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APPLICABILITY OF HYDROLOGIC MODELING
TO
TACTICAL MILITARY DECISION MAKING

A Thesis Presented

by

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Army Corps of Engineers

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ABSTRACT

Military operations in combat and training are effected by surface hydrology. Incorporation of historical and model-based analysis of hydrology into military plans will provide a sound basis for making decisions regarding the period of execution for a particular mission or an entire large scale operation. Present Army planning doctrine lacks sufficient hydrologic analysis of potential areas of operation for long range (years) planning purposes. Widely used hydrologic analysis techniques can fill the planning void. This thesis combines proven surface hydrologic methods and technologies, into standardized Army planning formats, to provide critical hydrologic information to military decision makers.

A background investigation validated the need for the incorporation of hydrologic information into decision making. A case study proved the value of hydrologic analysis.

A recent training exercise planned without hydrologic analysis experienced 10.86 inches of rainfall. As a result, major training events were canceled, there was greater damage to the environment, prolonged repair to training areas, and reduction in training time. The recommended dates for the exercise, derived by hydrologic analysis of the area of operation, based on the commander's intent, only recorded 0.05 inches of rain.

Detailed flexible plans increase the preparedness of military units. Operation "Just Cause" in Panama and Operation "Desert Shield" in the Persian Gulf are two recent examples of the increased need for rapid deployment plans to back up national policies. Hydrologic analysis of areas of contingency operation will strengthen the decisions concerning the optimum time of execution.

Accepted by the Faculty of the Graduate College, The University Of Vermont, in partial fulfillment of the requirements for the degree of Master of Science, specializing in Civil Engineering.

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Military operations in combat and training are affected by surface hydrology. Incorporation of historical and model-based analysis of hydrology into military plans will provide a sound basis for making decisions regarding the period of execution for a particular mission or an entire large scale operation. Present Army planning doctrine lacks sufficient hydrologic analysis of potential areas of operation for long range (years) planning purposes. Widely used hydrologic analysis techniques can fill the planning void. This thesis combines proven surface hydrologic methods and technologies, into standardized Army planning formats, to provide critical hydrologic information to military decision makers.

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Research for this thesis was truly conducted from coast to coast. Randall W. Bergman at the Defense Technical Information Center at Hanscom Air Force Base in Massachusetts sent valuable previous works and provided a light at the end of the "what kind of data is out there" tunnel.

Mr. Walsh at the OL-A USAF Environmental Technical Application Center in Ashville, N.C. provided all rainfall

data for the research. Mrs. Mary Peters of the U.S. Geological Survey National Center and NAWDEX graciously provided all requested stream flow data. Critical environmental information for the case study was provided with enthusiasm by the Directorate of Engineering and Housing at Fort Bragg, North Carolina. Mark Jourdan of the Waterways Experiment Station in Vicksburg, Mississippi, provided information on military hydrology that would have otherwise been overlooked The HEC-1 Flood Hydrograph package was provided by the Hydrologic Engineering Center, Davis, California. I am grateful to all of these professionals for their quick professional response to my requests.

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DEDICATION

This thesis and the long tiring effort that I put into it is dedicated to my Father, Kenneth F. Fisher. He was a man of little education but appreciated the value of it. I truly understand that "You can never get enough education."

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PURPOSE AND ORGANIZATION

> "War is a matter of vital importance to the State; the province of life or death; the road to survival or ruin. It is mandatory that it be thoroughly studied."
>
> "Appraise war in terms of five fundamental factors; moral influence, weather, terrain, command, and doctrine."
>
> Sun Tzu, 320-400 B.C.[25]

Even today, Sun Tzu's words from The Art Of War are the basic foundation for all military theories of war planning. This thesis continues the study of war by adding a new dimension to the fundamentals of weather, terrain, command, and doctrine.

1.1 Introduction

Throughout time hydrology has played an important part in the outcome of military operations. During World War II the Nazi war machine invaded Russia in what was documented as one of the greatest decision errors of the war[5].

The operation was code named Barbarossa and many different parameters influenced the time table for its execution. The original time table for the operation called for the attack to begin in early May 1941 with an expected victory 17 weeks later[5]. The whole operation was to be complete by the time the winter of 1941-1942 set in. The plan was delayed six weeks because of the campaign in Greece and was rescheduled for June of 1941[7,9]. The success of the Nazi campaign in Greece caused Hitler to believe his armies could accomplish anything. After the Greece Campaign, Hitler believed that Operation Barbarossa would only need three weeks to achieve his goals[5].

Even though the German High Command agreed with Hitler's evaluation of the armed forces, they recommended Operation Barbarossa be delayed so "unfavorable weather and swollen rivers[5]" would be avoided. For reasons not clearly understood, Hitler gave the word for the attack to begin on 22 June 1941. Seasonal rains and snows stalled the German War machine and assisted in its eventual defeat on the Eastern Front[5,7].

Hydrology also played a major roll in the invasion of Normandy during World War II. General Eisenhower delayed the execution of Operation Overlord two days because of inclement hydrological conditions[9,10]. Some forces were forced to turn back on 4 June 1944 because of the delay decision[9]. As D-Day (deployment day) approached, meteorologists kept the command group informed of the variable hydrologic conditions. A 36-hour window of clear weather allowed the commander to issue the command of execution for 6 June 1944 before the hydrological conditions got worse[10].

Decisions concerning the best time to conduct military operations depend on many parameters. History clearly shows that the outcome of military operations can be hydrologically dependent.

Correct decisions based on expected weather patterns will give commanders a decisive tactical advantage. Rain storm frequencies are cyclic and may be applied to planning of military operations. A well prepared hydrologic study of the area of operation will provide the commander with a basis for sound decisions regarding the conduct of a planned operation.

1.2 Problem Statement

The Army does not effectively use expected surface hydrology or storm frequencies as input parameters for decision making[47]. The historical accounts presented in the introduction to this chapter clearly show the need to incorporate surface hydrology into military planning.

Remote, highly sophisticated analysis of the surface hydrology and precipitation begins when an area of operation becomes an imminent area of interest or when an operation plan is converted to an operation order for execution. The time period in which a military operation is conducted is typically called the operation execution window. Important decisions about the operation execution window have usually been made by the time the short range hydrologic analysis has begun.

Decisions regarding execution windows for large scale operations or specific critical missions that are hydrologically vulnerable are presently made without the benefit of a detailed hydrologic analysis of the area of operation[47].

1.3 Facts Bearing on the Problem

The Army is currently shifting emphasis to more rapid deployment forces stationed in the continental United States rather than prepositioned forces out of the country[44,45]. More detailed plans must be prepared for contingencies around the world[44,45]. Hydrologic analyses of the potential areas of armed conflict will provide tactical commanders long range estimates of how hydrology can affect mission accomplishment. If given an option of when to schedule an operation, the analysis would provide historically based information for decisions regarding the best time for the window of execution.

The ongoing military force reduction due to the end of the Cold War and our nation's present budgetary situation will require the smaller military to be just as well trained with less money[45]. Realistic training improves combat readiness and field training is one of the most realistic and costly types of training that is conducted[16,44,45,46]. The effectiveness of training in the field can be very weather dependent.

It logically follows that soldier readiness would be improved and military budgets would be better spent on field exercises that maximize training time. Scheduling weather dependent operations for periods having hydrologic conditions that support the accomplishment of the commander's intent for the exercise would maximize training time, thus increase readiness.

Environmental impact of military exercises is becoming a prominent issue as environmental groups such as the Sierra Club and others get actively involved in environmental issues on military reservations and other training areas. U. S. Code of Federal Regulation 40[41] requires some large scale military exercises to have environmental assessments done as part of the planning approval process but the assessments are not all inclusive. An environmental assessment is outside the formal planning process presented in Army Field Manual 101-5 "Staff Organization and Operations[47]" and the information the assessment does provide can be overlooked.

The process for writing military plans is laid out in Army Field Manual 101-5 "Staff Organizations and

Operations[47]." This manual defines the format for the 5 paragraphs of a plan and for various Annexes that may be added to it. Typical annexes that are added to a plan include Intelligence, Movement, Logistics, Personnel and Administration, Communication and Electronics, Engineer, Fire Support, and Air Defense. An annex to a plan adds detail to specific aspects of the plan that directly impact the achievement of the commander's goals or intent. A hydrologic analysis (detailed in Appendix A) presented as an annex to a military plan, will form the basis for examining the impact of the military exercise with respect to sensitive lowlands and the impact of expected precipitation. Large military operations in an area will chew up the ground with vehicles, engineer equipment, and demolition, causing greater silting if the exercise is conducted during high runoff periods. The annex will recommend times of limited precipitation and low flows based on historic data, to minimize the impact on sensitive lowlands by military exercises.

1.4 Thesis Statement

It is hypothesized that military planning can be improved by the addition of a surface hydrologic analysis of the expected area of operation and that improved planning will result in increased readiness of the armed forces.

1.5 Thesis Objective

This thesis will adapt widely recognized civilian applications of hydrologic analysis into a military framework. Analysis of historic precipitation, river flows, lake levels, and data from a surface hydrologic computer model for an area of operation will be packaged into a military format that can provide commanders with information to base decisions on hydrologically vulnerable missions.

This thesis will adapt the civilian hydrologic applications into a draft Army Technical Manual (Appendix A) and validate its need and applicability by a background investigation (Chapter 2) and a case study (Chapter 3) on a large scale military exercise. The final implementing document will be the Army approved Technical Manual and an approved addition of a Hydrologic Annex (Appendix B) to Army Field Manual 101-5 "Staff Organization and Operations."

1.7 Summary

Operation plans and contingency plans do not include specific information regarding hydrologic conditions of an area of operation for decisions regarding when to conduct an operation[46,47]. Without hydrologic information, a commander makes decisions without regard for the historical hydrologic make-up of an area of operation. A Hydrologic Annex to a plan will provide critical information that has historically had a significant impact on the conduct of major miliary operations.

The draft Technical Manual in Appendix A, outlines the conduct of a hydrologic analysis of any area of operation to obtain critical data for presentation in a Hydrologic Annex to operation plans. This thesis is the first step toward an ultimate objective of having the Army adopt the proposed Technical Manual and add a section concerning the Hydrologic Annex to Field Manual 101-5.

Although there is a threat of war in the Persian Gulf, the political leaders of the United States are still faced with reducing the armed forces. The Chief of Staff of the Army, General Carl E. Vouno has indicated that the military will be required to have more forces in the continental United Stated prepared to rapidly deploy[44]. The addition of a Hydrologic Annex to operation and contingency plans increases the readiness of our military at no significant cost to the tax payer.

CHAPTER 2

BACKGROUND INVESTIGATION

2.1 Introduction

Military hydrology was found to be a very obscure research subject. Related works were found, but concentrated mainly on methods of including current immediate highly-technical weather data into ongoing military actions. No specific documentation for long range planning of hydrologic conditions related to military plans was found.

The U. S. Army Corps of Engineer's Hydrologic Engineering Center in Davis, California and the Corp's Waterways Experiment Station, based in Vicksburg, Mississippi have been given primary responsibility for investigating military hydrology. Technical reports from these organizations and many others are kept by the Defense Technical Information Center.

2.2 Summary and Critiques of Related Materials

In 1981, the U. S. Army Corps of Engineer Waterways Experiment Station published Miscellaneous Paper EL-79-6, "Military Hydrology, A Review of Army Doctrine on Military Hydrology[38]." The study was conducted to "review Army doctrine on military hydrology to determine its relevance to modern Army needs[38]." The study reviewed a total of 19 of the most current Army regulations, field manuals, training bulletins, and technical manuals that dictate Army doctrine in the field of military hydrology[38].

The 1981 study found that Army hydrologic doctrine still represented the technologies of the 1950's[38]. The general recommendation presented by the study was that Army doctrine needs to be updated to current technologies with respect to military hydrology[38]. Of direct significant importance was this finding:

> It is recommended that two manuals be published in the stream flow area. These manuals should be written for the hydrologist on the terrain team with the understanding that the user has knowledge of the material in FM 30-10 (Military Geographic Intelligence (Terrain)) and FM 21-30 (Terrain Analysis). Also the user would be expected to have an adequate background in math, computers, and remote sensing. One manual would be directed toward drainage analysis and stream flow monitoring and forecasting. The other would be directed toward remote sensing, precipitation monitoring, hydrologic computer modeling, and dam breach analysis[38].

Of the nineteen documents reviewed for Army doctrine related to hydrology, none have been updated and the recommended new manuals have not been produced. The proposed technical manual included in this thesis addresses the aspects of stream flow forecasting, precipitation forecasting, and hydrologic modeling.

A separate document by Garret J. Sullivan[40] was published by the Waterways Experiment Station in May of 1989. This study was on dam breach analysis for military planning and was called "Reservoir Analysis Model for Battlefield Analysis." His technical report does address the dam breach portion of the 1981 recommendation to the Chief of the Corps of Engineers.

Precipitation Estimation for Military Hydrology[35] and Military Hydrology: Report 8, Feasibility of Utilizing Satellite and Radar Data in Hydrologic Forecasting[39] are two related works that dealt with precipitation forecasting. These studies were primarily concerned with forecasting short range (days to weeks) with satellite photo imagery. This technology needs to be incorporated into tactical military planning. The way it is presented in the two documents suggests that the information is for use after a unit is deployed to the area of operation or is in the process of executing an operation order. In this case the decisions have already been made concerning when to conduct the planned exercise.

There are a number of prominent civilian hydrologists that have prepared texts of techniques and methodologies of storm frequency analysis and flood prediction. Chow[6], McCuen[20], and Hjelmfelt[17] have written texts that are well related to this thesis. These texts were critical to the writing of the draft Technical Manual with respect to surface hydrology and storm frequency. The civilian works reviewed and cited in the reference section were primarily written to give insight for the design of channels and to prevent the loss of life and property from flooding. A military application of the hydrologic techniques and methodologies by these authors and the many others has never been fully realized or published.

The HEC-1 Flood Hydrograph Package[31] is a user friendly computer package that provides many useful applications. It was designed to provide hydrologists insight into the reactions of various sizes and types of watersheds to precipitation runoff, snow-melt, and dam breach scenarios. The package is used for the prediction of flood waves with the intent of designing adequate protection of lives and property.

2.3 General Analysis of Previous Works.

Published military reports with independent or related topics of tactical decision making, hydrologic modeling, soil analysis, and environmental concerns do not fill the need of providing tactical commanders with adequate decision making information related to hydrologic conditions. Most studies are concerned with providing information with state of the art satellite imagery or recommend that techniques discussed in the text of the studies "could" or "should" be used for military decision making. They do not offer a practical way to do it.

The professional civilian works in hydrology are well thought out and very technically detailed but have not considered the military applications of their work. Most works are directed toward flood wave forecasting to prevent the loss of lives and property.

2.4 Unresolved Issues of Previous Works

Previous work does not address a way to combine the technologies and techniques of hydrology, hydrologic modeling, soil analysis, and environmental concerns into a condensed result that is useful to tactical commanders for decision making. The civilian references cited in this thesis fail to explore the possibilities that their techniques could be used for military planning.

Although there is a historic need to incorporate hydrology into military planning, there is presently no formal link between modern civilian hydrologic methods and tactical military decision making.

2.5 Summary

None of the related works make any type of reference or recommendation to the addition of a Hydrologic Annex to military operation plans. Review of related literature validates the theory that a Hydrologic Annex is a unique solution to a void in the tactical commander's decision making process. The review of literature brought out the Army's concern for updating its hydrological doctrine and also found that nothing formal has been done to modernize the doctrine.

The need to incorporate surface hydrology into military planning has also been realized by the U. S. Army Corps of Engineers', Construction Engineering Research Laboratory (CERL). A summary of A Climatic Basis for Planning Military Training Operation and Land Maintenance Activities, done by a team at CERL was published in the CERL Abstracts, Information Exchange Bulletin, in September of 1990[8]. The CERL summary enforces this thesis, because it recognizes the same military planning deficiency (Problem Statement page 3) and the ability to use historical precipitation to predict periods of minimum precipitation for the conduct of military exercises.

CHAPTER 3

RESULTS OF THE CASE STUDY

3.1 Introduction

The value of a Hydrologic Annex was validated by a case study involving the 82d Airborne Division at Fort Bragg North Carolina. Market Square III was conducted from 11-23 September 1989. It was used for the study because it was a large scale operation and was a familiar exercise. Market Square III involved 23,000 soldiers[1] and is considered a large scale joint service operation. It involves the entire 82d Airborne Division, a large involvement by XVIII Airborne Corps support units, elements from other divisions, plus Reserve and National Guard units[3]. The two week exercise moved the entire division from garrison to field locations on Fort Bragg and other places by large scale Airborne assault (parachuting), airland (deployment by aircraft to an airfield), and notional airland (road convoys). The exercise had 10 Division training objectives and 13 Joint training objectives[3]. Of primary concern for hydrologic analysis were the Division Commander's objectives of "two simultaneous brigade-size parachute assaults" and "conducting Division level offensive/defensive operations[3]."

The Market Square III Operation Plan used for validation was dated 11 September 1989. The planning process began on 10 November 1988 with an initial briefing to the Division Commander concerning the scenario[3]. The Operation Plan was scheduled to be in draft form on 30 June 1989 and published on 29 August 1989, less than a month before the exercise was to begin[3]. The actual Intelligence Estimate to the Market Square III Operation Plan discussed the impact of weather on the exercise[2]. It is not clear how the information regarding precipitation was obtained for the Intelligence Annex.

The case study of this thesis showed that the Intelligence Annex statement "precipitation is usually less in September than it is in any other month,[2] " is not valid and provided the commander with false information.

Because the operation plan was completed so close to the execution date it is assumed that the information provided in the Intelligence Annex was derived from weather predictions from the National Weather Service. These predictions were not provided to the commander in the earlier planing stages and hydrologic information was not available to the commanding general to base decisions on when to conduct the exercise. If a hydrologic study, as proposed in Appendix A, of the area of operation had been previously conducted and was in the Installation Training Guidance (a military document providing guidance on the conduct of training on the specific installation that is provided to all units), the staff could have taken the information and tailored it to the commander's intent and provided the necessary information in more accurate detail.

This case study shows how a Hydrologic Annex would have recommended that the exercise be conducted in October, not September as planned and executed. October was historically proven to be the month with hydrologic conditions that complemented the commander's intent for the exercise by being the month of lowest average precipitation.

3.2 Analysis of the Commander's Intent

This case study was done using the operation plan of Market Square III but without the benefit of looking at the data of what actually occurred.

The first phase of the case study involved the analysis of the commander's intent. The commander's stated training intent for the exercise included 10 Divisional training objectives and 13 joint training objectives[3]. The Commander's objectives or goals related to hydrologic analysis were[3]:

1. Exercise Corps and Divisional marshal and deployment systems.
2. Plan and execute joint operations to include two simultaneous brigade-size parachute assaults to establish a lodgement.

3. Conduct Division level offensive/defensive operations using mixed forces to include deep operations.
4. Stress the Corps and Divisional combat service support systems.
5. Exercise Corps and Division alert, marshal, and airborne/airland deployment assaults.
6. Employ Military Airlift Command combat tactics during the conduct of the airborne operations.
7. Employ joint air attack systems.
8. Execute Army airspace and control.
9. Exercise joint suppression of enemy air defenses.

Analysis showed that the exercise would involve massive airdrops of personnel, equipment, and supplies. Fort Bragg's tactical forward area (dirt) landing strips also would be used to deliver essential troops, equipment and war fighting materials into the scenario country of San Braggio by C130 cargo/transport planes. Execution of the exercise during a time of least precipitation would best support the achievement of the commander's intent[16]. An exercise window of no precipitation is unrealistic and some precipitation is needed to achieve Army goals of conducting realistic training to achieve combat readiness[44,45].

The Little River is a significant body of water that could directly influence the intent of the exercise as well as the tactical intent of the mission. There should be enough water flowing in the river to provide practical training for the soldiers without posing a serious safety threat.

The exercise would involve movement of some moderately heavy pieces of military equipment. Most of the movement would be done by High Mobility Multipurpose Vehicles that are very mobile and relatively light. The movement of the equipment over the sandy-silty soils at Fort Bragg[54,55,56,57] combined with disturbance of the soil from demolition charges and digging by engineer equipment, has the potential to increase the wash down of silt into the lowlands of the military reservation (Figure 3-1 presents an area map of Fort Bragg). An exercise period of low or no precipitation would drastically reduce the silt wash down into the lowlands[16]. The reduction of silt wash down would help to prevent degradation of the habitat of some of Fort Bragg's rare, threatened, or endangered species of plant life[14].

The Hydrologic Annex Decision Matrix, Figure 3-2, was used to determine that a full Hydrologic Annex was needed for the Market Square III operation plan. The Hydrologic Decision Matrix is a step-by-step method for analysis of the commander's intent with respect to hydrology. If an abbreviated annex would suffice, it would consist of any of the parts of a full annex. The choice of the sections for an abbreviated annex is at the discretion of the individual command.

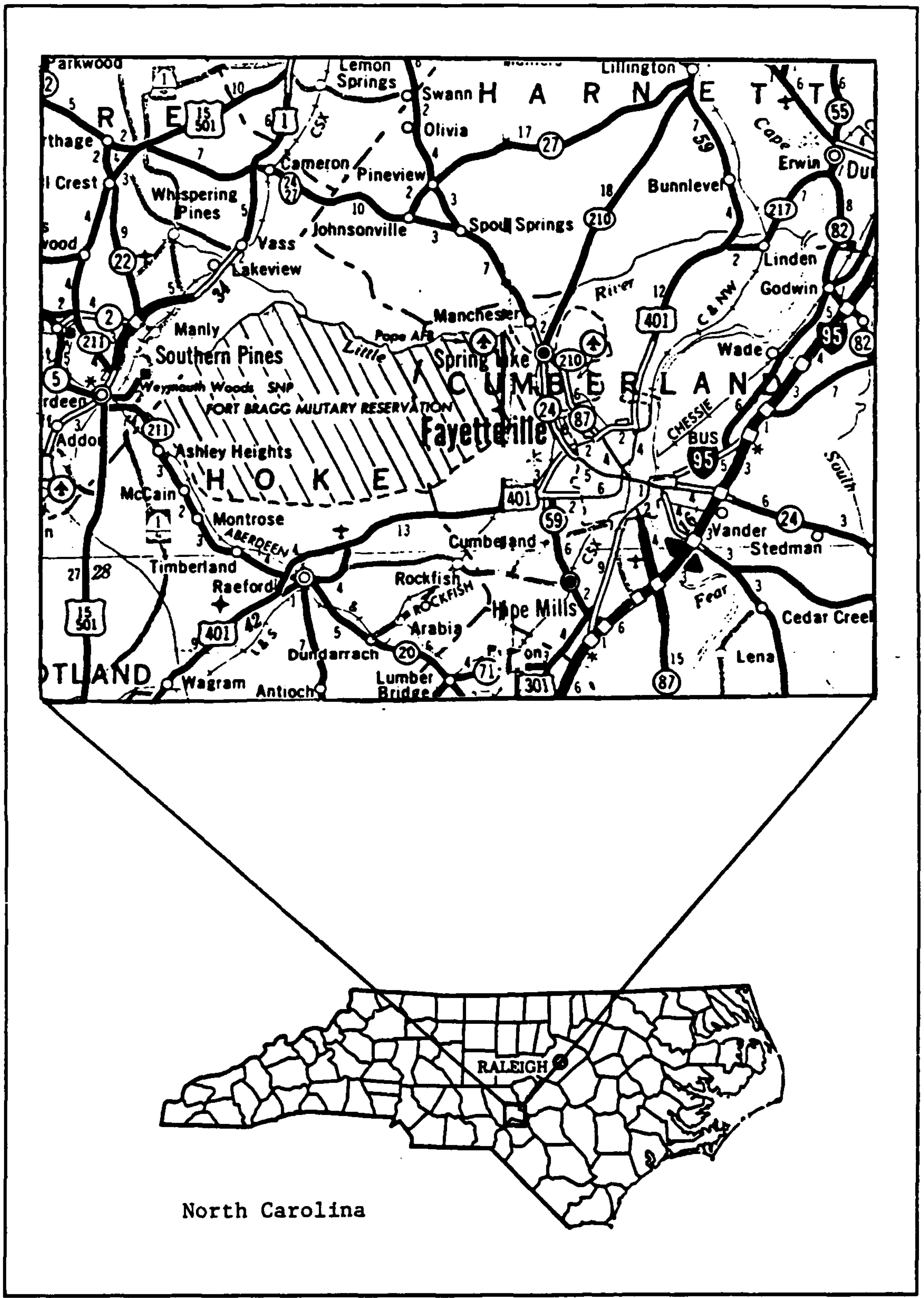


Figure 3-1. Area Map of Fort Bragg

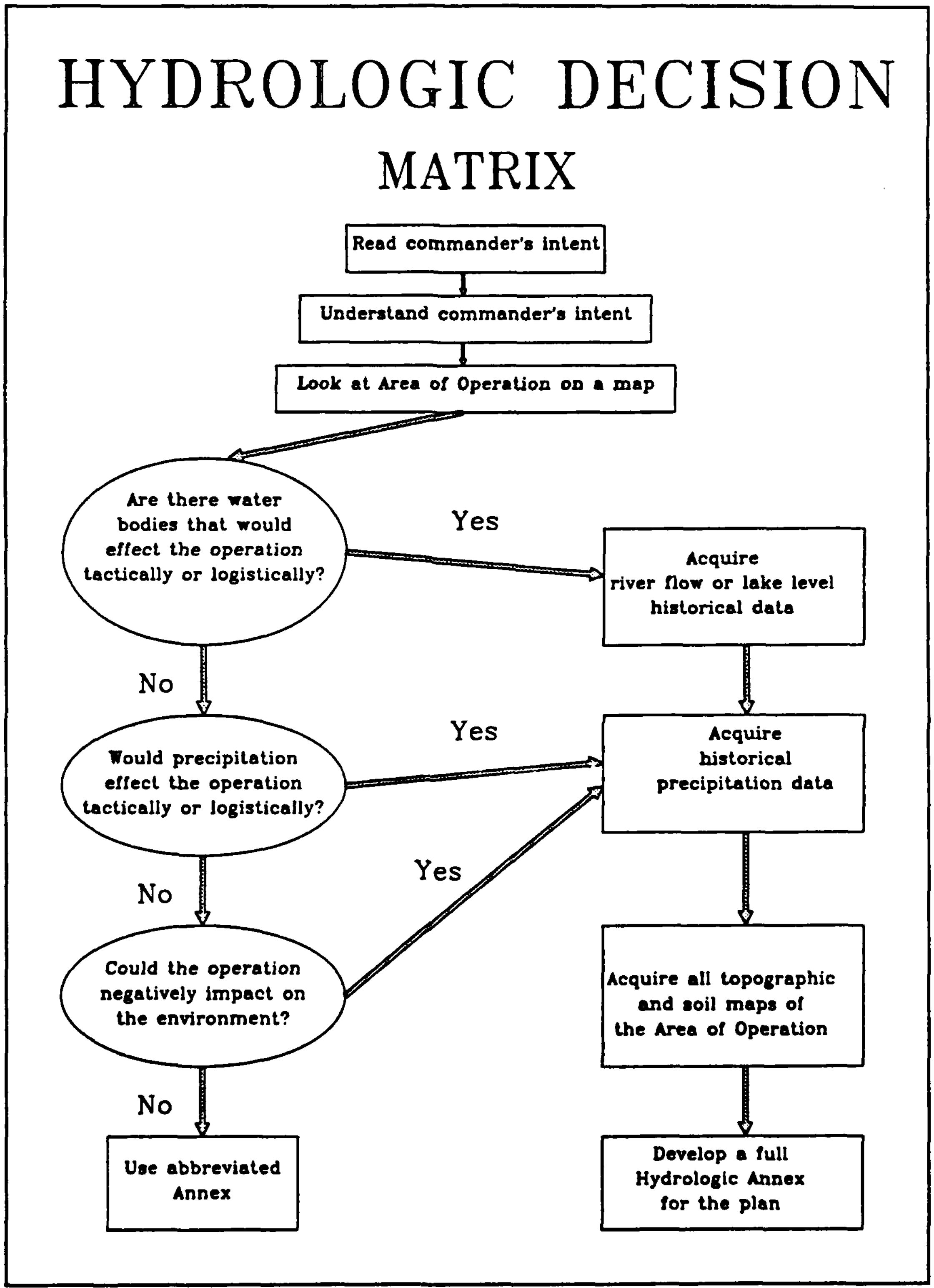


Figure 3-1. Hydrologic Decision Matrix

The hydrologic parameters that can influence the achievement of the commander's intent for any operation are not limited to, but include precipitation, river flows, lake levels, environmental impact, and unique storms. The establishment of the priority of hydrologic parameters and is unique to each operation. Prioritization of the hydrologic parameters is extremely important because it establishes the order of analysis and the weight to give each conclusion. The priority of hydrologic parameters for this case study was:

1. Precipitation
2. River Flows
3. Environmental
4. Unique Storms

Precipitation is the highest priority of evaluation because it can directly influence the achievement of the commander's goals for Airborne deployment. The Airborne portion is paramount to the exercise. River flow influences the unstated goal of river crossing training. Environmental impact must be kept at a minimum. Unique storms (hurricanes and tropical storms) must be considered but are unlikely events.

The above priority list of parameters is specifically for Market Square III. An Armor Division that consists of tanks and armored personnel carriers may determine that river flow is the first priority if the commander's intent is to exercise the fording capability of the equipment. The establishment of hydrologic parameter priorities is not a constant but is a function of the commander's intent[16].

3.3 Precipitation

Precipitation in the form of rain, snow, hail, or sleet will have an impact on any military operation. If just one soldier has to put on an extra garment of clothing because of precipitation then the impact of precipitation has been realized in a small way. If precipitation causes a training or tactical mission to be delayed or canceled then the precipitation has obviously had a significant impact on the planned operation. Precipitation can enhance clandestine, small unit movements or cancel large scale aerial movements[16,46].

The first step in the analysis of precipitation was to prove statistically that there was no significant difference in monthly average precipitation figures for 50 years of data or 30 years of data. The central limit theorem of statistical analysis was proved by a "Z" test with inference about the mean using statistical methods from Ott (1988)[23]. The normality assumption was proven by a Normality Plot of the residuals[19]. The regression of the Normality Plot data also had a correlation coefficient that was higher than the table value, which is another test for normality of the data. The 30-year data set was sufficient for statistical analysis. It was used for the completion of the precipitation analyses and recommended for use in the Technical Manual (Appendix A).

The analysis methods used in the Draft Technical Manual (Appendix A) are data dependent. The quality of the results of the hydrologic analysis depends on the amount and reliability of the data used. Military planners are advised to contact the Department of the Air Force, Environmental Technical Applications Center, Federal Building, Ashville, N. C. to acquire needed data. Some data may require specific security clearances. If only a small (less than 30 years) data base can be obtained, the results become less accurate but the methodology of the technical manual may still be used. If absolutely no precipitation data can be acquired, the procedures in the Draft Technical Manual are not applicable.

All available precipitation data for the Fort Bragg area was requested through the National Climatic Data Center (NCDC) in Ashville, North Carolina. Because of active duty officer status, requests for information were handled by the Department of the Air Force, Environmental Technical Applications Center. The Environmental Technical Applications Center is the military section of the NCDC.

The initial set of precipitation data was received on a set of 20 microfiche. The recording station is at the sewage treatment plant in Fayetteville, N. C., on the Cape Fear River. The gage is approximately 6 miles outside the south-eastern edge of the watershed. The terrain separating the gage and the watershed is flat to mildly undulating[43].

This one station was chosen because of the amount of historical data available. By using just one gage, the case study is more realistic to future studies that would have to be done on limited precipitation data. The data was not all inclusive but covered the years from 1880 to 1984.

The data from 1955-1984 was used for analysis because it was the most recent. The 30 years of precipitation data was transcribed onto prepared spreadsheet analysis templates. The graphs of Table 3-1 were used to determine the months of maximum and minimum precipitation, most and least frequent precipitation and how the month of the planned operation fits into the pattern of precipitation (graphs are plotted in Appendix B, Figures 7-9).

Table 3-1. Initial Precipitation Analysis Graphs

Y-Axis		X-Axis
Average precipitation	vs.	Month
Average days of precipitation	vs.	Month
Months of highest precipitation in a year	vs.	Month

From this point the graphs in Table 3-2 were made (see Figures 10-15 in Appendix B).

Table 3-2. Detailed Precipitation Analysis Graphs

Y-Axis		X-Axis
Average Precipitation	vs.	Days of the month of most precipitation
Average Precipitation	vs.	Days of the month of least precipitation
Average Precipitation	vs.	Days of the month the planned operation
% of each day that had Precipitation > 0.01 inch	vs.	Days of the month of most precipitation
% of each day that had Precipitation > 0.01 inch	vs.	Days of the month of least precipitation
% of each day that had Precipitation > 0.01 inch	vs.	Days of the month the planned operation

These graphs allowed inference concerning specific events and the historic probability of precipitation during critical days.

If an operation does not have a planned execution time frame, like a contingency plan, the Hydrologic Annex to that plan will provide valuable data for time frame planning. If the Hydrologic Annex is being prepared for an operation that has tentative or locked in dates, the planned dates should be graphed the same as the ones recommended in Table 3-2. A graph of the distinct dates will allow specific inference based on historical data for planning specific events. The operation date graphs will give information that would not stand out in the full monthly graph. Specific date analysis was done because of the nature of the case study.

The Market Square III Movement Table is a very important part of the Market Square III Operation Plan. The movement table is a detailed outline of the use of Air Force aircraft. Personnel parachute assaults onto Fort Bragg drop zones begin on 13 September 1989 (D-3) and continue through 17 September 1989 (D+1)[2]. Material drops and airland missions in the Fort Bragg area of operation were to continue until 21 September 1989 (D+5)[2]. One of the major stated training objectives of the exercise was the execution of "two simultaneous brigade-size parachute assaults[3]." This major training objective was planned for D-day (deployment-day), the 16th of September 1989, at 8:01 pm[2]. Information sources contacted during the research phase of this thesis could not remember or obtain information to confirm if this major deployment was canceled or delayed by the large rainstorm that hit on 16-17 September 1989. It is reasonable to think that the event was at least delayed by the storm.

By comparing the Market Square III Air Movement Table to the graphs from Table 3-2 (Figures 16 and 17, in Appendix B), it was established that although the average precipitation for the 16th of September is only 0.125 inches, there is a 33.5% historic chance that precipitation will occur on the 16th of September. The 16th of September is the worst day of the designated time frame to plan a major stated training objectives.

Precipitation Conclusions

Because of the planned airborne deployment of troops and equipment and the amount of air assault mission possible, the operation should be conducted during a period of least expected precipitation.

The average expected precipitation for the planned month of September is 4.6 inches. September has the third highest average precipitation of the 12 months. It averages 7.6 days of precipitation above 0.01 inches and is the third most likely month to have the most precipitation for the entire year.

Thirty years of record (1955-1984) show the lowest monthly total precipitation for September was 0.00 inches, recorded in 1966. The minimum precipitation for the month of September was only recorded once. The second minimum record for precipitation in September was 0.66 inches, it occurred in 1954. The highest amount of precipitation from 30 years of record (1955-1984) for the month of September was 10.86 from 1955.

Rain is the expected type of precipitation for the month of September. If the exercise is to be 13 days long and conducted in September, the 13 day period with the least average rainfall is from 15-27 September with 0.115 inches. The 13 day period with the highest average rainfall is from 2-14 September with 0.188 inches. The 11th to the 23d of September has an average precipitation of 0.14 inches. Table 3-3 is an example of the analysis to find the optimum 13 day window for the exercise. The results of Table 3-3 are presented in Table 3-4 and Table 3-5.

Table 3-3. Analysis of Execution Window for September

13 Day Window	Avg Precip. Inches	Percent Chance of Precip.
1-13	0.180	27.44
2-14	* 0.188	* 28.72
3-15	0.182	26.67
4-16	0.186	27.44
5-17	0.171	26.67
6-18	0.165	26.15
7-19	0.149	24.36
8-20	0.151	24.87
9-21	0.147	25.38
10-22	0.147	25.90
11-23	0.140	24.87
12-24	0.130	23.59
13-25	0.124	22.82
14-26	0.117	21.79
15-27	* 0.115	* 21.03
16-28	0.121	21.28
17-29	0.124	21.54
18-30	0.143	23.59

Table 3-4. September 13 Day Average Precipitation Analysis

	Average Precipitation inches		Dates
Maximum	0.188		2-14 September
Minimum	0.115		15-27 September
Exercise	0.140	(actual)	11-23 September

The 13 day period that has the least average % historical precipitation is from the 15th to the 27th of September with an average of 21.03% chance of getting rain on any of those 13 days. The maximum historical average is 28.72% and occurs between 2 and 14 September. The exercise period has a historical average of 24.87% precipitation per day. If the exercise had to be conducted in September, the 15th through the 27 would have been the recommended execution window. It should be recognized that the dates of maximum and minimum % of historical precipitation are the same dates for the most and least average precipitation.

Table 3-5. September 13 Day % Precipitation Analysis

	Percent Chance of Precipitation		Dates
Maximum	28.72		2-14 September
Minimum	21.03		15-27 September
Exercise	24.87	(actual)	11-23 September

Because the exercise is planned for a relatively high average historical % chance of precipitation, abort plans for airdrop and air assault missions should be fully prepared. Plastic bags to protect reserve parachutes should be planned. Chute shake-out and drying of wet parachutes should also be planned.

October is recommended if the conduct of Market Square III has the option of being moved to another time frame. The same type of analysis done in Table 3-3 was also done for October. The results of the October analysis are presented in Tables 3-6 and 3-7. The monthly average precipitation for October is 2.8 inches, 1.8 inches below the September average of 4.6 inches. The same analysis presented in Table 3-3 was done for the month of October. The parameters listed in Tables 3-6 and 3-7 are all below their like values of September.

Table 3-6. October 13 Day Average Precipitation Analysis

	Average Precipitation inches	Dates
Maximum	0.099	1-13 October
Minimum	0.067	7-19 October
Recommended	0.071	5-17 October

Table 3-7. October 13 Day % Precipitation Analysis

	Percent Chance of Precipitation	Dates
Maximum	27.95	14-26 October
Minimum	16.67	5-17 October (Recommended)

Recommendation

The dates of 5-17 October are specifically recommended for the conduct of the exercise because of their minimal historical percent of precipitation and relatively low historical average of daily precipitation.

3.4 River Flow

The Little River flows on the northern border of most of Fort Bragg and separates it from the Northern Training Area. The Little River was determined to have significant impact on the achievement of both the training and tactical intent of the commander. Maneuverability into the Northern Training Area for tactical and training purposes is an important part of the exercise. River crossing is an unstated training objective for the exercise that directly involves the Little River.

The Little River was found as a sub-basin of the Cape Fear River by using the Surface Water Supply Papers 2104, Part 2, South Atlantic Slope and Eastern Gulf of Mexico Basins, Volume 1, Basins from James River To Savannah River[49]. The Little River watershed had historic records at two significant locations. All available flow data for the two significant sites were requested through the National Water Data Exchange (NAWDEX), 421 National Center, Reston, VA 22092. Daily flow records for the Little River's gaging station in Linden N. C. dated from water year 1929 to 1971. The records from the Manchester N. C., Little River gaging station were from water year 1939 to 1950.

The records from the Linden station were selected for use in the case study because there were more than 30 years of data for statistical review. The station also was clearly labeled on the topographic map. The Linden station monitored 460 square miles of the watershed while the Manchester station only monitored 348 square miles of the watershed.

The acquired data was transferred into prepared spreadsheet analysis templates. Spreadsheet analysis templates were prepared to receive stream flow or lake level data and another was prepared to receive precipitation data. The flow/level and precipitation templates were stored on 5 1/4 inch floppy disks in Quattro Pro and Lotus 1-2-3 formats and will be provided with the Technical Manual. The six required graphs for flow analysis are listed in Table 3-8 (see Figures 1-6, Appendix B).

Table 3-8. Initial Flow Analysis Graphs

Y-Axis		X-Axis
Average total flow or lake level	vs	months
Average daily flow or lake level	vs	months
Minimum daily flow or lake level	vs	months
Average daily minimum flow or lake level	vs	months
Maximum average daily flow or lake level	vs	months
Average daily maximum flow or lake level	vs	months

From these flow graphs of the Little River it was concluded that the average flows of the planned execution month of September and the recommended month of October are not significantly different. Because they are significantly lower, the maximum and minimum flows of the compared months favor October for safety reasons. The daily September flow parameters of interest are presented in Table 3-9.

Table 3-9. September Flow Statistics

Average daily flow rate = 415 cfs
Average minimum flow rate = 313 cfs
Average maximum flow rate = 1,553 cfs
Maximum flow of record = 13,000 cfs in Sept 1945
Minimum flow of record = 32 cfs in Sept 1968

The daily October flow parameters of interest are presented in Table 3-10.

Table 3-10. October Flow Statistics

Average daily flow rate = 402 cfs
Average minimum flow rate = 168 cfs
Average maximum flow rate = 1,257 cfs
Maximum flow of record = 10,000 cfs in Oct 1930
Minimum flow of record = 31 cfs in Oct 1941

The average soldier can stand up in waist deep water that is traveling at 2 feet per second[12]. For example, if the flow in the river is at a July average of 400 cfs the ideal crossing site would need to be a combination of depth and width to provide a velocity of 2 feet per second or less. If a commander's staff was looking for a 3 foot deep crossing area to do rope bridging the crossing site would have to be 73 feet wide. This is an estimate based on a channel section of trapezoidal shape. A trapezoidal shape is a good estimate of the river shape[12].

The following is an example of a needed river width calculation to meet the 2 ft per second criteria:

A = area
b = desired width at the bottom of the channel
T = desired width at the top to the channel
z = assumed side slope of the channel
y = desired depth of the water
V = planned velocity
Q = planned flow rate

$z = 2 \qquad y = 3 \text{ ft} \qquad V = 2 \text{ ft/sec} \qquad Q = 400 \text{ cfs}$

$$A = \frac{Q}{V} = 400 \frac{\text{ft}^3}{\text{sec}} + 2 \frac{\text{ft}}{\text{sec}} = 200 \text{ ft}^2$$

$$b = \frac{(A - zy^2)}{y} = \frac{(200 \text{ ft}^2 - 2(3 \text{ ft})^2)}{3 \text{ ft}} = 60.67 \text{ ft}$$

$$T = b + 2zy = 60.67 \text{ft} + 2(2)3 \text{ft} = 72.67 \text{ft}$$

[Chow, p. 21]

With the above type of width estimation, a more accurate map reconnaissance may be done to locate an appropriate crossing site.

Using a standard safe velocity of 2 feet per second, a desired crossing depth of 3 feet, and a trapezoidal river shape:

- The average September flow rate of 415 cfs would require a river width of 76 feet. Map reconnaissance shows that finding a suitable crossing site is probable[43].

- The average maximum September flow rate of 1,553 cfs would require a 265 foot wide crossing site. Map reconnaissance shows that finding a suitable crossing site is improbable[43].

- The average minimum September flow rate of 131 cfs would require a 28 foot wide crossing site. Map reconnaissance shows that finding a suitable crossing site is very probable[43].

For tactical and safety purposes the operation would be best conducted at average river flows. This would provide effective training while lessening the safety concerns.

River Flow Conclusion

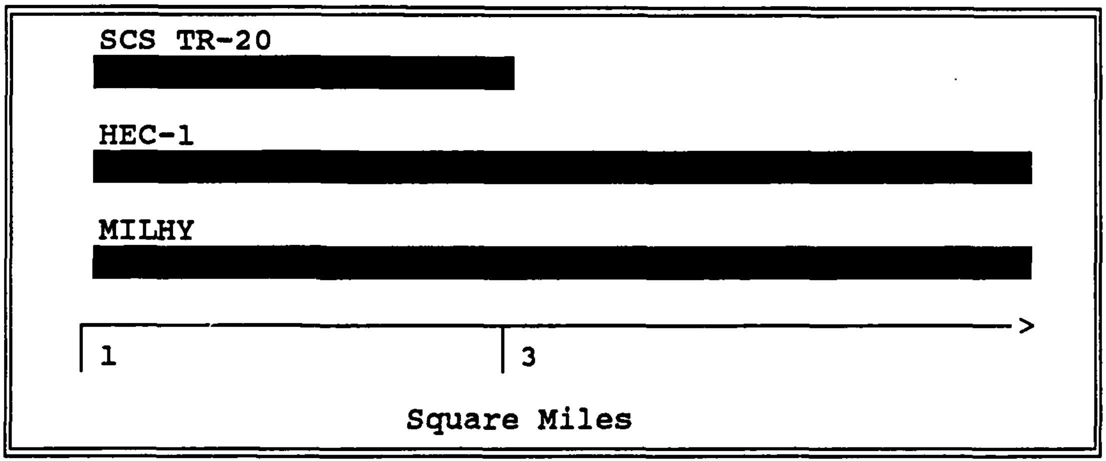
Given average flows, it is expected that the commander's river crossing intent involving the Little River can be accomplished by the troops and their equipment in either September or October. Safety reasons become the controlling parameter for decision making with respect to river flows.

The maximum flows of October are less than September. An October window of execution is recommended for safety reasons. This conclusion supports the recommended execution dates from the precipitation conclusion.

3.5 Hydrologic Model

The intent of using a hydrologic model is to provide the commander with flow information that can be used for decisions regarding friendly and enemy crossing activities. To analyze the watersheds of the significant bodies of water in the area of operation, watershed parameters and expected precipitation figures will be loaded into a computer modeling program. The important information that can be obtained from modeling are peak discharge for the precipitation of interest and the time the peak flow will reach the planned crossing area on a river or the peak stage of a lake. The HEC-1 Flood Hydrograph computer model is recommended for large watersheds that will normally be associated with military operations. Table 3-11 lists some available watershed hydrograph models and the size of the watersheds they are designed to work with.

Table 3-11. Available Watershed Models



[31,36,53]

Critical information such as what the peak flow rate will be at a planned crossing site for an expected precipitation and when the peak flow will reach the crossing site after the precipitation has begun, will be provided with suitable accuracy by a calibrated hydrologic model. This information can then be used to plan the timing of a crossing activity that may be critical to accomplishing the commander's intent.

An example of the applicability of a hydrologic model's information would be if a model was run for a watershed in an area of operation for the 2-year 24-hour storm of 3 inches of precipitation. Model results indicate that the peak flow would be 3000 cfs and it would reach the crossing area 15 hours after the precipitation began. In the scenario the commander is in the field and has the model information available from the Hydrologic Annex. The weather update from the intelligence staff informs the commander that the 2-year 24-hour storm is on the way. The commander can now push up the time for the attack across the river, delay the attack, or execute the crossing as planned based on the model information and current weather data.

The Corps of Engineers Hydrologic Engineering Center's HEC-1 Flood Hydrograph Package was used to model the flow in the case study watershed. HEC-1 was chosen for its ability to model large watersheds, its availability to the intended users of the methodology, its versatility, and its easy to edit input file.

The first step for using the computer model was to obtain the watershed input parameters. The parameters included the watershed area in square miles, the Soil Conservation Services Curve Number, precipitation, the percent of impervious area, Snyder's coefficients of Cp and Ct, and the recession coefficients RTIOR and QRCSN[31].

The total watershed area of 460 square miles was taken from the stream gauge data sheets provided by NAWDEX. The area was confirmed by map planimetering using a digital PLANIX planimeter made by Tamaya. The Soil Conservation Service (SCS) curve number was obtained by consulting the colored summary indexes of soil surveys of counties included in the watershed. Not all counties provided published soil surveys. For the counties of non-published surveys the soil groups inside the watershed were studied and found to coincide with the published surveys. The soil in the Fort Bragg case study watershed is dominated by sand and sandy clay. A curve number of 36 was chosen based upon SCS information provided by McCuen (1989)[20].

The precipitation data was obtained from a rain gage that was read at 0800 hours every morning. The precipitation values are 24 hour accumulations that includes rain, melted snow, sleet, and hail. For model input, the precipitation values were distributed over 24 hours by using the SCS 24-hour distribution chart for a type II storm. Type II was used because Fort Bragg falls into the type II range identified by the SCS[20].

The HEC-1 model used for the case study was calibrated using Little River flow data from the Linden gauging station. As an experiment the model was first run without routing through Mott Lake. Mott Lake is a significantly large body of water in the watershed but not in the area of operation. Two very critical parameters of the model are the base flow at the start of the precipitation and the recession constant of the watershed.

The model results of three possible base flows were tested against the recorded 24 hour mean flow of five historic test storms. The actual average base flow, the average daily flow per month, and the average minimum daily flow per month were all tested in the analysis.

The recession coefficients used by HEC-1 in the BF (base flow) record are QRCSN and RTIOR. The QRCSN is found from historical records and it is the point on the recession curve of the hydrograph where the straight line (on semi-log paper, cfs vs. time) begins[31]. It is recommended that the peak flow divided by the flow at that point be entered as a negative value. This will represent a ratio of peak flow to the point on the recession curve below which the base flow recession occurs. The ratio value is considered to be a constant for the specific watershed.

The value of RTIOR is also a ratio of recession flow. It is calculated as (qt+1)/q where the flow at QRCSN = q and qt = the q at plus one time increment[31]. The recession coefficients used in the analysis matrix are the observed values from the 6.1 inch storm of 31 August-1 September 1952. These coefficients were labeled as the standard coefficients.

The observed coefficients were calculated from each individual storm. The observed coefficients for the five test storms were plotted and analyzed for possible linear relationship. The null hypothesis that there was no linear relationship between the amount of 24 hour precipitation and QRCSN and RTIOR were tested to a 98% confidence level using statistical methods from Neter (1989)[22]. The hypothesis test revealed a linear relationship between QRCSN and the amount of 24 hour precipitation that falls on the watershed. The test also found no linear relationship for RTIOR[22]. The linear equation was used to derive the QRCSN values for the appropriate storms. The derived QRCSN was then used in the model with the average RTIOR.

The result of the initial analysis matrix showed that the model 24-hour average flows were closest to the recorded values when the average minimum daily flow was used as base flow and the standard coefficients were used. On the average the closest model average 24-hour flows were 20% above the recorded values.

The second analysis was run by routing the appropriate flows through Mott Lake. The analysis of 34 runs of the HEC-1 model for the watershed indicates that the best estimate of the flows for various precipitations will occur when the model is run for the derived standard coefficients and the average daily flow per month. The resultant flows for this type of model run were 9% low. The average standard deviation for the model runs was plus or minus 19. The result of the model testing/calibration showed that for this watershed the best results occur when the appropriate flows are routed through the lake. In general, the standard model recession coefficients obtained from the largest rainfall possible should be used. If actual base flow cannot be obtained, the best estimator is the average daily flow for the month of interest.

The hydrologic model suggests that the 2-year, 24-hour storm of 3.87 inches of precipitation will most probably peak in the proposed crossing area at 752 cfs, 14 hours after the start of the storm.

The 15-year, 24-hour storm of 6.0 inches of precipitation, has an 8% chance of being equaled or exceeded. It will most probably peak in the proposed crossing area at 6195 cfs, 16.5 hours after the start of the storm.

The 100-year 24-hour storm of 8.2 inches of precipitation, has a 1% chance of being equaled or exceeded. It will most probably peak in the proposed crossing area at 24382 cfs, 15.5 hours after the start of the storm.

The data used for the calibration of the model was from 1929-1971. It is assumed that the water control structure on Mott Lake was constructed sometime after the gaging station on the Little River was closed. The best available data was used for the calibration and the results of the model output reflect the dam with the lake at capacity.

The last record on file for the Little River gauging station at Linden was for the month of September of 1971. The expected flows for the Little River cannot be verified by actual recorded data. It is reasonable to expect that a new maximum average 24-hour flow would have been recorded if the gaging station was in operation during 16-17 September 1989, when this large rainstorm hit the Little River watershed. Based on the Precipitation-Duration-Frequency[21] chart of the Fort Bragg area (Figure 3-2) the rainfall of 8.25 inches in a 24-hour period is considered a 100-year storm. Any crossing operations planned for that time frame would have been canceled or delayed for peacetime safety reasons. If such an advance across high velocity

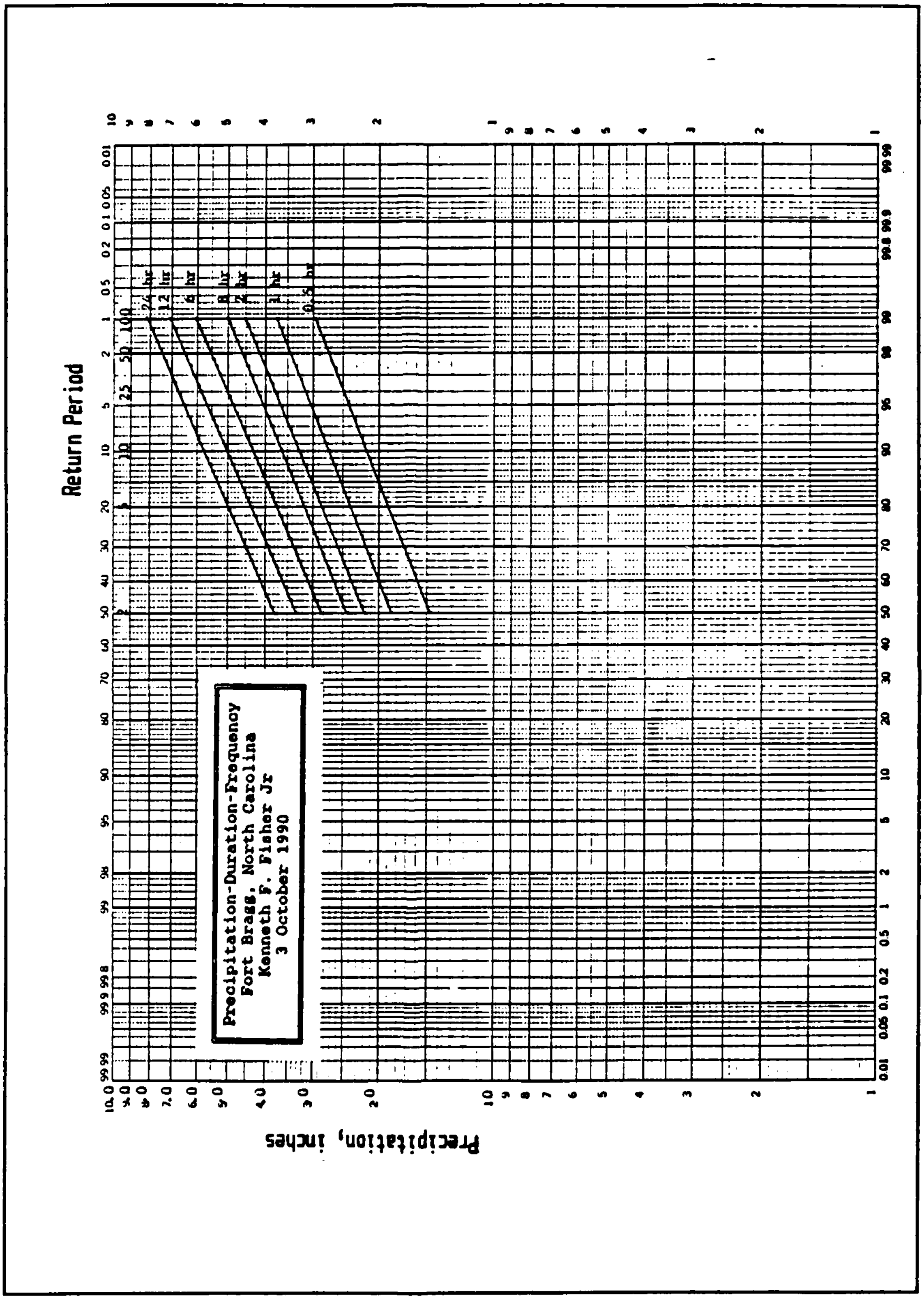


Figure 3-3. Precipitation-Duration-Frequency Graph

waters had to be made in an actual wartime mission, higher crossing casualties would have to be expected.

3.6 Environmental

The Environmental Assessment conducted by the Division Assistant Engineer's office was performed to standard[1]. The results of the assessment was a "finding of no significant impact[1]" will occur to the environment as a result of Market Square III. The assessment specifically addressed the air quality, land use, noise, endangered animal and plant species. All sensitive environmental ecosystems are cordoned off by specific colored bands around trees. The color coding of the areas combined with command influence are reasonable measures to prevent damage to the endangered areas.

Four of Fort Bragg's 19 rare, threatened, or endangered species of plants live in the wet, sandy, soils of the lowland marshes[1,14]. Although an after action environmental evaluation of the sensitive ecosystems of Fort Bragg was not available, it is reasonable to conclude that at least some of the susceptible areas received more than normal silt wash-down during Market Square III[16]. The extra wash-down is a result of the disturbed sandy-silty soil combined with the heavy rainfall.

Present planning techniques do not account for indirect damage caused by a military exercise. The Hydrologic Annex is a formal way to bring the indirect possibilities to the attention of the commander and make recommendations on an exercise window that will minimize damage.

Environmental Conclusion

There will be less impact to sensitive lowlands during a time of minimal precipitation. This conclusion supports the recommended window of execution based on precipitation.

3.7 Unique Storms

The Fort Bragg area of operation is susceptible to Tropical Storms and Hurricane activity. Analysis of 82 years of record indicates that tropical storms are more frequent than hurricanes. Hurricanes have not been recorded within 60 nautical miles of the area of operation. It can be expected that precipitation and outlying effects of hurricanes within 120 nautical miles would effect military operations. Residual hurricane effects may influence operations if the hurricane was within 240 nautical miles. For hurricane planning purposes, August and September should be avoided for Market Square III. These two months account for 72% of the historical hurricane activity that could negatively impact on military operations.

Tropical storm activity is more frequent in the area of operation. The historical season for tropical storms is from May to November. August and September should be avoided for major operational planning. These two months account for 53% of the tropical storm activity that could influence the area of operation for Market Square III. Although October accounts for 17% of the historic tropical storm activity, all recorded activity has been more than 60 nautical miles from Fort Bragg.

Unique Storm Conclusion

The hurricane and tropical storm season for the area of operation is from May to November. The months of May through November should not be used for planning if the threat of hurricane and tropical storm activity is to be avoided. Although there is a low historic percent chance of unique storm activity during the month of October it should not adversely impact on an exercise during this month. This conclusion does not conflict with the precipitation based recommendation for the window of execution.

3.8 Summary

The actual execution dates of 11-23 September 1989 were not the historically best times to conduct Market Square III. Of the 12 months of the year, September has the third highest average precipitation of 4.6 inches for a month.

September averages only 7.6 days out of 30 with precipitation above 0.01 inches or an average rainfall of about 0.6 inches. This amount of rainfall in a 24 hour period would be considered significant. It would have a delaying or canceling effect on most of the large scale airdrop deployment activities.

CHAPTER 4

CONCLUSIONS

4.1 Introduction

The methodology developed and technologies used in the conduct of this independent study are not unduly complex or involve complicated calculations to derive conclusions. The simplicity of the methodology and its presentation is intended to enhance acceptance by the Army. The conclusions of this chapter clearly show the value of providing tactical commanders with a Hydrologic Annex for making tactical military decisions.

4.2 Conclusions Regarding Objectives

A Hydrologic Annex meets the goal of providing the commander with information for decision making. The annex from the Market Square III case study (Appendix B) provides information in a concise format that is presently used by military planners. The annex is the result of a detailed hydrologic study, whose methodology is laid out in a Technical Manual format (Appendix A).

If the case study Hydrologic Annex prepared for Market Square III had been prepared for the actual operation plan, the divisional command group would have been better informed about the expected hydrologic conditions of the area of operation. Although the commander had other considerations influencing the exercise window decision, a Hydrologic Annex was not available as input to the decision making process.

The exercise was conducted from 11-23 September 1989. A large rainstorm hit the Fort Bragg area on 16-17 September 1989, dropping 8.25 inches of rain[50]. At least one major Air Assault mission was canceled because of the rain storm[13]. Hurricane Hugo hit the South Carolina coast between Charleston and Myrtle Beach on 21 September 1989 and caused 2.46 more inches of rain to fall on Fort Bragg during 20-22 September 1989. A total of 10.86 inches of rain fell on Fort Bragg during the exercise period[50].

The Hurricane shortened the exercise by 3 days[13]. Repair to training areas on Fort Bragg was delayed[13]. Engineer companies were getting calls to go down range to fill holes and repair disturbed roads through July 1990[13].

The recommended days for the exercise were 5-17 October. During the recommended period 0.05 inches of rain fell on the Fort Bragg area[50]. This exercise would have benefitted from the more favorable hydrologic conditions. The case study precipitation summary is presented in Table 4-1.

Table 4-1 Precipitation Summary

Hydrologic Analysis Recommended Dates	5-17 October
Precipitation Predicted	0.92 inches
Actual Precipitation	0.05 inches
Exercise Planned and Executed Dates	11-23 September
Precipitation Predicted	1.82 inches
Actual Precipitation	10.86 inches

The military preparedness of any unit would be directly improved by the addition of a Hydrologic Annex to its operation and contingency plans. Having statistically sound information based on historical records enhances a tactical decision maker's ability to choose the most advantageous times to execute critical missions. When missions are enhanced by hydrologic conditions the likelihood of achieving the commander's intent is greatly improved.

Weather is one of the most unpredictable fundamental factors of war. The more information that is provided about weather, the more prepared we can be to counteract it or use it to our advantage.

Environmental awareness is an ever growing issue on military installations. Commanders are held responsible for the actions of their units. Commanders are more frequently being held responsible for environmental damage caused by their units.

Environmental assessments are required for large scale out of the ordinary training activities. These assessment documents are reviewed by the command groups of divisions and higher but are documents outside the mainstream of military planning.

The addition of a Hydrologic Annex in formal military plans brings the environmental considerations into the realm of decision making. A Hydrologic Annex recommending a window of execution based on the minimum amount of damage to sensitive environmental ecosystems in the area of operation would give commanders a moral and sometime legal basis to decide when to conduct an exercise.

The Hydrologic Annex will not replace the environmental assessment process. However, the annex does look at the possible indirect damage to sensitive ecosystems.

4.3 Applicability of a Hydrologic Annex

The Hydrologic Annex is designed for long range (years) planning. A Divisional contingency plan that has a Hydrologic Annex prepared for a specific area of operation provides a basis to make decisions concerning the best time to execute the plan. The recommendations in the annex are historically based and provide the best estimate until actual current conditions can be obtained. The added preparedness that the annex provides can mean the difference between success and failure of tactical and strategic missions.

Once a general hydrologic analysis of an area of operation is done it can be applied to different plans. The basic information from this case study's hydrologic analysis can be adopted by Fort Bragg and placed in the post training guidance. The basic precipitation and flow data can be used by all planners on the post as well as Reserve and National Guardsmen when they plan training on the post.

Cyclic training such as Market Square exercises can be planned for conditions that would more suit the training needs. Based on the case study's Hydrologic Annex and this thesis' findings the next Market Square should be scheduled for an execution window in October.

Once the information is in a plan or an installation training regulation it has a long shelf life. Because it is based on statistical data, the information produced by the hydrologic analysis will not change significantly over the years. An analysis need only be redone if major changes in climate have occurred or every 30 years. The recommended updates are based on hydrologic sense and statistical theorems.

4.4 Summary Conclusions

The Army has been aware of its outdated hydrologic doctrine since 1981 and but not published new manuals to update the doctrine. The adoption of a Hydrologic Study

Technical Manual (draft version in Appendix A) and the addition of a Hydrologic Annex section to Field Manual 101-5 "Staff Organization and Operations[47]" will fill the hydrologic void in military decision making.

If the case study Hydrologic Annex had been available to the 82d Airborne Division Commander and staff during the decision process for the window of execution, the recommended dates may have been adopted. If the recommended dates were adopted, Market Square III would have been a more effective training exercise that caused less damage to the environment. The experienced 10.86 inches of precipitation would only have been 0.05 inches of rain. Critical missions would not have been canceled. Hurricane Hugo would not have shortened the exercise. Repairs of the training areas would not have been delayed. Less damage would have been done to the sensitive lowland ecosystems.

CHAPTER 5

FUTURE RESEARCH

This work has focused on precipitation and river flow as the parameters of the hydrologic analysis of a watershed. Hurricane and other severe storms will impact on the conduct of military operations. The importance of severe weather on tactical military operations was realized during the conduct of this study. Time limitations did not allow an in-depth analysis of this important area except what was mentioned in the precipitation sections of the thesis.

Tidal analysis is another important aspect of hydrology related to military operations. Tides have played an important part of hydrologic military history. From the coastal battles fought by raiding Vikings in medieval times to the landing at Inchon during the Korean War, military planners have understood the importance of tides. Tides and coastal waterways influenced by tides are another hydrologic area not covered by this thesis. Tidal analysis would provide valuable information to military commander's if presented as part of the Hydrologic Annex.

The initial thesis proposal expressed a desire to incorporate forecasting of soil conditions for military mobility purposes. The concept was to forecast soil conditions based on historical precipitation data. Research has shown that the parameters involved in forecasting soil conditions go beyond the total scope of this work. Long range soil mobility forecasting would be a valuable addition to a Hydrologic Annex. A future methodology for soil mobility forecasting could easily be incorporated into a Hydrologic Annex. At present, sensing of soil moisture conditions may be done by aerial photography and satellite photo imagery. It is recommended that these state of the art techniques be used as soon as a contingency area of operation becomes a likely area of action.

A recommendation for future upgrade of the world hydrologic data base is to have every U. S. embassy around the world monitor and record precipitation and temperature. This minimum data can then be consolidated by the National Climatic Data Center and published as part of the Selective Guide to Climatic Data Sources[51]. This new data base would allow limited analysis of precipitation in countries that are potential threats and where the data may otherwise be inaccessible.

This thesis effectively used a Case Study for validation and will be presented through Army channels for adoption. It is recommended that several more case studies be done on other exercises as part of the Army acceptance process. Future case studies may reveal other applications for the Draft Technical Manual and the Hydrologic Annex, while further proving the conclusions of this thesis.

CHAPTER 6

SUMMARY

A Hydrologic Annex that is developed by the methodology in the Technical Manual will increase military readiness, continue to validate its worth, and formally increase environmental awareness in the area of military planning. The purpose of the thesis was to develop a methodology that will provide tactical commanders information on the hydrologic aspects of the area of operation for decision making. By analyzing the historic data of precipitation and river flows/lake levels, recommendations can be made to the commander on when hydrologic conditions in the area of operation will best support the commander's intent.

If a commander intends to conduct large scale parachute assaults and cannot logistically afford to get that many parachutes wet, a period of least likely occurrence of rain would best suit his needs. The lowest historic precipitation month can be found. The best suited time frame within that month, can be recommended to the commander before the final decision is made on when to conduct the exercise.

If the intent of an exercise is to attack across a river or training to attack across a river, the level of risk can be assessed or standardized. The period of historic choice flow rates may be selected for the dates of the attack or training.

Analysis of the hydrologic make-up of an area of operation will provide the tactical commander with information that can maximize training time and give him valuable insight that will strengthen the odds of success. Recommendations are presented to the commander in a Hydrologic Annex. The annex is in a format that is presently used by military planners and will become part of the operation plan for the exercise.

The stated objectives have been met. The unique approach to military planning provides long range insight to probable hydrologic conditions of an area of operation. This improves the readiness of the units that the plan applies to. A practical hydrologic analysis methodology is presented in Technical Manual format. The case study has validated the usefulness of the methodology.

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APPENDICES

The following pages are a methodology (Appendix A) that outlines the hydrologic analysis to be performed. The format is that of a standard Army technical manual.

Appendix B is the actual case study resulting from following the methodology of the draft technical manual.

APPENDIX A

DRAFT TECHNICAL MANUAL

DRAFT

Department of the Army

Technical Manual
No.

HYDROLOGIC STUDY TECHNICAL MANUAL

Chapter 1. BACKGROUND
Section I. Introduction

Chapter 2. HYDROLOGIC ANALYSIS OF THE COMMANDER'S INTENT
Section I. Basic Concepts
II. Prioritization
III. Precipitation Impact
IV. Significant Bodies of Water
V. Environmental Impact
VI. Unique Storms

Chapter 3. ASSEMBLING DATA
Section I. Maps
II. Soil Surveys
III. Historic Precipitation Data
IV. Historic Stream Flow Data
V. Watershed Modeling
VI. Environmental
VII. Unique Storms

Chapter 4. ANALYSIS OF DATA
Section I. Watershed
II. Soil
III. Precipitation
IV. Stream flow
V. Hydrologic Model
VI. Environmental
VII. Unique Storms

Chapter 5. DATA CONCLUSIONS
Section I. Watershed
II. Soil
III. Precipitation
IV. Stream flow

Chapter 6. HYDROLOGIC ANNEX

APPENDICES

A. SCS CURVE NUMBER SELECTION

B. HYDROLOGIC ANNEX FORMAT

C. HYDROLOGIC ANALYSIS REPORT FORMAT

D. POINTS OF CONTACT

DRAFT

CHAPTER 1

BACKGROUND

Section I. Introduction

1-1. Purpose and Scope

This manual provides detailed information for military staffs to analyze historical stream flow, lake level and precipitation data to determine the impact of hydrology on an operation or contingency plan. The hydrologic analysis can then be formalized into a Hydrologic Annex written specifically for the planned operation. The intent of the manual is to present a brief and concise methodology for a hydrologic study of a given area of operation. The study includes analysis of historic hydrologic data and computer model output that can be presented in a Hydrologic Annex of an operation or contingency plan for use by a commander in decision making. This manual is not Army specific and could apply to the formation of a Hydrologic Annex for any military service plan. The hydrologic study and Hydrologic Annex are intended for long range planning where hydrologic conditions could have a significant impact on an exercise or mission.

1-2. Comments

Users of this publication are encouraged to submit recommended changes or comments to improve the manual. Comments should be keyed to the specific page, paragraph, and line of text in which change is recommended. Reasons should be provided for each comment to insure understanding and complete evaluation. Comments should be forwarded directly to Commandant, U.S. Army Engineer School. Fort Leonard Wood, Missouri, 65473.

1-3 Application

The Hydrologic Annex can be used by a tactical commander to evaluate the conduct of an upcoming operation with respect to historic and model hydrologic conditions. Commanders and staffs can apply the Hydrologic Annex information to decide the amount of airborne, air assault, river crossing operations, and close air support that is to be planned.

A second major application of the Hydrologic Annex is in the area of intelligence gathering. The annex would show the most probable times of rain or when rivers will be at their lowest flows; possible times the enemy may use to their advantage to attack.

The Hydrologic Annex to a plan also will supply the tactical peacetime commander with information related to the environmental impact of the operation.

1-4 Needed Equipment

The hydrologic analysis of the planned area of operation is technically oriented and will need the following equipment:

- Personal Computer with 640k RAM with a hard drive.
- Compatible printer for the computer
- A copy of the HEC-1 Hydrologic Analysis software package or the watershed model that may apply
- Scientific Calculator
- Engineer's scale
- Planimeter
- Spreadsheet software package (recommended)

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CHAPTER 2

HYDROLOGIC ANALYSIS OF THE COMMANDERS INTENT

Section I. Basic Concepts

The first important aspect of producing a Hydrologic Annex is to determine what type of Hydrologic Annex is needed for the operation being planned. To assist in the determination process Figure 2-1 has been provided as a guide. The first step in the decision making process is to know the commander's intent. Key information from the commander's intent would be the amount of airborne, air assault, or river crossing operations that may be conducted during the operation. If the commander's intent does not include information on these key issues then the operation's officer should be consulted to determine if the operation will include any of these weather sensitive missions.

The commander's intent for the operation is very important and must be completely understood. If there are any questions concerning any aspect of the intent, the commander or the appropriate staff section should be consulted at once to discharge any false impressions or unclear points.

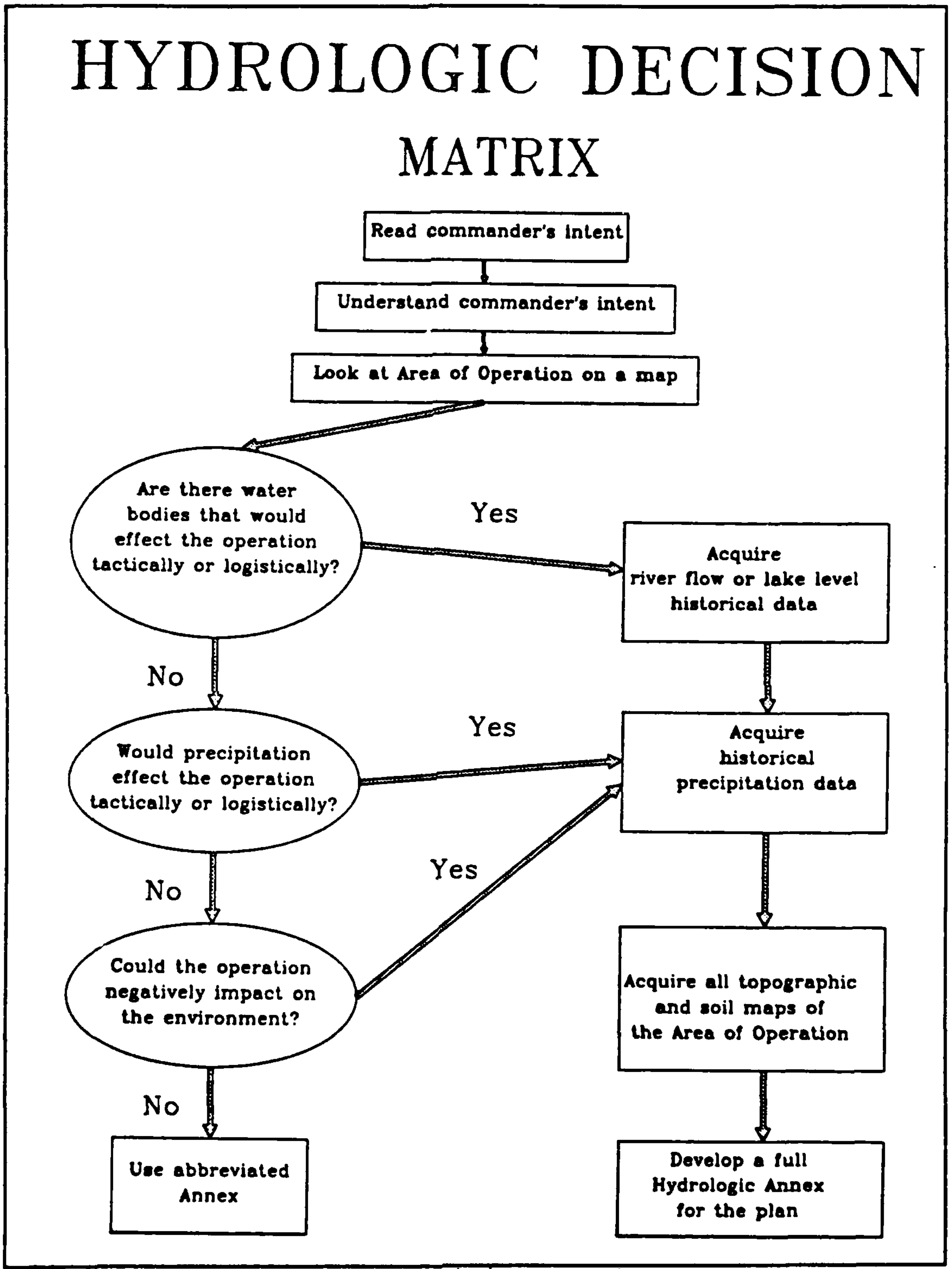

Figure 2-1. Hydrologic Decision Matrix

Section II. Prioritization

The hydrologic parameters that can influence the achievement of the commander's intent for any operation are not limited to but include precipitation, river flow, lake level, environmental impact, and unique storms. The establishment of the priority of hydrologic parameters is unique to each operation. Prioritization of hydrologic parameters is necessary to establish the order of analysis and the weight to give each conclusion.

For an airborne operation the highest priority may be precipitation, followed by river flows if river crossing will be involved, and then other parameters. An armor division may determine that river flow is the first priority if the commander's intent is to exercise the fording capability of the equipment.

The hydrologic methodology may be used by any branch of the Army or any of the Armed Services. The establishment of hydrologic parameter priorities is not a constant but is a function of the commander's intent.

Section III. Precipitation Impact

Based on the type of operation being planned and the number of weather sensitive missions that are involved in the operation, precipitation could be a deciding factor on when the operation is to be executed or how many of the previously mentioned missions will be relied on for mission accomplishment. Precipitation could be in the form of rain, snow, sleet, or hail and may have a significant effect on the achievement of the planned goals of the exercise. Precipitation could have an effect of washing out roads needed for supply routes or maybe the operation requires a minimum depth in the major water bodies of the area of operation to accomplish its mission.

If precipitation could significantly affect the planned operation, 30 years of historical precipitation data should be acquired for the hydrologic analysis that will produce the Hydrologic Annex.

If an abbreviated annex would suffice, it would consist of any of the parts of a full annex. The choice of sections for an abbreviated annex is at the discretion of the individual command.

Section IV. Significant Bodies of Water

With the commander's intent completely understood, a map of the area of operation must be scrutinized. Items of specific interest are bodies of water that would or could influence the conduct of the exercise in the area of operation. Though there are bridges over streams, lakes, or rivers they still must be considered as having an influence on the conduct of the operation either tactically or logistically. Bridges may not be available when needed.

If there are significant water bodies in the area of operation, 30 years of historical river flow or lake level data should be acquired. Based on the central limit theorem of statistics, 30 years of data will provide a statistically sound basis for inference. Using less than 30 years of data widens the confidence interval of the derived conclusions.

Section V. Environmental Impact

The environmental impact of a military operation or exercise can be minimized by proper planning. If analysis the commander's intent and the area of operation show that the exercise will take place near or in sensitive environmental ecosystems then a Hydrologic Annex should be included in the operation plan to be used by the commander in his decision making process. If the exercise is conducted during a time of expected high precipitation then the chances are greater that the sensitive ecosystems could be negatively impacted. Though the exercise may not be conducted in a specific lowland that has endangered plant or animal life, vehicles moving through streams or river beds upstream could cause a greater wash down of silt that may significantly damage the sensitive ecosystem that supports some endangered species.

Information on sensitive ecosystems for United States military installations can usually be obtained from Range Control offices or the Directorate of Engineering and Housing will have a branch established for environmental issues. A full Hydrologic Annex should be developed if any negative impact on the environment is possible.

Section VI. Unique Storm Impact

Unique storm activity must also be analyzed for its possible impact on the achievement of the commander's intent. Hurricanes, tropical storms, or tornado seasons are the obvious unique storms common to the continental United States. Other parts of the world may have other unique storms that must be considered.

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CHAPTER 3

ASSEMBLING DATA

Section I. Maps

Scrutinizing the map or maps of the area of operation is the first step after understanding the commander's intent for the operation. Maps will be needed to determine the size of the watershed and other hydrologic information. A map with proper contour intervals is highly recommended to properly outline watersheds. The maps should be initially studied to find any significant bodies of water that could influence the achievement of the commanders intent. The needed maps are normally obtained through a member of the units' intelligence staff. Standard 1:50,000 Defense Mapping Agency maps are usually sufficient to do all the map portions of a hydrologic analysis. If Defense Mapping Agency maps are not available for a particular area of operation try to get similar maps with adequate contour lines to do the work.

As a bare minimum, tourist travel maps of an area will render some hydrologic information about the area of operation. Most basic area maps will show the major lakes and streams. Some will label the dominant high ground as local points of interest. This minimum information can be used to acquire some hydrologic information.

Section II. Soil Surveys

An analysis of the soils of the area of operation is needed as input for the hydrologic model. The United States Department of Agriculture's Soil Conservation Service has an office in each state and usually at the county level of each state. The counties will have the more detailed analysis of the soil configurations in that specific county. To obtain the soil data for an area of operation and its related watersheds, more than one county office may need to be contacted. It is wise to start with the state office and work down to the county offices. The state office will have the necessary phone numbers and addresses of all the county offices. Soil surveys should be obtained for the entire area of operation if practical. If it is not practical then the soil surveys should only be obtained for the watersheds of the major water bodies that have been identified as having possible impact on the success of the planned operation.

Soil information also may be obtained from air photo imagery and satellite photo imagery. Trained specialists will be needed to interpret soil information from this data.

Section III. Historic Precipitation Data

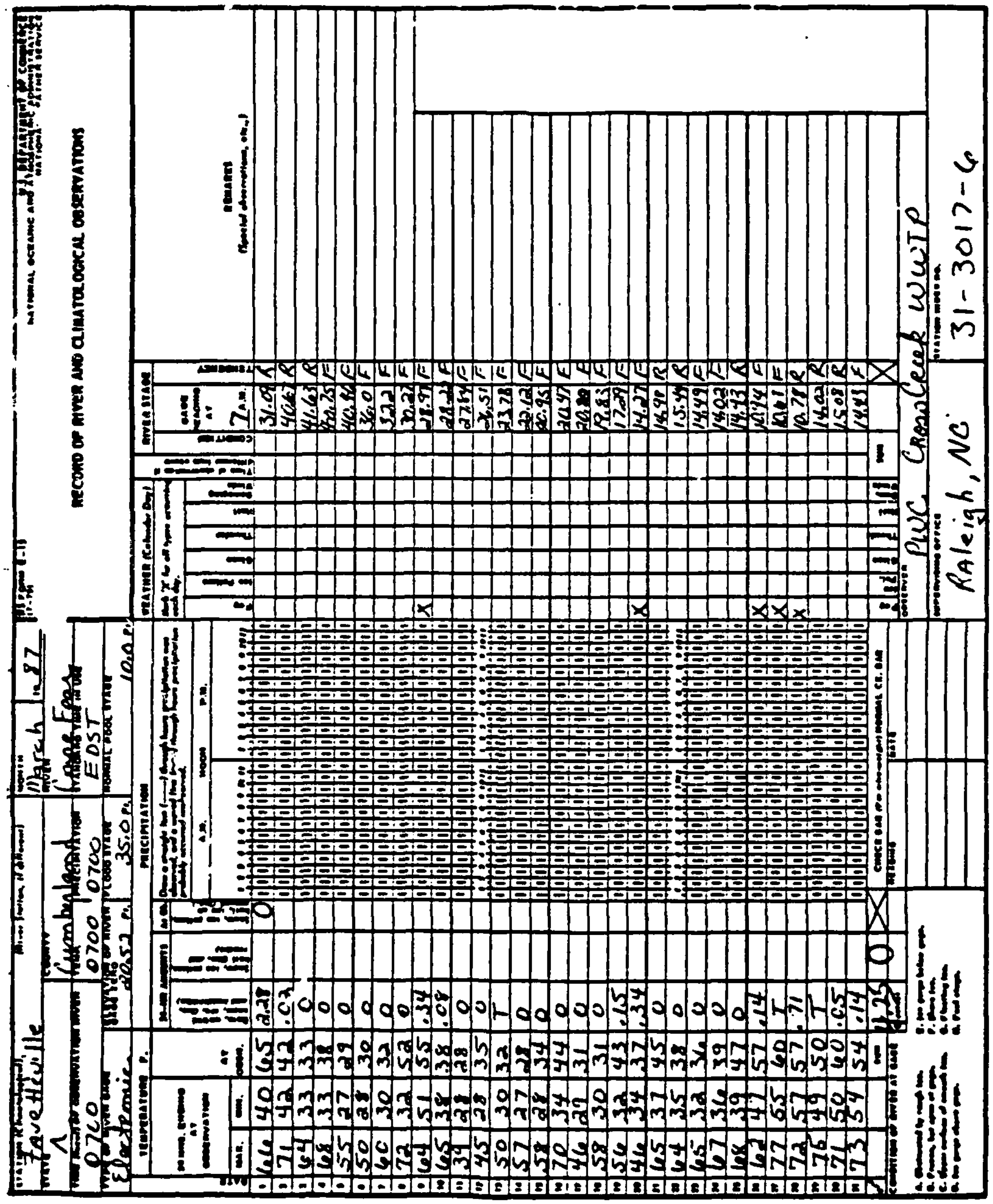
If the hydrologic decision making process requires a full Hydrologic Annex be developed, at least 30 years of historical precipitation data must be used for reliable statistical analysis of all the hydrologic parameters. Some data may require specific security clearances. If only a small (less than 30 years) data base can be obtained, the results become less accurate but the methodology of the technical manual may still be used. If absolutely no precipitation data can be acquired, the procedures in this Draft Technical Manual are not applicable.

Precipitation gauging stations are located throughout the United States. These official gauging and recording stations religiously monitor the precipitation every day and stations with automatic or electronic gauges can provide more specific data. All registered precipitation stations in the United States report the precipitation readings to the U.S. Department of Commerce's, National Climatic Data Center in the Federal Building, Ashville, NC 28801-2723. To obtain precipitation data for Department of Defense related projects the point of contact in the National Climatic Data Center is:

Department of the Air Force
OL-A, USAF Environmental Technical Applications Center (MAC)
Federal Building, Ashville, NC 28801-2723

The commercial phone number to this branch is 704-259-0218. The data obtained from the National Climatic Data Center is available in microfiche or paper format. The data are typically arranged one month to a page with the precipitation listed as a 24-hour amount for all the days of that particular month. Figure 3-1 is an example of the type of data received from the National Climatic Data Center. This data will be needed for the hydrologic analysis. Temperature readings are normally included for each day of the month and may be analyzed for other purposes. Precipitation values normally represent the amounts or rain, melted snow, etc., in inches.

The USAF section of the National Climatic Data Center also has precipitation data for different countries in various parts of the world. An index of world wide information is the "Guide to Standard Weather Summaries and Climatic Services," (NAVAIR 50-1C-534) prepared by Naval Oceanography Command Detachment, Ashville N.C. It may be obtained through the USAF section of the National



RECORD OF RIVER AND CLIMATOLOGICAL OBSERVATIONS

U.S. DEPARTMENT OF COMMERCE
NATIONAL OCEANIC AND ATMOSPHERIC ADMINISTRATION
NATIONAL WEATHER SERVICE

STATION: Fayetteville		MONTH: March	19 87
STATE: A	COUNTY: Cumberland	RIVER: Cape Fear	
TIME OF OBSERVATION RIVER: 0700	TEMP.: 0700	PRECIPITATION: 0700	STANDARD TIME IN USE: EDST
TYPE OF RIVER GAGE: Electronic	ELEVATION OF RIVER GAGE ZERO: 20.52 ft.	FLOOD STAGE: 35.0 ft.	NORMAL POOL STAGE: 10.0 ft.

DATE	TEMPERATURE F. MAX.	MIN.	AT OBSN.	PRECIPITATION 24-HR AMOUNTS			WEATHER (Calendar Day)	RIVER STAGE GAGE READING AT 7 A.M.	TENDENCY
1	66	40	65	2.28		0		31.09	R
2	71	42	42	.02				40.67	R
3	64	33	33	0				41.63	R
4	68	33	38	0				40.75	F
5	55	27	29	0				40.46	F
6	50	28	30	0				36.0	F
7	60	30	32	0				32.2	F
8	72	32	52	0				30.27	F
9	64	51	55	.34			X	28.97	F
10	65	38	38	.08				28.23	F
11	39	28	28	0				27.64	F
12	45	28	35	0				26.51	F
13	50	30	32	T				23.78	F
14	57	27	28	0				22.12	F
15	58	28	34	0				20.95	F
16	70	34	44	0				20.47	F
17	46	29	31	0				20.80	F
18	58	30	31	0				19.83	F
19	56	32	43	.15				17.29	F
20	46	34	37	.34			X	14.27	F
21	65	37	45	0				14.98	R
22	64	35	38	0				15.44	R
23	65	32	36	0				14.49	F
24	67	36	39	0				14.02	F
25	68	39	47	0				14.93	R
26	62	47	57	.14			X	10.94	F
27	77	65	60	T			X	10.61	F
28	72	57	57	.71			X	10.78	R
29	76	49	50	T				14.02	R
30	71	50	40	.05				15.08	R
31	73	54	54	.14				14.43	F
✓			SUM	4.25	0	☒			☒

CONDITION OF RIVER AT GAGE

CHECK BAR

OBSERVER: PWC Cross Creek WWTP

SUPERVISING OFFICE: Raleigh, NC

STATION INDEX NO.: 31-3017-6

Figure 3-1. Example Data From NCDC

Climatic Data Center. The data provided through the NAVAIR manual is not as accurate as the data from the United States and Canada, but it is available for planning purposes upon specific request. For areas of interest where no precipitation data is available, best estimates of a similar area of the world that has the same climatic characteristics may be used with varying results.

Unique storm data should also be acquired. A hurricane, tornado, or tropical storm season would be considered a significant event that would impact on military operations. Information on unique storms could be obtained from the weather service or local monitoring installations.

Section IV. Historic Stream Flow/Lake Level Data

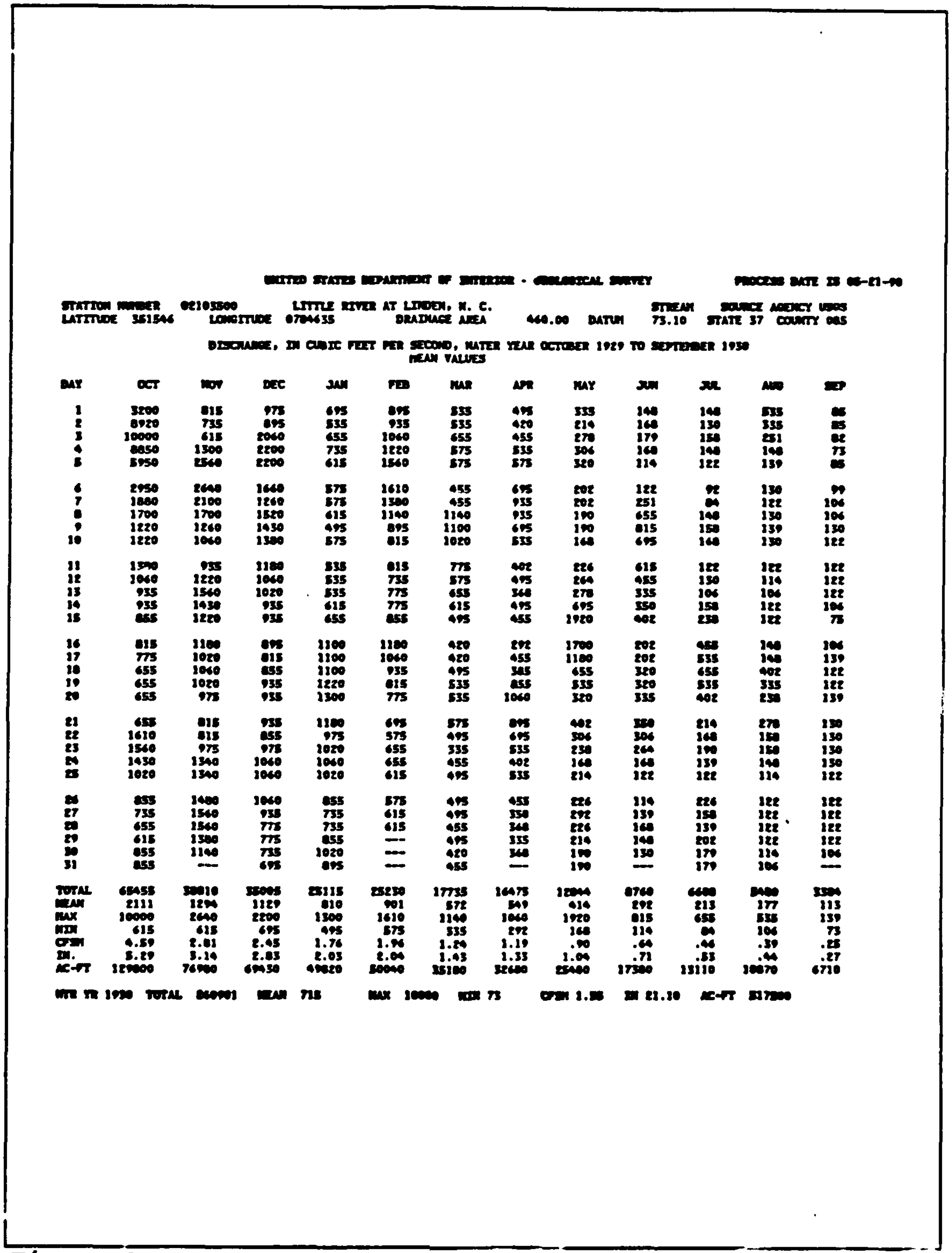
If it has been determined that there are significant water bodies in the area of operation that may impact on the success of the operation the historic lake level and or stream/river gage data will be very valuable for the hydrologic analysis. Within the United States the U.S. Geological Survey publishes yearly volumes of the Water Surface Supply Papers. Within these volumes are the stream flows of all gaged and reported streams back through the 1800's for some gages.

Map analysis of the area of operation will determined the water bodies that will impact on the operation. When the watersheds of these water bodies have been identified and outlined on maps, it can be determined if the watersheds of interest are major identifiable watersheds in the Surface Water Supply Papers. The watershed of interest may be a sub watershed of one of the major watersheds identified by the Water Supply Papers. For example, the watershed of the Little River at Fort Bragg is located as a sub-basin of the Cape Fear River by looking in Surface Water Supply Papers 2104, Part 2, South Atlantic Slope and Eastern Gulf of Mexico Basins, Volume 1, Basins from James River to Savannah River. If the set of Surface Water Supply Papers being referenced are complete, at least 30 years of data should be extracted for analysis.

If the appropriate Surface Water Supply Papers cannot be obtained and time will allow, the U.S. Geological Survey's National Center office at Mail Stop 421, Reston, Virginia 22092, is available to provide all the historical gage data to specific gage numbers upon request. To acquire the data directly from the U.S.G.S. National Center, a formal memorandum requesting specific years of interest or all available historical gage data for specific gage(s) should be sent to the Reston, Virginia, office. The data sent to the requester will include yearly, by month charts that provide the average daily discharge in cubic feet per second with monthly statistical data at the bottom of the chart. Figure 3-2 is an example of a data chart obtained through the U.S.G.S. National Center.

Section V. Watershed Modeling

To completely analyze the watershed of the significant bodies of water in the area of operation, watershed parameters and expected precipitation figures will be loaded into a computer modeling program. The important information that can be obtained from modeling are indications of the peak discharge for the precipitation of interest and the time the peak flow will reach the crossing point on a river or the peak stage of a lake. The HEC-1 Flood Hydrograph computer model is recommended for the large watersheds that will normally be dealt with by military operations. Table 3-1 lists some available watershed hydrograph models and the size of the watersheds they are designed to work with.



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                     UNITED STATES DEPARTMENT OF INTERIOR - GEOLOGICAL SURVEY          PROCESS DATE IS 06-21-90

STATION NUMBER   02103500        LITTLE RIVER AT LINDEN, N. C.                 STREAM    SOURCE AGENCY USGS
LATITUDE  351546      LONGITUDE  0784635         DRAINAGE AREA      460.00   DATUM    73.10   STATE 37  COUNTY 085

                 DISCHARGE, IN CUBIC FEET PER SECOND, WATER YEAR OCTOBER 1929 TO SEPTEMBER 1930
                                              MEAN VALUES

DAY        OCT      NOV      DEC      JAN      FEB      MAR      APR      MAY      JUN      JUL      AUG      SEP

  1       3200      815      975      695      895      535      495      335      148      148      535       86
  2       8920      735      895      535      935      535      420      214      168      130      335       85
  3      10000      615     2060      655     1060      655      455      278      179      158      251       82
  4       8850     1300     2200      735     1220      575      535      306      168      148      148       73
  5       5950     2560     2200      615     1560      575      575      320      114      122      139       86

  6       2950     2640     1660      575     1610      455      695      202      122       92      130       99
  7       1880     2100     1260      575     1380      455      935      202      251       84      122      106
  8       1700     1700     1520      615     1140     1140      935      190      655      148      130      106
  9       1220     1260     1430      495      895     1100      695      190      815      158      139      130
 10       1220     1060     1380      575      815     1020      535      168      695      168      130      122

 11       1380      935     1180      535      815      775      402      226      615      122      122      122
 12       1060     1220     1060      535      735      575      495      264      455      130      114      122
 13        935     1560     1020      535      775      655      368      278      335      106      106      122
 14        935     1430      935      615      775      615      495      695      350      158      122      106
 15        855     1220      935      655      855      495      455     1920      402      238      122       75

 16        815     1180      895     1100     1180      420      292     1700      202      475      148      106
 17        775     1020      815     1100     1060      420      455     1180      202      535      148      139
 18        655     1060      855     1100      935      495      385      655      320      655      402      122
 19        655     1020      935     1220      815      535      855      535      320      535      335      122
 20        655      975      935     1300      775      535     1060      320      335      402      238      139

 21        655      815      935     1180      695      575      895      402      350      214      278      130
 22       1610      815      855      975      575      495      695      306      306      168      158      130
 23       1560      975      975     1020      655      335      535      238      264      190      158      130
 24       1430     1340     1060     1060      655      455      402      168      168      139      148      130
 25       1020     1340     1060     1020      615      495      535      214      122      122      114      122

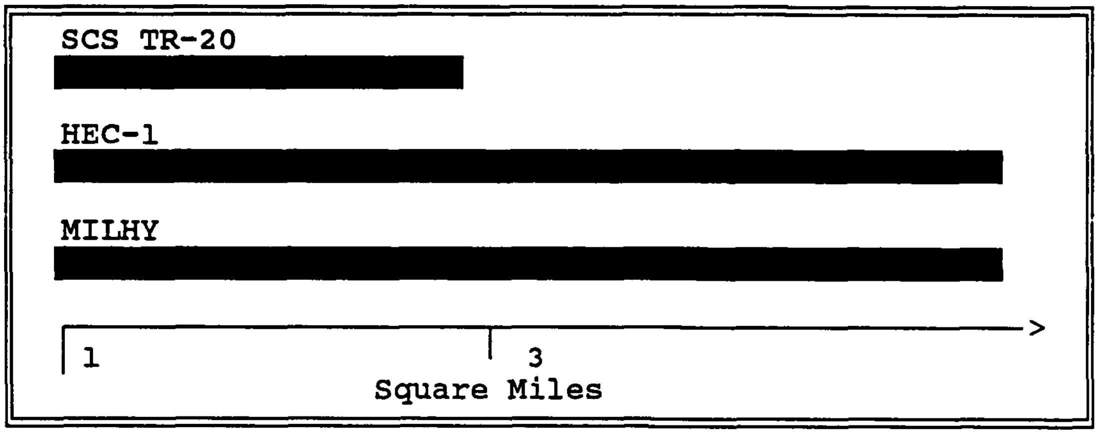
 26        855     1480     1060      855      575      495      455      226      114      226      122      122
 27        735     1560      935      735      615      495      350      292      139      158      122      122
 28        655     1560      775      735      615      455      368      226      168      139      122      122
 29        615     1380      775      855      ---      495      335      214      148      202      122      122
 30        855     1140      735     1020      ---      420      368      190      130      179      114      106
 31        855      ---      695      895      ---      455      ---      190      ---      179      106      ---

TOTAL    65455    38810    35005    25115    25230    17735    16475    12844     8760     6608     5480     3384
MEAN      2111     1294     1129      810      901      572      549      414      292      213      177      113
MAX      10000     2640     2200     1300     1610     1140     1060     1920      815      655      535      139
MIN        615      615      695      495      575      535      292      168      114       84      106       73
CFSM      4.59     2.81     2.45     1.76     1.96     1.24     1.19      .90      .64      .46      .39      .25
IN.       5.29     3.14     2.83     2.03     2.04     1.43     1.33     1.04      .71      .53      .44      .27
AC-FT   129800    76980    69430    49820    50040    35180    32680    25480    17380    13110    10870     6710

WTR YR 1930  TOTAL  260901   MEAN  715        MAX  10000   MIN 73      CFSM 1.55   IN 21.10   AC-FT  517500
```

Figure 3-2. Example Data Chart From U.S.G.S.

Table 3-1. Available Watershed Models



To acquire the most up to date working copy of the HEC-1 package a memorandum should be sent to Commander, Hydrologic Engineering Center, Corps of Engineers (ATTN: Hydrologic Research Manager), 609 Second Street, Davis CA 95616. The memorandum should explain the need for the package and what format that you would like the package sent to you (ie...IBM compatible floppy disks).

Section VI. Environmental

All possible information concerning the environmental status of the area of operation must be obtained to evaluate the potential hydrologic impact. Knowledge of the endangered, rare, or threatened species of animal and plant life is necessary for an analysis.

Larger than normal silt runoff will occur during a time of heavy rainfall. If the surface soils have been disturbed by recent vehicle and demolition, the silt runoff will increase even more during heavy precipitation. The excessive silt runoff will proceed to fill sensitive lowland ecosystems. The destruction of the lowland ecosystem could lead to the elimination of some species that live in the lowlands or survive on elements of the food chain that are produced by the lowland.

Environmental information can be obtained from the military installations involved in the exercise being planned. Army installations typically have an environmental office within the structure of the Directorate of Engineering and Housing.

The state environmental office or office of natural resources is a source of information for environmental issues both on and off the military training facility.

Section VII. Unique Storms

Unique storm data within the United States should be obtained from the National Climatic Data Center along with the precipitation data. Specific storm types must be identified in the request for information.

DRAFT

CHAPTER 4

ANALYSIS OF DATA

Section I. Watershed

4-1-1. Introduction

If there have been one or more significant bodies of water identified in the area of operation the specific characteristics of that watershed must be identified for use in the HEC-1 Hydrologic Analysis model or the appropriate model of choice. The watershed parameters of interest for input into the computer model are usually the drainage area, the total length of the watershed, the length of the main stream, the average slope, and the curve number of the soil groups involved.

4-1-2. Drainage Area

The drainage area of the watershed is the area that contributes precipitation input to the body of water. The drainage area can be found by studying the contours on a Defense Mapping Agency map of the watershed. The boundaries of the watershed follow the high ridge line surrounding the watershed. Intermittent streams and flowing streams will be a guide to the boundaries of the contributing drainage area. Obtaining maps for the hydrologic study was discussed in Chapter 3, Section 1 of this technical manual. Drainage area also may be provided from gage station data that may be obtained from sources discussed in Chapter 3, Section II. The final drainage area should be calculated in the units required by the computer model being used. It may best suit the model of choice if the watershed area can be split into sub-watersheds.

The total length of the watershed is the straight line distance from the outlet of the watershed to the furthermost edge of the watershed. The length of the main stream is the measured distance along the main stream to the furthest edge of the watershed. The length of the main stream can be found using tick-mark procedure that is also used to find actual road mileage on a map. The average slope of the watershed is easily found by selecting 30 points inside the watershed and getting the slope at each of those points. The point slope can be found by dividing the difference in elevation between the contour intervals on either side of the point by the shortest distance between the two contour intervals. The 30 slopes are then averaged to find the average slope of the watershed. The selected points must be spread throughout the watershed to obtain the best estimate of the average slope.

4-1-3. Soil Conservation Service (SCS) Curve Number

The curve number of the watershed depends on the soil groups of the watershed. The curve number will be used by the computer model to determine the amount of runoff that will occur from a given storm of a specific precipitation and duration. Different soils and different vegetal or man-made covers on the soil also have input on what the SCS Curve Number will be. Appendix A is taken from Hydrologic Analysis and Design by R. H. McCuen (1989) and has its basis in the SCS National Engineering Handbook, Section 4, Hydrology, and should be used to determine the curve number for the watershed or the watershed's sub-watersheds.

Section II. Soil

4-2-1. Introduction

Soil analysis will be needed for determination of the SCS Curve Number. The Curve Number is critical information for running HEC-1, the flood routing hydrologic model discussed in the next section. The soil analysis also may give insight on how the soils will act if the expected precipitation should occur. This portion of the hydrologic analysis will involve the use of the SCS soil surveys or comparable soil data of the area of operation and specifically the watersheds of interest.

4-2-2. Methodology

This methodology is directly for use with SCS Soil Survey data. The quickest way to gain the necessary information concerning the watershed(s) of interest in the area of operation is to consult the General Soil Map usually at the beginning of the last section of the survey. The General Survey Map is color coded into the dominate soil groups of the specific area addressed by that soil survey. The color coded areas should be transposed over the area of operation map on an overlay. The watershed(s) of the area also should be marked on the map. The watershed should be associated with its soil groups by percents of area covered by the overlay. From this data the SCS Curve Number can be derived by using the SCS Curve Number derivation information provided in Appendix 1. If the watershed is divided into sub-watersheds, then the curve number of each sub-watershed should be determined.

A more accurate, detailed, and time consuming way to use the soil surveys of the watershed is to link them together to form the watershed area. From this composite map the soil groups should be color coded and colored in on the actual map or an overlay. Each different soil section is then plainimetered and its area recorded. After each soil section has been plainimetered the total area for each soil type is summed. The percent of each soil type is calculated and the appropriate curve number is assigned. The curve numbers of the soil groups are then weighted by the percent of the area they cover and a composite curve number is found. This curve number can then be used in any of the computer programs to model the stream flow for the expected precipitation.

Section III. Precipitation

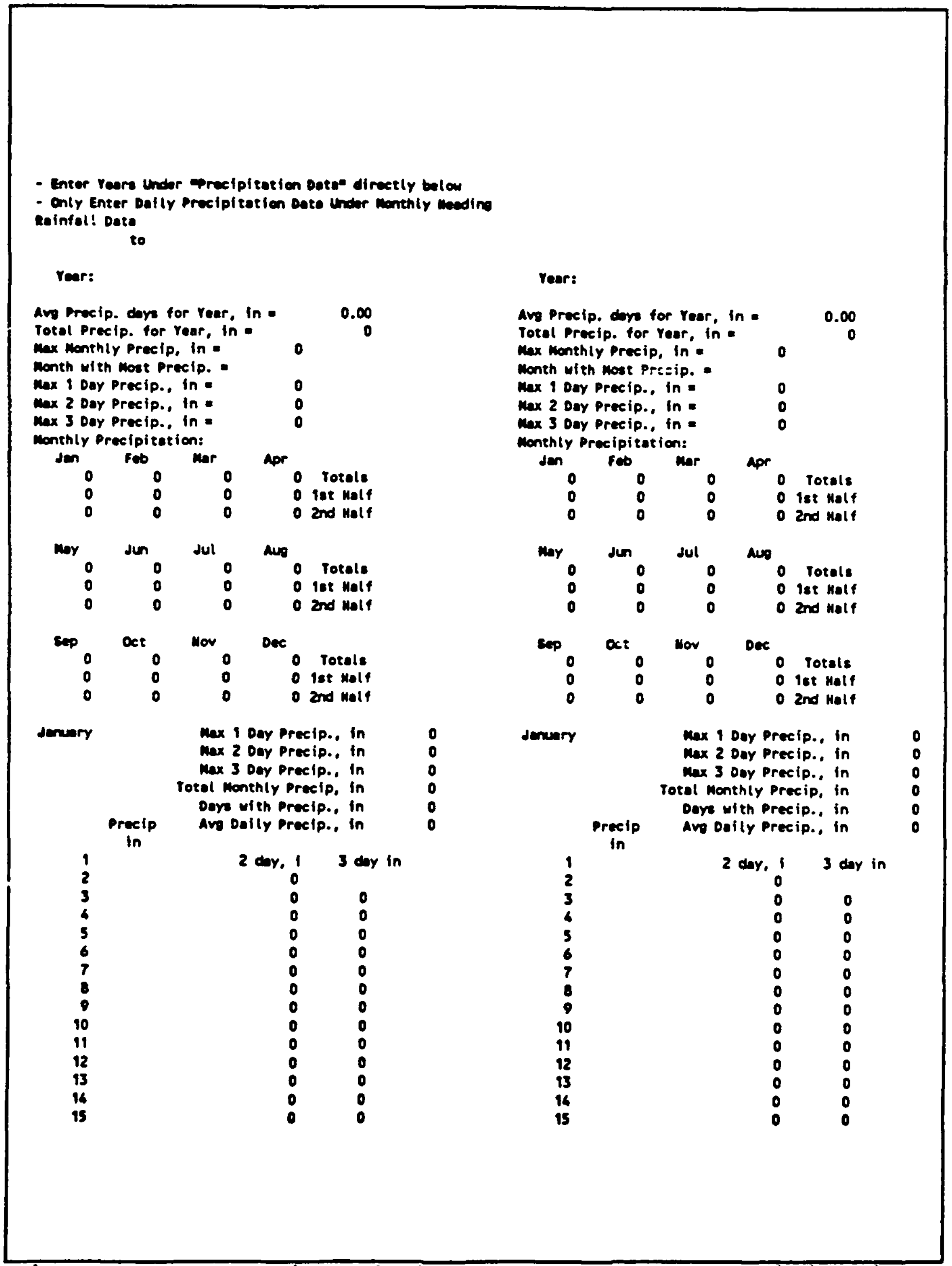
4-3-1. Introduction

The precipitation analysis is the most important aspect of a hydrologic analysis for the development of a Hydrologic Annex. Precipitation in the form of rain, snow, hail, or sleet will have an impact on any military operation. If one soldier has to put on an extra garment of clothing because of precipitation then the impact of precipitation has been realized in a small way. If the precipitation causes a training or tactical mission to be delayed or canceled then the precipitation has obviously had a significant impact on the planned operation.

4-3-2. Methodology

As with stream flow or lake level data, the best way to organize and analyze the obtained data is with a spreadsheet application. The provided diskette has a template named PRECIP.WQ1/WK1 that will allow the user to input the needed spreadsheet template for precipitation data organization. Figure 4-1 is a portion of a blank spreadsheet template for precipitation data. Figure 4-2 is the same portion of the template with historic precipitation data in the appropriate cells.

Because of the size of the spreadsheet it may require that data be divided into three years of precipitation data per floppy disk. The provided spreadsheet is set up to accommodate 3 years of historic precipitation data. The precipitation is put into the appropriate days of each month. The spreadsheet will automatically calculate the 1, 2, and 3 day maximum inches of precipitation for each time period in the month. Total precipitation, the amount of days in the month that had rain and the daily average of precipitation for that month are also calculated and



```
- Enter Years Under "Precipitation Data" directly below
- Only Enter Daily Precipitation Data Under Monthly Heading
Rainfall Data
          to

  Year:

Avg Precip. days for Year, in =        0.00
Total Precip. for Year, in =              0
Max Monthly Precip, in =          0
Month with Most Precip. =
Max 1 Day Precip., in =          0
Max 2 Day Precip., in =          0
Max 3 Day Precip., in =          0
Monthly Precipitation:
  Jan     Feb     Mar     Apr
     0       0       0       0  Totals
     0       0       0       0 1st Half
     0       0       0       0 2nd Half

  May     Jun     Jul     Aug
     0       0       0       0  Totals
     0       0       0       0 1st Half
     0       0       0       0 2nd Half

  Sep     Oct     Nov     Dec
     0       0       0       0  Totals
     0       0       0       0 1st Half
     0       0       0       0 2nd Half

January              Max 1 Day Precip., in        0
                     Max 2 Day Precip., in        0
                     Max 3 Day Precip., in        0
                   Total Monthly Precip, in       0
                     Days with Precip., in        0
        Precip       Avg Daily Precip., in        0
          in
     1                   2 day, i     3 day in
     2                        0
     3                        0          0
     4                        0          0
     5                        0          0
     6                        0          0
     7                        0          0
     8                        0          0
     9                        0          0
    10                        0          0
    11                        0          0
    12                        0          0
    13                        0          0
    14                        0          0
    15                        0          0
```

```
  Year:

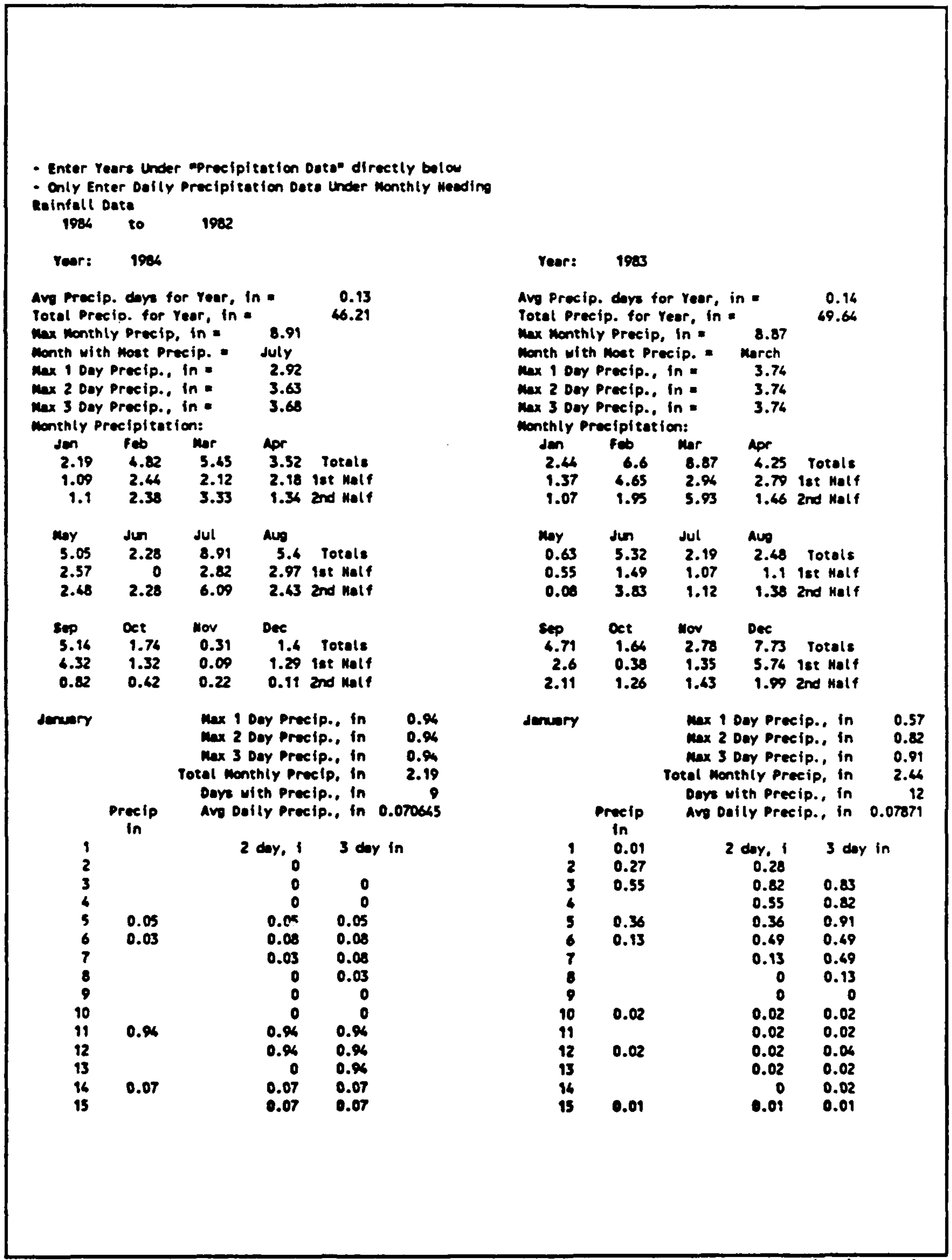
Avg Precip. days for Year, in =        0.00
Total Precip. for Year, in =              0
Max Monthly Precip, in =          0
Month with Most Precip. =
Max 1 Day Precip., in =          0
Max 2 Day Precip., in =          0
Max 3 Day Precip., in =          0
Monthly Precipitation:
  Jan     Feb     Mar     Apr
     0       0       0       0  Totals
     0       0       0       0 1st Half
     0       0       0       0 2nd Half

  May     Jun     Jul     Aug
     0       0       0       0  Totals
     0       0       0       0 1st Half
     0       0       0       0 2nd Half

  Sep     Oct     Nov     Dec
     0       0       0       0  Totals
     0       0       0       0 1st Half
     0       0       0       0 2nd Half

January              Max 1 Day Precip., in        0
                     Max 2 Day Precip., in        0
                     Max 3 Day Precip., in        0
                   Total Monthly Precip, in       0
                     Days with Precip., in        0
        Precip       Avg Daily Precip., in        0
          in
     1                   2 day, i     3 day in
     2                        0
     3                        0          0
     4                        0          0
     5                        0          0
     6                        0          0
     7                        0          0
     8                        0          0
     9                        0          0
    10                        0          0
    11                        0          0
    12                        0          0
    13                        0          0
    14                        0          0
    15                        0          0
```

Figure 4-1. Portion of Blank Template for Precipitation



```
- Enter Years Under "Precipitation Data" directly below
- Only Enter Daily Precipitation Data Under Monthly Heading
Rainfall Data
   1984     to       1982

  Year:     1984                                           Year:     1983

Avg Precip. days for Year, in =        0.13               Avg Precip. days for Year, in =        0.14
Total Precip. for Year, in =          46.21               Total Precip. for Year, in =          49.64
Max Monthly Precip, in =      8.91                        Max Monthly Precip, in =      8.87
Month with Most Precip. =     July                        Month with Most Precip. =     March
Max 1 Day Precip., in =       2.92                        Max 1 Day Precip., in =       3.74
Max 2 Day Precip., in =       3.63                        Max 2 Day Precip., in =       3.74
Max 3 Day Precip., in =       3.68                        Max 3 Day Precip., in =       3.74
Monthly Precipitation:                                    Monthly Precipitation:
   Jan      Feb      Mar      Apr                            Jan      Feb      Mar      Apr
   2.19     4.82     5.45     3.52  Totals                   2.44      6.6     8.87     4.25  Totals
   1.09     2.44     2.12     2.18 1st Half                  1.37     4.65     2.94     2.79 1st Half
    1.1     2.38     3.33     1.34 2nd Half                  1.07     1.95     5.93     1.46 2nd Half

   May      Jun      Jul      Aug                            May      Jun      Jul      Aug
   5.05     2.28     8.91      5.4  Totals                   0.63     5.32     2.19     2.48  Totals
   2.57        0     2.82     2.97 1st Half                  0.55     1.49     1.07      1.1 1st Half
   2.48     2.28     6.09     2.43 2nd Half                  0.08     3.83     1.12     1.38 2nd Half

   Sep      Oct      Nov      Dec                            Sep      Oct      Nov      Dec
   5.14     1.74     0.31      1.4  Totals                   4.71     1.64     2.78     7.73  Totals
   4.32     1.32     0.09     1.29 1st Half                   2.6     0.38     1.35     5.74 1st Half
   0.82     0.42     0.22     0.11 2nd Half                  2.11     1.26     1.43     1.99 2nd Half

 January               Max 1 Day Precip., in    0.94       January               Max 1 Day Precip., in    0.57
                       Max 2 Day Precip., in    0.94                             Max 2 Day Precip., in    0.82
                       Max 3 Day Precip., in    0.94                             Max 3 Day Precip., in    0.91
                     Total Monthly Precip, in   2.19                           Total Monthly Precip, in   2.44
                       Days with Precip., in       9                             Days with Precip., in      12
          Precip       Avg Daily Precip., in 0.070645                 Precip     Avg Daily Precip., in 0.07871
            in                                                          in
      1                    2 day, i    3 day in                 1     0.01          2 day, i    3 day in
      2                           0                             2     0.27              0.28
      3                           0        0                    3     0.55              0.82    0.83
      4                           0        0                    4                       0.55    0.82
      5     0.05               0.05     0.05                    5     0.36              0.36    0.91
      6     0.03               0.08     0.08                    6     0.13              0.49    0.49
      7                        0.03     0.08                    7                       0.13    0.49
      8                           0     0.03                    8                          0    0.13
      9                           0        0                    9                          0       0
     10                           0        0                   10     0.02              0.02    0.02
     11     0.94               0.94     0.94                   11                       0.02    0.02
     12                        0.94     0.94                   12     0.02              0.02    0.04
     13                           0     0.94                   13                       0.02    0.02
     14     0.07               0.07     0.07                   14                          0    0.02
     15                        0.07     0.07                   15     0.01              0.01    0.01
```

Figure 4-2. Portion of Filled Template for Precipitation Data presented at the data block at the start of each monthly input section. The yearly data organization is at the top of each column. The data sheets from all the years must be consolidated after printout and the necessary graphs can then be constructed. The spreadsheet also includes a macro named "Print." When the macro is run it will print the needed precipitation data summaries. The "Print" macro is stored in column A and begins in cell A-1.

The bar graphs in Table 4-1 will be needed to draw the necessary conclusions for inclusion in the Hydrologic Annex.

Table 4-1. Initial Precipitation Analysis Graphs

Y-Axis		X-Axis
Average precipitation	vs.	Month
Average days of precipitation	vs.	Month
Months of highest precipitation in a year	vs.	Month

From these three graphs the months of highest and lowest precipitation, most and least frequent precipitation, and how the month of the planned operation fits into the pattern of precipitation. From this point the graphs in Table 4-2 should be made. These graphs will allow inference concerning specific events and the likeness of precipitation during critical days. If an operation does not yet have a planned execution time frame, as a contingency plan, then the Hydrologic Annex to that plan will provide valuable data for time frame planning. If the Hydrologic Annex is being prepared for an operation that has tentative or locked in dates, the planned dates should be graphed the same as the above graphs but just for the specific dates. The operation date graphs will give specific information that otherwise may be missed in the full monthly graph. Another set of

Table 4-2. Detailed Precipitation Analysis Graphs

Y-Axis		X-Axis
Average Precipitation	vs.	Days of the month of most precipitation
Average Precipitation	vs.	Days of the month of least precipitation
Average Precipitation	vs.	Days of the month the planned operation
% of each day that had Precip. > 0.01 inch	vs.	Days of the month of most precipitation
% of each day that had Precip. > 0.01 inch	vs.	Days of the month of least precipitation
% of each day that had Precip. > 0.01 inch	vs.	Days of the month the planned operation

graphs also can be made for any other month of interest once the data is organized on a spreadsheet.

The actual historical data can be compared to the design storms presented in the Soil Conservation Service's Technical Paper #40 (TP-40). TP-40 presents the expected precipitation of major storms and their frequency for the entire continental United States. Two valuable graphs can be constructed from the data in TP-40. The first graph will be a Precipitation-Duration-Frequency plot and the second will be the Intensity-Duration-Frequency graph. Actual precipitation can be referenced to these graphs and the storm in question can be identified.

Constructing the Precipitation-Duration-Frequency and Intensity-Duration-Frequency graphs. In The U.S.A.

1. Find the area of operation on a map in relation to county borders.

2. Obtain a copy of the United States Department of Commerce, Weather Bureau's Technical Paper No. 40, Rainfall Frequency Atlas of the United States, for durations from 30 minutes to 24 hours and return periods from 1 to 100 years, May 1961.

3. Set up a spread sheet to receive the rainfall data that will be extracted from TP-40. The spreadsheet should be divided into 7 sections. Each section should have columns for the Frequency in years, duration in hours, rainfall in inches, and intensity in inches/hour.

4. The frequency in year column should be the same for every section and contain the values 1, 2, 3, 10, 25, 50, and 100. These frequencies reflect the frequency breakdown of TP-40.

5. The duration in hours column will reflect the same value for each section. Section 1 will reflect a duration in hour of 0.5, section 2 will reflect a duration in hour of 1, section 3 will reflect a duration in hour of 2, section 4 will reflect a duration in hour of 3, section 5 will reflect a duration in hour of 6, section 6 will reflect a duration in hour of 12, and section 7 will reflect a duration in hour of 24. These durations reflect the data presented in TP-40.

6. The rainfall in inches is taken from the isopluvial maps presented in TP-40. To accurately read the expected rainfall from any of the maps:

a. Find the area of operation on the isopluvial maps listed in TP-40 as charts 1-49.

b. Pinpoint the center of the area of operation on chart 1.

c. Use an engineer scale to best find the expected rainfall. Example: Find the expected 1-year 30-minute rainfall in inches for Boston MA.

(1) Use Chart 1

(2) Use 20 scale of an engineers scale

(3) lower limit is .6 inches

(4) upper limit is 0.8 inches

(5) shortest distance between the limits and through Boston MA = 26.

(6) Boston = 22

(7) 22/26 = 0.85

(8) upper limit of 0.8 minus lower limit of 0.6 = 0.2

(9) 0.2 X 0.85 = 0.17

(10) lower limit of 0.6 + 0.17 = 0.77

Boston Massachusetts expected 1-year 30-minute rainfall is 0.77 inches.

7. The above procedure is followed for each of the 49 charts of TP-40 and the rainfall data is recorded in the rainfall in inches column of the spreadsheet.

8. The last column of the spreadsheet is the intensity in inches per hour column. This column should contain a simple equation that divides the rainfall figure by the duration.

9. The data is then plotted on probability paper. Keuffel and Esser company's probability X 2 log cycle paper (46-8040) is recommended.

10. The left side of the log-probability paper or y-axis will be used for the precipitation in inches. The top of the paper is used to plot the return periods as follows:

Log-Probability Value	Return Period
50	2
20	5
10	10
4	25
2	50
1	100

11. The precipitation vs. return period data is plotted on one sheet of log-probability paper and the intensity vs. return period is plotted on another.

12. These two graphs will be used to determine the probability of the expected rainfall during a given time frame. Examples of a Precipitation-Duration-Frequency graph is presented in Figure 4-3.

Storm seasons and monthly historic storm data should be plotted on an appropriate graph and analyzed for trends. In most cases a standard or stacked bar graph will graphically represent historic unique storm data.

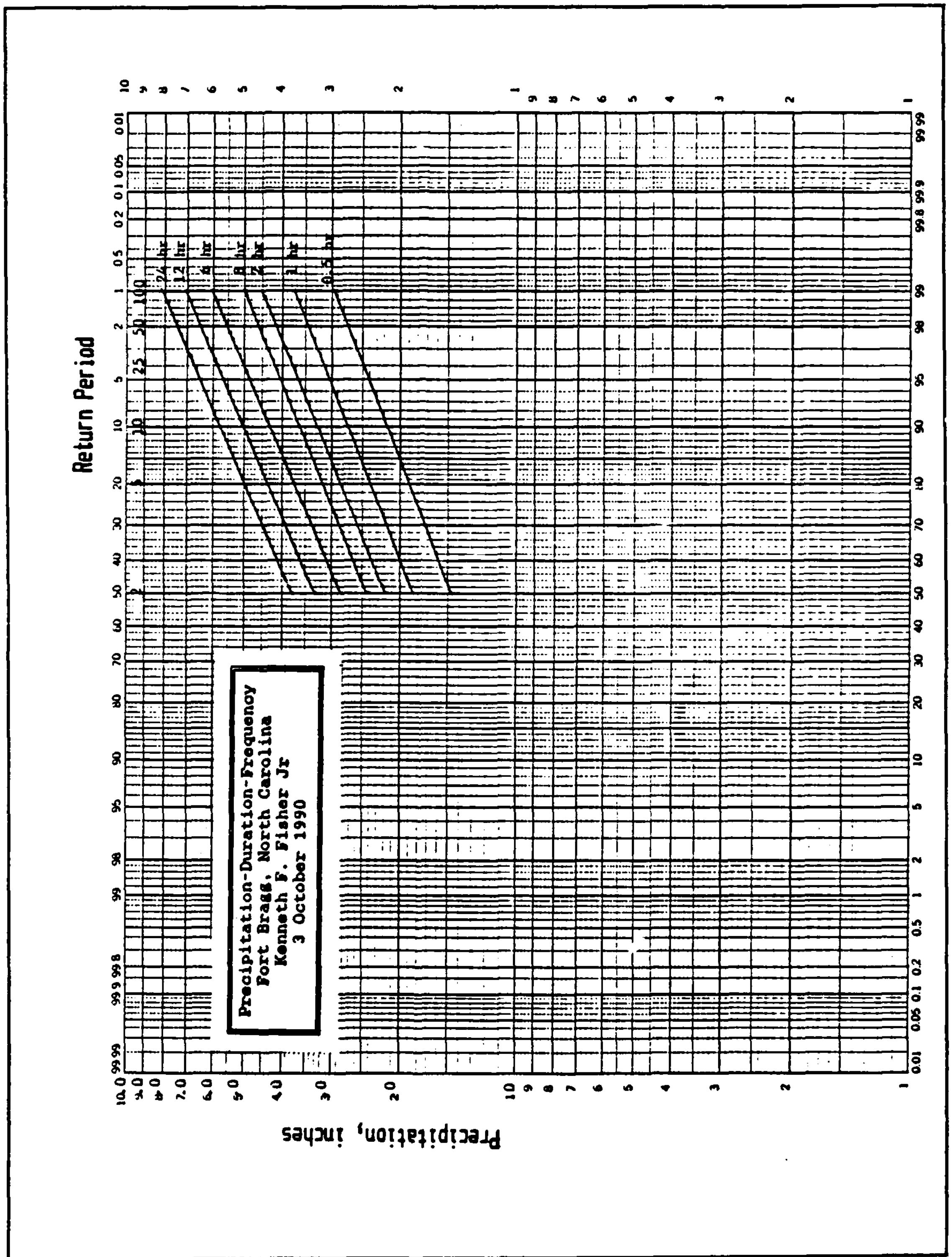


Figure 4-3. Precipitation-Duration-Frequency Graph

Section IV. Stream Flow

4-4-1. Introduction

If the analysis of the commander's intent using Figure 2-1 has indicated the need for river flow or lake level historical data then the significant water body has been determined to have possible influence on the outcome on the operation in planning. River, stream, or lake gauge data will provide information that will allow the high and low months of flow to be determined as well as the historic high and low flow rates or lake levels. This analysis will provide the commander information on when accomplishment of specific training or tactical mission objectives would be most or least favorable. The information derived from the flow or water level analysis will be presented to the commander in the Hydrologic Annex.

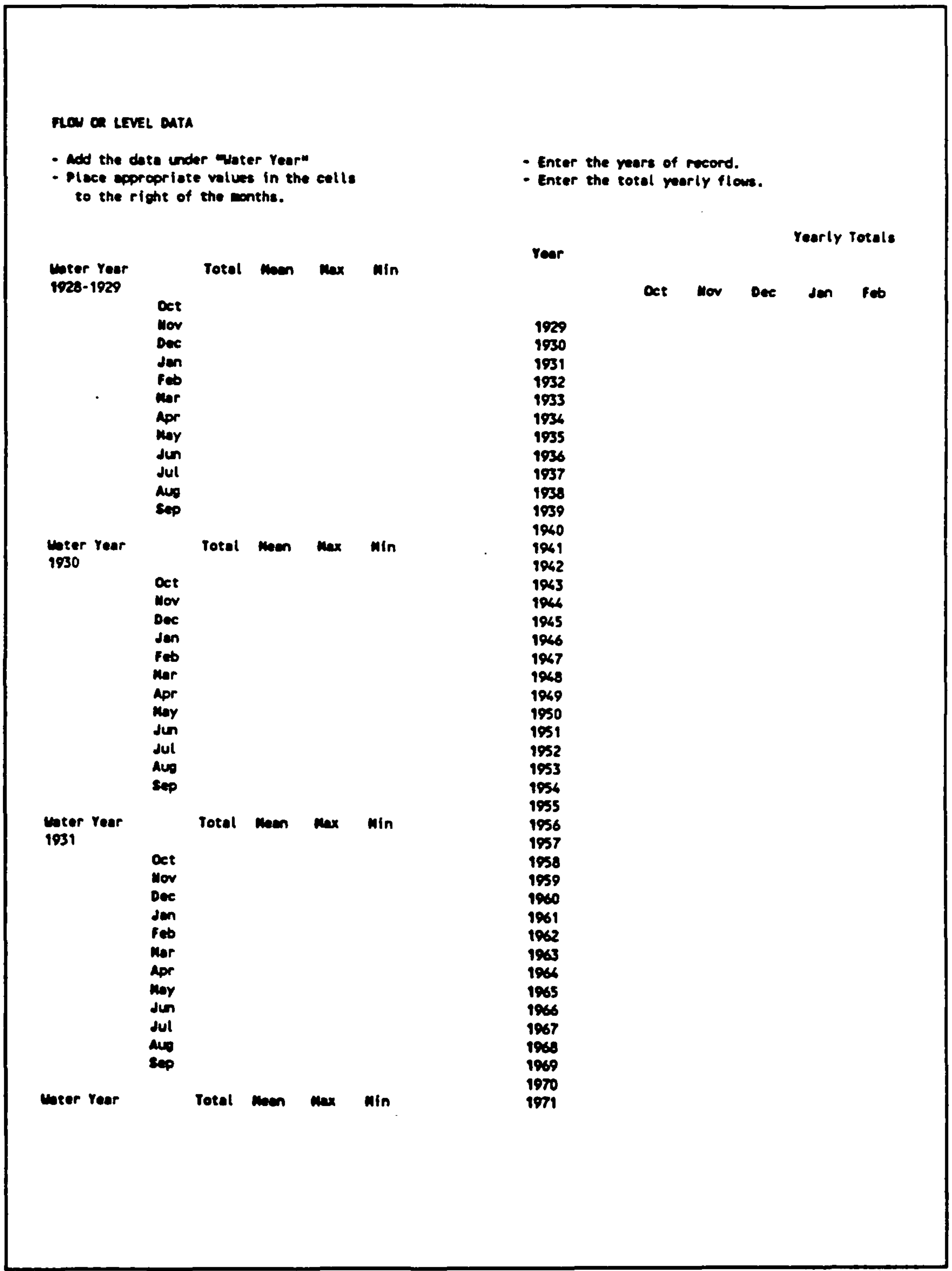
4-4-2. Methodology

Inference cannot be derived from unorganized acquired data. Manual organization of the data is possible but time consuming. The best way to analyze the data is with a spreadsheet software package. Graphic representation of the data will provide a visual portrait of the data that is easy to read and derive conclusions. The bar graphs needed for a full analysis are in Table 4-3.

Table 4-3. Initial Flow Analysis Graphs

Y-Axis		X-Axis
Average total flow or lake level	vs	months
Average daily flow or lake level	vs	months
Minimum daily flow or lake level	vs	months
Average daily minimum flow or lake level	vs	months
Maximum average daily flow or lake level	vs	months
Average daily maximum flow or lake level	vs	months

The 2 floppy disk provided with this manual have data organization templates that were set up using Quattro Pro by Borland. One disk has the templates set up for direct use by Quattro Pro and the other has the templates set up in Lotus 1-2-3 format. This format makes the spreadsheet accessible to most spreadsheet programs. The template FLOW.WQ1/WK1 may be used to organize the historic data to produce the needed graphs. Figure 4-4 is a portion of the blank flow data spreadsheet template. Figure 4-5 is the same portion of the spreadsheet template with historic data in the appropriate columns. A good spreadsheet program also will be able to produce the bar graphs from the data imputed into the spreadsheet. The Quattro Pro version of the



FLOW OR LEVEL DATA

- Add the data under "Water Year"
- Place appropriate values in the cells to the right of the months.

- Enter the years of record.
- Enter the total yearly flows.

Water Year		Total	Mean	Max	Min
1928-1929					
	Oct				
	Nov				
	Dec				
	Jan				
	Feb				
	Mar				
	Apr				
	May				
	Jun				
	Jul				
	Aug				
	Sep				
Water Year		Total	Mean	Max	Min
1930					
	Oct				
	Nov				
	Dec				
	Jan				
	Feb				
	Mar				
	Apr				
	May				
	Jun				
	Jul				
	Aug				
	Sep				
Water Year		Total	Mean	Max	Min
1931					
	Oct				
	Nov				
	Dec				
	Jan				
	Feb				
	Mar				
	Apr				
	May				
	Jun				
	Jul				
	Aug				
	Sep				
Water Year		Total	Mean	Max	Min

Year	Yearly Totals				
	Oct	Nov	Dec	Jan	Feb
1929					
1930					
1931					
1932					
1933					
1934					
1935					
1936					
1937					
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1942					
1943					
1944					
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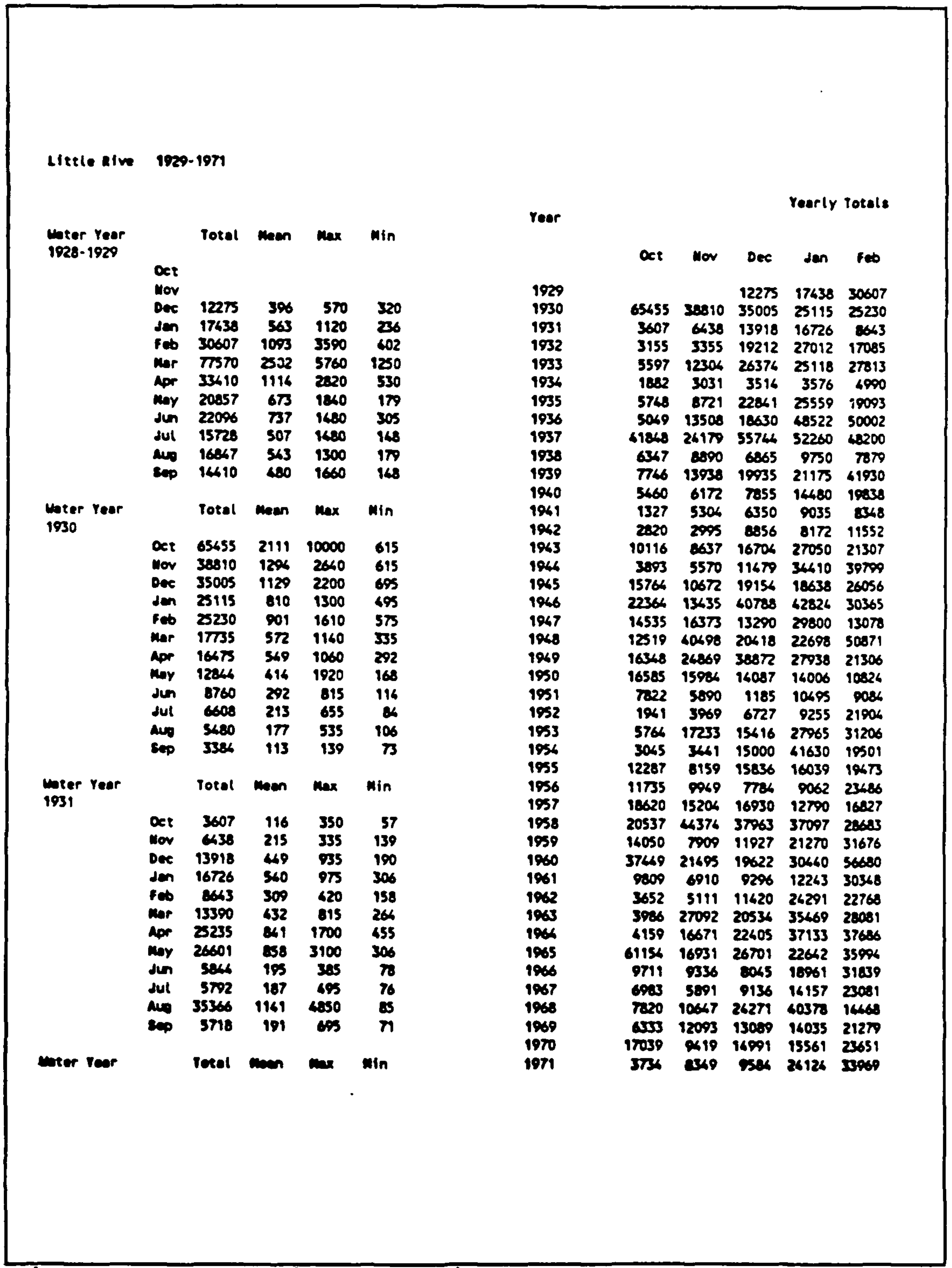
1963					
1964					
1965					
1966					
1967					
1968					
1969					
1970					
1971					

Figure 4-4. Portion of a Blank Flow Spreadsheet Template



Little Rive 1929-1971

Water Year 1928-1929		Total	Mean	Max	Min
	Oct				
	Nov				
	Dec	12275	396	570	320
	Jan	17438	563	1120	236
	Feb	30607	1093	3590	402
	Mar	77570	2502	5760	1250
	Apr	33410	1114	2820	530
	May	20857	673	1840	179
	Jun	22096	737	1480	305
	Jul	15728	507	1480	148
	Aug	16847	543	1300	179
	Sep	14410	480	1660	148

Water Year 1930		Total	Mean	Max	Min
	Oct	65455	2111	10000	615
	Nov	38810	1294	2640	615
	Dec	35005	1129	2200	695
	Jan	25115	810	1300	495
	Feb	25230	901	1610	575
	Mar	17735	572	1140	335
	Apr	16475	549	1060	292
	May	12844	414	1920	168
	Jun	8760	292	815	114
	Jul	6608	213	655	84
	Aug	5480	177	535	106
	Sep	3384	113	139	73

Water Year 1931		Total	Mean	Max	Min
	Oct	3607	116	350	57
	Nov	6438	215	335	139
	Dec	13918	449	935	190
	Jan	16726	540	975	306
	Feb	8643	309	420	158
	Mar	13390	432	815	264
	Apr	25235	841	1700	455
	May	26601	858	3100	306
	Jun	5844	195	385	78
	Jul	5792	187	495	76
	Aug	35366	1141	4850	85
	Sep	5718	191	695	71

Water Year		Total	Mean	Max	Min

Yearly Totals

Year	Oct	Nov	Dec	Jan	Feb
1929			12275	17438	30607
1930	65455	38810	35005	25115	25230
1931	3607	6438	13918	16726	8643
1932	3155	3355	19212	27012	17085
1933	5597	12304	26374	25118	27813
1934	1882	3031	3514	3576	4990
1935	5748	8721	22841	25559	19093
1936	5049	13508	18630	48522	50002
1937	41848	24179	55744	52260	48200
1938	6347	8890	6865	9750	7879
1939	7746	13938	19935	21175	41930
1940	5460	6172	7855	14480	19838
1941	1327	5304	6350	9035	8348
1942	2820	2995	8856	8172	11552
1943	10116	8637	16704	27050	21307
1944	3893	5570	11479	34410	39799
1945	15764	10672	19154	18638	26056
1946	22364	13435	40788	42824	30365
1947	14535	16373	13290	29800	13078
1948	12519	40498	20418	22698	50871
1949	16348	24869	38872	27938	21306
1950	16585	15984	14087	14006	10824
1951	7822	5890	1185	10495	9084
1952	1941	3969	6727	9255	21904
1953	5764	17233	15416	27965	31206
1954	3045	3441	15000	41630	19501
1955	12287	8159	15836	16039	19473
1956	11735	9949	7784	9062	23486
1957	18620	15204	16930	12790	16827
1958	20537	44374	37963	37097	28683
1959	14050	7909	11927	21270	31676
1960	37449	21495	19622	30440	56680
1961	9809	6910	9296	12243	30348
1962	3652	5111	11420	24291	22768
1963	3986	27092	20534	35469	28081
1964	4159	16671	22405	37133	37686
1965	61154	16931	26701	22642	35994
1966	9711	9336	8045	18961	31839
1967	6983	5891	9136	14157	23081
1968	7820	10647	24271	40378	14468
1969	6333	12093	13089	14035	21279
1970	17039	9419	14991	15561	23651
1971	3734	8349	9584	24124	33969

Figure 4-5. Portion of a Filled Flow Spreadsheet Template

spreadsheet named FLOW.WQ1 will automatically create the needed graphs as the historic data is put into the spreadsheet. Other spreadsheet programs may require the graphs to be constructed.

Section V. Hydrologic Model

4-5-1. Introduction

Hydrologic computer modeling is used to estimate flows in rivers and streams of gauged and ungaged watersheds. There are a few computer models in use by professionals. Soil Conservation Service's TR-55 and TR-20 are primarily used for small watersheds under 2000 acres. The Army Corps of Engineer Hydrologic Engineering Center's HEC-1 Flood Hydrograph computer model is best used with large watersheds although it has the capability of using SCS methods for smaller watersheds. Because significant bodies of water that would act on military operations are expected to have large watersheds, HEC-1 is recommended to obtain model flow data. Flow data provided to a commander as a Hydrologic Annex will provide expert information that may be used to make decisions regarding river crossing operations. Crossing operations are critical to most operations in the tactical and safety sense.

4-5-2. Methodology

HEC-1 will provide the user with a wealth of information given the most accurate input data available. The basic input needed for the model will be determined by the method used. The HEC-1 Flood Hydrograph Package Users Manual is not detailed enough for hydrologically untrained personnel but for the qualified individual this manual is a wealth of knowledge. The users manual, the manual regarding ungaged watersheds, as well as the software can be obtained by the procedure outlined in Chapter 3, Section V. Basic data that will be needed for input into the model will be the watershed area in square miles the curve number(s) to be used, and the rainfalls to be considered. The watershed should be broken into sub-watersheds if the curve number or slope varies significantly. Specific information for use with precipitation input to be used with the Snyder's Unit Hydrograph in the model will require a Time to Peak (TP) coefficient and a Storage Coefficient (CP).

The Time to Peak coefficient is related to the specific watershed and should be obtained from actual hydrographs of the watershed in study. These values are typically between 1.8 - 2.2 with an average of 2.0. Very steep watersheds will have a TP of 0.4. The storage coefficient also should be calibrated for the watershed in study but its values are typically between 0.4 -0.8 with large CP's associated to small TP's.

Table 4-4 is taken from Viesman's Hydrology (1989) textbook and represents a range of Ct's and Cp's for across the continental United States.

Table 4-4. Coefficient Ranges

Location	Range of Ct	Average Ct	Range of Cp	Average Ct
Appalachian Highlands	1.8-2.2	2.0	0.4-0.8	0.6
West Iowa	0.2-0.6	0.4	0.7-1.0	0.8
Southern California	---	0.4	---	0.9
Ohio	0.6-0.8	0.7	0.6-0.7	0.6
Eastern Gulf of Mexico	---	8.0	---	0.6
Central Texas	0.4-2.3	1.1	0.3-1.2	0.8
North and Mid-Atlantic States	---	0.6/sqtS	---	---
Sewered Urban Areas	0.2-0.5	0.3	0.1-0.6	0.3
Mountainous Watersheds	---	1.2	---	---
Foothills Areas	---	0.7	---	---
Valley Areas	---	0.4	---	---
Eastern Nebraska	0.4-1.0	0.8	0.5-1.0	0.8
Corps of Engineers Training Course	0.4-8.0	0.3-0.9	---	---

S = Channel Slope [Viesman, Lewis, Knapp, 1989. p 208]
sqtS = square root of S

For foreign lands best estimates must be made from this table with respect the resemblance of the actual area of operation. The average flow of a river should be used as the best estimate of base flow when base flow is not known. If possible the model should be calibrated using monitoring and gaging of rainfall and river flows. If calibration is not possible, do a best estimate calibration using historic rainfall and river gage data. The model should be run for the return period storms of 2 year, 10 year, 50 year, and 100 year 24 hour storms. Flow in cubic feet per second and time to peak at the respective points of interest such as crossing points should be noted. For lake and reservoir inference the respective model may require detailed elevation information to render time to peak and flow rate at point of interest.

Section VI. Environmental

4-6-1. Introduction

The analysis of environmental data is dependent on the environmental concerns of the area of operation. The analyst must consider the indirect effects as well as the direct effects the planned operation will effect the environment with respect to surface hydrology.

4-6-2. Methodology

The methodology for analyzing the possible effects to the environment is specific for each each operation and each area of operation. The methodology for analysis begins back with the analysis of the commander's intent. The next step is to gather all the available information on environmental sensitive ecosystems and endangered, rare, or threatened animals and plant life in the area of operation. Relate the endangered, rare, or threatened animals and plant life to the known sensitive ecosystems and identify the areas on the map. Combine the environmental information with the hydrologic analysis of the area done in earlier sections of the study. Relate the areas on the map with the planned operation and analyze direct and indirect impact on the environment with respect to the operation and hydrology.

An example of direct impact on the environment would be if a vehicle river crossing operation was being planned for an area where endangered plant-life was known to be flourishing. The plant may live on the bottom of the stream and would not be effected by a crossing in high water but a low water crossing would devastate the stream bed killing the plants.

Indirect impact on sensitive ecosystems is not obvious but can be seen by a logical analysis process. An endangered bird nest in the mud of lowlands. An exercise during the nesting season may cause excess silting if it is also a time of high precipitation. The silt wash-down would negatively impact on the nests. In this case the operation would indirectly impact on sensitive ecosystems of endangered species and should be scheduled for a time of minimum precipitation or when the nesting season is over.

Section VII. Unique Storms

4-7-1. Introduction

The existence and frequency of unique storms is regionally dependent. Hurricanes, tropical storms, and tornados are some of the unique storms that would impact a military operation.

4-7-2. Methodology

The data acquired for unique storms should be analyzed with the same procedures outlined in the precipitation section of this manual. Bar graphs of the storm occurrences verses months will allow the analyst to determine the best times to schedule the operation.

CHAPTER 5

DATA CONCLUSIONS

The objective of this chapter is to make conclusions about the data that has been collected, organized and analyzed and relate the conclusions to the commander's intent for the planned operation. It is these conclusions that will form the Hydrologic Annex. The format for the conclusions is not all inclusive but gives basic examples of the type of questions that can and should be answered concerning the planned operation.

Section I. Watershed

5-1-1. Watershed Characteristics

- Is there a significant water body in the area of operation that will or could influence the ability to achieve the commander's intent?

- Where is the significant body of water?

- What is the size or zone of influence of the watershed?

- Are there any environmentally sensitive areas in the area of operation or the watershed that could be influenced by the operation?

5-1-2. Example Conclusions

- There is one significant water body in the area of operation. The body of water is the little river and it could have a direct impact on achieving the commander's intent of training small unit river crossing operations during Market Square III.

- The watershed for the little River is 460 square miles and is along the northern border of Ft. Bragg and flows between the main training areas and the Northern Training Area.

- There are environmentally sensitive areas in the maneuver area of the area of operation. The sensitive areas are the red-cocaded woodpecker habitats and the low lying marsh areas around Sicily Drop Zone that are quail habitats that would be effected by excess silt flowing down the streams caused by demolition, digging, or excess traffic in the stream beds.

Section II. Soil

5-2-1. Soil Impact on Operation

The soil impact on the operation is directly related to the precipitation that occurs during the operation.

- Will the impact on the operation due to soil be different for the different expected low normal and high precipitation?

- What is the basic soil make-up of the area of operation?

- Will soil conditions enhance digging operations?

5-2-2. Example Conclusions

- The soil makeup of the area of operation is primarily sand with sandy clay or sandy loam in the lowlands and creeks.

- The higher sandy soils that dominate the area of operation will not be affected by variants of precipitation. Dry conditions will produce a great deal of dust that will impact on maintenance activities and personal hygiene operations. It will directly affect the airland operations on the forward landing strips.

- Digging operations for most of the area of operation should be somewhat easy for both equipment and individual efforts.

Section III. Precipitation

5-3-1 Precipitation Impact on Operation

- What precipitation will best support the commander's intent for the operation?

- What is the expected high, low, and normal levels of precipitation for the time frame of the planned operation?

- What form of precipitation is expected during the planned operation.

- How will the high, low, and normal expected levels of precipitation impact on the operation?

- Based on precipitation, is there any special equipment that will be needed for the operation to enhance success or safety?

- Is there a better time frame to conduct the operation? If so, when is it?

- When would the operation least affect the environmentally sensitive areas or the area of operation?

5-3-2. Example Conclusions

- Based on the commander's intent of exercising the deployability and maneuverability of units involved, minimum to no precipitation would be best. Although minimum precipitation would help to control dust on the non-paved main supply routes.

- The highest 24 hour rainfall to expect is 6.5 inches. The minimum rainfall above a trace is most likely to be .01 inches.

- During the month of September, rain or hail are the types of precipitation that can be expected.

- The month of September is one of the three months of highest precipitation. If expected precipitation levels occur, it will negatively impact on airborne and air assault operations.

- No specific special precipitation equipment is recommended.

- The month of October is recommended for the conduct of the planned operation. October statistically has considerably less precipitation than any other month of the year.

- The sensitive marshlands around Sicily drop zone would be least affected during times of no precipitation. October would be the best time to conduct the operation it has the lowest average precipitation and the least percentage of days with precipitation over 0.01 inches.

Section IV. Stream Flow

5-4-1. Stream Flow Impact on Operation

- What stream flow will best support the commander's intent for the operation?

- What is the expected high, low, and normal levels for the time frame of the planned operation?

- How will the high, low, and normal expected levels for the river or stream impact on the operation?

- Is there any special equipment that will be needed for the operation to enhance success or safety?

- What is the time the operation would least affect the environmentally sensitive areas or the area of operation?

- If the operation is conducted in the planned time frame, would the impact to the environmental sensitive areas be severe or minimal?

- How long will it take for the stream or river to rise significantly once the highest expected precipitation begins.

- What is the expected flow rate during the planned operation?

5-4-2. Example Conclusions

- It appears that a normal flow rate will best support the commander's intent. There must be enough flow to challenge the soldiers and the normal flow rate will be in reasonable safety limits. The maximum expected flow rate will cause the river to be too swift at the known crossing points and would be outside the reasonable safety limits.

- No special equipment will be needed to conduct the river crossing portion of the operation if the river is flowing at a normal or below normal level. If the river is flowing at the maximum expected flow, boats and extra safety personnel and ropes are recommended for the crossing operation.

- The environmentally sensitive regions of the area of operation are not specifically affected by the flow rate in the major body of water. An evaluation of this parameter is not warranted.

- Based on the data provided by HEC-1 the river will significantly swell at its outlet 8 hours after the maximum expected precipitation.

- The expected flow rate during the conduct of the operation is from 50 to 75 cfs. Crossing site widths and depths should be planned accordingly to obtain a velocity that is acceptable.

All conclusions should be referenced back to the initial conclusion and recommendation made in the highest prioritized hydrologic parameter. If the conclusions of the lower prioritized parameters differ with the initial conclusion and recommendation, the prioritization may need to be reevaluated.

If the lesser prioritized parameters all have the same recommendation but it differs from the highest priority recommendation, the combined lesser parameters may outweigh the initial conclusion. In this case the combined lesser parameter conclusion and recommendation will be provided in the Hydrologic Annex.

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CHAPTER 6

HYDROLOGIC ANNEX

The Hydrologic Annex is prepared for any operation plan contingency plan, or regional training plan or guideline. The annex is a straight forward presentation of the hydrologic analysis discussed in the previous chapters with emphasis placed on the conclusions of the analysis. The format outlined in Appendix B presents a concise hydrologic evaluation of the planned area of operation with respect to the intent of the commander for the conduct of the operation. The annex should be done as soon as the commander's intent for the operation is made known because both tactical and logistical planners will find the information in the annex a very valuable planning tool. The primary purpose of the annex is to provide the commander with data to consider during the decision making process.

Once a hydrologic study has been done for an area it may be used for future operation in that area. For example, the hydrologic study of Fort Bragg, North Carolina may be used to put together the Hydrologic Annex for Market Square III as well as any other operations conducted in the future. Thus the information from the hydrologic analysis could become a part of the post training plan and used by all units on that installation.

An example of a Hydrologic Annex format is also included in Appendix B.

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APPENDIX A
SCS CURVE NUMBER SELECTION

This appendix presents charts and information for the selection of the U.S. Department of Agriculture Soil Conservation Service's curve number. The detailed information can be found in the SCS National Engineering Handbook Section 4, Hydrology (with amendments), dated 1964.

1. Hydrologic Soil Group

Defining the hydrologic soil group is the first step in determining the curve number for a soil. Normally the SCS soil surveys will identify the soils by different parameters including infiltration rates. Use this Table 1 to identify the soil groups needed for determining the curve number for the study watershed.

Table 1. Soil Groups

Group	Minimum Infiltration Rate (in/hr)
A	0.30-0.45
B	0.15-0.30
C	0.05-0.15
D	0-0.05

McCuen (1989)

2. Curve Numbers

Table 2 is taken from McCuen (1989) and lists curve numbers for various land usage and hydrologic soil groups. All curve numbers are given for antecedent soil moisture content II which is average.

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Table 2. Curve Numbers

Land Use Description	Average % impervious	Curve Numbers for Hydrologic Soil Group			
		A	B	C	D
Fully developed urban areas (vegetation established)					
Lawns, open spaces, parks, golf courses, cemeteries, etc.					
Good condition; grass cover on 75% or more of the area		39	61	74	80
Fair Condition; grass cover on 50% to 75% of the area		49	69	79	84
Fair Condition; grass cover on 50% or less of the area		68	79	86	89
Paved parking lots, roofs, driveways		98	98	98	98
Streets and roads					
Paved with curbs and storm sewers		98	98	98	98
Gravel		76	85	89	91
Dirt		72	82	87	89
Paved with open ditches		83	89	92	93
Commercial and business areas	85	89	92	94	95
Industrial districts	72	81	88	91	93
Row houses, town houses, and residential with lot sizes 1/8 acre or less	65	77	85	90	92
Residential : average lot size					
1/4 acre	38	61	75	83	87
1/3 acre	30	57	72	81	86
1/2 acre	25	54	70	80	85
1 acre	20	51	68	79	84
2 acre	12	46	65	77	82
Developing urban areas (no vegetation)					
Newly graded area		77	86	91	94

Table 2 (continued)

Land Use	Treatment Practice	Hydrologic Condition	A	B	C	D
Cultivated agricultural land						
Fallow	Straight row		77	86	91	94
	Conservation tillage	Poor	76	85	90	93
	Conservation tillage	Good	74	83	88	90
Row crops	Straight row	Poor	72	81	88	91
	Straight row	Good	67	78	85	89
	Conservation tillage	Poor	71	80	87	90
	Conservation tillage	Good	64	75	82	85
	Contoured	Poor	70	79	84	88
	Contoured	Good	65	75	82	86
	Contoured & conservation tillage	Poor	69	78	83	87
		Good	64	74	81	85
	Contoured & terraces	Poor	66	74	80	82
	Contoured & terraces	Good	62	71	78	81
	Contoured & terraces & conservation tillage	Poor	65	73	79	81
		Good	61	70	77	80
Small Grain	Straight row	Poor	65	76	84	88
	Straight row	Good	63	75	83	87
	Conservation tillage	Poor	64	75	83	86
	Conservation tillage	Good	60	72	80	84
	Contoured	Poor	63	74	82	85
	Contoured	Good	61	73	81	84
	Contoured & conservation tillage	Poor	62	73	81	84
		Good	60	72	80	83
	Contoured & terraces	Poor	61	72	79	82
	Contoured & terraces	Good	59	70	78	81
	Contoured & terraces & conservation tillage	Poor	60	71	78	81
		Good	58	69	77	80
Close-seeded legumes or rotation meadow	Straight row	Poor	66	77	85	89
	Straight row	Good	58	72	81	85
	Contoured	Poor	64	75	83	85
	Contoured	Good	55	69	78	83
	Contoured & terraces	Poor	63	73	80	83
	Contoured & terraces	Good	51	67	76	80

Table 2 (continued)

Land Use	Treatment Practice	Hydrologic Condition	A	B	C	D
Noncultivated agricultural land						
Pasture or range	No mechanical treatment	Poor	68	79	86	89
	No mechanical treatment	Fair	49	69	79	84
	No mechanical treatment	Good	39	61	74	80
	Contoured	Poor	47	67	81	88
	Contoured	Fair	25	59	75	83
	Contoured	Good	6	35	70	79
Meadow		--	30	58	71	78
Forested-grass or orchards-evergreen or deciduous		Poor	55	73	82	86
		Fair	44	65	76	82
		Good	32	58	72	79
Brush		Poor	48	67	77	83
		Good	20	48	65	73
Woods		Poor	45	66	77	83
		Fair	36	60	73	79
		Good	25	55	70	77
Farmsteads		--	59	74	82	86
Forest-range						
Herbaceous		Poor		79	86	92
		Fair		71	80	89
		Good		61	74	84
Oak-aspen		Poor		65	74	
		Fair		47	57	
		Good		30	41	
Juniper-grass		Poor		72	83	
		Fair		58	73	
		Good		41	61	
Sage-grass		Poor		67	80	
		Fair		50	63	
		Good		35	48	

2. Soil Moisture Condition

Table 3 presents conversions for antecedent soil moisture condition II to corresponding conditions I and III. This conversion may be useful to account for pre-wetting of the soil before the major precipitation of study in a hydrologic computer model.

Table 3. Moisture Conversions

	Corresponding Curve Number for Condition	
Curve Number for Condition II	I	III
100	100	100
95	87	99
90	78	98
85	70	97
80	63	94
75	57	91
70	51	87
65	45	83
60	40	79
55	35	75
50	31	70
45	27	65
40	23	60
35	19	55
30	15	50
25	12	45
20	9	39
15	7	33
10	4	26
5	2	17
0	0	0

APPENDIX B
HYDROLOGIC ANNEX FORMAT

ANNEX Z (HYDROLOGIC) to OPERATION PLAN 10-89 99 (US) DIVISION
Reference: Map series V742, CLIFDALE SPECIAL, sheet 5154 II
edition 1963, 1:50,000.

Time Zone Used Throughout the Plan : Romeo

1. SITUATION

a. Enemy Forces.

(1) Defensive effort with respect to expected hydrologic conditions

(2) Offensive effort with respect to expected hydrologic conditions

b. Friendly Forces.

c. Attachments and Detachments.

(1) Equipment needed to lessen the impact of the expected hydrologic conditions

(2) Equipment that will not be needed because of expected the hydrologic conditions

d. Assumptions

2. MISSION

3. EXECUTION

a. Concept of the Operation.

b. Expected Hydrologic Impact.

(1) River crossing operations

(2) Airborne operations

(3) Air Assault operations

(4) Environmental

(5) Ground Mobility

c. Coordinating Instructions.

4. SERVICE SUPPORT

a. Hydrologic impact on ground supply lines.

b. Hydrologic impact on air supply lines.

c. Hydrologic impact on amphibious supply lines.

5. COMMAND AND SIGNAL

a. Hydrologic impact on FM communication.

b. Hydrologic impact on AM communication.

c. Hydrologic impact on Tactical Satellite communication.

d. Hydrologic impact on land line communication.

APPENDIX C
HYDROLOGIC ANALYSIS REPORT FORMAT

A. Commander's Intent

1. Stated
2. Analysis
    a. Precipitation
    b. Bodies of water
    c. Environment

B. Precipitation

1. Summary
2. Recommended dates of execution
3. Conclusions

C. Flow Analysis

1. Summary
2. Recommended dates of execution
3. Conclusions

D. Environmental Analysis

1. Summary
2. Recommended dates of execution
3. Conclusions

E. Graphs

1. Average total flow vs. Months

2. Average daily flow vs. Months

3. Minimum daily flow or the vs. Months

4. Average daily minimum flow vs. Months

5. Maximum average daily flow vs. Months

6. Average daily maximum flow vs. Months

7. Average precipitation vs. Months

8. Average days of precipitation vs. Months

9. Months of highest precipitation in a year vs. Months

10. Average precipitation vs. Days of the month of most precipitation

11. Average precipitation vs. Days of the month of least precipitation

12. Average precipitation vs. Days of the month of the planned operation

13. % of each day that had precipitation > 0.01 inch vs. Days of the month of most precipitation

14. % of each day that had precipitation > 0.01 inch vs. Days of the month of least precipitation

15. % of each day that had precipitation > 0.01 inch vs. Days of the month of the planned operation

16. Average precipitation vs. Planned days of the exercise

17. % of each day of the exercise that had precipitation over the years of record

18. Hurricane Count vs. Months (if applicable)

19. Tropical Storm Count vs. Months (if applicable)

20. Miscellaneous graphs

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POINTS OF CONTACT

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APPENDIX B

HYDROLOGIC ANNEX FOR THE CASE STUDY

ANNEX Z (HYDROLOGIC) to OPERATION PLAN 10-89 99 (US) DIVISION
Reference: Map series V742, CLIFDALE SPECIAL, sheet 5154 II
edition 1963, 1:50,000.

Time Zone Used Throughout the Plan : Romeo

1. SITUATION

From analysis of the hydrologic study of the area of the operation, the commanders intent and environmental impact is best supported during the 13 day period from 5-17 October. October has the lowest average precipitation. During this period the historical average % days of precipitation is at it's lowest. The recommended execution dates are justified in Appendix 1 (Data Conclusions from the Hydrologic Study) of this annex. The following analysis is based on the present plan's proposed execution dates of 11-23 September.

a. Enemy Forces.

(1) If the Little River approaches historic high flow rates of 13,000 cubic feet per second the enemy may attempt to use the river as a defensive barrier. Once the enemy is over the existing bridges they could be destroyed and the expected average flow rate of the Little River could hinder or prohibit advancement of the division's equipment. The Little River could be used as a defensive line for enemy operations. Expected average flow rates of 415 cubic feet per second will pose a minimal challenge for crossing operations.

(2) Expected average flow rates of the Little River should not hinder the enemy's movement into the northern area of San Braggio if the bridges were not available. If flow rates approach the river's historic high flow rates, the enemy's ability to cross the river will be greatly degraded. The relatively high expected precipitation may be used by the enemy to cover covert gorilla operations.

b. Friendly Forces. Forces should be prepared to operate in a wet environment.

c. Attachments and Detachments.

(1) Divisional assets will be adequate for expected hydrologic conditions.

(2) Contingencies should be planned for Corps river crossing assets to be made available if above average rainfall causes unacceptable flow rates in the Little River.

d. Assumptions

2. MISSION. (see original operation plan)

3. EXECUTION

a. Concept of the Operation.

(1) Expected, average precipitation for the month of October is 4.6 inches of rain.

(2) The planned exercise period of 11-23 September has a 24.87% historic average of receiving rain on any one of the days.

(3) Expected, average flow in the Little River is 415 cubic feet per second.

(4) Hydrologic Model Data.

(a) The 2 year 24 hour storm has a 50% probability of occurring on any day and produces 3.87 inches of precipitation. This storm will most probably peak in the proposed crossing area at 752 cfs, 14 hours after the start of the rainfall.

(b) The 15 year 24 hour storm has an 8% probability of occurring on any day and produces 6.0 inches of precipitation. This storm will most probably peak in the proposed crossing area at 6195 cfs, 16.5 hours after the start of the rainfall.

(c) The 100 year 24 hour storm has an 1% probability of occurring on any day and produces 8.2 inches of precipitation. This storm will most probably peak in the proposed crossing area at 24382 cfs, 15.5 hours after the start of the rainfall.

(d) The hurricane and tropical storm season for the area of operation is from May to November.

b. Expected Hydrologic Impact.

(1) River crossing operations will not be hindered by expected, average flow rates of 415 cubic feet per second.

(2) Airborne operations must have well thought out contingency and delay plans due to the relatively high historic probability of precipitation. The planned date for the 2 Brigade simultaneous airborne assault has the highest historic probability of precipitation of all of the planned days of the exercise.

(3) Air Assault operations must be prepared to be conducted in wet weather.

(4) Environmental considerations do not favor a large scale operation in the month of September. The relatively high expected precipitation will cause excessive silt wash-down into the lowlands that are sensitive ecosystems of rare, threatened, or endangered plant life.

(5) Ground Mobility should not be effected by the expected precipitation

c. Coordinating Instructions.

4. SERVICE SUPPORT

a. Hydrologic impact on ground supply lines will be minimal. Some washed out roads may occur in low lying areas.

b. Expected hydrologic conditions do not favor resupply by air.

5. COMMAND AND SIGNAL

Communications should be prepared to operate in a wet environment.

APPENDIX 1 (Hydrologic Analysis of AO) to ANNEX Z (Hydrologic Annex) to OPERATION PLAN 10-89, 82d Airborne Division

Reference: Map Series, V742, sheets 5054 I and II;
sheets 5153 I and IV;
sheets 5154 I thru IV;
sheets 5253 I and IV;
sheets 5254 I thru IV;
sheets 5352 I and IV.

Time Zone Used: Romeo

A. Commander's Intent

1. Exercise

a. Divisional Training Objectives

(1) Exercise Corps and Divisional marshal and deployment systems.

(2) Plan and execute joint operations to include two simultaneous brigade-size parachute assaults to establish a lodgement.

(3) Exercise Division command control systems, to include assault, Tactical Air Command, main, and rear Command Posts.

(4) Conduct Division level offensive/defensive operations using mixed forces to include deep operations.

(5) Integrate Combined Air Support and Army aviation into the ground scheme of maneuver.

(6) Plan and execute rear area combat operations.

(7) Exercise all facets of the Division intelligence system to include recon, counter-recon and security operations.

(8) Stress the Corps and Division combat service support systems.

(9) Conduct 15 Separate Battalion/Company External evaluations.

(10) Exercise available Corps "D" package and CAPSTONE reserve component units.

b. Joint Training Objectives

(1) Exercise Corps and Division alert, marshal, and airborne/airland deployment procedures.

(2) Plan and execute joint missions, to include two brigade-size simultaneous parachute assaults.

(3) Exercise TACS/AAGS interface.

(4) Employ ABCCC and Jackpot during the airborne assaults.

(5) Employ Military Airlift Command combat tactics during the conduct of airborne operations.

(6) Employ Joint air attacks teams.

(7) Execute Army airspace command and control (A2C2).

(8) Exercise planning for and simulation off surface-to-air threat.

(9) Employ IFF procedures between ADA and air assets.

(10) Integrate CAS and Army aviation into the ground scheme of maneuver.

(11) Exercise joint suppression of enemy air defenses.

(13) Exercise the joint intelligence systems.

Tactical

We must commit sufficient combat power with the tactical mobility necessary to reestablish the international border. I envision two Division Ready Brigades conducting simultaneous parachute assaults to maximize the element of surprise and to quickly project an overwhelming amount of combat power on the ground. Units must be prepared for opposition from Coronan-backed insurgents and regulars during initial assaults. Position forces will forward to halt the movement of CORONAN elements moving SAN CITA. Conduct an aggressive defense in depth, and take advantage of restrictive terrain. CORONAN commanders must be forced to react to our defensive array so that we can quickly seize the initiative. Once the CORONAN momentum is halted, we will counterattack to restore the international border. During offensive operations, my goal is to destroy the Coronan Armed Forces' offensive capability and deny them the ability to withdraw forces across the border intact. Infiltration attacks and the use of blocking positions along the enemy routes of withdrawal should be the basis of our operations. We must aggressively maintain contact. Once the border is restored and the CAF in LAS FLORES are destroyed, I want to hand over the border region to LAS

FLORES forces. This operation should be completed within 30 days.

Analysis of Intent

The exercise will involve massive airdrops of personnel, equipment, and supplies. Fort Bragg's tactical (dirt) forward area landing strips will also be used to deliver essential troops, equipment and war fighting materials into the scenario country of San Braggio. Execution of the exercise during a time of least amount of precipitation would support the achievement of the commander's intent. An exercise window of no precipitation is statistically unrealistic and would not provide realistic training for the trooper's in the field.

The Little River is a significant body of water that could directly influence the intent of the exercise as well as the tactical intent of the mission. There should be enough water flowing in the river to provide practical training for the soldiers without posing a serious safety threat.

The exercise will involve the movement of some moderately heavy pieces of equipment but the majority of the movement will be done by High Mobility Multipurpose Vehicles that are highly mobile but relatively light. The movement of these equipment over the sandy soils located at Fort Bragg combined with the disturbing of the soil from demolition charges and engineer equipment digging, has the potential to dramatically increase the wash down of silt into the lowlands of the fort. A exercise period of low or no precipitation will drastically reduce the silt wash down into the lowlands.

The reduction of silt wash down will help to prevent degradation of the habitat of some of Fort Bragg's rare, threatened, or endangered species of plant life.

B. Flow Analysis

Summary

The average flows of the planned execution month of September and the recommended month of October are not significantly different. The maximum and minimum flows of the compared months do favor October for safety reasons because they are significantly lower.

Recommended dates of execution

It is expected that the commander's intent involving the Little River could be accomplished in either month by the troops and their equipment. Safety reasons favor the execution of the mission in the month of October.

Stream Flow Conclusions

Average flow in the river will best meet the commanders intent for river crossing training.

The average soldier will be able to stand up in waist deep water that is traveling at 2 feet per second. If the flow in the river is at the September average of 400 cfs the ideal crossing site would need to be a combination of depth and width to provide a velocity of 2 feet per second or less.

If a commandeer was looking for a 3 foot deep crossing point to do rope bridging the crossing site would have to be 73 feet wide. With this information a more accurate map reconnaissance may be performed.

The daily September (the expected execution month for the operation) flow parameters of interest are presented in Table 1. All graphs associated with all Tables are in Section E.

Table 1. September Flow Statistics

Average daily flow rate = 415 cfs
Average minimum flow rate = 313 cfs
Average maximum flow rate = 1,553 cfs
Maximum flow of record = 13,000 cfs in Sept 1945
Minimum flow of record = 32 cfs in Sept 1968

The daily October (the recommended execution month for the operation) flow parameters of interest are presented in Table 2.

Table 2. October Flow Statistics

Average daily flow rate = 402 cfs
Average minimum flow rate = 168 cfs
Average maximum flow rate = 1,257 cfs
Maximum flow of record = 10,000 cfs in Sept 1945
Minimum flow of record = 31 cfs in Sept 1968

Using the standard safe velocity of 2 feet per second:

- The average September flow rate of 415 cfs would require a river width of 76 feet. Map reconnaissance shows that finding a suitable crossing site is probable.

- The average maximum September flow rate of 1,553 cfs would require 265 foot wide crossing site. Map reconnaissance shows that finding a suitable crossing site is improbable.

- The average minimum September flow rate of 131 cfs would require 28 foot wide crossing site. Map reconnaissance shows that finding a suitable crossing site is very probable.

For tactical and safety purposes the operation would be best conducted at average river flows. This would provide effective training while lessening the safety concerns.

The hydrologic model indicates that:

- The 2 year 24 hour storm of 3.87 inches with a 50% chance of occurring will most probably peak in the proposed crossing area at 752 cfs, 14 hours after the start of the storm.

- The 15 year 24 hour storm of 6.0 inches with an 8% chance of occurring but has happened twice in the period of record will most probably peak in the proposed crossing area at 6195 cfs, 16.5 hours after the start of the storm.

- The 100 year 24 hour storm of 8.2 inches with an 1% chance of occurring will most probably peak in the proposed crossing area at 24382 cfs, 15.5 hours after the start of the storm.

- River crossing operations should have normal crossing and safety equipment on hand.

C. Precipitation

Summary

The proposed execution dates of 11-23 September 1989 not the historically best times to conduct Market Square III. Of the 12 months of the year, September has the third highest average precipitation of 4.6 inches for the month. September averages only 7.6 days out of 30 with precipitation above 0.01 inches. Combining these two averages means that you typically see one quarter of the days of the month with an average rainfall of about 0.60 inches of rain per day. This amount of rainfall in a 24 hour period would be considered significant and would have a delaying or canceling effect on most of the large scale deployment activities of Market Square III.

Recommended dates of execution

The dates of 5-17 October are specifically recommended for the conduct of the exercise because of their relatively low historical average of daily precipitation.

Precipitation Conclusions

Because of the planned airborne deployment of troops and equipment and the amount of air assault mission possible, the operation should be conducted during a time period of minimal expected precipitation.

The average and expected precipitation for the planned month of September is 4.6 inches. September has the third highest average precipitation of all the 12 months. It averages 7.6 days of precipitation above 0.01 inches and is the third most likely month to have the most precipitation for the entire year.

The lowest amount of precipitation from 30 years of record (1955-1984) is an average of 2.04 inches that occurred between 1940 and 1942.

The highest amount of precipitation from 30 years of record (1955-1984) is an average of 8.91 inches that occurred between 1955 and 1957.

Rain is the most expected type of precipitation during the month of September.

If the exercise is to be 13 days long conducted in September, the 13 day period that has the least average % historical precipitation is from the 15th to the 27th of September with an average of 21.03% chance of getting rain on any of those days. The maximum historical average is 28.72% and occurs between 2 and 14 September. The exercise period has a historical average of 24.87% precipitation.

Table 3. September 13 Day % Precipitation Analysis

	Percent Chance of Precipitation	Dates
Maximum	28.72	2-14 September
Minimum	21.03	15-27 September
Exercise	24.87	11-23 September

The 13 day period with the least average rainfall of 0.115 inches is from 15-27 September. The 13 day period with the highest average rainfall of 0.188 inches is from 2-14 September. The 11th to the 23d of September has an average precipitation of 0.14 inches. It should be recognized that the dates of most and least average % of historical precipitation are the same dates for the most and least average precipitation.

Table 4. September 13 Day Average Precipitation Analysis

	Average Precipitation inches	Dates
Maximum	0.188	2-14 September
Minimum	0.115	15-27 September
Exercise	0.140	11-23 September

Because the exercise is planned for an average historical % chance of precipitation, abort plans for airdrop and air assault missions should be fully prepared.

Plastic bags to protect reserve parachutes should be planned for as well as chute shake out for wet parachutes.

October is recommended if the conduct of Market Square III has the option of being moved to another time frame. The monthly average precipitation for October is 2.8 inches, 1.8 inches below the September average of 4.6 inches. The parameters listed in Tables 5 and 6 are all below their like values of September.

Table 5. October 13 Day Average Precipitation Analysis

	Average Precipitation inches	Dates
Maximum	0.099	1-13 October
Minimum	0.067	7-19 October
Recommended	0.071	5-17 October

Table 6. October 13 Day % Precipitation Analysis

	Percent Chance of Precipitation	Dates
Maximum	27.95	14-26 October
Minimum	16.67	5-17 October (Recommended)

D. Environmental Analysis

Summary

From a hydrologic standpoint the environmental stability of the area of operation would be least effected during times of relatively low precipitation. Low precipitation will prevent added silt from washing down into the lowlands from intermittent stream beds and runoff areas that will have their compacted soils loosened by vehicle traffic, engineer equipment digging, and demolition. Of primary environmental concern are the rare, threatened, and endangered species of plants that flourish in the lowland ecosystems that may be significantly impacted by increased silt buildup in the lowlands.

Recommended dates of execution

The historic low precipitation during October supports an environmental reason for conduct of the exercise in that month.

Environmental Conclusions

The environmentally sensitive wet lands will be least effected by the large scale exercise during times of low rainfall. The above precipitation analysis supports the execution of the exercise in October for environmental reasons.

For environmental purposes the operation should be conducted during minimum flow periods. This will minimize the silt washed into the sensitive lowlands of Ft Bragg. For this reason it is recommended that the exercise be conducted during the months of October. October's average flow rate is 13 cfs lower than September's average flow rate. All of the parameters of interest for flow are lower in October except for the average minimum value. This data supports the environmental reasons for conducting the operation in October.

E. Graphs

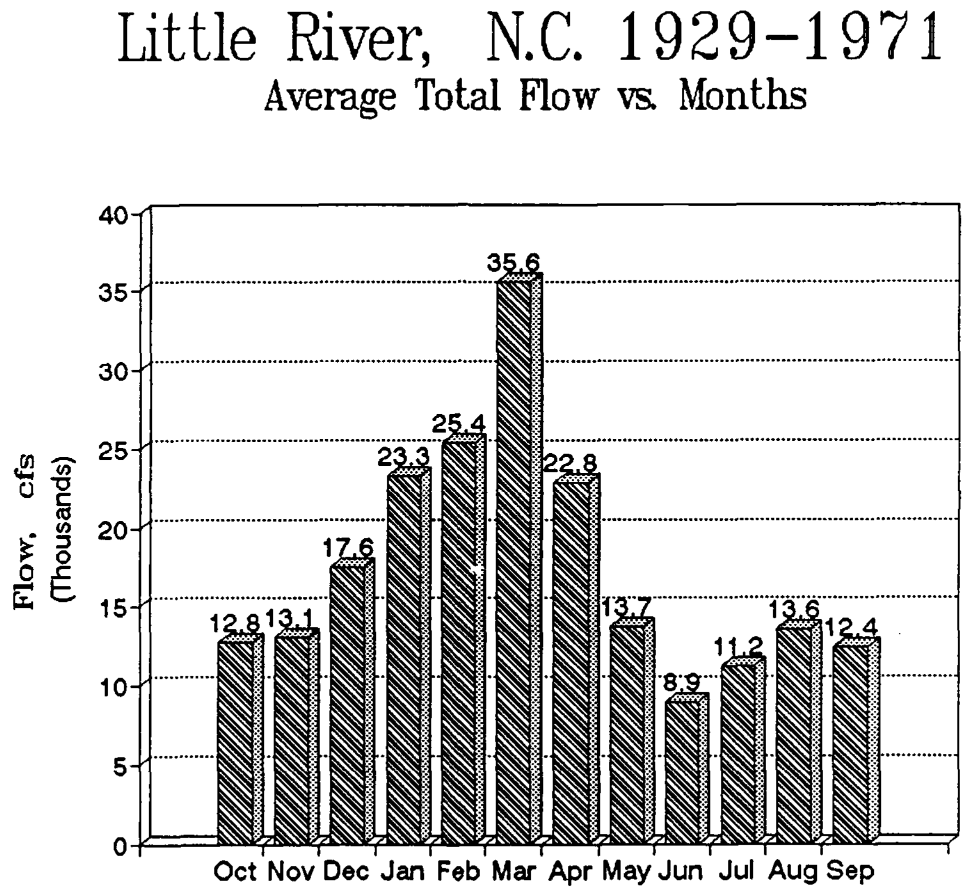

Figure 1. Average Total Flow vs. Months

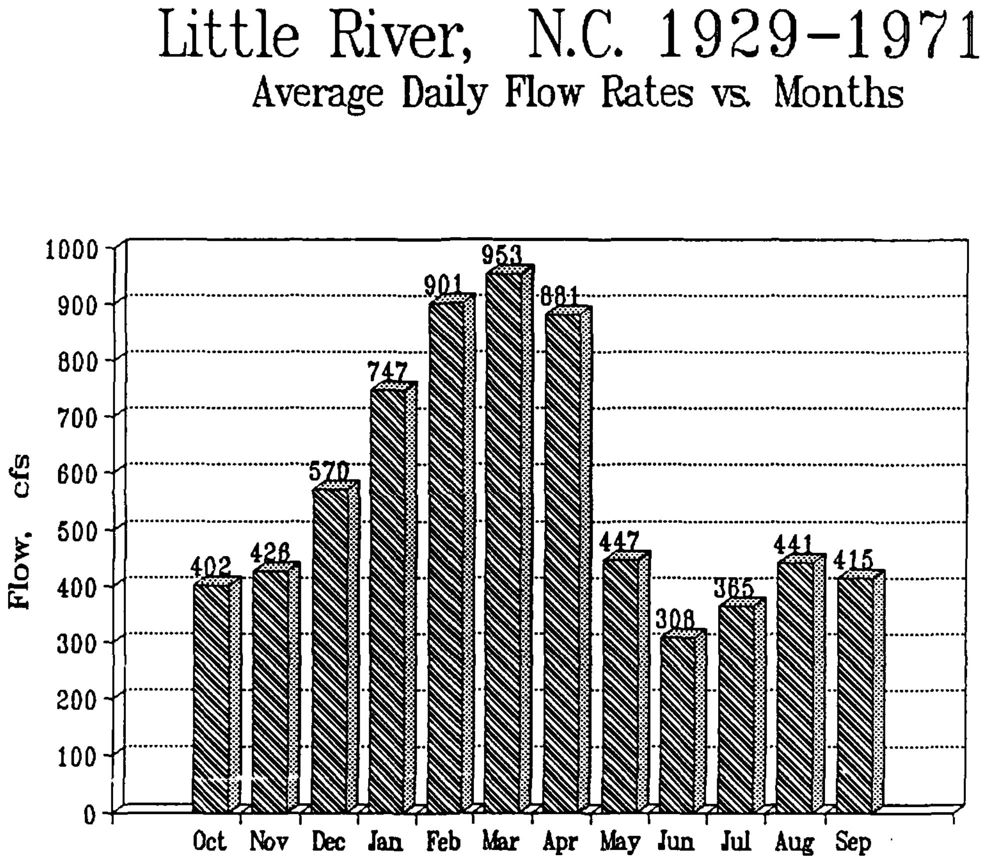

Figure 2. Average Daily Flow vs. Months

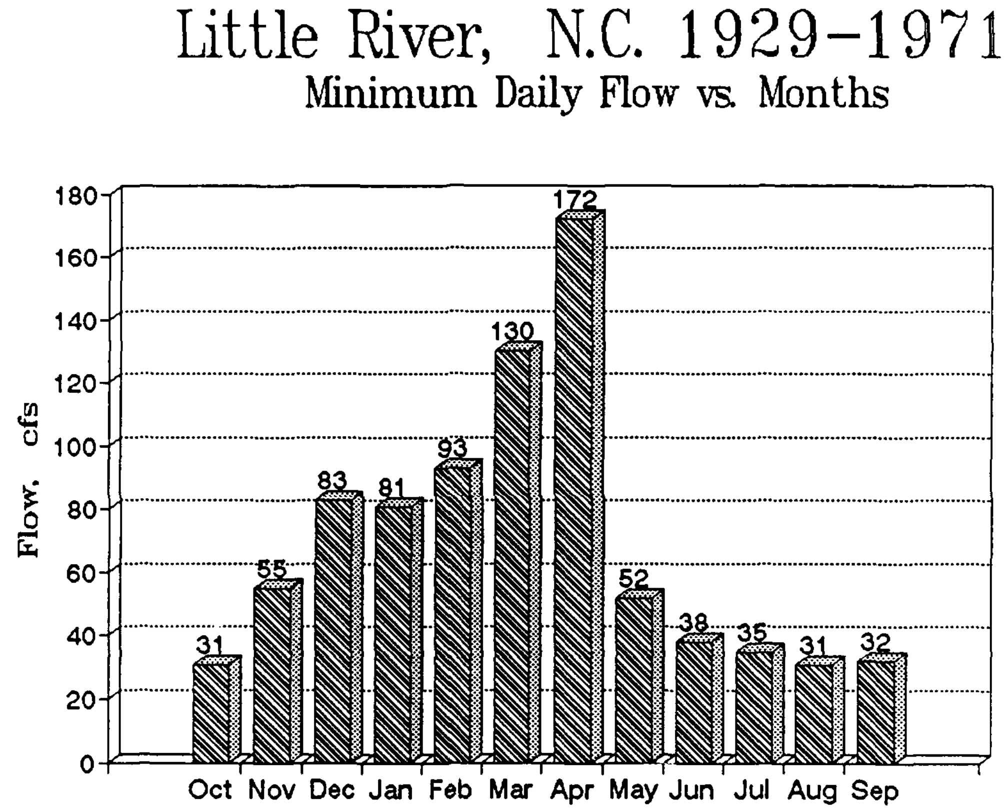

Figure 3. Minimum Daily Flow vs. Months

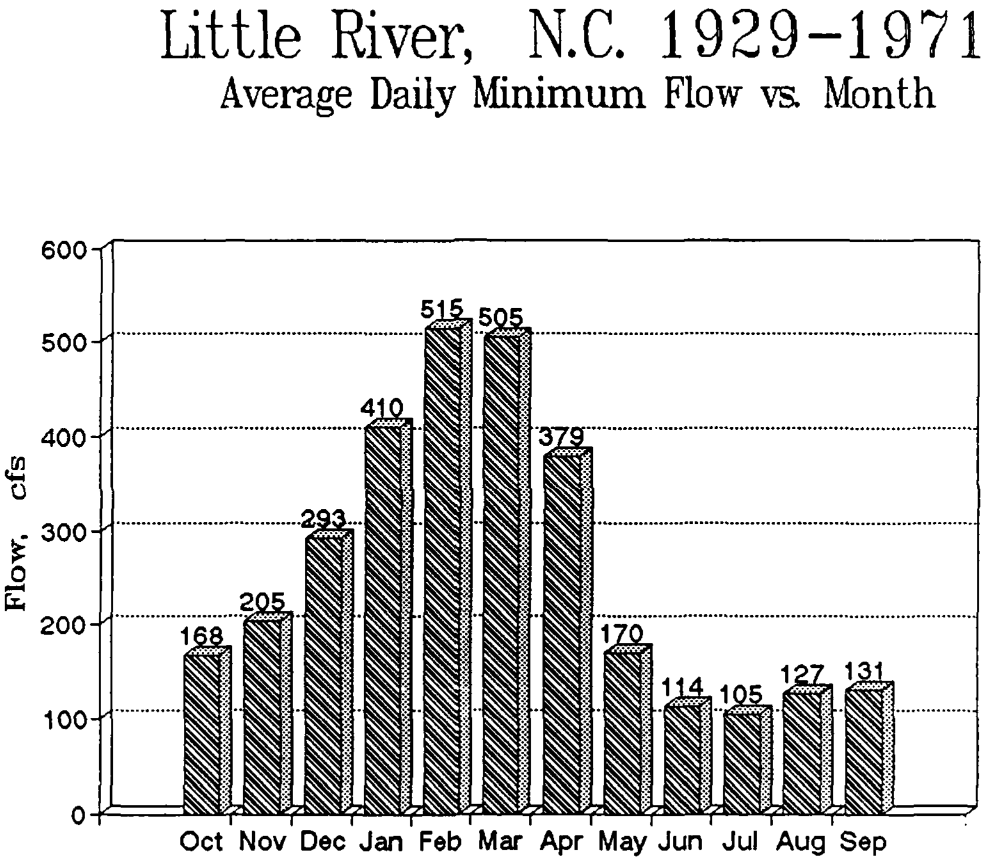

Figure 4. Average Daily Minimum Flow vs. Months

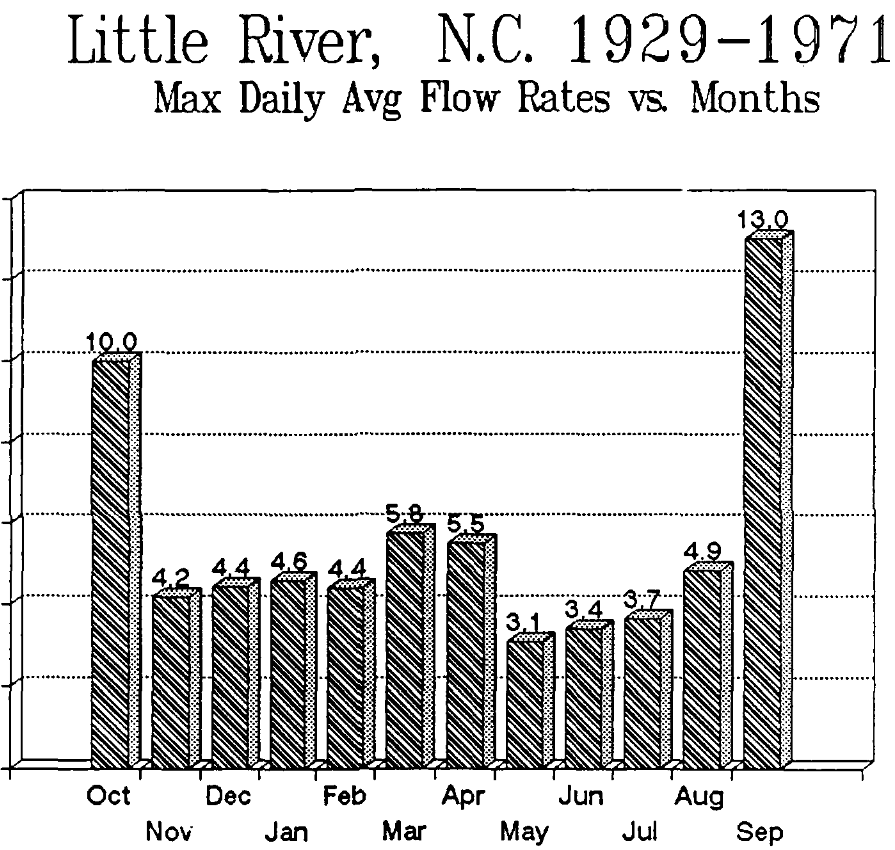

Figure 5. Maximum Average Daily Flow vs. Months

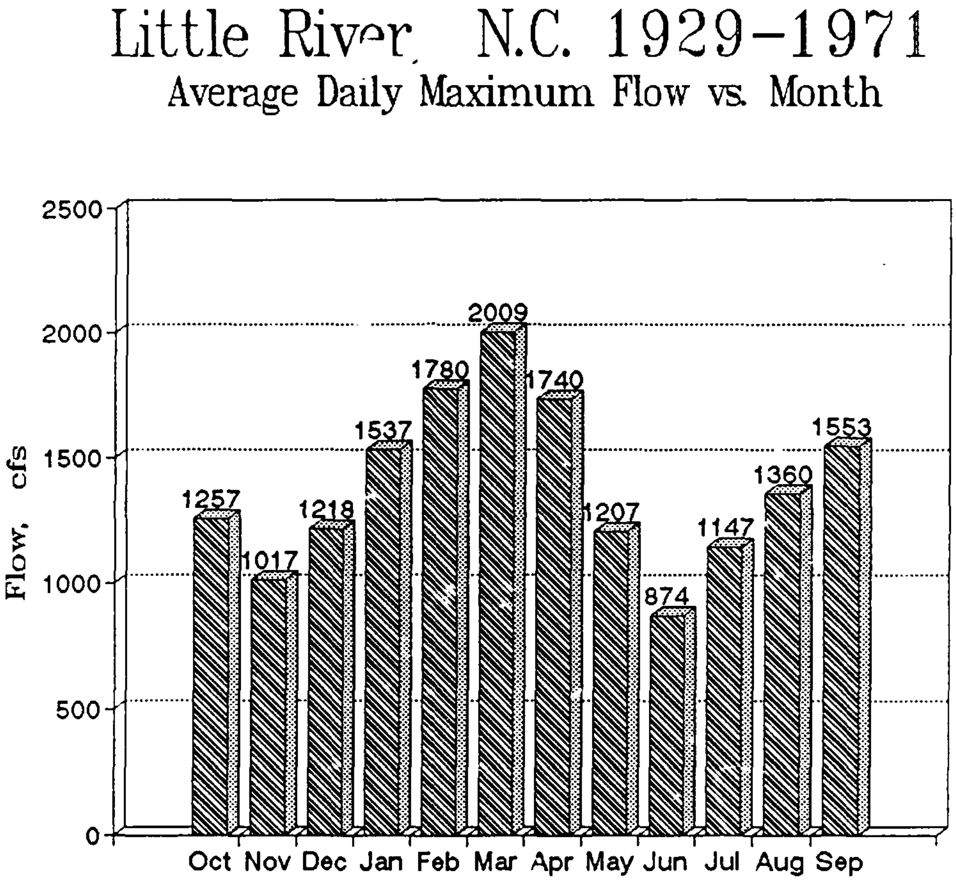

Figure 6. Average Daily Maximum Flow vs. Months

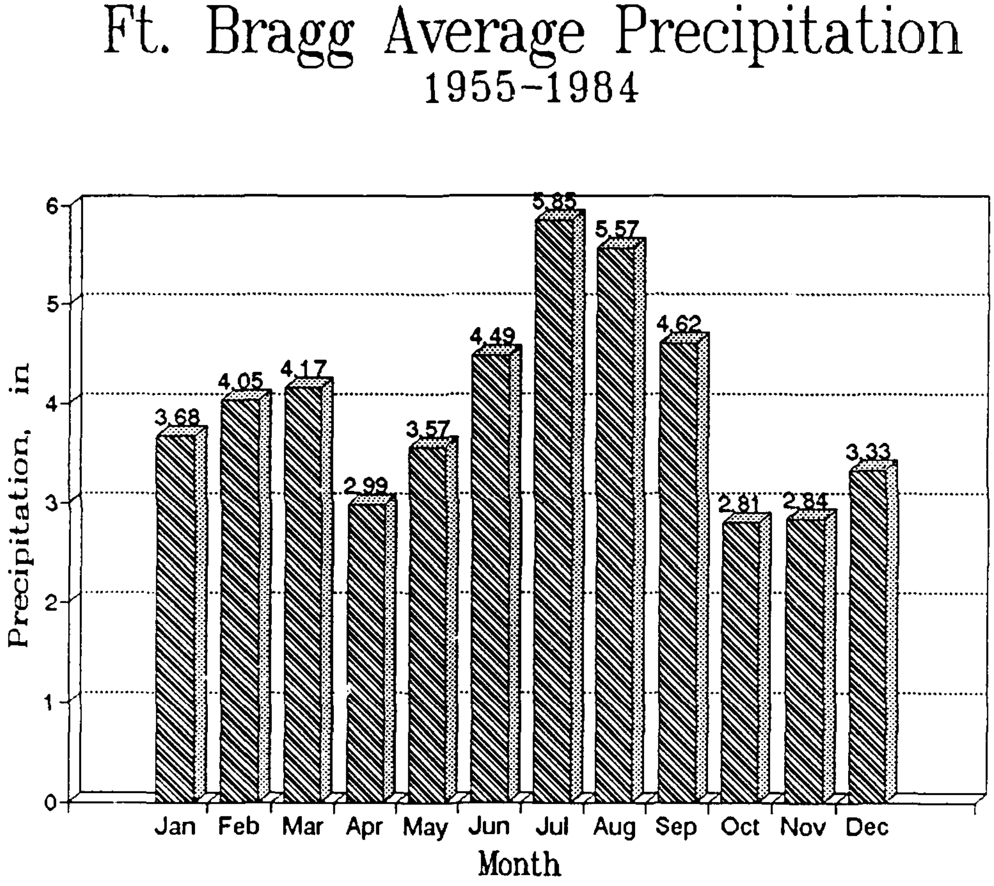

Figure 7. Average Precipitation vs. Months

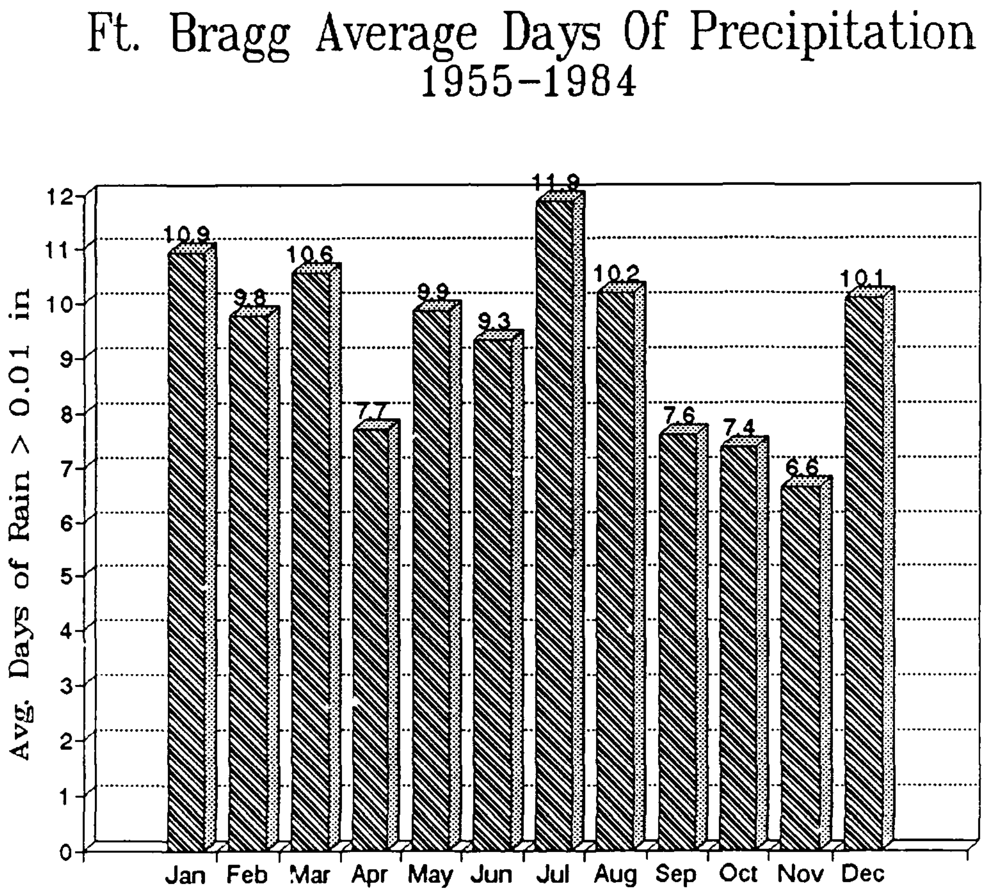

Figure 8. Average Days of Precipitation vs. Months

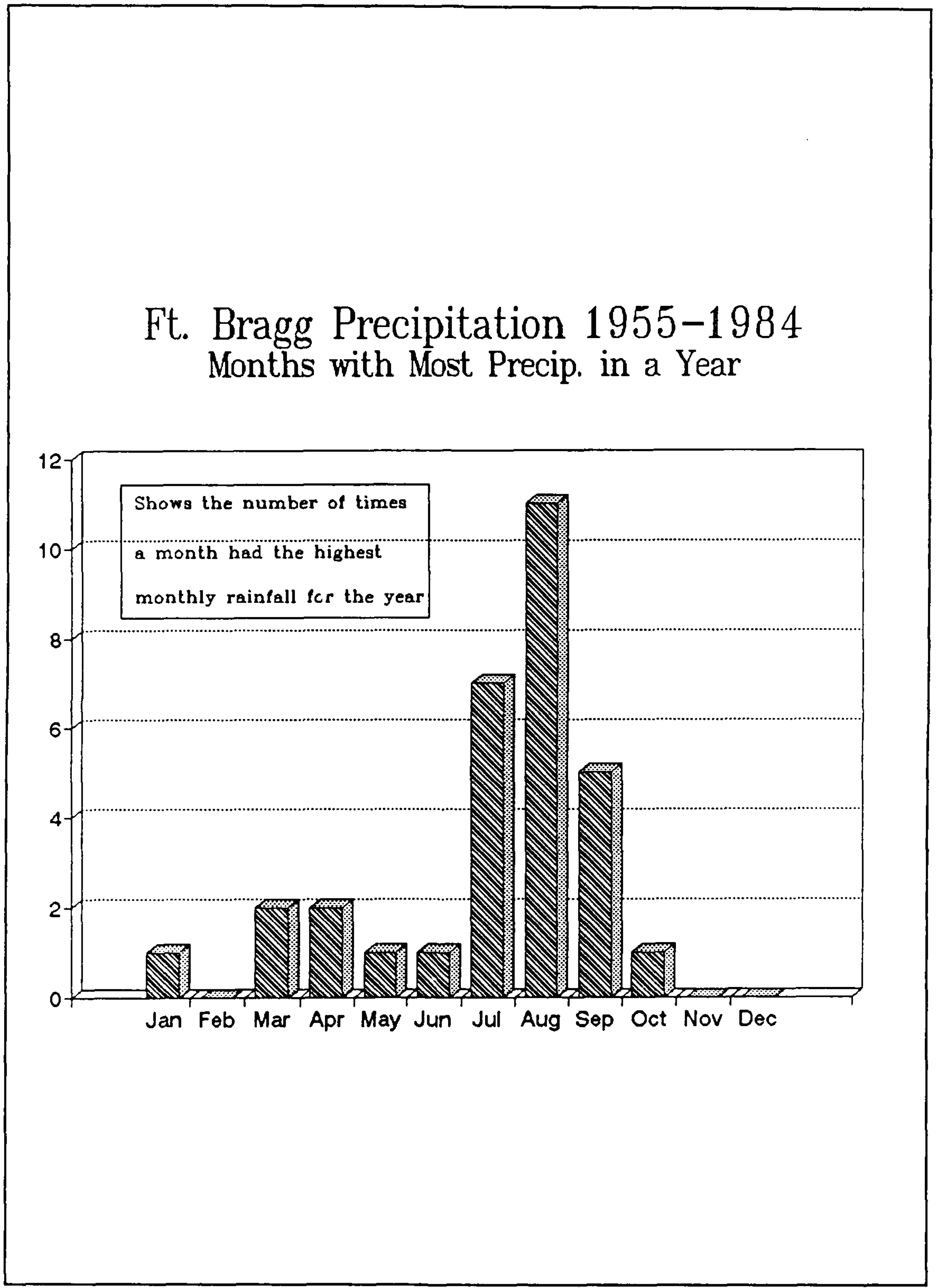

Figure 9. Months of Highest Precipitation in a Year vs. Months

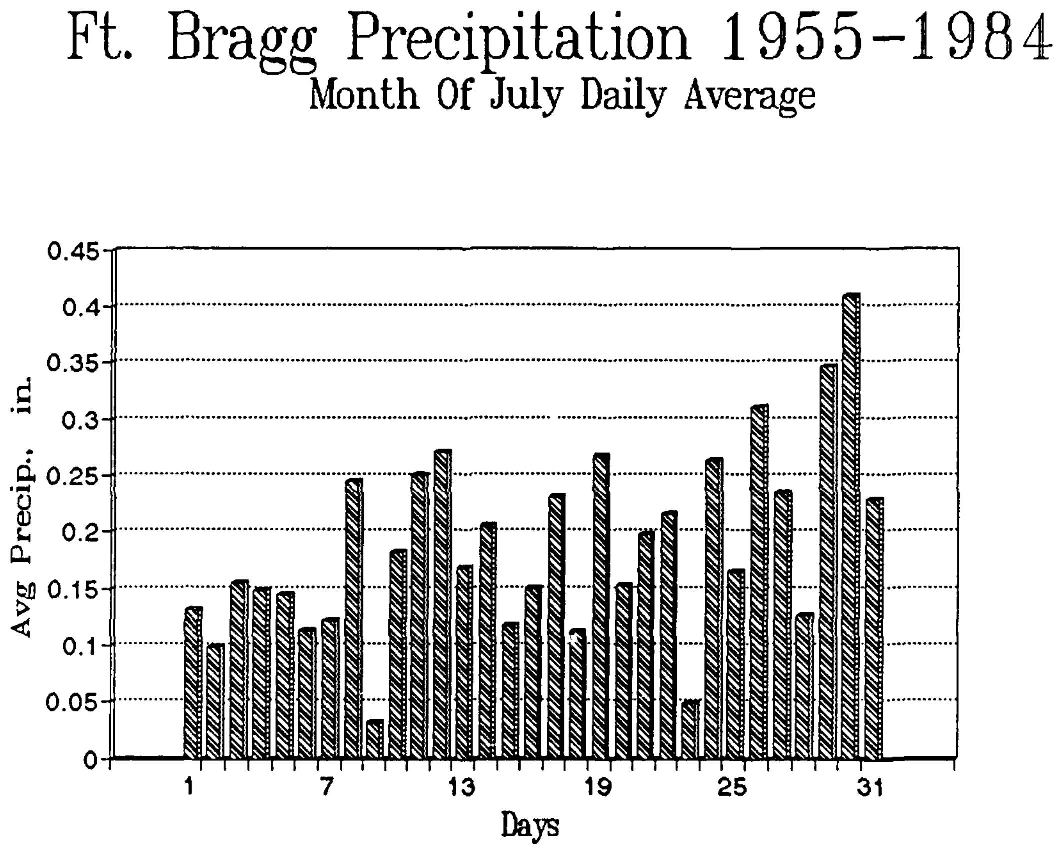

Figure 10. Average Precipitation vs. Days of the Month of Most Precipitation

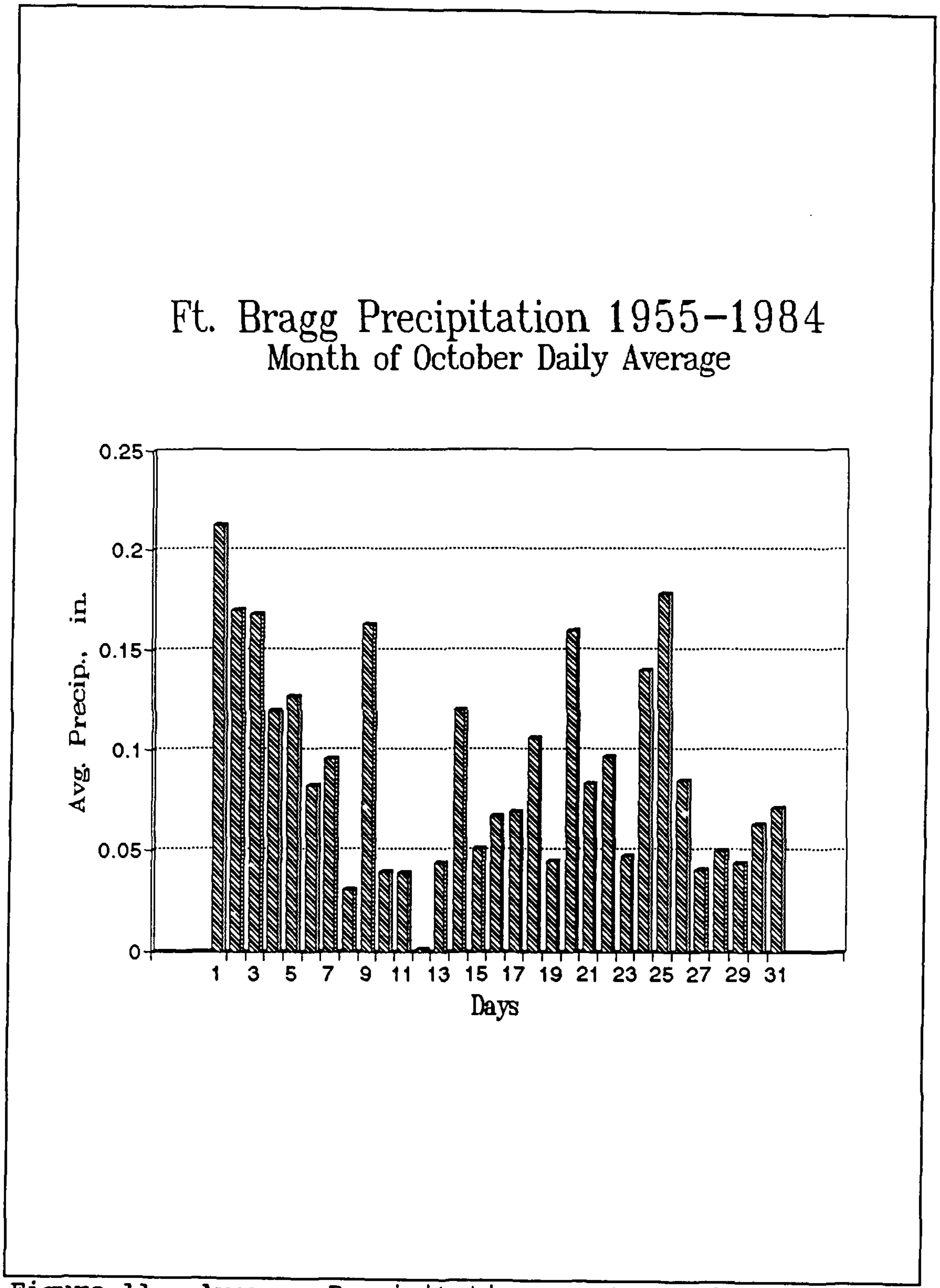

Figure 11. Average Precipitation vs. Days of the Month of Least Precipitation

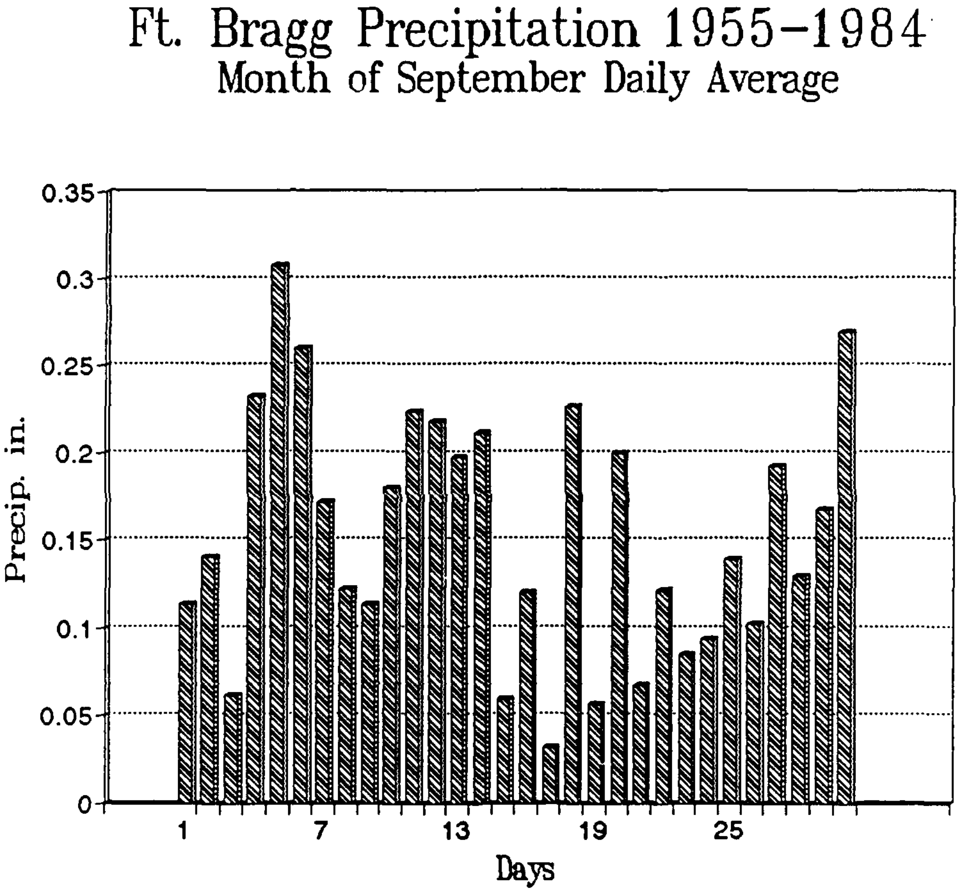

Figure 12. Average Precipitation vs. Days of the Month of the Planned Operation

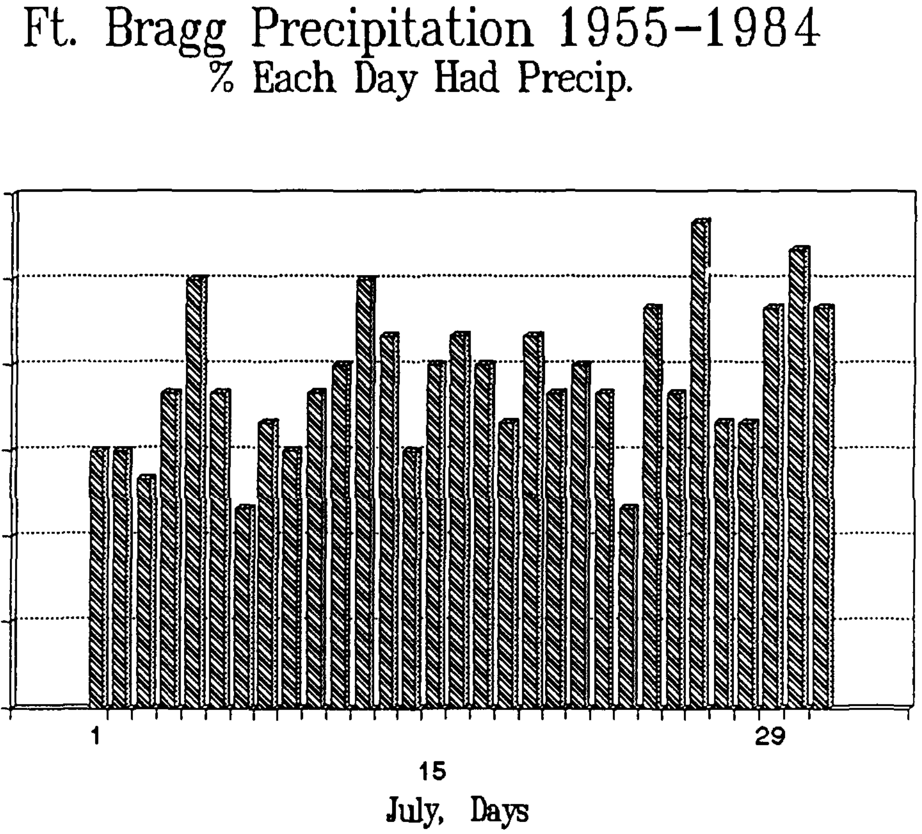

Figure 13. % of Each Day that had Precipitation > 0.01 inch vs. Days of the Month of Most Precipitation

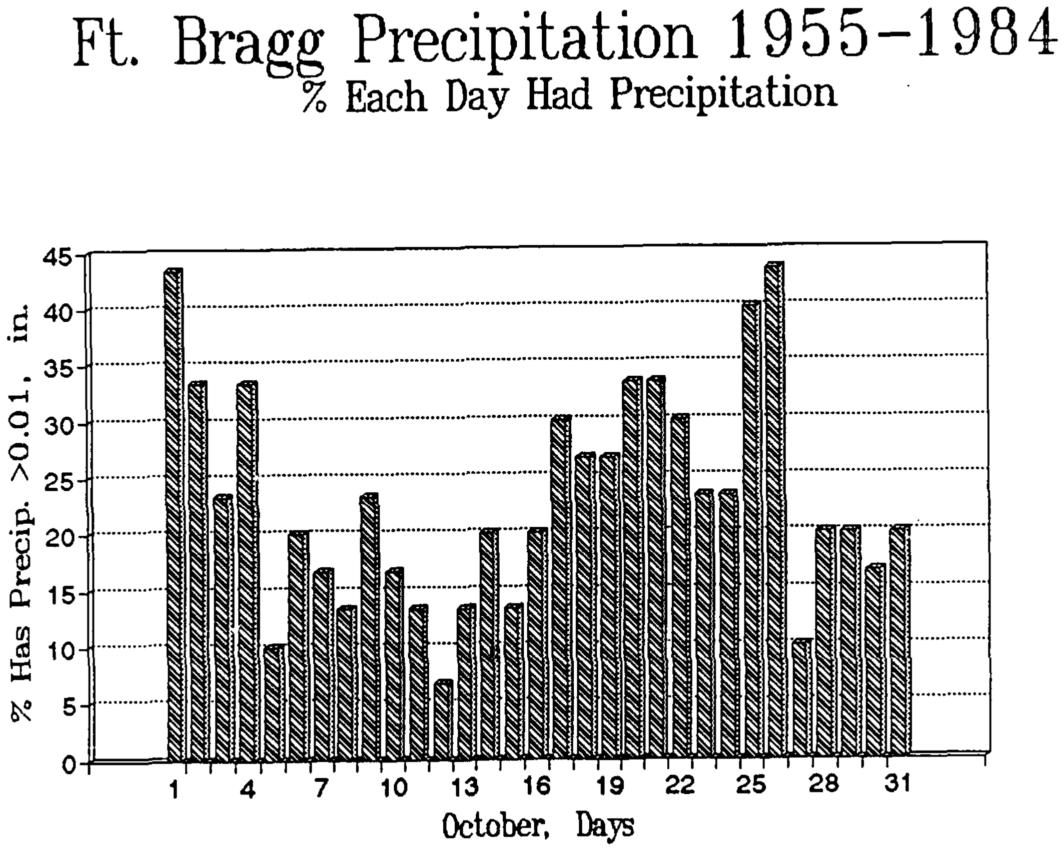

Figure 14. % of Each Day that had Precipitation > 0.01 inch vs. Days of the Month of Least Precipitation

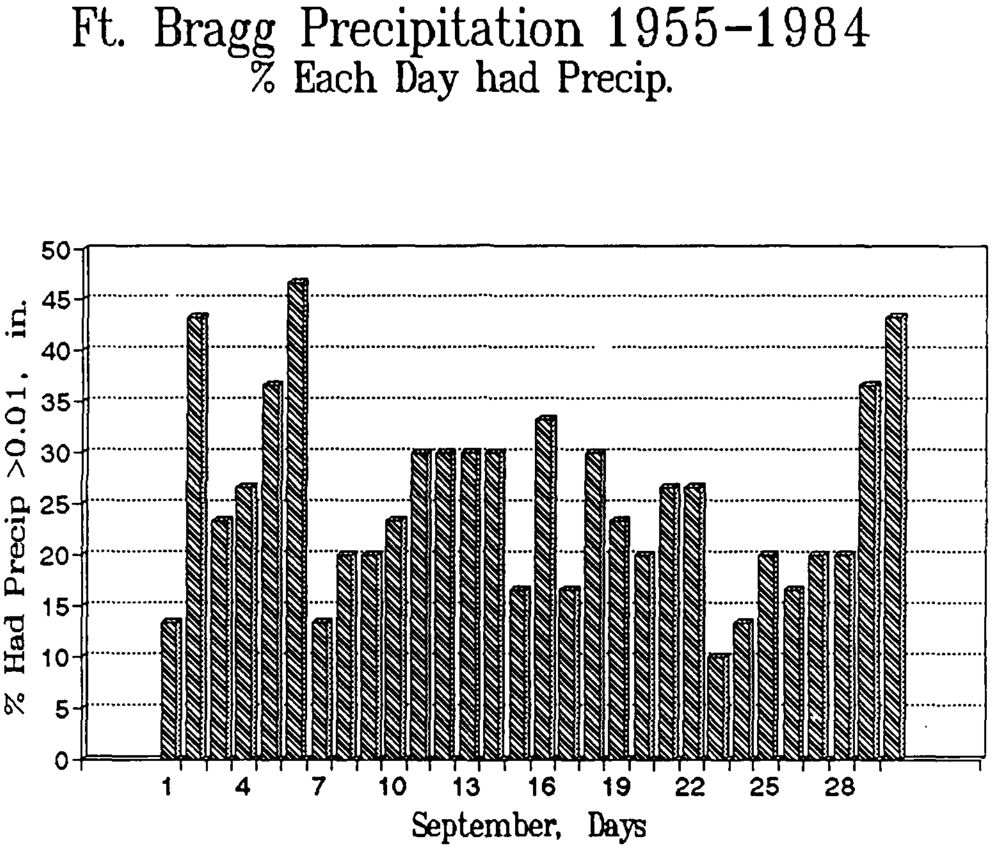

Figure 15. % of Each Day that had Precipitation > 0.01 inch vs. Days of the Month of the Planned Operation

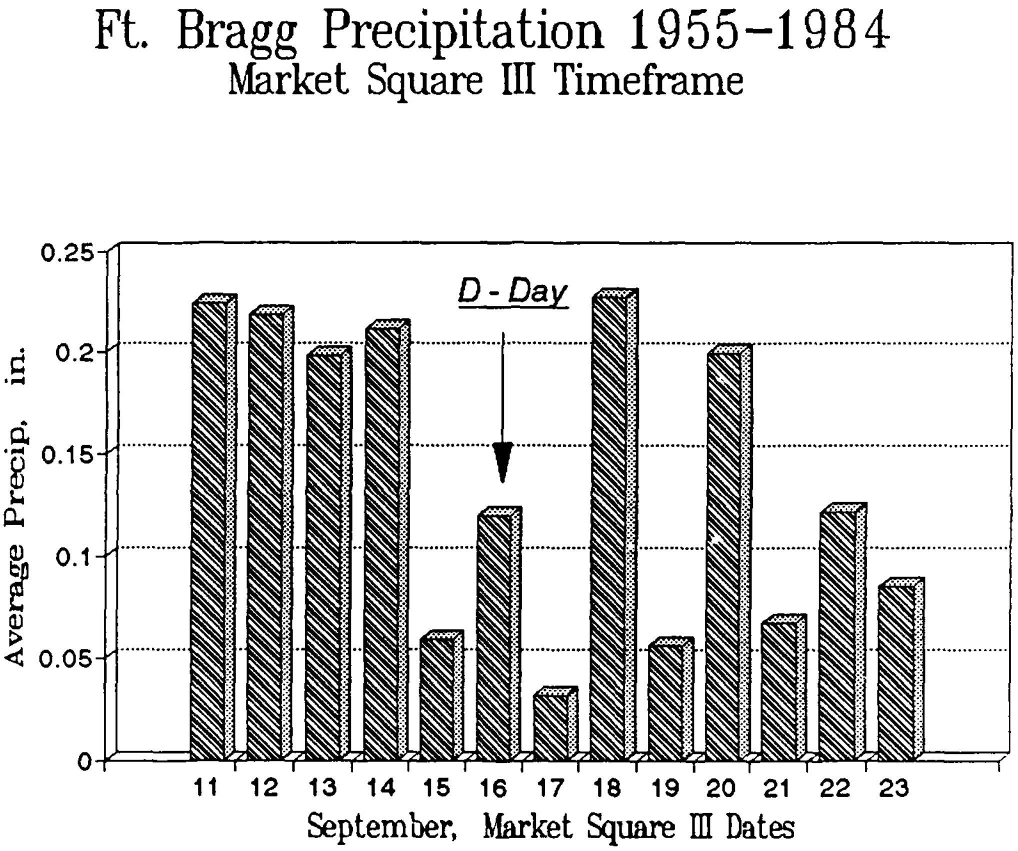

Figure 16. Average Precipitation vs. Planned Days of the Operation

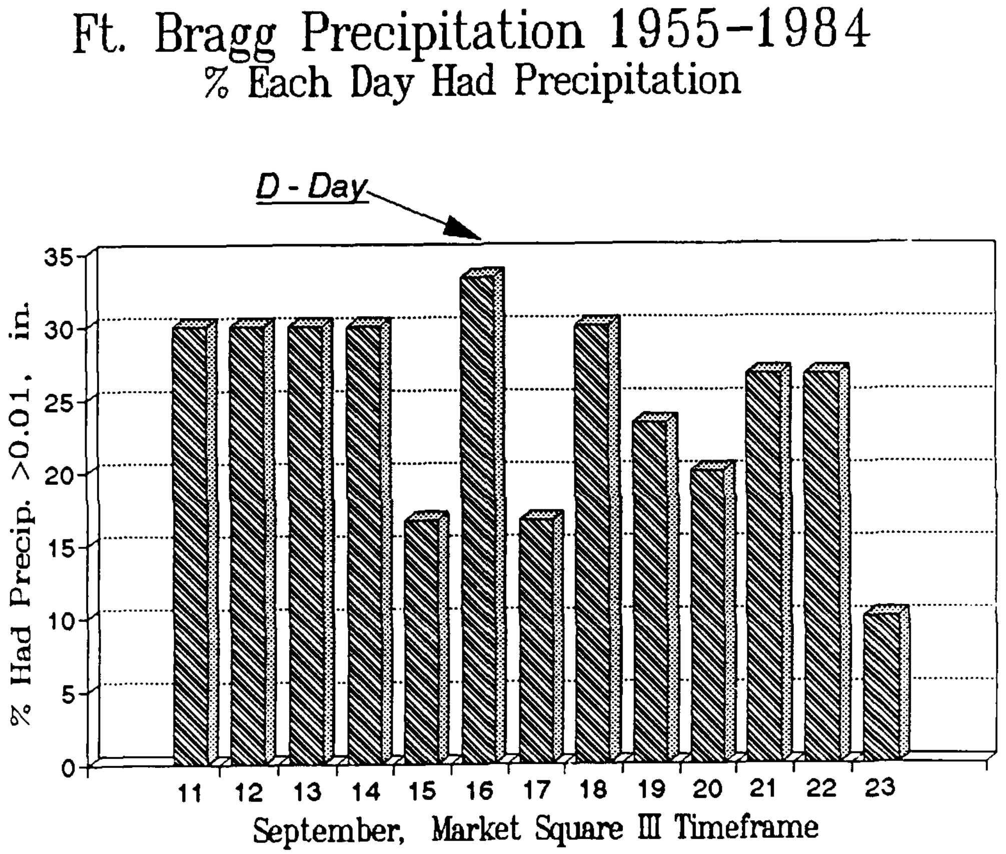

Figure 17. % of Each Day of the Exercise that had Precipitation over the Years of Record

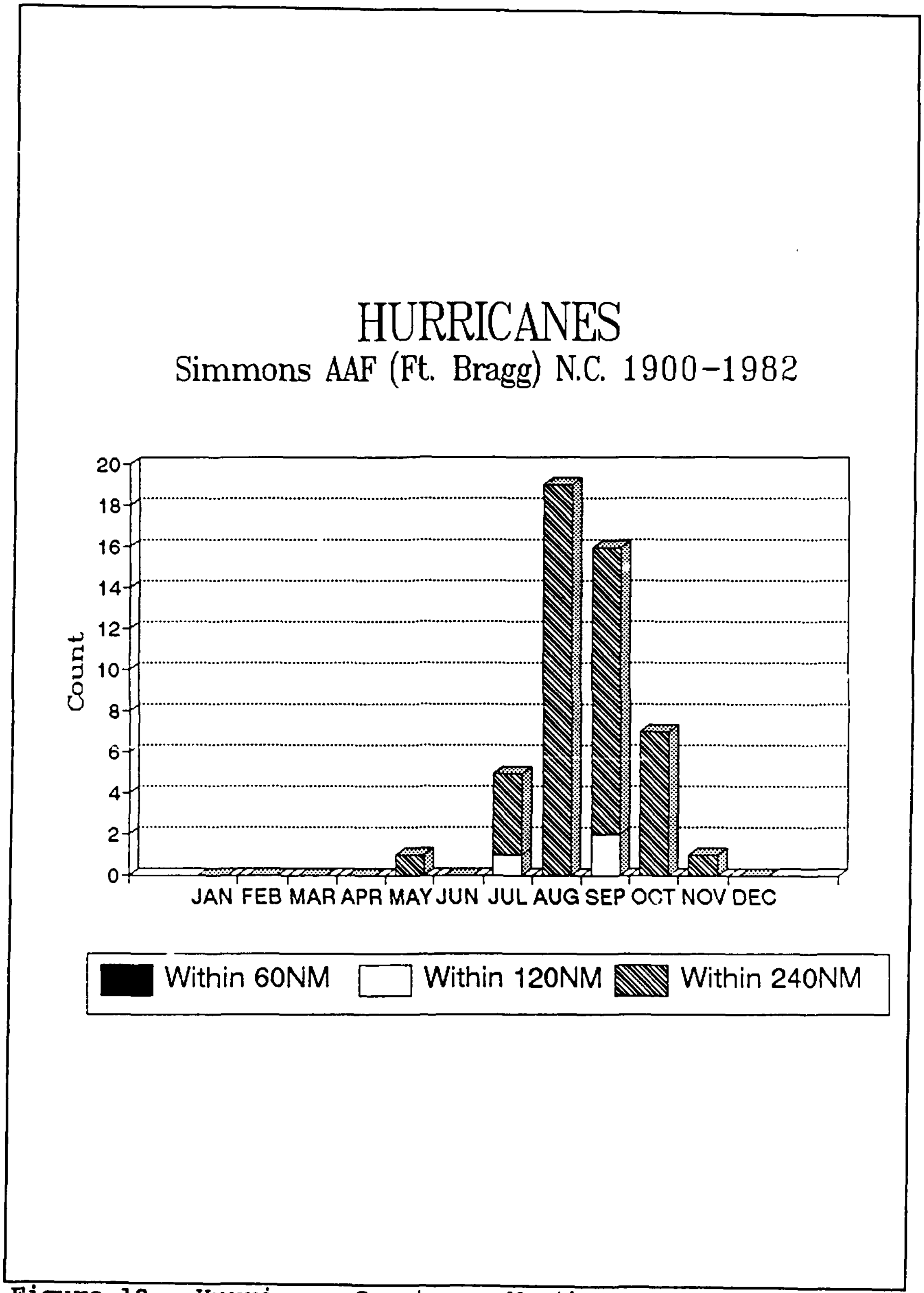

Figure 18. Hurricane Count vs. Month

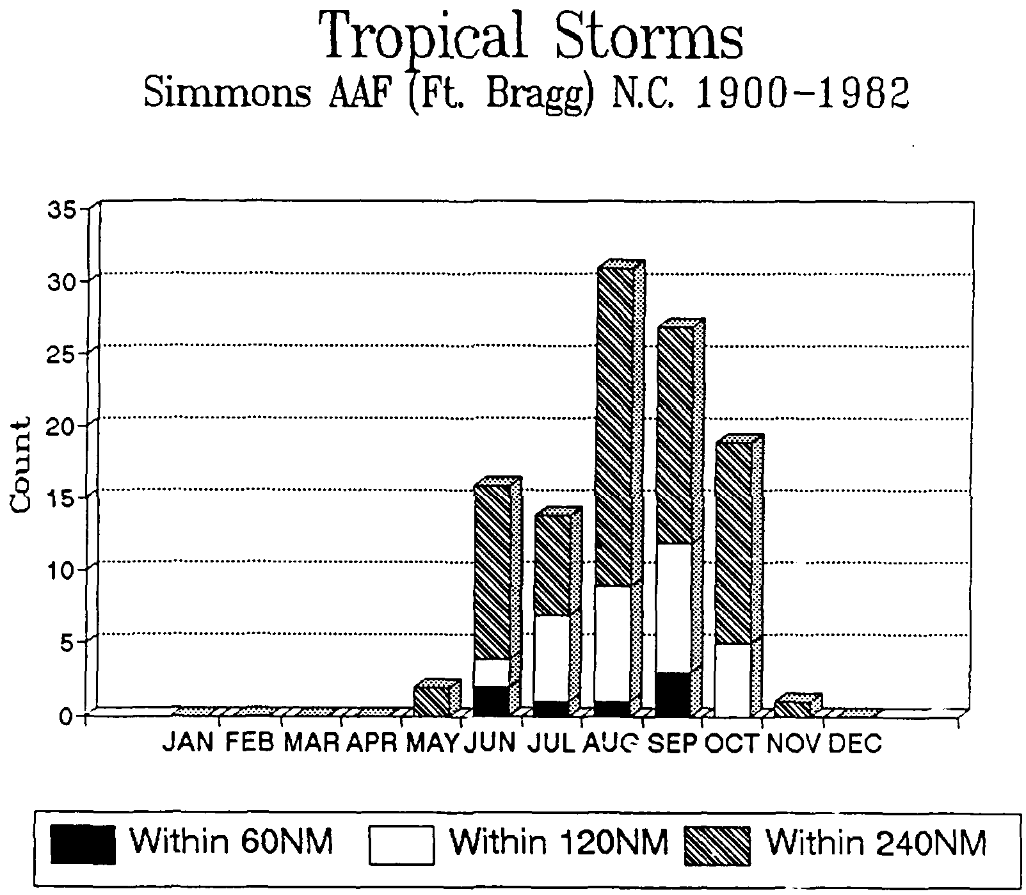

Figure 19. Tropical Storm Count vs. Months