flows on and below the ground. Thus, the flood-forecasting problem requires extensive use of hydrological techniques.

Hydrology's relationship to flood prediction has been discussed extensively (e.g., Ishihara 1970; Linsley et al. 1986; Bedient and Huber 1988; National Research Council 1988). One integral component of the relationship is the connection between rainfall and runoff. The amount of rain that stays on the surface and then collects in lakes, rivers, and low-lying areas depends primarily on the soil-moisture content, which can be parameterized by an Antecedent Precipitation Index (API) (Sittner et al. 1969). Combined graphically with the amount, duration, and time of year of a rain event, the API produces a runoff value for a given location (Figure 4). Since the early 1970s, the National Weather Service River Forecast System (NWSRFS) has used a more detailed, computerized soil-moisture accounting procedure than the API, the Sacramento Watershed Model (Monro and Anderson 1974; Kitanidis and Bras 1980), to compute runoff in six-hour increments.

Another important part of the flood-forecasting procedure, applicable mainly to areas around rivers and lakes, is the computation of the temporal and spatial distribution of runoff. Some factors that govern such a distribution are local topography, channel geometry, watershed size, and flood-control structures. A hydrograph, which indicates runoff variability, depicts the volume flow rate of water passing a stationary river gauge. Based on upstream

Figure 4. Typical graph for calculating runoff using the Antecedent Precipitation Index (API). The value of the API is calculated using an empirical formula like the one given above. The dashed line connects the API to the week of the year, the duration, and the amount of precipitation of a rain event to produce the depth of storm runoff. Storm runoff and API are measured in inches, where 1 in. = 2.54 cm (From Richards and Strahl 1969).

hydrographs, the times and heights of flood crests along a river's path may be calculated using a channel routing technique such as the Muskingum method (Linsley et al. 1986). The California/Nevada River Forecast Center (CNRFC) in Sacramento, a branch of the NWSRFS, runs computer programs to obtain, forecast, and verify the required data.

The Redwood City NWSFO monitors ALERT streamflow gauges along several northern California rivers, including the Russian, Napa, and Salinas, to supplement the CNRFC guidance. Real-time measurements from the gauges provide runoff and flood information needed for flood prediction, especially in mountainous and other difficult forecast areas.

(3) Procedure

Strem (1990) described a typical methodology that forecasters in northern California employ in flood prediction. Operational forecasting responsibility is shared by local National Weather Service (NWS) offices, like the one in Redwood City, and regional River Forecast Centers, such as the CNRFC in Sacramento. Both receive NMC model guidance; satellite and radar information, from which cloud cover and precipitation data can be deduced; surface and upper-air weather observations; snowpack data; and readings from ALERT and other automated warning systems. The CNRFC adds climatic facts and QPFs prepared by local NWS offices and feeds the acquired data into various hydrologic simu-

lation models. If the models indicate the potential for flash, river, or urban flooding within 72 hours, appropriate forecasts and guidance information are sent to local offices in the affected areas. Hydrographs produced from the model are translated into river heights and times, and areas where 0.5 inch of rain per hour is expected for at least a 3-hour period are noted as potential flood zones, as are poorly drained or saturated-soil locations where rainfall persists for extended periods. River-flood forecasts are normally issued to local offices two or three times daily, and flash- and urban-flood advisories are distributed as needed.

According to Barbato (1990), the Redwood City office disseminates flood watches and warnings to government agencies and the general public in the San Francisco and Monterey Bay areas. Information from the CNRFC and the NMC is refined by measurement from the ALERT system, observations of Sacramento radar, and rule-of-thumb expertise gleaned from forecasters. Flood watches are issued when all available information indicates favorable conditions for urban or flash flooding within 24 hours or for river flooding within 72 hours. Flood warnings are released when flooding is imminent or has been reported by automated gauges or human observers.

(4) Evaluation of Procedure

Computers have dramatically improved the understanding and forecasting of floods. For example, advances in data-

storage capacity and processing speed have made possible the routine use of realistic numerical-simulation models of the atmosphere and the soil. Additionally, computer networks and powerful portable computers allow predictions, rainfall and streamflow data, and other vital information to be distributed widely and quickly.

Progress in data collection also has been beneficial. An automated gauge network such as the ALERT system enables rapid notice of localized flooding problems and convenient verification of short-term forecasts (Taylor and Weikel 1989). Estimates from satellite and radar observations show small- and large-scale precipitation patterns, which can be especially valuable in ungauged areas. In addition, both space- and ground-based instruments can monitor soil moisture, erosion, vegetation, and other information needed to keep hydrologic models accurate.

Researchers have identified several areas in which flood prediction can be improved. Georgakakos and Hudlow (1984) stated that producing accurate QPFs is one of the most challenging problems. First, QPFs are generally not sufficiently precise to use in hydrologic models for predictions at specific points or in small watersheds beyond 30-60 minutes. Also, a study of the performance of QPFs issued by the NMC showed that forecast errors grew as the observed amount of precipitation increased (Charba et al. 1988). Related difficulties include a 50% average

error in hourly radar and satellite rainfall estimates (Trapp 1990) and unreliable orographic precipitation predictions due to "smoothing" in models of complex terrain (Schaaake 1990).

Other investigators have discussed additional points of concern. Schaaake (1990) mentioned the estimation of runoff in ungauged areas. The prediction of floods in places where urbanization or agricultural activities have altered the landscape is a problem raised by Bedient and Huber (1988). A third point, made by Georgakakos (1986b), is the need to extend warning times, especially before flash floods.

(5) Recent and Future Research

Statistical techniques have received widespread attention in recent years as ways to make better flood forecasts. Such methods compensate for inexact understanding of physical processes. For example, the National Research Council (1988) discussed using "synthetic" storms, or composites of previously observed events, to calculate probabilities of precipitation amounts from future storms. The Council also studied "storm transposition," a way to improve areal rainfall estimates by assuming that "meteorologically homogeneous" regions exist where a major storm that occurs at a specific place in a region can happen anywhere in it. Another approach, proposed by Schaaake (1990), would allow forecasters to manipulate a "stochastic precip-

itation generator." Any number of equally likely precipitation patterns could be simulated and their individual effects on different parts of a river system noted and stored for future reference. Georgakakos and Hudlow (1984) added that streamflow forecasts could be made more reliable if they were based on probability-weighted QPFs rather than on "contingency" QPFs, which are basically of the "hit-or-miss" variety.

Several researchers have written about the need to couple computerized, real-time prediction of precipitation and streamflow and to train forecasters in hydrometeorology, the interactions between hydrological and meteorological processes. To achieve these goals, Němec (1986) proposed requirements for a Forecasting Operational Real-Time Hydrological System (FORTH). Such a system would include real-time data collection, transmission, and processing; files containing current and historical information about models and hydrometeorological parameters; and components to update, evaluate, and disseminate forecasts. Georgakakos (1986b) has constructed and tested a hydrometeorological model that combines statistical methods with physical-process representations (Figure 5). Among its features are capabilities to update soil-moisture conditions from precipitation observations and rainfall data from streamflow measurements. The model, part of a proposed Integrated Hydrometeorological Forecast System (Figure 6), points out

Figure 5. Schematic representation of a stochastic-dynamic hydrometeorological model. Note the feedback between the observed and predicted precipitation, soil moisture, and runoff (From Georgakakos and Hudlow 1984).

INTEGRATED HYDROMETEOROLOGICAL FORECAST SYSTEM

Figure 6. Proposed Integrated Hydrometeorological Forecast System, incorporating a flash-flood model similar to that depicted in Figure 5 (From Georgakakos and Hudlow 1984).

the essential links between hydrology and meteorology about which few forecasters are knowledgeable (Georgakakos 1986a) and which need to be emphasized to both current and future meteorologists.

Schaake (1990) detailed future advances likely to benefit flood prediction. Graphical user interfaces will make visualization of the causes and effects of floods easier. More precise rainfall estimates will result from the combination of Next-Generation Weather Radar (NEXRAD) (Figure 7), automatic-rain-gauge, satellite, and cloud-model data. Finally, high-resolution graphical terrain models and remote- and ground-sensing of soil conditions will increase understanding of runoff, evaporation, and other hydrological processes.

c. Artificial Intelligence

Studies on representing human intelligence in computerized form began three decades ago. Some of the first practical applications, and those that continue to receive much attention, were expert systems. These programs capture knowledge of a particular field, or domain, like medical diagnosis. The collection of knowledge, called the knowledge base, serves as the permanent structure that acts on incoming data. The separation of knowledge from data and flexible problem-solving strategies are two unique expert-program traits. Whereas a traditional program may prescribe a single method for fixing a leaky water pipe, an expert

Figure 7. Example of a rainfall-intensity display from the Next-Generation Weather Radar (NEXRAD). Intensities are given in inches per hour (From Schaafe 1990).

system can propose several solutions by breaking the task down into a series of subtasks and rule-of-thumb comparisons a plumber would do, like checking several faucet settings and the severity of the leak for each one.

(1) Intelligent Tutoring Systems (ITS)

Clancey (1987) discussed the application of AI and expert-system techniques to tutoring programs. An intelligent tutoring system (ITS), especially one written in an AI-oriented language such as OPS-5 (Brownston et al. 1985) or Smalltalk (Pinson and Weiner 1988), should be able to solve the problems it presents to students; explain the steps in the solution; and analyze each pupil's answers individually, rather than following a fixed procedure. A dialogue with an ideal ITS (Figure 8) may begin with a student requesting data to solve a problem, such as determining why a local station cannot be picked up on a radio receiver. Then, an "expert simulator" scans the knowledge base to find possible "next steps," like adjusting the radio's antenna or checking the batteries. A "modeller" compares responses from the current user with those from both previous students and the simulator and then updates the "student model" with evaluations of accuracy and skill level. Based on this information, the tutor may explain its answers and provide either more basic or more advanced facts and problems.

Figure 8. Functional diagram of an ideal intelligent tutoring system (ITS) (From Clancey 1987).

A central question in ITS design is how the program should control the instructional process. During the 20-year history of ITS, programs have ranged from non-intrusive "coaches" to strict-monitoring "tutors." Carbonell (1970) designed the first teaching system that incorporated AI, "SCHOLAR." The program dealt with factual knowledge of South American geography, and it allowed a user to make assumptions with degrees of certainty during a learning session. Though considered a breakthrough when introduced, SCHOLAR is now considered primitive, partly because it could not explain wrong answers.

The "WHY" program, a significant modification of SCHOLAR, was constructed by Collins and Stevens (1980). The system employed the "Socratic" method by asking questions and providing many case studies from its knowledge base, thereby forcing a student to formulate general principles and find inconsistencies in his or her understanding. Tested on the meteorology domain, WHY taught cause-and-effect relationships among physical processes. The program did not build a student model: it could only evaluate individual responses.

A third tutoring program, the Sophisticated Instructor for Electronics (SOPHIE) (Brown et al. 1982), simulated circuit construction and fault diagnosis. The system, programmed in FORTRAN, was "reactive"; it did not teach systematically, but it evaluated a student's hypotheses about a

problem and offered a selection of methods to follow at every step of a solution process.

Wenger (1987) and Carroll and McKendree (1987) addressed other issues in ITS design. One is interface construction, which involves the clarity and convenience of a program for any potential user. Currently, question-and-answer formats are the most common, but graphical programming and natural-language dialogue are slowly emerging as desirable and feasible alternatives. Another point to keep in mind is the "grain of analysis," or how specific domain information should be to provide optimum assistance to a student. A third issue is how to organize a system's knowledge. While IF-THEN rules are a favorite form, they can become cumbersome as a knowledge base grows. An answer for this problem may lie in frame-based representation, in which information about objects like diseases or minerals is grouped in a structured form. Each frame acts as a prototype to guide the classification of new data, and the frames are organized hierarchically so that they inherit properties from and impart them to frames to which they are connected.

(2) ITS in Meteorology

Interest in applying AI to meteorology has emerged during the past few years. Many researchers have concentrated on the potential benefits to weather forecasting (Zubrick and Racer 1988). For example, data collection,

especially in mountains and other remote areas, is often either spatially or temporally inadequate, and atmospheric models are incomplete. A primary advantage of expert systems is that they can adjust their reasoning to account for such missing information. Additionally, expert programs can accept and store subjective knowledge, like a local forecaster's experience, and combine it with numerical data and confidence levels, thus potentially improving forecasting accuracy. Capturing its details in an expert system can streamline the forecasting process, and integrating the process into an ITS may help students understand the procedure and, at the same time, appreciate the power of AI.

Stevens and Collins (1980) discussed the strategies and skills a tutoring program should possess in order to teach a complex subject like meteorology. Specifically, in studying evaporation, the investigators found that a true ITS must contain multiple models of a concept so that pupils can broaden and deepen their knowledge, test hypotheses, and make predictions. For example, one model, simulating the basic facts of the evaporation process, could depict air and water molecules as billiard balls. Faster evaporation at higher temperatures could be shown by water "balls" escaping into the air "balls" at an increasing rate. Adding a second, functional model that describes cause-and-effect relationships among temperature, humidity, and wind

would allow students to see and adjust the links not explicit in the simulation model. In addition, models of the water cycle and of climate can highlight evaporation as a local aspect of global processes, such as cloud formation and frontal development.

The Forecaster's Intelligent Discussion Expert System (FIDES) (Moninger et al. 1989) attempts to collect the skills of experienced forecasters in observing, analyzing, diagnosing, and predicting summertime convection over the high plains of Colorado. Users interact with FIDES via menus of hemispheric-scale, synoptic-scale, and mesoscale atmospheric features. Current or future data for all features relevant to a particular forecast problem are entered, and the knowledge base can be searched for details of or the reasoning behind a feature's importance as well as for the system's preferred forecasting method. The knowledge, represented in a frame-based scheme, and the interactive menus have been implemented using the expert-system-prototyping program NEXPERT. Evaluation of FIDES is in progress.

Reiss and Hofmann (1988) developed "TEACHMET," an expert system to teach weather prediction to undergraduate students in meteorology. Initial work on the system has concentrated on capturing information about precipitation forecasting and storing it using the software package ES/P Advisor. A student "converses" with TEACHMET about the

details of a forecast he wants to make, including which observations and maps to look at and the reasons for using such information. At the end of a tutoring session, TEACHMET makes the actual forecast, but students can ask the system to defend its solution in order to draw their own conclusions.

(3) ITS in Hydrology

As in meteorology, the emergence of expert systems in hydrology is a fairly recent phenomenon. One system that has potential application in flood forecasting is "FLOOD ADVISOR" (Rossman and Siller 1987). The program, written in C, estimates design floods for civil-engineering projects. Though not strictly a tutoring system, FLOOD ADVISOR can provide a user advice on and run one of several flood-estimation algorithms based on inputs prescribed by the user.

Fayegh and Russell (1986) described another expert system that could be incorporated into an ITS. The system assists in predicting the flow behavior of a river with varying amounts of historical data. For five user-described cases ranging from a complete lack of rainfall and stream-flow data in the vicinity of a river to a "relatively long" period of record for both types of information, the system offers probabilities of future flood crests and the reasoning behind such forecasts.

The capabilities of a typical ITS currently are rudimentary when compared against a human teacher. However, research into natural-language dialogue and into models of how students learn and apply new ideas continues to find ways to improve the intelligence of computerized tutors.

CHAPTER 3

SYSTEM DESCRIPTION

The work detailed in this section forms the basis for an intelligent tutoring system to teach flood-forecasting methods applicable to northern California. The program's components (Figure 9) have been coded in FORTRAN 77 (Ellis 1990) on an IBM PC. Pupils can gain access to the system via a keyboard and a monitor.

a. Knowledge Collection

An important part of any expert system is the knowledge base. Such a collection can include descriptions of objects, cause-and-effect relationships, rules of thumb, case histories, and confidence levels. In an ITS, the knowledge base is supplemented by methods that attempt to communicate information, increase understanding, probe misconceptions, and evaluate progress. Thus, the effectiveness of an ITS is strongly influenced by the preparatory work done in knowledge compilation and organization.

Knowledge for the flood-forecasting tutor was gathered from several sources. Written questions were submitted to and conversations conducted with experts at the NWSFO in Redwood City (Barbato 1990; Trapp 1990) and the CNRFC in Sacramento (Strem 1990). Additionally, textbooks, conference papers, and journal articles were consulted. Information was sought on the hydrometeorological characteristics

Figure 9. System overview.

of past floods, the typical methods that are currently used in flood prediction, the quality and availability of required data, the role of expert judgment, and areas in which improvements in forecast timeliness and accuracy are needed.

b. Knowledge Codification

Following the inquiries into the forecasting process, a knowledge base with three components and a group of exercises to test a pupil's understanding was organized. Characteristic of many expert programs, the knowledge was represented in more than one format. The complete contents of the knowledge base and the exercise set, including Figures 23-40, are listed in the Appendix.

Two sections were written in essay form. One, entitled "Introducing Flood Forecasting," gives a brief description of the subject's importance. The other includes case studies of the January 1982 and February 1986 California flood events. It contains written descriptions accompanied by precipitation and river data and weather maps showing the progression of each event.

The "Forecasting Procedure" section contains seven files arranged in a "tree" structure (Figure 10). The vocabulary list is written in a dictionary-like style, giving important words and a short description of each. For areas in which a relatively large amount of information was assembled, a "frame" structure for capturing knowledge

Figure 10. File structure of the "Forecasting Procedure" section.

was devised. Details of the data collected, models used, and forecasts issued by the NMC in Washington, D.C., the CNRFC in Sacramento, and the NWSFO in Redwood City are grouped into "slots" of the frames, as are crucial hydrological characteristics affecting whether or not flooding takes place. For example, the "24-Hour QPF" frame includes slots on the forecast's purpose, inputs, issuance times, period of validity, and outputs (Figure 11). A similar frame format is employed in the "Meteorological Characteristics" file, and the frames are linked in a hierarchical arrangement (Figure 12). Within each frame, the "Parent" designator shows that properties are inherited from frames "higher" in the tree, and the "Child" slot indicates that characteristics are passed to lower frames. Thus, the "Quasi-Stationary Storm Track" frame receives properties from "Tropical Air Mass" and "Polar Air Mass" and imparts traits to "Prolonged Precipitation."

The component named "Exercises" presents questions and simulated forecasting cases that assist and assess a student's progress in grasping the important concepts of flood forecasting. The queries that are currently stored require numerical or short-phrase answers. With each question comes the correct answer and rejoinders to "correct" and "incorrect" responses. "Branch" questions, labelled with non-zero numbers after the decimal point (e.g., 1.10, 1.20), provide queries related to the "root" question (e.g.,

OBJECT: 24 HOUR QPF
PURPOSE: SHOW ISOHYETAL MAP AND PROVIDE REASONING BEHIND
FORECAST
INPUTS: SAME AS 6-HOUR QPF
FORECAST LENGTH: 24 HOURS ENDING 1200 UTC
ISSUED: 4 FORECASTS:
1. "PRELIMINARY" 0730 UTC DAY 1 = VALID 1200 UTC DAY 1
TO 1200 UTC DAY 2
2. "FINAL" 1030 UTC DAY 1 = VALID TIME SAME AS # 1
3. 1030 UTC DAY 1 = VALID 1200 UTC DAY 2 TO 1200 UTC
DAY 3
4. 1930 UTC DAY 1 = VALID TIME SAME AS # 1
OUTPUT: ISOHYETAL MAP WITH DISCUSSION OF REASONING,
FORECASTER CONFIDENCE, COMPARISON WITH MODEL RESULTS, AND
LOCAL EFFECTS

Figure 11. Example of the frame structure used to store
knowledge. The frame shows the characteristics of the
24-hour QPF issued by the NMC.

Figure 12. Depiction of a portion of the hierarchical arrangement of frames in the "Meteorological Characteristics" file. This view shows factors leading to heavy precipitation.

1.00) that probe potential areas in which a pupil's misconceptions or lack of understanding may have led to a wrong response to the root. Simulations allow a user to request stored data and compare his prediction and reasoning to the tutor's answer.

c. Program Structure and Features

The tutoring program that gives a user access to the knowledge base and the exercises consists of a main program and 15 associated subroutines (Figure 13). It also contains a brief user's manual to the program. Pupils open a session with the tutor by typing "FLOOD" at the Disk Operating System (DOS) prompt. The program prints a welcoming message and then requests a user identification code. Next, it displays the topic menu from which a desired section is selected (Figure 14). A similar menu format guides a student's actions and movements within and between sections.

Typing "1" following the display of the main menu in Figure 14 opens the "Introducing Flood Forecasting" file. After every tenth line of this file and after every entry or tenth line in other knowledge files, the program provides a list of options. In the present case, the user can either continue to read the text file by entering "C" or leave the file and return to the main menu by typing "R" (Figure 15).

A user who chooses "2" from the main topic menu can study various aspects of the "Forecasting Procedure."

Figure 13. Program overview. The "Screen" subroutine displays user options in each of the four parts, and Part 2 can be entered from Parts 3 and 4.

```
Jethro C:\MSFORT\CYRIL>flood  
WELCOME TO THE INTELLIGENT TUTOR  
FOR FLOOD FORECASTING
```

```
IF YOU WISH TO SEE A USER MANUAL, TYPE 0  
IF NOT, TYPE 1
```

```
1
```

```
PLEASE ENTER YOUR I.D. WORD (MAX 6 CHARACTERS):  
'cyril'
```

```
PLEASE CHOOSE ONE OF THE FOLLOWING TOPICS:
```

```
1 = INTRODUCING FLOOD FORECASTING  
2 = THE FORECASTING PROCEDURE  
3 = A CASE STUDY  
4 = EXERCISES  
TYPE 5 TO QUIT PROGRAM
```

Figure 14. Illustration of the beginning of a tutoring session. User responses in this figure and in succeeding figures are underlined.

PLEASE CHOOSE ONE OF THE FOLLOWING TOPICS:

- 1 = INTRODUCING FLOOD FORECASTING
- 2 = THE FORECASTING PROCEDURE
- 3 = A CASE STUDY
- 4 = EXERCISES

TYPE S TO EXIT PROGRAM

1

THIS PROGRAM IS DESIGNED TO MAKE YOU AWARE OF THE BASICS OF FLOODS A FLOOD FORECASTING, WITH SPECIFIC APPLICATION TO NORTHERN CALIFORNIA. IT INCLUDES DISCUSSIONS OF PAST NORTHERN CALIFORNIA FLOODS, HYDROMETEOROLOGICAL ASPECTS OF FLOODS AND THEIR PREDICTION, AND THE FORECASTING PROCEDURE. IT ALSO CONTAINS CASE STUDIES OF PAST FLOOD EVENTS AND EXERCISES TO SHARPEN YOUR KNOWLEDGE.

FLOOD FORECASTING IS A COMPLEX PROBLEM FOR SCIENTISTS AND, POTENTIALLY, A LIFE-AND-DEATH CONCERN FOR THE GENERAL PUBLIC. UNDERSTANDING OF THE CRITICAL METEOROLOGICAL AND HYDROLOGICAL

OPTIONS FOR PART ONE

- C = CONTINUE READING FROM SAME FILE
- R = RETURN TO MAIN MENU

TO VIEW PICTURES, TYPE C WHILE HOLDING DOWN THE Ctrl KEY, THEN TYPE display AT THE PROMPT. TO RETURN TO THIS PROGRAM, PRESS Esc KEY TWICE, TYPE Y, AND THEN TYPE text AT THE PROMPT. FIND PROPER PROGRAM SECTION, AND CONTINUE AS BEFORE

C

PARAMETERS INVOLVED HAS INCREASED MARKEDLY IN THE PAST HALF-CENTURY AS COMPUTERS HAVE EMERGED. CONCURRENT WITH PROGRESS ON THE SCIENTIFIC SIDE, HOWEVER, HAS COME A GROWING HUMAN TOLL. FROM 1920 TO 1980, FLOODS KILLED OVER 1000 AMERICANS, MAKING THEM THE DEADLIEST SEVERE-WEATHER EVENTS. AS PREVIOUSLY UNDEVELOPED AREAS BECAME POPULATED, WATER FLOW IS INEVITABLY ALTERED, THUS ENHANCING THE POTENTIAL FOR DEVASTATING FLOODS. CLEARLY, WEATHER FORECASTERS NEED TO COMPREHEND FULLY THE HYDROLOGICAL PHENOMENA THAT INFLUENCE WHERE AND WHEN FLOODS OCCUR.

FLOODS REGULARLY PUNCTUATE THE METEOROLOGICAL HISTORY OF NORTHERN

OPTIONS FOR PART ONE

- C = CONTINUE READING FROM SAME FILE
- R = RETURN TO MAIN MENU

TO VIEW PICTURES, TYPE C WHILE HOLDING DOWN THE Ctrl KEY, THEN TYPE display AT THE PROMPT. TO RETURN TO THIS PROGRAM, PRESS Esc KEY TWICE, TYPE Y, AND THEN TYPE text AT THE PROMPT. FIND PROPER PROGRAM SECTION, AND CONTINUE AS BEFORE

R

Figure 15. Illustration of the options and actions possible within the "Introducing Flood Forecasting" file.

Access to the files in this section is controlled by a series of submenus and indices (Figure 16). Besides the options described for Part 1, two special ones are available. Option "T" allows one to transfer between subjects contained underneath "Characteristics" and "Forecast Ingredients and Products," while option "S" enables entry into a different subtopic (Figure 17).

Main topic "3" deals with case studies of the January 1982 and February 1986 flood events in northern California. A user reading about these events can take advantage of the "C" and "R" options as discussed for Part 1, and can also select the "E" option, which enters Part 2 and allows one to clarify the meaning or importance of some aspect of the studies.

Topic "4" is a set of flood-forecasting exercises and simulations. A pupil can choose to practice flood-forecasting skills by using numerical and pictorial data in analyzing a realistic situation. After composing a response on paper, students may compare their reasoning to that displayed by the tutor. Following the simulation, or immediately after entering the topic, one can do a set of exercises (Figure 18). After typing "1.0" in order to view the first question, and depending on whether a response is correct or incorrect, the program prints an appropriate rejoinder. Following an incorrect reply, the student can either review the appropriate section noted in the rejoinder

PLEASE CHOOSE ONE OF THE FOLLOWING TOPICS:

- 1 = INTRODUCING FLOOD FORECASTING
- 2 = THE FORECASTING PROCEDURE
- 3 = A CASE STUDY
- 4 = EXERCISES

TYPE 5 TO QUIT PROGRAM

2

CHOOSE ONE OF THE FOLLOWING SUBTOPICS

- 1 = VOCABULARY
- 2 = CHARACTERISTICS
- 3 = FORECAST INGREDIENTS AND PRODUCTS
- 4 = GENERAL FORECAST PROCEDURE

2

CHOOSE FROM

- 1 = METEOROLOGICAL CHARACTERISTICS
- 2 = HYDROLOGICAL CHARACTERISTICS

1

CHOOSE A # FOR DESIRED WORD OR CASE

- 1 BLOCK NR. AK / TROUGH NR. HI
- 2 BLOCK NEAR HI / WEST COAST TROUGH / ZONAL FLOW
- 3 500 MB TEMPERATURE
- 4 500 MB WIND
- 5 TROPICAL AIR MASS
- 6 POLAR / MARITIME AIR MASS
- 7 FREEZING LEVEL
- 8 QUASI-STATIONARY STORM TRACK / FRONTAL BAND
- 9 UPPER-LEVEL DISTURBANCE
- 10 SURFACE WIND
- 11 PRECIPITABLE WATER
- 12 PROLONGED PRECIPITATION
- 13 HEAVY PRECIPITATION
- 14 LIGHT PRECIPITATION

Figure 16. Illustration of a typical series of submenus displayed after selection of the "Forecasting Procedure" topic.

a) FREEZING LEVEL

IMPORTANCE: WARM AIR MASSES RAISE THE ELEVATION BELOW WHICH ACCUMULATED SNOW MELTS - THIS CAN CAUSE INCREASED RUNOFF INTO BASINS IN OR NEAR MOUNTAIN RANGES AND CAUSE FLOODING EVEN AFTER LITTLE OR NO PRECIP. IN THE AREA.

PRECURSOR: TROPICAL AIR MASS = HIGH

POLAR / MARITIME AIR MASS = LOW

MONITORED DATA: SURFACE TEMPERATURES IN MOUNTAINOUS AREAS.

PARENT: TROPICAL AIR MASS, POLAR / MARITIME AIR MASS

CHILD: HIGH FLOOD POTENTIAL, LOW FLOOD POTENTIAL

OPTIONS FOR PART TWO

A = RETURN TO LOCN. IN PART 4 WHERE "E" WAS CHOSEN

C = CONTINUE READING FROM SAME FILE

R = RETURN TO MAIN MENU

S = RETURN TO SUBMENU

T = RETURN TO TOPIC MENU UNDER SUBMENU SUBJECT

TO VIEW PICTURES, TYPE C WHILE HOLDING DOWN THE Ctrl KEY, THEN TYPE display AT THE PROMPT. TO RETURN TO THIS PROGRAM, PRESS Esc KEY TWICE, TYPE Y, AND THEN TYPE text AT THE PROMPT. FIND PROPER PROGRAM SECTION, AND CONTINUE AS BEFORE

I

CHOOSE FROM

1 = METEOROLOGICAL CHARACTERISTICS

2 = HYDROLOGICAL CHARACTERISTICS

2

b) HYDROGRAPH

PURPOSE: DEPICT VOLUME FLOW RATE (DISCHARGE) PAST OR STAGE AT A GIVEN POINT ALONG A RIVER OVER A CERTAIN TIME PERIOD.

INPUTS: STORM MAGNITUDE AND DURATION, SOIL MOISTURE CONDITIONS.

RUNOFF

OUTPUT: DISCHARGE (VOLUME FLOW RATE) OR STAGE VS. TIME. (SEE FIG. 24)

OPTIONS FOR PART TWO

A = RETURN TO LOCN. IN PART 4 WHERE "E" WAS CHOSEN

C = CONTINUE READING FROM SAME FILE

R = RETURN TO MAIN MENU

S = RETURN TO SUBMENU

T = RETURN TO TOPIC MENU UNDER SUBMENU SUBJECT

S

CHOOSE ONE OF THE FOLLOWING SUBTOPICS

1 = VOCABULARY

2 = CHARACTERISTICS

3 = FORECAST INGREDIENTS AND PRODUCTS

4 = GENERAL FORECAST PROCEDURE

Figure 17. Illustrations of the actions of options "T" and "S." (a) Option "T" was selected while reading the "Meteorological Characteristics" file. (b) Option "S" was chosen while reading the "Hydrological Characteristics" file.

```

PLEASE CHOOSE ONE OF THE FOLLOWING TOPICS:
  1 = INTRODUCING FLOOD FORECASTING
  2 = THE FORECASTING PROCEDURE
  3 = A CASE STUDY
  4 = EXERCISES
TYPE S TO QUIT PROGRAM
4
IF YOU WISH TO TRY A SIMULATED FORECAST EXPERIENCE, TYPE Y. IF NOT, TYPE N
N
IF YOU WISH TO DO EXERCISES, TYPE X
X
IF YOU ARE NEW TO THIS PROGRAM, TYPE 1.0 AT THE PROMPT
IF YOU WISH TO START AT A QUESTION OTHER THAN 1.0, TYPE <INTEGER>.0
IF YOU WISH TO VIEW YOUR EVALUATION FILE, TYPE 0.0

1.0
*****
OPTIONS FOR PART 3 AND 4
  A = RETURN TO PART 4 SIMULATION (FROM PART 3)
  C = CONTINUE READING FROM SAME FILE
  E = GO TO PART 2 TO REVIEW MATERIAL (FROM EXER.)
  R = RETURN TO MAIN MENU
  Y = REVIEW CASE STUDY IN PART 3 (TO DO SIMUL.)
TO VIEW PICTURES, TYPE C WHILE HOLDING DOWN THE Ctrl KEY. THEN TYPE
display AT THE PROMPT. TO RETURN TO THIS PROGRAM, PRESS Esc KEY TWICE,
TYPE Y. AND THEN TYPE text AT THE PROMPT. FIND PROPER PROGRAM SECTION,
AND CONTINUE AS BEFORE
*****
C
Q: 1: OROGRAPHIC PRECIPITATION OVER CALIF. IS GENERALLY GREATEST WHEN
LOW-LEVEL WINDS ARE FROM WHAT DIRECTION (IN DEGREES)?
*****
A NUMERICAL RESPONSE IS REQUIRED
222.5
THE ANSWER IS AROUND 225. TO CLARIFY YOUR UNDERSTANDING, REVIEW
"METEOROLOGICAL CHARACTERISTICS" OR DO THE SET OF QUESTIONS THAT
FOLLOW.

```

Figure 18. Illustration of the choices presented to the user upon entering the "Exercises" section.

or answer a set of follow-up questions. Typing "C" causes the program to ask a new question, while entering "E" interrupts the question-and-answer session and recalls Part 2 so that any desired material can be reviewed (Figure 19). The user may exit Part 2 and resume the exercises by typing "A" (Figure 20). After leaving Part 4 with the "R" option, or during a future tutoring session, the pupil may check his or her performance on previously completed exercises by re-entering Part 4 and typing "0.0" to view an evaluation file (Figure 21).

A user can end a tutoring session at any time by returning to the main topic menu and typing "5." This action will terminate the program with a closing message (Figure 22).

d. Evaluation

Several positive aspects may be discerned in the intelligent tutoring program at its current stage of development. First, the presence in the same system of knowledge from both hydrology and meteorology sets the stage for future expansions that could satisfy the pressing need for hydro-meteorological education cited by researchers (e.g., Georgakakos 1986a; Schaake 1990). In addition, the structured nature of the program and of the frame-based knowledge encourages straightforward modifications when necessary. Also, the convenience of having essential flood-forecasting information collected in one location and the

Q: AT APPROXIMATELY WHAT LONGITUDE (WEST) WOULD AN OMEGA BLOCK BE
CENTERED FOR THE POTENTIAL OF SEVERE FLOODING TO EXIST

130

AT AROUND 165. REVIEW METR. CHARACTERISTICS

OPTIONS FOR PART 3 AND 4

C = CONTINUE READING FROM SAME FILE

E = GO TO PART 2 TO REVIEW MATERIAL

R = RETURN TO MAIN MENU

E

CHOOSE ONE OF THE FOLLOWING SUBTOPICS

1 = VOCABULARY

2 = CHARACTERISTICS

3 = FORECAST INGREDIENTS AND PRODUCTS

2

CHOOSE FROM

1 = METEOROLOGICAL CHARACTERISTICS

2 = HYDROLOGICAL CHARACTERISTICS

1

CHOOSE A # FOR DESIRED WORD OR CASE

- 1 BLOCK NR. AN / TROUGH NR. HI
- 2 BLOCK NEAR HI / WEST COAST TROUGH / ZONAL FLOW
- 3 500 MB TEMPERATURE
- 4 500 MB WIND
- 5 TROPICAL AIR MASS
- 6 POLAR / MARITIME AIR MASS
- 7 FREEZING LEVEL
- 8 QUASI-STATIONARY STORM TRACK / FRONTAL BOLD
- 9 UPPER-LEVEL DISTURBANCE
- 10 SURFACE WIND
- 11 PRECIPITABLE WATER
- 12 PROLONGED PRECIPITATION
- 13 HEAVY PRECIPITATION
- 14 LIGHT PRECIPITATION

FREEZING LEVEL

IMPORTANCE: WARM AIR MASSES RAISE THE ELEVATION BELOW WHICH ACCUMULATED
SNOW MELTS - THIS CAN CAUSE INCREASED RUNOFF INTO BASINS IN OR NEAR
MOUNTAIN RANGES AND CAUSE FLOODING EVEN AFTER LITTLE OR NO PRECIP.
IN THE AREA.

PRECURSOR: TROPICAL AIR MASS = HIGH

POLAR / MARITIME AIR MASS = LOW

MONITORED DATA: SURFACE TEMPERATURES IN MOUNTAINOUS AREAS.

PARENT: TROPICAL AIR MASS. POLAR / MARITIME AIR MASS

CHILD: HIGH FLOOD POTENTIAL. LOW FLOOD POTENTIAL

Figure 19. Illustration of the "E" option of Part 4.
Selection of "E" causes the system to exit Part 4 and
enter Part 2.

```

OPTIONS FOR PART TWO
  A = RETURN TO LOCN. FROM WHICH "E" WAS CHOSEN
  C = CONTINUE READING FROM SAME FILE
  R = RETURN TO MAIN MENU
  S = RETURN TO SUBMENU
  T = RETURN TO TOPIC MENU UNDER SUBMENU SUBJECT
"A"
*****
*****

OPTIONS FOR PART 3 AND 4
  C = CONTINUE READING FROM SAME FILE
  E = GO TO PART 2 TO REVIEW MATERIAL
  R = RETURN TO MAIN MENU
"C"
*****

Q:  WHAT TYPE OF RAIN REGIME IS MOST COMMONLY THE CAUSE OF N. CALIF.:
    FLOODING
    1 = CONVECTIVE OR SHORT, INTENSE PRECIPITATION
    2 = CONTINUOUS, MODERATE RAIN FOR EXTENDED PERIODS
    ~~~~~
2

```

Figure 20. Illustration of the "A" option of Part 2. If a user wishes to return to the exercises, he selects "A" and then "C." The question-and-answer session then picks up where it was interrupted.

PLEASE CHOOSE ONE OF THE FOLLOWING TOPICS:

- 1 = INTRODUCING FLOOD FORECASTING
- 2 = THE FORECASTING PROCEDURE
- 3 = A CASE STUDY
- 4 = EXERCISES

TYPE 5 TO QUIT PROGRAM

4

IF YOU ARE NEW TO THIS PROGRAM, TYPE 1.0 AT THE PROMPT

IF YOU WISH TO VIEW YOUR EVALUATION FILE, TYPE 0.0

0.0

1.000000	CORRECT
2.000000	CORRECT
3.000000	INCORRECT
4.000000	CORRECT
5.000000	CORRECT

Figure 21. Example of a student's evaluation file. This can be displayed after re-entering Part 4.

PLEASE CHOOSE ONE OF THE FOLLOWING TOPICS:
1 = INTRODUCING FLOOD FORECASTING
2 = THE FORECASTING PROCEDURE
3 = A CASE STUDY
4 = EXERCISES
TYPE 5 TO QUIT PROGRAM
5

THANK YOU FOR USING
THE INTELLIGENT TUTOR
FOR FLOOD FORECASTING
Stop - Program terminated

Figure 22. Illustration of the termination of a session.

interactive format of the program should attract students to the system.

Restrictions imposed by the FORTRAN programming language somewhat limit the capabilities of the program. For example, consider question 2.00 in the exercise set, "In what situation is QPF considered least accurate?" Since the tutor lacks natural-language understanding, users must answer with either numbers or single letters associated with pre-determined responses (e.g., "A = Light, B = Moderate, C = Heavy Precipitation"). Another potentially distracting feature is the display of options after every text line in Parts 1-3. This can result in the text being interrupted in mid-sentence or mid-paragraph. Changes in the program that would allow the options to be listed more naturally, either between paragraphs or in a fixed position on the screen, could ease this problem.

CHAPTER 4

RECOMMENDATIONS FOR FURTHER RESEARCH

Several areas exist in which modifications and improvements can be made to the flood-forecasting tutor to give it more "intelligence" and to make it more valuable for a student. Potential research opportunities range from expanding the knowledge base to creating graphical tools.

The knowledge base of the tutoring program can be enhanced by using the knowledge-acquisition methods discussed by Hoffman (1987), who applied them specifically to meteorology. After collecting general forecasting expertise, Hoffman probed deeper into specialists' thought processes by presenting "tough cases" and "limited-information" tasks. The subtleties of a forecaster's methodology, including heuristics and analogies to previous situations, were then extracted. Such knowledge, often essential to solving problems in complex domains, is difficult for an expert to isolate and codify without the intervention of a "knowledge engineer" who has some understanding of the expert's field. However, students need to gain an appreciation of the importance of this kind of expertise, especially in domains like flood forecasting in which understanding of physical processes and their interactions is incomplete.

The limitations imposed by FORTRAN, a procedure-based language, on the intelligence of the tutoring program may

be eased or eliminated in three ways. First, the present program could be revised using the tools that will become available as part of the new "FORTRAN 90" standard. For example, "modules" containing data types or generic procedures can be declared in a program and be made available to or hidden from other modules, program parts, or subroutines. Such modules can imitate the hierarchical arrangement of the "Meteorological Characteristics" file; a module called "Heavy Precipitation" could "lock out" "Polar Air" but allow traits of "Surface Wind" and "Tropical Air" to be inherited by it. Other FORTRAN 90 features, like pointers and recursive subroutines, will allow "tree" data structures to be modified and manipulated more easily than is possible under FORTRAN 77. This could make possible more focused searches for desired knowledge; based either on a user request or on the pattern of correct or incorrect responses, the system could automatically find and display information like the optimum wind direction for orographic precipitation.

Another possible way to give the tutor a more AI-like quality is to construct an "intelligent front end," a program written in an AI-based language, that would serve as an interface between a pupil and the FORTRAN-coded tutor. With such an adjustment, the tutoring program could provide users with beneficial AI features like a detailed explanation of why an answer to an exercise was wrong. At the

same time, it would be possible to continue modifying the knowledge base and the exercise set via FORTRAN.

A third option for adjusting the program would be to rewrite each component of the tutor in a frame- or object-based language (Wenger 1987). While this would require a program builder to have or acquire knowledge of a language much different from FORTRAN, the relative ease with which information could be added and a general increase in the program's flexibility would make maintenance of the system easier and the teaching process more realistic.

The incorporation of graphical tools would significantly boost the tutor's value. Satellite and radar pictures to show precipitation patterns and hydrographs to depict a river's behavior could reinforce the currently available information. Linking the program with data-collection networks like ALERT and computer-model and satellite-picture transmissions could provide students with valuable experience and insight as they view real-time flood events.

CHAPTER 5

CONCLUSION

An intelligent tutor designed to teach students about northern California flooding has been described and its implementation initiated. Expert knowledge from the fields of hydrology and meteorology was collected and stored in the files of the system's knowledge base. Also included was a set of exercises designed to test a pupil's knowledge. In addition, a FORTRAN 77 program to guide a student through a tutoring session, to allow him to study the available knowledge, and to ask him short-answer questions has been constructed and tested.

Positive aspects of the tutor in its current form are that it is interactive, and that it demonstrates the range of forms in which knowledge can be represented in an intelligent system and, therefore, the need for the program to be flexible. The constraints FORTRAN places on the system, including its lack of natural-language understanding, need to be alleviated so that the tutor can operate more effectively.

A variety of ways in which the system can be made more intelligent were detailed. They range from broadening the knowledge base to rewriting the system in a frame-based language. Whatever course the program's development may take in the future, it is hoped that the intelligent tutor

for flood forecasting will encourage awareness of the complexity and the importance of the flood-prediction process.

APPENDIX A
PROJECT CODE

The following pages list the intelligent tutoring program's FORTRAN code, knowledge files, exercise set, and user manual. Also included are Figures 23-40. In order to gain access to the program, a student types "FLOOD" at the DOS prompt. Precipitation and river data, weather maps, and diagrams were collected from several sources (Burnash et al. 1973; National Oceanic and Atmospheric Administration 1982, 1986a, b, c; Barbato 1986; California Department of Water Resources 1991).

PROGRAM FLOOD

```

C      THIS PROGRAM IS AN INTELLIGENT TUTOR THAT TEACHES STUDENTS
C      ABOUT FLOOD FORECASTING. THE CURRENT VERSION, WRITTEN
C      IN FORTRAN-77, IS DESIGNED TO SERVE AS A DEMONSTRATION
C      OF HOW THE TECHNIQUES OF ARTIFICIAL INTELLIGENCE CAN BE
C      APPLIED TO THE METEOROLOGY/HYDROLOGY DOMAIN.
C      A USER OF THIS PROGRAM SHOULD BE FAMILIAR WITH BASIC
C      METEOROLOGICAL CONCEPTS. SINCE THE PROGRAM CONCENTRATES
C      ON FORECASTING THE OCCURRENCE OF FLOODS RATHER THAN
C      PREDICTING THE METEOROLOGICAL PRECURSORS TO THEM, A
C      BACKGROUND IN HYDROLOGY IS NOT ASSUMED.
C      THE PROGRAM PROVIDES SEVERAL OPTIONS FOR THE USER, INCLUDING
C      AN INTRODUCTION TO FLOOD FORECASTING, A DISCUSSION AND
C      "LIBRARY" OF KNOWLEDGE ABOUT THE FORECASTING PROCESS,
C      A CASE STUDY OF NORTHERN CALIFORNIA FLOOD PREDICTION, AND
C      A COLLECTION OF EXERCISES TO TEST A PUPIL'S KNOWLEDGE.
C
C      GLOBAL VARIABLES:
C
C      NAME = A MAXIMUM 6 CHARACTER I.D. REQUESTED FROM EACH USER AT
C             THE BEGINNING OF A SESSION
C
C      OPTION = A RESPONSE GIVEN BY A USER TO A LIST OF POSSIBLE
C              ACTIONS TO TAKE DURING A SESSION
C
C      TOPIC = A NUMERICAL RESPONSE FROM A USER INDICATING WHICH
C             SECTION TO ENTER (PRESENTLY, #1 - 4)
C
C      QUEST = A COUNTER FOR THE "EXERCISES" SECTION (PART 4)
C             INDICATING "ROOT" OR <INTEGER>.0 QUESTIONS
C
C      QUESTTREE = A COUNTER FOR PART 4 INDICATING "BRANCHES" OR
C                <INTEGER>.<INTEGER> QUESTIONS, WHICH ARE ACCESSED
C                WHEN THE ROOT IS ANSWERED INCORRECTLY
C
C      LOCAL VARIABLES:
C
C      LINE = CONTAINS TEXT LINES
C
C      I, J = COUNTERS THAT CONTROL WHEN OPTIONS FOR EACH PART ARE
C            DISPLAYED
C
C      TOPICTEMP = STORES TOPIC (3 OR 4) FROM WHICH TOPIC 2 HAS BEEN
C                CALLED
C
C      CHOICE = CONTAINS KEY FOR SUBJECT CHOSEN IN SUBMENU OF TOPIC 2
C
C      SUBCHOICE = CONTAINS KEY FOR SUBJECT CHOSEN UNDER "CHOICE"
C
C      CHARRESP, NUMRESP = CONTAINS CHARACTER OR NUMBER RESPONSE
C                        (WHICHEVER IS APPROPRIATE) FROM PUPIL TO
C                        EXERCISES
C
C      CHARANSWER, NUMANSWER = CONTAINS CORRECT ANSWER IN (CHARACTER,
C                        NUMBER) FORM
C
C      QLINE = CONTAINS 'CHARAC' OR 'NUMBER' READ FROM EACH EXERCISE
C             SETS THE DATA TYPE OF THE RESPONSE EXPECTED FROM PUPIL
C
C      QUESTION = COMPANION TO QLINE: CONTAINS THE NUMBER OF THE
C                CURRENT EXERCISE
C
C      START = CONTAINS KEY REPRESENTING WHETHER USER WISHES TO SEE
C              HIS EVALUATION FILE OR TO DO THE EXERCISES

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C      X = CONTAINS EXERCISE # IN EVALUATION FILE
C
C      GRADE = COMPANION TO X: CONTAINS "CORRECT"/"INCORRECT" FROM
C      STUDENT'S EVALUATION FILE
C
C      SUBQUEST = COUNTER FOR "BRANCH" QUESTIONS
C

CHARACTER NAME*6
INTEGER TOPIC, SEEMANUAL
COMMON/BLOCK1/NAME
COMMON/BLOCK2/TOPIC
COMMON/BLOCK3/QUEST, QUESTTREE

PRINT*, 'WELCOME TO THE INTELLIGENT TUTOR'
PRINT*, '      FOR FLOOD FORECASTING'
PRINT*, 'IF YOU WISH TO SEE A USER MANUAL, TYPE 0.'
PRINT*, 'IF NOT, TYPE 1'
READ*, SEEMANUAL
IF (SEEMANUAL.EQ.0) CALL MANUAL
PRINT*, ' '
PRINT*, 'PLEASE ENTER YOUR I.D. WORD (MAX 6 CHARACTERS):'
READ*, NAME
CALL MAINMENU
5  IF (TOPIC.EQ.1) CALL ONE
   IF (TOPIC.EQ.2) CALL TWO
   IF (TOPIC.EQ.3) CALL THREE
   IF (TOPIC.EQ.4) CALL FOUR
   IF (TOPIC.EQ.5) GOTO 20
   GOTO 5
20 PRINT*, 'THANK YOU FOR USING '
   PRINT*, 'THE INTELLIGENT TUTOR'
   PRINT*, 'FOR FLOOD FORECASTING'
   STOP
   END

SUBROUTINE ONE

INTEGER I, J, TOPIC
CHARACTER OPTION*1, LINE*72
COMMON/BLOCK1/NAME
COMMON/BLOCK2/TOPIC
COMMON/BLOCK3/QUEST, QUESTTREE

C      THIS SUBROUTINE DIRECTS THE INTRODUCTORY PORTION OF THE
C      TUTOR. IT DISCUSSES BRIEFLY THE IMPORTANCE OF FLOOD
C      FORECASTING.

I = 1
J = 0
TOPIC = 1

C      READ AND DISPLAY INTRODUCTORY FILE

OPEN (UNIT = 7, FILE = 'INPUTIFF.TXT')
10 READ (7, '(A72)', END = 99) LINE(1:72)
   PRINT*, LINE
   J = J + 1
   IF (J.NE.(1*10)) GOTO 10
   I = I + 1
   CALL SCREEN(OPTION)
   IF (OPTION.EQ.'C') GOTO 10
99  CLOSE (UNIT = 7)
   RETURN
   END

```

```

SUBROUTINE TWO

C      THIS SUBROUTINE DISCUSSES FLOOD FORECASTING PROCEDURES USED
C      ON NORTHERN CALIFORNIA RIVERS. TOPICS DISCUSSED INCLUDE
C      REQUIRED INPUT DATA, FORECASTING RULES, COMPUTER MODELS,
C      AND OUTPUT INFORMATION. CRITICAL DATA RANGES AND
C      RELIABILITY OF DATA, RULES, AND MODELS WILL ALSO BE
C      INCLUDED.

      INTEGER CHOICE, TOPIC, TOPICTEMP
      CHARACTER*1 OPTION
      COMMON/BLOCK1/NAME
      COMMON/BLOCK2/TOPIC
      COMMON/BLOCK3/QUEST, QUESTTREE

      TOPICTEMP = TOPIC
      TOPIC = 2

C      LIST OF SUBTOPICS

5      PRINT*, ' '
      PRINT*, 'CHOOSE ONE OF THE FOLLOWING SUBTOPICS'
      PRINT*, ' 1 = VOCABULARY'
      PRINT*, ' 2 = CHARACTERISTICS'
      PRINT*, ' 3 = FORECAST INGREDIENTS AND PRODUCTS'
      PRINT*, ' 4 = GENERAL FORECAST PROCEDURE'
      READ(*,8,ERR=5) CHOICE
      FORMAT (I2)
      PRINT*, ' '

C      DETERMINE WHICH SUBTOPIC TO ENTER

      IF (CHOICE.EQ.1) GOTO 7
      IF (CHOICE.EQ.2) CALL CHARAC(OPTION)
      IF (CHOICE.EQ.3) CALL INGRED(OPTION)
      IF (CHOICE.EQ.4) THEN
15         OPEN (UNIT = 7, FILE = 'INPUTPROC.TXT')
            CALL READFILE
            CALL SCREEN(OPTION)
            IF (OPTION.EQ.'C') GOTO 15
        END IF
        GOTO 99

7      IF (CHOICE.EQ.1) OPEN (UNIT = 7, FILE = 'INPUTVOC.TXT')

C      DISPLAY INDEX OF CHOSEN FILE; DISPLAY USER OPTIONS TO CONTINUE

10     CALL DICTMENU
        CALL SCREEN(OPTION)
        IF (OPTION.EQ.'C') GOTO 10
99     CLOSE (UNIT = 7)
20     IF (OPTION.EQ.'S') GOTO 5
        TOPIC = TOPICTEMP
        RETURN
      END

```

```

SUBROUTINE THREE

C      THIS SUBROUTINE PROVIDES A CASE STUDY OF HOW A RIVER FLOOD
C      FORECAST IS PERFORMED. BASED ON THE TECHNIQUES DISCUSSED
C      PREVIOUSLY, THE STUDY SHOWS THE USER THE PROCEDURES AND
C      REASONING BEHIND A TYPICAL FORECAST. THE CONTENTS OF
C      PART 2 CAN BE RECALLED FOR REFERENCE.

      INTEGER I, J, TOPIC
      CHARACTER OPTION*1, LINE*72
      COMMON/BLOCK1/NAME
      COMMON/BLOCK2/TOPIC
      COMMON/BLOCK3/QUEST, QUESTTREE

      I = 1
      J = 0
      TOPIC = 3

C      READ AND DISPLAY CASE STUDY DISCUSSION LIST AND USER OPTIONS

      OPEN (UNIT = 7, FILE = 'INPUTCS.TXT')
10     CALL OBJMENU
      CALL SCREEN(OPTION)
      IF (OPTION.EQ.'C') GOTO 10
      REWIND 7
99     CLOSE (UNIT = 7)
      IF (OPTION.EQ.'E') THEN
        CALL TWO
      END IF
      IF (OPTION.EQ.'Y') THEN
        REWIND 7
        CLOSE (UNIT=7)
        RETURN
      END IF
      RETURN
END

SUBROUTINE FOUR

C      THIS SUBROUTINE PROVIDES EXERCISES ON THE VARIOUS PARTS OF THE
C      FORECASTING PROCEDURE. THE USER CAN GAIN ACCESS TO
C      INFORMATION PRESENTED IN PART 2 TO OBTAIN DETAILS OR
C      IMPROVE UNDERSTANDING

      CHARACTER*6 NAME, QLINE
      CHARACTER*72 LINE, CHARANSWER
      CHARACTER*1 OPTION, SIMUL, EXER, CHOICE, CHARRESP
      REAL QUEST, QUESTTREE, NUMRESP, START, NUMANSWER, QUESTION
      INTEGER TOPIC
      COMMON/BLOCK1/NAME
      COMMON/BLOCK2/TOPIC
      COMMON/BLOCK3/QUEST, QUESTTREE

      I = 1
      J = 0
      QUEST = 1.0
      QUESTTREE = 0.1
      TOPIC = 4
      NUMRESP = 0.0
      CHARRESP = 'X'

```

```

OPEN (UNIT = 8, FILE = NAME)
PRINT*, 'IF YOU WISH TO TRY A SIMULATED FORECAST EXPERIENCE.'//
+   ' TYPE Y. IF NOT, TYPE N'
READ(*, '(A1)') SIMUL
IF ((SIMUL.NE.'Y').AND.(SIMUL.NE.'N')) GOTO 3
IF (SIMUL.EQ.'Y') THEN
1   OPEN (UNIT = 9, FILE = 'INPUTSIMUL.TXT')
    READ (9, '(A72)', END = 99) LINE(1:72)
    IF (LINE(2:4).EQ.'+++') GOTO 2
    PRINT*, LINE
    J = J + 1
    IF (J.NE.(I*10)) GOTO 1
    I = I + 1
4   PRINT*, 'TYPE N TO CONTINUE'
    READ(*, '(A1)') CHOICE
    IF (CHOICE.NE.'N') GOTO 4
    IF (CHOICE.EQ.'N') GOTO 1
2   CALL SCREEN(OPTION)
    IF (OPTION.EQ.'Y') CALL THREE
    GOTO 1
99  REWIND 9
    CLOSE (UNIT = 9)
END IF

6   PRINT*, 'IF YOU WISH TO DO EXERCISES, TYPE X'
    READ(*, '(A1)') EXER
    IF (EXER.NE.'X') RETURN

C   READ STUDENT RECORD OR GO DIRECTLY TO QUESTIONS

80  PRINT*, 'IF YOU ARE NEW TO THIS PROGRAM, TYPE 1.0 AT THE'//
+   ' PROMPT'
    PRINT*, ' '
    PRINT*, 'IF YOU WISH TO START AT A QUESTION OTHER THAN 1.0.'//
+   ' TYPE <INTEGER>.0'
    PRINT*, ' '
    PRINT*, 'IF YOU WISH TO VIEW YOUR EVALUATION FILE, TYPE 0.0'
    PRINT*, ' '
    READ(*, 2000, ERR=80) START
    IF (START.EQ.0.0) THEN
        REWIND 8
        CALL EVALFILE
        REWIND 8
        GOTO 80
    END IF
    IF (START.EQ.1.0) QUEST = START
    IF (START.GT.1.0) QUEST = START

C   DISPLAY USER OPTIONS TO CONTINUE QUESTIONS, LEAVE PART 4, OR
C   REFERENCE PART 2

5   CALL SCREEN(OPTION)
    IF (OPTION.EQ.'R') GOTO 990
    IF (OPTION.EQ.'E') THEN
        CALL TWO
        GOTO 5
    END IF
    IF (OPTION.EQ.'Y') CALL THREE

C   START READING QUESTIONS

7   OPEN (UNIT = 9, FILE = 'INPUTEXS.TXT')
    LINE = ' '
    IF (EOF(9)) GOTO 999

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```

5      READ (9, FMT = 1000) QUESTION, OLINE(1:6)
      IF (START.EQ.-1.0) GOTO 11
      IF (QUESTION.NE.START) THEN
9          READ (9, '(A72)') LINE(1:72)
          IF ((LINE(2:4).EQ.'***') .OR. (LINE(2:4).EQ.'---')) GOTO 8
          GOTO 9
      END IF
      START = -1.0
1000   FORMAT(F5.2, 2X, A6)

C      INITIALIZE DATA TYPE REQUIRED FOR USER RESPONSE

11      IF (OLINE(1:6).EQ.'NUMBER') NUMRESP = 0.0
      IF (OLINE(1:6).EQ.'CHARAC') CHARRESP = 'X'

C      PRINT QUESTION

10      READ (9, '(A72)') LINE(1:72)
      PRINT*, LINE
      IF (LINE(2:4).NE.'+++') GOTO 10
      IF (OLINE(1:6).EQ.'CHARAC') GOTO 12

C      NUMERICAL RESPONSE

110     PRINT*, 'A NUMERICAL RESPONSE IS REQUIRED (IN DECIMAL FORM)'
      READ(*,2000,ERR=110) NUMRESP
      READ (9,*) NUMANSWER
      IF (NUMANSWER.EQ.NUMRESP) CALL CORRECT
      IF (NUMANSWER.NE.NUMRESP) CALL INCORRECT(OPTION)
      NUMRESP = 0.0
      GOTO 20

C      CHARACTER RESPONSE

      READ (9, '(A72)') CHARANSWER
      IF (CHARANSWER(2:).EQ.CHARRESP(1:)) CALL CORRECT
      IF (CHARANSWER(2:).NE.CHARRESP(1:)) CALL INCORRECT(OPTION)
      CHARRESP = 'X'

20      GOTO 5
990     CLOSE (UNIT = 9)

2000    FORMAT (F7.3)
999     RETURN
      END

```

SUBROUTINE MAINMENU

```

C      THIS SUBROUTINE DISPLAYS THE MAIN TOPIC MENU

      INTEGER TOPIC
      COMMON/BLOCK1/NAME
      COMMON/BLOCK2/TOPIC
      COMMON/BLOCK3/QUEST, QUESTTREE

10      PRINT*, ' '
      PRINT*, 'PLEASE CHOOSE ONE OF THE FOLLOWING TOPICS:'
      PRINT*, '  1 = INTRODUCING FLOOD FORECASTING'
      PRINT*, '  2 = THE FORECASTING PROCEDURE'
      PRINT*, '  3 = A CASE STUDY'
      PRINT*, '  4 = EXERCISES'
      PRINT*, 'TYPE 5 TO QUIT PROGRAM'
      READ (*,20,ERR=10) TOPIC

20      FORMAT (I2)
      PRINT*, ' '
      RETURN
      END

```

```

SUBROUTINE SCREEN(OPTION)

C      THIS SUBROUTINE SHOWS ON THE SCREEN THE OPTIONS FOR
C      PROGRESSING THROUGH EACH PART OF THE PROGRAM

      INTEGER TOPIC
      CHARACTER*1 OPTION
      COMMON/BLOCK1/NAME
      COMMON/BLOCK2/TOPIC
      COMMON/BLOCK3/QUEST, QUESTTREE

10  PRINT*, '*****'
      PRINT*, ' '
      IF (TOPIC.EQ.1) THEN
        PRINT*, 'OPTIONS FOR PART ONE'
        PRINT*, '  C = CONTINUE READING FROM SAME FILE'
        PRINT*, '  R = RETURN TO MAIN MENU'
      ELSE IF (TOPIC.EQ.2) THEN
        PRINT*, 'OPTIONS FOR PART TWO'
        PRINT*, '  A = RETURN TO LOCN. IN PART 4 WHERE "E" WAS'
        PRINT*, '        CHOSEN'
        PRINT*, '  C = CONTINUE READING FROM SAME FILE'
        PRINT*, '  R = RETURN TO MAIN MENU'
        PRINT*, '  S = RETURN TO SUBMENU'
        PRINT*, '  T = RETURN TO TOPIC MENU UNDER SUBMENU SUBJECT'
      ELSE IF ((TOPIC.EQ.3).OR.(TOPIC.EQ.4)) THEN
        PRINT*, 'OPTIONS FOR PART 3 AND 4'
        PRINT*, '  A = RETURN TO PART 4 SIMULATION (FROM PART 3)'
        PRINT*, '  C = CONTINUE READING FROM SAME FILE'
        PRINT*, '  E = GO TO PART 2 TO REVIEW MATERIAL (FROM EXER.)'
        PRINT*, '  R = RETURN TO MAIN MENU'
        PRINT*, '  Y = REVIEW CASE STUDY IN PART 3 (TO DO SIMUL.)'
      END IF
      PRINT*, 'TO VIEW PICTURES, TYPE C WHILE HOLDING DOWN THE'//
+      PRINT*, 'Ctrl KEY, THEN TYPE'
+      PRINT*, 'display AT THE PROMPT.  TO RETURN TO THIS PROGRAM.'//
+      PRINT*, 'PRESS Esc KEY TWICE,'
+      PRINT*, 'TYPE Y, AND THEN TYPE text AT THE PROMPT.  FIND'//
+      PRINT*, 'PROPER PROGRAM SECTION,'
      PRINT*, 'AND CONTINUE AS BEFORE'

      PRINT*, '*****'

SUBROUTINE EVALFILE

C      THIS SUBROUTINE DISPLAYS A STUDENT'S RECORD ON ANSWERING THE
C      QUESTIONS IN PART 4.

      REAL X
      CHARACTER GRADE*11, NAME*6
      COMMON/BLOCK1/NAME
      COMMON/BLOCK2/TOPIC
      COMMON/BLOCK3/QUEST, QUESTTREE

500  IF (EOF(8)) GOTO 9999
      READ (8, 1000) X, GRADE
1000  FORMAT (F5.2, 2X, A11)
      PRINT*, X, GRADE
      GOTO 500
9999  RETURN
      END

```

```

SUBROUTINE CORRECT

C      THIS SUBROUTINE IS CALLED AFTER A CORRECT RESPONSE TO AN
C      < INTEGER >.0 QUESTION.

CHARACTER*72 LINE, QLINE*6
REAL QUEST, QUESTION
COMMON/BLOCK1/NAME
COMMON/BLOCK2/TOPIC
COMMON/BLOCK3/QUEST, QUESTTREE

C      WRITE TO STUDENT RECORD

      IF (EOF(8)) THEN
        BACKSPACE 8
        GOTO 35
      END IF
30     READ (8, 1000)
      IF (.NOT.(EOF(8))) GOTO 30
35     WRITE (8, 1000) QUEST, 'CORRECT'
1000    FORMAT (F5.2, 2X, A11)
      QUEST = QUEST + 1.0

C      WRITE REJOINDER TO CORRECT RESPONSE; SEARCH FOR NEXT
C      <INTEGER>.0 QUESTION

      READ (9, '(A72)') LINE(1:72)
      PRINT*, LINE
40     READ (9, '(A72)') LINE(1:72)
      IF (LINE(2:4).EQ.'---') GOTO 50
      IF (LINE(2:4).EQ.'***') GOTO 99
      IF ((LINE(2:4).EQ.'+++').OR.(LINE.NE.' ')) GOTO 40
50     READ (9, FMT = 2000) QUESTION, QLINE(1:6)
      IF (EOF(9)) GOTO 99
2000    FORMAT (F5.2, 2X, A6)
      IF (QUEST.NE.QUESTION) GOTO 40
99     ENDFILE 8
      RETURN
      END

SUBROUTINE INCORRECT(OPTION)

C      THIS SUBROUTINE IS CALLED WHEN AN INCORRECT RESPONSE IS GIVEN
C      TO AN <INTEGER>.0 QUESTION.

CHARACTER*72 LINE, CHARRESP, CHARANSWER
CHARACTER*6 QLINE
CHARACTER*1 OPTION
REAL NUMRESP, QUEST, QUESTTREE, START, NUMANSWER
COMMON/BLOCK1/NAME
COMMON/BLOCK2/TOPIC
COMMON/BLOCK3/QUEST, QUESTTREE

C      WRITE TO STUDENT RECORD

      IF (EOF(8)) THEN
        BACKSPACE 8
        GOTO 25
      END IF
20     READ (8, 2000)
      IF (.NOT.(EOF(8))) GOTO 20
25     WRITE (8, 2000) QUEST, 'INCORRECT'
2000    FORMAT (F5.2, 2X, A11)

```



```

C      WRITE REJOINDER TO INCORRECT RESPONSE

30     READ (9, '(A72)') LINE(1:72)
40     READ (9, '(A72)') LINE(1:72)
      IF (LINE(2:4).EQ.'---') GOTO 50
      IF (LINE(2:4).EQ.'***') GOTO 200
      PRINT*, LINE
      GOTO 40

C      DISPLAY USER OPTIONS TO CONTINUE WITH BRANCH QUESTIONS, LEAVE
C      PART 4, OR REFERENCE PART 2

50     CALL SCREEN(OPTION)
      IF (OPTION.EQ.'C') GOTO 55
      IF (OPTION.EQ.'E') THEN
        CALL TWO
        GOTO 50
      ELSE IF (OPTION.EQ.'R') THEN
        GOTO 250
      END IF

C      START READING BRANCH QUESTIONS

55     LINE = ' '
      SUMQUEST = QUEST + QUESTTREE
60     READ (9, '(F5.2, 2X, A6)') SUMQUEST, QLINE(1:6)
      IF (EOF(9)) GOTO 250

C      DATA TYPE SET FOR PUPIL RESPONSE

      IF (QLINE(1:6).EQ.'NUMBER') NUMRESP = 0.0
      IF (QLINE(1:6).EQ.'CHARAC') CHARRESP = 'X'

C      PRINT QUESTION

65     READ (9, '(A72)') LINE(1:72)
      IF (LINE(2:4).NE.'+++') PRINT*, LINE
      IF (LINE(2:4).NE.'+++') GOTO 65
      IF (QLINE(1:6).EQ.'CHARAC') GOTO 75

C      NUMERICAL RESPONSE

68     PRINT*, 'A NUMERICAL RESPONSE IS REQUIRED (IN DECIMAL FORM)'
      READ(*,5000,ERR=68) NUMRESP
      READ (9,*) NUMANSWER
      IF (NUMANSWER.EQ.NUMRESP) GOTO 100
      IF (NUMANSWER.NE.NUMRESP) GOTO 150

C      CHARACTER RESPONSE

      READ (9, '(A72)') CHARANSWER
      IF (CHARANSWER(2:).EQ.CHARRESP(1:)) GOTO 100
      IF (CHARANSWER(2:).NE.CHARRESP(1:)) GOTO 150

C      PRINT REJOINDER TO CORRECT RESPONSE, WRITE TO STUDENT RECORD

100    READ (9, '(A72)') LINE(1:72)
      PRINT*, LINE
      WRITE (8, 2000) SUMQUEST, 'CORRECT'

101    CALL SCREEN(OPTION)
      IF (OPTION.EQ.'E') THEN
        CALL TWO
        GOTO 101
      ELSE IF (OPTION.EQ.'R') THEN
        ENDFILE 8
        RETURN
      END IF

```

```

QUESTTREE = QUESTTREE + 0.1
NUMRESP = 0.0
CHARRESP = 'X'
120 READ (9, '(A72)') LINE(1:72)
IF (LINE(2:4).EQ.'---') GOTO 50
IF (LINE(2:4).EQ.'***) GOTO 200
GOTO 120

C WRITE TO STUDENT RECORD

150 WRITE (8,2000) SUMQUEST, 'INCORRECT'
QUESTTREE = QUESTTREE + 0.1
NUMRESP = 0.0
CHARRESP = 'X'
GOTO 30
200 QUEST = QUEST + 1.0
250 ENDFILE 8
5000 FORMAT (F7.3)
RETURN
END

```

SUBROUTINE READFILE

```

C THIS SUBROUTINE READS FILES IN THE TREE STRUCTURE OF PART 2

INTEGER I, J
CHARACTER LINE*72, CHOICE*1
COMMON/BLOCK1/NAME
COMMON/BLOCK2/TOPIC
COMMON/BLOCK3/QUEST, QUESTTREE

I = 1
J = 0
10 READ (7, '(A72)') LINE(1:72)
IF (EOF(7)) THEN
PRINT*, LINE(1:72)
REWIND 7
GOTO 99
END IF
PRINT*, LINE
J = J + 1
IF (J.EQ.(I*10)) THEN
I = I + 1
20 PRINT*, ' '
PRINT*, 'TYPE N TO CONTINUE, X TO EXIT'
READ(*, '(A1)') CHOICE
IF ((CHOICE.NE.'N').AND.(CHOICE.NE.'X')) GOTO 20
PRINT*, ' '
IF (CHOICE.EQ.'X') RETURN
GOTO 10
END IF
GOTO 10
99 RETURN
END

```

```

SUBROUTINE INGRED(OPTION)

C      THIS SUBROUTINE ACCESSES SUBTOPIC 3 OF PART 2

      INTEGER SUBCHOICE
      CHARACTER*1 OPTION
      COMMON/BLOCK1/NAME
      COMMON/BLOCK2/TOPIC
      COMMON/BLOCK3/QUEST, QUESTTREE

C      DISPLAY SUBTOPIC CHOICES, PROMPT USER SELECTION, SHOW OPTIONS

5      PRINT*, ' '
      PRINT*, 'CHOOSE FROM'
      PRINT*, ' 1 = NMC DATA'
      PRINT*, ' 2 = CNRFC DATA'
      PRINT*, ' 3 = WSFO REDWOOD CITY DATA'
      READ(*,1000,ERR=5) SUBCHOICE
      IF (SUBCHOICE.GT.3) GOTO 5
      PRINT*, ' '
      IF (SUBCHOICE.EQ.1) OPEN (UNIT = 7, FILE = 'INPUTNMC.TXT')
      IF (SUBCHOICE.EQ.2) OPEN (UNIT = 7, FILE = 'INPUTCNR.TXT')
      IF (SUBCHOICE.EQ.3) OPEN (UNIT = 7, FILE = 'INPUTWSO.TXT')
10     CALL OBJMENU
      CALL SCREEN(OPTION)
      IF (OPTION.EQ.'C') GOTO 10
      IF (OPTION.EQ.'T') GOTO 5
      IF (OPTION.EQ.'S') RETURN
1000    FORMAT (I2)
      RETURN
      END

```

```

SUBROUTINE CHARAC(OPTION)

C      THIS SUBROUTINE ACCESSES SUBTOPIC 2 OF PART 2

      INTEGER SUBCHOICE
      CHARACTER*1 OPTION
      COMMON/BLOCK1/NAME
      COMMON/BLOCK2/TOPIC
      COMMON/BLOCK3/QUEST, QUESTTREE

C      DISPLAY SUBTOPIC 2; PROMPT USER FOR CHOICE; DISPLAY OPTIONS

5      PRINT*, ' '
      PRINT*, 'CHOOSE FROM'
      PRINT*, ' 1 = METEOROLOGICAL CHARACTERISTICS'
      PRINT*, ' 2 = HYDROLOGICAL CHARACTERISTICS'
      READ(*,1000,ERR=5) SUBCHOICE
      IF (SUBCHOICE.GT.2) GOTO 5
      PRINT*, ' '
      IF (SUBCHOICE.EQ.1) OPEN (UNIT = 7, FILE = 'INPUTMET.TXT')
      IF (SUBCHOICE.EQ.2) OPEN (UNIT = 7, FILE = 'INPUTHYD.TXT')
10     CALL OBJMENU
      CALL SCREEN(OPTION)
      IF (OPTION.EQ.'C') GOTO 10
      IF (OPTION.EQ.'T') GOTO 5
      IF (OPTION.EQ.'S') RETURN
1000    FORMAT (I2)
      RETURN
      END

```

```

SUBROUTINE DICTMENU

C      THIS SUBROUTINE EXTRACTS ENTRIES FROM DICTIONARY-LIKE FILES
C      AND PLACES THEM IN AN INDEX FILE FROM WHICH THE USER
C      CAN SELECT ANY DESIRED ENTRY

      CHARACTER LINE*72
      INTEGER CHOICE, SWITCH
      COMMON/BLOCK1/NAME
      COMMON/BLOCK2/TOPIC
      COMMON/BLOCK3/QUEST, QUEST1/EE

C      CREATE AND POSITION INDEX FILE, INITIALIZE COUNTER

      SWITCH = 0
      OPEN (UNIT = 8, FILE = 'WORD.TXT')
      REWIND 8
      K = 1

C      READ FROM DICTIONARY-LIKE FILE, EXTRACT ENTRIES, AND WRITE
C      EACH ENTRY AND ITS ASSOCIATED NUMBER INTO INDEX FILE

10     READ (7, '(A72)') LINE (1:72)
      IF (EOF(7)) THEN
        REWIND 7
        GOTO 30
      END IF
      IF (LINE(2:4).NE.'+++') GOTO 10
2000   FORMAT (I2, 2X, A60)
      WRITE (8,2000) K, LINE(6:60)
      K = K + 1
      GOTO 10
30     REWIND 8

C      SHOW THE INDEX FILE AND PROMPT USER FOR A SELECTION

      PRINT*, 'CHOOSE A # FOR DESIRED WORD'
      PRINT*, ' '
      DO 40 J = 1, K - 1
        L = J
        READ (8, 2000) L, LINE(6:60)
        PRINT*, L, ' ', LINE(6:60)
40     CONTINUE
      REWIND 8
45     PRINT*, 'A NUMERICAL RESPONSE IS REQUIRED '
      READ(*,5000,ERR=45) CHOICE
      IF (CHOICE.GT.L) GOTO 45
      PRINT*, ' '

C      SHOW THE EXPLANATION ASSOCIATED WITH THE SELECTED WORD

      CALL READENTRY(CHOICE, SWITCH)
5000   FORMAT (I2)
      RETURN
      END

```

```

SUBROUTINE OBJMENU

C      THIS SUBROUTINE EXTRACTS OBJECTS FROM FRAME-LIKE FILES AND
C      STORES THEM IN AN INDEX FILE FOR LATER VIEWING

      CHARACTER LINE*72
      INTEGER CHOICE, SWITCH
      COMMON/BLOCK1/NAME
      COMMON/BLOCK2/TOPIC
      COMMON/BLOCK3/QUEST, QUESTTREE

C      INITIALIZE AND POSITION INDEX FILE, INITIALIZE COUNTER

      OPEN (UNIT = 8, FILE = 'WORD.TXT')
      REWIND 8
      K = 1

C      EXTRACT OBJECTS FROM FRAME-LIKE FILES AND STORE EACH OBJECT
C      WITH AN ASSOCIATED NUMBER IN THE INDEX FILE

10      READ (7, '(A72)') LINE (1:72)
      IF (EOF(7)) THEN
          REWIND 7
          GOTO 30
      END IF
      IF ((LINE(2:8).NE.'OBJECT:') .AND. (LINE(2:6).NE.'DATE:')) GOTO 10
2000      FORMAT (I2, 2X, A60)
      IF (LINE(2:8).EQ.'OBJECT:') THEN
          WRITE (8, 2000) K, LINE(10:60)
          SWITCH = 1
      ELSE IF (LINE(2:6).EQ.'DATE:') THEN
          WRITE (8, 2000) K, LINE(8:)
          SWITCH = 2
      END IF
      K = K + 1
      GOTO 10
30      REWIND 8

C      SHOW INDEX FILE AND PROMPT USER FOR A SELECTION

      PRINT*, 'CHOOSE A # FOR DESIRED WORD OR CASE'
      PRINT*, ' '
      DO 40 J = 1, K - 1
          IF (SWITCH.EQ.1) THEN
              READ (8, 2000) L, LINE(10:60)
              PRINT*, L, ' ', LINE(10:60)
          ELSE IF (SWITCH.EQ.2) THEN
              READ (8, 2000) L, LINE(8:)
              PRINT*, L, ' ', LINE(8:)
          END IF
40      CONTINUE
      REWIND 8
45      PRINT*, 'A NUMERICAL RESPONSE IS REQUIRED '
      READ(*,5000,ERR=45) CHOICE
      IF (CHOICE.GT.L) GOTO 45
      PRINT*, ' '

C      SHOW ATTRIBUTES OF CHOSEN OBJECT

      CALL READENTRY(CHOICE, SWITCH)
5000      FORMAT (I2)
      RETURN
      END

```

```

SUBROUTINE READENTRY(CHOICE, SWITCH)

C   THIS SUBROUTINE DISPLAYS DEFINITIONS FROM DICTIONARY-LIKE FILES
C   AND ATTRIBUTES FROM FRAME-LIKE FILES

CHARACTER ENTRY*60, LINE*72, CONT*1
INTEGER CHOICE, SWITCH, LOCATE
COMMON/BLOCK1/NAME
COMMON/BLOCK2/TOPIC
COMMON/BLOCK3/QUEST, QUESTTREE

C   INITIALIZE COUNTERS TO BE USED IN FINDING AND DISPLAYING
C   DEFINITIONS AND ATTRIBUTES

L = 1
J = 1
I = 1

C   MATCH USER-SELECTED NUMBER WITH ITS ASSOCIATED ENTRY

3   READ (8, 2000) J, ENTRY
   IF (CHOICE.EQ.J) GOTO 10
   J = J + 1
   GOTO 5
2000 FORMAT (I2, 2X, A60)
10  REWIND 8

C   DISPLAY APPROPRIATE WORD OR OBJECT

15  READ (7, '(A72)') LINE(2:72)
   IF ((LINE(6:).EQ.ENTRY(6:)).AND.(SWITCH.EQ.0)) THEN
     PRINT*, LINE(6:)
     GOTO 18
   ELSE IF ((LINE(10:).EQ.ENTRY(10:)).AND.(SWITCH.EQ.1)) THEN
     PRINT*, LINE(10:)
     GOTO 18
   ELSE IF ((LINE(8:).EQ.ENTRY(1:)).AND.(SWITCH.EQ.2)) THEN
     PRINT*, LINE(8:)
     GOTO 18
   END IF
   GOTO 15

C   DISPLAY ASSOCIATED DEFINITION OR ATTRIBUTES

20  READ (7, '(A72)') LINE(2:72)
   IF (EOF(7)) GOTO 30
   IF (LOCATE.LE.L) GOTO 22
   IF (L.NE.(I*10)) GOTO 27
   I = I + 1
   GOTO 27
22  PRINT*, LINE
   IF (LINE(2:4).EQ.'***') GOTO 30
   IF (L.EQ.(I*10)) THEN
     I = I + 1
     PRINT*, ' '
     PRINT*, '***TO CONTINUE READING, TYPE 4 IN SINGLE QUOTES**'
     READ*, CONT
     PRINT*, ' '
   END IF
27  L = L + 1
   GOTO 20
30  REWIND 7
3000 FORMAT (I4)
   RETURN
   END

```

THIS PROGRAM IS DESIGNED TO MAKE YOU AWARE OF THE BASICS OF FLOODS AND FLOOD FORECASTING, WITH SPECIFIC APPLICATION TO NORTHERN CALIFORNIA. IT INCLUDES DISCUSSIONS OF PAST NORTHERN CALIFORNIA FLOODS, HYDROMETEOROLOGICAL ASPECTS OF FLOODS AND THEIR PREDICTION, AND THE FORECASTING PROCEDURE. IT ALSO CONTAINS CASE STUDIES OF PAST FLOOD EVENTS AND EXERCISES TO SHARPEN YOUR KNOWLEDGE.

FLOOD FORECASTING IS A COMPLEX PROBLEM FOR SCIENTISTS AND, POTENTIALLY, A LIFE-AND-DEATH CONCERN FOR THE GENERAL PUBLIC. UNDERSTANDING OF THE CRITICAL METEOROLOGICAL AND HYDROLOGICAL PARAMETERS INVOLVED HAS INCREASED MARKEDLY IN THE PAST HALF-CENTURY AS COMPUTERS HAVE EMERGED. CONCURRENT WITH PROGRESS ON THE SCIENTIFIC SIDE, HOWEVER, HAS COME A GROWING HUMAN TOLL. FROM 1980 TO 1986, FLOODS KILLED OVER 1000 AMERICANS, MAKING THEM THE DEADLIEST SEVERE-WEATHER EVENTS. AS PREVIOUSLY UNDEVELOPED AREAS BECOME POPULATED, WATER FLOW IS INEVITABLY ALTERED, THUS ENHANCING THE POTENTIAL FOR DEVASTATING FLOODS. CLEARLY, WEATHER FORECASTERS NEED TO COMPREHEND FULLY THE HYDROLOGICAL PHENOMENA THAT INFLUENCE WHERE AND WHEN FLOODS OCCUR.

FLOODS REGULARLY PUNCTUATE THE METEOROLOGICAL HISTORY OF NORTHERN CALIFORNIA. AMONG THE MOST NOTABLE ARE THE FLOODS OF 1955, 1964, 1982, AND 1986. THE EFFECTS OF BOTH URBAN AND AGRICULTURAL DEVELOPMENT ARE INCREASINGLY ACKNOWLEDGED AS ESSENTIAL FACTORS IN PREDICTING FLOODS. ***

THIS FILE CONTAINS A VOCABULARY LIST USEFUL IN UNDERSTANDING FLOOD FORECASTING

+++ ALERT
AUTOMATED LOCAL EVALUATION IN REAL-TIME. A PRECIPITATION AND STREAMFLOW GAUGING SYSTEM THAT PROVIDES HOURLY OBSERVATIONS FOR UPDATING SHORT-TERM FORECASTS. ESPECIALLY IMPORTANT WHERE DATA COLLECTION IS OTHERWISE SPARSE OR INFREQUENT (LIKE SANTA CRUZ MOUNTAINS). SEE ALSO PART 2, FORECAST INGREDIENTS AND PRODUCTS, WSFO DATA FOR DETAILS.

+++ ANTECEDENT PRECIPITATION INDEX (API)
A QUANTITY THAT ESTIMATES THE AMOUNT OF SOIL MOISTURE (DEPTH, IN INCHES) PRESENT BEFORE A STORM. THIS PARAMETER WAS USED BY THE NATIONAL WEATHER SERVICE (NWS) UNTIL THE EARLY 1970S, WHEN IT WAS REPLACED BY THE MORE DETAILED AND COMPUTERIZED SACRAMENTO SOIL MOISTURE ACCOUNTING MODEL. SEE ALSO: SACRAMENTO MODEL IN PART 2, FORECAST INGREDIENTS AND PRODUCTS, CNRFC DATA.

+++ BLOCKING (OMEGA) HIGH
A HIGH-PRESSURE AREA WHICH DIVERTS JET-STREAM FLOW FROM ITS NORMAL PATH. A BLOCKING HIGH OVER THE GULF OF ALASKA IS OFTEN RESPONSIBLE FOR PROLONGED AND/OR HEAVY RAIN OVER CALIFORNIA SEE ALSO: PART 2, METEOROLOGICAL CHARACTERISTICS AND PART 3, 1986 CASE STUDY FOR DETAILS.

+++ FETCH-
THE "REACH" OR DISTANCE DOMINATED BY A SINGLE PATTERN. FOR EXAMPLE, IN THE 1986 FLOOD, THE FETCH WAS A WESTERLY-TO- SOUTHWESTERLY FLOW THAT EXTENDED FROM CALIFORNIA TO HAWAII, AND IT BROUGHT MOIST, TROPICAL AIR THAT ENHANCED THE AMOUNT AND INTENSITY OF PRECIPITATION. SEE ALSO PART 3, 1986 CASE STUDY.

+++ FLOOD STAGE
THE RIVER HEIGHT (ABOVE MEAN SEA LEVEL) AT WHICH FLOODING BEGINS TO OCCUR. SEE ALSO: WARNING STAGE AND PART 3, 1986 CASE STUDY.

+++ HYDROGRAPH
A PLOT OF RIVER HEIGHT OR VOLUME FLOW RATE (CUBIC FEET PER SECOND)
VS. TIME AT A FIXED RECORDING STATION. SEE ALSO: PART 2, HYDRO-
LOGICAL CHARACTERISTICS FOR DETAILS.

+++ HYDROMETEOROLOGY
STUDY OF THE INTERACTIONS BETWEEN METEOROLOGICAL AND HYDRO-
LOGICAL PROCESSES.

+++ HYETOGRAPH
GRAPH OF TOTAL RAINFALL OR RAIN INTENSITY. USUALLY DISPLAYED AS A
CONTOUR MAP. SEE ALSO PART 3, 1986 CASE STUDY FOR DETAILS.

+++ NEXRAD
NEXT GENERATION WEATHER RADAR. DOPPLER RADAR SYSTEM TO BE INSTALLED
IN THE 1990 S. ONE PURPOSE OF NEXRAD IS TO USE ITS REFLECTIVITY DATA
TO IMPROVE QPF S OVER SMALL AREAS.

+++ OROGRAPHIC
PRECIPITATION MECHANISM IN WHICH AIR FLOWING ACROSS A MOUNTAIN RANGE
IS LIFTED AND COOLED AND MOISTURE IS RELEASED IN CALIFORNIA, OROGRAPHIC
PRECIPITATION IS MOST ABUNDANT WHEN LOW-LEVEL WINDS ARE FROM THE
SOUTHWEST (225), CAUSING MOST RAIN TO BE DEPOSITED ON WEST-
FACING SLOPES AND LEAVING THE EASTERN SIDE IN A "RAIN SHADOW". SEE
ALSO: PART 3, 1986 CASE STUDY FOR DETAILS.

+++ QPF
QUANTITATIVE PRECIPITATION FORECAST. A PREDICTION ISSUED BY THE NWS
CONCERNING THE EXPECTED AMOUNT OF PRECIPITATION OVER A GIVEN STATION
OR FORECAST AREA. SEE ALSO: PART 2, FORECAST INGREDIENTS AND PRODUCTS,
PART 3, 1986 CASE STUDY, AND QPRF FOR DETAILS.

+++ QPRF
QUANTITATIVE PRECIPITATION RATIO FORECAST. A "NORMALIZED" QPF
METHOD USED IN NORTHERN CALIFORNIA. QPRFS COMPARE THE AMOUNT OF RAIN
EXPECTED AT A CERTAIN STATION DURING 6-HOUR PERIODS TO A COMPUTED
RAINY-DAY NORMAL. SEE ALSO: QPF, RAINY DAY NORMAL, PART 2,
FORECAST INGREDIENTS AND PRODUCTS, WSFO DATA AND PART 3, 1986
CASE STUDY FOR DETAILS.

+++ RAIN (INTENSITIES)
LIGHT = LESS THAN .10 INCH/HOUR.
MODERATE = BETWEEN .10 AND .30 INCH/HOUR.
HEAVY = GREATER THAN .30 INCH/HOUR.

+++ RAINY DAY NORMAL
A CALCULATED PRECIPITATION AMOUNT USED AS THE BASIS FOR THE QPRF
R.D.N. = NORMAL MONTHLY PRECIPITATION / # DAYS IN MONTH WITH > .10
INCH PRECIP. SEE ALSO QPRF AND PART 3, 1986 CASE STUDY FOR DETAILS.

+++ RESPONSE TIME
FOR A GIVEN BASIN, RAINFALL PATTERN, AND SOIL-MOISTURE
CONDITION, THE TIME BETWEEN THE BEGINNING OF RAIN AND FLOOD OCCURRENCE.

+++ RUNOFF
WATER THAT DOES NOT EVAPORATE OR GO INTO STORAGE UNDERGROUND.
SURFACE RUNOFF FLOWS ABOVE GROUND, AND SUBSURFACE RUNOFF FLOWS
THROUGH THE UPPER LAYERS OF SOIL TO A RIVER OR OTHER BODY OF WATER.

+++ SACRAMENTO MODEL
A SET OF HYDROLOGIC ROUTINES USED TO PREDICT STREAMFLOW. SEE ALSO:
PART 2, FORECAST INGREDIENTS AND PRODUCTS, CNRFC DATA FOR DETAILS.

+++ SNOW (FREEZING) LEVEL
THE HEIGHT (ABOVE MEAN SEA LEVEL) BELOW WHICH RAIN FALLS OR SNOWPACK
MELTS AND ABOVE WHICH SNOW ACCUMULATES. HIGH FREEZING LEVELS, SUCH
AS THOSE ACCOMPANYING THE TROPICAL AIR MASS THAT HELPED TRIGGER THE
HEAVY 1986 RAIN, ACCELERATE RUNOFF. SEE ALSO: PART 2, METEOROLOGICAL
CHARACTERISTICS.

+++ WARNING STAGE
THE RIVER HEIGHT (ABOVE BOTTOM, IN FEET) AT WHICH THE CNRFC
(CALIFORNIA/NEVADA RIVER FORECAST CENTER) ALERTS THE PUBLIC AND
GOVERNMENT AGENCIES TO THE POSSIBILITY OF RIVER FLOODING. SEE ALSO:
FLOOD STAGE AND PART 3, 1986 CASE STUDY.

+++ ZONAL FLOW
A WEST-TO-EAST JET STREAM ALIGNMENT THAT TENDS TO CARRY RELATIVELY
MILD AND DRY AIR FROM THE NORTH PACIFIC OVER CALIFORNIA. SEE ALSO:
PART 3, 1986 CASE STUDY.

THIS FILE CONTAINS METEOROLOGICAL CHARACTERISTICS OF FLOOD EVENTS

OBJECT: BLOCK NR. AK / TROUGH NR. HI
IMPORTANCE: A STRONG HIGH PRESSURE AREA IN THE VICINITY OF THE GULF OF
ALASKA OR A LOW CENTERED NEAR HAWAII (AS SEEN ON 500 MB CHART) CAN
STEER "WARM" STORMS TOWARD CALIFORNIA.
PRECURSORS: COLD LOW MOVING OFF ALASKA AND A LOW OVER CANADA MAY
PRECEDE THE FORMATION OF A BLOCK. A CUTOFF LOW THAT DRIFTS INTO THE
CENTRAL PACIFIC MAY START A COUNTERCLOCKWISE FLOW OF TROPICAL AIR.
MONITORED DATA: NMC UPPER AIR CHARTS (ESP. 500 MB)
CHILD: 500 MB TEMPERATURE, 500 MB WIND

OBJECT: BLOCK NEAR HI / WEST COAST TROUGH / ZONAL FLOW
IMPORTANCE: "COOL-TO-COLD" 500 MB PATTERN LIMITS THE MOISTURE-CARRYING
POTENTIAL OF STORMS THAT ORIGINATE IN THE GULF OF ALASKA.
PRECURSORS: HIGH PRESSURE BUILDS FROM TROPICAL PACIFIC, COLD AIR
MIGRATES SOUTH FROM THE ARCTIC OR CANADA, OR A NEAR-NORMAL JET STREAM
PATTERN HOLDS.
MONITORED DATA: NMC UPPER-AIR CHARTS (ESP. 500 MB)
CHILD: 500 MB TEMPERATURE, 500 MB WIND

OBJECT: 500 MB TEMPERATURE
IMPORTANCE: RULE-OF-THUMB IN DETERMINING THE NORTHERN LIMIT OF TROPICAL
AIR OVER CALIF.; INDICATOR OF MOISTURE AVAILABILITY.
DESCRIPTOR: TROPICAL > -20 C, POLAR < -40 C.
MONITORED DATA: NMC 500 MB UPPER-AIR CHART, LOCAL (OAKLAND) SOUNDING
PARENT: BLOCK NR. AK / TROUGH NR. HI, BLOCK NR. HI / WEST COAST TROUGH /
ZONAL FLOW
CHILD: TROPICAL AIR, POLAR / MARITIME AIR

OBJECT: 500 MB WIND
IMPORTANCE: RULE-OF-THUMB IN DETERMINING CHARACTERISTICS OF UPPER-
LEVEL AIR MASS, BOTH OF AN APPROACHING STORM AND OF THE FORECAST AREA
DESCRIPTOR: TROPICAL = SW QUADRANT, POLAR = NW QUADRANT
MONITORED DATA: NMC 500 MB UPPER-AIR CHART, SOUNDING.
PARENT: BLOCK NR. AK / TROUGH NR. HI, BLOCK NR. HI / WEST COAST TROUGH /
ZONAL FLOW.
CHILD: TROPICAL AIR, POLAR / MARITIME AIR

OBJECT: TROPICAL AIR MASS
 IMPORTANCE: HIGH MOISTURE CONTENT CAN BE TAPPED BY PASSING DISTURBANCES
 AND LEAD TO HEAVY RAINFALL.
 PRECURSOR: 500 MB TEMP. $> -20^{\circ}\text{C}$
 500 MB WIND DIRECTION = SW QUADRANT.
 MONITORED DATA: NMC 500 MB UPPER AIR CHARTS.
 PARENT: 500 MB TEMP., 500 MB WIND
 CHILD: FREEZING LEVEL, HEAVY PRECIP., QUASI-STATIONARY STORM TRACK /
 FRONTAL BAND

 OBJECT: POLAR / MARITIME AIR MASS
 IMPORTANCE: COLD AIR LIMITS AMOUNT OF MOISTURE THAT CAN BE CARRIED.
 PRECURSOR: 500 MB TEMP $< -30^{\circ}\text{C}$
 500 MB WIND DIRECTION = NW QUADRANT.
 MONITORED DATA: NMC 500 MB UPPER-AIR CHARTS.
 PARENT: 500 MB TEMP., 500 MB WIND
 CHILD: LIGHT PRECIP., FREEZING LEVEL, QUASI-STATIONARY STORM TRACK /
 FRONTAL BAND

 OBJECT: FREEZING LEVEL
 IMPORTANCE: WARM AIR MASSES RAISE THE ELEVATION BELOW WHICH ACCUMULATED
 SNOW MELTS - THIS CAN CAUSE INCREASED RUNOFF INTO BASINS IN OR NEAR
 MOUNTAIN RANGES AND CAUSE FLOODING EVEN AFTER LITTLE OR NO PRECIP.
 IN THE AREA.
 PRECURSOR: TROPICAL AIR MASS = HIGH
 POLAR / MARITIME AIR MASS = LOW
 MONITORED DATA: SURFACE TEMPERATURES IN MOUNTAINOUS AREAS.
 PARENT: TROPICAL AIR MASS, POLAR / MARITIME AIR MASS
 CHILD: HIGH FLOOD POTENTIAL, LOW FLOOD POTENTIAL

 OBJECT: QUASI-STATIONARY STORM TRACK / FRONTAL BAND
 IMPORTANCE: MULTIPLE DISTURBANCES MAY MOVE ACROSS THE SAME AREA,
 PROLONGING AND INCREASING RAINFALL.
 PRECURSOR: BLOCKS
 MONITORED DATA: SATELLITE PICTURES SHOWING CLOUD BANDS, NMC 500 MB
 HEIGHT CHARTS.
 PARENT: TROPICAL AIR MASS, POLAR AIR MASS
 CHILD: PROLONGED PRECIP.

 OBJECT: UPPER-LEVEL DISTURBANCE
 IMPORTANCE: UPPER-LEVEL DISTURBANCES (VORTICITY MAXIMA) MOVING TOWARD A
 FORECAST AREA CAN TRIGGER RAIN, ESPECIALLY IN AREAS OF HIGH INSTABILITY
 (E.G., IN A TROPICAL AIR MASS).
 DESCRIPTOR: 500 MB VORTICITY $> 12 * 10^{(-5)}$
 500 MB VORTICITY ADVECTION = POSITIVE
 MONITORED DATA: 500 MB NMC CHARTS SHOWING VORTICITY CENTERS AND
 MOVEMENT
 CHILD: HEAVY PRECIP., LIGHT PRECIP., PROLONGED PRECIP.

 OBJECT: SURFACE WIND
 IMPORTANCE: IN AREAS WHERE OROGRAPHIC INFLUENCES ARE IMPORTANT (FOR
 EXAMPLE, ALONG COAST RANGE), SURFACE WIND AFFECTS AMOUNT AND LOCATION
 OF PRECIP. DEPOSITED. A SW WIND (PERPENDICULAR TO THE COAST RANGE)
 LEADS TO HIGHEST AMOUNTS.
 MONITORED DATA: COASTAL AND MTN. WINDS WHERE AVAILABLE
 CHILD: HEAVY PRECIP.

OBJECT: PRECIPITABLE WATER
 IMPORTANCE: THE UPPER LIMIT ON THE AMOUNT OF RAINWATER AVAILABLE TO FALL.
 DESCRIPTOR: RULE-OF-THUMB TO FIND PRECIPITABLE WATER VIA SURFACE DEWPOINT TEMPERATURE

DEWPOINT TEMP. (SFC, F)	PRECIP. WATER (IN.)
40	.50
55	1.05
65	1.68
75	2.62

MONITORED DATA: SURFACE DEWPOINT
 CHILD: HEAVY PRECIP., LIGHT PRECIP.

OBJECT: PROLONGED PRECIPITATION
 IMPORTANCE: MOST NORTHERN CA FLOODS RESULT FROM PROLONGED MODERATE RAIN AFTER SOIL BECOMES SATURATED AND RUNOFF BEGINS. THE EXCESS RUNOFF CAN EITHER CAUSE SIGNIFICANT RIVER RISES OR FLASH FLOODING NEAR MTN. SLOPES OR IN POORLY DRAINED AREAS.
 PRECURSORS: QUASI-STATIONARY FRONT ACROSS CA, DISTURBANCES MOVING WEST-TO-EAST ACROSS FRONT IN TRAIN-LIKE FASHION.
 MONITORED DATA: SATELLITE PICTURES, CNRFC GUIDANCE, ALERT OR OTHER HOURLY PRECIP. DATA, QPF/QPRF, EXCESSIVE RAINFALL OUTLOOK.
 PARENT: QUASI-STATIONARY STORM TRACK / FRONTAL BAND

OBJECT: HEAVY PRECIPITATION
 IMPORTANCE: HIGH PRECIPITATION RATES OFTEN INDUCE FLASH FLOODING OR RAPID INCREASES IN RIVER LEVELS AND OFTEN OCCUR IN ISOLATED AREAS WHERE DATA COLLECTION IS MINIMAL AND FORECASTING IS DIFFICULT
 PRECURSORS: TROPICAL MOISTURE (SOUTHWESTERLY WIND)
 MONITORED DATA: ALERT DATA, CNRFC GUIDANCE, SFC WIND DIRECTION
 PARENT: SURFACE WIND, TROPICAL AIR MASS

THIS FILE CONTAINS HYDROLOGICAL CHARACTERISTICS OF FLOOD EVENTS

OBJECT: ANTECEDENT PRECIPITATION INDEX (API)
 PURPOSE: USED TO PARAMETERIZE SOIL-MOISTURE CONDITIONS IN A BASIN. USED UNTIL EARLY 1970S BY CNRFC, BEFORE BEING REPLACED BY MORE DETAILED SACRAMENTO MODEL.

INPUTS: DAILY EVAPOTRANSPIRATION RATE AND PRECIP.

FORMAT: $I(D) = K * I(D-1) + P(D)$,

WHERE: $I(D)$, $I(D-1)$ = CURRENT AND PREVIOUS DAY API (DEPTH)

K = EVAPOTRANSPIRATION FACTOR, USU. TAKEN AS .9 (I.E., SOIL MOISTURE IS DEPLETED AT RATE OF 10% PER DAY WHILE NO PRECIP. FALLS)
 $P(D)$ = PRECIP. (DEPTH) OF CURRENT DAY.

(SEE FIG. 23)

OUTPUT: A RELATION SUCH AS THAT IN FIG. 4 MAY BE USED TO DETERMINE THE DEPTH OF RUNOFF, WHICH CAN THEN BE CONVERTED TO FLOW RATE AND STAGE VIA THE METHODS DISCUSSED UNDER SACRAMENTO MODEL.

OBJECT: HYDROGRAPH
 PURPOSE: DEPICT VOLUME FLOW RATE (DISCHARGE) PAST OR STAGE AT A GIVEN POINT ALONG A RIVER OVER A CERTAIN TIME PERIOD.
 INPUTS: STORM MAGNITUDE AND DURATION, SOIL MOISTURE CONDITIONS, RUNOFF

OUTPUT: DISCHARGE (VOLUME FLOW RATE) OR STAGE VS. TIME. (SEE FIG. 24)

OBJECT: EVAPOTRANSPIRATION
 PURPOSE: ACCOUNT FOR DEPLETION OF SOIL MOISTURE THROUGH DRYING. THE MAGNITUDE AND DURATION OF E.T. AFFECTS HOW MUCH RAIN IT TAKES TO PRODUCE RUNOFF. FOR EXAMPLE, DESERT ENVIRONMENTS HAVE HIGH E.T. RATES WHICH CAUSE THE SOIL TO HARDEN RAPIDLY AND MAKE FLASH FLOODING POSSIBLE EVEN AFTER VERY SHORT-DURATION CONVECTIVE RAINFALL.
 INPUT: TEMPERATURE, WIND, HUMIDITY (FROM CLIMATOLOGICAL RECORDS)
 OUTPUT: RATE OF DRYING GIVEN IN DEPTH/DAY THAT WOULD OCCUR FROM AN OPEN PAN.

THIS FILE CONTAINS RELEVANT FORECAST INFORMATION GENERATED BY THE
NATIONAL METEOROLOGICAL CENTER

OBJECT: 500 MB HEIGHT CHARTS (N. AMER. AND N. HEMISPHERE)
PURPOSE: PROVIDE ANALYSIS AND FORECAST OF 500 MB HEIGHT PATTERN.
USED TO DETECT BLOCKS, JET-STREAM POSITION, AREAS OF TROPICAL AIR,
AND VORTICITY PATTERNS.
INPUTS: SOUNDINGS FROM LAND AND SEA STATIONS, LFM, NGM, HVM MODEL RUNS.
ISSUED: EVERY 6 HOURS BEGINNING AT 0000 UTC
OUTPUT: CIRCULATION CENTERS, PLOTTED SOUNDINGS, GEOPOT. HEIGHT CONTOURS
AT 60 DAM INTERVALS (510 = 5100 DAM). SEE FIG. 36A FOR AN EXAMPLE.

OBJECT: SURFACE CHARTS (N. AMER. AND N. HEMISPHERE)
PURPOSE: PROVIDE ANALYSIS AND FORECAST OF SURFACE FEATURES OF SYNOPTIC-
SCALE WEATHER SYSTEMS. USED TO TRACK LOW-PRESSURE CENTERS, FRONTS,
AND PRECIPITATION AREAS.
INPUTS: SURFACE LAND AND SEA OBSERVATIONS, SOUNDINGS
ISSUED: N. AMER. MAPS - EVERY 3 HOURS DAILY BEGINNING AT 0000 UTC.
N. HEMISPHERE MAPS - EVERY 6 HOURS DAILY BEGINNING AT 0000 UTC.
OUTPUTS: FRONTS, ISOBARS (4 MB INTERVALS), CIRCULATION CENTERS,
PLOTTED STATION DATA (SEE FIG. 37)

OBJECT: 6 HOUR QUANTITATIVE PRECIPITATION FORECAST (QPF)
PURPOSE: UPDATE 24 HOUR QPF AND EXCESSIVE RAINFALL FORECAST
INPUTS: SURFACE, UPPER AIR, SATELLITE, AND RADAR REPORTS; SHORT-RANGE
LIMITED-AREA FINE MESH MODEL (LFM) AND NESTED GRID MODEL (NGM) DATA
FORECAST LENGTH: 2 CONSECUTIVE 6-HOUR PERIODS
ISSUED: 0230, 0730, 1430, 1930 UTC DAILY
OUTPUT: .25", .5", 1.0", 2.0" SIX-HOURLY RAINFALL CONTOURS ON
AN ISOHYETAL MAP (SEE FIG. 25) ***

OBJECT: 24 HOUR QPF
PURPOSE: SHOW ISOHYETAL MAP AND PROVIDE REASONING BEHIND FORECAST
INPUTS: SAME AS 6-HOUR QPF
FORECAST LENGTH: 24 HOURS ENDING 1200 UTC
ISSUED: 4 FORECASTS:
1. "PRELIMINARY" 0730 UTC DAY 1 = VALID 1200 UTC DAY 1 TO 1200 UTC
DAY 2
2. "FINAL" 1030 UTC DAY 1 = VALID TIME SAME AS # 1
3. 1030 UTC DAY 1 = VALID 1200 UTC DAY 2 TO 1200 UTC DAY 3
4. 1930 UTC DAY 1 = VALID TIME SAME AS # 1
OUTPUT: ISOHYETAL MAP WITH DISCUSSION OF REASONING, FORECASTER
CONFIDENCE, COMPARISON WITH MODEL RESULTS, AND LOCAL EFFECTS
(SEE FIG. 26).

OBJECT: EXCESSIVE RAINFALL OUTLOOK
PURPOSE: SHOW REGIONS WITH FLASH-FLOOD POTENTIAL
INPUTS: SAME AS 6-HOUR QPF
FORECAST LENGTH: 15, 21, 24 HOURS
ISSUED: 3 FORECASTS:
1. 0730 DAY 1 = VALID DAY 1 1200 TO DAY 2 1200
2. 1530 DAY 1 = VALID DAY 1 1500 TO DAY 2 1200
3. 1930 DAY 1 = VALID DAY 1 2100 TO DAY 2 1200
OUTPUT: 3 TYPES:
1. MAP SHOWING WHERE TOTAL RAINFALL MAY EXCEED 5"
2. MAP SHOWING WHERE RAINFALL APPROACHES FLASH-FLOOD GUIDANCE VALUES
OF LOCAL RIVER FORECAST CENTERS OR WHERE LONG DURATION RAINFALL MAY
LEAD TO EXCESSIVE RUNOFF
3. MAP SHOWING WHERE ISOLATED HEAVY RAINFALL MAY OCCUR IN THE WEST
DUE TO SUMMERTIME OROGRAPHIC EFFECTS (SEE FIG. 27)

OBJECT: EVALUATION
12, 24, 36, 48 HOUR PRODUCTS SMOOTH OUT FLASH FLOOD AND MESOSCALE
EFFECTS
POINT QPF S HAVE < 60 MINUTE RELIABILITY
HEAVIER RAINFALL AMOUNTS TEND TO BE UNDERESTIMATED BY QPF S

THIS FILE CONTAINS RELEVANT FORECAST INFORMATION GENERATED BY THE CALIFORNIA/NEVADA RIVER FORECAST CENTER

OBJECT: SACRAMENTO SOIL MOISTURE ACCOUNTING MODEL
PURPOSE: MONITOR SOIL CONDITIONS IN RIVER BASINS AND PROVIDE FORECAST HYDROGRAPHS. DETERMINISTIC (BASED ON MATHEMATICAL DESCRIPTIONS OF PHYSICAL PROCESSES) AND LUMPED (TREATS ENTIRE WATERSHED AS UNIFORM, GIVING AVERAGE VALUES TO SUCH VARIABLES AS OPF AND EVAPOTRANSPIRATION) FOR AN OVERVIEW OF THE MODEL SEE FIG. 28.
INPUTS: NMC AND LOCAL OPF S. AUTOMATED PRECIP. GAUGE READINGS (LIKE ALERT), DAILY OPEN PAN EVAPORATION RATES (ED, IN./DAY) FROM CLIMATOLOGICAL RECORDS.
IMPORTANT COMPONENTS:
BASIN RAINFALL = RAINFALL VALUES FORECAST OR OBSERVED FOR A SET OF STATIONS ARE WEIGHTED TOGETHER TO DETERMINE BASIN RAIN (IN.)
TOTAL EVAPOTRANSPIRATION = $E(1) + E(2) + E(3)$ = E.T. FROM UPPER AND LOWER ZONES AND FROM PORTION OF BASIN SURFACE COVERED BY WATER.
UPPER ZONE = RESERVOIR CONTAINING AMOUNT OF WATER STORED IN UPPER SOIL LAYERS AND INTERCEPTED BY VEGETATION ON THE SURFACE.
LOWER ZONE = GROUNDWATER STORAGE
TENSION WATER = WATER DEPLETED ONLY BY EVAPOTRANSPIRATION.
FREE WATER = WATER DEPLETED BY PERCOLATION AND DRAINAGE INTO THE SOIL
PERCOLATION = RATE OF WATER TRANSFER BETWEEN UPPER AND LOWER ZONES.
A FUNCTION OF UPPER ZONE FREE WATER CONTENT AND TOTAL LOWER ZONE CONTENT.
DIRECT RUNOFF = MOISTURE RUNOFF (VOLUME FLOW RATE) AFTER RAIN FALLS ON IMPERVIOUS SOIL.
SURFACE RUNOFF = RUNOFF AFTER UPPER ZONE FREE RESERVOIR IS FULL
INTERFLOW = RUNOFF WITHIN THE UPPER SOIL LAYER. A FUNCTION OF UPPER ZONE FREE WATER CONTENT, DRAINAGE RATE FROM THAT ZONE, FRACTION OF BASIN THAT REMAINS PERVIOUS.
BASE FLOW = DRAINAGE FROM LOWER ZONE FREE WATER.
PCTIM (DECIMAL FRACTION) = FRACTION OF BASIN AREA THAT IS PERMANENTLY IMPERVIOUS (CANNOT ABSORB RAINFALL).
ADIMP (DECIMAL FRACTION) = FRACTION OF BASIN THAT BECOMES IMPERVIOUS AFTER THE UPPER ZONE TENSION WATER RESERVOIR IS FILLED BY RAIN.
DIRECT RUNOFF OCCURS OFF THE PORTION OF THE SOIL (POTIM = ADIMP + PCTIM.)
SARVA (DECIMAL FRACTION) = PORTION OF BASIN SURFACE COVERED BY LAKES, RIVERS, ETC.
UZTWC, UZTWM, LZTWC, LZTWM (DEPTH) = UPPER AND LOWER ZONE TENSION WATER CONTENT AND MAX. CAPACITY.
UZFWC, UZFWM (DEPTH) = UPPER ZONE FREE WATER CONTENT AND MAX. CAPACITY.
FORECASTS: 6 HOUR TIME STEPS UP TO 36 HOURS INTO THE FUTURE
OUTPUTS: THOSE IMPORTANT TO FLOOD FORECASTING ARE DIRECT RUNOFF AND SURFACE RUNOFF. THE TOTAL RUNOFF (DIRECT + SURFACE + INTERFLOW + BASEFLOW) IS CONVERTED TO A UNITGRAPH (SEE FIG. 29) SHOWING RUNOFF FOR A UNIT OF RAINFALL DEPTH.
EVALUATION: OPF S LIMIT FORECAST PRECISION TO LARGE WATERSHEDS; DATA COLLECTION AND PHYSICAL UNDERSTANDING IS TOO LIMITED TO PREDICT SMALL-SCALE RUNOFF VARIATIONS

OBJECT: CHANNEL ROUTING
PURPOSE: TO COMBINE FORECAST HYDROGRAPHS ALONG A RIVER IN ORDER TO PREDICT HOW A FLOOD WAVE WILL MOVE AND HOW DOWNSTREAM RIVER STAGES WILL BE AFFECTED
INPUTS: UPSTREAM HYDROGRAPHS, MUSKINGUM METHOD PARAMETERS (SEE FIG. 30)
FORECAST: FLOW RATE PAST A GIVEN POINT AT 6-HOUR TIME STEPS
OUTPUT: PREDICTED RIVER STAGES (CONVERTED FROM OUTFLOWS BY STAGE-DISCHARGE RELATIONSHIPS FOR PARTICULAR RIVERS. SEE FIG. 31.
PURPOSE: GUIDE LOCAL WEATHER SERVICE OFFICES IN ISSUING FLOOD FORECASTS
INPUTS: SACRAMENTO MODEL, CHANNEL ROUTING, CLIMATOLOGY, RADAR AND SATELLITE PRECIP. ESTIMATES. LOCAL OPF DATA, EXPERT JUDGMENT
FORECASTS: WHEN FLOODING IS POSSIBLE, ISSUED UP TO 3 TIMES DAILY OR AS NEEDED

THIS FILE CONTAINS RELEVANT FORECAST INFORMATION GENERATED BY THE
NATIONAL WEATHER SERVICE FORECAST OFFICE IN REDWOOD CITY

OBJECT: QUAN. PRECIP. FCST. (OFF)

PURPOSE: BASED ON THE OPRF, PROVIDES GUIDANCE TO LOCAL OFFICIALS ON
HOW MUCH PRECIP. TO EXPECT AT SPECIFIC STATIONS OR IN BASINS.

INPUTS: OPRF, WIND DIR. (TO ACCOUNT FOR OROGRAPHIC EFFECTS),
FORECASTER EXPERTISE.

FORECASTS: SPECIFIC STATIONS AND BASINS WITHIN THE 17 OPRF FORECAST
AREAS ARE LISTED WITH FOUR 6-HOURLY OFFS.

ISSUED: TWICE DAILY WHEN PRECIP. IS EXPECTED

OUTPUT: PRECIP. EXPECTED WITHIN FOUR CONSECUTIVE 6-HOURLY PERIODS AND
THE COMBINED TOTAL FOR THE 24-HOUR PERIOD. FOR BASINS, EXPECTED SNOW
LEVEL IS ALSO REPORTED (SEE FIG. 32).

OBJECT: QUAN. PRECIP. RATIO FCST. (OPRF)

PURPOSE: PROVIDE LOCALIZED OFF S TO SUPPLEMENT THE NMC S OFF S.

INPUTS: UPPER AIR CHARTS FOR PREVIOUS 2 DAYS, NMC MODEL FORECASTS FOR
FOLLOWING 2 DAYS, SATELLITE AND RADAR INFO., ALERT / HOURLY
PRECIPITATION DATA.

FORECASTS: FOUR CONSECUTIVE 6-HOUR PERIODS FOR 17 FORECAST AREAS OF
30-MILE RADIUS, LOCATED ALONG 6 WSW-ENE LINES THROUGH CALIFORNIA FROM
THE OREGON BORDER TO A LINE CONNECTING FT. CONCEPCION WITH TEHACHAPIS.

ISSUED: TWICE DAILY WHEN PRECIP. IS EXPECTED

OUTPUT: NUMERICAL CODE IN THE FORM:

<FORECAST AREA NUMBER> <8-DIGIT PRECIP.CODE>

WHERE THE 8 DIGITS ARE FOUR PAIRS GIVING A COMPARISON OF EXPECTED
PRECIP. TO NORMAL RAINY DAY PRECIP. FOR EACH OF FOUR 6-HOUR PERIODS.
FOR EXAMPLE, 10121416 MEANS THAT FCST. PRECIP. FOR 4 SUCCEEDING
PERIODS WILL BE 1.0, 1.2, 1.4, 1.6 TIMES DAILY NORMAL, FOR A TOTAL
OF 5.2 TIMES NORMAL FOR A 24-HOUR PERIOD.

(SEE FIGS. 33-4)

EVALUATION: USEFUL IN MOUNTAINOUS AREAS, ESPECIALLY WHEN VALIDATED BY
ALERT DATA

OBJECT: ALERT / HOURLY PRECIP. DATA

PURPOSE: MONITOR AUTOMATED PRECIP. AND STREAMFLOW GAUGES TO DETERMINE
LOCALIZED FLOODING POTENTIAL. ESPECIALLY USEFUL IN REMOTE AREAS AND
WHERE FLASH FLOODING IS POSSIBLE.

OUTPUT: HOURLY PRECIP. / RIVER REPORTS (MORE OFTEN IN HEAVY PRECIP.)
FROM AUTOMATED GAUGES MAINTAINED BY THE NATIONAL WEATHER SERVICE,
CALIFORNIA DEPARTMENT OF WATER RESOURCES, U.S. GEOLOGICAL SURVEY, AND
U.S. BUREAU OF RECLAMATION. REPORTS RECEIVED DIRECTLY BY THE WEATHER
SERVICE CAN TRIGGER ALARMS WHEN A RIVER IS APPROACHING WARNING STAGE.
DATA IS ALSO TRANSMITTED VIA COMPUTERS AT THE CALIFORNIA DATA EXCHANGE
CENTER (SEE FIG. 35).

OBJECT: FLOOD FORECASTS

PURPOSE: NOTIFY PUBLIC AND GOVT. AGENCIES OF POSSIBLE FLOODING

INPUTS: ALL NMC, CNRFC, WSFO DATA AND FORECASTER EXPERTISE

FORECASTS: RIVER, FLASH, AND URBAN FLOOD WATCHES AND WARNINGS

ISSUED: WATCHES = CONDITIONS FAVORABLE FOR FLOOD

WARNINGS = FLOODING IMMINENT

FLASH FLOOD WARNING = UP TO 6 HOURS AHEAD

RIVER FLOODING = AT POINTS, UP TO 72 HRS. AHEAD

URBAN FLOODING = 24 HOURS AHEAD

UPDATED 2-3 TIMES DAILY

OUTPUT: COUNTIES / CITIES COVERED, AMOUNT OF PRECIPITATION EXPECTED,
PLACES AND TIMES OF RIVER CRESTS (WHEN APPLICABLE)

THESE ARE SOME POINTS TO FOLLOW IN A GENERAL FORECAST PROCEDURE PRIOR TO A FLOOD EVENT.

1. CHECK 500 MB NORTHERN HEMISPHERE (NH) CHARTS FOR SIGNS OF CHANGES IN JET-STREAM FLOW (BLOCK FORMING OVER) GULF OF ALASKA, STRONG LOW NEAR HAWAII, OR WEST COAST TROUGH.
2. CHECK CURRENT AND FORECAST 500 MB TEMPERATURE AND PRESSURE FOR TYPE OF MOISTURE REGIME IN THE FORECAST AREA.
3. IF BLOCK OCCURS, WATCH FOR VORTICITY MAXIMA FOLLOWING A QUASI-STATIONARY STORM TRACK AND FOR LONG FETCHES OF TROPICAL MOISTURE (VIA SATELLITE PICTURES), ESPECIALLY IF JET BREAKS THROUGH UNDER BLOCK. IF JET STREAM CARRIES POLAR AIR OR IS ZONAL, THE AMOUNT OF PRECIPITATION ASSOCIATED WITH IT PROBABLY WILL NOT CAUSE FLOODING.
4. AS POTENTIAL RAIN-CAUSING DISTURBANCES MOVE CLOSER (WATCH FOR NEARBY VORTICITY MAXIMA AND 500 MB POSITIVE VORTICITY ADVECTION (PVA), CONSULT NMC AND LOCAL QPFS, PREDICTED SNOW LEVELS, AND CNRFC FORECASTS FOR GUIDANCE ON WHERE AND WHEN RIVER/FLASH/URBAN FLOODING MAY OCCUR.
5. CONTINUOUSLY CHECK SURFACE WIND, SURFACE DEWPOINT TEMPERATURE, AND SATELLITE AND RADAR ANALYSIS FOR RAINFALL RATES AND POSSIBLY PROLONGED RAINFALL FROM A SERIES OF DISTURBANCES.
6. VERIFY RAINFALL ESTIMATES FROM ALERT AND HOURLY PRECIPITATION DATA AND RIVER RISES FROM AUTOMATED GAUGES AND OBSERVER REPORTS.

SIMULATION)

USE DATA FROM 1982 AND 1986 CASE STUDIES TO CHARACTERIZE RUSSIAN RIVER BEHAVIOR.
 ASSUME A LINEAR RELATIONSHIP BETWEEN API AND RIVER HEIGHT.
 ASSUME , FOR RUSSIAN RIVER, THAT FLOODING STARTS AT GUERNEVILLE WITHIN 24 HOURS AFTER CLOVERDALE AND HEALDSBURG API EXCEED 7.5 AND SANTA ROSA API EXCEEDS 6.0.
 FOR JANUARY, 1982. CASE, DETERMINE FLOOD / NO FLOOD STATE ALONG RUSSIAN RIVER. ESTIMATE RIVER CREST AND DATE, AND IDENTIFY FACTORS AFFECTING YOUR FORECAST.
 AFTER YOU HAVE ATTEMPTED A FORECAST, COMPARE RESULTS WITH THE DISCUSSION THAT FOLLOWS.

THE 1982 BLOCKING PATTERN WAS NOT AS PERSISTENT AS THAT IN 1986. THE PUSH OF TROPICAL AIR WAS NOT AS STRONG, AND DEWPOINTS WERE RELATIVELY LOW IN NORTHERN CALIFORNIA; THESE FACTORS LIMITED THE AMOUNT AND DURATION OF PRECIPITATION.

THE API READINGS OF THE JANUARY, 1982, CASE WERE WELL BELOW THOSE TAKEN DURING THE NEAR-RECORD FEB., 1986, FLOOD PERIOD. THE API PEAKS OF 1986 WERE AROUND 15 IN CLOVERDALE AND HEALDSBURG AND 10 IN SANTA ROSA, WHILE IN 1982 THEY WERE AROUND 8 FOR ALL 3 STATIONS. IN 1982, THE API EXCESS OVER THE ASSUMED FLOOD THRESHOLD LEVEL WAS ABOUT 1/10 OF THE EXCESS IN 1986 FOR CLOVERDALE AND HEALDSBURG, AND WAS ABOUT 1/2 IN SANTA ROSA. AVERAGING THE 3 STATION S EXCESSES TOGETHER TO GET ABOUT 1/4 OF THE 1986 EXCESS, AND KNOWING GUERNEVILLE FLOOD STAGE OF 32 FEET AND 1986 CREST OF CREST OF 48 FEET ESTIMATE THE CREST AT 36 FT. ON JANUARY 5, COMPARED WITH THE ACTUAL LEVEL OF 35 FEET.

THIS FILE CONTAINS CASE STUDIES OF EAST CA. FLOODS

DATE: JANUARY 2-5, 1982

PLACE: NORTHERN CALIFORNIA

THIS EVENT SHOWCASES A RARE COMBINATION OF EVENTS THAT LED TO HEAVY RAINFALL.

A STRONG OMEGA BLOCK WAS INDICATED IN DECEMBER 1981 OVER THE MID-PACIFIC BY THE PATTERN OF 522 AND 564 DAM CONTOURS AT 500 MB. ALSO, PRECIPITATION FOR THE TWO MONTHS PRIOR TO THE EVENT WAS UP TO 200 PERCENT OF NORMAL IN THE AREA.

BY JAN. 1, WESTERLY WINDS STRENGTHENED OVER THE PACIFIC AND SPREAD TO THE CALIFORNIA COAST, BRINGING SUBTROPICAL AIR AND RAISING MOISTURE CONTENT. ALSO, A WEAK DISTURBANCE NEAR HAWAII BEGAN MOVING EAST TOWARD WASHINGTON AND STRENGTHENING. AT THE SAME TIME, AN ALASKAN STORM BROUGHT COLD AIR AND LOW SNOW LEVELS TO NORTHERN CALIF.

DURING THE NEXT 48 HOURS, THE SURFACE LOW AND AN ASSOCIATED FRONT HAD MOVED TO THE PACIFIC NORTHWEST. THE FRONTAL ZONE STRETCHED THROUGH NORTHERN CALIF. AND INTO THE EASTERN PACIFIC. STRONG SOUTHWEST FLOW AT THE SURFACE AND ALOFT (UPTO 60 KNOTS AT 700 MB - OAKLAND SOUNDING AT 4 PM, JAN 4) CONTINUED FOR THE DURATION OF THE STORM. A STRONG TEMPERATURE GRADIENT DEVELOPED ACROSS THE FRONT AT 38 NORTH LATITUDE. THE INTERACTION OF COLD AND WARM AIR AND THE SLOW MOVEMENT OF THE FRONT "SIDEWAYS" (SW-NE) ACROSS CALIFORNIA ALSO CONTRIBUTED TO HEAVY RAIN, ESPECIALLY OVER THE MOUNTAINS OF MARIN AND SANTA CRUZ COUNTIES. (SEE FIGS. 36-7 FOR MORE DETAILS).

FLOODING WAS MOST INTENSE IN SMALL WATERSHEDS AND DEVELOPED AREAS, BUT MOST FLOODING WAS BELOW RECORD LEVELS BECAUSE OF THE RELATIVELY SPOTTY NATURE OF THE HEAVY RAIN. EVALUATION OF THE FORECAST PROCEDURE SHOWED THAT NMC MODELS WERE GOOD, ESPECIALLY IN IDENTIFYING LARGE-SCALE FEATURES, BUT THAT SATELLITE PICTURES WERE NEEDED TO VERIFY THE STRONG MOISTURE INFLUX.

DATA FOR THE 1982 CASE AS IT AFFECTED THE RUSSIAN RIVER FOLLOWS. FOR STATION LOCATIONS AND RAINY-DAY NORMALS, SEE 1986 CASE.

ANTECEDENT PRECIPITATION (NOV. 1981 - JAN. 1982)

API IS INITIALIZED AT 1.00" TWO MONTHS BEFORE THE JANUARY STORM
API IS CALCULATED ONLY FOR DAYS ON WHICH PRECIP. OCCURS.

NOVEMBER

DATE

PRECIP./API

6	10	11	12
13	14	15	16
17	18	19	21
22	23	24	25
26	27		

CLOVERDALE (TOTAL = 13.58", SURPLUS = 7.97")

	.20 / .55	.60 / 1.09	1.10 / 2.08
2.60 / 4.48		2.10 / 5.73	1.60 / 6.75
			2.70 / 6.69
.10 / 6.12	1.80 / 7.31	.10 / 6.68	
.10 / 5.51			

HEALDSBURG (TOTAL = 13.34", SURPLUS = 7.93")

2.32 / 3.74	.03 / 3.39	2.68 / 5.74	1.29 / 6.45
.69 / 6.50	.01 / 5.86	.00 / 5.29	2.82 / 7.58
.01 / 6.83	1.52 / 7.67	.03 / 6.93	.01 / 6.26
.23 / 5.86	.38 / 5.66		

SANTA ROSA (TOTAL = 8.91", SURPLUS = 5.17")

.01 / .60	.12 / .40	.01 / .37	.59 / .93
.21 / 1.04	1.60 / 2.54	.21 / 2.50	1.01 / 3.26
.73 / 3.66			1.26 / 3.66
1.85 / 5.15	.03 / 4.66	.78 / 4.97	.01 / 4.49
.31 / 4.35	.29 / 4.20		

DECEMBER

6	7	8	9
10	12	13	14
15	16	18	19
20	21	26	28
29	30	31	

CLOVERDALE (TOTAL = 12.02", SURPLUS = 3.35")

.40 / 2.32			.90 / 2.59
	.40 / 2.29	.40 / 2.46	
.10 / 2.09		4.60 / 6.13	3.00 / 8.51
.40 / 8.06	.10 / 7.36	.10 / 4.44	.30 / 3.90
1.90 / 5.41		.60 / 4.98	

HEALDSBURG (TOTAL = 13.06", SURPLUS = 4.97")

.01 / 2.33	.08 / 2.18		.56 / 2.32
.01 / 2.10	.34 / 2.04	.38 / 2.22	.08 / 2.07
.10 / 1.97		2.26 / 3.69	4.64 / 7.96
.82 / 7.99	.24 / 7.43	.01 / 4.40	.04 / 3.60
2.60 / 5.84	.08 / 5.34	.68 / 4.88	

SANTA ROSA (TOTAL = 11.29", SURPLUS = 5.42")

	.12 / 1.58	.01 / 1.44	
.32 / 1.48	.06 / 1.26	.31 / 1.45	.39 / 1.69
.21 / 1.61	.01 / 1.46	.09 / 1.27	5.23 / 6.38
2.43 / 8.17	.17 / 7.52		
.85 / 4.09	1.21 / 4.69		

JANUARY

1	2	3	4
5			

CLOVERDALE

.62 / 5.10	1.09 / 5.68	2.85 / 7.96
.02 / 7.09		

HEALDSBURG

.58 / 5.15	.38 / 5.01	.24 / 4.75	3.68 / 7.95
.45 / 7.61			

SANTA ROSA

.51 / 4.73	.37 / 4.63	.05 / 4.21	3.07 / 6.86
2.02 / 8.19			

HOURLY PRECIPITATION DATA (JAN. 3-5, 1982)

* = STATION NOT OPERATING

STATION: CLOVERDALE

DATE	PRECIP. (IN.)	IN HOUR	ENDING AT					
(A)	1	2	3	4	5	6	7	8
(A/P)	9	10	11	12	1	2	3	4
(P)	5	6	7	8	9	10	11	12
3								1.00
4					.10	.20	.10	.10
5	.10	*	*	*	*	*	*	*
	*	*	*	*	*	*	*	*
	*	*	*	*	*	*	*	*

STATION: SEBASTOPOL

3								.10
		.10	.10	.10	.10	.20	.20	.20
4	.40	.40	.70	1.10	.50			

STATION: THE GEYSERS

3					.02	.06	.06	.09
	.12	.09	.14	.19	.11	.27	.15	.15
4	.21	.36	.18	.18	.24	.29	.25	.23
	.11						.03	
				.01	.08	.17	.11	.07
5	.01							

STATION: VENADO

3							.10	.10
	.20	.10	.20	.30	.20	.40	.30	.20
4	.30	.30	.40	.30	.40	.20	.40	.30
	.30	.10	.10		.10	.10	.10	
					.10	.10	.20	
5	.10							

STATION: YORKVILLE

3			.10		.10	.10		.10
	.10	.10	.20	.10	.20	.30	.20	.20
4	.30	.20	.20	.30	.20	.20	.20	.10
	.20							
				.10	.10	.10		.10

DATE: FEBRUARY 12 - 21, 1986

PLACE: NORTHERN CA, ESP. RUSSIAN RIVER AREA

THE FLOOD EVENT OF 1986 RESULTED FROM PROLONGED HEAVY RAINFALL OVER NORTHERN CALIFORNIA. THE FOCUS OF THE DESCRIPTION GIVEN HERE IS ON THE CONDITIONS THAT WERE FORECASTED AND OBSERVED OVER THE RUSSIAN RIVER AREA IN MENDOCINO AND SONOMA COUNTIES.

PRE-STORM CONDITIONS:

FEB. 10 - 12: OVER THE WESTERN PACIFIC, THE PREVAILING STRONG ZONAL FLOW BEGAN TO SHIFT SOUTHWARD AND TO INTENSIFY AS A COLD LOW PRESSURE AREA MOVED OFF ASIA (SEE FIGS. 38A). WEST OF 145 W LONGITUDE, THE ZONAL FLOW SHIFTED FROM NEAR 40 N LATITUDE TO NEAR 30 N. THIS SHIFT BROUGHT AN INCREASE IN 500 MB TEMPERATURES OVER THE MID-PACIFIC, INDICATING AN INFLUX OF WARM, MOIST, TROPICAL AIR. THIS CONDITION PERSISTED THROUGH FEB. 22.

AS THE COLD LOW MOVED OFF ASIA, A STRONG BLOCKING HIGH BEGAN TO FORM OVER THE NORTHEAST PACIFIC. BY FEB. 12, AN OMEGA HIGH WAS CENTERED AT 40 N, 130 W (SEE FIGS. 38B). THE STRONG WESTERLY WINDS OVER THE WESTERN PACIFIC BEGAN TO BE DIVERTED, WITH ONE BRANCH OF THE JET FLOWING "OVER THE TOP" INTO ALASKA AND DOWN THE WEST COAST OF NORTH AMERICA AND A SECOND "BREAKING THROUGH" UNDERNEATH (SEE FIGS. 38C).

AS THE SECOND BRANCH OF THE JET POSITIONED ITSELF IN A WSW - ENE ALIGNMENT FROM NEAR HAWAII TO THE WEST COAST OF THE U.S., TROPICAL AIR BEGAN MOVING OVER CALIFORNIA. IN CONTRAST TO A "COLD" STORM IN EARLY FEBRUARY, DURING WHICH A 500 MB TEMPERATURE OF -26 C WAS RECORDED AT OAKLAND (SEE FIG. 38A), SIMILAR READINGS TAKEN AS THE FIRST OF A SERIES OF MID-FEBRUARY HEAVY RAINS APPROACHED AND ARRIVED SHOWED A RISE TO -20 AND THEN TO -16 C (SEE FIGS. 38D). AN ADDITIONAL RULE-OF-THUMB INDICATING THE PRESENCE OF TROPICAL AIR WAS THE SHIFT IN 500 MB WIND DIRECTION FROM NW TO WSW (SEE MAPS 38E). NOTE THE ESPECIALLY STRONG WINDS IN ADVANCE OF THE HEAVY RAINS ON FEB. 14 AND 17.

THE PERSISTENCE OF THE OMEGA BLOCK SET UP A QUASI-STATIONARY STORM TRACK AND ALLOWED A 3000-MILE-LONG LOW-LEVEL FETCH TO DEVELOP BETWEEN HAWAII AND CALIFORNIA. FOUR MAJOR DISTURBANCES PASSED THROUGH THE RUSSIAN RIVER AREA IN MID-FEBRUARY. THE FIRST BROUGHT LIGHT RAIN BEGINNING ON THE 11TH AND PERSISTENT LIGHT RAIN WITH SOME HEAVIER BURSTS ON THE 12TH. NO MAJOR FLOODING OCCURRED BECAUSE PRECIPITATION OVER THE PRECEDING MONTHS HAD TENDED TO BE BELOW NORMAL AND THE API WAS NOT EXCESSIVELY HIGH COMPARED TO THE 1982 CASE, DURING WHICH THERE WAS ONLY MINOR FLOODING (THE API IS USED AS A GAUGE OF SOIL MOISTURE HERE BECAUSE SACRAMENTO MODEL DATA IS PRESENTLY UNAVAILABLE).

THE SECOND STORM MOVED IN AROUND MIDDAY OF THE 13TH WITH LIGHT RAIN. FREQUENT BURSTS OF MODERATE-TO-HEAVY RAIN OCCURRED FROM THE EVENING OF THE 13TH THROUGH MIDDAY OF THE 14TH, AND LIGHT RAIN CONTINUED THROUGH THE MORNING OF THE 15TH BEFORE TAPERING OFF TO SHOWERS LATER IN THE DAY. FLOODING BEGAN ALONG THE SOUTHERN REACHES OF THE RIVER AS THE RAIN BURSTS OF THE 14TH WERE ENDING.

THE THIRD STORM IN THE SERIES PROMPTED A FLOOD WATCH TO BE ISSUED FOR THE RUSSIAN RIVER VALLEY ON THE AFTERNOON OF THE 16TH. SCATTERED SHOWERS STARTED DURING THE MORNING AND DEVELOPED INTO PERSISTENT, LIGHT-TO-MODERATE RAIN THAT LASTED UNTIL THE EARLY MORNING OF THE 18TH. THE HEAVIEST 24-HOUR PRECIPITATION AMOUNTS OCCURRED DURING THIS PERIOD. THE ENTIRE LENGTH OF THE RUSSIAN RIVER WAS NOW IN FLOOD, WITH NEAR-RECORD CRESTS BEING PREDICTED OR OCCURRING AT THE SOUTHERN END.

THE FINAL STORM BROUGHT MOSTLY SCATTERED, LIGHT RAIN FROM MIDDAY OF THE 18TH THROUGH MOST OF THE 19TH. A FEW SHOWERS LINGERED INTO THE 20TH. THE RIVER RECEDED FROM THE NORTH STARTING ON THE 18TH AND DROPPED BELOW FLOOD STAGE IN THE SOUTH ON THE 20TH.

BY FEBRUARY 20TH, AN UPPER-LEVEL LOW HAD REPLACED THE OMEGA HIGH IN THE GULF OF ALASKA, AND A RIDGE BEGAN TO FORM ALONG 150 W, GRADUALLY CUTTING OFF THE TROPICAL FLOW OVER THE EASTERN PACIFIC. THE RIDGE COVERED CALIFORNIA BY THE 23RD, DRYING THE ATMOSPHERE AND ENDING THE RAINFALL (SEE FIGS. 38G).

DATA CONCERNING THE FLOOD ALONG THE RUSSIAN RIVER FOLLOWS. NOTE OROGRAPHIC INFLUENCE NEAR UKLAH. (DUE TO THE STRONG SW SURFACE WIND)

NORMAL PRECIPITATION AMOUNTS

STATION (ELEV.)	RAINY DAY NORM(IN./# RAINY DAYS NOV.	DEC.-JAN.-FEB
WILLITS(1350)	.86 / 7.9	.91 / 10.0
UKIAH(823)	.71 / 7.5	.80 / 9.7
UKIAH 4WSW(1900)	.71 / 7.5	.80 / 9.7
HOPLAND(500)	.85 / 7.2	.90 / 9.3
YORKVILLE(1100)	.95 / 7.3	1.00 / 9.4
CLOVERDALE(320)	.83 / 6.8	.88 / 9.1
HEALDSBURG(77)	.90 / 6.0	.95 / 9.0
VENADO(1260)	1.15 / 6.5	1.20 / 9.1
GUERNEVILLE(20)	.95 / 6.6	1.00 / 9.0
SANTA ROSA(167)	.64 / 5.8	.68 / 8.7

DAILY PRECIPITATION (FEB. 12-21, 1986) (INCHES)

STATION (ELEV.)	12 17	13 18	14 19	15 20	16 21
WILLITS(1350)	.98 1.23	1.01 1.90	2.55 1.37	2.91 .22	5.50 .44
COYOTE(670)	.41 2.38	1.49 1.56	1.00 .86	2.10 .71	1.17 .21
UKIAH(823)	.67 4.12	1.07 .64	2.74 1.00	1.88 .24	2.03 .27
UKIAH(1900)	.42 4.73	1.60 2.15	1.22 1.38	3.04 1.07	2.45 .48
HOPLAND(500)	1.12 2.86	.46 .67	3.66 .79	1.58 .40	2.23 .01
YORKVILLE(1100)	2.00 4.00	1.00 1.50	4.90 2.20	2.30 .40	3.90 .10
CLOVERDALE(320)	.62 3.95	1.61 2.53	2.59 1.08	5.03 .51	1.13 .10
HEALDSBURG(77)	1.80 4.47	.86 .68	5.01 1.54	2.86 .28	1.95 .13
VENADO(1260)	3.60 8.40	1.60 1.40	5.50 2.40	2.70 .20	4.80 .00
GUERNEVILLE(20)	1.97 7.25	1.18 1.30	3.20 1.35	2.10 1.10	2.90 .20
SANTA ROSA(167)	.44 4.15	.89 .68	3.48 1.56	1.20 .39	1.35 .28

6-HOURLY OFF VS. OBSERVATIONS (FEB. 12-21, 1986)

STATION: YORKVILLE

DATE	OFF / ACTUAL (IN.) FOR 6-HOUR PERIOD ENDING	4 AM	10 AM	4 PM	10 PM
12	0.0 / 0.0	.1 / .3	.3 / .3	1.0 / .9	
13	.6 / .1	.1 / 0.0	.1 / 0.0	.9 / .4	
14	1.0 / 1.2	.8 / 1.2	1.5 / 1.6	.8 / 1.1	
15	1.0 / .8	.5 / .2	.6 / 1.1	.3 / .4	
16	.1 / .6	.3 / .5	.4 / 1.4	.6 / .9	
17	.6 / 1.5	1.5 / 1.2	1.6 / 1.3	2.0 / .7	
18	1.5 / .1	.3 / .3	1.2 / .3	.8 / .7	
19	.6 / .6	.7 / .6	.8 / .4	.2 / .6	
20	0.0 / .1	.2 / .1	.2 / .2	.2 / .1	
21	0.0 / 0.0	0.0 / 0.0	.1 / 0.0	.1 / .1	

STATION: VENADO

12	0.0 / 0.0	.1 / .7	.3 / .7	1.2 / 1.6
13	.7 / 1.2	.1 / 0.6	.1 / 0.9	1.1 / .7
14	1.2 / 1.6	0.0 / 1.5	1.8 / 1.5	.7 / .5
15	1.3 / .9	.6 / .2	.7 / 1.2	.4 / .8
16	.1 / .1	.3 / .7	.5 / 1.9	.7 / 1.5
17	.7 / 2.2	1.8 / 2.6	1.9 / 2.8	2.4 / 1.4
18	1.8 / .3	.3 / .2	1.4 / .3	1.0 / .7
19	.7 / .5	.9 / .9	1.0 / .8	.3 / .3
20	0.0 / .1	.2 / .2	0.0 / 0.0	0.0 / 0.0

HOURLY PRECIPITATION DATA (FEB. 12-21, 1986)

* = STATION NOT OPERATING

STATION: CLOVERDALE

DATE	PRECIP. (IN.) IN HOUR ENDING AT:							
	(A) 1	2	3	4	5	6	7	8
	(A/P) 10	11	12	1	2	3	4	
	(P) 5	6	7	8	9	10	11	12
12								.10
			.10					
13	.10		.10	.10		.10		
	.10			.10		.10	.10	.10
	.10	.10	.10	.10	.40	.10	.30	
14						.10	.30	.30
15	.30	.30	.20	.10	.20	.20	.10	.10
	.20	.30	.30	.20	.50	.50	.20	
	.30	.10	.20	.20	.20	.10	.30	.10
16	.10	.10	*	*	*	*	*	*
	*	*	*	*	*	*	*	*
	*	*	*	*	*	*	*	*
17	*	*	*	*	*	*	*	*
	*	*	*	*	*	*	*	*
	*	*	*	*	*	*	*	*
18	*	*	*	*	*	*	*	*
	*	*	*	*	*	*	*	*
	*	*	*	*	*	*	*	*
19	*	*	*	*	*	*	*	*
	*	*	*	*	*	*	*	*
	*	*	.10		.20	.10	.10	
20				.10	.10	.10	.10	
				.10				.10
				.10	.10			

STATION: SEASTOPOL

12				.10		.10		.10
	.10	.10	.10		.10		.20	.20
	.30	.30	.10	.30		.10		
13								
				.10	.10		.10	.20
14	.30	.30	.30	.10	.10	.40	.10	
	.10		.10	.10	.20	.10		
							.20	.10
16					.10			
			.20	.10	.30	.10	.30	.30
	.30	.20	.40	.20		.10	.10	.10
17	.20	.20	.20	.10	.20	.10	.40	.20
	.20	.40	.40	.30	.20	.10	.20	.20

18									.10
		.20	.20	.50	.10				
19	.10			.30	.10				
			.10				.40		

STATION: VENADO

12	.10	.10	.10	.10		.10	.20	.10
	.20	.10	.10	.10	.10	.10	.10	.20
	.30	.20	.40	.40	.10	.20	.20	
13								
				.10	.20	.40	.30	.60
14	.70	.40	.10	.50	.20	.20	.10	.20
	.50	.30	.30	.60	.50	.10		
	.10	.10				.30		.30
15	.20	.30	.10			.10	.10	
			.30	.30	.20		.30	.10
		.10	.10	.20	.10	.10		.10
16					.10	.10	.10	.10
	.10	.20	.30	.20	.50	.30	.40	.20
	.20	.10	.30	.30	.20	.40	.30	.40
17	.50	.40	.40	.20	.30	.40	.50	.40
	.50	.40	.50	.50	.60	.50	.50	.30
	.30	.50	.30	.30	.20	.30	.20	.10
18		.10		.10	.10		.10	.20
							.10	
19	.10		.10	.30	.10	.10		
		.10	.10	.10	.20	.30	.30	.10
				.30		.30	.10	.10
		.10	.10	.10				.10
20					.10			.10

STATION: YORKVILLE

12	.10	.10	.10	.10		.10		.10
		.10		.10		.10		.10
	.10	.20	.10	.30	.10	.10		.10
13								
				.10	.10	.20	.30	.30
14	.30	.10		.20	.10	.10	.10	.20
	.30	.40	.10	.30	.50	.40	.20	.10
	.10	.10	.30	.10	.30	.20	.30	.10
15	.20	.10		.10		.10		
		.10	.20	.20	.10	.30	.10	.20
	.10		.20	.10			.10	.10
16	.20	.10		.10			.10	.10
	.10	.20	.20	.30	.30	.20	.20	.20
	.10	.20	.20	.10	.10	.20	.30	.40
17	.10	.30	.20	.20	.20	.30	.30	.20
	.10	.10	.30	.20	.20	.10	.20	.30
	.20	.10	.20	.20		.10		
18				.10	.10	.10		.10
			.10				.10	.10
	.10	.20	.20	.20				
19		.10	.30	.10	.30		.10	
	.10	.10		.10	.10	.10	.10	
		.20	.10	.30			.10	
20								
	.10		.10				.10	
		.10						

ANTECEDENT PRECIPITATION (NOV. 1985 - FEB. 1986)

API IS INITIALIZED AT 1.00" AT BEGINNING OF NOV.
API IS COMPUTED ONLY FOR DAYS ON WHICH PRECIP. OCCURS

NOVEMBER

DATE

PRECIP. / API

9	10	11	12
15	16	17	20
23	24	25	26
28	29	30	

CLOVERDALE (TOTAL = 5.55", DEFICIT = .22")

	.20 / .55		
	.23 / .38		
.38 / .87	1.49 / 1.83	1.00 / 2.65	
1.00 / 3.15	1.00 / 3.83	.24 / 3.68	

HEALDSBURG (TOTAL = 4.92, DEFICIT = .92")

.03 / .42	.39 / .76	.27 / .96	
.06 / .69	.08 / .70		
.22 / .85	.69 / 1.46	1.08 / 2.39	
1.04 / 2.78	1.06 / 3.56		

SANTA ROSA (TOTAL = 4.50" , SURPLUS = .79")

	.72 / 1.07	.09 / 1.05	.06 / 1.07
.02 / .77	.11 / .80	.01 / .73	.01 / .84
.13 / .52	1.85 / 2.32	.06 / 2.15	.02 / 1.95
.01 / 1.77	.01 / 1.60	.01 / 1.45	

DECEMBER

1	2	3	4
5	6	7	8
29	30	31	

CLOVERDALE (TOTAL = 4.48", DEFICIT = 3.77")

	2.60 / 5.64	.23 / 5.30	.02 / 4.75
.36 / 4.67		.54 / 4.33	
.20 / .63	.52 / 1.08	.01 / .99	

HEALDSBURG (TOTAL = 4.98", DEFICIT = 2.93")

.65 / 3.86	2.50 / 5.97	.04 / 5.41	.04 / 4.91
.33 / 4.75	.09 / 4.75	.42 / 4.35	
.65 / 1.08	.25 / 1.22	.01 / 1.11	

SANTA ROSA (TOTAL = 3.72", DEFICIT = 1.77")

.23 / 1.54	1.44 / 2.87	.05 / 2.64	
.21 / 2.58	.01 / 2.33	.49 / 2.59	.02 / 2.75
.47 / .73	.79 / 1.44	.01 / 1.31	

JANUARY

1	4	5	6
7	10	11	14
15	16	17	18
19	20	22	23
24	29	30	31

CLOVERDALE (TOTAL = 9.37", DEFICIT = .35")

.07 / .96	.32 / 1.03	.61 / 1.54	.28 / 1.66
			.19 / .91
.48 / 1.30	1.69 / 2.86	1.54 / 2.11	.03 / 3.73
	.07 / 3.09		.49 / 2.74
	.32 / 1.78	1.87 / 3.47	1.41 / 4.53

HEALDSBURG (TOTAL = 9.89", DEFICIT = .33")

.03 / 1.03	1.13 / 2.05	.31 / 2.16	
		.01 / 1.16	.09 / .93
.68 / 1.52	3.27 / 4.64	.17 / 4.34	.02 / 3.93
.02 / 3.56		.04 / 2.63	.37 / 2.74
	2.00 / 3.46	.46 / 3.57	1.29 / 4.50

SANTA ROSA (TOTAL = 6.64", DEFICIT = .36")

.02 / 1.20	.82 / 1.69	.31 / 1.83	.02 / 1.67
.01 / 1.52	.01 / 1.12		.39 / 1.13
.17 / 1.18	1.72 / 2.78	.79 / 3.30	.01 / 2.98
.05 / 2.73			.41 / 2.20
.01 / 1.99	.96 / 2.14	.27 / 2.19	.67 / 2.04

FEBRUARY

CLOVERDALE (TOTAL = 22.13", SURPLUS = 14.88")

1	2	3	4
5	11	12	13
14	15	16	17
18	19	20	21
22			

1.27 / 5.35	.05 / 4.86	1.47 / 5.84	.18 / 5.44
.01 / 4.91		.62 / 2.97	1.61 / 4.28
2.59 / 6.44	5.03 / 10.6	1.13 / 10.9	3.95 / 13.7
2.53 / 14.9	1.08 / 14.5	.51 / 14.5	.10 / 12.3

HEALDSBURG (TOTAL = 21.55", SURPLUS = 14.26")

.04 / 4.09	1.32 / 5.00	.79 / 5.29	
.01 / 4.30	.20 / 2.48	1.80 / 4.04	.86 / 4.49
5.01 / 9.05	2.86 / 11.0	1.95 / 11.8	4.47 / 15.1
.68 / 14.3	1.54 / 14.4	.29 / 13.3	.13 / 12.1

SANTA ROSA (TOTAL = 15.94", SURPLUS = 11.25")

.02 / 1.88	1.16 / 2.85	.25 / 2.82	
.01 / 2.29	.04 / 1.26	.44 / 1.57	.89 / 2.30
3.48 / 5.55	1.20 / 6.00	1.35 / 6.75	4.15 / 10.2
.69 / 9.88	1.58 / 10.5	.39 / 9.82	.28 / 9.11
.02 / 8.22			

RIVER HEIGHT DATA

STATION	WARNING STAGE (FT.)	FLOOD STAGE (FT.)	CREST/DATE (FT.)	DATES OF FLOOD
HOFLAND	16	21	22.9/2-17	2/17-20
HEALDSBURG	15	19	25.8/2-17	2/14-18
HACIENDA BR.	31	34	48.6/2-18	2/14-20
GUERNEVILLE	29	32	48.9/2-18	2/14-20

1.00 NUMBER
Q: OROGRAPHIC PRECIPITATION OVER CALIFORNIA IS GENERALLY GREATEST WHEN
LOW-LEVEL WINDS ARE FROM WHAT DIRECTION (IN DEGREES)

225
CLOSE ENOUGH! ON TO THE NEXT QUESTION
THE ANSWER IS AROUND 225. TO CLARIFY YOUR UNDERSTANDING, REVIEW
"METEOROLOGICAL CHARACTERISTICS" OR DO THE SET OF QUESTIONS THAT
FOLLOW.

1.10 CHARAC
Q: WHAT TYPE OF LANDFORM IS IMPLIED BY "OROGRAPHIC"

MOUNTAINS
CORRECT
THE RIGHT ANSWER IS MOUNTAINS. REVIEW VOCABULARY.

1.20 NUMBER
Q: WHAT IS THE DEGREE MEASURE FOR SOUTH

180
CORRECT
THE CORRECT ANSWER IS 180. REVIEW METR TEXTS

2.00 CHARAC
Q: IN WHAT SITUATION IS OPF CONSIDERED LEAST ACCURATE

HEAVY PRECIPITATION
CORRECT
HEAVY PRECIPITATION. REVIEW METR. CHARACTERISTICS

3.00 NUMBER
Q: AT APPROXIMATELY WHAT LONGITUDE (WEST) WOULD AN OMEGA BLOCK BE
CENTERED FOR THE POTENTIAL OF SEVERE FLOODING TO EXIST

165
RIGHT
AT AROUND 165. REVIEW METR. CHARACTERISTICS

4.00 NUMBER
Q: WHAT TYPE OF RAIN REGIME IS MOST COMMONLY THE CAUSE OF N. CALIF.:
FLOODING
1 = CONVECTIVE OR SHORT, INTENSE PRECIPITATION
2 = CONTINUOUS, MODERATE RAIN FOR EXTENDED PERIODS

2
CORRECT
USUALLY, #2. CONSULT METR. CHARACTERISTICS OR CASE STUDY, 1962

5.00 NUMBER
Q: WHAT IS A RULE-OF-THUMB 500 MB TEMPERATURE (- C) FOR MEASURING THE
NORTHERN EXTENT OF TROPICAL AIR

20
CORRECT
AROUND -20. TEMPERATURES ABOVE THIS INDICATE SUBTROPICAL MOISTURE IS
IN THE AREA, AN IMPORTANT PRECURSOR OF HEAVY RAIN. REVIEW METR.
CHARACTERISTICS.

THIS IS A BRIEF USER MANUAL DESCRIBING THE
STRUCTURE OF THE INTELLIGENT TUTOR FOR FLOOD
FORECASTING AND WAYS TO EXPAND THE KNOWLEDGE BASE.

**** TO CONTINUE WHENEVER THE TEXT STOPS PRINTING,
PRESS 1****

1

4 PARTS COMPOSE THE INTELLIGENT TUTOR

1. PART 1 = "INTRODUCTION TO FLOOD FORECASTING."
THIS PART IS A TEXT FILE THAT DESCRIBES THE
IMPORTANCE OF FLOOD FORECASTING, AND THE CRUCIAL
HYDROLOGICAL AND METEOROLOGICAL LINKS TO THE FORE-
CASTING PROBLEM. IT IS CONTAINED IN FILE
INPUTIFF.TXT

1

2. PART 2 = "THE FORECASTING PROCEDURE." THIS
PART CONTAINS THE KNOWLEDGE USED BY FORECASTERS
DURING A PREDICTION PROCESS. REFLECTING THE DIVER-
SITY OF THE KNOWLEDGE COLLECTED FROM VARIOUS EXPERTS,
THE FILES IN THIS PART ARE STRUCTURED IN SEVERAL
WAYS.

a. A VOCABULARY LIST IS CONTAINED IN INPUTVOC.TXT
IT CONTAINS A DESCRIPTION OF IMPORTANT WORDS WRITTEN
IN A DICTIONARY-LIKE STYLE.

b. A COLLECTION OF METEOROLOGICAL CHARACTERISTICS
IS CONTAINED IN FILE INPUTMET.TXT . THESE TRAITS
ARE ARRANGED IN A FRAME STRUCTURE, A WAY TO SUC-
CINCTLY STORE KNOWLEDGE. THIS STRUCTURE AND HOW TO
EXPAND IT IS EXPLAINED IN A LATER SECTION.

c. A COLLECTION OF HYDROLOGICAL CHARACTERISTICS IS
CONTAINED IN FILE INPUTHYD.TXT . IT CONTAINS SOME
GENERAL, QUALITATIVE RULES GOVERNING HOW CONCEPTS OF
HYDROLOGY ENTER INTO THE FORECASTING PROBLEM.

1

d. THE RESPONSIBILITIES OF THE NATIONAL METEOROLOG-
ICAL CENTER AS THEY RELATE TO FLOOD FORECASTING ARE
CAPTURED IN THE FRAME STRUCTURE OF FILE INPUTNMC.TXT

e. THE RESPONSIBILITIES OF THE CALIFORNIA/NEVADA
RIVER FORECAST CENTER ARE CAPTURED IN THE FRAME
STRUCTURE OF FILE INPUTCNR.FOR

f. THE RESPONSIBILITIES OF THE REDWOOD CITY
NATIONAL WEATHER SERVICE FORECAST OFFICE ARE CAPTURED
IN THE FRAME STRUCTURE OF FILE INPUTWSO.TXT

3. PART 3 = "CASE STUDY" THIS PART CONTAINS
DESCRIPTIONS OF THE EVOLUTION OF AND THE FORECASTING

OF PAST NORTHERN CALIFORNIA FLOOD EVENTS. SUCH
DESCRIPTIONS HELP THE STUDENT SEE THE CONCEPTS OF
PART 2 IN ACTION. EACH FLOOD EVENT IS CAPTURED IN A
FRAME IN THE FILE INPUTCS.TXT

1

4. PART 4 = "EXERCISES" THIS PART ALLOWS THE PUPIL TO TEST HIS AWARENESS OF THE FORECASTING PROCESS THROUGH A SERIES OF SHORT-ANSWER TYPE QUESTIONS, CONTAINED IN FILE INPUTEXS.TXT . AS THE STUDENT ANSWERS QUESTIONS, HIS RECORD OF CORRECT AND INCORRECT ANSWERS IS STORED IN A FILE NAMED AFTER THE USER I.D., PROVIDED AT THE BEGINNING OF A TUTORING SESSION. THE USER MAY SEE THIS RECORD WHEN HE ENTERS PART 4 IN SUBSEQUENT SESSIONS.

1

SPECIAL FEATURES AND NOTES FOR PROGRAM USERS

1. UPON ENTERING THE PROGRAM USING THE PHRASE "FLOOD" THE USER WILL SEE A REQUEST FOR A USER I.D. THIS MUST BE NO MORE THAN 6 CHARACTERS (NUMBERS OR LETTERS) LONG AND BE ENCLOSED IN SINGLE QUOTES (AS IS THE CASE FOR ALL CHARACTER REPLIES). THE I.D. SERVES AS THE NAME FOR THE STUDENT RECORD IN PART 4.

2. USERS MOVE WITHIN AND BETWEEN FILES AND DIFFERENT PARTS OF THE PROGRAM BY WAY OF SCREEN MENUS. THE MAIN TOPIC MENU GIVES A CHOICE OF THE 4 PROGRAM PARTS DISCUSSED PREVIOUSLY. FILES IN THE TREE STRUCTURE OF PART 2 ARE ACCESSED BY SUBMENUS OF TOPICS. IN PART 4, THE USER CAN CHOOSE WHETHER TO GO IMMEDIATELY TO THE EXERCISES OR, IF HE WANTS TO SEE HOW HE HAS DONE ON PREVIOUS EXERCISES, HE CAN VIEW HIS STUDENT RECORD BY ENTERING THE APPROPRIATE NUMBER.

1

OPTIONS TO MOVE AROUND WITHIN FILES APPEAR EVERY 10 TEXT LINES IN PARTS 1 - 3 AND AFTER EVERY EXERCISE IN PART 4. EVERY PART INCLUDES OPTIONS TO CONTINUE READING FROM THE SAME FILE OR TO RETURN TO THE MAIN TOPIC MENU TO CHOOSE ANOTHER ONE OF THE PARTS 1 - 4. PARTS 3 AND 4 CONTAIN THE ADDITIONAL OPTION OF TRANSFERRING TO TOPIC 2 TO REVIEW DESIRED MATERIAL AND CLARIFY ONE'S UNDERSTANDING. THE TREE STRUCTURE OF PART 2 CAN BE CLIMBED UP OR DOWN, AND CAN BE EXITED AT ANY POINT IN ORDER TO RETURN TO TOPICS 3 OR 4, USING AVAILABLE OPTIONS.

1

3. PART 4 EXERCISES ARE SHORT-ANSWER IN FORMAT. ANSWERS THAT THE USER GIVES MUST MATCH PRECISELY THE ONES STORED IN THE EXERCISE FILE, OTHERWISE THEY ARE COUNTED INCORRECT. THIS LIMITATION IS A PRODUCT OF THE NATURE OF FORTRAN - A COMPUTATIONALLY-ORIENTED LANGUAGE NOT EMINENTLY SUITED FOR HANDLING NATURAL-LANGUAGE DIALOGUE OR INEXACT LANGUAGE. THIS PROBLEM MAY BE RECTIFIED IN THE FUTURE WITH A MORE SUITABLE LANGUAGE.

1

ADVICE FOR THOSE WHO WANT TO EXPAND THE PROGRAM

1. NO TUTORING PROGRAM EXISTS THAT IS TRULY "INTELLIGENT." THE KNOWLEDGE BASE AND EXERCISES COMPILED FOR THIS PROGRAM ARE ORGANIZED IN THE FORM OF IF-THEN RULES, FRAMES, AND ORDINARY TEXT. HANDLING THIS ASSORTMENT OF INFORMATION WOULD BE A CHALLENGING TASK FOR ANY TUTORING PROGRAM, EVEN ONE WRITTEN IN A MORE ARTIFICIAL-INTELLIGENCE ORIENTED LANGUAGE THAN FORTRAN. WHAT FOLLOWS ARE GUIDELINES ON WAYS TO IMPROVE THE PROGRAM WITHOUT HAVING TO HAVE AN EXTENSIVE BACKGROUND IN EITHER ARTIFICIAL-INTELLIGENCE OR FORTRAN 77.

1

2. THE INTELLIGENT TUTOR FOR FLOOD FORECASTING IS COMPOSED OF A MAIN PROGRAM AND TWELVE SUBROUTINES. COMMENTS ABOUT THE FUNCTION OF EACH PART OF THE PROGRAM ACCOMPANY THE CODE, AND A DISCUSSION OF THE VARIABLES USED IS IN THE MAIN PROGRAM, "FLOOD." THE KNOWLEDGE BASE FOR THIS PROGRAM WAS CREATED VIA KEY-BOARD INPUT. FOR EXAMPLE, THE FILE "INPUTIFF.FOR" FOR PART 1 WAS CREATED AND STORED FROM THE ROUTINE "INPUTIFF.FOR." IN THE FORM "WRITE (7,*) <TEXT>" . EACH LINE OF TEXT COULD HAVE A MAXIMUM OF 72 CHARACTERS; CONCATENATION IN ORDER TO REACH AS CLOSE TO 72 AS POSSIBLE WAS DONE BY:

```
WRITE (7,*) <1ST PART>//  
+      <2ND PART>  
WHERE "+" INDICATES A CONTINUATION OF THE PREVIOUS  
LINE (PLACED IN COLUMN 6) AND THE WRITE STATEMENT CAN  
CAN BE STARTED ANYWHERE AFTER COLUMN 7.
```

1

THE REST OF THE KNOWLEDGE BASE WAS CONSTRUCTED IN A SIMILAR FASHION TO THAT DISCUSSED ABOVE. SLIGHT VARIATIONS TO THE ABOVE METHOD WERE EMPLOYED FOR THE EXERCISE FILE. IN THAT FILE, EACH QUESTION WAS HEADED BY A LEADER LIKE:

```
WRITE (7,*) <NUMBER> <DATA TYPE>  
WHERE <NUMBER> IS THE DECIMAL NUMBER OF THE QUESTION  
AND <DATA TYPE> IS EITHER "NUMBER" OR "CHARAC"  
DEPENDING ON THE KIND OF RESPONSE REQUIRED. THIS  
LINE IS FOLLOWED BY THESE, IN ORDER: QUESTION,  
CORRECT ANSWER, REJOINDER TO CORRECT RESPONSE, AND  
REJOINDER TO INCORRECT RESPONSE. ROOT QUESTIONS,  
NOTED AS <INTEGER> .0, ARE FOLLOWED BY BRANCH QUERIES  
SIGNIFIED BY <INTEGER OF ROOT>. <INTEGER LARGER  
THAN 0>. TO ALLOW THE SYSTEM TO FIND THE QUESTIONS  
EASILY, THE FOLLOWING FILE MARKINGS ARE USED: "+++"  
BETWEEN THE QUESTION AND THE CORRECT ANSWER, "----"  
BETWEEN ROOT AND BRANCH AND BETWEEN CONSECUTIVE  
BRANCH QUESTIONS AND "****" BEFORE EVERY ROOT AND AT  
THE END OF THE EXERCISE FILE
```

1

3. THE KNOWLEDGE BASE WAS CONSTRUCTED WITH INFORMATION GLEANED FROM EXPERTS AND FROM WRITTEN MATERIALS. IT WAS THEN CONVERTED INTO ORDINARY TEXT, IF-THEN RULES, OR A FRAME STRUCTURE. FOR THOSE NOT FAMILIAR WITH AI AND WANTING TO ADD KNOWLEDGE, IT IS SUGGESTED THAT THEY THINK THROUGH THEIR REASONING

PROCESS AND WRITE DOWN ANY KNOWLEDGE THEY DEEM IMPORTANT. THEN, LOOK FOR SIMPLE CAUSE-AND-EFFECT RELATIONSHIPS (IF-THEN RULES) OR MORE COMPLEX LINKS OR SPECIFIC INSTANCES OF GENERAL CASES (LIKE "PRECIPITATION" IN THE KNOWLEDGE BASE) APPROPRIATE FOR FRAMES (DISCUSSED BELOW). IT IS BEST, HOWEVER, TO SECURE A PERSON FAMILIAR WITH KNOWLEDGE ACQUISITION (A KNOWLEDGE ENGINEER) IN ORDER TO FULLY EXPLORE KNOWLEDGE THAT AN EXPERT MAY NOT BE ABLE TO EXPRESS BY HIMSELF.

1

4. THE FRAME-BASED STRUCTURE DISCUSSED EARLIER HAS BEEN TOUTED AS AN ECONOMICAL WAY TO STORE KNOWLEDGE AND DEPICT THE WAYS IN WHICH THE KNOWLEDGE IS RELATED. FRAMES ARE ORGANIZED AROUND A ROOT IDEA, SUCH AS PRECIPITATION. INFORMATION THAT CHARACTERIZES THE ROOT IS STORED WITH IT IN SLOTS, WHICH CAN INCLUDE THINGS LIKE INDICATORS (OF PRECIPITATION) AND IMPORTANCE (PRECIP. MAY CAUSE FLOODS). FRAMES ARE RELATED TO EACH OTHER BY PARENT-CHILD LINKS. CHILD FRAMES MAY BE CONSIDERED AS SPECIFIC INSTANCES OF THE GENERAL, PARENT, FRAME. THEY INHERIT THE PROPERTIES OF A PARENT, IN ADDITION TO HAVING THEIR OWN. CHILD FRAMES MAY HAVE CHILDREN OF THEIR OWN, AND THE STRUCTURE CAN BE EXPANDED HORIZONTALLY OR VERTICALLY INTO TREE FORM.

Figure 23. Graphical illustration of the change of the Antecedent Precipitation Index (API) with time (From Linsley et al. 1986).

Figure 24. Illustration of a typical hydrograph (From Linsley et al. 1986).

Figure 25. Illustration of a typical 6-hour Quantitative Precipitation Forecast (QPF) issued by the National Meteorological Center (NMC) (From Corfidi and Comba 1989).

222Z LBC738
 PAUS1 1216 141116
 NTC DAY 1 AND DAY 2 OFF DISCUSSION...REF AFOS GRAPHICS 540 540
 VALTD 151200 AND 161200

A CRIPPLING WINTER SHOW STORM MAY BEING HAVOC OVER LARGE AREA IN THE
 TX PNMK NEAR TO SRH UT. SNOWFALL AMTS OF OVER A FOOT ARE PSBL.

BIGGEST POST PROBLEM IS WHERE TO LOCATE RAIN/SNOW LINE SINCE MODELS
 DIFFER ON STORM TRACK AFTER 21 HRS. PREFER MORE NW HIGH TRACK SINCE
 LFN GENERALLY BRINGS HOT AIRS TOO QUICKLY END AS WPC LOW LIFTS OUT OF
 SOUTHWEST AND SINCE NW HIGH HAS SLIGHT NEG HEIGHT BARS ACROSS EAST BCOON
 MAY BE BEGINNING ITS FCST. BESTIES...A MORE MAD PSN OF THE SFC LOW FTES
 ROSENBLUMS RULE: AS LOWS DEEPEN THEY USUALLY TRACK FARTHER WEST THAN
 FCST BY THE NUMERICAL GUIDANCE. A MORE MAD TRACK LEAVES IT UP
 FOR GUESSES FOR HOW MUCH SNOW IS LIKELY...INITIAL COLD TEMPS SUGGEST
 SIGNIFICANT AMTS ARE PSBL BEFORE A CHGVR TO RAIN.

STG OVERLAPPING CONNECTION NOW ONE OK...SRH IS IN AREA OF PAK
 654 WARM INJECTION. WITH WPC SYSTEM SO FAR WEST...TRAINING OF
 CELLS IS LIKELY WITH PAK RAFL AMTS EXCEEDING 3 INCHES. FURTHER
 R...OVERLAPPING AND IMPACT OF EVENTUAL CONVA HEAD WILL LEAD TO POP AMTS
 OF OVER AN INCH...MUCH OF IT FALLING AS SNOW. TO THE S...THE OPEN GULF
 AND DENSE MOISTURE WILL CONT TO CAUSE INSTABILIZATION. AS SFC PAK PONG
 END...A SQUALL LINE SHUD EXIST. HIGH FCSTS DO ET SLY WINDS OVER LA WHERE
 WPC LVL DIFFERENCE WILL BE FAVORABLE. THERE...RAFL WILL GENERALLY RUN
 BTWN 1 AND 3 INCHES. LFN LOOKS TOO FAST WITH OFF MID ATL STRESS WHILE
 HIGH LOOKS TOO BRY ACROSS SOUTH.

ON DAY 2...PREFERRED HIGH TRACK SUGGESTING CHGVR TO RAIN ONE POC OF LAR
 PG WITH WPC SHUD WRAPPED AROUND BACK SIDE OF LOW ACROSS UT AND WPC PG.
 NW IDEA OF BULPS SECONDARY LOW ALONG E CST LOOKS GOOD BASED ON SPACING
 AND IDEA THAT HEIGHT FALLS WILL START WORKING OUT. THE SECONDARY LOW
 WILL PROVIDE AREA OF PROXIM SFC CONVERGENCE VICINITY NJ...ALLOWING WPC
 RAIN TO IMP. ELSEWHERE ALG E CST OVERLAPPING IS EXPECTED TO PRODUCE FWT
 POP AMTS. INTERIOR NEW ENGLAND MAY REMAIN SHUD IF SECONDARY GETS GOING
 FAST ENUF...BUT CSTL SECTIONS SHUD BE MOSTLY BAD. CONNECTION ALONG
 TRAILING PNT CAROLINAS WILL BE BOSS SINCE SFC CONVERGENCE AND IMFLW
 IS EXPECTED TO WORK. HOWEVER...PWS WILL BE HIGH AND ATMOSPHERE WILL BE
 UNSTABLE SO SCTD WPC RAIN IS PSBL WITH POK AMTS FIT TO CLIMATELOGICAL
 POK SRH APLNG...WHERE GEOGRAPHICS MAY LEAD A HND. JUNKER

Figure 26. Illustration of a typical 24-hour QPF issued by the NMC (From Corfidi and Comba 1989).

NFDQFFRD
 TTAA00 KNFD 290712
 NMC EXCESSIVE RAINFALL POTENTIAL OTLOOK...REF AFOS GRAPHIC 94E
 VALID JAN 291200 TO 301200Z

RAINFALL IS EXPECTED TO EXCEED FF GUIDANCE VALUES TO RT OF A LINE FROM
 SHV 603SHV POE PSX CRP HQI 20ELRD BSM GGG SHV.

VERY HEAVY RAINFALL EVENT ON TAP FOR SE TX. LO LVL SELV FLOW WILL OVRN
 SFC BNDRY OVR SERN TX WITH ADDED LO LVL CHNGCE COMING FROM TIGHT INVERTED
 SFC TROF. WK S/WV ROTATING ACROSS TX AT 18Z IS DEPICTED EXTREMELY WELL BY
 NGM 500MB GRIDPOINT WINDFIELD FCSTS..MUCH BETTER THAN ON CONVENTIONAL
 CHARTS. JUST AS IMPRESSIVE IS THE TROF AT THE 250MB JET LVL AS WELL AS
 THE UPPER DIFFLUENCE FROM RT REAR QUADRANT OF EXITING JET AND LEFT FRONT
 QUADRANT OF APPROACHING WIND MAX. ONE MORE IMPORTANT FEATURE IS THAT THE
 THICKNESS FVALUES FAIL TO RISE INVOF STG SLY FLOW..USUALLY A GOOD
 INDICATOR OF HVY RAINFALL. THESE DYNAMIC FEATURES COUPLED WITH VERY
 HIGH AVBL MSTR POINT TO A HIGH PROBABILITY OF EXCESSIVE RAFL AMTS
 NEARING 3 INCHES IN 3 HRS OR LESS. SOKICH

Figure 27. Illustration of a typical excessive rainfall outlook issued by the NMC (From Corfidi and Comba 1989).

Figure 29. Development of a unit hydrograph. Several unit hydrographs covering different storm durations are normally computed to determine a river's characteristic behavior. Storm runoff derived from an API chart or from the Sacramento Model can be correlated with discharge per unit runoff past a given point (From Linsley, et. al. 1986).

A general equation for water storage in a section of river is

$$(I_1 + I_2)t/2 - (O_1 + O_2)t/2 = S_2 - S_1,$$

where I = inflow rate (vol. unit time)
 O = outflow rate (vol./unit time)
 S = storage (volume)
 t = time period between 1 and 2

Thus, the difference between the average inflow and outflow within a specified time period is assumed to equal the storage. In solving this equation, I_1 , I_2 , O_1 , and S_1 are known and O_2 and S_2 must be determined.

The Muskingum channel-routing equation is

$$S = K(xI + (1 - x)O),$$

where S = storage (volume)
 K = storage constant (ratio of storage to discharge (time))
 x = relative importance of inflow and outflow in determining storage, ranging from $x = 0$ (no effect from inflow) to $x = 1$ (no effect from outflow). Usually ranges between 0 and 0.3.
 O = outflow or discharge (volume/unit time)
 I = inflow (volume/unit time)

The values of K and x are determined from previous floods.

After the Muskingum equation is substituted into the storage equation,

$$O_2 = c_0 I_2 + c_1 I_1 + c_2 O_1$$

where $c_0 = -(Kx - 0.5t)/A$
 $c_1 = -(Kx + 0.5t)/A$
 $c_2 = (K - Kx - 0.5t)/A$
 $A = (K - Kx + 0.5t)$
 t = period between times 1 and 2

The value of O_2 , the discharge at the outflow point, becomes O_1 , the inflow at a downstream point. In this way, discharges can be computed for any river point.

Figure 30. Mathematical description of the Muskingum channel-routing method for computing inflow and outflow through specified sections of a river.

Figure 31. Sample stage-discharge relationship for computing river height as a function of the volume of runoff (From Linsley et al. 1986).

STATION DATA VALUES									
ID	NAME	OFF-->	1ST PD	2ND PD	TOTAL	SNOW LEVEL			
0-6HR	6-12HR	0-24HR	0-6HR	6-12HR	0-24HR	SNOW LEVEL			
1	LYC11HUSK VALLEY		2.24	2.32	10.36	5000			
2	LYC11HUSK VALLEY		1.16	1.26	5.37	5000			
3	LYC11HUSK VALLEY		1.82	2.02	8.39	5100			
4	LYC11HUSK VALLEY		1.26	1.39	5.80	5200			
5	LYC11HUSK VALLEY		1.02	1.08	4.72	5300			
6	LYC11HUSK VALLEY		1.21	1.33	5.60	5200			
7	LYC11HUSK VALLEY		1.74	1.86	7.99	5500			
8	LYC11HUSK VALLEY		1.57	1.68	7.24	5500			
9	LYC11HUSK VALLEY		1.88	2.00	8.63	5600			
10	LYC11HUSK VALLEY		1.35	1.44	6.21	5800			
11	LYC11HUSK VALLEY		1.72	1.84	7.93	5900			
12	LYC11HUSK VALLEY		1.35	1.44	6.21	5900			
13	LYC11HUSK VALLEY		1.42	1.52	6.55	6000			
14	LYC11HUSK VALLEY		1.50	1.60	6.90	6000			
15	LYC11HUSK VALLEY		1.50	1.60	6.90	6000			
16	LYC11HUSK VALLEY		1.42	1.52	6.55	6000			
17	LYC11HUSK VALLEY		0.65	0.74	3.10	6300			
18	LYC11HUSK VALLEY		0.36	0.43	1.85	7000			
19	LYC11HUSK VALLEY		0.51	0.59	2.64	7200			
20	LYC11HUSK VALLEY		0.26	0.30	1.39	7800			
21	LYC11HUSK VALLEY		0.03	0.06	0.40	8000			
22	LYC11HUSK VALLEY		0.41	0.49	2.07	8000			
23	LYC11HUSK VALLEY		1.17	1.21	5.18	8500			
24	LYC11HUSK VALLEY		0.82	0.94	4.09	8500			
25	LYC11HUSK VALLEY		0.51	0.60	2.56	8500			
26	LYC11HUSK VALLEY		0.90	0.97	4.20	8500			
27	LYC11HUSK VALLEY		1.29	1.38	5.94	8500			
28	LYC11HUSK VALLEY		1.50	1.58	7.75	8500			
29	LYC11HUSK VALLEY		1.56	1.95	8.06	8500			
30	LYC11HUSK VALLEY		1.50	1.88	7.75	8500			
31	LYC11HUSK VALLEY		1.34	1.66	6.89	8500			
32	LYC11HUSK VALLEY		0.33	0.61	2.62	8500			
33	LYC11HUSK VALLEY		1.51	1.76	7.45	8500			
34	LYC11HUSK VALLEY		0.92	0.97	4.35	8500			
35	LYC11HUSK VALLEY		1.50	1.50	6.75	8500			
36	LYC11HUSK VALLEY		0.97	1.01	4.52	8500			
37	LYC11HUSK VALLEY		1.35	1.40	6.27	8500			
38	LYC11HUSK VALLEY		1.19	1.23	5.52	8500			
39	LYC11HUSK VALLEY		1.14	1.21	5.35	8500			
40	LYC11HUSK VALLEY		0.61	0.71	3.14	7000			
41	LYC11HUSK VALLEY		0.49	0.45	2.59	7200			
42	LYC11HUSK VALLEY		0.92	1.12	4.26	7200			
43	LYC11HUSK VALLEY		0.80	1.00	5.18	7200			
44	LYC11HUSK VALLEY		0.84	1.03	5.99	7200			
45	LYC11HUSK VALLEY		0.54	0.70	3.10	7200			
46	LYC11HUSK VALLEY		0.54	0.65	2.75	7900			
47	LYC11HUSK VALLEY		0.96	1.08	4.64	8200			
48	LYC11HUSK VALLEY		1.10	1.35	5.51	8500			
49	LYC11HUSK VALLEY		0.90	0.90	4.05	8500			
50	LYC11HUSK VALLEY		0.14	0.84	3.70	8500			

Figure 32. Typical QPF station and basin data issued during the 1986 California flood event (From Barbato 1986).

NUMERIC UNCORRECTED
 TEND 00 KNO 121134
 HNS SAN FRANCISCO QPRF 3 AM PST MON FEB 17 1986
 RAINY DAY RATIOS FOR 4 SIX HOURLY PERIODS BEGINNING 4 AM PST MON

1 161820 10101215 13131520 12131570
 2 13161820 00010112 12131520
 3 13161820 00010112 12131520
 4 04070810 00010112 12131520
 5 04070810 00010112 12131520
 6 01010203 00010112 12131520

SYNOPSIS...BROAD FRONTAL ZONE WITH CONSIDERABLE SUBTROPICAL AIR
 EXTENDS FROM THE GULF OF CALIFORNIA WESTWARD FOR ABOUT
 1000 MILES. THE FRONT IS LOCATED IN THE CENTRAL HAWAIIAN ISLANDS.
 THIS FRONTAL BAND IS FORECAST TO MOVE SLOWLY EASTWARD WITH THE
 HEAVIER PRECIPITATION MOVING SOUTHEAST OVER THE DISTRICT. THIS
 BAND WILL HAVE COPIOUS AMOUNTS OF RAIN AND MOVE THROUGH VERY
 SLOWLY. RAIN WILL BE 5000 HOURS THE FRONT WILL BE 1000 HOURS
 SOUTHWEST HAWAII, HNL.

DECODE FIRST LINE: 1 161820
 a b c d

- a = 1st 6-hour Period = 1.5 times a normal rainy day amount
- b = 2nd 6-hour Period = 1.0 times a normal rainy day amount
- c = 3rd 6-hour Period = 2.0 times a normal rainy day amount
- d = 4th 6-hour Period = 2.0 times a normal rainy day amount

To obtain forecast precipitation for a point, multiply the
 applicable QPRF value by the rainy day normal for the point.
 Interpolate for the appropriate month in the table. Interpolate
 between two forecast values to obtain a forecast value.
 Interpolate between two QPRF values to obtain a forecast
 precipitation for a basin. Use Table 3 to obtain a range of
 values to be expected over the 30-mile radius circle.

Figure 33. Sample Quantitative Precipitation Ratio Forecast (QPRF) and map showing forecast areas (From Barbato 1986).

Table 2
RAINY DAY AVERAGES FOR RIVER BASINS (in.)

	Oct.	Nov.	D-J-F	Mar.	Apr.
Smith	1.25	1.30	1.40	.95	.85
Total Klamath above					
Klamath Glen	.70	.80	.50	.65	.60
Klamath Local	1.00	1.10	1.15	.90	.80
Klamath above Orleans	.70	.80	.80	.60	.55
Trinity-Hoopa to Lewiston	.50	.70	.75	.60	.55
Trinity above Lewiston	.70	.80	.85	.70	.65
Redwood	1.00	1.10	1.15	.80	.75
Mad	.90	1.00	1.05	.80	.75
Eel above Scotia	.90	1.00	1.05	.75	.65
SF Eel above Miranda	1.00	1.20	1.25	.95	.85
Eel above Ft Seward	.75	.85	.90	.70	.60
Van Duzen	.90	1.10	1.15	.85	.80
Russian above Hopland	.70	.85	.90	.75	.65
Russian above Healdsburg	.75	.90	.95	.85	.75
Russian above Guerneville	.80	.95	1.00	.90	.80
Napa above St Helena	.80	.95	1.00	.85	.75
Napa above Napa	.75	.90	.95	.80	.70
San Francisco Bay Streams	.40	.55	.50	.40	.35

Figure 34. Sample tabulation of rainy-day normals. December, January, and February are considered climatologically similar months and therefore share the same rainy-day normal (From Barbato 1986).

STATION	DATE	A. M. HOUR ENDING												P. M. HOUR ENDING												
		1	2	3	4	5	6	7	8	9	10	11	12	1	2	3	4	5	6	7	8	9	10	11	12	
		MONTHLY MAXIMUM AMOUNTS												MONTHLY MAXIMUM AMOUNTS												
		APPLY HEADING AS APPROPRIATE												APPLY HEADING AS APPROPRIATE												
MINUTES		1	2	3	45	60	75	90	105	120	135	150	165	180	ACCUMULATION											
MINUTES		15	30	45	60	75	90	105	120	135	150	165	180	ACCUMULATION												
MINUTES		15	30	45	60	75	90	105	120	135	150	165	180	ACCUMULATION												
MINUTES		15	30	45	60	75	90	105	120	135	150	165	180	ACCUMULATION												
MINUTES		15	30	45	60	75	90	105	120	135	150	165	180	ACCUMULATION												
MINUTES		15	30	45	60	75	90	105	120	135	150	165	180	ACCUMULATION												
MINUTES		15	30	45	60	75	90	105	120	135	150	165	180	ACCUMULATION												
MINUTES		15	30	45	60	75	90	105	120	135	150	165	180	ACCUMULATION												
MINUTES		15	30	45	60	75	90	105	120	135	150	165	180	ACCUMULATION												
MINUTES		15	30	45	60	75	90	105	120	135	150	165	180	ACCUMULATION												
MINUTES		15	30	45	60	75	90	105	120	135	150	165	180	ACCUMULATION												
 												
MINUTES		15	30	45	60	75	90	105	120	135	150	165	180

Figure 36a. A 500 mb constant-pressure analysis chart for 1 January 1982 at 0000 UTC. It covers the northern Pacific Ocean, the western portion of North America, and the extreme northeastern part of Asia. For reference, northeastern Asia is at the upper right, Alaska is along the center right edge, Hawaii is near the center left edge, and California is near the lower center of the map.

Figure 36c. Same as Figure 36a for 5 January 1982 at 0000 UTC.

Figure 37b. Same as Figure 37a for 2 January 1982 at 0000 UTC.

Figure 37c. Same as Figure 37a for 3 January 1982 at 0000 UTC.

Figure 37d. Same as Figure 37a for 4 January 1982 at 0000 UTC.

Figure 37e. Same as Figure 37a for 5 January 1982 at 0000 UTC.

Figure 37f. Same as Figure 37a for 5 January 1982 at 1200 UTC.

Figure 38a. A 500 mb constant-pressure chart for 3 February 1986 at 1200 UTC. It covers a region similar to that in Figure 36a.

Figure 38b. Same as Figure 38a for 10 February 1986 at 1200 UTC.

Figure 38c. Same as Figure 38a for 13 February 1986 at 0000 UTC.

Figure 38d. Same as Figure 38a for 14 February 1986 at 1200 UTC.

Figure 38e. Same as Figure 38a for 17 February 1986 at 0000 UTC.

Figure 38f. Same as Figure 38a for 23 February 1986 at 0000 UTC.

Figure 38g. Same as Figure 38a for 24 February 1986 at 1200 UTC.

Figure 39. A North American surface-analysis chart for 17 February 1986 at 1200 UTC. Grey shading indicates precipitation (From National Oceanic and Atmospheric Administration 1986b).

Figure 40a. Map of California with the area covering the Russian River basin bounded by a dashed line in boxes 10 and 14 (From California Department of Water Resources 1991).

Figure 40b. Detail of the northern half of the bounded area in Figure 40a. Precipitation- and river-gauge stations that are used in the case studies are boxed.

Figure 40c. Detail of the southern half of the bounded area in Figure 40a.

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