CZ-214

Final Report-New Grant Task 2

# STUDY OF NON-POINT SOURCE THERMAL POLLUTION IN JABEZ BRANCH

Prepared by

KENNETH YETMAN
POWER PLANT AND ENVIRONMENTAL REVIEW DIVISION
OF THE
TIDEWATER ADMINISTRATION
MARYLAND DEPARTMENT OF NATURAL RESOURCES



February, 1991



this work was provided in part by the Coastal Resources Division, Tidewater
on, Maryland Department of Natural Resources through a grant from the
ean and Coastal Resources Management, National Oceanic and Atmospheric
on.

# STUDY OF

# NON-POINT SOURCE THERMAL POLLUTION

# IN

# JABEZ BRANCH

Prepared by

KENNETH YETMAN
POWER PLANT AND ENVIRONMENTAL REVIEW DIVISION
OF THE
TIDEWATER ADMINISTRATION
MARYLAND DEPARTMENT OF NATURAL RESOURCES

February, 1991

Funding for this work was provided in part by the Coastal Resources Division, Tidewater Administration, Maryland Department of Natural Resources through a grant from the Office of Ocean and Coastal Resources Management, National Oceanic and Atmospheric Administration.

# ACKNOWLEDGMENTS

Several members of the Power Plant and Environmental Review Divisions staff assisted in this study. Greg Galbreath and Merion Geremia helped gather and manage the large volume of field data collected. Kate Meade assembled the information on land use and Dr. William Hodges provided valuable assistance and guidance throughout this study.

The Coastal Resource Division, Tidewater Administration, Maryland Department of Natural Resources provided funding to support this work through a grant from the Office of Ocean and Coastal Resource Management, National Oceanic and Atmospheric Administration. Funding and assistance were also provided by the Maryland State Highway Administration.

# Executive Summary

In 1990, the Maryland Department of Natural Resources began a monitoring study of non-point source thermal pollution in Jabez Branch. Jabez Branch was unique because it was the only stream in the Maryland Coastal Plain which supported a natural reproducing trout population. Highway construction and land use changes in the stream's watershed have altered drainage patterns and today trout are no longer present in the stream. The primary objective of the present investigation is to identify the potential sources of non-point thermal pollution affecting the upper portion of Jabez Branch where trout once existed. This is being done by studying the spatial and temporal patterns in which thermal pollution occurs within the catchment during a variety of summer rain storm events. Field monitoring in the first year has concentrated on collecting baseline information on stream flows, water temperature, rainfall and land use.

Results from the 1990 land use surveys indicate that nearly 50% of the left fork watershed of Jabez Branch remains forested and much of the remaining land is in agricultural use. It is estimated that at present less than 4 % of the left fork watershed is covered with impervious surfaces. Despite the fairly low level of urban development, results indicate that runoff generated within the watershed increases stream water temperature near the tolerance limit of brook trout.

The relatively large rises in stream water temperatures appear to be the result of two factors. First, the left fork of Jabez Branch is a small stream with a summer base flow of only 0.3 cfs. Because normal base flow in the stream is low, even a small amount of warm surface runoff can have a dramatic impact on stream water temperature. The second factor is that development in the left fork watershed is concentrated in the upper sections of the drainage basin. When it rains, runoff from commercial, residential and agriculture land in the upper watershed concentrates in drainage channels and quickly flows down stream. This runoff has not only been heated from contact with roads and other warm surfaces, but the volume of water originating from the upper watershed is relatively large. As this heated runoff moves down stream, it changes water temperature along the entire length of the left fork of Jabez Branch.

The largest rise in water temperature in the lower left fork of Jabez Branch during 1990 occurred on July 12 during a 2.65 inch rain event that occurred in the late afternoon (18:30) on a fairly warm day (31.7°C or 89.1°F). Water temperature on the left fork rose from 17°C (62.6°F) to 23.9°C (75°F) as stream flows increased from 0.3 cfs to 17.5 cfs. Monitoring of runoff within the left fork watershed found that the runoff from a road was 28°C (82.4°F) at the beginning of the storm and the temperature of the runoff from an industrial roof was 24.5°C (77.9°F). In the more urbanized portions of the watershed, the temperature of the runoff was initially above 27°C (80.6°F) and then dropped to just below 25°C (77°F) during the storm. Runoff primarily from agriculture land was around 23°C (73.4°F) at the start of the storm and rose during the rain event to 25°C (77°F). During the July 12 rain storm, the temperature of the surface runoff from a forested subdrainage basin remained fairly constant at around 22°C (71.6°F).

One surprising finding in 1990 was the relatively low pH in the center portion of the left fork of Jabez Branch. During base flow conditions the pH in the mid-section of the stream was 5.2. Water at this pH is considered to be fairly acidic and can be stressful to many aquatic organisms. In addition to pH levels varying along the stream's length, pH also fluctuated when it rained. Continuous monitoring of pH near the mouths of the left and right forks indicates the pH of the stream can drop as much as 1 pH unit shortly after the beginning of a rain event.

# INTRODUCTION

Before settlers came to this country, forests dominated the eastern seaboard. In these precolonial times, it is believed that most streams in Maryland above the fall line and some streams below the fall line, such as Severn Run, supported natural reproducing brook trout populations. As forests were cut down, flow patterns in Maryland streams changed and many streams became degraded, losing their ability to support trout (Barry, 1958; Powell, 1967). Trout are very sensitive to changes in water quality especially increases in water temperature. When present, trout are generally an indicator of a healthy cold water stream system.

While the general causes for the historical decline of trout and other aquatic resources in Maryland are known, little information on the specific impact that land use changes have had on aquatic systems is available. Questions on how much development can occur in a watershed before a fish population is affected or how much a specific land use change could raise water temperatures in a stream can not be answered at this time. Certainly, if Maryland is to protect its remaining healthy streams and possibly restore other degraded waters, we must have a better basic understanding of the cumulative effects that land use changes have on the State's streams.

Jabez Branch is a tributary to Severn Run in Anne Arundel County, Maryland (Figure 1). The stream was unique because it was the only remaining stream in Maryland's Coastal Plain which supported a natural reproducing trout population. In 1987, however, field surveys by the Maryland Department of Natural Resources (DNR) found that a severe decline in the trout population had occurred, and the most recent surveys done in December, 1990 indicate that brook trout are no longer present in Jabez Branch. The initial decline of brook trout in Jabez Branch is believed to be linked to highway construction which altered drainage patterns and created a new warm water discharge to the stream. Corrective action was taken to eliminate the warm water discharge created by highway construction; however, storm water temperature monitoring and fish surveys indicate that non-point source thermal pollution remains a problem in the stream.

An field monitoring study began in 1990 to examine non-point source thermal pollution problems on Jabez Branch. For the most part, non-point source thermal pollution only occurs when it rains. Since rain storms are both episodic and variable in size, monitoring must be done over several years so that a wide range of possible environmental conditions can be seen. This report is a presentation of the results from the first summer's monitoring.

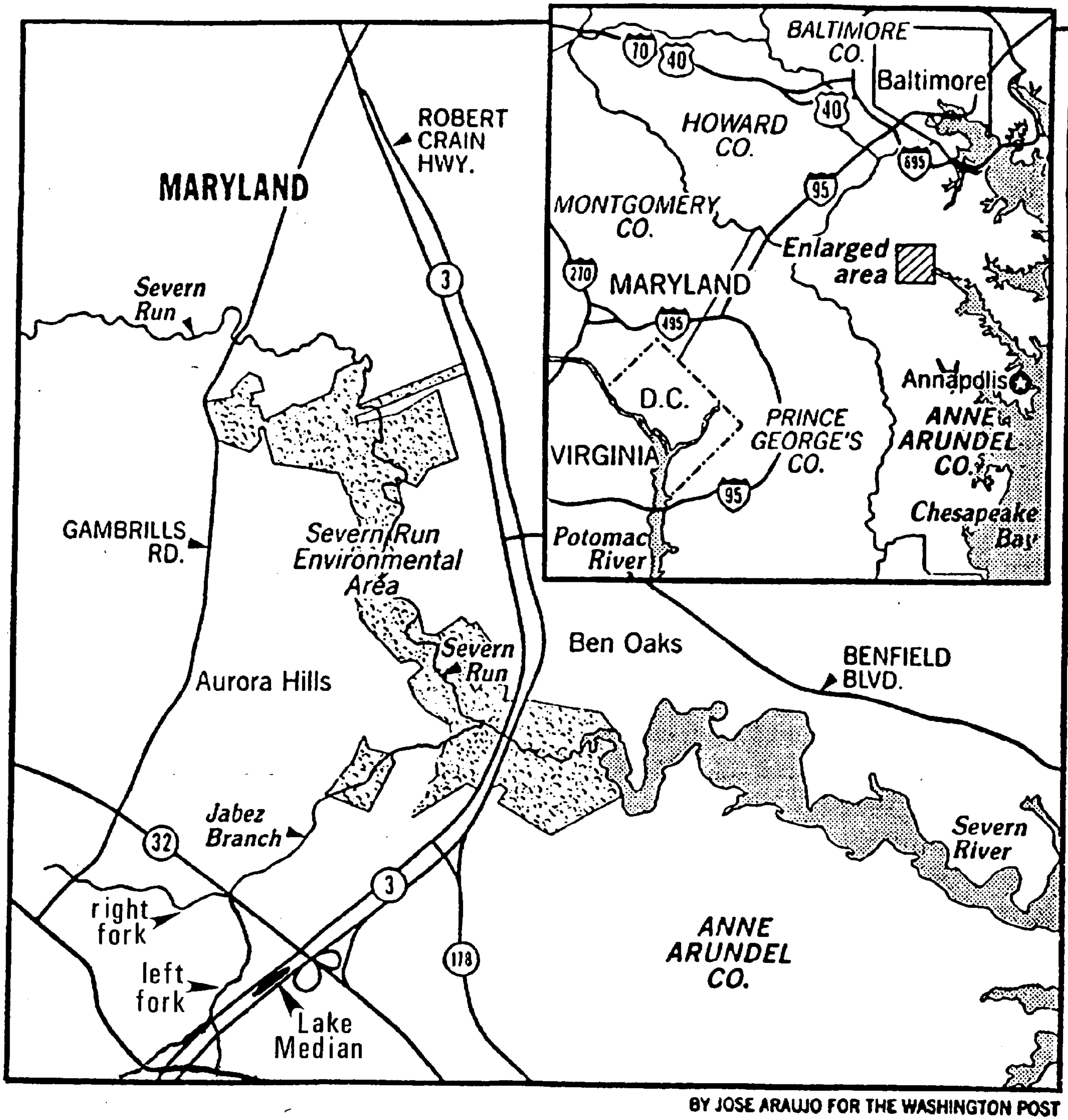


Figure 1. Map showing location of Jabez Branch. (Origional figure from March 27, 1989 Washington Post)

The present investigation of Jabez Branch represents a unique opportunity to document a trout stream at the critical turning point in its ability to support a trout population. Hopefully, once the non-point source pollution problems on Jabez Branch are better understood, the actions needed to restore this unique natural resource will also be clearer.

The primary objective of this investigation is to identify the potential sources of non-point thermal pollution affecting the upper portion of Jabez Branch where trout once existed. This is being done by studying the spatial and temporal patterns in which thermal pollution occurs within the catchment during a variety of summer rain storm events.

# BACKGROUND INFORMATION

## MARYLAND TROUT STREAMS AND JABEZ BRANCH

Brook trout were first discovered in Jabez Branch in October 1977. At that time, it was believed that trout were present only upstream of Maryland Route 32 (Figure 2). Since the initial discovery, DNR biologists have conducted periodic electrofishing surveys of the stream. Data from these surveys are shown in Table 1. The earliest extensive survey of Jabez Branch, in 1986, showed that in addition to the brook trout present above Rt. 32, brook trout were also present downstream. Trout were collected in the mainstem of Jabez Branch both above and below Hog Farm Road and in the Hog Farm Road tributary. The 1986 survey also indicated that the highest density of brook trout in Jabez Branch occurred in the stream's upper left fork. The success of trout in the left fork is believed to be due to the large amount of spring water that flows into this segment of the stream.

In September 1987, routine surveys by the Department's Freshwater Fisheries Program discovered that a severe decline in the Jabez Branch trout population had occurred (Table 1). Further investigation revealed that construction of I-97 had

Table 1. Number of brook trout collected in Jabez Branch.

| | Distance Surveyed (yards) | 1977 Oct. & Nov. | 1980 June | 1983 Nov. | 1986 Nov. & Dec. | 1987 Aug. thru Oct. | 1987 Dec. | 1988 Dec. & Jan. 1989 | 1989 Dec. & Jan. 1990 | 1990 Dec. |
|---|---|---|---|---|---|---|---|---|---|---|
| Left Fork | unknown | | common | | | | | | | |
| | 164 | 6 | | | | | | | | |
| | 175 | | | 8 | | | | | | |
| | 350 | | | | 24 | | | | | |
| | 383 | | | | | 1 | 0 | 0 | 0 | 0 |
| Right Fork | 350 | | | | 11 | | | | | |
| | 631 | | | | | 3 | 1 | | | |
| | ≈1,333 | | | | | | | 4 | 2 | 0 |
| Upper Mainstem (Rt. 32 to Hog Farm Rd.) | 100 | | | | 3 | | | | | |
| | 219 | 0 | | | | | | | | |
| | 631 | | | | | 2 | | 0 | 0 | 0 |
| Lower Mainstem (Hog Farm Rd. to Severn Run) | 100 | | | | 0 | | | | | |
| | ≈133 | | | | | 1 | | | | |
| | 200 | | | | 1 | | | | | |
| | 433 | | | | 0 | | | | | |
| | 2,233 | | | | | 7 | | 1 | 0 | 0 |
| Hog Farm Rd. Tributary | 200 | | | | 2 | | | | | |
| | ≈587 | | | | | | 0 | | | |
| | ≈633 | | | | | 0 | | 0 | 0 | 0 |
| Gambrill Rd. Tributary | 250 | | | | | | 0 | | | |
| | ≈800 | | | | | 0 | | | | |
| Warfield Tributary | 200 | | | | 0 | | | | | |

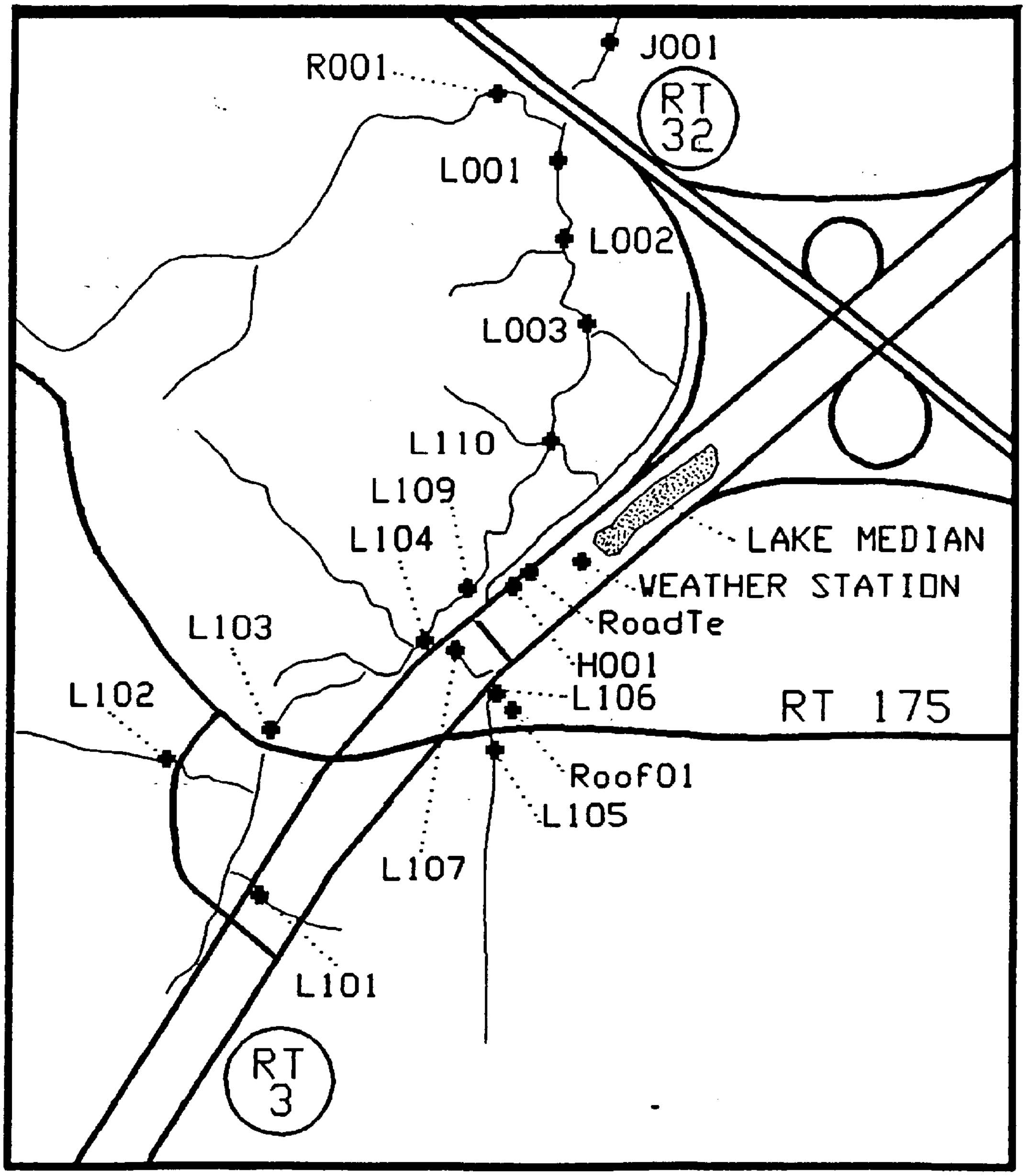


Figure 2. Map showing location of sampling station in upper Jabez Branch watershed in 1990.

created a new retention basin which was discharging heated water into the left fork of Jabez Branch. The State Highway Administration was notified and the discharge was eliminated in the spring of 1988.

Following the discovery of the decline of trout in Jabez Branch, a second fish survey was done in December, 1987 to obtain seasonal data comparable to the survey done in 1986. Results of the second survey confirmed that few trout remained in the stream (Table 1).

In 1988, two continuous recording thermographs were placed in Jabez Branch to monitor summer water temperatures. Results indicated that water temperatures, both in the left fork and in the stream's mainstem, experienced several sharp temperature rises. Further analysis of this data in combination with rainfall data collected at BWI airport located 7.5 miles north of Jabez Branch, indicated that sharp temperature rises in the stream corresponded to local rain events. For example, on August 29, 1988 water temperature in the left fork rose from 17.5°C to 23°C within a sixty minute period following a one-inch rainfall. Temperature rises such as these are a major concern not only because the high temperatures may exceed the upper tolerance limit of brook trout, but also because very rapid changes in water temperature can be extremely stressful to the entire aquatic ecosystem.

Winter fish surveys of Jabez Branch have continued since the initial decline in the trout population was discovered. In the three years since 1987, one-pass electrofishing surveys were done in all areas where brook trout had previously been collected, or in areas where trout were suspected to be present. Results indicate that a steady decline in the trout population has continued (Table 1). In 1988, electrofish surveys of Jabez Branch collected only 5 brook trout (four young-of-the-year and one adult), and in 1989, only 2 yearling brook trout were found. The most recent survey was completed in December, 1990, and was unable to find any brook trout anywhere within the stream. It is now believed that a brook trout population no longer exists in Jabez Branch.

Past surveys of Jabez Branch indicated that the highest standing crops of brook trout in Jabez Branch have traditionally occurred in the left fork. The left fork has also been observed to have the greatest spring water influence. It is the opinion of the Maryland Freshwater Fisheries staff that the repopulation of brook trout into the left fork is essential for the restoration of a natural reproducing trout population in Jabez Branch (Bachman, personal communication). The reason for the failure of brook trout to repopulate the left fork is not known at present. It is suspected, however, that high and rapid water temperature changes may have prevented brook trout from reestablishing themselves in this area. Repopulation of brook trout into the left fork may also be affected by the scarcity of fish in the system. After the initial decline of trout in Jabez Branch in 1987, there may have been too few individuals left in the system to sustain a reproducing population. Now that it is known that no native brook trout are left in Jabez Branch, the Freshwater Fisheries Program of DNR is preparing a restocking plan for the stream.

## EFFECTS OF URBANIZATION

The effects of urbanization on a catchment and drainage system are numerous, particularly in terms of hydrology and microclimatology. The following discussion is provided as an overview and pertains primarily to those impacts which affect runoff and heat transfer processes.

In a mature forest, rain is intercepted and stored by the tree canopy until the storage capacity is exceeded. Once rain reaches the surface, it is held in the humus layer which aids in infiltration of rain water into the underlying soil. Runoff in a mature forest rarely occurs at the surface as overland flow. Instead, water moves laterally as throughflow within the soil until it is discharged as base flow or delayed storm flow through a stream bank. Typically, any overland flow component of runoff is limited to areas adjacent to existing channels which have become saturated by subsurface drainage or runoff; therefore, true surface runoff occurs primarily after soil storage is exceeded by drainage saturation.

As forests are cut down, they are replaced by impervious surfaces (e.g., roads and parking lots) or by surfaces which are greatly altered (e.g. farm fields and lawns). Surface hydrology changes accordingly and affects a catchment's response to rainfall events. The changes in land use have pronounced effects on the mechanisms which regulate runoff generation.

Generally, surface changes due to urbanization reduce infiltration, and the amount of rainfall which becomes surface runoff increases. Additional effects include a reduction in depression storage (i.e., water held in surface depressions) and an increase in overland flow velocities. The result is an acceleration of hydrological processes which produces a flashier runoff regime with higher peaks developed more rapidly and with shorter lag times.

Surface modifications influence the amount of water and the timing of runoff reaching a stream; however, the extent to which these changes have a measurable impact on hydrological processes is governed (at least in part) by the magnitude, frequency and duration of rain storm events. Flood peaks increase relative to their respective return periods, but extreme events within urbanized areas barely increase over those which occur in undeveloped watersheds. The reason is simple: during high magnitude (or extended duration) storms the catchment becomes fully saturated with maximally extended networks so that the hydrological response of a rural watershed replicates that of an urban basin (Richards, 1982). In effect, hydrological impacts associated with urbanization are most pronounced during storms of intermediate magnitude.

Surface alterations due to urbanization also affect the microclimatology of an area largely through changes that influence heating of a surface and transfer of heat to air or water. In this case, shade is a primary factor, and reductions in shading increase the amount of solar radiation reaching the surface. As shading is reduced due to surface changes, the reflectance (albedo) of an area is altered. In general terms, the reflectance of a surface is a relative indicator of surface heating. A surface with a high reflectance tends to heat less rapidly and less intensely than a surface with a low reflectance.

As rain falls in an urbanized environment, the runoff produced on a surface is heated more rapidly and to a higher temperature than runoff generated within a forested environment. The runoff can be very warm especially if it originated on a road surface or a parking lot which has been heated by the sun just prior to a rain event.

Another effect of urbanization is on ground water. Water that previously infiltrated into the ground is now flowing overland. This results in a reduction of ground water recharge which can lead to a decline in the water table or dewatering of a perched water zone. Under these circumstances springs can dry up and base flow discharge to a stream can be reduced drastically. In some headwater areas the stream may become completely dry except when it rains. As base flow is reduced, the temperature of stream flow will rise. This puts additional stress on cold water organisms like trout, and if the water temperature rises high enough, the stream will no longer be able to support trout.

# METHODS

## SAMPLING STATIONS

Non-point thermal pollution problems have already been documented in the left fork of Jabez Branch (Figure 1) and this watershed was the focus of monitoring efforts in 1990. Field monitoring in the first year has concentrated on collecting baseline information on stream flows, water temperature, rainfall and land use.

A total of 18 monitoring stations were established in 1990 (Figure 2). A list of the sampling stations along with a description of their location, parameters measured, sampling period and sampling frequency is presented in Table 2. The sampling stations fall into 4 groups:

* **Meteorological Station**

A automated weather station was established in the upper left fork watershed near Lake Median between the north and south-bound lanes of Rt. 3. Air temperature, humidity, solar radiation, and rainfall were recorded every 7.282 minutes using a Datalynx data logger. Fluctuations in

Table 2. Name and location of sampling stations in Jabez Branch watershed in 1990 along with information on parameters measured, sampling period at each station and recording frequency.

| Station name | Location | Parameters Measured | Sampling Period | Recording frequency |
|---|---|---|---|---|
| Weather | South end of lake Median | Air temp., rainfall, humidity, solar radiation, and lake level | 6/5/90 to on going | 7 min. |
| J002 | Mainstem of Jabez Br. ≈600 ft. upstream of Hog Farm Rd. | Water temp. | 6/5/90 to 10/9/90 | 5 min. |
| R001 | Right fork of Jabez Br. ≈800 ft. above Rt. 32 culvert | Water temp., conductivity, pH, dissolved oxygen | 6/15/90 to 10/2/90 | 10 min. or less |
| L001 | Left fork of Jabez Br. ≈200 ft. above Rt. 32 culvert | Flow, water temp. conductivity, pH, dissolved oxygen | 6/15/90 to 10/2/90 | 10 min. or less |
| L002 | Left fork of Jabez Br. ≈650 ft. above Rt. 32 culvert | Water temp. | 6/11/90 to 9/24/90 | 5 min. |
| L003 | Left fork of Jabez Br. ≈1200 ft. above Rt. 32 culvert | Water temp. | 6/11/90 to 10/9/90 | 5 min. |
| L110 | Unnamed intermittent tributary ≈25 ft. from stream mouth | Water temp. | 6/7/90 to 10/9/90 | 5 min. |
| L109 | Top of cement channel near Charles Hall Rd. | Water temp., peak water levels | 6/5/90 to 10/8/90 | 5 min. |
| L107 | Rt. 3 south culvert near Suburban Propane | Water temp. | 6/18/90 to 10/8/90 | 5 min. |

| | | | | |
|---|---|---|---|---|
| L106 | Rt. 3 north culvert near Maryland muffler | Water temp. | 6/7/90 to 10/8/90 | 5 min. |
| L105 | Millersville Rd culvert at Hansel Dr. intersection | Water temp. | 6/18/90 to 7/12/90 | 5 min. |
| L104 | Sir Walter Dr. culvert | Water temp. | 6/7/90 to 6/20/90 | 5 min. |
| L103 | Rt. 175 culvert | Water temp. | 6/7/90 to 10/8/90 | 5 min. |
| L102 | McKnew Rd. culvert | Water temp. | 6/5/90 to 9/17/90 | 5 min. |
| L101 | Rt. 3 north culvert near "Bull Shed" restaurant | Water temp. | 6/5/90 to 10/8/90 | 5 min. |
| Roadte | Asphalt along Rt. 3 south near Charles Hall Rd. | Road temp. | 6/7/90 to 10/8/90 | 5 min. |
| H001 | Runoff from Rt. 3 south near Charles Hall Rd. | Water temp. | 6/7/90 to 10/8/90 | 5 min. |
| Roof01 | Down spout drain at Maryland Mustang | Water temp. | 7/12/90 to 10/8/90 | 5 min. |

water levels in Lake Median were also monitored using a pressure sensor deployed in the lake. Rainfall was measured using a tipping bucket rain gauge which recorded rainfall in 0.01 inch intervals. In addition to the continuous monitoring equipment, a backup cumulative rain gauge that measured total rainfall was at the site and a staff gauge was deployed in Lake Median. Routine readings were taken from both the backup cumulative rain gauge and staff gauge along with measurements of air temperature and humidity using a sling psychrometer. Field measurements were compared to data from the automatic monitoring equipment to verify accuracy.

* **Perennial Stream Stations**

A total of five perennial stream stations were established in 1990: three stations were along the left fork of Jabez Branch (Station L001, L002 & L003); one station was on the right fork (Station R001) and one station was on the mainstem of Jabez Branch (Station J002) downstream of the confluence of the left and right forks (Figure 2). Water temperatures were measured at 5 or 10 minute intervals at all stations using either a Ryan Tempmentor or Hydrolab DataSonde-1. In addition, conductivity, pH and dissolved oxygen levels were measured at 10 minute intervals with the Hydrolab DataSondes at Stations L001 and R001. Stream discharge data for the left fork of Jabez Branch were recorded at 5 minute intervals at a gauging station established at Station L001 by the U.S. Geological Survey. Weekly measurements of water temperature and other water quality variables were made at the perennial stream stations to verify the accuracy of the measurements made by the continuous monitoring equipment.

* **Intermittent Channel Stations**

At the beginning of the study, the upper watershed of the left fork of Jabez Branch was divided into 11 subdrainage basins. A photomap showing the subdrainage areas is presented in Figure 3. Once the drainage patterns in the upper watershed of the left fork were known, sampling stations were established at points where the runoff from one or more subdrainage areas concentrated. In most cases, the temperature probes were located in intermittent channels either above or below road crossings. The probes were suspended on a stick just above the bottom of the intermittent channel and measurements were taken at 5 minute intervals using Ryan Tempmentors. Due to equipment and time constraints, monitoring stations were not established in all 11 subdrainage basins (Table 2). Priority in establishing and maintaining stations was given to sites that drained an area dominated by a single land use type.

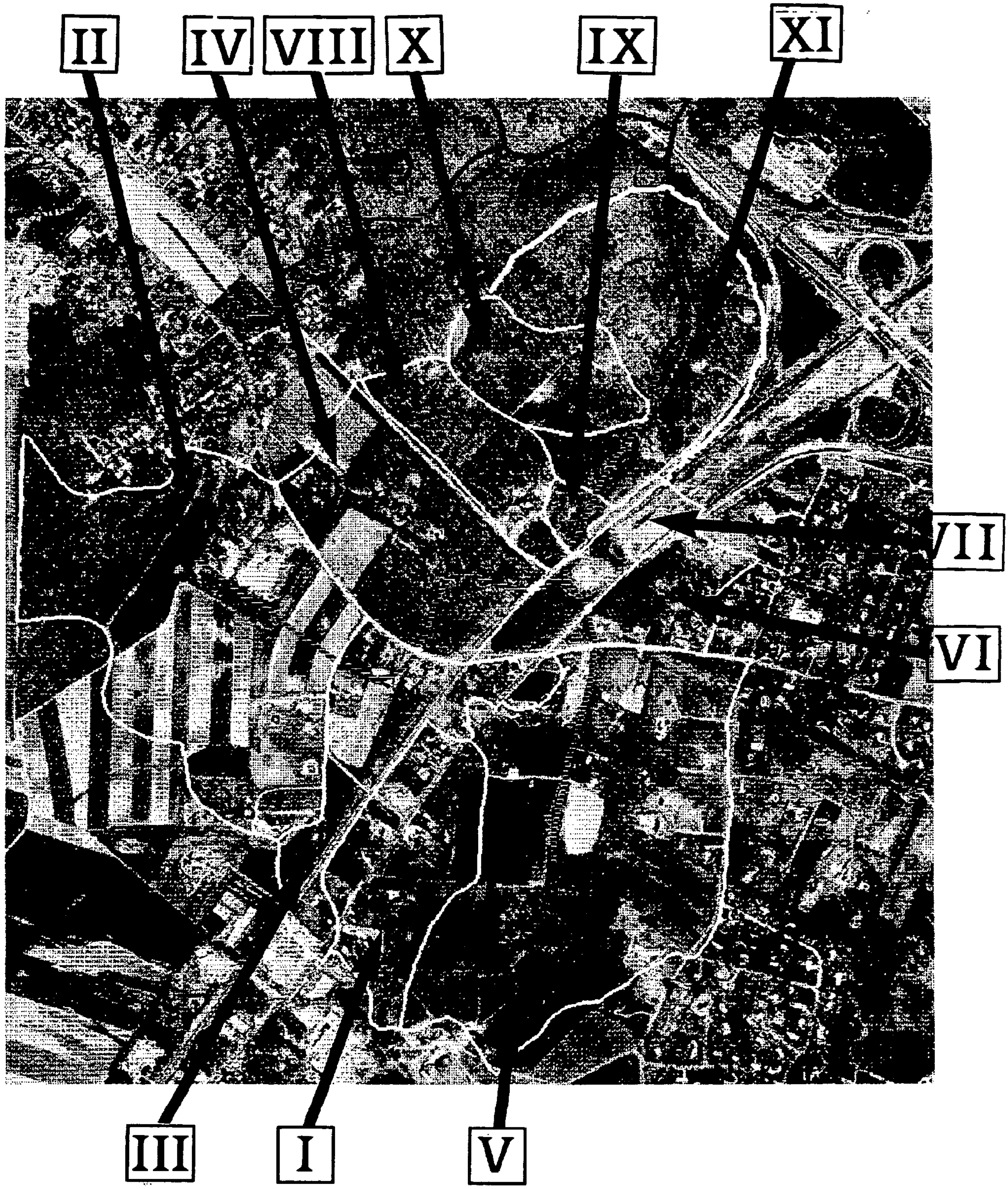


Figure 3. MIPS photomap showing the 11 subdrainage areas in the upper left fork of Jabez Branch.

* **Special Land Use Stations**

Temperatures were monitored at 2 special land use sites in 1990. At the first site, a temperature probe was embedded into the asphalt along south bound Rt. 3 to monitor the temperature of the highway's surface (Station RoadTe). A second temperature monitor was also deployed at the site and was designed to record the temperature of the runoff diverted from the highway. This was done by channeling some of the highway runoff to a probe that was suspended just above the highway surface. The second special land use site measured the temperature of the runoff from the roof of an industrial building in the watershed. The temperature probe was located at the bottom of one of the roof gutter's down spouts. Temperature measurements at all special land use sites were made at 5 minute intervals using Ryan tempmentors.

## Stream Profile Survey

In addition to the 18 stations in which continuous monitoring equipment was deployed, a stream profile survey of the left fork of Jabez Branch was done on June 28, 1990. Water temperature, flow velocity, pH and conductivity measurements were done along every 100 feet of stream channel starting at the mouth of the stream.

## Land Use Estimates

Land use in the upper watershed of the left fork of Jabez Branch was determined from photographs taken during a low altitude aerial survey done on February 13, 1990. Photographs were scanned into the Department's "Map and Image Processing System" (MIPS). The MIPS raster images were then registered and a second registered vector file of the 11 subdrainage basins was overlaid onto the original raster images. Land use in each subdrainage basin was then determined using the planimeter function in MIPS. In addition to estimating the land use areas, the MIPS planimeter was used to estimate the total amount of impervious area in each basin. A MIPS photomap showing one of the delineated subdrainage basins is presented in Figure 4.

Figure 4. Enlargement of subdrainage area VI. The MIPS enlargement was produce from a low altitude aerial photograph taken on February 13, 1990.

# Results

## Land Use

Land use in the left fork watershed of Jabez Branch was divided into 6 categories (ie., agriculture, forest, lightly forested, residential, commercial and highways). Result of land use surveys are shown in Table 3.

A total of 597 acres (0.93 sq. miles) are present in the left fork watershed. In 1990, approximately half (48 %) of this land was forested or lightly forested. The majority of the forested land was located in the lower or northern portion of the watershed (Figure 3, Subdrainage Basins IV, VIII, IX, X & XI). The remaining land in the watershed of the left fork was used for agriculture (27.7 %) or was either residentially (18.3 %) or commercially (3.0 %) developed. The agriculture, residential and commercially developed lands were located in the upper or southern portion of the watershed (Figure 3, Subdrainage Basins I, II, III, V, VI & VII).

In general, when it rains in the left fork watershed, runoff from agricultural fields, residential neighborhoods and commercial lots in the upper portion of the basin will flow into

Table 3. Estimates of land use (acres) in the watershed of the left fork of Jabez Branch.

| Sub-basin # (Station #) | I (L101) | II (L102) | III (L103) | IV (L104) | V (L105) | VI (L106) | VII (L107) | VIII | IX (L109) | X (L110) | XI (L001) | Total |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Agriculture | 14.7 | 55.3 | 14.3 | 9.2 | 69.6 | 1.0 | 0 | 0 | 0 | 1.1 | 0 | 165.2 |
| Forest | 15.0 | 39.0 | 7.9 | 48.0 | 9.8 | 6.9 | 9.3 | 25.6 | 2.9 | 27.1 | 71.0 | 262.5 |
| Lightly Forested | 3.4 | 3.9 | 0 | 0.4 | 7.8 | 0.8 | 5.0 | 0 | 0.1 | 0 | 2.5 | 23.9 |
| Residential | 5.9 | 16.4 | 19.4 | 0.5 | 50.0 | 7.6 | 0 | 3.0 | 1.8 | 0 | 4.9 | 109.1 |
| Commercial | 0 | 9.9 | 2.2 | 0 | 2.5 | 1.4 | 1.8 | 0 | 0 | 0 | 0 | 17.8 |
| Highway | 3.7 | 0.5 | 5.1 | 2.0 | 2.1 | 1.7 | 1.4 | 0.2 | 0 | 0 | 1.9 | 18.6 |
| Total area | 42.7 | 125.0 | 48.9 | 60.1 | 141.8 | 19.4 | 17.5 | 28.8 | 4.8 | 28.2 | 80.3 | 596.9 |
| Estimated impervious area | 3.0 | 6.5 | 1.6 | 0.4 | 3.7 | 2.1 | 1.0 | 1.4 | 0.1 | 0 | 2.3 | 22.1 |
| Percent impervious area | 7.0% | 5.2% | 3.3% | 0.7% | 2.6% | 10.8% | 5.7% | 4.9% | 0.2% | 0% | 2.9% | 3.7% |

drainage channels and move down into a wide intermittent stream channel. The channel conveys intermittent flow for approximately 2000 ft. until the runoff reaches the headwaters of the perennial flowing portion of the stream. The left fork of Jabez Branch continues another 2500 ft. before joining with the right fork.

Land use in each of the 11 subdrainage basins is shown in Table 3 along with an estimate of the amount of impervious area present. Of the 11 sections examined, Subdrainage Basin VI is the most urbanized with 46% of the land in either residential or commercial use. The least disturbed subdrainage basin is X which is 96% forested. Subdrainage Basins II and V have the largest amount of agricultural land. The agricultural land in Subdrainage Basin II is owned by the U.S. Naval Academy's Dairy and in 1990 was used to grow a grain crop in the spring and corn during the late summer and early fall.

## Base Flow Conditions

Stream flow in the left fork of Jabez Branch has been monitored continuously for over a year by the U.S. Geological Survey. The USGS gauging station is located at Station L001 which is approximately 200 ft. above the confluence with the right fork. During the summer, base flow at Station L001 was around 0.3 cfs. In addition to the USGS gauging station at

Station L001, a Hydrolab Datasonde-1 was also deployed to monitor temperature, conductivity, pH and dissolved oxygen levels in the stream. Measurements of most parameters were taken every 10 minutes. Results from summer monitoring indicated that during fair-weather conditions, base flow water temperatures in the lower left fork of Jabez Branch varied from 15°C (59°F) at night to as high as 18°C (64.4°F) at mid-day on very hot days when air temperatures exceeded 32°C (89.6°F). Conductivity and pH at Station L001 remained fairly constant at 5.5 and 70 μmhos/cm respectively. Dissolved oxygen levels were monitored only from June 15 to 21. During this time period dissolved oxygen levels ranged from 8.5 to 9.6 mg/l.

A Hydrolab Datasonde-1 was also deployed in the right fork of Jabez Branch approximately 300 ft. above the confluence of the two forks. All base flow water quality values were approximately the same as those recorded on the left fork except for temperature which tended to be 2°C (3.6°F) above the left fork.

On June 28, 1990, a base flow stream profile survey of the left fork of Jabez Branch was done. Temperature, stream flow, pH and conductivity were measured at 100 feet intervals along the entire length of the perennial reach of the stream. Results of the survey are shown in Figure 5. Starting at the stream's headwaters, discharge increased steadily in the upper portion of the left fork to approximately 0.2 cfs within 1000 ft of the stream's mouth. Stream flow measurements then fluctuated around

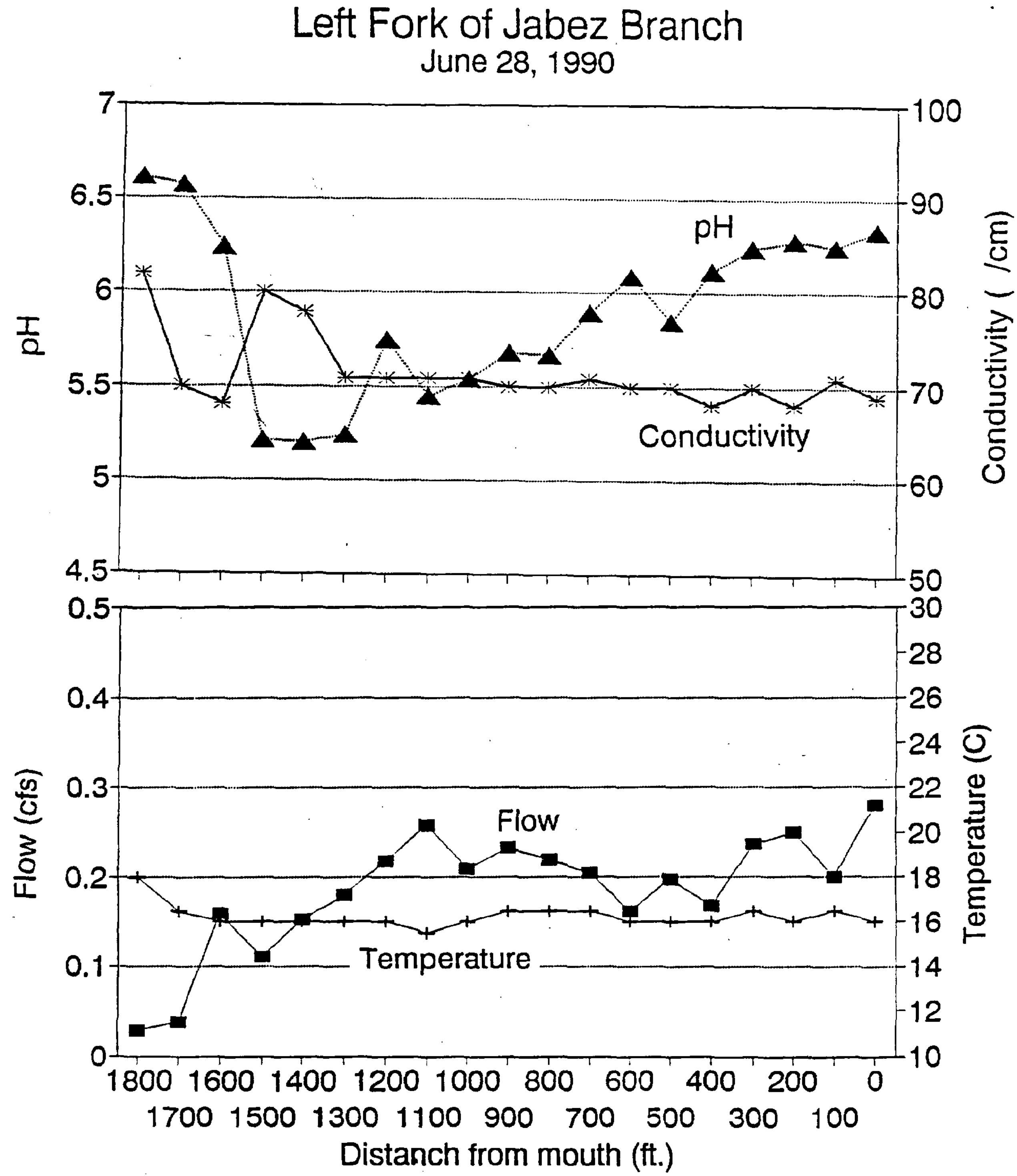


Figure 5. Results of stream profile survey of the left fork of Jabez Branch done on June 28, 1990.

0.2 cfs in the stream's lower section until just before merging with the right fork where it rose to 0.3 cfs. Temperature remained fairly constant around 16°C (60.8°F), and conductivity varied between 70 and 82 µmhos/cm in the upper portion of the stream and then remained fairly constant at 70 µmhos/cm down stream. The pH of the water in the left fork was 6.6 in the headwater of the stream, but dropped to 5.2 at approximately 1500 feet above the stream's mouth. The pH of the stream then rose steadily to 6.3 just before the channel merges with the right fork.

## Summer Storm Events

Between June 1 and September 30, a total of 29 precipitation events were recorded at the weather station in the upper Jabez Branch watershed. (Figures 6 through 9). Seventeen of these events were small, resulting in less than 0.25 inches of precipitation. Results from Station L001 near the mouth of the left fork showed no changes in either stream flow or water temperature following these small rain events. Of the remaining 12 rain events, 7 produced between 0.25 and 1.0 inches of rain, 4 produced 1 to 2 inches of rain and 1 large rain event produced over 2.65 inches of rain.

Changes in stream flow and water temperature in Jabez Branch

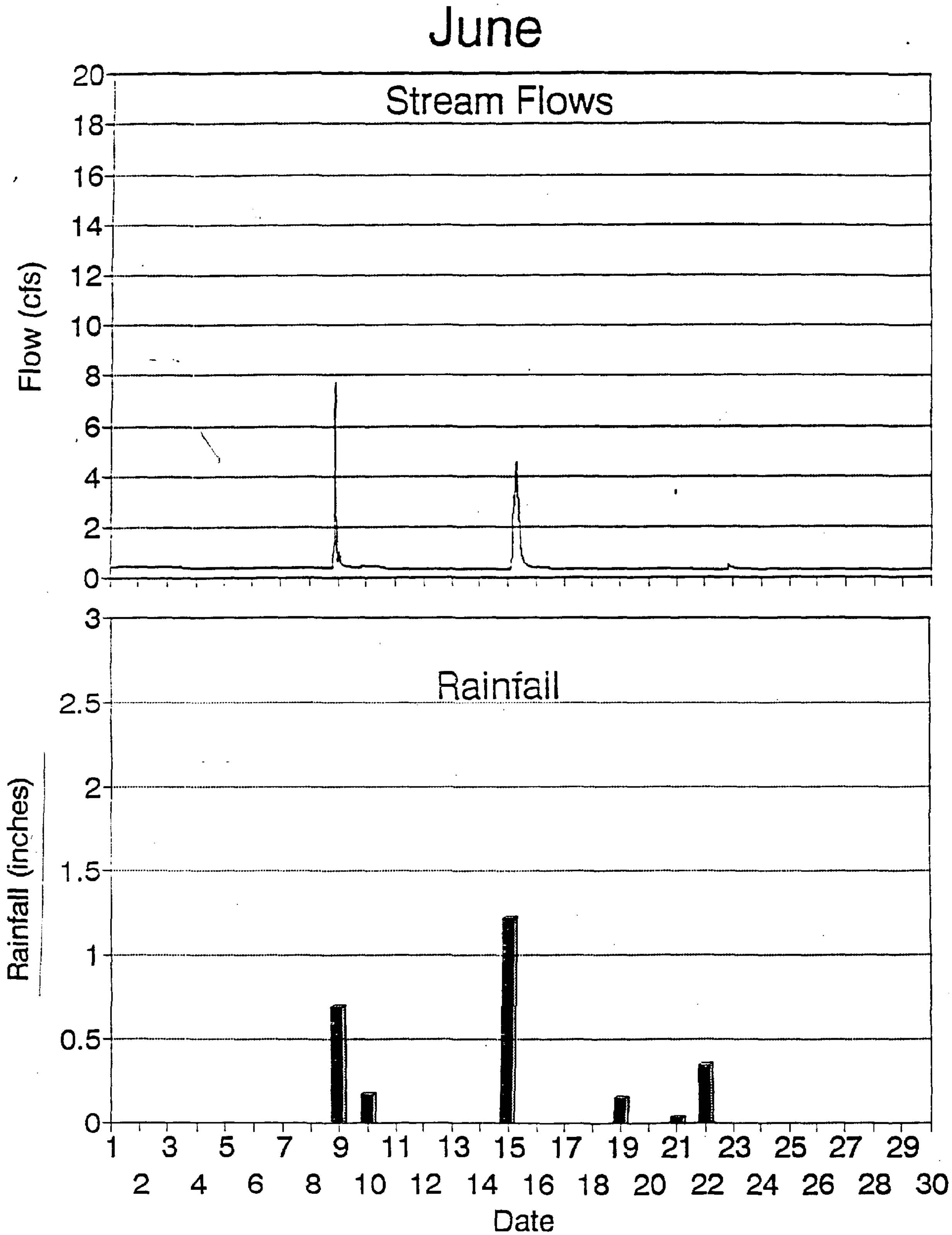


Figure 6. Graphs of stream flow (top) at Station L001 on the left fork of Jabez Branch and total daily rainfall (bottom) at the Lake Median weather station during June, 1990.

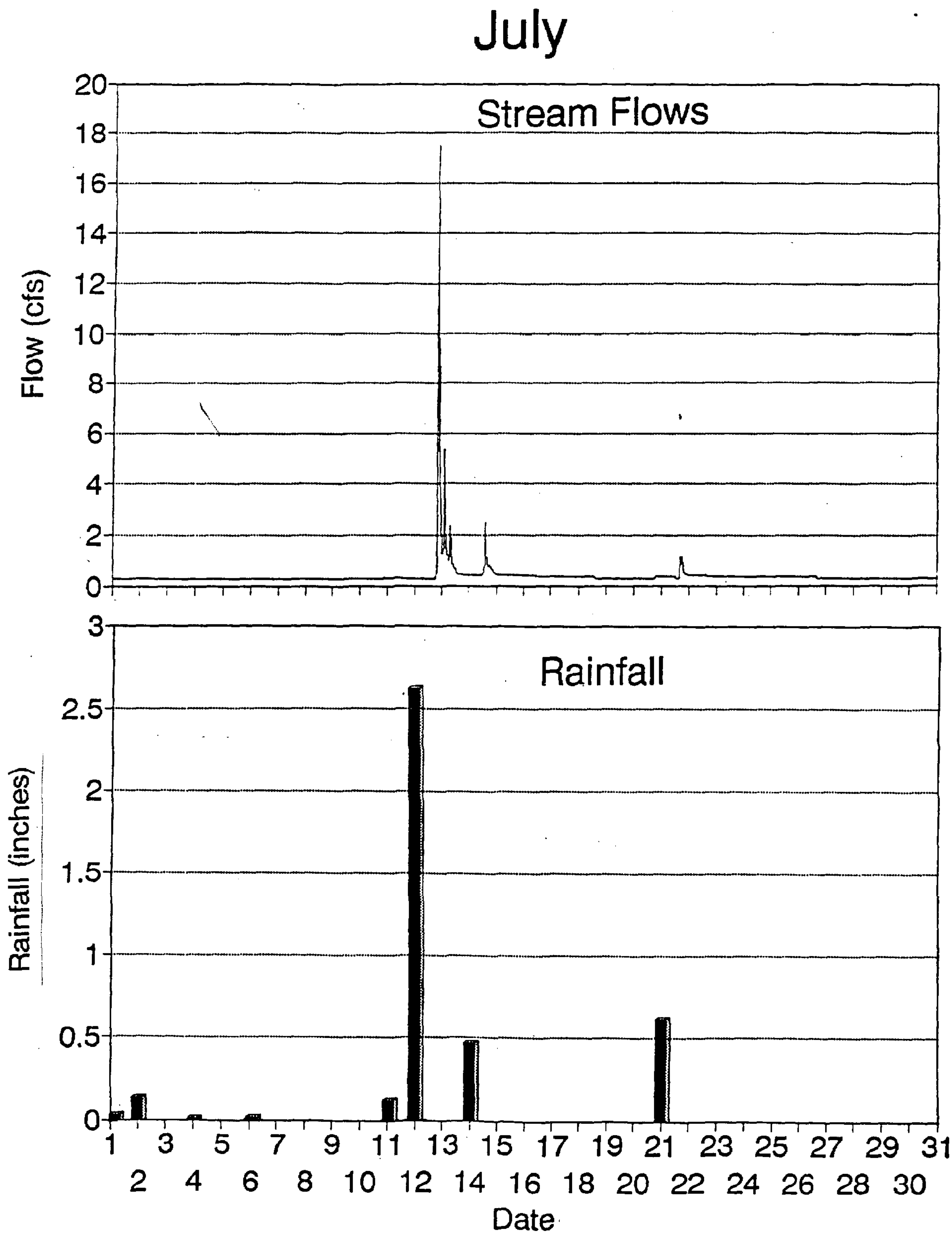


Figure 7. Graphs of stream flow (top) at Station L001 on the left fork of Jabez Branch and total daily rainfall (bottom) at the Lake Median weather station during July, 1990.

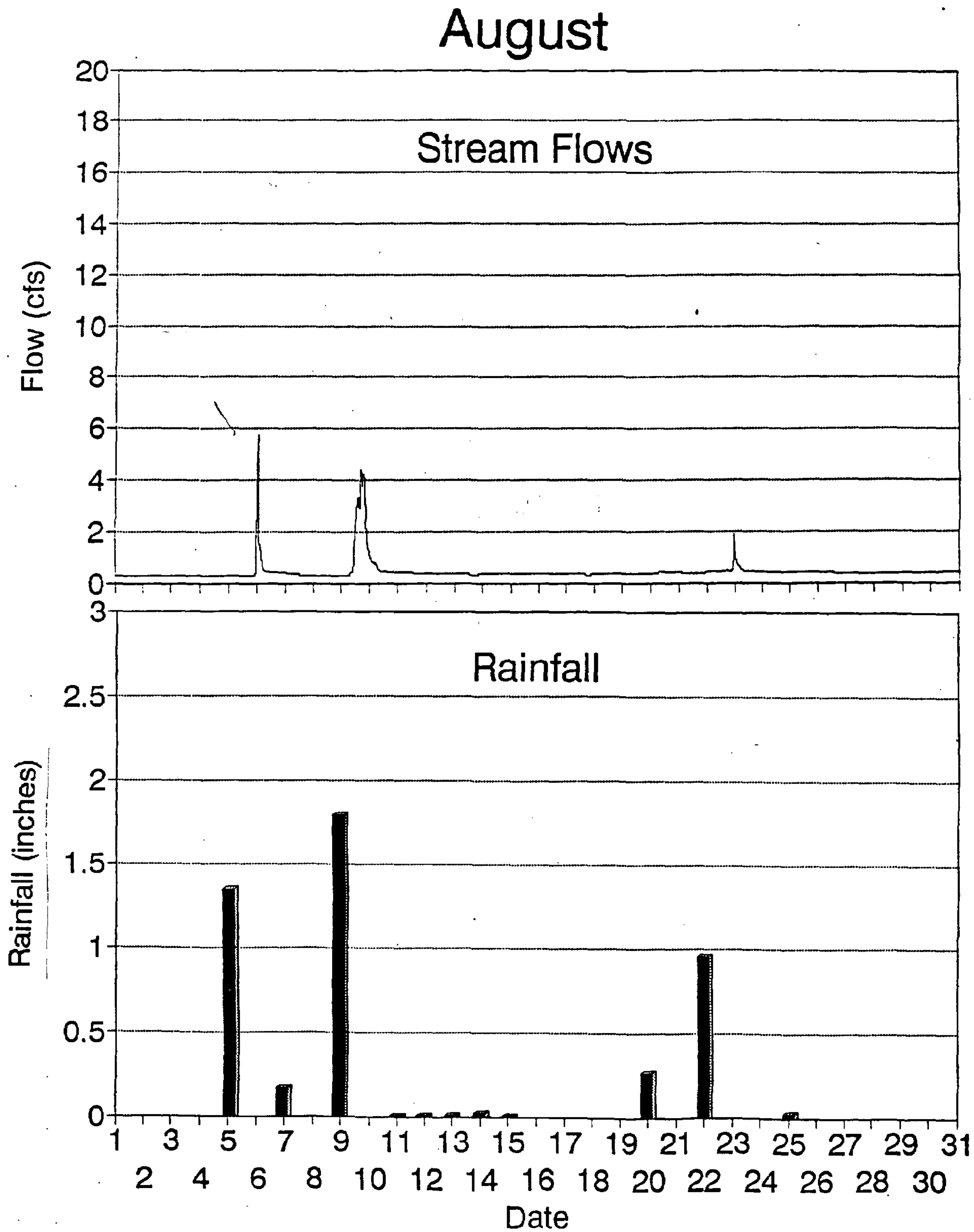


Figure 8. Graphs of stream flow (top) at Station L001 on the left fork of Jabez Branch and total daily rainfall (bottom) at the Lake Median weather station during August, 1990.

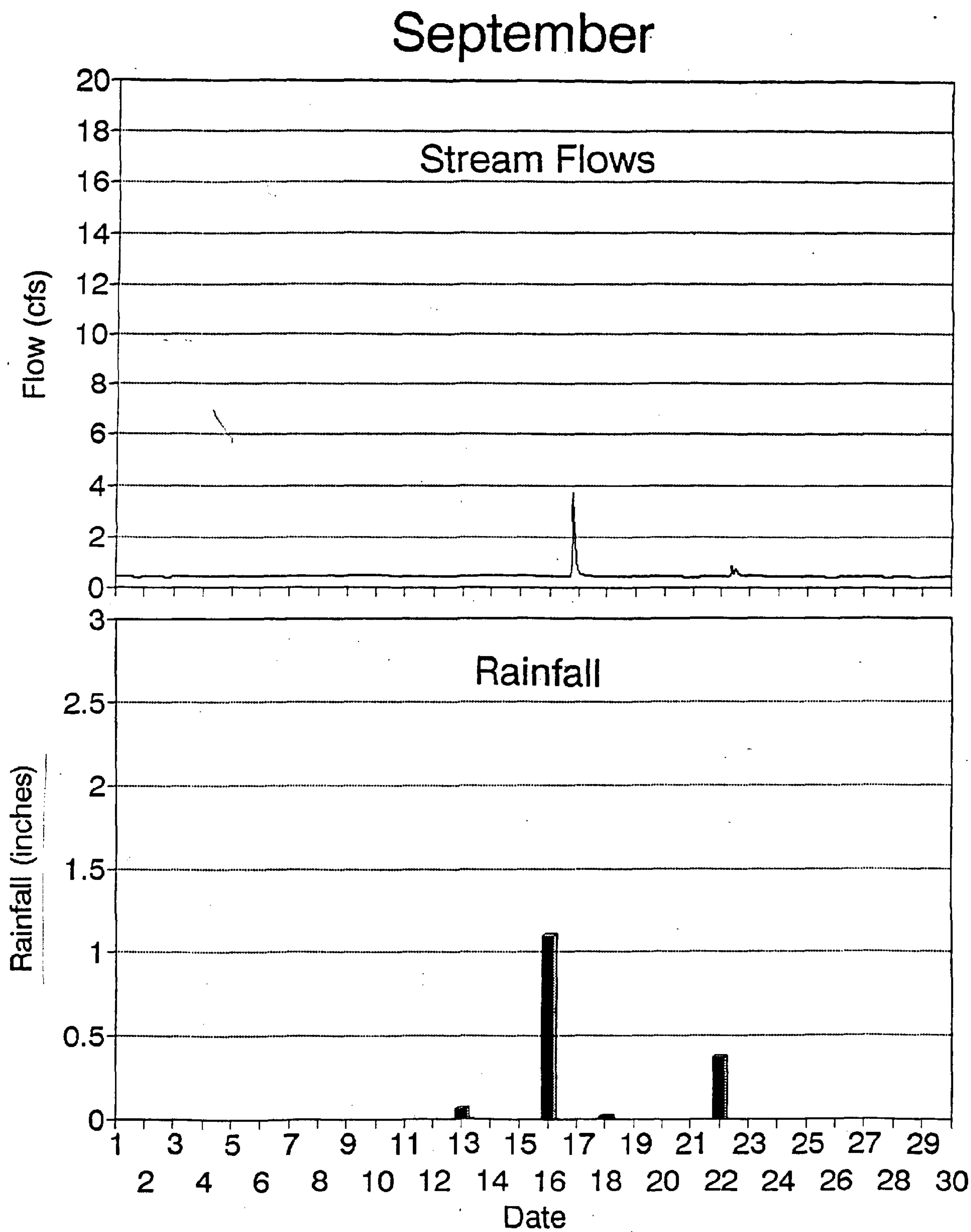


Figure 9. Graphs of stream flow (top) at Station L001 on the left fork of Jabez Branch and total daily rainfall (bottom) at the Lake Median weather station during September, 1990.

varied depending on the size of the rain event. The results of runoff and stream monitoring from three different size rain events in 1990 will be discussed in the following sections. The first rain event was the largest and produced 2.65 inches of rain on July 12 and 13. The second rain event occurred on August 5 & 6, and was a moderate size event producing 1.37 inches of rain. The third was a slightly small rain event which produced 1.14 inches of rain on September 16.

## July 12 & 13, 1990 (2.65 inches of rain)

On July 12, 1990, it began to rain at approximately 18:30. The exact time of the beginning of the rain event is not known because of problems with the tipping bucket rain gauge at the weather station on Jabez Branch. The amount of rain recorded by the tipping bucket rain gauge (Figure 10) was about half of that reported at BWI airport and at the backup rain gauge that was also located at the Jabez Branch weather station site. It was later discovered that the funnel on the top of the tipping bucket rain gauge was clogged and responsible for the faulty readings. Nonetheless, we do know that the greatest amount of precipitation occurred in the first few hours of the storm, and data from the backup rain gauge suggest that the rainfall pattern recorded at BWI Airport is a close approximation of that which occurred in the upper Jabez Branch watershed on July 12.

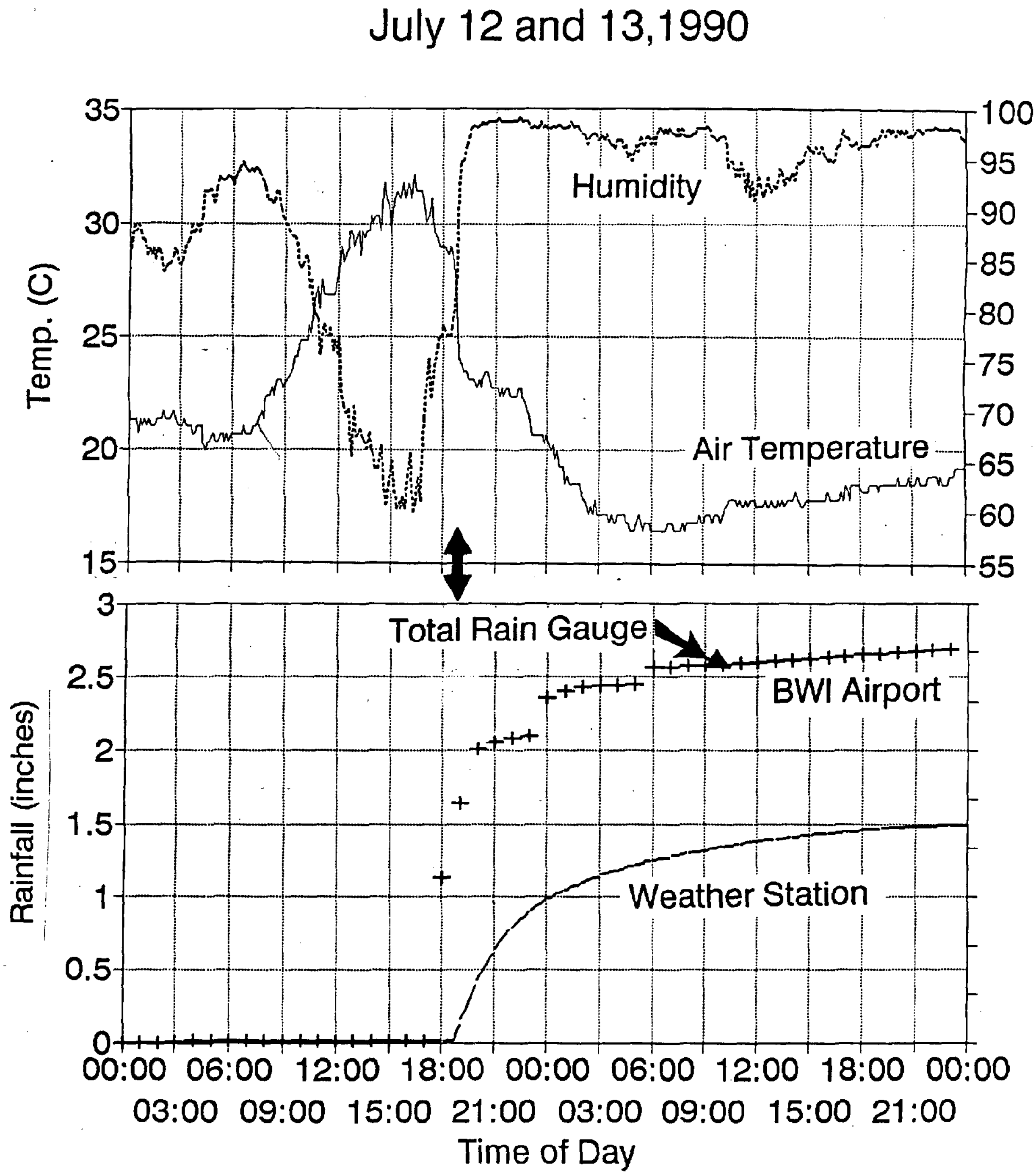


Figure 10. Graphs showing air temperature (top), humidity (top) and rainfall (bottom) at Lake Median weather station and BWI airport on July 12 and 13, 1990. Arrows indicates beginning of rain event.

Other measurements from the Jabez Branch weather station are shown in Figure 10. Air temperatures on July 12 reached a high of 31.7°C (89.1°F) at 15:41 in the afternoon and cooled to around 29°C (84.2°F) before it began to rain. At the start of the rain event, air temperatures dropped to 23°C (73.4°F). No monitoring devices were established in 1990 to measure the temperature of the rain water. It is believed, however, that during the rain event the temperature of the rain water will be approximately the same as the recorded air temperature. Additional measurements will be needed to verify this.

Figure 11 shows results of temperature and flow monitoring along the left fork of Jabez Branch. Station L109, is located at the head of the intermittent stream channel and measures the temperature of runoff from the upper developed sections of the watershed as they flow into the lower forested section. This station records air temperature until runoff reaches the probe. During the storm of July 12, the recorded temperature at Station L109 increased to 25.8°C (78.4°F) when runoff reached this station. The next downstream monitoring station is L003 which was located just below the headwaters of the stream in the perennial stream channel. At the beginning of the rain event, water temperature rises from 17.1°C (62.8°F) to 19°C (66.2°F) at Station L003. This initial rise was followed by a second rapid temperature rise to 23.9°C (75°F). The last Station is L001, which was located near the mouth of the left fork. Temperature

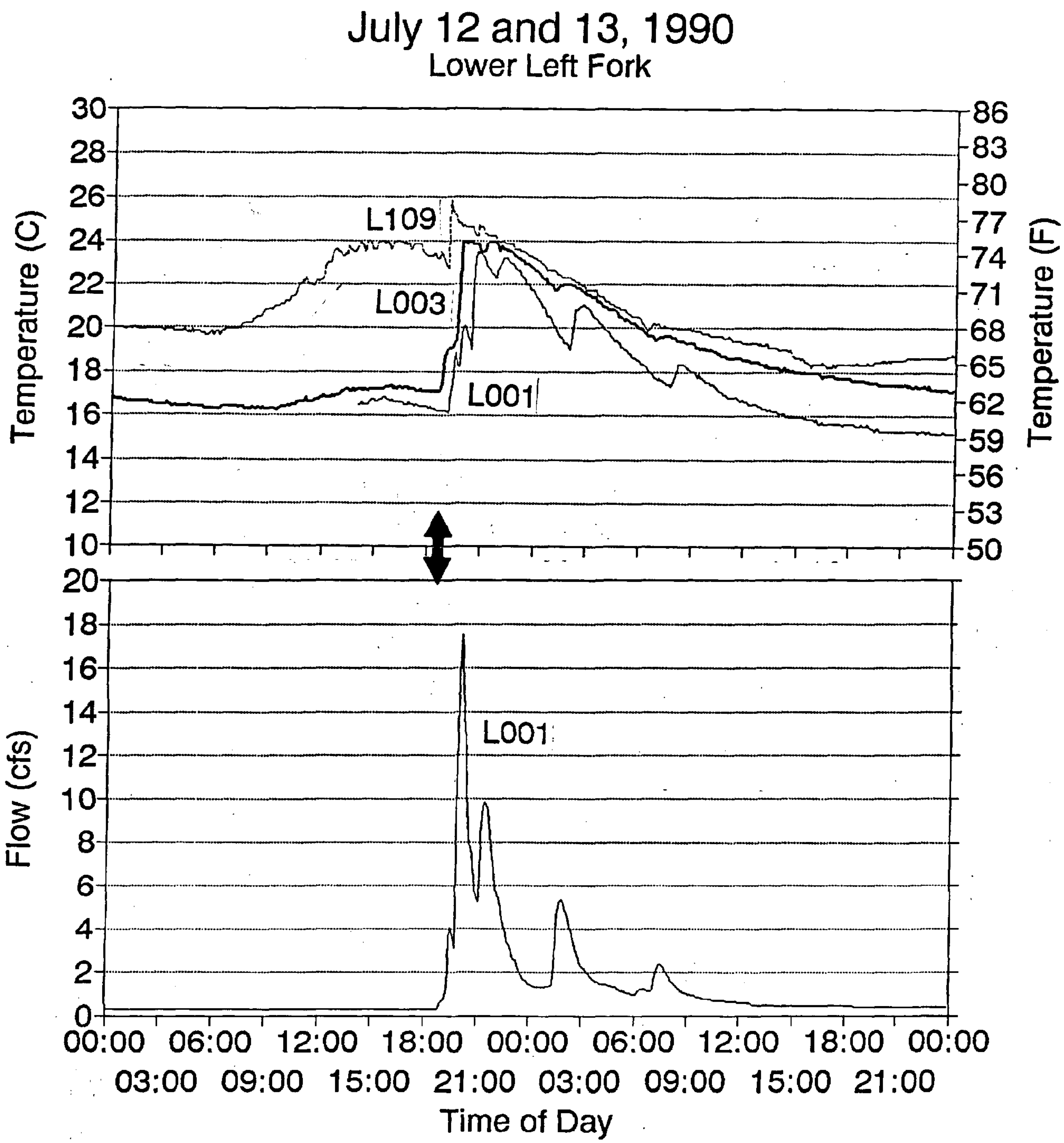


Figure 11. The top graph shows the temperatures recorded at Stations L109, L003 and L001 along the main channel of the left fork of Jabez Branch on July 12 and 13, 1990. The bottom graph shows stream flow (cfs) at Station L001 during the same time period. Arrows indicate beginning of rain event.

monitoring at Station L001 also indicated an initial rise in water temperature from 16.2°C (61.2°F) to 20°C (68°F) shortly after the beginning of the rain event. The initial small rise in water temperature was quickly followed by a second larger increase to 23.5°C (74.3°F).

Stream flow monitoring indicated that the temperature rise at Station L001 corresponded to increases in stream flow. During the first rise in water temperature, discharge at Station L001 increased from 0.3 to 4.0 cfs. This was then quickly followed by a second rise to 17.5 cfs as the wave of heated runoff from the upper developed portion of the watershed reached this station.

A similar rise in water temperature was seen in the right fork of Jabez Branch at Station R001 (Figure 12). Water temperature in the lower right fork rose to a high of 23.2°C (73.8°F). The change in water temperature, however, was not as great as that on the left fork because base flow water temperature on the right fork was already higher.

In addition to changes in temperature, both the right and left forks of Jabez Branch experienced similar changes in stream pH following the rain event. At the beginning of the storm the pH of both the left and right forks dropped 0.4 and 0.9 pH units respectively. This initial drop was soon followed by a rise in the pH of both streams to around 6. An earlier profile survey of the left fork of Jabez Branch indicated that the middle portion

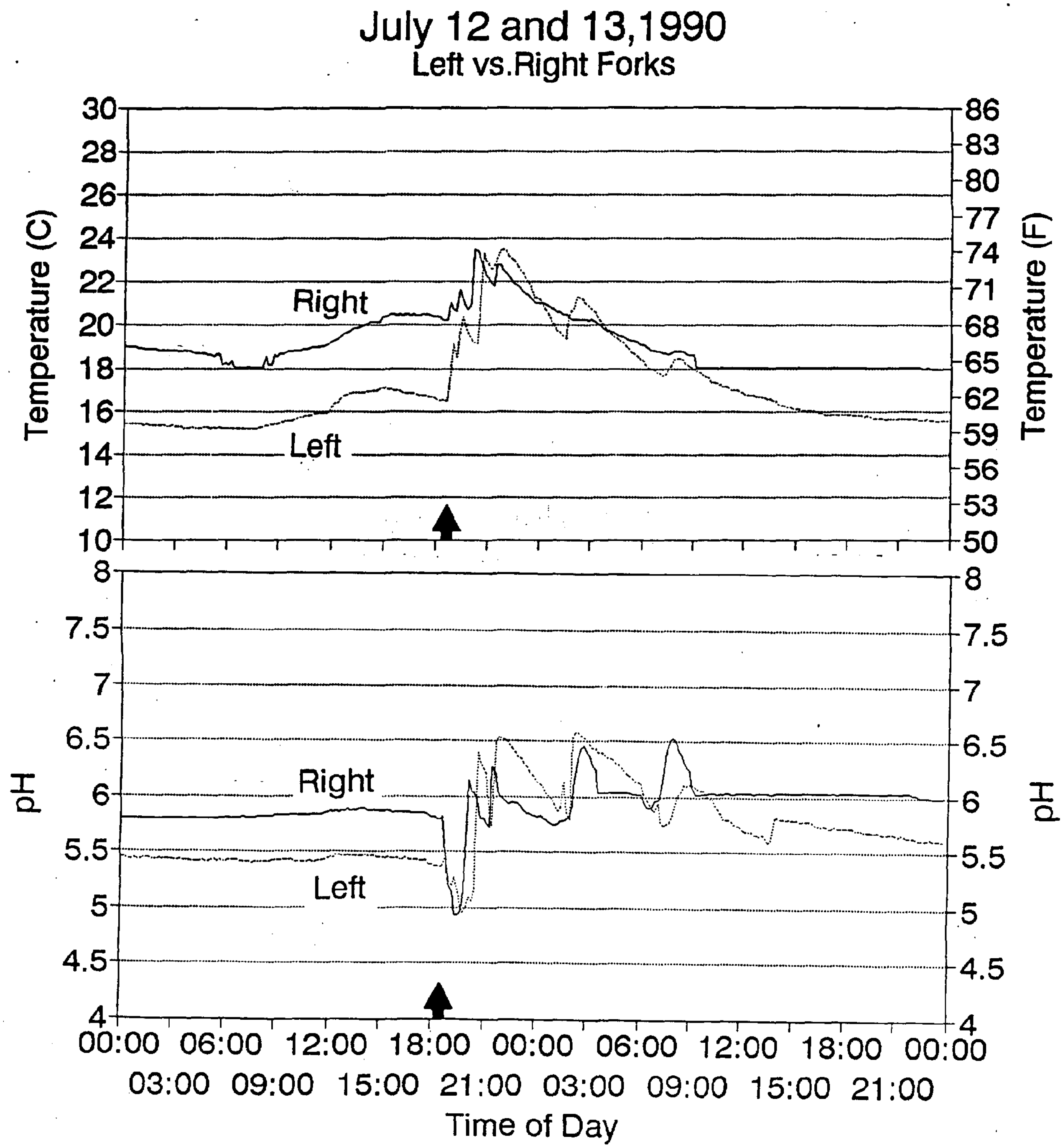


Figure 12. Graphs showing comparisons of continuous temperature (top) and pH (bottom) measurements from the left and right forks of Jabez Branch on July 12 and 13, 1990. Arrows indicate beginning of rain event.

of the stream did have reduced pH levels (Figure 5). The initial drop in pH seen at Stations L001 and R001 may be due to either the reduced pH water upstream moving downstream quickly at the beginning of the rain event or because the pH of the runoff entering the stream at the beginning of the storm is lower. Additional monitoring of pH above Station L001 will be needed to determine the cause of the changes seen in 1990.

Temperature monitoring results in the upper intermittent channels of the left fork of Jabez Branch are shown in Figure 13. The arrow on the graphs indicates the start of the July 12 rain event. Prior to the beginning of the rain event, the temperature recorders are measuring air temperatures in the intermittent stream channels. Temperature recorders at Stations L101, L102 and L103 monitored the runoff primarily from agriculture land. Results indicated that at the beginning of the rain event, the temperature of the runoff at these stations, as initially around 23°C (73.4°F). As the storm progressed temperature measurements at these stations rose to 25°C (77°F). Stations L106 and L107, on the other hand, receive runoff from the more urbanized sections of the watershed (Table 3). The temperature monitors at these stations showed that the runoff from the more urbanized sections was initially above 27°C (80.6°F) and then dropped to just below 25°C (77°F). In contrast to these stations in the upper watershed, Station L110 measured the temperature of runoff from a 96 % forested drainage basin. The temperature of the runoff from the forested section of the left fork remained fairly

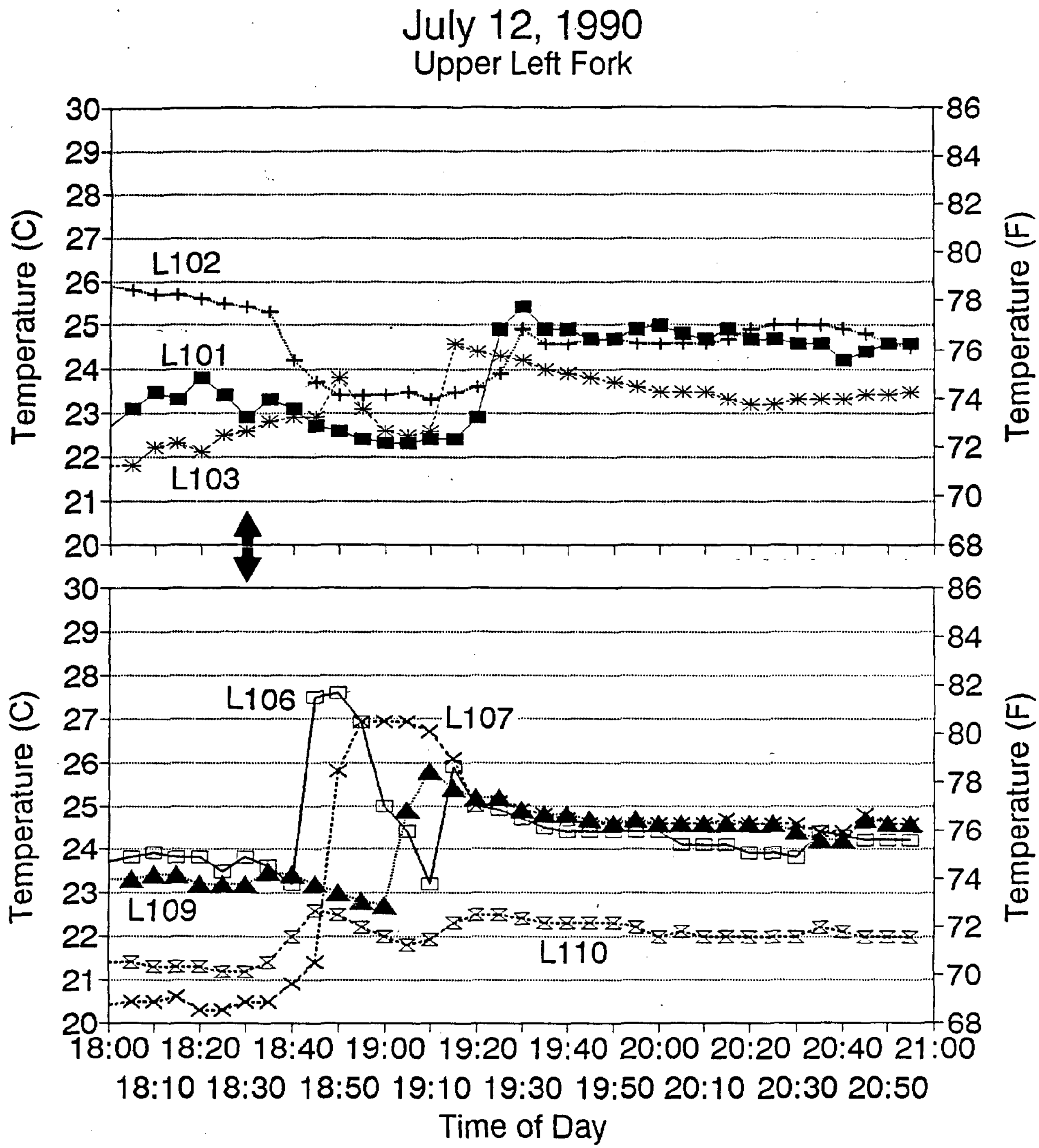


Figure 13. Temperature measurements from intermittent drainage channels in the upper left fork of Jabez Branch on July 12, 1990 between 18:00 and 21:00. Arrows indicate beginning of rain event.

constant at around 22°C (71.6°F).

Results of monitoring at the two special land use stations are shown in Figure 14. On July 12, the temperature of the road's surface (Station RoadTe) reached a high of 45.3°C (113.5°F) and cooled to 37°C (98.6°F) just prior to the beginning of the rain event. The road's surface temperature then dropped to around 30°C (86°F) shortly after it began to rain. The probe measuring the temperature of the highway runoff was positioned just above the road's surface and tended to remain approximately 6°C (10.8°F) below the temperature of the road surface in dry weather. Once the rain started, the temperature of the water running off of the highway was initially just below 28°C (82.4°F) and later dropped to between 26°C (78.8°F) and 25°C (77°F).

Results of temperature monitoring of runoff from an industrial roof in the watershed indicated that the temperature of the roof runoff at the beginning of the storm was 24.5°C (77.9°F). As the storm progressed, the runoff temperature dropped to between 23°C (73.4°F) and 22°C (71.6°F).

### August 5 & 6, 1990 (1.37 inches of rain)

August 5 was a cloudy humid day with air temperatures reaching a high of 27.2°C (81°F) at 15:52 (Figure 15). Trace

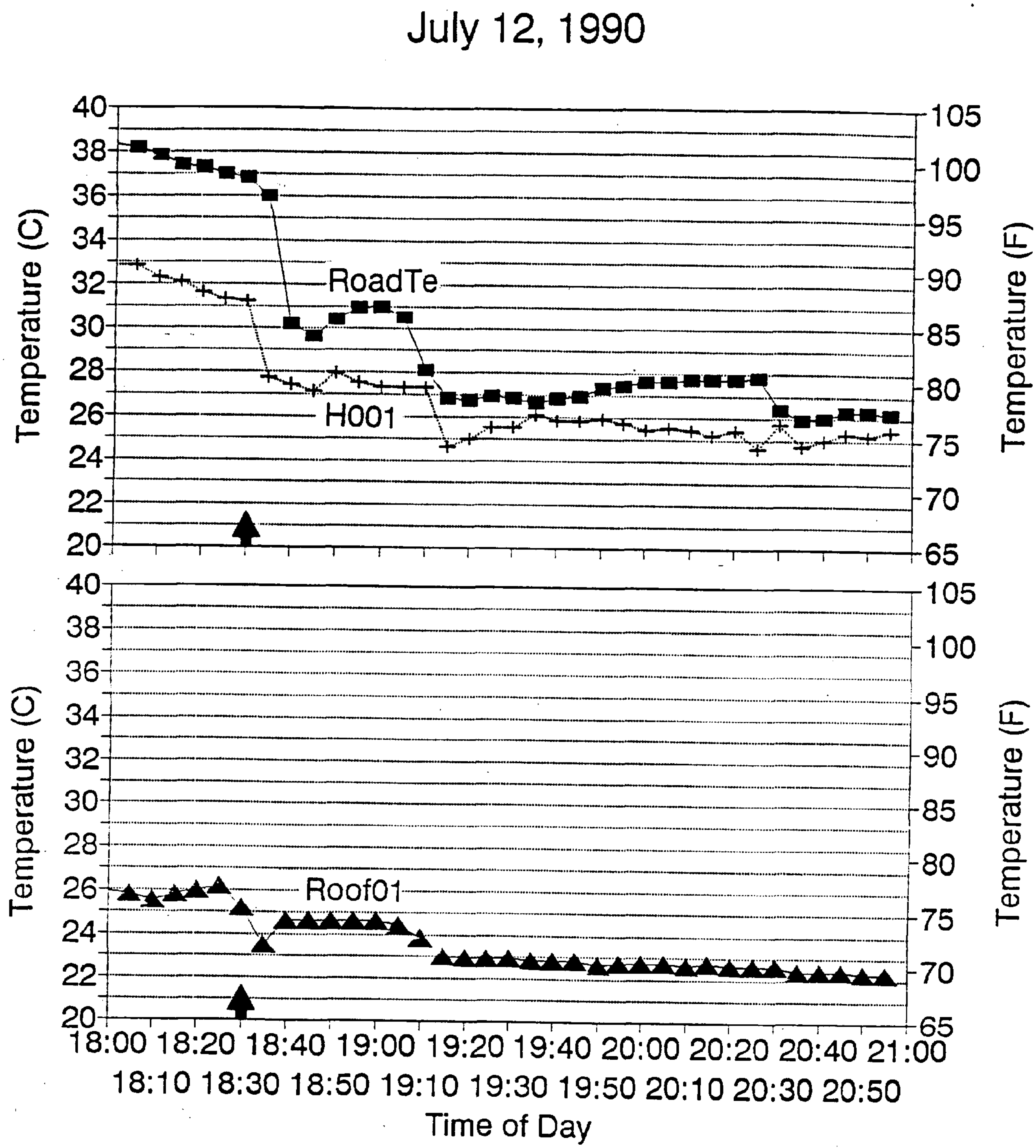


Figure 14. Temperature measurements from the special land use monitoring stations in the upper watershed of the left fork of Jabez Branch on July 12, 1990 between 18:00 and 21:00. In the top graph Station RoadTe shows the temperature of the surface of Rt. 3 while Station H001 shows the temperature of the highway runoff. The bottom graph shows the temperatures measured in the drain from an industrial roof in the watershed. Arrows indicate beginning of rain event.

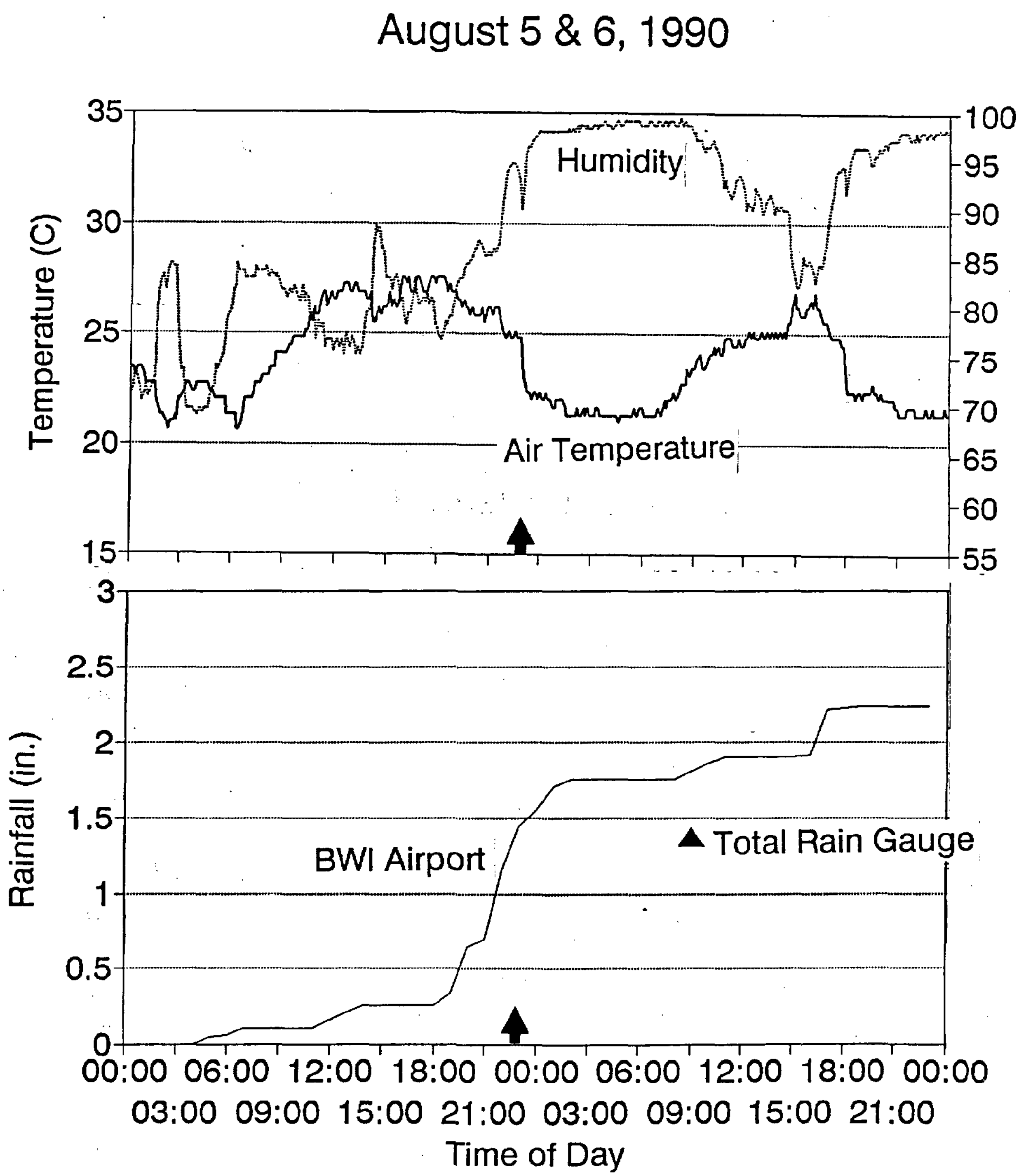


Figure 15. Graphs showing air temperature (top), humidity (top) and rainfall (bottom) at Lake Median weather station and BWI airport on August 5 and 6. Arrows indicate beginning of rain event.

amounts of rain were reported throughout the day at BWI Airport with a moderately size rain event occurring in the evening (Figure 15). Data from the field weather station and the backup rain gauge at Jabez Branch indicate that the rain event occurred at night at approximately 23:00. The exact time it started to rain in the Jabez Branch watershed is unknown because the tipping bucket rain gauge at the field weather station was not functioning. The backup rain gauge which measures total rainfall indicates that 1.37 inches of rain fell in the area that night.

Figure 16 shows the temperatures recorded at Stations L001, L003 and L109, along the left fork of Jabez Branch, and stream discharge at the USGS gauging station. Temperature measurements show the same general patterns as those of the July 12 rain event. At the beginning of the storm a small immediate rise in water temperature occurred at Stations L003 and L001 along with a rise in discharge at Station L001. This initial rise was then followed by much greater temperature and flow increases. The increase in temperature and flow, however, were not as great as had been seen on July 12. Water temperatures on August 5 increased only 5.2°C (9.4°F), as opposed to the 7.3°C (13.1°F) that occurred on July 12. The difference in the size of the temperature increases between the two rain events is believed due to three reasons. First, the amount of rainfall on August 5 was only half as much as on July 12. Second, air temperature on August 5 reached a high of only 27.2°C (81°F) while on July 12 the high for the day was 31.7°C (89.1°F). Finally, the rain

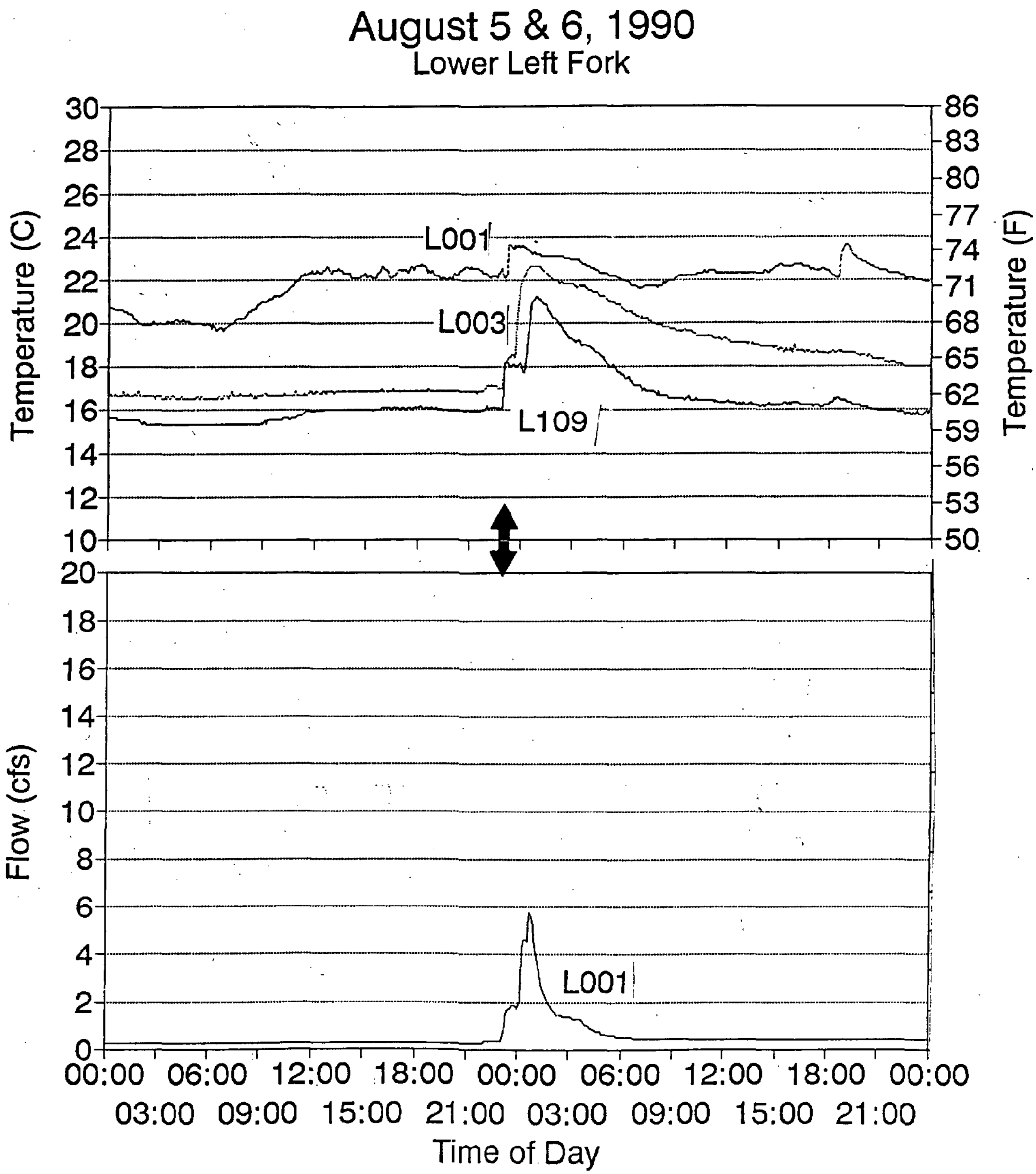


Figure 16. The top graph shows the temperatures recorded at Stations L109, L003 and L001 along the main channel of the left fork of Jabez Branch on August 5 and 6, 1990. The bottom graph shows stream flows (cfs) at Station L001 during the same time period. Arrows indicate beginning of rain event.

event on August 5, occurred at night (23:00), whereas on July 12, the rain started in the late afternoon (18:30). Because the rain event occurred at night on August 5, roads and other surfaces in the watershed had some time to cool. However, despite the fact that the August 5 rain event occurred at night following only a moderately warm day, water temperatures in the left fork of Jabez Branch still exceeded the Maryland water quality standard for natural trout waters of 20°C (68°F).

Monitoring data for pH was obtained only from Station L001 during this time period. The pH levels (Figure 17) at Station L001 showed the same initial drop at the beginning of the rain event as on July 12 (Figure 12) before rising to around 6.

Results of temperature monitoring of runoff in the upper drainage channels on the left fork are shown in Figure 18. Prior to the beginning of the rain event, these recorders measured air temperature. At the start of the rain event, the temperatures of the runoff at Stations L101, L102 and L103 were all around 22°C (71.6°F). Temperatures then rose slightly at Stations L101 and L102 to 23°C (73.4°F), while at Station L003, the temperature of the runoff dropped to near 21°C (69.8°F). At Stations L106 and L107 which drain more developed sections of the watershed, the temperature of the runoff was just below 24°C (75.2°F). At Station L110, which monitors the runoff from a forested section of the watershed, the temperature of the runoff was just below 22°C (71.6°F).

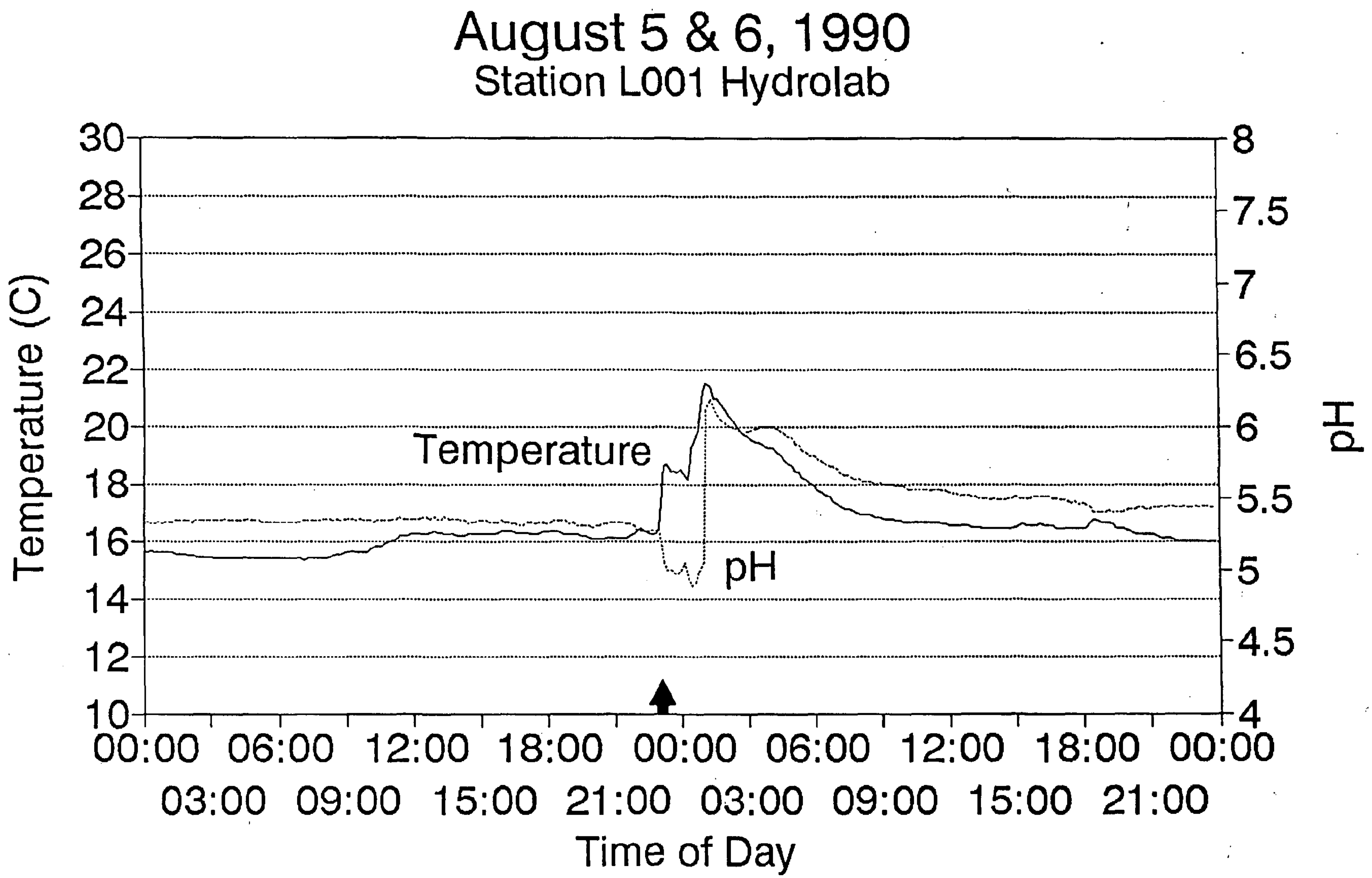


Figure 17. Graphs showing continuous temperature and pH measurements from the left fork of Jabez Branch on August 5 and 6, 1990. Arrow indicate beginning of rain event.

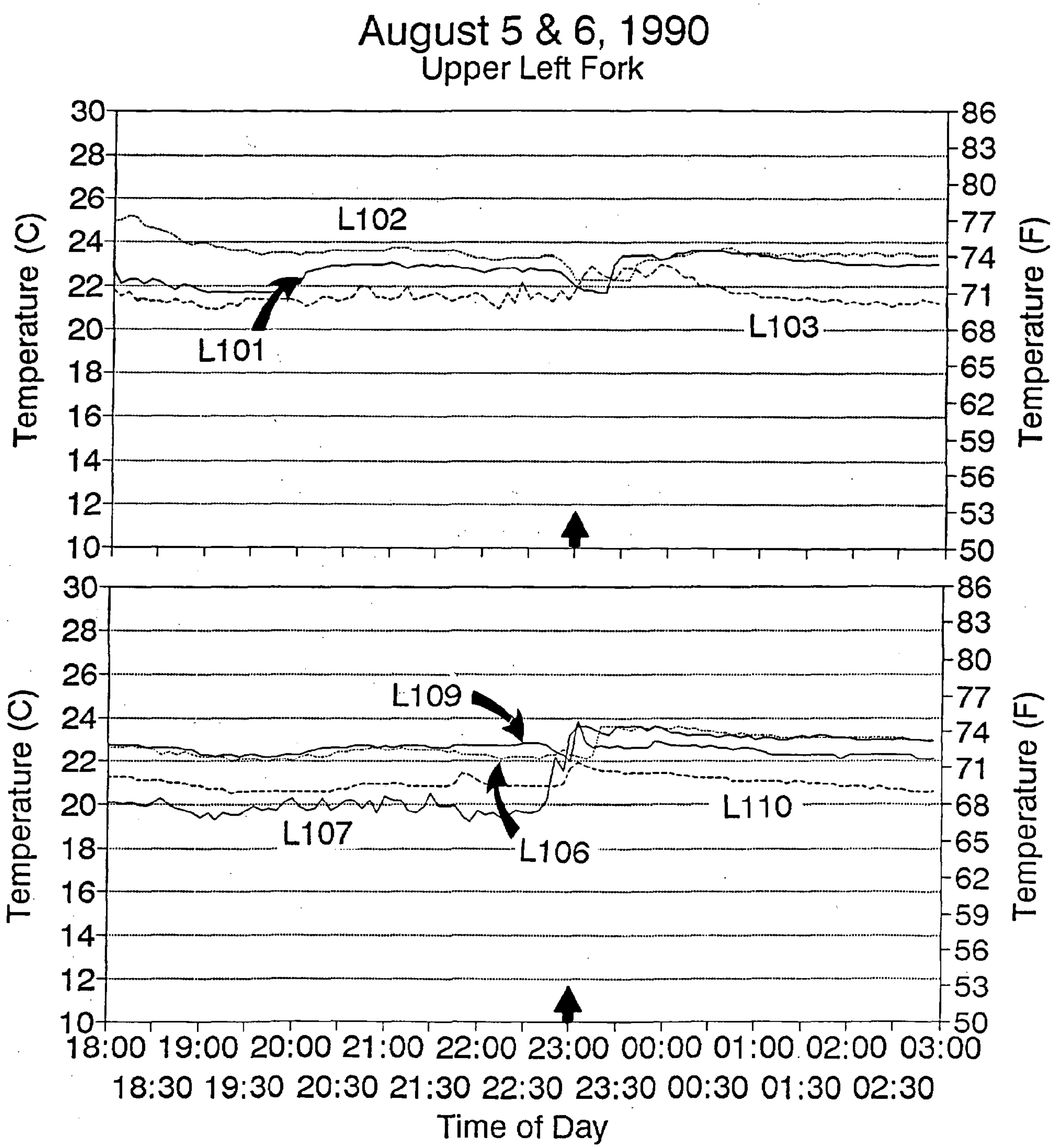


Figure 18. Temperature measurements from intermittent drainage channels in the upper left fork of Jabez Branch on August 5 and 6, 1990 between 18:00 and 3:00. Arrows indicate beginning of rain event.

Results from the two special land use monitoring sites are given in Figure 19. The temperature of the road's surface reached a high of 37.2°C (98.6°C) at 12:45 and cooled to 26°C (78.8°F) at the beginning of the rain event. Due to equipment problems, no measurements of the temperature of the runoff for the highway were obtained. The temperature of the water from an industrial roof was 23°C (73.4°C) at first and dropped to 22°C (71.6°C) later in the storm.

## September 16 & 17, 1990 (1.14 inches of rain)

The final rain event occurred on September 16 and produced 1.14 inches of rain. Air temperatures preceding this rain event reached a high of only 23.4°C (74°F) at 14:55. Air temperatures then dropped to 20.9°C (69.7°F) before it began raining at 17:30 (Figure 20).

As shown in Figure 21, monitoring stations along the main stream channel of the left fork of Jabez Branch recorded much smaller temperature rises for the September 16 rain event than in the other two previously discussed storms. Results from Station L109 indicate that the temperature of the runoff from the developed upper section of the watershed reached a high of only 19.5°C (67.1°F). As runoff moved downstream to Station L003, the

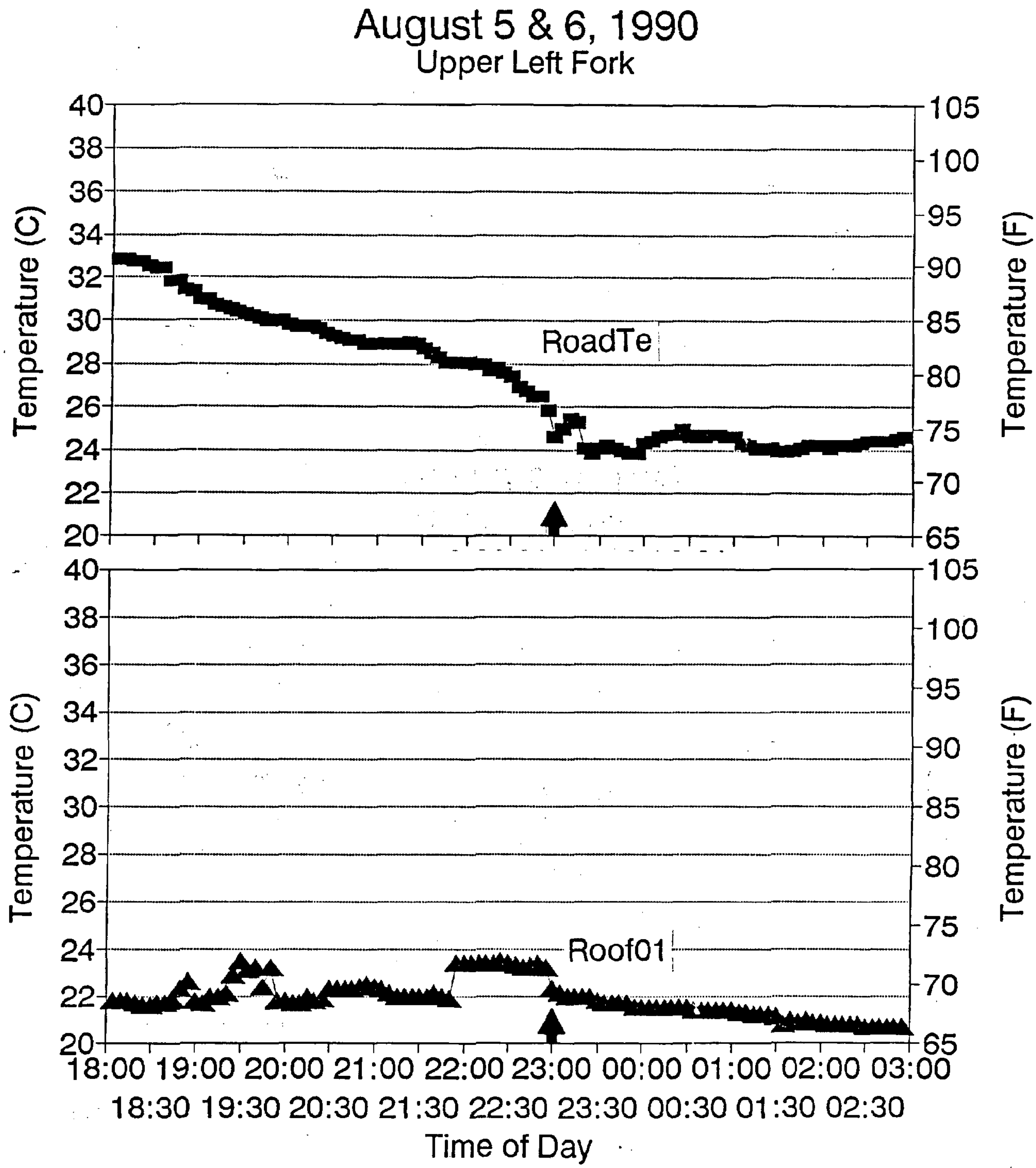


Figure 19. Temperature measurements from the special land use monitoring stations in the upper watershed of the left fork of Jabez Branch on August 5 and 6, 1990 between 18:00 and 3:00. In the top graph Station RoadTe shows the temperature of the surface of Rt. 3, and the bottom graph shows the temperatures measured in the drain from an industrial roof in the watershed. Arrows indicate beginning of rain event.

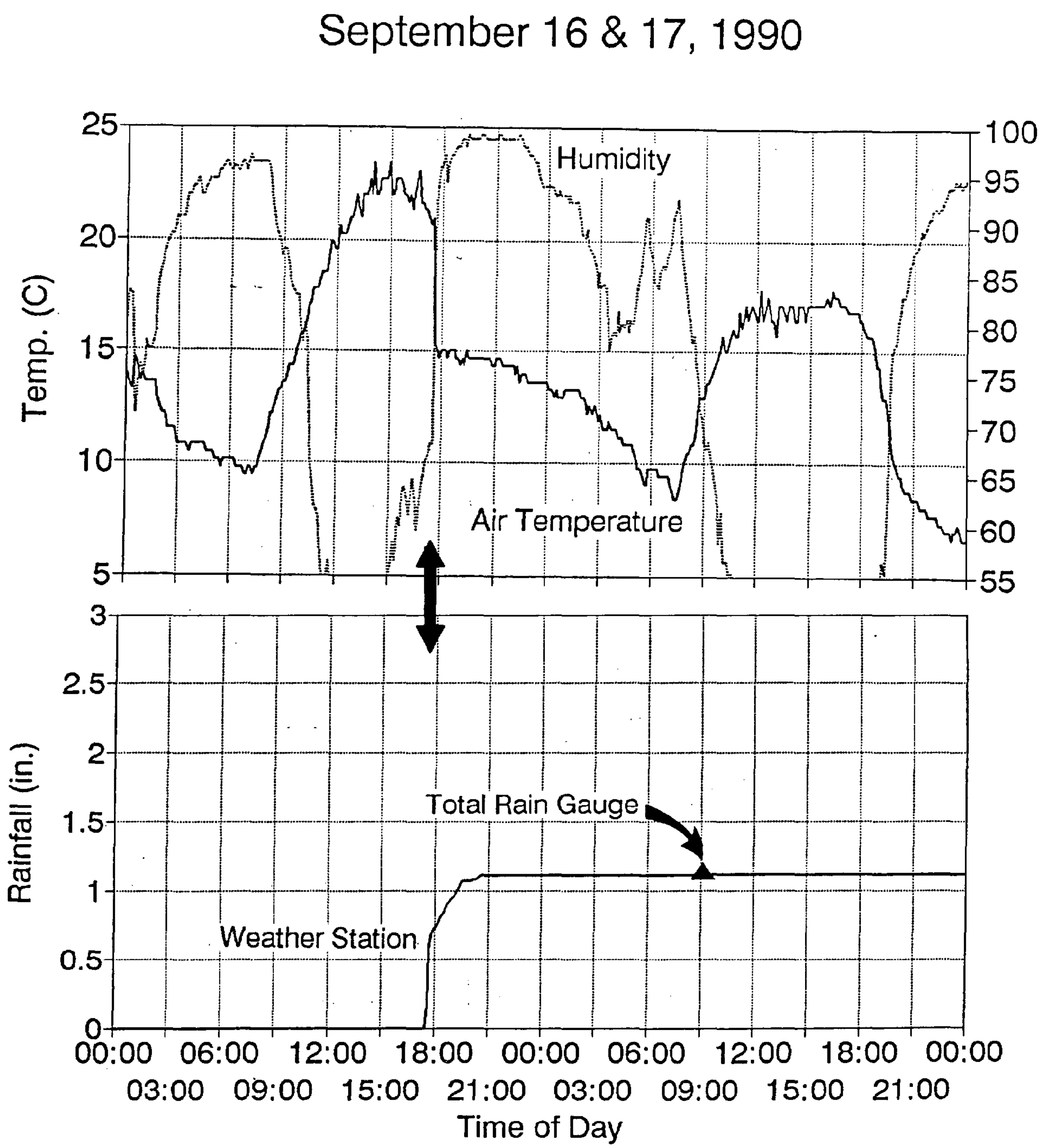


Figure 20. Graphs showing air temperature (top), humidity (top) and rainfall (bottom) at Lake Median weather station and BWI airport on September 16 and 17, 1990. Arrows indicate beginning of rain event.

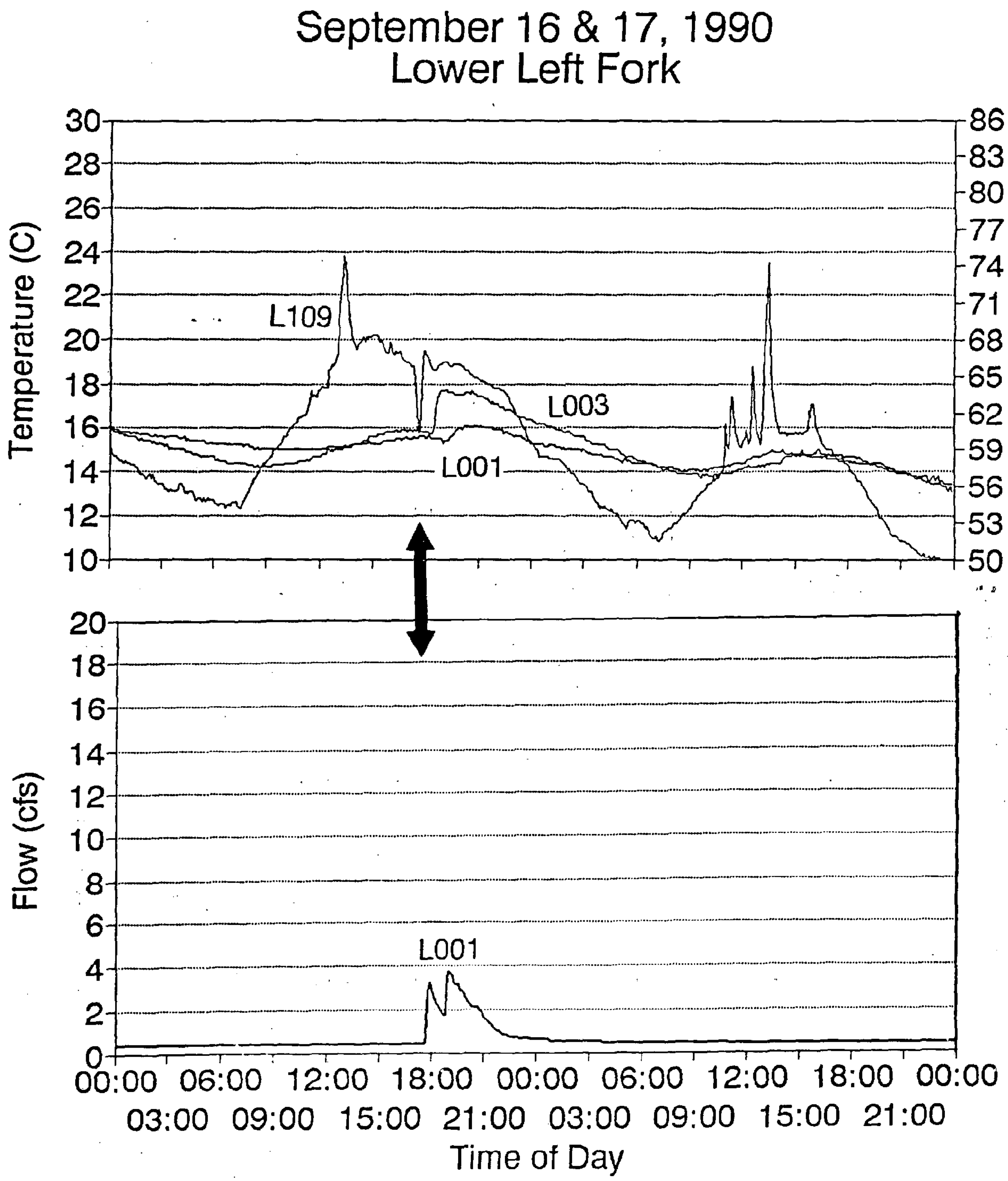


Figure 21. The top graph shows the temperatures recorded at Stations L109, L003 and L001 along the main channel of the left fork of Jabez Branch on September 16 and 17, 1990. The bottom graph shows stream flows (cfs) at Station L001 during the same time period. Arrows indicate beginning of rain event.

water temperature high dropped to 17.7°C (63.9°F). Finally, when the runoff from the upper portion of the watershed reached Station L001 at the mouth of the left fork, only a 0.6°C (1.1°F) rise in water temperature to 16.1°C (61°F) was recorded. The peak flow at Station L001 was 3.8 cfs (Figure 21).

As reported in the two previously discussed rain events, both temperature and pH changes followed the same patterns on both the left and right forks of Jabez Branch (Figure 22). Water temperatures on both streams rose around 0.5°C (0.9°F) and pH on both forks initially dropped at the beginning of the rain event and then rose to around 6 when runoff from the upper portion of the watershed reached the mouth of both forks.

In the upper developed portion of the watershed, the temperature of runoff from urbanized sections of the watershed (Stations L106 and L107) was above 19°C (66.2°F) (Figure 23). Runoff temperature from the more agricultural areas (Stations L101 and L102) were between 17°C (62.6°F) and 19°C (66.2°F) (Figure 23).

Figure 24, shows results from the two special land use sites. At the Rt. 3 site, the temperature of the surface of the highway reached a high of 46.2°C (115.2°F) at 15:05 in the afternoon and cooled to around 28°C (82.4°F) before it started raining. After the rain began, the temperature of the runoff from the highway was 22°C (71.6°F). The temperature of the

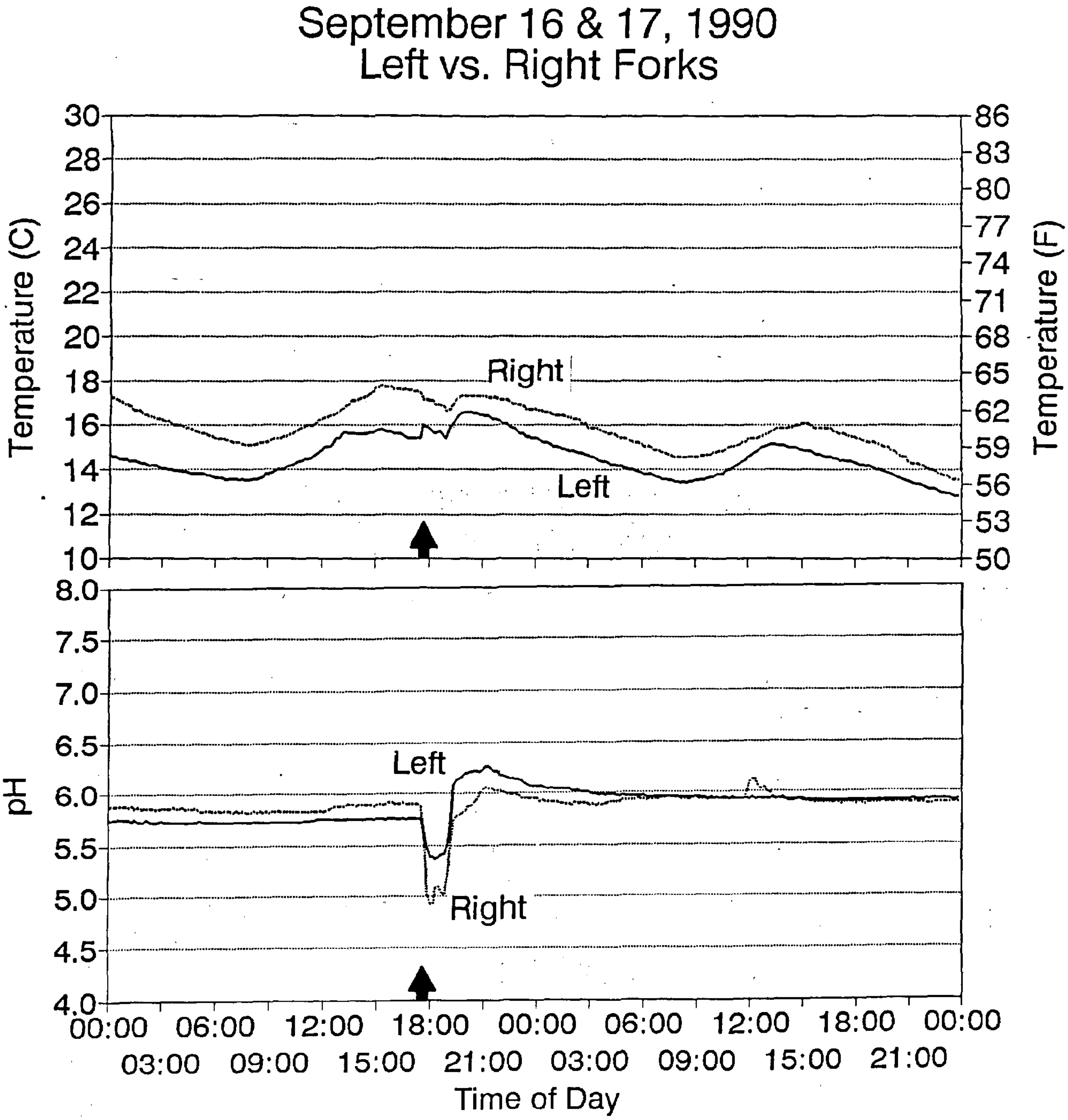


Figure 22. Graphs showing comparisons of continuous temperature (top) and pH (bottom) measurements from the left and right forks of Jabez Branch on September 16 and 17, 1990. Arrows indicate beginning of rain event.

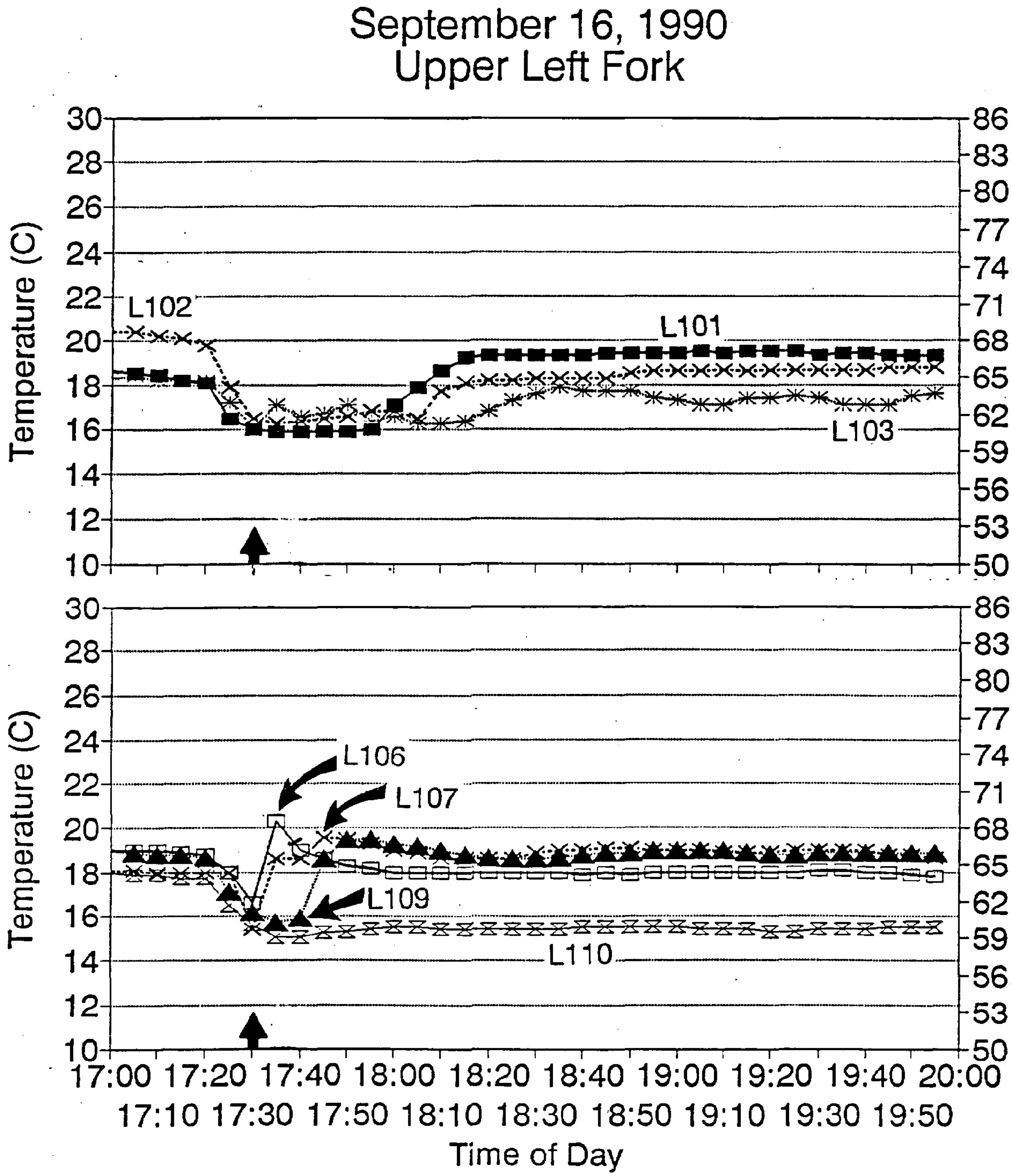


Figure 23. Temperature measurements from intermittent drainage channels in the upper left fork of Jabez Branch on September 16, 1990 between 17:00 and 20:00. Arrows indicate beginning of rain event.

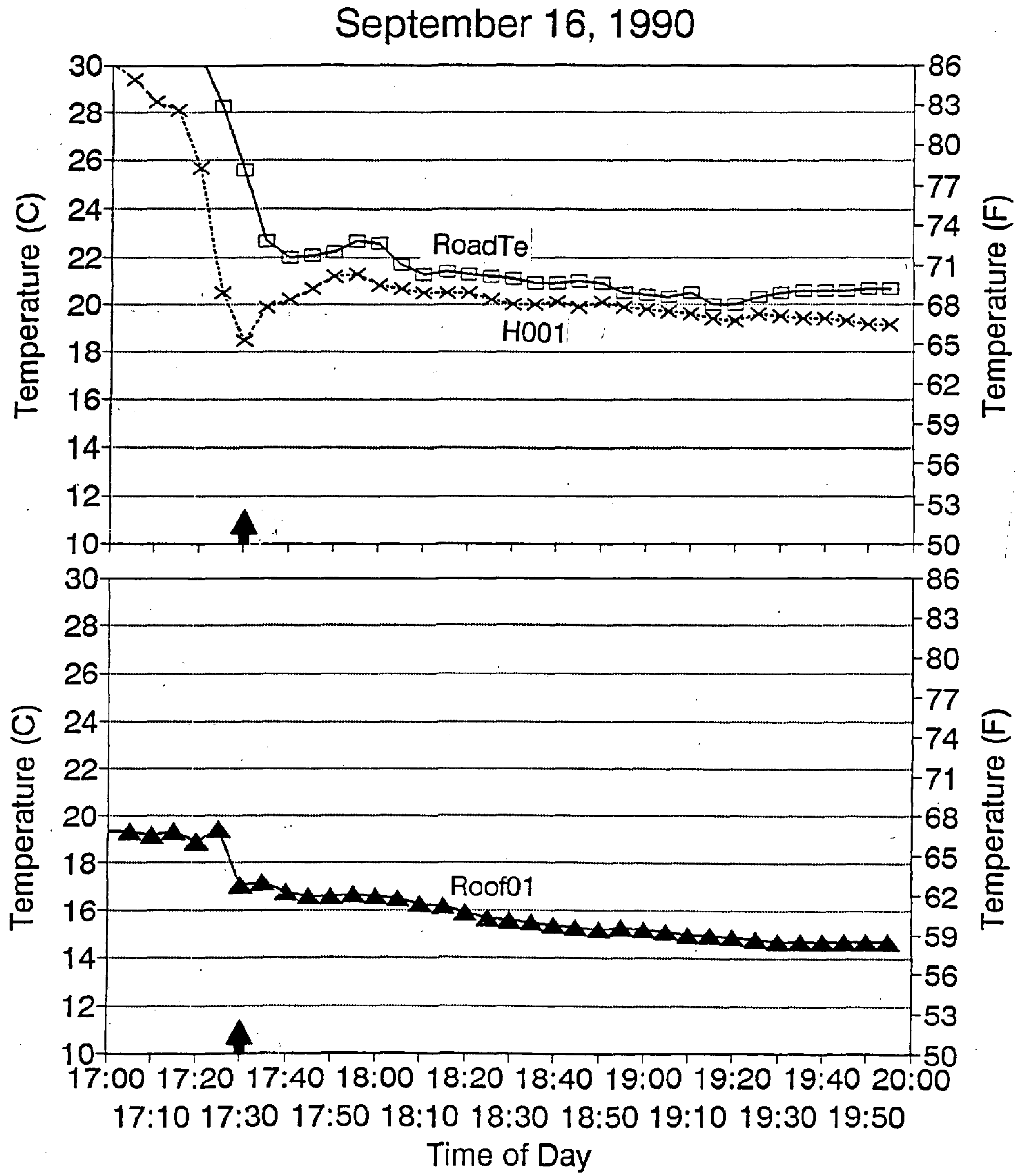


Figure 24. Temperature measurements from the special land use monitoring stations in the upper watershed of the left fork of Jabez Branch on September 16, 1990 between 17:00 and 20:00. In the top graph Station RoadTe shows the temperature of the surface of Rt. 3 while Station H001 shows the temperature of the highway runoff. The bottom graph shows the temperatures measured in the drain from an industrial roof in the watershed. Arrows indicate beginning of rain event.

runoff from the industrial roof during the September 16 storm was initially 17.1°C (62.8°F) and later dropped to 15°C (59°F).

## Discussion

The principal objective of the first summer of non-point thermal pollution monitoring on Jabez Branch was to collect baseline data on land uses, runoff patterns and runoff temperatures from different sections of the left fork watershed. This information is needed for future analysis that will combine recorded runoff temperatures with estimates of the volume of runoff originating from different sections of the watershed. By combining temperature measurements with estimates of runoff volumes, the thermal loadings from each area can be determined. The ultimate goal of this work is to develop a thermal loading budget for the left fork of Jabez Branch which can be used to determine the relative effects of different land use areas on temperature changes in the stream.

Results from the 1990 land use surveys indicate that nearly 50% of the left fork watershed of Jabez Branch remains forested and much of the remaining land is in agricultural use. It is estimated that at present less than 4 % of the left fork watershed is covered with impervious surfaces. Despite the fairly low level of urban development, results indicate that runoff generated within the watershed increases stream water temperature near the upper tolerance limit of brook trout. The relatively large rises in stream water temperatures appear to be the result of two factors. First, the left fork of Jabez Branch is a small stream with a summer base flow of only 0.3 cfs. Because normal base flow in the stream is low, even a small amount of warm surface runoff can have a dramatic impact on stream water temperature. The second factor is that development in the left fork watershed is concentrated in the upper sections of the drainage basin. When it rains, it appears that runoff from commercial, residential and agriculture land in the upper watershed concentrates in drainage channels and quickly flows down stream. This runoff has not only been heated from contact with roads and other warm surfaces, but the volume of water originating from the upper watershed is also believed to be fairly large. As this heated runoff moves down stream, it changes water temperature along the entire length of the left fork of Jabez Branch.

Results indicate that the magnitude of the water temperature changes resulting from non-point source thermal pollution in Jabez Branch depends on the intensity of the rain event and meteorological conditions prior to the storm. Small rain events producing less that 0.25 inches of rain had no effect on water temperature in Jabez Branch. Almost all of the rain water during these small events is retained on the land and little or no overland runoff to the stream is generated. For storms that produced more than 0.25 inches of rain, the magnitude of the water temperature rise in the stream depended on the time of storm occurrence, the intensity of the storm, the amount of runoff generated and how warm the day was prior to the start of the storm event. The largest rise in water temperature observed during 1990 occurred on July 12 during a 2.65 inch rain event that occurred in the late afternoon (18:30) on a fairly warm day (31.7°C or 89.1°F). Water temperature on the left fork rose from 17° (62.6°F) to 23.9°C (75°F). Other storm events produced small temperature rises in the stream, however, it is important to note that during the summer of 1990, all storms that produced an inch or more of rain occurred in either the late afternoon or at night after surface cooling had started. No significant rain events occurred during mid-afternoon when roads and other surfaces in the watershed tend to be the hottest. It is believed that a large afternoon thunderstorm on a very hot day would generate the warmest runoff and largest temperature rise in the stream.

The data collected during 1990 provides important information on the differences in runoff temperatures from different subdrainage basins in the Jabez Branch watershed. On July 12, meteorological data collected at the Jabez Branch weather station indicated that air temperatures dropped from 29°C (84.2°) to 23°C (73.4°F) at the beginning of the storm. Although the temperature probe at the Jabez Branch weather station is sheltered and designed to measure air temperatures, it is believed that air temperature during a rain storm is also an indication of the temperature of the rain water. Additional measurements, however, will need to be done in 1991 to verify this. Runoff monitoring indicated that the temperature of the runoff from forested land (Subdrainage Basin X, Figure 3) was around 22.5°C (72.5°F). This is very close to air temperatures during the storm and suggests that the temperature of runoff from a forest will be close to the temperature of the rain. In the more developed sections of the watershed the temperature of the runoff was warmer. The warmest runoff came from Subdrainage Basin VI which was also the most urbanized subdrainage basin. Initially the runoff from Subdrainage Basin VI was just below 28°C (82.4°F). This is the same temperature measured at Station H001 which monitored the temperature of the runoff from Rt. 3. As the storm progressed, the temperature of the runoff from Subdrainage Basin VI and the other more urbanized subdrainage basins dropped to around 24.5°C (76.1°F). In the more agricultural areas of the watershed, the temperature of the runoff was initially around 23°C (73.4°F) which was only slightly above the temperature of the runoff coming from forested lands (Subdrainage Basin X). As the storm progressed, however, the runoff from the mostly agriculture areas increased to around 25°C (77°F).

In addition to the increased temperatures, it is important to remember that the volumes of water coming from these areas also increased. In a forest, only a small amount of water reaches the stream as overland runoff while almost all of the rain water that falls on a road or parking lot will quickly move into the stream as overland flow. It is believed that the combination of increased water temperatures and increased water volumes from urbanized sections of the watershed are responsible for the temperature rises seen in Jabez Branch.

During this study, the largest rise in water temperature in Jabez Branch occurred during a large storm on July 12. Smaller rain events, however, did produce significant stream water temperature rises, even when they occurred at night. On August 5 for example, the rain event occurred at night (23:00) following a cloudy day when air temperatures had reached a high of only 27.2°C (81°F). Despite these fairly moderate weather conditions, water temperatures in Jabez Branch still rose 5°C (9°F) from 16°C (60.8°F) to 21°C (69.8°F). During the rain event on August 5 air temperatures were 22°C (71.6°F) and the temperature of the runoff from all of the monitored subdrainage basins except the forested Subdrainage Basin X was around 23°C (73.4°F). The runoff for Subdrainage Basin X was slightly cooler at 21°C (69.8°F). This means that even with very little heating of the runoff from contact with roads and other surfaces in the upper watershed, the temperature of the water in the stream still rose above the Maryland water quality standard of 20°C (68°F). These results suggest that since the temperature of rain can frequently exceed 20°C (68°F) any change in land use that increases the amount of surface runoff entering a trout stream will increase water temperature fluctuations. Trout, however, are capable of withstanding small temperature rises above 20°C (68°F) so long as the increases are not for an extended duration.

One surprising finding in 1990 was the relatively low pH in the center portion of the left fork of Jabez Branch. During base flow conditions the pH in the mid-section of the stream was as low as 5.2. Water at this pH is considered to be fairly acidic and can be stressful to many aquatic organisms (Baker et al., 1990). There is very little historical information on pH in Jabez Branch and it is unknown at this time if the relatively low pH recorded during the stream survey is a recent phenomenon or if it is a longstanding characteristic of the stream. Of the 3 species of trout common to Maryland, brook trout are the most tolerant of low pH waters (Baker and Christensen, 1990; Baker et al., 1990, Johansson et. al., 1977).

In addition to pH levels varying along the stream's length, the pH of the stream also fluctuated during rain events. Continuous monitoring of pH near the mouths of the left and right forks indicates the pH of the stream can drop as much as 1 pH unit shortly after the beginning of the rain event. It is unclear if the initial drop in pH at these stations is due to the transport of a slug of more acidic water from upstream, or if the pH of the runoff generated at the beginning of the rain event was more acidic. Additional monitoring of pH in other sections of the stream will be needed to examine this question.

## Future Work

Overall, the results from the 1990 monitoring of Jabez Branch has provided information on the temperature coming from different sections of the stream's watershed. In order to determine the individual contribution that each subdrainage basin is having on temperature downstream, not only the temperature of the runoff, but also the volume and rate at which the runoff moves downstream must also be taken into consideration. In 1991, additional work will be done to determine the amount of runoff coming from the different sections of the watershed. A Soil Conservation Service TR-55 runoff model has already been completed by the Maryland State Highway Administration for the upper left fork of Jabez Branch. This model will be modified using data collected from our land use surveys to provide an initial estimate of the volumes of runoff originating from different sections of the watershed. In addition, field monitoring in Jabez Branch in 1991 will concentrate on measuring runoff volumes from the different subdrainage basins.

# LITERATURE CITED


Bachman, Robert A., personal communication. Chief of Freshwater Fisheries Program, Maryland Department of Natural Resources. Annapolis, MD.

Baker, J.P., D.P. Bernard, S.W. Christensen, M.J. Sale, J. Freda, K. Heltcher, L. Rowe, P. Scanion, P. Stokes, G. Suter, and W. Warren-Hicks, 1990. Biological effects of changes in surface water acid-base chemistry. State-of-Science/Technology Report 13. National Acid Precipitation Assessment Program, Washington, D.C.

Baker, J.P. and S.W. Christensen, 1990. Effects of acidification on biological communities in aquatic ecosystems. In: D.F. Charles, ed. Acidic Precipitation and Surface Water Acidification: Regional Case Studies. Springer-Verlag, New York.

Barry, Edwin M., 1958. Maryland trout report. Maryland Commission of Fisheries, Inland Fish Management.

Johanessen, N., P. Runn and G. Milbrink, 1977. Early development of three salmonid species in acidified water. Zoon 5:127-132.

Powell, Albert M., 1967. Historical information of Maryland Commission of Fisheries.