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# Weather and Evapotranspiration Studies in a Saltcedar Thicket, Arizona

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# Weather and Evapotranspiration Studies in a Saltcedar Thicket, Arizona

*By* T. E. A. VAN HYLCKAMA

S T U D I E S   O F   E V A P O T R A N S P I R A T I O N

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## CONVERSION TABLE

| Multiply SI Unit                                                       | By                      | To obtain inch-pound<br>or cgs units                                             |
|------------------------------------------------------------------------|-------------------------|----------------------------------------------------------------------------------|
| <i>Area</i>                                                            |                         |                                                                                  |
| square centimeters (cm <sup>2</sup> )                                  | 0.155                   | square inches (in. <sup>2</sup> )                                                |
| square meters (m <sup>2</sup> )                                        | 10.76                   | square feet (ft. <sup>2</sup> )                                                  |
| square kilometers (km <sup>2</sup> )                                   | 247.1044                | acres                                                                            |
| <i>Electricity and Magnetism</i>                                       |                         |                                                                                  |
| millisiemens (mS)                                                      | 1.0                     | millimhos (mmho)                                                                 |
| <i>Energy</i>                                                          |                         |                                                                                  |
| joules (J)                                                             | $9.4787 \times 10^{-1}$ | British thermal units<br>(mean) (Btu)                                            |
|                                                                        | 0.2388                  | calories (cal)                                                                   |
| <i>Energy/Area Time</i>                                                |                         |                                                                                  |
| watt/meter <sup>2</sup> (W/m <sup>2</sup> )                            | $5.2895 \times 10^{-3}$ | Btu/foot <sup>2</sup> -minute                                                    |
|                                                                        | $1.434 \times 10^{-3}$  | cal/centimeter <sup>2</sup> -minute<br>(cal cm <sup>-2</sup> min <sup>-1</sup> ) |
| <i>Heat</i>                                                            |                         |                                                                                  |
| watt/meter <sup>2</sup> -kelvin<br>(Wm <sup>-2</sup> K <sup>-1</sup> ) | 0.1761                  | Btu/ft <sup>2</sup> -hour-°F                                                     |
| joules/kilogram-kelvin<br>(J kg <sup>-1</sup> K <sup>-1</sup> )        | $2.388 \times 10^{-1}$  | Btu/poundmass-°F                                                                 |
| <i>Length</i>                                                          |                         |                                                                                  |
| nanometers (nm)                                                        | $0.3937 \times 10^{-1}$ | mils                                                                             |
| micrometers (μm)                                                       | 0.03937                 | "                                                                                |
| millimeters (mm)                                                       | 0.03937                 | inches (in.)                                                                     |
| centimeters (cm)                                                       | 0.3937                  | "                                                                                |
| meters (m)                                                             | 3.281                   | foot (ft)                                                                        |
| kilometers (km)                                                        | 0.621                   | miles                                                                            |
| <i>Mass</i>                                                            |                         |                                                                                  |
| kilograms (kg)                                                         | 2.205                   | pound mass (lbm)                                                                 |
| <i>Mass/Volume (Density)</i>                                           |                         |                                                                                  |
| kilogram/meter <sup>3</sup><br>(kg/m <sup>3</sup> )                    | $6.24 \times 10^{-2}$   | poundmass/foot <sup>3</sup>                                                      |
|                                                                        | 0.001                   | gram/cm <sup>3</sup> (g cm <sup>-3</sup> )                                       |
| <i>Power</i>                                                           |                         |                                                                                  |
| watt (W)                                                               | 3.412                   | Btu/hour                                                                         |
|                                                                        | 0.2388                  | calories/second (cal/s)                                                          |
| <i>Pressure</i>                                                        |                         |                                                                                  |
| kilopascal (kPa)                                                       | 0.2953                  | inches of mercury (in. Hg)                                                       |
|                                                                        | 10                      | millibar (mb)                                                                    |
| <i>Temperature</i>                                                     |                         |                                                                                  |
| degrees Celsius (°C)                                                   | 1.8°C + 32              | degrees Fahrenheit (°F)                                                          |
| kelvin (K)                                                             | (K - 273.15) 1.8 + 32   | " " "                                                                            |
| <i>Velocity</i>                                                        |                         |                                                                                  |
| meter/second (m/s)                                                     | 2.237                   | miles/hour (mph)                                                                 |
| <i>Volume</i>                                                          |                         |                                                                                  |
| cubic meters (m <sup>3</sup> )                                         | $0.81 \times 10^{-3}$   | acre-feet (a/f)                                                                  |



## STUDIES OF EVAPOTRANSPIRATION

# WEATHER AND EVAPOTRANSPIRATION STUDIES IN A SALT CEDAR THICKET, ARIZONA

By T. E. A. VAN HYLCKAMA

### ABSTRACT

Water use by saltcedar, *Tamarix chinensis*, was studied from 1961 through 1967 near Buckeye, Ariz. The test site was located on the rim of the Gila River flood plain and was bordered on the north, east, and west sides by fetches of dense saltcedar thickets 1 or more kilometers wide. On the south side, however, the fetch was less than 100 meters.

The climate of the area, typical of the Sonoran Desert, is characterized by low humidities, strong winds, and temperature extremes of  $<-10^{\circ}\text{C}$  in winter and  $>50^{\circ}\text{C}$  in summer. Potential evaporation values are among the highest observed in the United States.

Rates and quantities of evapotranspiration were observed in six plastic-lined evapotranspirometers (tanks) whose 81 square-meter surfaces were planted to saltcedar having heights and density equal to those of the surroundings.

The test site was further equipped with instrumentation to measure the following data: solar short-wave radiation; long- and short-wave net radiation; albedo; humidity, temperature, and wind profiles in and over the vegetation; soil-temperature gradients and soil-heat flux; moisture content of the soil; and carbon dioxide content of the air. Detailed studies were made of the microclimate in and over a typical saltcedar thicket. Analyses showed that, above the vegetation, the wind profiles in more than 80 percent of the observations were logarithmic. Within the thickets considerable turbulence and irregular wind inversions (tunneling) occurred during daylight hours.

It was concluded that transport constants for momentum, heat, and vapor are the same more than 80 percent of the time because plots of windspeed versus temperature at different heights and of windspeeds versus vapor pressure at those heights fall on straight lines. Fluxes of carbon dioxide and vapor are closely related. Vapor fluxes diminish, as do rates of photosynthesis, during hot afternoons when temperatures exceed  $40^{\circ}\text{C}$ , suggesting a variable stomatal resistance factor.

Estimates of potential evapotranspiration rates using various models were plotted against measured values. For rough estimates of total yearly quantities of evapotranspiration, three independent methods gave values closest to those measured by evapotranspirometers with the shallowest (1.5 m) depth to water and with low salinity of soil moisture. (The effects of depth-to-water and of salinity have been discussed extensively in "Water use by saltcedar as measured by the water-budget method" (van Hylckama, 1974, U.S. Geological Survey Professional Paper 491-E).

For short-term estimates (of the order of 1 hour) the 1966 combination method of C. H. M. van Bavel gave results that were too high during daytime hours. When appropriate corrections were made by taking stomatal and aerodynamic resistances into account, the calculated values fitted the measured ones very well. This shows that

saltcedar reacts to extremely high windspeeds and temperatures by stomatal closure, thus diminishing evapotranspiration even though water is freely available (as it is in evapotranspirometers with favorable water and soil conditions). That riparian vegetation always uses water at a potential rate cannot be taken for granted, and quantitative estimates of salvageable water based upon that assumption may at times be far too large.

### INTRODUCTION

#### SALT CEDAR AND OTHER PHREATOPHYTES

Saltcedar, *Tamarix chinensis*,<sup>1</sup> is one of more than 70 species listed by Robinson (1958) as phreatophytes, a word derived by Meinzer (1923; 1927) from the two Greek words *φρεατος* (phreatos = well) and *φυτον* (phuton = plant). These plants are called phreatophytes because they have root systems with access to ground water or to water in the capillary fringe above it. It has sometimes been assumed that they can use water at a rate equal to, or greater than, the rate of potential evapotranspiration, even during long periods of drought. Whether this is always true is debatable, as will be discussed later in this report. A fact is that many phreatophytes, especially saltcedar, grow densely along rivers and reservoirs, and the expression riparian vegetation (from the Latin *ripa*=border) seems to be more appropriate and descriptive.

Phreatophytes were estimated by Robinson (1958) to cover 16 million acres (65,000 km<sup>2</sup> in the 17 Western States and to consume nearly 25 million acre-feet ( $31 \times 10^9 \text{ m}^3$ ) of water per year; they were expected to spread and to consume even more water in the years after 1958. As for saltcedar alone, Robinson (1965) estimated that in 1961 there were 900,000 acres (3600 km<sup>2</sup>) covered by saltcedar using 3.5 million acre-feet ( $4.3 \times 10^9 \text{ m}^3$ ) of water per year.

However there are reasons to believe that these numbers may be greatly exaggerated. For instance,

<sup>1</sup>In earlier studies the names *T. gallica* L. and *T. pentandra* Pall. are used. The name *T. chinensis* Lour. is preferred now by taxonomists (Horton and Campbell, 1974).

Robinson reported that of the 900,000 acres (3600 km<sup>2</sup>) just mentioned, about half were in Texas and that nearly half of those, or about 218,000 acres (880 km<sup>2</sup>), were located along the Pecos River and its tributaries. But that is far larger an area than the entire flood plain of that river and its feeders, including all agricultural land (J. S. Horton, written commun., 1977). Nonetheless, Robinson's data served to create active, even alarmist<sup>2</sup> interest in the phreatophyte problem and have encouraged the development of many action programs. The data also created the desire to know how much water these plants actually use and whether there are means of making this amount available for more beneficial use.

In this report procedures of studying water use are discussed, methods of measuring evapotranspiration are presented, the microclimate of vegetation on a typical flood plain is described, and methods of indirectly estimating water use by saltcedar are evaluated.

#### LITERATURE

O. E. Meinzer (former Geologist-in-charge, Division of Ground Water, U.S. Geological Survey) who did much to call attention to the economic significance of phreatophytes in arid and semiarid regions, might have been surprised if he could have foreseen the amount of study that would be devoted to evapotranspiration and related topics. A single bibliography (Robinson and Johnson, 1961) emphasizing papers on evaporation and transpiration from the United States from the early 1800's until 1958 contains more than 600 titles. Humphreys (1962) assembled 804 references (mostly American) dated between 1802 and 1960. Horton (1973) collected over 700 references to evapotranspiration as related to phreatophyte management. There is very little overlap in these compilations, and, although there is a lot of speculation and empiricism, there is also very little in all this that specifically deals with the physical relationships between water use by phreatophytes and climatologic and meteorologic events.

Research into the ecology of phreatophytes in general, and of saltcedar in particular, has been going on now for more than 25 years. Gatewood and others (1950) were probably the first to draw attention to the potentially large amount of water that saltcedar could transpire under favorable conditions. Since that time literature and study projects have proliferated enormously. The Phreatophyte Subcommittee of the Pacific

Southwest Interagency Committee (1965) compiled more than 500 references on phreatophytes and related subjects, nearly all more recent than 1950, while Robinson (1964) listed 48 projects pertaining to phreatophyte research. By 1965 a large number of these projects had been in progress for 2 or more years. In spite of the dedicated efforts of many agencies, including the U.S. Department of Agriculture's Agricultural Research Service, the U.S. Forest Service, the U.S. Geological Survey, and several University Experiment Stations, the complexity of the problem is such that we are still unable to just go into the field, set up some, preferably simple, instrumentation and determine in the course of 2-6 months how much water is used by phreatophytes in that area and to estimate with reasonable certainty if and how much water can be diverted to economical use by eradication or conversion of the vegetation.

The present study clarifies some of the problems and suggests possible solutions, but also describes in detail the difficulties one can expect while trying to solve such problems. Many of them have been discussed in the following papers, reporting on one or more aspects of the Buckeye Project (in chronological order):

- van Hylckama, T. E. A., 1960, Measuring water use by saltcedar: Proc. Fourth Ann. Ariz. Watershed Symposium, Watershed Management Div., State Land Dept., State of Ariz., Phoenix, p. 22-26.
- 1961, Natural recharge of ground water, in Fletcher, J. E., and Bender, G. L., eds, Ecology of ground water in the southwestern United States: 37th Ann. Meeting of the Southwest and Rocky Mountain Div. of Am. Assoc. for the Adv. of Sci., Arizona State Univ., Tempe, Ariz., p. 21-41.
- 1963, Growth, development, and water use by saltcedar (*Tamarix pentandra*) under different conditions of weather and access to water: Publ. 62, Internat. Assoc. Sci. Hydrology, Comm. for Evaporation, UNESCO, Paris, p. 75-86.
- Shakur, Abdul, 1964, Evapotranspiration from a stand of saltcedar: Masters Thesis, Dept. of Hydrology, Tucson, Univ. of Ariz., 73 p.
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- 1966b, Effects of soil salinity on the loss of water from vegetated and fallow soil: Publ. 83, Internat. Assoc. Sci. Hydrology, UNESCO, Paris, p. 636-644.
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- 1970a, Water use by saltcedar: Water Resources Research, v. 6, p. 728-735.
- 1970b, Winds over saltcedar: Agr. Meteorology, v. 7, p. 217-233.
- Ripple, C. D., Rubin, Jacob, and van Hylckama, T. E. A., 1972, Estimating steady-state evaporation rates from bare soil under conditions of high water tables: U.S. Geol. Survey Water-Supply Paper 2019-A, 39 p.
- van Hylckama, T. E. A., 1974, Water use by saltcedar as measured by the water budget method: U.S. Geol. Survey Prof. Paper 491-E, 30 p.

<sup>2</sup>In the literature, saltcedars have been described as "water hogs" (Douglas, 1954), "aggressive" (Robinson, 1965), "greedy" (Douglas, 1965), "insidious" (Sebenik and Thames, 1968), "thieves" (Robinson, 1952), and "water-stealing culprits" (U.S. Information Service, 1965). These expressions indicate the emotional and propagandistic attitude that is sometimes taken towards the phreatophyte problem.

- 1975, Estimating evapotranspiration by homoclimates: *Geog. Rev.*, v. 65, p. 37–48.

The following papers were presented but only printed in abstracts:

- van Hylckama, T. E. A., 1962, Use of water by saltcedar as measured by the water budget method: *Jour. Geophys. Research*, v. 67, p. 3535.
- 1964, Evaporation from bare soil: *Am. Meteorol. Soc. Bull.*, v. 45, p. 540.
- 1968b, Wind profiles over saltcedar: *Am. Meteorol. Soc. Bull.*, v. 49, p. 769.
- 1968c, Carbon dioxide and saltcedar growth: Southwestern and Rocky Mountain Div. of the Am. Assoc. Adv. Sci., Proc. 44th Ann. Meeting, El Paso, Texas, p. 5.
- 1969b, Plant growth and water use as affected by salinity of soil moisture and density of stand: *Arid Lands in a Changing World*, Abstracts of contributed papers, Am. Assoc. Adv. Sci., Comm. on Arid Lands, Tucson, Ariz., 2 p.
- 1972, Leaf resistance in saltcedar, in Adams, W. P. and Hel-leiner, F. M., eds., *International Geography 1972*, Univ. Toronto Press, p. 204.

#### ACKNOWLEDGMENTS

Under a memorandum of understanding dated May 4, 1959, "concerning studies of consumption of water by phreatophytes and related problems," the U.S. Geological Survey "will take the leadership in the preparation of reports and the publication of results of the studies conducted under the agreement" while the U.S. Bureau of Reclamation would be mainly responsible for the construction of the tanks and the flood protection of the area. In particular, the help and assistance of Curtis W. Bowser, Robert Mason, and Leslie C. Pampel, all members of the Bureau, is gratefully acknowledged.

The late Thomas W. Robinson together with Curtis W. Bowser conceived the idea of using 20-mil (about 0.5 mm) black vinyl plastic as a cheap and easy-to-install lining for the evapotranspirometers and supervised the installation of the first two. G. Earl Harbeck, Jr., gave general supervision to the work of the Survey. Oliver E. Leppanen designed and constructed the wind-recording equipment. Jack L. Sidders supervised the construction of the tanks and aided in the installation of the complex plumbing and the electrical circuitry required for the study. He also performed nearly all the maintenance during the 6½-year duration of the project.

Many others, among them a number of graduate and undergraduate students, helped in taking around-the-clock readings for periods of 3 or 5 days and assisted in the very time-consuming transcription of the strip-recording data into numerical and calibrated values.

I am grateful for very helpful criticisms of the first draft of this report made by J. S. Horton, U.S. Forest

service, (retired), and D. C. Davenport of the University of California at Davis (Dept. of Land, Air, and Water Resources).

#### METHODS OF STUDYING WATER USE

##### A BIT OF HISTORY

All plants need water for growth and development and most of them must transpire considerable quantities in order to grow and develop. That plants need water has been known undoubtedly since the time our earliest ancestors began to practice agriculture. One of the first to measure this water use was van Helmont (1655), who found that a 5-pound willow sapling in 5 years grew up to a 169-pound tree and concluded that the 164 pound increase came exclusively from the water.<sup>3</sup>

That plants transpire however, was first described by Stephen Hales (1727). He presented data on the quantities of water transpired by different plants under different conditions. Figure 1 shows just two of the dozens of experiments described by Hales and gives an idea of his painstaking work. Hales' studies were not improved upon until nearly a century later when many physiologists and physicists began to study the plant-soil-water relationships more intensively. Initially the transpiration phenomenon was only of scientific or academic interest; later, when economic considerations became urgent, the amount of water transpired without apparent benefit to man became the center of attention and the concept that transpired water is wasted became prevalent.

To find out how "wasteful" saltcedar is, one must know how much water the plant uses under various circumstances. The basic method is essentially the same as that used by van Helmont and Hales: measure the water applied and after a definite time reweigh container plus plant and compute from these data the water lost by transpiration and evaporation from the soil. The crux is that in this manner only one or at most a few plants are studied, and one cannot safely extrapolate that use to hectares or acres much less to thousands of them planted to such crops or covered by such vegetation.

Therefore, since vegetation conversions, of which eradication is the extreme, cost money, one must make an estimate of the quantities of water that are used by the total vegetation to be converted or eradicated for the purpose of computing cost-benefit ratios.

<sup>3</sup>"Omnia\*\*\*vegetabilia\*\*\*ex solo aquae elemento prodire hac mechanica didici"—freely translated: "That all vegetable matter comes solely from elements of water, I proved by this experiment." Then follows the description of how van Helmont planted, weighed, watered, and reweighed his willow tree. The actual weight of van Helmont's pounds is not certain.

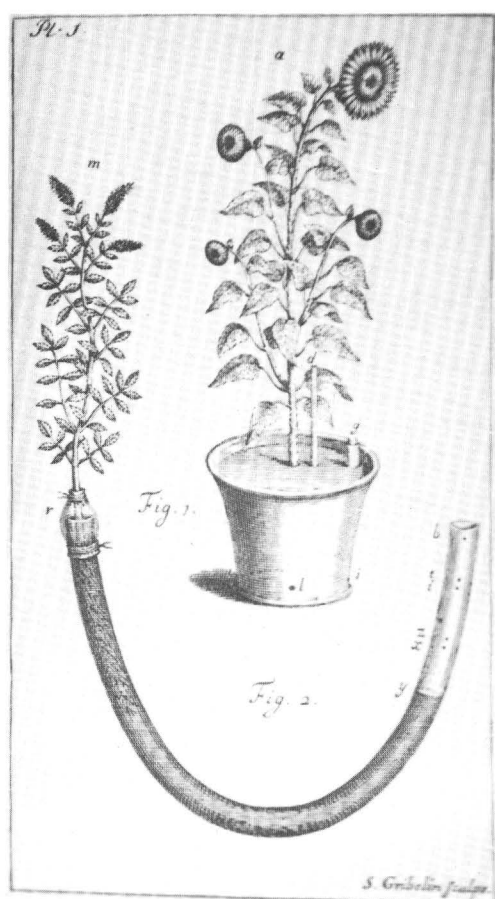


FIGURE 1.—A reproduction of plate 1 in Hales' (1727) "Vegetable Staticks." The drawings were used to illustrate experiments I and VI. Plant on the left is a spearmint, *Mentha spicata*; the one on the right is a sunflower, *Helianthus annuus*.

#### HYDROLOGIC METHODS

The most straightforward way of determining water use by saltcedar by means of containers (the lysimeter method, mentioned in any textbook on hydrology) was discussed in another chapter of the Professional Paper 491 series (van Hylckama, 1974). However, finding a suitable location for evapotranspirometers or lysimeters is often difficult; the construction is expensive; and the maintenance, until reliable results are obtained, very time consuming, especially if one is, as in this case, dealing with tall vegetation. (Saltcedar can reach a height of 5–7 m by the time it is 10 or more years old.)

There are two other ways to measure water use by hydrologic (sometimes called water-balance) methods. The first is the natural-catchment or watershed-hydrology method of which Culler (1970) described a good example. Troubles with this method are discussed in the reference and will not be dealt with here. The second, called the "change-in-soil-moisture" method,

consists of monitoring the changes in soil moisture, usually over the depth of the root zone. However, instrumentation difficulties do not make this method very reliable over periods of less than 7–10 days, and large errors may occur if drainage is not measured or goes unnoticed (van Bavel and others, 1968) or if fluxes from the water table are neglected (E. P. Weeks, written commun., 1978).

#### MICROMETEOROLOGIC METHODS

Answers could be obtained much faster, and certainly with less destruction, if one could evaluate the climatic and meteorological inputs that determine the reactions of the plants and the amount of water used or transpired by them. Such methods of measuring water use or evapotranspiration are available, do not require lysimeters, and do not depend on empiricism or educated guesses. They can be classified as vapor-flow, bulk-aerodynamic, energy-balance, and combination methods.

There are two types of vapor-flow methods. The atmospheric-water-balance method is analogous to the hydrologic balance in that it considers the quantities of moisture entering and leaving a column of air (rather than that entering or leaving a mass of soil or a watershed). The other is known as the eddy-correlation, eddy-flux, or eddy-transfer method. In this method the vertical turbulent fluxes of vertical wind and vapor in the atmosphere are measured over very short intervals, a few seconds at most. The method requires extremely sensitive wind and water-vapor sensors and needs elaborate recording systems to assimilate the enormous amount of data accumulating during a day or even an hour. Since neither the sensors nor the integrating circuits or computers were available at the Buckeye Project, this method was not used but it will be mentioned together with the theory of the other methods and their instrumentation.

The bulk-aerodynamic and the energy-balance methods go back, in principle at least, more than 2000 years. When Aristotle noticed that water, put on a plate, slowly disappeared, he said, "the wind does it." Others, during his lifetime, accused the sun. While the wind causes the aerodynamic or turbulence process, the sun causes the energy- or heat-balance process. These two systems still operate today; they are no longer theory as they were in Aristotle's days because now we have the instruments to measure them and their effects.

The fourth method is actually a fusing of the effects of wind and sun and a number of equations have been proposed to estimate water losses by this combination method.

## EMPIRICAL METHODS

Faster methods (apart from more or less educated guesses) involve one of the many empirical equations for computing potential evapotranspiration from readily available climatological parameters. Because such equations are empirically derived, claims as to their accuracy or inaccuracy are often without experimental foundation. In order to test the claims, many field experiments have been set up, mostly in the southwestern parts of the United States, where vegetation conversion is considered to be most effective. However, too often only scant attention is paid to the effects of the ambient weather upon water losses, and efficient verification of accuracy and applicability of an empirical relationship remain debatable if not impossible. For instance, only a few of the projects listed by Robinson (1964) and only a few of the articles compiled by the Phreatophyte Subcommittee (1965) are concerned with the input forces and ambient conditions that determine the rate of water use by phreatophytes, and even fewer articles if one considers saltcedar alone. Of these few the papers by Gatewood and others (1950), Blaney (1957), Dylla and Muckel (1964), McDonald and Hughes (1968), Robinson (1970), Culler (1970), Culler and others (1970), Hughes (1972), and McQueen and Miller (1972) are probably the most pertinent.

## THE BUCKEYE TEST SITE

## LOCATION, SOIL, AND WATER

The study site and its characteristics have been described in detail elsewhere (van Hylckama, 1974), and only a brief statement is required here. Figures 2 and 3 show the location and the layout of the project. Figure 4, an aerial photograph of the area, and figure 5, a photograph of the test site as seen from a 4-meter-high platform, show the density of vegetation on the flood plain at the experimental site.

In choosing a location for evapotranspirometers an important consideration is the extent of the vegetation surrounding the proposed area. As a rule of thumb, it is assumed that homogeneous vegetation should extend over a radius 100 times the height of the vegetation under study (see Monteith, 1973, for a detailed discussion). As figure 4 shows, the vegetation does not extend that far to the south, and the map of figure 3 indicates such a desirable fetch only in a southwesterly direction. However, under natural conditions saltcedar predominates in this region as flood-plain vegetation along rivers and washes or as strips of riparian vegetation along lakes and reservoirs. Especially when winds blow normal to rather than parallel to the river, the fetch will quite likely be too short and oasis effects are

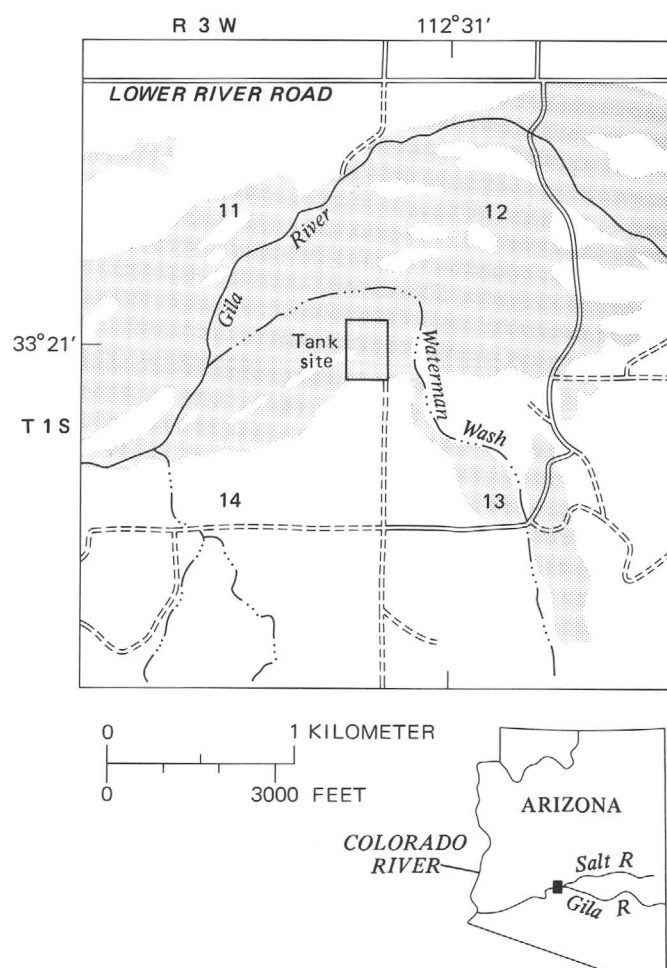


FIGURE 2.—Location of the Buckeye test site.

to be expected. The large rates of evaporation one finds in the literature are most likely due to these facts of nature.

Whereas then the location of the evapotranspirometers at the Buckeye Project was as good as one can get in an area of flood-plain vegetation, and whereas the instrumentation was quite adequate to provide reliable results, the construction had one big drawback: no provisions were made for draining the tanks. The consequences of the resulting increase in salinity of the ground water in the tanks have been discussed elsewhere (van Hylckama, 1974). However, when salinity was abated by proper flushing, reliable water-budget data could be derived for short periods of the order of days and hours as will be shown later on.

Even though flushing made possible short-period determination of evapotranspiration, one can never be sure how representative such evapotranspirometers are. The Buckeye tanks probably gave results that would be valid for the flood-plain vegetation along the Salt River between Tempe, Ariz., and the confluence with the Gila River, from that confluence a few tens of

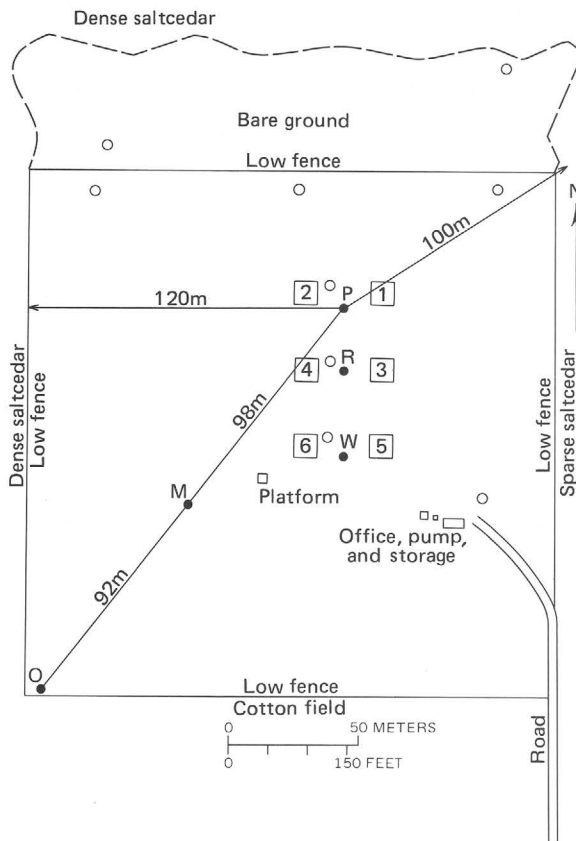


FIGURE 3.—Sketch of the project site, southeast of Buckeye, Ariz., showing position of main features. P, R, W are instrument masts for wind and temperature profiles, radiation, and wind direction respectively; M and O, additional masts. Numbers 1 through 6 indicate evapotranspirometers forming part of the saltcedar thickets, constructed in 1959. Tanks 7 through 11 (not indicated in the figure) were constructed in 1962 in the area marked "bare ground." Open circles indicate location of access tubes to determine soil moisture outside the tanks.

kilometers upstream along the Gila and downstream to Gila Bend, Ariz., provided depth to ground water and soil-moisture salinity are taken into account.

The soil at the project site is a sandy to fine sandy loam belonging to the Entisol soil order. It consists mainly of alluvial sediments deposited by floods of the Waterman Wash. Table 1 presents some physical and chemical characteristics. The physical ones are averages of 12 samples taken from evapotranspirometers number 1 through 6 (see fig. 3). The chemical ones are presented as the range of samples taken from the 6 tanks in 1963 and as the range of samples taken from all 11 tanks in 1966. The large range and the changes between the 1963 and 1966 data are mostly due to the treatments of the tanks, such as flushing, change in quality of water, and so on.

Water for irrigating tanks and surroundings came



FIGURE 4.—View from an airplane of the project site shortly after planting the first five tanks (1959). Camera looks to the north.



FIGURE 5.—View of the project site in 1963 as seen from a 4-m-high platform. The main instrument mast is visible right of center. White Tank Mountains north of Buckeye in the left background. Camera looks to the northeast. Arrow points to the mast carrying radiation instruments. See fig. 19.

from a well drilled to a depth of 25 m in 1959 and deepened to 43 m in 1960. The change in quality due to this procedure is clearly shown in the data of table 2.

#### CLIMATE

The climate at the project site is arid. Mean annual temperature at Buckeye is 20.6°C and mean annual rainfall is 190 mm.

The monthly mean temperatures at the project site do not vary much from year to year. The means of the 6½ years of operation are presented in figure 6, which also shows the long-time means for the town of Buck-

TABLE 1.—Analyses of soils at the Buckeye project

[USWCL: United States Water Conservation Laboratory, (USDA), Tempe, Arizona, U of A: The University of Arizona, Agricultural Experiment Station, Tucson, Arizona; USBR: United States Bureau of Reclamation, Phoenix Development Office, Soils Laboratory, Phoenix, Arizona. Physical characteristics are expressed as mean percentage of 12 samples and standard deviations. Moisture characteristics are expressed as percentage H<sub>2</sub>O by volume. One millibar = 100 N/m<sup>2</sup> = 100 Pa;  $\sigma$  = standard deviation]

| Mechanical analysis of sandy loam, USWCL |                           |                |           |
|------------------------------------------|---------------------------|----------------|-----------|
| Classification                           | Particle diameter         | Percent        |           |
| clay                                     | less than 2 $\mu\text{m}$ | 7.0 $\pm$ 0.8  |           |
| silt                                     | 2–20 $\mu\text{m}$        | 9.2 $\pm$ 3.0  |           |
| silt                                     | 21–50 $\mu\text{m}$       | 24.5 $\pm$ 3.0 |           |
| sand                                     | over 50 $\mu\text{m}$     | 59.2 $\pm$ 7.4 |           |
| Chemical analysis                        |                           |                |           |
| Chemical sample                          | Depth (cm)                | U of A 1963    | USBR 1966 |
| Ca + Mg (Meq/100 g)                      | 25                        | ----           | 0.3–1.9   |
|                                          | 75                        | ----           | 0.3–1.3   |
|                                          | 125                       | ----           | 0.2–2.0   |
| Na + K (Meq/100 g)                       | 25                        | 1.8–4.7        | 0.6–4.7   |
|                                          | 75                        | 1.8–4.8        | 0.8–4.4   |
|                                          | 125                       | 1.6–3.5        | 1.0–5.3   |
| Cl (mg/L)                                | 25                        | 1060–1850      | 620–5950  |
|                                          | 75                        | 530–2530       | 1110–7650 |
|                                          | 125                       | 200– 830       | 1280–9650 |
| Total dissolved solids (g/L)             | 25                        | ----           | 1.7–14.0  |
|                                          | 75                        | ----           | 2.6–13.6  |
|                                          | 125                       | ----           | 3.0–10.7  |
| pH                                       | 25                        | 7.9–8.1        | 7.5–8.1   |
|                                          | 75                        | 7.9–8.1        | 7.5–7.9   |
|                                          | 125                       | 8.0–8.1        | 7.5–7.8   |
| Moisture characteristics                 |                           |                |           |
| Millibars                                | Percent                   | $\sigma$       |           |
| 20                                       | 40.0                      | 2.6            |           |
| 40                                       | 33.5                      | 2.2            |           |
| 80                                       | 29.2                      | 1.9            |           |
| 120                                      | 26.9                      | 2.4            |           |
| 160                                      | 24.7                      | 3.8            |           |
| 200                                      | 22.2                      | 4.7            |           |
| 300                                      | 17.3                      | 4.1            |           |
| 500                                      | 13.2                      | 3.2            |           |
| 1000                                     | 10.6                      | 2.2            |           |

eye according to Weather Bureau data (U.S. Dept. of Commerce, 1955).

Maximum temperature at Buckeye may reach 49°C, usually in July and August, but at the test site, temperatures as high as 52°C have several times been recorded and, whereas the lowest temperature at the Buckeye weather station is given as –10°C, temperatures as low as –12°C at the test site were not uncommon. In winter, the above-ground plumbing had to be protected with electrical heating coils.

Wind directions are highly variable. Figure 7 shows wind roses for the calendar year and for the growing seasons at the project, compared with long-term averages observed at Sky Harbor Airport east of Phoenix,

TABLE 2.—Analyses of irrigation water at the Buckeye project

[All analyses made by the U.S. Geological Survey. All values in milligrams per liter except where otherwise indicated]

|                                            | June 9, 1959 | May 11, 1960 | Feb. 20, 1961 | Apr. 26, 1962 | May 6, 1963 |
|--------------------------------------------|--------------|--------------|---------------|---------------|-------------|
| SiO <sub>2</sub>                           | 27           | 31           | 46            | 35            | 31          |
| Ca                                         | 290          | 475          | 505           | 475           | 396         |
| Mg                                         | 39           | 91           | 126           | 125           | 122         |
| Na + K                                     | 512          | 960          | 1200          | 1250          | 1150        |
| HCO <sub>3</sub>                           | 207          | 366          | 416           | 403           | 405         |
| SO <sub>4</sub>                            | 265          | 662          | 836           | 878           | 836         |
| Cl                                         | 1140         | 1880         | 2250          | 2250          | 1980        |
| Total dissolved solids                     | 4280         | 4860         | 5210          | 4720          | 4720        |
| Hardness as CaCO <sub>3</sub>              | 880          | 1560         | 1780          | 1700          | 1490        |
| pH                                         | 7.4          | 7.4          | 7.5           | 7.3           | 6.8         |
| Specific conductivity $\mu$ mho/cm at 25°C | 4.30         | 6.97         | 8.21          | 8.32          | 7.57        |

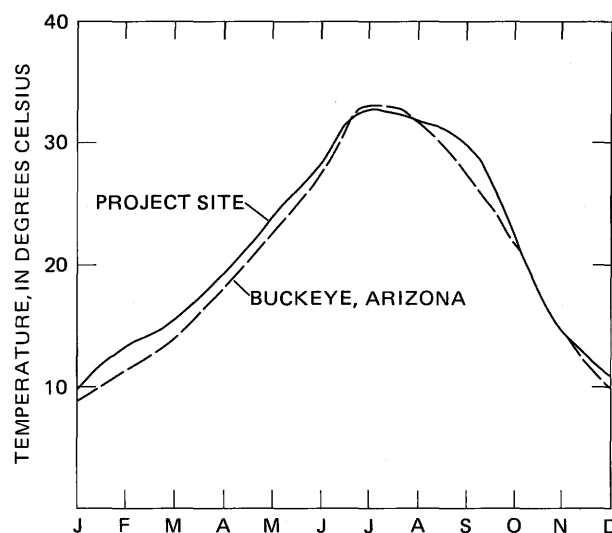


FIGURE 6.—Mean monthly temperatures (1961–67) at the project site and 30-year means at Buckeye, Ariz.

less than 80 km to the east of the test site. It is clear that the main directions at the airport are E and SE, while those at the project are NE and SW or W. This difference is undoubtedly due to the effect of the mountains to the north and east of the project site. The wind directions also vary considerably by time of day as shown in figure 8. The significance of these wind directions will be shown in the discussion of the advective term in the energy- and mass-transfer equations.

Windspeeds also are quite variable. The monthly means for the 2 years for which complete data were available are given in figure 9; the data are compared with long-time averages observed at the Sky Harbor Airport. That the speeds at the airport are generally higher is not surprising because they were measured at the control tower level and those at the project at only 4 m.

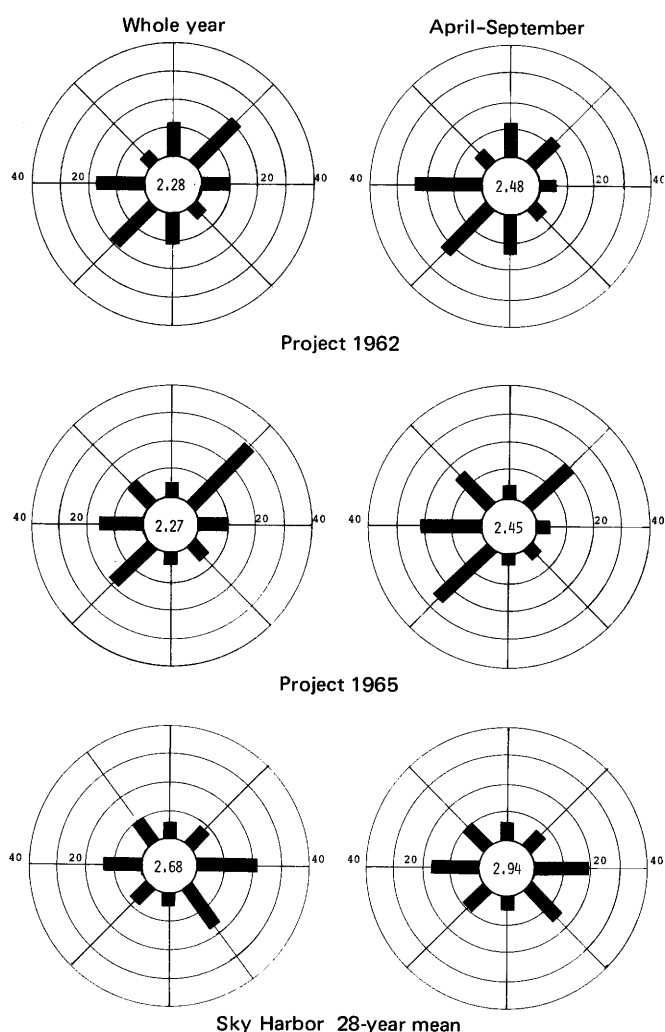


FIGURE 7.—Wind roses for the Buckeye project site (1962, top; 1965, middle) and for Sky Harbor Airport, Phoenix, Ariz. (1930–58 mean values, bottom). Means for the calendar year (left); for the 6 warmest months of the year (right). Numbers in the centers are mean windspeeds, in meters per second.

Rainfall, as shown in figure 10, is quite erratic and scanty although 1965 and 1966 showed annual totals of more than 200 mm each and are higher than the long-term averages given by the broken line in that figure.

Solar radiation is intense, as can be expected. Figure 11 shows the observed radiation as a percent of the maximum possible radiation at the project-site latitude; the atmospheric transmission coefficient is assumed to be 0.9. Note the dip in radiation intensity due to thunderstorm activities in the late summer.

Finally, the fluctuations in the dew-point temperature, given in figure 12, were computed from observed air temperatures and relative humidities.

#### VEGETATION

As can be seen from figure 4, a considerable amount of clearing of the saltcedar vegetation was necessary

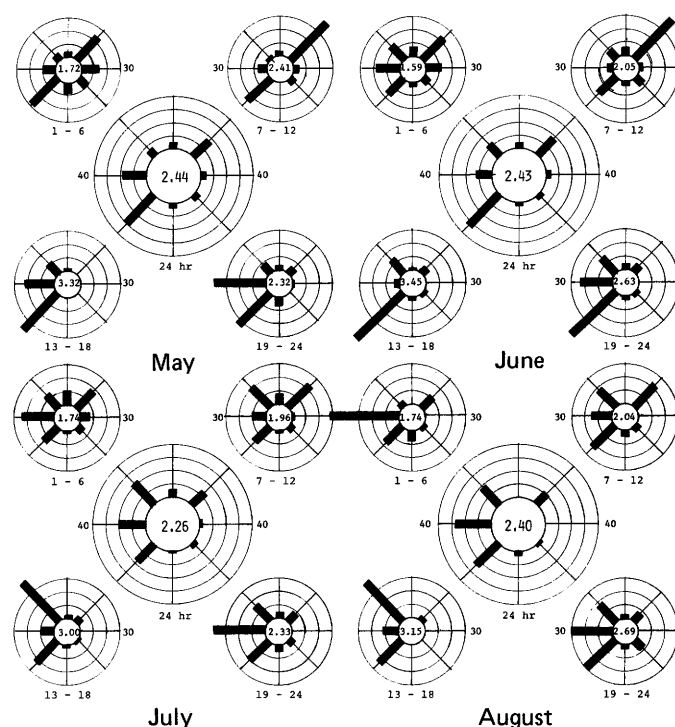


FIGURE 8.—Mean wind directions for 6-hour and daily periods for the months of May, June, July, and August, 1965. Numbers in the center are windspeeds for the periods, in meters per second.

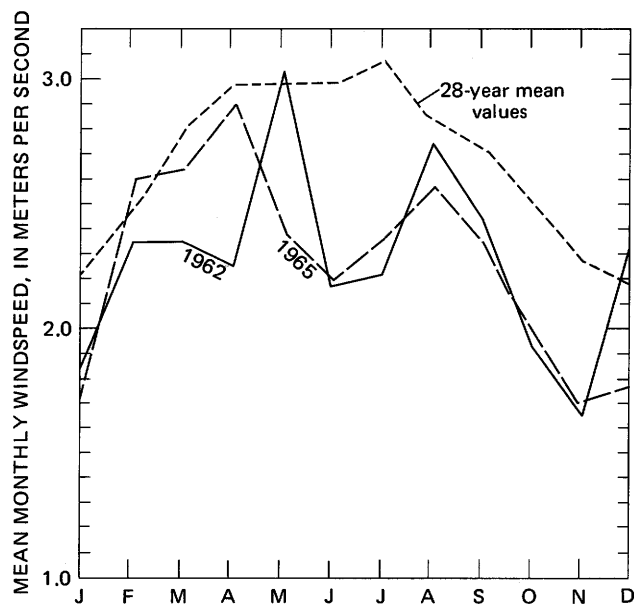


FIGURE 9.—Mean monthly windspeeds at the Buckeye project site in 1962 and 1965, and at Sky Harbor Airport, Phoenix, Ariz. (1930–58 mean values).

before the evapotranspirometers could be installed. But as figure 5 shows, by 1963 vegetation on the cleared area was nearly equal in height and density to the original one. In open places, inside as well as outside the test area, a number of grasses and forbs grew

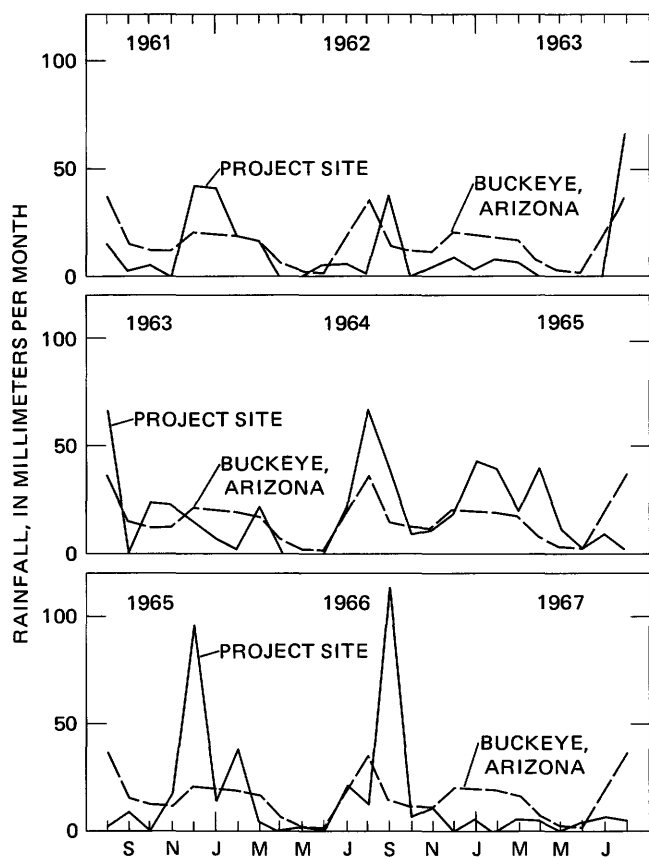


FIGURE 10.—Monthly rainfall at the Buckeye project site and monthly mean (1930–58) at Buckeye, Ariz.

up from seeds washed in with floods of the Waterman Wash. Some of these are roadside weeds, others are members of the mesquite associations occurring outside the riparian areas along the lower Gila River and its tributaries. Table 3 gives a list of these plants together with some characteristics. According to Kearney and Peebles (1960), quite a few of the species normally grow at higher altitudes. They are washed down in the frequent floodings of the Waterman Wash. It is also noteworthy that none of these plants is known to be an indicator or edicator<sup>4</sup> (Chikishev, 1965) of soil or soil-moisture characteristics, except possibly pigweed, *Chenopodium rubrum*, and the quail plant, *Heliotropium curassavicum*, which seem to prefer alkali or saline soil.

Soon after the replanting of the cleared areas (fig. 4 is an example) most of this herbaceous vegetation disappeared, leaving saltcedar as a nearly 100-percent dominant species. There is undoubtedly a shading effect, but an important cause of this phenomenon is the capacity of saltcedar to exude salt (Campbell and Strong, 1964; Hem, 1967) through openings in the

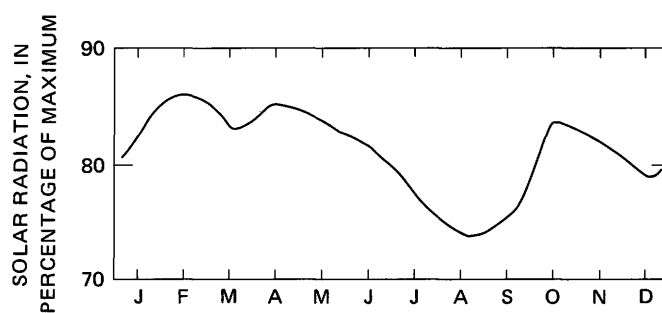


FIGURE 11.—Solar radiation in percentage of maximum possible; transmission coefficient assumed to be 0.9; plot based on mean values for 1961–67.

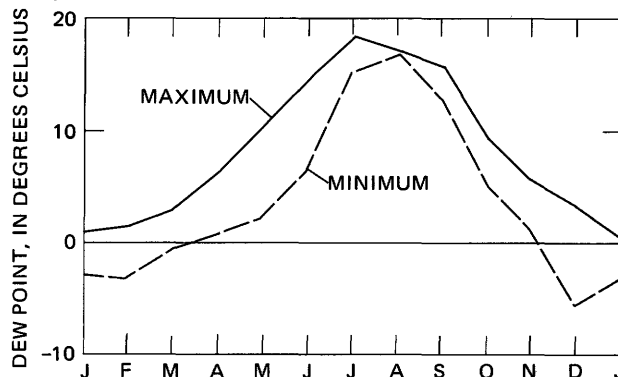


FIGURE 12.—Dew-point temperatures at the Buckeye project; plot based on mean values for 1961–67.

scalelike leaves that are constructed very much like the water-guttating hydathodes one finds in hydrophytes and other plants growing under conditions of frequent high relative humidities. Since saltcedar is a halophyte, such glands could well be named halohodes (van Hylckama, 1966). The exuded crystals are hygroscopic and on cool mornings tiny drops are formed on the leaflets. This salty "dew," from which the saltcedar gets the first part of its common name, falls on the ground and kills any emerging seedling. One rarely finds an intruder in a saltcedar thicket. The conductivity of the soil-moisture extracts taken from the surfaces of the soils at the project site was often as high as 45 mmho/cm at 25°C (millimho per centimeter), or 45 mS/cm (millisiemen per centimeter) at 298°K.

Another point of interest is the genotypical variability of saltcedar. The plant can have the appearance of a small tree, as along the lower Colorado River near Yuma, Ariz., or it can take on a more shrublike appearance as at the Buckeye Project site, or the plants can be tall but spindly, as along the Rio Grande near Bernardo, New Mex. The color of the flower can also vary from red through shades of pink to near white; the time and character of bloom can also vary greatly. Variations are mostly due to genetic characteristics and not to environmental factors (J. S. Horton, written commun., 1977).

<sup>4</sup> An edicator is a plant species that is an indicator of more than one soil or soil-moisture characteristic.

TABLE 3.—Plants (other than saltcedar) observed growing at the Buckeye project site, 1961–66

[Abbreviations used in columns are the following: For value of plant: W symbolizes weed and F forage plant. For abundance: a, abundant and c, common. For usual habitat: as, alkali or saline soils, dr, dry areas; gs, gravelly soil; ma, moist areas; rs, road sides; ss, sandy soils; wl, waste lands; ws, washes. For origin of plants: E, European; I, introduced from places other than European; and (-), no specific information available. Nomenclature follows Kearny and Peebles (1960)]

| Plant                                                    | Value | Quantity | Habitat | Origin |
|----------------------------------------------------------|-------|----------|---------|--------|
| <b>Annals and Biennials</b>                              |       |          |         |        |
| <b>Grasses:</b>                                          |       |          |         |        |
| <i>Eragrostis cilianensis</i> (love grass) -----         | W     | a        | wl      | E      |
| <i>Schismus barbatus</i> (six week grass) -----          | F     | a        | ss      | E      |
| <i>Polypogon monspeliensis</i> (rabbit foot grass) ----- | F     | c        | ma      | I      |
| <i>Echinochloa colonum</i> (cock spur) -----             | F     | c        | ma      | E      |
| <b>Forbs:</b>                                            |       |          |         |        |
| <i>Eriogonum deflexum</i> (skeleton weed) -----          | -     | a        | ss      | -      |
| <i>Chenopodium incisum</i> (goose foot) -----            | -     | -        | dr      | -      |
| <i>Chenopodium rubrum</i> (pig weed) -----               | W     | -        | as      | E      |
| <i>Chenopodium leptophyllum</i> (goose foot) -----       | -     | -        | dr      | -      |
| <i>Salsola kali</i> (Russian thistle) -----              | W     | -        | wl      | E      |
| <i>Acanthochiton wrightii</i> (green stripe) -----       | F     | -        | dr      | -      |
| <i>Abronia villosa</i> (sand verbena) -----              | -     | -        | ss      | -      |
| <i>Argemone intermedia</i> (prickle poppy) -----         | -     | -        | ss      | -      |
| <i>Tribulus terrestris</i> (caltrop) -----               | W     | a        | rs      | E      |
| <i>Mentzelia albicaulis</i> (blazing star) -----         | -     | -        | dr      | -      |
| <i>Nama demissum</i> -----                               | -     | -        | ss      | -      |
| <i>Amsinckia tessellata</i> (fiddle neck) -----          | -     | -        | ss      | -      |
| <i>Plantago purshii</i> (plantain) -----                 | -     | a        | dr      | -      |
| <i>Verbesina encelioides</i> (crown beard) -----         | -     | a        | wl      | -      |
| <i>Palafoxia linearis</i> -----                          | -     | -        | ss      | -      |
| <i>Pectis papposa</i> (fetid marigold) -----             | -     | -        | gs      | -      |
| <i>Sonchus oleraceus</i> (sow thistle) -----             | W     | -        | wl      | E      |
| <b>Perennials</b>                                        |       |          |         |        |
| <b>Grasses:</b>                                          |       |          |         |        |
| <i>Cynodon dactylon</i> (Bermuda grass) -----            | W     | a        | -       | -      |
| <i>Sorghum halepense</i> (Johnson grass) -----           | W     | a        | wl      | -      |
| <b>Forbs:</b>                                            |       |          |         |        |
| <i>Sphaeralcea ambigua</i> (globe mallow) -----          | -     | -        | dr      | -      |
| <i>Petalonyx thurberi</i> (sandpaper plant) -----        | -     | -        | ss      | -      |
| <i>Mentzelia puberula</i> (stick leaf) -----             | -     | -        | gs      | -      |
| <i>Heliotropium curassavicum</i> (quail plant) -----     | -     | -        | as      | -      |
| <i>Solanum elaeagnifolium</i> (horse nettle) -----       | -     | -        | ss      | -      |
| <i>Nicotiana trigonophylla</i> (tobacco) -----           | -     | -        | ws      | -      |
| <b>Shrubs:</b>                                           |       |          |         |        |
| <i>Prosopis juliflora</i> (mesquite) -----               | -     | c        | ws      | -      |
| <i>Cercidium floridum</i> (palo verde) -----             | -     | -        | ws      | -      |
| <i>Lycium fremontii</i> (desert thorn) -----             | -     | -        | ss      | -      |
| <i>Encelia farinosa</i> (brittle bush) -----             | -     | -        | gs      | -      |

## EVAPOTRANSPIRATION AND ITS CALCULATION

Although evaporation, transpiration, and evapotranspiration all involve the same process, namely the change of water into vapor, a distinction should be made between evaporation and transpiration. Such a distinction has not always been made. For instance, Thornthwaite (1948), Penman (1956), and many other workers, at times considered vegetation to be a mere inert transporter of water or vapor, but later investigators found that at least some plants exercise a pronounced control over the rate of their transpiration. See also Monteith (1963), Tanner (1963), and (for lively discussions) Lee (1967; 1968a; b), Idso (1968), and van Bavel (1968).

### EVAPORATION

Originally two methods to compute evaporation indirectly were tested over open water surfaces. Both

methods consider the transformation of water into vapor as a surface phenomenon, similar to what happened to the water on Aristotle's plate when exposed to sun and wind. If the plate is covered and remains at a constant temperature, the number of molecules leaving the water surface eventually become equal to the number entering the surface, at which time the air above the water is said to be saturated with water vapor. Any increase in water molecules in this space would cause condensation and the moisture would fall back to the water surface. If the cover is removed and wind blows over the plate, vapor is taken away. The original balance is upset, an excess of molecules leaves the water surface and the supply is depleted at a rate which (among other things) depends upon the speed of the air moving over the surface. This in brief is the principle of the aerodynamic method.

On the other hand, assuming that there is no wind but that there is a change in temperature, (which

under natural conditions would be caused by the sun's energy), the water is heated, the molecules move faster and more leave the surface. The air in turn also becomes heated and capable of absorbing more water molecules since the solar heat represents an incoming supply of energy which is transposed into the energy represented by warmer water and warmer air. Computations based on this principle are called energy-budget methods.

Thus, if the wind during the mass-transfer process does not heat or cool and if the air flowing over the surface is already saturated, no evaporation will take place due to the movement of air. Under such circumstances one could use an energy-budget method pure and simple. Under natural conditions, however, one must combine the principles of energy budget and aerodynamics if one desires to arrive at reliable results. This is especially true in areas where the air is dry and the wind very often strong—in other words, under conditions typical for the Buckeye Project and for the vast majority of areas in the arid and semiarid southwest.

#### TRANSPIRATION

If evaporation takes place through the surfaces of plants, it is called transpiration. In most plants growing in or under water or growing under very moist conditions, much of this transpiration takes place through the epidermis and its waxy covering, the cuticle (from the Latin *cutis* = skin). This water loss through the cuticle of stems and leaves is called cuticular transpiration. But in most land plants the outer surface is covered with dense hairs, with heavy layers of wax or, on stems, with corky bark. Under such circumstances cuticular transpiration accounts for only a small fraction of the total. Most transpiration then occurs through little openings in the leaves called stomata—plural of the Greek word *στομα* (stoma = mouth).<sup>5</sup> It is through these openings that during daylight carbon dioxide is taken up for the process of photosynthesis and water is transpired. It should be noted that a small exchange of carbon dioxide and vapor can also take place through much larger openings (lenticels) in the outer surface of branches and stems.

The size of the stomata varies with the plant species but those of saltcedar measure, when open, about  $7 \times 20 \mu\text{m}$  with an open-pore size of about  $60 \mu\text{m}^2$  (Campbell and Strong, 1964). Figure 13 shows schematic drawings of a stoma and a typical distribution of stomata over a leaf surface. Unlike most deciduous

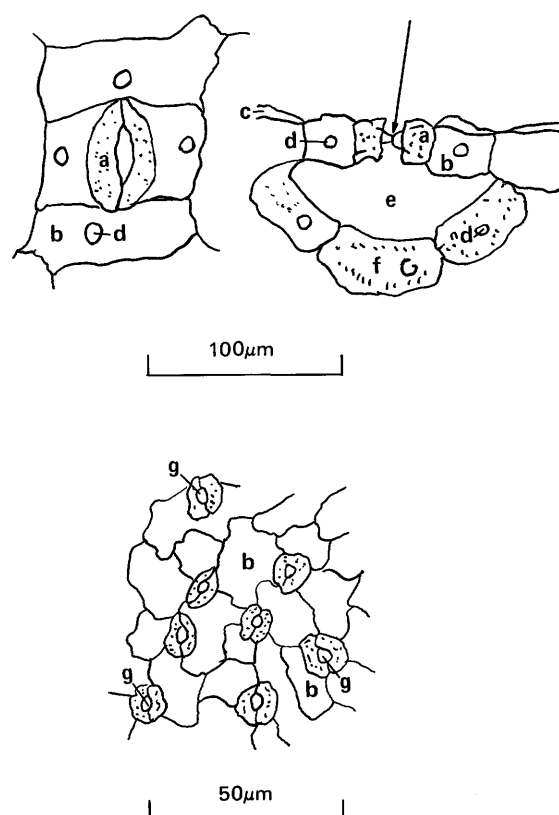


FIGURE 13.—One stoma in surface view (top left) and in cross section (top right); view of some stomata distributed over the underside of a leaf (bottom). The dotted lines in the cross section (arrow) indicate position and shape of the guard cells (a) in closed position. Schematic after Fitting, Schumacher, Harder, and Firbas (1951): a, guard cell (one of two); b, epidermis cells with cuticle (c); d, nucleus in cell; e, substomatal air space; f, parenchyma (thin-walled tissue cells); g, open stomata. Dots in cells indicate chloroplasts where water and carbon dioxide are combined to form sugars with the help of solar energy.

trees, which usually have their stomata only on the underside of the leaves, the scalelike leaves of saltcedar have stomata all over the surface. These leaves are about 1.6 mm long and somewhat egg shaped; the largest diameter is about 0.8 mm. Since there are about 250 stomata per  $\text{mm}^2$  (Tomanek and Ziegler, 1960) it follows that at most about 1.5 percent of the leaf surface is open for the passage of water vapor.

Stomata react differently to ambient influences, depending on the species of the plant. Some stomata close partially or completely at night, others (for instance pineapple, *Ananas sativas*)<sup>6</sup> are wide open during that time. In some species they open during periods of high

<sup>5</sup> Saltcedar can also exude some liquid water through hydathodes at the end of vascular bundles in the leaves. Hydathodes in saltcedar usually are found about 1 mm below the leaf tips (Kisser, 1956). For the salt glands, see section on "Vegetation."

<sup>6</sup> Cacti and other succulents are capable of taking up  $\text{CO}_2$  during the night with little loss of water. Then, during times of sunshine, the  $\text{CO}_2$  is photosynthetically combined with water and other chemicals in the plant cells to build plant material (Walter, 1973).

wind, in others they close, but all close when the plant is under water stress, at which time the turgor in the guard cells (see fig. 13) diminishes, resulting in closure of the openings.

#### FLOW RESISTANCE

One can now visualize a series of resistances against the movement of water and vapor. Disregarding the resistances against water movement in the soil, from the soil to the roots, and from the roots through the plant, which do not concern us here, it is intuitively clear that a resistance develops when water moves through the thin-walled parenchyma cells surrounding the substomatal cavity and vaporizes. The vapor then has to pass through a comparatively small opening to reach the ambient air. This is called the stomatal resistance (Monteith, 1963; Smirnov, 1963). Just outside the stomata and along the surface of the leaves is a layer, a few tens of molecules thick, where the flow is only laminar and the diffusion molecular, causing an external resistance. Further resistances occur within and above the canopy of a vegetation.

It seems clear from the above that transpiration must be considered a phenomenon decidedly different from that of evaporation. But because evaporation from soil surfaces and from wet leaves (after dew or rain) can occur simultaneously with transpiration, the term evapotranspiration is commonly used when the loss of water from vegetated surfaces is considered.

In the following pages it will be shown that the inclusion of a resistance term in evapotranspiration equations used at the Buckeye project leads to water-loss data that fit the measured ones better than when no resistance term is used.

In the discussion of the methods used to estimate evapotranspiration only the principles are considered. There are many variations proposed and in use. Only those tested at the Buckeye Project will be mentioned during the data analysis.

#### VAPOR-FLOW METHODS

Two methods are considered to belong in this group, and they differ greatly in approach. One, the atmospheric water-balance method, measures the amount of vapor that enters and leaves a tall column of air over a large area. The other, the eddy-correlation method, measures vertical vapor flow as close as possible to the evaporating surface.

#### THE ATMOSPHERIC WATER BALANCE

Basically, the estimation of evapotranspiration by the atmospheric water balance method is analogous to

the soil-water balance method. For the latter we have the equation:

$$P = RO + E \pm \Delta S \quad (1)$$

in which  $P$  is precipitation,  $RO$  is runoff,  $E$  is evaporation, and  $\Delta S$  is the change in soil-moisture storage. Deep percolation and underground drainage are neglected.

Instead of considering a block of soil with the surface at its upper boundary, one can consider the volume of air with the soil surface at its lower boundary and the top, say, at the 500 millibar level (50 kPa [kilopascal], about 5.5 km above sea level). Then  $\Delta S$  becomes a change in the quantity of moisture in the air which can be due to evaporation from soil or plants (vertical components) or to moisture entering or leaving the air column more or less horizontally. This "horizontal" component is an advective term and has to be considered not only in the atmospheric water balance but also in the combination methods to be discussed later.

With this in mind, one can write:

$$E = P - (\nabla \cdot M \pm \Delta W) \quad (2)$$

in which  $\nabla \cdot M$  is the difference between the moisture in the atmosphere entering and leaving the column. The quantity  $\nabla \cdot M$  is usually called "divergence" if it is positive and "convergence" if negative. It can be measured by radiosonde observation. The change in precipitable water (analogous to  $\Delta S$  in equation 1) is denoted by  $\pm \Delta W$ . Since precipitation in this procedure is considered to be a measurable quantity,  $E$  can be computed and compared with data derived from more direct measurements such as lysimetry.

Täumer (1955) was probably the first one to make complete investigations over a 10 000 km<sup>2</sup> area for individual months and to compare meteorologic results with lysimeter data published by Kalweit (1953). More recently Rasmusson (1967; 1968) and Malhotra (1969) used the dense radiosonde network over the North American continent (an area at least 1000 times as large as Täumer's) to compute monthly values. It is obviously difficult to check the results of this type of studies against those obtained from conventional methods and one must resort to more esoteric methods such as seasonal changes in latitude or in the wobble of the earth caused by the movement of large air masses (Munk and McDonald, 1960; van Hylckama, 1970b).

It is therefore not surprising that an attempt to apply the principle of equation 2 at the test site failed. The distance (92 m between the masts O and M in fig. 3) was far too short and the height of the sensing elements (2 m above the vegetation) was far too small to enable the successful integration of windspeed, tem-

perature, and vapor-pressure data for the computation of an increase in water vapor due to transpiration.

#### THE EDDY-CORRELATION METHOD

Since evaporation and transpiration are basically surface phenomena, the first from the surfaces of free water and the second from the surfaces of plants, it is logical to measure these phenomena as close to the surface as possible. But technically this is difficult to do. However, during the last 20 years sensing and recording equipment has been greatly improved (L. J. Fritschen, oral commun., 1977). Although the Buckeye Project was not equipped for this model, it shall be mentioned here because of its promising potential.

The eddy-correlation method can be considered the most fundamental approach to the measurement of evapotranspiration because the turbulent air movements that give rise to eddy diffusion are measured together with the fluctuations in humidity.

An eddy can probably best be visualized as being a parcel or "glob" of air with a long or short history of existence of its own. Brunt (1952, p. 219) did not consider it likely that any definition could be given which would be universally acceptable. He wrote, "The eddies which form the edge of a stream flowing into a mill pond are of the nature of vortices with vertical axis, but the name 'eddy' as used in discussing motion in the atmosphere is not restricted to circular motions. We can only define eddy as a physical entity which disturbs the uniform flow of air and this definition will include rotating eddies, convection currents, and any other type of disturbance."

This method, also known as the eddy-transfer method, rests on the idea that a moving parcel of air carries with it, on its journey up, down, or sideways, the heat, water vapor, dust, and momentum it contained at the start. That this is not necessarily so is one of the difficulties in applying this method and some other methods of estimating water losses or evapotranspiration, as will be discussed later on.

If measured close to the surface and with sufficient frequency (of the order of once per second or more often) the mean upward flux of humidity (or any other property of the atmosphere) per unit mass can be given as:

$$F = \overline{\rho_a w q} \quad (3)$$

where  $\rho_a$  is the density of the air,  $w$  its vertical velocity,  $q$  its humidity, and where the bar indicates the average condition during a selected period. Now any change can be expressed as an average and the deviation from that average during such a period. Hence:

$$\rho_a = \bar{\rho}_a + \rho'_a, \quad w = \bar{w} + w', \quad \text{and} \quad q = \bar{q} + q' \quad (4)$$

where a prime gives the instantaneous deviations from the mean. Thus we can write:

$$F = \overline{(\rho_a + \rho'_a)(w + w')(q + q')} \quad (5)$$

which can be expanded to:

$$F = \overline{\bar{\rho}_a \bar{w} \bar{q} + \bar{\rho}_a \bar{w} q' + \bar{\rho}_a w' \bar{q} + \bar{\rho}_a w' q' + \rho'_a \bar{w} \bar{q} + \rho'_a \bar{w} q' + \rho'_a w' \bar{q} + \rho'_a w' q'} \quad (6)$$

Because the sum of the deviations from the mean is zero by definition, all terms in this equation that have a single prime go to zero but the product of two such primed quantities does not. With this in mind, and also neglecting density fluctuations which are small close to the ground, we have:

$$F = \rho_a \bar{w} \bar{q} + \overline{\rho'_a w' q'} \quad (7)$$

The effective rate of upward diffusion of water vapor past the measuring point is now given by  $w'q'$ , which is called the eddy flux, and this can be obtained by separately measuring  $w$  and  $q$ . These values can be multiplied and integrated over a measuring time period, and the product of the individual mean values over that period can be subtracted.

The instrumentation for direct measurements of the eddy and its properties has been under development since the work of Swinbank (1951). (Also see Perepelkina, 1959.) These instruments use hot-wire anemometers and fine-wire dry and wet thermocouples and even more sensitive instruments are under study (Dyer, 1961; Goltz and others, 1970; Hicks and Goodman, 1971). The fact that enormous quantities of data have to be converted into required output over periods of 5, 10, or more minutes and the resulting requirement for integrating circuits, analog computers, or digital microprocessor networks, makes this method very expensive.

This discussion of the eddy-correlation method is included here to emphasize its importance. It is the only method that is independent of the characteristics of the surfaces over which measurements are made. The instrumentation can be easily moved about and installed for any desired time over any surface to determine evapotranspiration rates and, if suitable, to provide ground-truth data for remote-sensing (including satellite) studies.

#### BULK-AERODYNAMIC METHODS

There are two methods that belong in this category: the Dalton approach and the profile approach.

## THE DALTON APPROACH

This method is so called because it was Dalton (1802) who recognized the principles of the atmospheric vapor flow close to a surface at which evaporation occurs. He reasoned that vapor transfer had to occur along a gradient of moisture concentration and that the efficiency of this concentration depends on the turbulence of the air (hence on the windspeed) above the surface. In other words,

$$E_0 = f(\bar{u}) (e_0 - e_a) \quad (8)$$

in which  $f(\bar{u})$  is a function of the mean windspeed, often given as:

$$f(\bar{u}) = a (1 + b\bar{u}) \quad (9)$$

or

$$f(\bar{u}) = c\bar{u} \quad (10)$$

$E_0$  is the evaporation rate,  $e_0$  and  $e_a$  are respectively the pressures at the evaporating surface at height  $z = 0$  and in the air above it (for practical purposes 1 or 2 m),  $\bar{u}$  is the average windspeed, and  $a$ ,  $b$ , and  $c$  are constants.<sup>7</sup>

Several investigators have given numbers to these constants, for instance Rohwer (1931) has:

$$E_0 = 0.4 (1 + 0.27 \bar{u}_0) (e_0 - e_a) \text{ mm/day} \quad (11a)$$

where  $\bar{u}$ , the mean wind at the surface, is in miles per hour and the vapor pressures are in mm Hg. Penman (1948) modified this to:

$$E_0 = 0.4 (1 + 0.17 \bar{u}_2) (e_0 - e_a) \text{ mm/day} \quad (11b)$$

with  $\bar{u}$  at 2 m above the surface. Other variations are given by Kuznetsov and Fedorova (1968). Harbeck (1962) developed this variation for estimating evaporation from reservoirs:

$$E_0 = Nu (e_0 - e_a) \quad (11c)$$

where  $N$  is a coefficient related to the reservoir's surface area. Since the variables are comparatively easy to measure close to the evaporating surfaces, average values over periods of half an hour or longer can be obtained. The method is an integral part of the combination approach which will be discussed later.

<sup>7</sup>The use of two constants in the wind function  $a(1 + b\bar{u})$  can be considered an admission of the fact that many cup-type anemometers have considerable starting and stalling speeds, that is, it takes a comparatively strong wind to get them going and they keep turning for a considerable time after the wind has died down (G. E. Harbeck, Jr., written commun., 1955).

## THE AERODYNAMIC OR PROFILE APPROACH

The method is called profile approach because it considers temperature, humidity, and wind speeds at two or more levels above the surface, rather than at the surface alone. This sounds like a simplification, but the shape of the profiles depend so much on the stability or instability of the air that, unless the wind profile is logarithmic, large deviations from observed evapotranspiration values can be expected.

In the aerodynamic methods, we distinguish three vertical fluxes which result from the turbulent diffusion in the lower layers of the atmosphere. They are  $\tau$ , the flux of momentum,  $A$  the flux of sensible heat, and  $V$  the flux of water vapor. They are expressed as follows:

$$\tau = \rho_a K_m \frac{\partial u}{\partial z} \quad (12)$$

$$A = \rho_a c_p K_A \frac{\partial T}{\partial z} \quad \text{and} \quad (13)$$

$$V = \rho_a K_v \frac{\partial q}{\partial z} \quad (14)$$

The  $K$ 's are exchange coefficients respectively for mass ( $m$ ), heat ( $A$ ), and vapor ( $v$ );  $c_p$  is the specific heat for dry air;  $T$  is the temperature; and the other symbols are as defined before.

Any other type of atmospheric flux can be expressed in a similar manner. For instance, for carbon dioxide flux,  $F_c$ , we would have

$$F_c = K_c \frac{\partial C}{\partial z} \quad (15)$$

where  $C$  is the  $\text{CO}_2$  content as mass per volume. Intuitively it seems reasonable to assume that the exchange coefficients ( $K$ ) would be the same for all four equations. That this is not always so causes difficulties in applying the aerodynamic approach. For instance, assuming that  $K_m = K_v$  and that the wind profile is logarithmic, Thornthwaite and Holzman (1942) proposed the following equation for evapotranspiration ( $E$ ):

$$E = \rho_a k^2 \frac{(q_2 - q_1) (u_2 - u_1)}{[\ln(z_2/z_1)]^2} \quad (16)$$

where  $k$  is von Karman's coefficient, often taken as 0.40 or 0.41, (see section on "Winds"). Later, other workers (for instance Pasquill, 1950 and Pierson and Jackman, 1975) attempted to correct the aerodynamic

equation for conditions of instability. The methods then became very complex, requiring very accurate and frequent measurements of windspeed, specific humidity, and temperature at three or more elevations above the surface. Webb (1965) presents a good review of this method.

#### ENERGY-BUDGET METHOD

Penman (1956, p. 16) starts his discussion of the energy balance as follows: "The fundamental basis of the energy balance approach is unchallenged: the challenge is to our ability to measure or estimate all the quantities needed to exploit the principle of the conservation of energy."

The energy-budget, or heat-budget method, is one of the theoretical methods based on the principle of the conservation of energy. Evaporation and transpiration are essentially the same thing. In both cases about 2450 joules (585 calories) are needed to evaporate 1 g of water at summer temperature. The energy to do this comes directly or indirectly from the sun.

At the top of the atmosphere the earth receives on each square meter perpendicular to the sun's rays about 1400 W or 2 cal cm<sup>-2</sup> min<sup>-1</sup>, but a large part of the radiation is reflected back into space by dust, water vapor, and clouds; another part is scattered into the air; and a third part heats the soil and therewith the air. How much reaches the plants and the ground depends on latitude and season, on weather conditions, on elevation of the place, and on its exposure. The quantity may vary from practically zero under heavy overcast to more than 1000 W m<sup>-2</sup> on high mountains above the clouds.

If we now measure all those different types of radiation, incoming and outgoing, and also the changes in temperature in the soil and in the air, and take into account that at times considerable quantities of hot air are brought into the test site by advection, we can set up a balance sheet. On one side we have all the incoming radiation, on the other the sum of all that goes out plus what is stored in the soil, in the air, and in the vegetation. If we do this, we find that the two sides do not balance. The difference is that part of the radiation which is used to evaporate water either from the surfaces of lakes or from moisture on and in the soil, or from water on and in the plants. Thus we have a method of indirectly measuring the amount of water transpired, which is the only item in the balance sheet that we cannot measure directly.

If the energies consumed in photosynthesis or liberated by metabolic processes are neglected we can write:

$$R_n = LE + A + G \quad (17)$$

in which  $R_n$  is the net radiative flux received by the surface,  $G$  is the heat flux into or out of the ground,  $A$  and  $LE$  are the sensible heat flux and latent-heat flux into the air respectively, and  $L$  is the latent heat of evaporation.

In this equation  $R_n$  and  $G$  can readily be measured, but the partitioning of the energy between evaporation and heating of the air has to be approached indirectly. The ratio  $A/LE$ , usually called the Bowen ratio ( $\beta$ ), was found by Bowen (1926) to be:

$$\beta = A/LE = c \left[ \frac{T_o - T_a}{e_o - e_a} \right] \frac{p}{1000} \quad (18)$$

where  $c$ , according to Bowen, varies between 0.58 and 0.66 depending on the state of the atmosphere. Note that this ratio was used to compute evapotranspiration over open water.  $T_o$  and  $T_a$  are the temperatures of the water surface and of the air above it;  $e_o$  is the saturation vapor pressure at  $T_o$ , and  $e_a$  the actual vapor pressure at the elevation of  $T_a$ . Over Lake Hefner (U.S. Geological Survey, 1954), where  $T_a$  and  $e_a$  were measured at 2 m above the surface, single-day average values were found to vary from -20.02 to +31.50 although most of the time they lay between -0.5 and +0.5.

From the flux-gradient equations discussed (13 and 14) it follows that, if  $K_A = K_r$  and atmospheric pressure is assumed to be constant,  $\beta$  can also be expressed as

$$\beta = \frac{c_p K_A \frac{\delta T}{\delta z}}{L K_r \frac{\delta q}{\delta z}} \quad \text{or} \quad \gamma \frac{\Delta T}{\Delta q} \quad (19)$$

where  $\gamma$  is the psychrometer constant, which has a value of about 0.65 °C<sup>-1</sup>. If vapor pressure ( $e$ ) differences are used instead of specific humidity ( $q$ ) values the dimensions are mb/°C. If  $\beta$  can be considered constant with height, the energy balance can also be written as:

$$E = \frac{R_n - G}{L} \left[ \frac{LE}{A + LE} \right] = \frac{R_n - G}{L} \frac{1}{1 + \beta} \quad (20)$$

or  $LE = R_n / (1 + \beta)$  if  $G$  can be neglected.

Table 4 shows the values of  $\gamma \Delta T / \Delta e$  for a 24-hour period at five different paired levels. The values are quite erratic, although most of the time when they are negative or positive together, they indicate some consistency with height. However, there are large deviations: for instance between 0300 and 0400 the values range from -0.78 to -13.65 and between 1400 and 1500 from -0.07 to +0.33.

TABLE 4.—Values of  $\gamma$  ( $\Delta T/\Delta e$ ) for a 24-hour period, May 5 and 6, 1966

[ $\Delta T$  and  $\Delta e$  are differences in temperature ( $^{\circ}\text{C}$ ) and vapor pressure (mb) between a lower and higher level;  $\gamma$  is the psychrometer constant taken to be 0.65 mb/ $^{\circ}\text{C}$ . The vegetation is 3 m tall and forms an even stand]

| Start of measuring periods<br>(time in hours) | Instrument heights above ground in meters |          |         |         |         |
|-----------------------------------------------|-------------------------------------------|----------|---------|---------|---------|
|                                               | 11 and 7                                  | 11 and 5 | 7 and 5 | 7 and 4 | 5 and 4 |
| 5                                             | -2.92                                     | -2.60    | -1.95   | -3.25   | -4.55   |
| 6                                             | -2.81                                     | -2.21    | -1.30   | -2.16   | -3.90   |
| 7                                             | 1.30                                      | 0.65     | 0       | -0.65   | -1.30   |
| 8                                             | 0.21                                      | 0.26     | 0.33    | 0.21    | 0       |
| 9                                             | 0.07                                      | 0.08     | 0.09    | 0.21    | 0.39    |
| 10                                            | 0.37                                      | 0.49     | 0.65    | 0.81    | 1.09    |
| 11                                            | 0.05                                      | 0.25     | 0.51    | 0.56    | 0.65    |
| 12                                            | 0.33                                      | 0.23     | 0.12    | 0.47    | 1.02    |
| 13                                            | 0.33                                      | 0.33     | 0.65    | 0.31    | -0.18   |
| 14                                            | -0.07                                     | 0.08     | 0.26    | 0.29    | 0.33    |
| 15                                            | 0.52                                      | 0.14     | -0.33   | -0.05   | 0.39    |
| 16                                            | 0                                         | 0.17     | 0.39    | 0.10    | 0.21    |
| 17                                            | 0.37                                      | 0.12     | -0.33   | -0.49   | -0.65   |
| 18                                            | -0.54                                     | -0.59    | -0.65   | -0.92   | -1.63   |
| 19                                            | -0.46                                     | -0.49    | -0.52   | -0.86   | -1.30   |
| 20                                            | -0.65                                     | -1.03    | -1.56   | -1.54   | -1.51   |
| 21                                            | -1.69                                     | -1.37    | -0.98   | -1.30   | -1.73   |
| 22                                            | -0.65                                     | -0.91    | -1.30   | -0.43   | -1.30   |
| 23                                            | -0.65                                     | -1.02    | -1.51   | -1.78   | -2.60   |
| 24                                            | -3.58                                     | -4.11    | -5.20   | -3.25   | -1.30   |
| 1                                             | -2.44                                     | -1.95    | -1.46   | -1.51   | -1.63   |
| 2                                             | -5.20                                     | -3.90    | -2.60   | -2.81   | -3.25   |
| 3                                             | -0.78                                     | -0.92    | -1.30   | -5.41   | -13.65  |
| 4                                             | -6.83                                     | -6.28    | -5.20   | -3.90   | -2.60   |

The effect of the value of  $\beta$  on the computed  $LE$  values can be shown as follows:

Assume  $R_n = 1 \text{ cal cm}^{-2} \text{ min}^{-1}$  or  $60 \text{ cal cm}^{-2} \text{ hr}^{-1}$  (a nice summer mid-day value). Then if

$$\begin{array}{cccccccccccc} \beta = & -2.0 & -1.0 & -0.5 & -0.1 & 0 & 0.1 & 0.5 & 1.0 & 2.0 & , \\ LE = & -0.1 & ? & +2.0 & 1.1 & 1.0 & .091 & 0.67 & 0.50 & 0.33 \end{array}$$

where ? indicates that the  $LE$  value is undetermined.

Of course, during daylight, positive values are to be expected since temperature and vapor-pressure differences are nearly always negative. Nonetheless, as  $\beta$  increases from 0 to 2.0,  $LE$  diminishes from 1.0 to 0.33. Such differences can be avoided by integrating temperature and vapor pressure data over a large area and avoiding instrument bias by frequently changing the position of the sensing devices. Also, observations have to be made very close to the transpiring surface. Suomi and Tanner (1958) (p. 301) present a fascinating description of such instrumentation and mention that "on occasion plants even brushed against the bottom sensors". At the Buckeye Project the system was rigid, and the lower sensor was placed 1 m above the top of the vegetation. These are the main reasons that the energy-budget, using the Bowen ratio, could not be used at the Buckeye Project.

#### COMBINATION METHODS

The instrumentation seemed better adapted to the use of a combination of the energy-budget and a mass-

transfer term. Penman (1948) combined the energy balance and the aerodynamic balance into the following equation:

$$E_0 = \frac{\Delta/\gamma H_0 + E_a^*}{\Delta/\gamma + 1} \quad (21)$$

in which the saturation vapor pressure at the surface replaces the actual vapor pressure. The actual vapor pressure is very difficult to measure. In this equation,  $E_0$  is the potential evaporation from open water;  $H_0$  is the net gain of radiation at a water surface;  $E_a^* = f(u)(e_s - e_a)$  (see equation 8); and  $\Delta$  is the slope of the curve when saturation vapor pressure is plotted against temperature. Modifying this method, van Bavel (1966) derived the following expression for the instantaneous evaporation rate:

$$LE_0 = \frac{\Delta/\gamma H + L B_r d_a}{\Delta/\gamma + 1} \quad \text{cal cm}^{-2} \text{ min}^{-1} \quad (22)$$

in which  $B_r$  is defined as

$$B_r = \frac{\rho_a \epsilon k^2}{p} \frac{u_a}{[\ln(z_a/z_0)]^2} \quad \text{g cm}^{-2} \text{ min}^{-1} \text{ mb}^{-1} \quad (23)$$

where  $\epsilon$  is the ratio of the molecular weights of water and air, (0.622),  $z_0$  the roughness parameter,  $H$  the sum of energy inputs at the surface (except  $A$  and  $LE$ ), and  $d_a$  the vapor pressure deficit ( $e_s - e_a$ ), with  $e_s$  the saturation vapor pressure.

This equation has been applied in the analysis of the Buckeye data and often has been given values at variance with the measured ones. Better agreement can be obtained if resistance terms are incorporated in the equation. Monteith (1963 and 1965) showed that the external resistance can be expressed as

$$r_a = [\ln(z_a/z_0)]^2 / u_a k^2 \text{ sec cm}^{-1} \quad (24)$$

and the stomatal resistance as

$$r_s = (\Delta/\gamma + 1) (E_0/E_a - 1) r_a \text{ sec cm}^{-1} \quad (25)$$

where  $E_a$  is the actual evapotranspiration as measured with a lysimeter, for instance.

Because the above equation contains both  $E_0$  and  $E_a$ , the stomatal resistance can be computed from measured values of these terms. The values so obtained can then be used to compute the evapotranspiration rates according to the following equation (the equation contains both resistance values):

$$E_0 = 1/L \frac{(\Delta/\gamma) H + [(\rho\epsilon)/p] (d_a/r_a)}{\Delta/\gamma + 1 + r_s/r_a} \quad (26)$$

Examples of the results will be given later.

## INSTRUMENTATION

Basically the instrumentation chosen to measure the various components in the aerodynamic and energy budgets was the same as that used in earlier investigations by the U.S. Geological Survey at Lake Hefner and Lake Mead (U.S. Geol. Survey, 1954; and Harbeck and others, 1958) and described in detail by Anderson, Anderson, and Marciano (1950). These studies, however, dealt with evaporation from open water, and for studies over tall vegetation certain adjustments had to be made.

The characteristic high temperatures and strong winds of this area frequently produce blowing dust and dust devils. This dust made it highly unlikely that reliable results could be obtained by the use of evaporation pans or a Cumming's radiation integrator. These instruments, therefore, were not installed.

Unlike the lake investigation just mentioned, where recording milliammeters were used, strip-chart recorders were used which had built-in amplification and automatic zero references, so no ice buckets or Dewar flasks were necessary.

The two kinds of recorders used printed a record every 60 seconds, sampling in sequence the electrical output from a series of 12 or 16 different sensors. An example is given in figure 14.

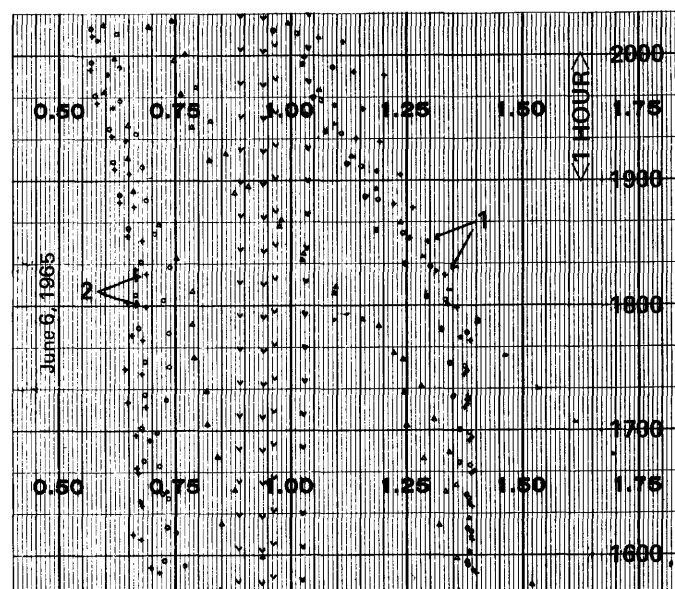


FIGURE 14.—Example of a 16-point strip chart about % of actual size, with date and times. The numbers, millivolts, must be converted into degrees Celsius by means of a template or by graphical means, because the relation between millivolts and degrees Celsius is not linear. The instrument prints four symbols in four colors (not shown here). Examples: Arrows 1 point to brown crosses, the dry-bulb temperature 11 meters above the ground; arrows 2 point to red crosses, the wet-bulb temperature, both recorded as millivolts.

During the Lake Hefner investigations, anemometers were usually placed on top of the radiation shields. In the Buckeye Project, as in the Lake Mead studies, cup rotors were placed at the level of the thermocouples.

Other variations will be mentioned below.

## THE ATMOSPHERE: WIND AND TEMPERATURE

### WIND

Because it was unknown what wind and temperature profiles would look like over the rough surfaces of saltcedar thickets, wind speeds and temperatures were measured 11, 7, 5, and 4 m above the ground, the average height of the vegetation being 3 m. A fifth anemometer was installed underneath the canopy about 2 m above ground. To the southwest (from which the prevailing wind presumably blew<sup>8</sup>) two masts were erected (O and M in fig. 3), each with an anemometer 5 m above ground.

The transmitters originally installed were of the three-cup variety; they were made of aluminum and

<sup>8</sup>To determine the location of the auxiliary masts (O and M in fig. 3), information on winds was obtained from the Litchfield Park Naval Air Facility, 21 km east of the project site, but the data proved not to be representative of those at the project. See the section on "The Atmospheric Water Balance."

weighed about 140 grams each. The system was connected to counting devices regulated by mechanical and magnetic switches as described by Anderson, Anderson, and Marciano (1950). However, the starting and stalling speed of these transmitters (explained in the section on "The Dalton Approach") was far too high to obtain reliable wind profiles over tall vegetation. Moreover, the counting devices broke down frequently, because they could not withstand the rigors of the climate. All anemometers, therefore, were replaced with a much more sensitive system. A new type of transmitter, consisting of three light plastic cups of 5 cm diameter attached to 5 cm long arms, weighed only 32.5 g. The counting devices were driven by photoelectric cells. These sensitive anemometers performed very well. Those at the auxiliary masts (O and M in fig. 3) were at times installed inside the vegetation and made it possible to construct wind patterns inside the thickets. See the section on "Winds."

The counting mechanisms indicated every fifth and every fiftieth turn of the rotor on a strip chart. An example is given in figure 15. The number of "pips" per hour was manually converted to meters per second using a calibration table.

#### AIR TEMPERATURE

Air temperatures were measured with copper-constantan thermocouples connected to the strip recorders. The thermocouples were protected from direct sunlight with aluminum shields of the type described by Anderson, Anderson, and Marciano (1950); they are outlined in figure 16. At this site these "coolie hats" had a tendency to corrode, to lose their reflectivity, and to become less effective shields. Covering them with adhesive aluminum foil proved to be a very practical and lasting remedy.

Mean hourly temperatures were found by averaging the five or six values on the strip charts (see fig. 15) over 1-hour periods. Most of the averaging could be done graphically. Especially valuable was a commercially available data-reading device connected to a counter which greatly facilitated transposing data manually from the strip charts to graphs and tables.

#### PRECIPITATION AND WATER VAPOR

##### RAINFALL

Precipitation was measured with three standard-type recording rain gages, one placed outside the saltcedar thickets, one on the 4-m platform, and one inside the thickets. Plastic wedge-shaped rain gages were installed on all tanks at about 1.50 m above ground.

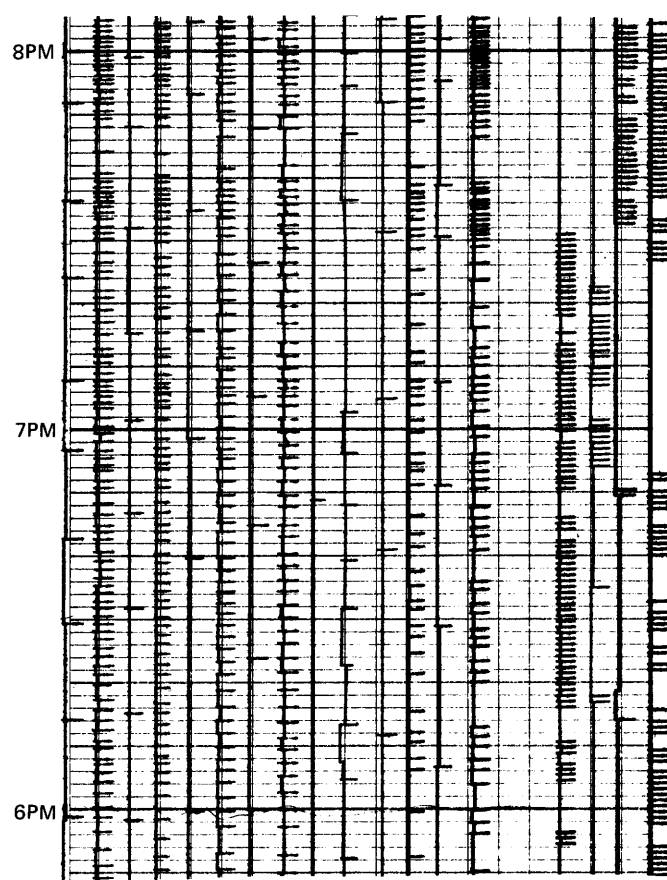


FIGURE 15.—Windspeed record for June 21, 1965 between 1200 and 1600 (marked 6 p.m. and 8 p.m. on this chart). The two columns on the left are the windspeed "pips" for the anemometer 11 m above ground; the 11th to 14th columns are the records for the anemometers inside the thickets counting five times as fast as the others; the four columns on the right give the wind directions, N, E, S, and W, respectively. About  $\frac{2}{3}$  actual size.

Precipitation data show that the rainfall was typical of the Sonoran Desert. During the summer, heavy thunder storms did occur, and 24-hour rainfalls of 30 mm and more were not uncommon. The heaviest rainfall during the project period, which resulted from hurricane Helga, was 115 mm in 3 hours, on September 16, 1966.

##### WATER VAPOR

Water vapor, expressed in millibars (1 mb = 100 Pa) was computed from the dry and wet bulb thermocouples records. The wet thermocouples were kept permanently wet with wicks fed from reservoirs (fig. 16). All thermocouples above the vegetation had sufficient ventilation due to the system illustrated in figure 17. Those close to and inside the vegetation were ventilated with fans driven by small electric motors.

A nomogram was constructed (fig. 18) to convert dry and wet bulb temperatures into vapor pressures, under

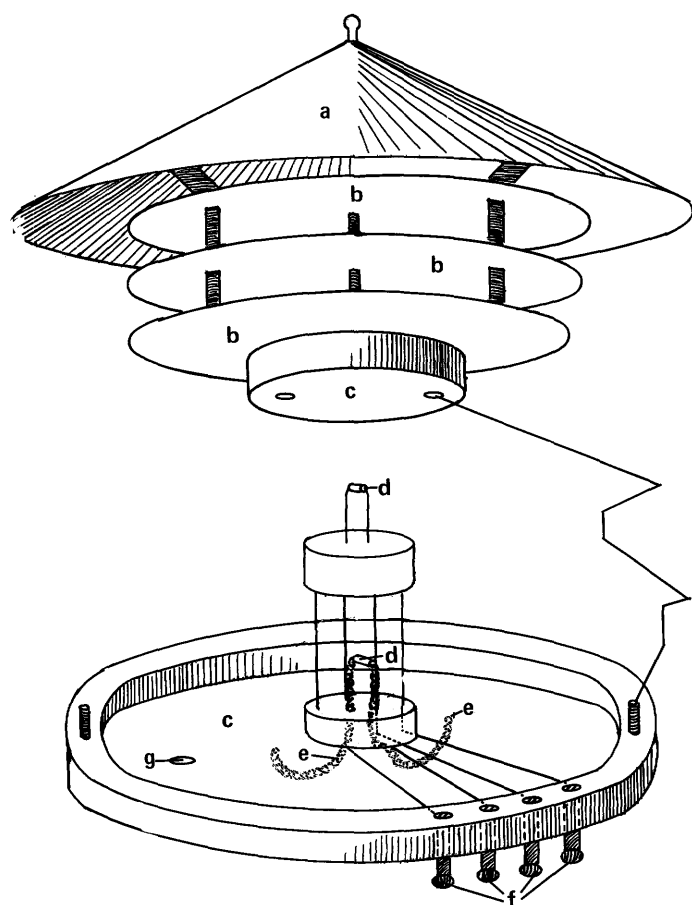


FIGURE 16.—Sketch of the air-temperature sensing system. a, radiation shield; b, plates holding the ventilator systems (see fig. 17); c, wet and dry thermocouple assemblies (enlarged below); d, dry and wet thermocouples, the wet one covered by wick e, the ends of which are floating in the reservoir; f, wire connectors to the recorder; g, vent screw to allow refilling of the reservoir.

the assumption of a constant atmospheric pressure of 985 mb (98.5 kPa) (the test site is 260 m above sea level).

#### RADIATION

The total hemispherical incoming solar radiation was measured with a pyrliometer designed for measuring the intensity of solar radiation from  $0.3 \mu\text{m}$  to  $5.0 \mu\text{m}$ . Nearly all the solar energy received at the earth's surface arrives in these wavelengths. The instrument consists of two concentric rings, the inner one is painted with lampblack, the outer one has a cover of magnesium oxide which strongly reflects solar radiation. The difference in the temperature of the two rings gives a measure of the solar radiation. This sensing element is hermetically sealed in a bulb of soda-lime glass. The total reflected solar radiation was measured with a similar instrument mounted upside down.

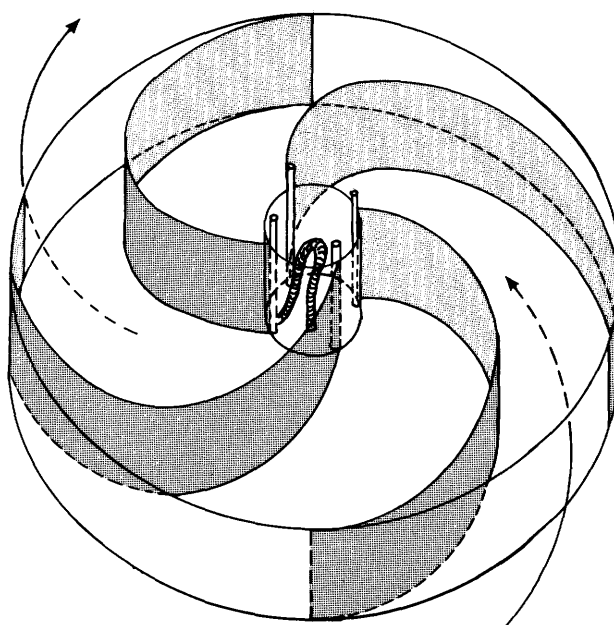


FIGURE 17.—Schematic diagram of the ventilator system. Both dry and wet thermocouples are ventilated; the dry one between top and middle plates (see fig. 16), the wet one between middle and bottom plates. (From Anderson and others, 1950.)

The total short- and long-wave incoming and reflected radiation was measured with a radiometer similar to the one used for the lake studies. Unlike that instrument which had a reflecting surface on the underside, this one was painted black on both surfaces and therefore acted as a net radiometer, recording the differences between incoming and outgoing radiation.

The sensing element measured about  $100 \times 100 \text{ mm}$ , four times larger than that of the instruments used in the lake studies. This plate was ventilated by a fishtail nozzle blower to eliminate the effect of gusts of wind on the calibration. The accuracy of such a radiometer depends greatly on the uniformity of the blackness on both surfaces. Amusingly, the cooling wind was apparently very attractive to doves nesting in the neighborhood and frequent cleaning and repainting of the top surface was necessary. Painting the retaining equipment with a sticky substance discouraged undesirable visitors with some measure of success. Figure 19 shows the radiation mast shortly after installation.

Net radiometers of the type used here, and also the soil heat-flow plates to be discussed later, measure heat flow by means of thermopile voltages. The voltage needs a correction for temperature of the plate and each instrument has its own calibration factor. This makes transcribing of heat-flow data tedious and very time consuming. An adjustable nomogram was constructed to facilitate this procedure (fig. 20). Details and theory are given in Appendix B.

## SOIL TEMPERATURE, HEAT FLOW, AND SOIL MOISTURE

## SOIL TEMPERATURE

The term  $G$  in the energy budget (equation 17) is often neglected when data are computed for periods of a day or longer. Over bare ground they certainly cannot be neglected over shorter periods. However, when the soil, as at the Buckeye project, is thoroughly protected by a dense stand of tall vegetation, the hourly and even daily changes become very small. Nonetheless, to have a complete picture of the situation, thermocouples were installed at 0, 10, 45, and 90 cm below the surface in tanks number 2 and 6, and thermocouples were also installed outside tank 6 at the same depths. If the moisture content is known (as it was) and a thermal conductivity can reasonably assumed to be known (as it could), then measurement of incoming or outgoing heat is possible by a graphical analysis to be discussed later.

## HEAT-FLOW PLATES

In addition to the thermocouples, heat-flow plates were installed in tanks 2 and 6 at 1 cm below the surface. They work on the same principle as the net radiometer but are much smaller (about  $29 \times 86$  mm) so as to interfere as little as possible with the soil-moisture movement. Because such a small surface may not produce representative data, three plates were installed in each tank and connected in such a way that the strip-chart recorder printed the mean value of each of the triplets. Unfortunately, these plates were very difficult to seal against the corrosive action of the soil moisture. Hence only a few sets of reliable soil heat-flow data could be obtained from these plates.

Blackwell and Tyldesley (1965, p. 142) report that their tests reveal a variation in the calibration of their soil heat-flux plates of about  $\pm 30$  percent, and they continue: "Allowing for the use of unrepresentative calibrations, storage errors, and sampling difficulties, it would be unrealistic to claim an overall accuracy of much better than  $\pm 20$  percent."

The experience at the Buckeye Project was similar. Table 5 illustrates some of the difficulties. It gives the calibration factors for four plates as provided by the manufacturers at time of purchase and at two later dates. Neither the drastic change in factors nor the drop in significant figures underpins trust in the heat-flow records. Luckily, as will be shown later, the flows are small anyway and the actual values were of little importance in the energy budgets.

## SOIL MOISTURE

Soil moisture and soil-moisture changes were measured by the neutron-scattering method (van

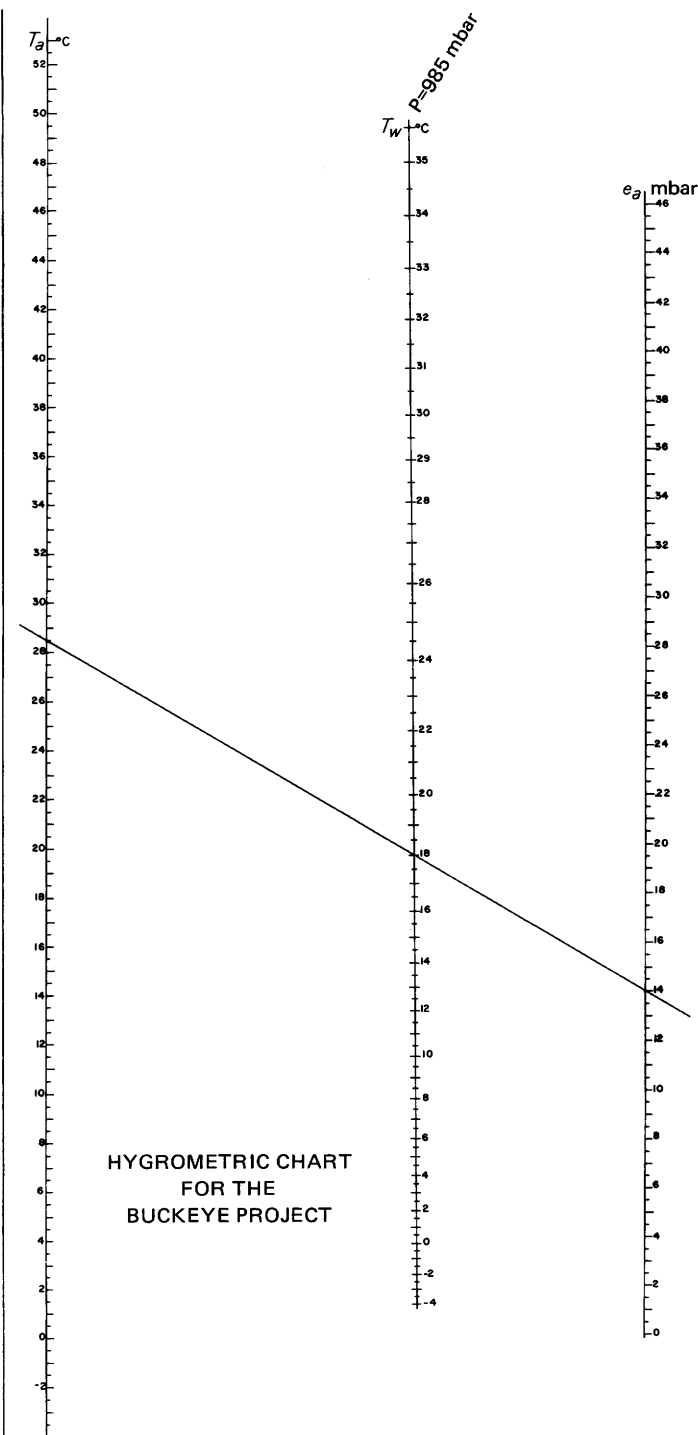


FIGURE 18.—Nomogram to convert a given set of dry and wet bulb temperatures into vapor pressure expressed in millibars assuming a constant atmospheric pressure of 985 mb (98.5 kPa). Connect air temperature ( $T_a$ ) with a straight line to the wet-bulb temperature ( $T_w$ ) and continue this line to the  $e_a$  line to read vapor pressure. Example:  $T_a = 28.5$ ,  $T_w = 18.0$ ,  $e_a = 14.0$ .

Hylckama, 1974, p. E16–E18). Readings were taken at least once a month, but during periods of intensive observations, the frequency was increased to two or four times per day.

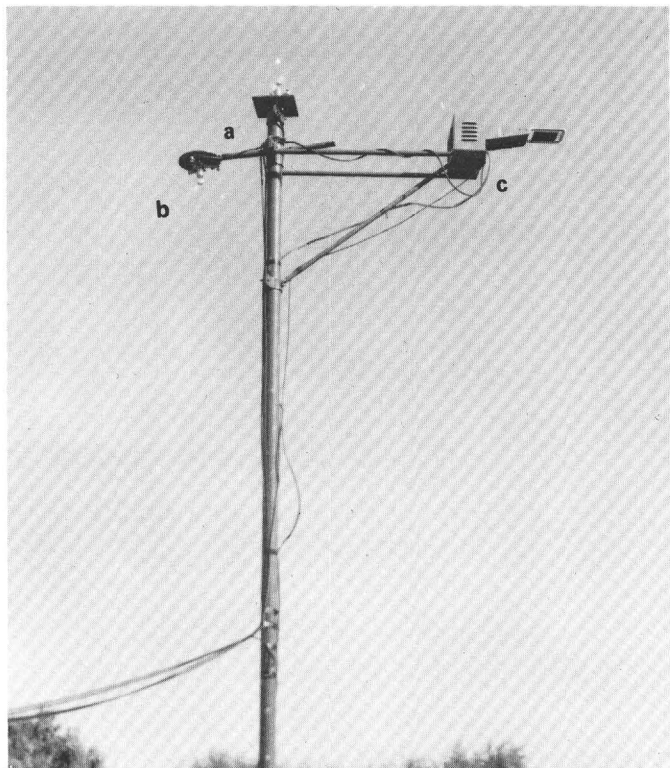


FIGURE 19.—Radiation mast with pyrhemometers up (a) and down (b) and with the net radiometer (c). Mast is 7 m tall or 4 m above the mean height of the vegetation. At the time the photograph was taken the soil was still bare. Compare with figure 5.

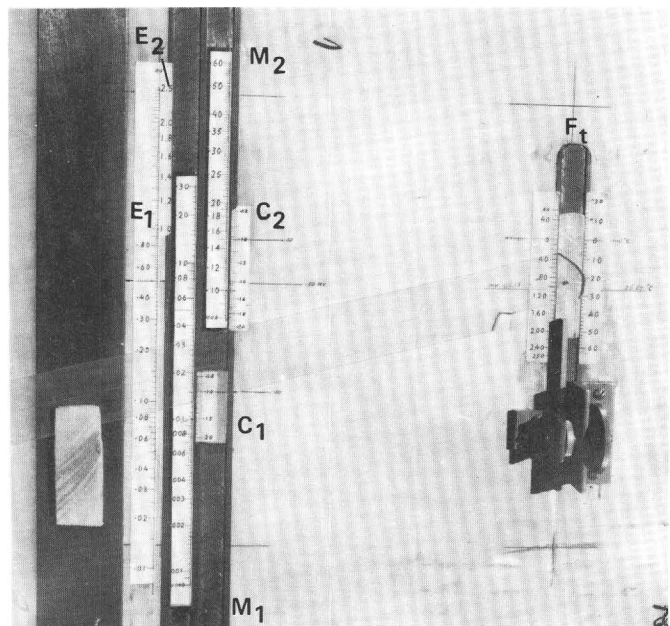


FIGURE 20.—Adjustable nomogram for the computation of heat flow.  $E_1$  and  $E_2$ : milvolt scale (data read from strip charts, see fig. 14);  $F_1$ : movable scale to adjust for plate temperature;  $M_1$  and  $M_2$ : heat-flow scales to read calories per square centimeter per minute, adjustable to the calibration constant scales  $C_1$  and  $C_2$ . See Appendix B for details.

TABLE 5.—Heat-flow plate calibration factors

| Plate Nos. | At purchase time | Recalibrated on |               |
|------------|------------------|-----------------|---------------|
|            |                  | December 1961   | February 1963 |
| 314        | 0.09666          | 0.0747          | 0.072         |
| 315        | 0.13872          | 0.0828          | 0.075         |
| 316        | 0.12021          | 0.08365         | 0.081         |
| 317        | 0.14259          | 0.0849          | 0.080         |

Batteries of tensiometers were installed in all the tanks at depths commensurate with the water levels in the various tanks (fig. 21). Readings were taken 5 days a week and at 2-hour intervals during periods of intensive observations. Figure 22 shows such an event at night. In this way, periodic changes in soil moisture could be detected quickly.

Directions of soil-moisture movement can also be detected with these instruments by converting the tensiometer readings to manometer readings. Some of the results were used in the studies by Ripple, Rubin, and van Hylckama (1972), so they will not be discussed here.

#### WATER-USE MEASUREMENTS

The instrumentation to measure the water use is described extensively by van Hylckama (1974, p. E7–

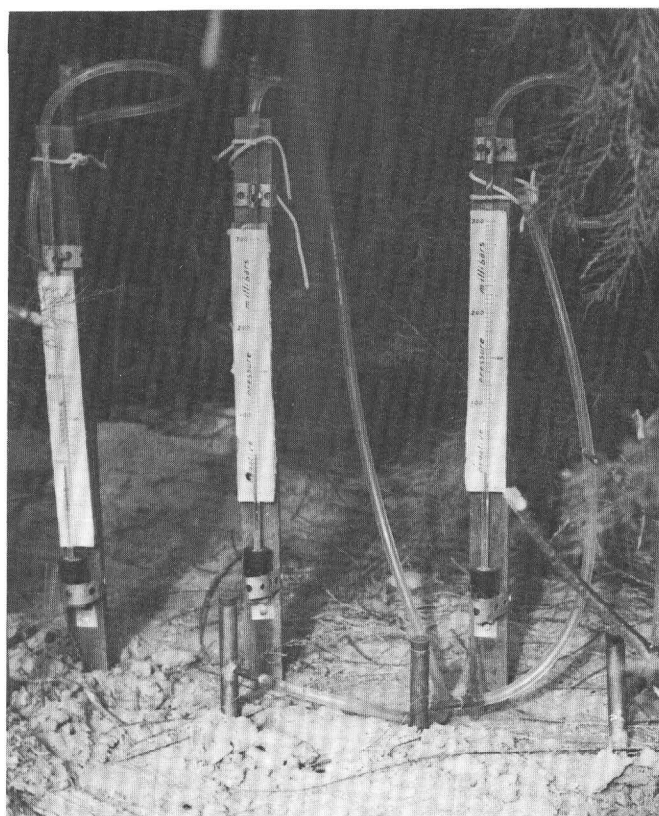


FIGURE 21.—Tensiometers installed in one of the tanks. Instruments were made at the project from commercially available parts.

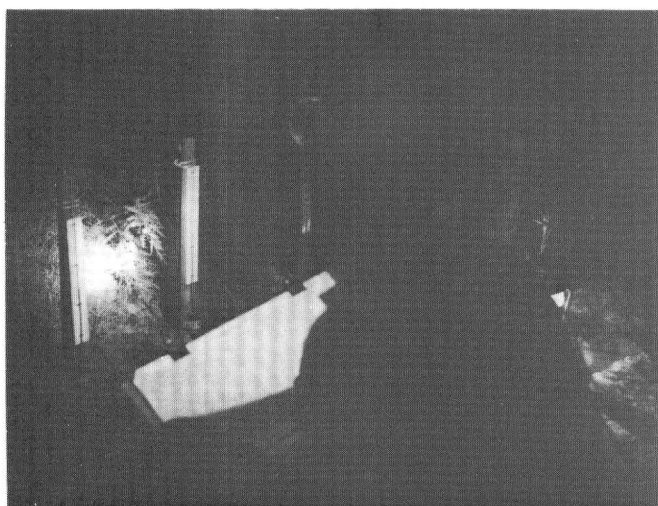


FIGURE 22.—Taking tensiometer readings at night during one of the intensive observation periods; observer (back to camera) is using a headlamp. See the section on "The Special Observation Periods."

E8.). As mentioned on p. E20–E22 of that report, it was possible to analyze the frequency of fillings and to construct curves of water use over 24-hour periods. An even more refined analysis could be made if the on-off recorders were set for daily instead of weekly charts. An example of a daily chart is given in figure 23. Not only could the times of filling be more accurately determined, the duration of a filling could also be known and a much more detailed picture could be obtained to construct curves of hourly water use. Daily charts were always installed during periods of intensive observations when the water meters were read at 2-hour intervals.

### THE MICROCLIMATE OF A SALT CEDAR THICKET

#### WHY THE MICROCLIMATE?

To fully understand and appreciate the methods of estimating evapotranspiration it is helpful to discuss some aspects of the weather inside and above saltcedar thickets such as occur near Buckeye, Ariz. After all, a saltcedar thicket, or any other flood-plain vegetation, comprises a much more complex environment than that on which most evapotranspiration equations are based.

For example, Penman (1956, p. 20) defined potential evapotranspiration as "the amount of water transpired in unit time by a short green crop completely shading the ground, of uniform height and never short of water". Only the "never short of water" applies to the saltcedar in and around the evapotranspirometers, and the evaporating surface is not so well modeled by a two-dimensional surface as is a close-cropped lawn (or

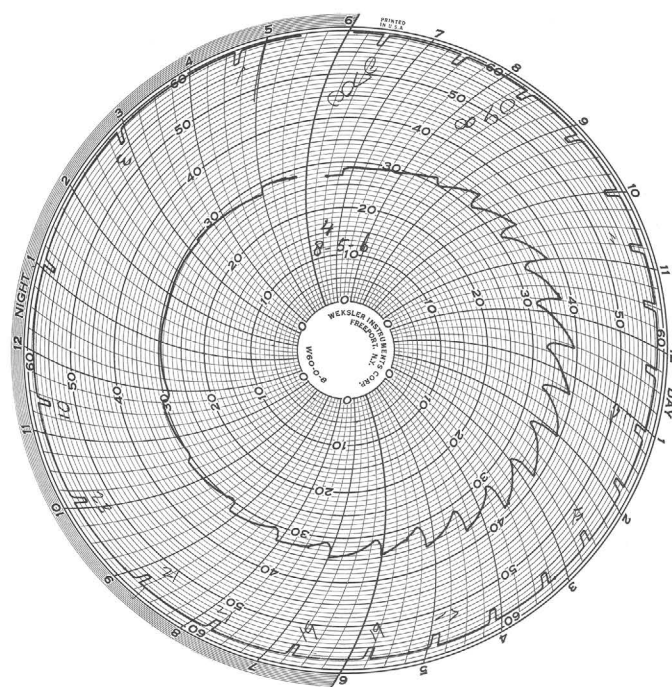


FIGURE 23.—Event recording chart indicating time and duration of tank filling. The jagged line near the center indicates water temperature. About ½ actual size.

turf as Penman calls it). Thornthwaite and Mather (1955, p. 20) specify a number of conditions necessary to fit the definition of potential evapotranspiration: "First, the albedo of the evaporating surface must be a standard. Second, the rate of evapotranspiration must not be influenced by the advection of moist or dry air\*\*\*\*." Certainly these conditions are not met in any riparian saltcedar thicket or flood-plain vegetation.

Furthermore, temperatures, vapor pressures, and wind profiles inside the thickets may affect the evapotranspiration rates just as much as do those above the vegetation where they are usually measured. Also, the roughness length is often assumed to be constant but can, as will be shown, vary greatly with changing wind speeds and even seasonally.

#### THE SPECIAL OBSERVATION PERIODS

The instruments described earlier, by and large, worked faithfully, but did not always record truthfully. Bees and sometimes ants, discovering a source of moisture in the wicks of the hygrometers, caused strange fluctuations in the wet-bulb temperatures. So did dust devils which in the course of a few minutes could turn the wicks from white to brown. The actions of doves changing the reflectivity of the net-radiometer plate was mentioned already. Finally, the very sensitive anemometer system was open to undesirable infestation by spiders and other "bugs."

At this point an explanation is in order on the kind of recording used at the Buckeye Project (see fig. 14). As already mentioned in the section on "Instrumentation," one item is recorded every minute, which means that on a 16-point recorder one phenomenon (for instance, the dry-bulb temperature at 11 m) is recorded less than 4 times per hour. On a 12-point recorder it is recorded 5 times per hour. There is, therefore, a time lapse of 16 or 12 minutes between readings of each transmitter. During the morning and evening hours quite a few "things" change rather rapidly. At such times it is easily possible that anomalous data show up caused by infrequency of recording rather than by instrument failures or unusual happenings in the atmosphere.

For long-term averages all this is not serious because such anomalies are easily spotted and can be eliminated before monthly, weekly, or even daily means are computed. However, to compute potential evapotranspiration from energy-budget and mass-transfer equations, short-term, even instantaneous, values are needed.

For this reason special observation periods were organized. Each period lasted 3 days, during which time

all instruments were checked every 2 hours around the clock (see fig. 22) and records were kept of those instruments that did not record automatically, such as tensiometers and, most important, watermeters on the tanks. Before such periods, all instruments were checked for proper calibration, cleaned and adjusted if necessary, and coworkers were instructed into the proper methods of checking and recording. Also clocks were set to true local solar time so that it was exactly 1200 (noon) when the sun was exactly at  $180^\circ$ . The hourly averages of the data so collected are presented in Appendix A for the convenience of those who desire to analyze the information further. In addition, 15 5-day periods, selected from the records for their likelihood of accuracy and completeness, are preserved for future reference.

#### DAILY CYCLES OF TEMPERATURE AND HUMIDITY

Figure 24 shows the cycles of temperature and humidity. The vegetation was, on the average, 3 m tall, so the lower readings were taken inside the vegetation. It is clear that these readings were generally higher during the day and very much lower during the night; in other words, the vegetation was exposed to greater

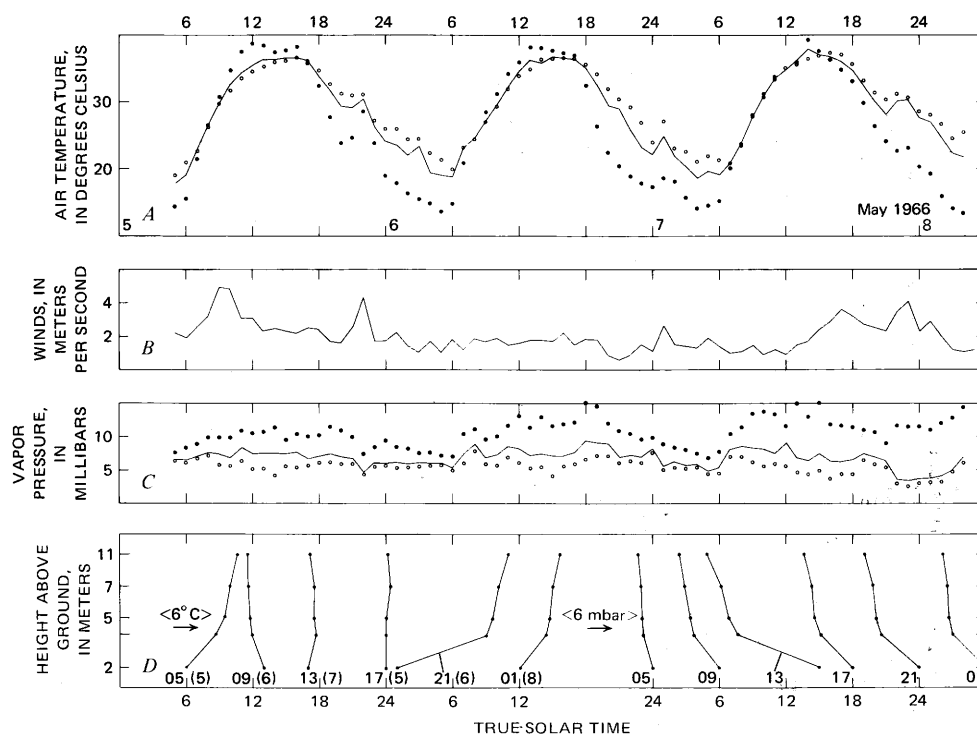


FIGURE 24A.—Some microclimatic characteristics of the Buckeye project site, May 1966. A, March of temperature (degrees Celsius), 11 m (open circles), 5 m (solid line), and 2 m (dots) above ground; B, Windspeeds (meters per second) 7 m above ground; C, March of vapor pressure (millibars) for the same days 11 m (open circles), 5 m (solid line), and 2 m (dots) above ground; D, (left) six temperature profiles at 0500, 0900, 1300, 1700, 2100, and 0100 hours (true local time) on dates indicated by the number in parentheses; D, (right) six vapor-pressure profiles for the same times.

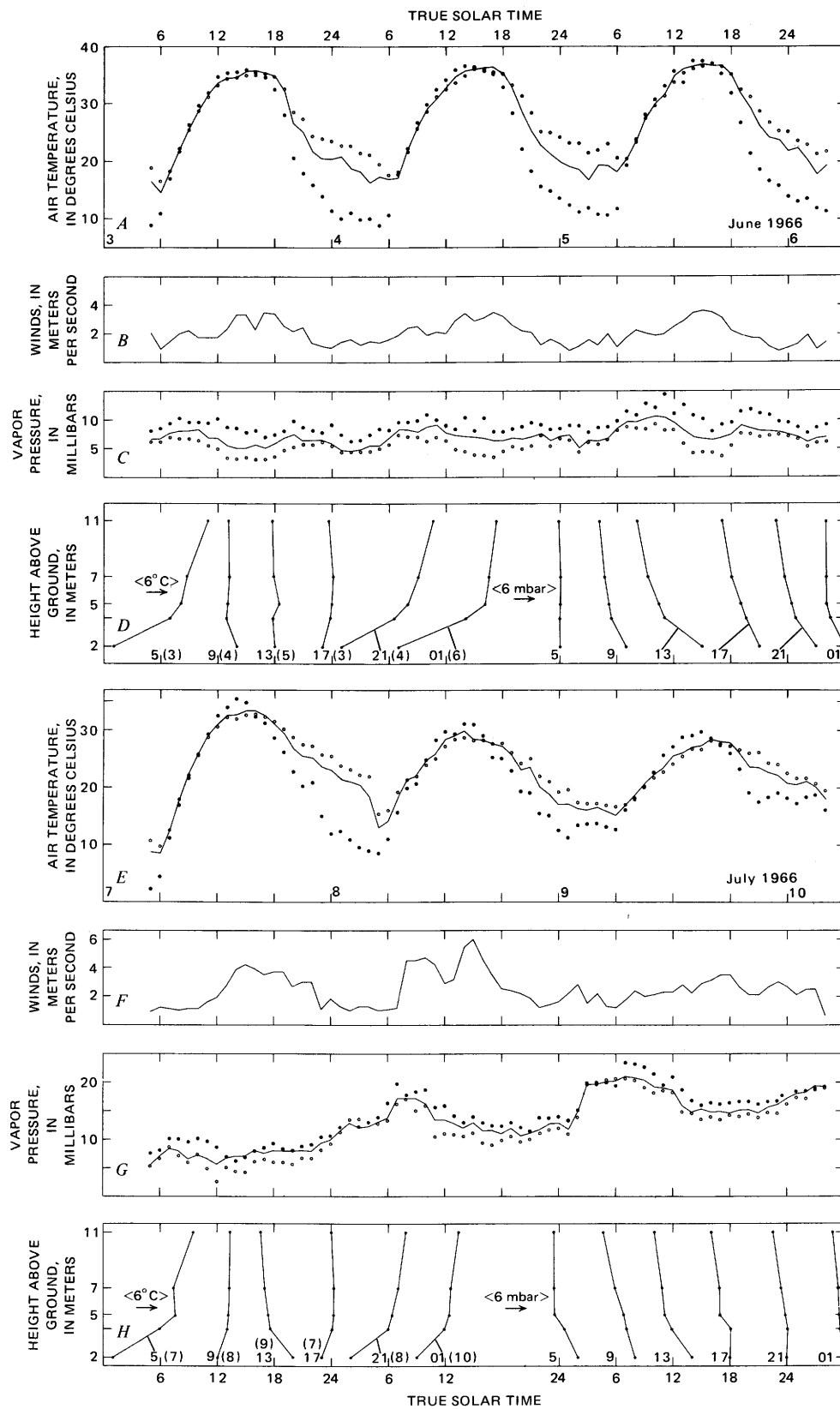


FIGURE 24B.—Some microclimatic characteristics of the Buckeye project site, June and July 1966. A and E, March of temperature (degrees Celsius) 11 m (open circles), 5 m (solid lines), and 2 m (dots) above ground; B and F, Windspeeds (meters per second) 7 m above ground; C and G, March of vapor pressure (millibars) from the same days, 11 m (open circles), 5 m (solid lines), and 2 m (dots) above ground; D and H, (left) six temperature profiles at 0500, 0900, 1300, 1700, 2100, and 0100 hours (true local time) on dates indicated by the number in parentheses; D and H, (right) six vapor-pressure profiles for the same times.

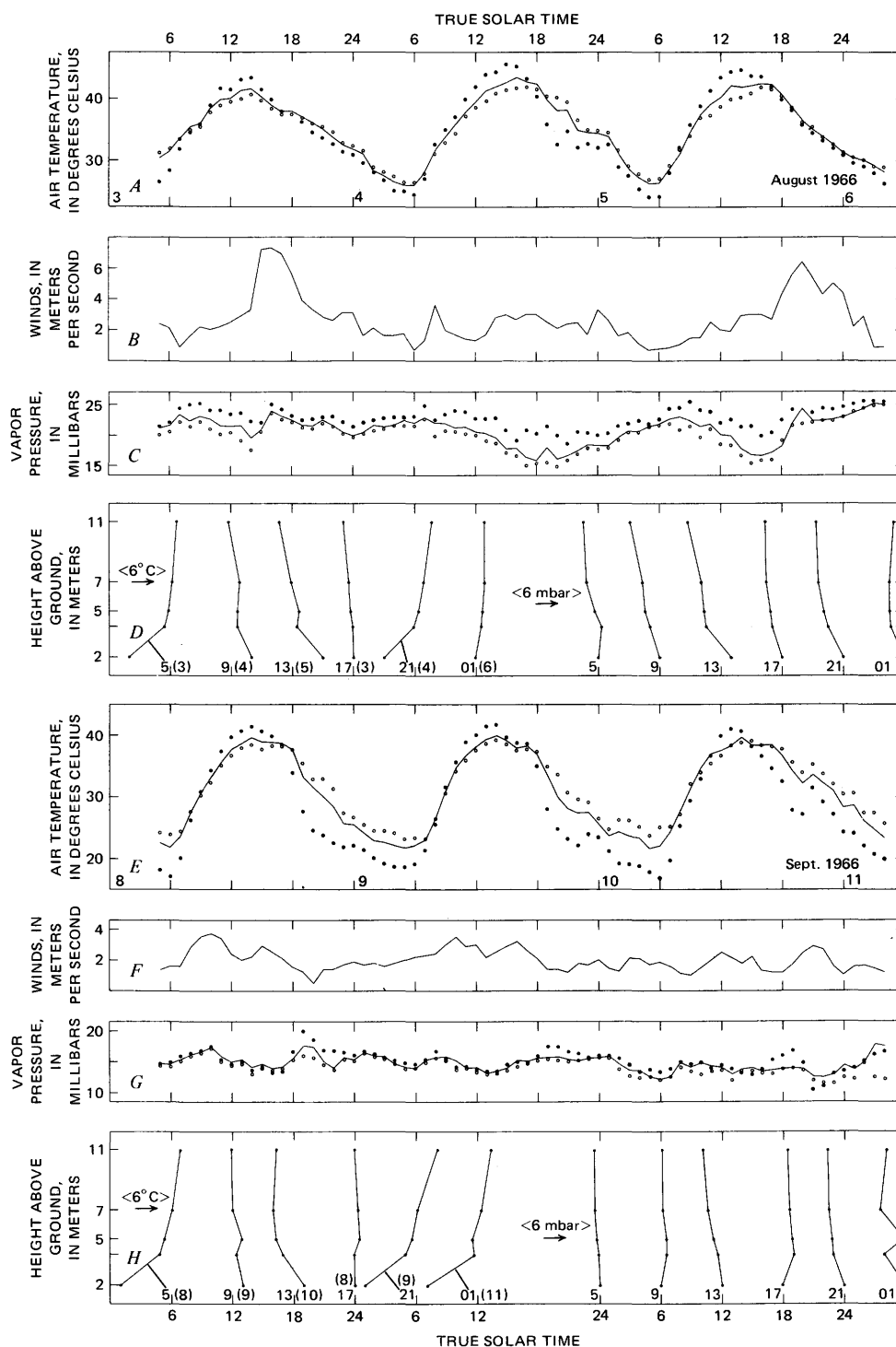


FIGURE 24C.—Some microclimatic characteristics of the Buckeye project site, August and September 1966. Legend see figure 24B.

temperature extremes than the air above it. The humidity was also much higher under than above the canopy, as is to be expected from a vegetation transpiring at the potential rate. September shows a decrease in vapor pressure inside the vegetation, and so does March, as can be expected. However, May 1967 shows a much lower vapor pressure inside the vegetation than

May 1966. This lower vapor pressure was due to an increase in salinity of the ground water in the evapotranspirometers; it thus indicates a lower evapotranspiration rate.

Figure 24 also shows selected temperature and vapor profiles illustrating better than the graphs the difference in steepness of gradients between the values in-

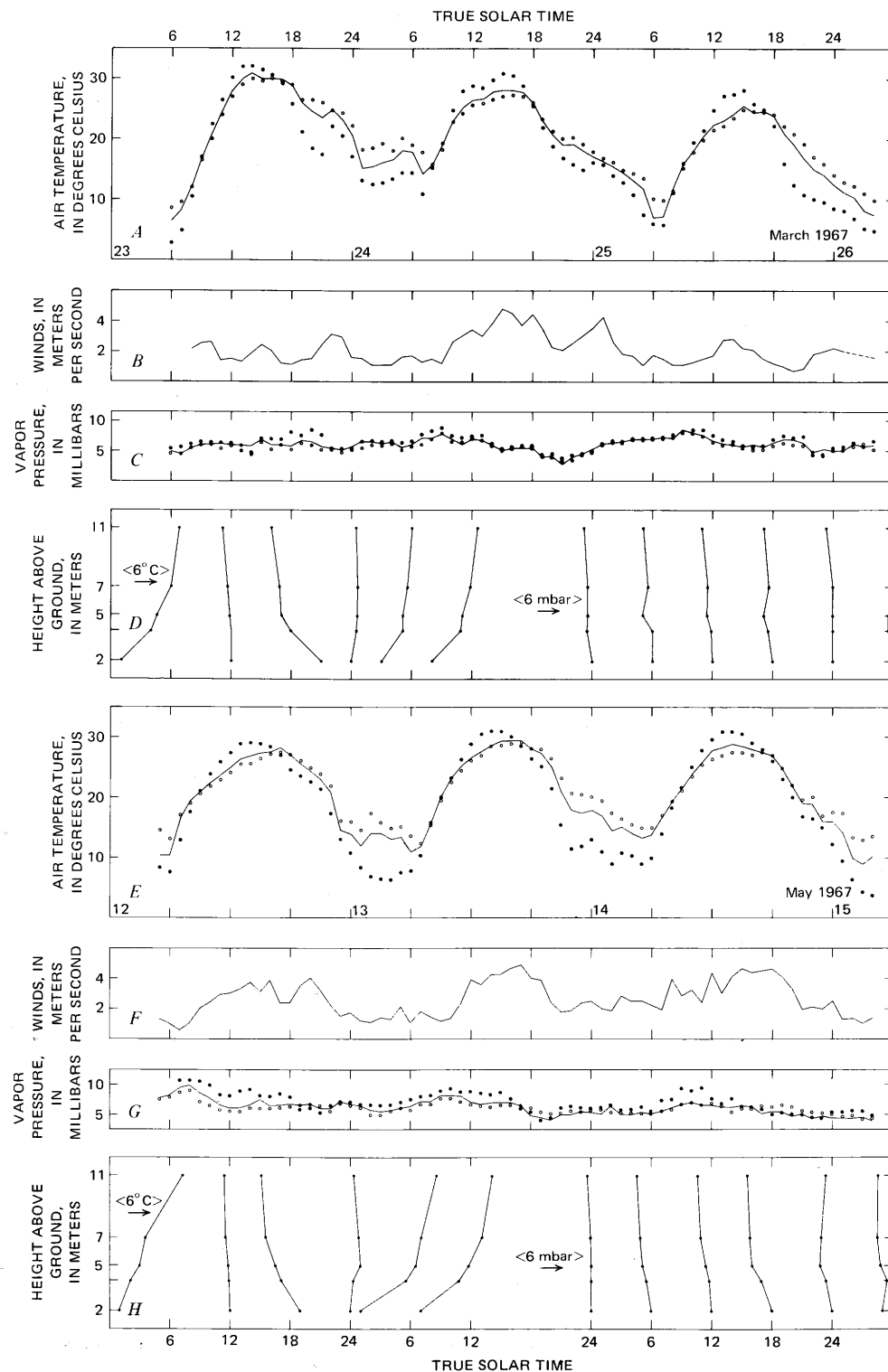


FIGURE 24D.—Some microclimatic characteristics of the Buckeye project site, March and May 1967.  
Legend see figure 24B.

side and those above the vegetation. Some anomalies should be pointed out: for instance at 0100 on September 11 there is a large increase in vapor between 4 and 5 m. This increase seems impossible because it

would indicate a downward movement of moisture and possibly dew formation when the air temperature inside the vegetation is 20°C! Similar but smaller anomalies can be observed in the March and May 1967

profiles and can probably be explained only by some malfunctioning of the instruments.

### WINDS

Figure 24 further illustrates the fluctuations of wind speeds 7 m above the ground (about 4 m above the vegetation). The curves show that during the observation periods wind speeds were in the light to gentle breeze range on the Beaufort scale (less than 4 m/s). Notable exceptions occurred in the afternoons of July 8 and August 3 when wind increased to a moderate breeze of more than 6 m/s, and another wind, perhaps more unexpectedly, increased to 6 m/s, in the evening of August 5.

The profiles of the winds above the thickets will be discussed presently. What concerns us first is what happens inside the thickets.

In September 1966 two anemometers were installed 0.5 and 1 m above ground inside the saltcedar on tank 6. By marking the values for the windspeeds at appropriate heights for each hour, one can draw lines of equal windspeed (isotachs). Together they give a clear picture of what happens during a day. Isotach curves peaking upward indicate that winds are slowing down; those pointing down indicate that winds increase. Most interestingly during some times of the day winds of higher velocity seem to "tunnel" through the vegetation. Figure 25 shows five examples. Another example was given by van Hylckama (1970a). Unfortunately, related data such as vertical windspeeds and vapor pressure fluctuations were not observed. The tunneling phenomenon is true through, and has been reported elsewhere (in particular by Allen, 1968). Such ventilation makes it possible for large quantities of sensible heat to be removed, and thus may well affect the rate of evapotranspiration.

Nearly all energy-budget and mass-transfer methods, or a combination of these, assume that the plots of instantaneous windspeeds (or of those averaged over periods of 4 hours or less) versus the logarithm of height lie on straight lines. It was therefore desirable to analyze the wind data to verify the occurrence of such conditions at the project site. About 2000 profiles were studied using border-punch cards of which figure 26 is an example (Casey and Perry, 1951). This system allows rapid selection of information by grouping profiles according to windspeed, date, temperature, roughness length ( $z_0$ ), friction velocity ( $u_*$ ), stability ratios ( $SR$ ), and zero displacement ( $d$ ).

For each profile the stability ratio was determined, expressed as (Deacon, 1953)

$$SR = \frac{T_{11} - T_5}{u_7^2} \quad \text{or} \quad \frac{T_7 - T_4}{u_5^2} \quad (27)$$

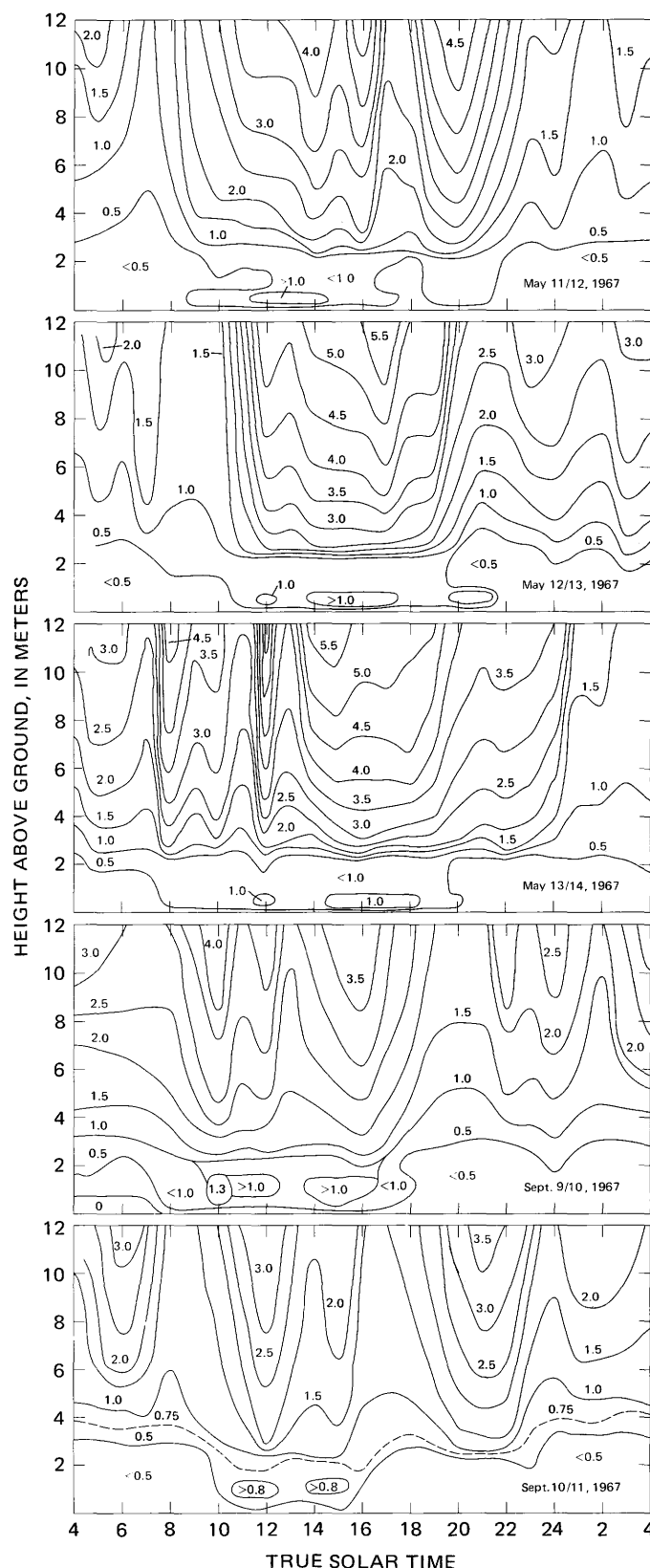


FIGURE 25.—Distribution of windspeeds (isotachs) within and above a stand of saltcedar near Buckeye, Ariz. The vegetation is about 3 m tall. The numbers near the isotachs indicate windspeeds in meters per second. Isotachs above 11 m are extrapolated.

| Year                       | Day              | Hour |
|----------------------------|------------------|------|
| BUCKEYE PROJECT            |                  |      |
| WIND ANALYSIS              |                  |      |
| SOB/PENTAD <u>III - 1</u>  |                  |      |
| 196 <u>6</u>               | Hour # <u>22</u> |      |
| Calendar date <u>7 - 6</u> |                  |      |
| WINDSPEEDS cm/sec          |                  |      |
| $u_{11}$ <u>384</u>        | $u_7$ <u>298</u> |      |
| $u_5$ <u>249</u>           | $u_4$ <u>191</u> |      |
| $u_{1.5}$ <u>12</u>        |                  |      |
| TEMP. DIFFERENCES _____ °C |                  |      |
| $T_{11-4}$ <u>2.4</u>      |                  |      |
| $T_{7-5}$ _____            |                  |      |
| WIND RATIOS                |                  |      |
| $R_{7/4}$ <u>1.56</u>      |                  |      |
| $R_{5/4}$ <u>1.30</u>      |                  |      |
| STABILITY RATIOS           |                  |      |
| $SR_7$ <u>0.146</u>        |                  |      |
| $SR_5$ _____               |                  |      |
| $z_0$ = <u>140.0</u> cm    |                  |      |
| $u_*$ = <u>77.3</u> cm/sec |                  |      |
| WIND DIRECTION <u>W</u>    |                  |      |
| $d = 0$                    |                  |      |

FIGURE 26.—Example of a border-punched card used for the wind-profile analyses at the Buckeye Project.

in which the subscripts give the heights above ground (m),  $T$  is temperature (°C), and  $u$  is windspeed (m/s).  $SR$  is indicative of the stability of the air. Negative numbers occur when the temperature at high elevation is lower than below, creating unstable conditions if the

difference is larger (more negative) than the lapse rate. The latter, however, is of the order of 0.06°C per 6 m, and usually, can be neglected. Strong inversions usually connected with low windspeeds give rise to high stability ratios. More than 50 percent of all cases showed an  $SR$  between  $-0.10$  and  $+0.10$  with about half of them negative and half positive.

The variables needed to describe the logarithmic profile are the roughness length and the friction velocity. Both can be determined graphically; Lemon (1963) and Sellers (1965) explain the procedure.

If neutral stability conditions exist, that is, when  $SR$  is close to zero, windspeed increases linearly with the logarithm of height and we have (Sellers, 1965),

$$\frac{\Delta u}{\ln z_2 - \ln z_1} = \frac{\Delta u}{\ln (z_2/z_1)} = \text{constant}, \quad (28)$$

in which  $\Delta u$  is the difference between wind speeds at heights  $z_2$  and  $z_1$ . However, there is an elevation at which the wind speed becomes zero due to friction between the air and the vegetation or the soil. This height is called the roughness length ( $z_0$ ), and we have

$$u_z = (\text{constant}) \ln (z/z_0), \quad (29)$$

where  $u_z$  is the wind speed at height  $z$ . If the plots of windspeed fall on a straight line, the roughness length is easily determined graphically by extending this line to zero. Figure 27 shows a roughness length of 0.2 m for the windspeeds plotted on line C.

The "constant" referred to is only constant for one particular profile, but increases with an increase of  $\Delta u$ . The flatter the profile, that is, the smaller the angle between the profile line and the abscissa, the larger the constant becomes. Laboratory experiments of turbulent flow in pipes show that this constant depends on the rate at which momentum is transferred (which is fast for a "flat" profile) and on the air density. Thus

$$\text{constant} = \frac{1}{k} \left[ \frac{\tau}{\rho_a} \right]^{1/2} = \frac{u_*}{k} \quad (30)$$

where  $\tau$  is the vertical transfer of momentum,  $\rho_a$  is the air density,  $u_*$  is called "friction velocity," and  $k$  a constant of proportionality. The constant was named after von Karman who first studied this phenomenon.

The von Karman constant actually varies with the temperature gradient. Sheppard (1946) shows that  $k$  varies from 0.32 at a positive gradient of 0.56° to 0.61°C/m at a negative gradient of 1.66°C/m. The gradient at the project varied from  $-0.34^\circ$  to  $+0.56^\circ\text{C/m}$ , but two-thirds of the observations showed a negative gradient and the bulk of these was on the order of

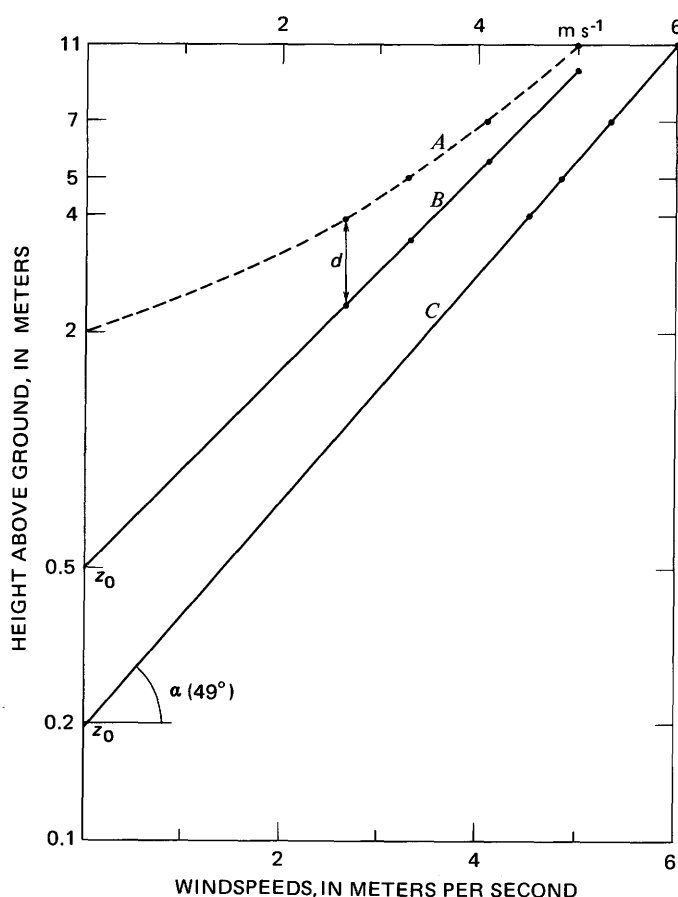


FIGURE 27.—Graphical determination of roughness length ( $z_0$ ), friction velocity ( $u_*$ ), and zero displacement ( $d$ ). Curve A is a hypothetical set of windspeeds at 11, 7, 5, and 4 m extended to 0 m/s. Line B is derived by plotting the indicated speeds of curve A 1.5 m ( $d$ ) below those "observed" on that curve, giving  $z_0 = 0.5$  m. Line C connects another set of hypothetical windspeeds at indicated elevations. This line is straight and the extension gives  $z_0 = 0.2$  m. The angle ( $\alpha$ ) is about  $49^\circ$ , hence  $u_* = 100k/\tan 49 = 35.6$ ,  $k$  being von Karman's constant, taken as  $= 0.41$ .

$-0.10^\circ$  to  $-0.20^\circ/\text{m}$ . Thus, use of an average value of 0.41 seems reasonable. Monteith and Szeicz (1960) and van Bavel (1966) used the same value.

With this in mind we can now write

$$u = \frac{u_*}{k} \ln \frac{z}{z_0} \quad (31)$$

The friction velocity can be obtained from the slope of the wind profile. As an example, line C in figure 27 makes an angle of  $49^\circ$  with the abscissa, hence we have  $u = 100k/\tan 49 = 35.6$ , remembering that  $\ln z_0$  is a constant.

Actually,  $z_0$  is the integration constant for

$$\delta \bar{u} / \delta z = u_* / k z \quad (32)$$

the differential equation of the profile of mean wind

velocity above ground. This equation strictly holds over flat surfaces such as ice and snow or very short smooth vegetation. Under such conditions  $z_0$  can be considered to be an invariable property of the surface. Tall vegetation waving in the breeze does not offer such a convenient roughness length. Equation 31 therefore has been empirically modified to

$$u = \frac{u_*}{k} \ln \frac{z - d}{z_0} \quad (33)$$

in which  $d$  is the zero-plane displacement. It can be regarded as a measure of the wind penetrating the vegetation or as a level above which the normal turbulent exchange takes place. Sutton (1953) points out that, if  $d$  and  $z_0$  are regarded as independent arbitrary constants, equation 33 cannot be derived from the original differential equation 32 because that is an equation of the first order whose solution must involve not more than one arbitrary constant.

A zero displacement also can be determined graphically as illustrated in figure 27. Assume a curve A drawn through 4 points at which windspeeds are measured; continuing this curve to the zero line would indicate that at 2 m above the ground the velocity is zero. By lowering the points, we find by trial and error that if each of the speeds are plotted at 1.5 m below the original elevation, the points do lie on a straight line and form a logarithmic profile, with a  $z_0$  at 0.5 m and 1.5 is the zero-plane displacement ( $d$ ). The  $d$  values for the Buckeye Project data, however, are so variable and random and even negative (when a curve of type A in figure 27 is convex instead of concave) that, as Sellers (1965, p. 150) states: "it is almost impossible to attach any real physical significance to them" and "in practically all cases and within the accuracy of the measurements the wind profile above the vegetation can be described just as well by equation 31 as by equation 33." This is not surprising, remembering that  $d$  is an empirical constant.

The profile above tall vegetation, however, is affected by that vegetation, and  $z_0$  actually becomes an adjusted roughness length. Such an adjusted roughness length changes with the steepness of the profile and also with the stability ratio. For instance, by grouping wind ratios  $u_7/u_4$  (the ratio of the wind speed at 7 m over that at 4 m) and evaluating the modified roughness length in each of these groups (which can be accomplished quickly by sorting the border-punch cards), one can plot the means so obtained as shown in figure 28. Similarly, the modified roughness length can be plotted against stability ratios, as shown in figure 29. These are the roughness lengths that have been used in the mass-transfer and combination equations to be discussed later.

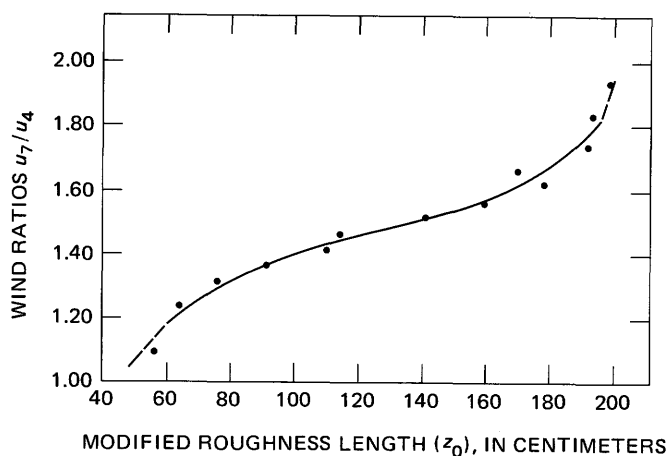


FIGURE 28.—Relation between modified roughness length and the ratio of windspeeds at 7 m to those at 4 m. Only the means of  $z_0$  and  $u_7/u_4$  for each stability group are plotted.

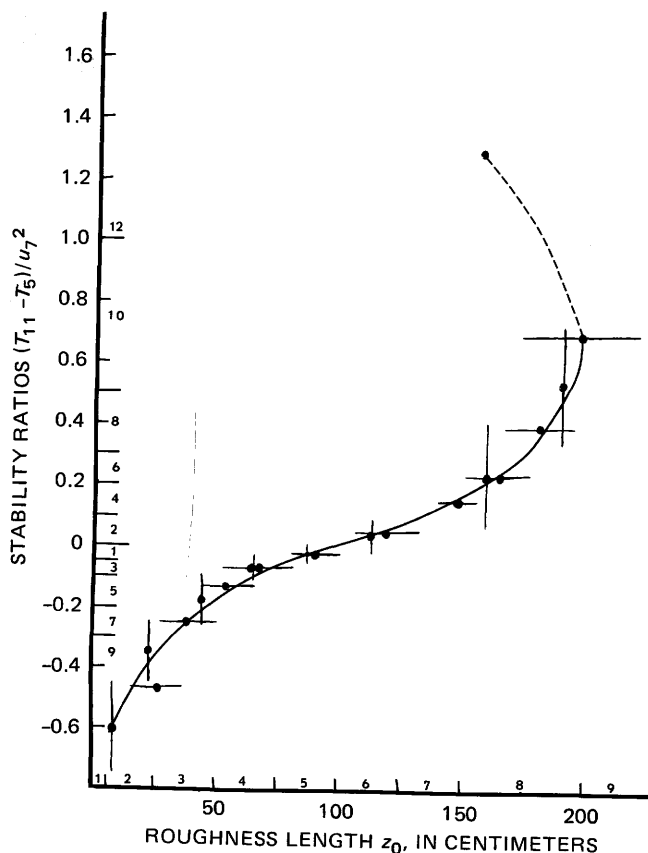


FIGURE 29.—Modified roughness length versus stability ratio. A dot on a horizontal short line indicates the mean  $z_0$  for each stability group. A dot on a vertical short line indicates the mean  $SR$  for each  $z_0$  group. The length of the lines indicates the standard deviation. Numbers on the inside of the axes indicate the groupings of the ranges of  $z_0$ 's and  $SR$ 's for which means were computed using the border-punch cards (see fig. 26).

## RADIATION

Figure 30 shows the march of radiation and heat flow for the seven 3-day periods mentioned earlier. The curves of the total short-wave (direct and diffuse) solar radiation show that most of the time there was a clear sky. Variable cloudiness occurred on July 7; August 3 was overcast as was March 24. Reflected radiation is also quite regular, but the change in reflectivity with the change in cloudiness is clearly shown in the record. Net radiation, consisting of the total short- and long-wave radiation coming in, minus that going out, follows the march of the total short-wave radiation quite faithfully, except on May 5, 1966, where between 1200 and 1500 an unusual pattern can be observed which is not easily explainable. A warm rain could cause this kind of record, but there was no rain during any of the observation periods; nor do temperature and wind profiles show anything unusual.

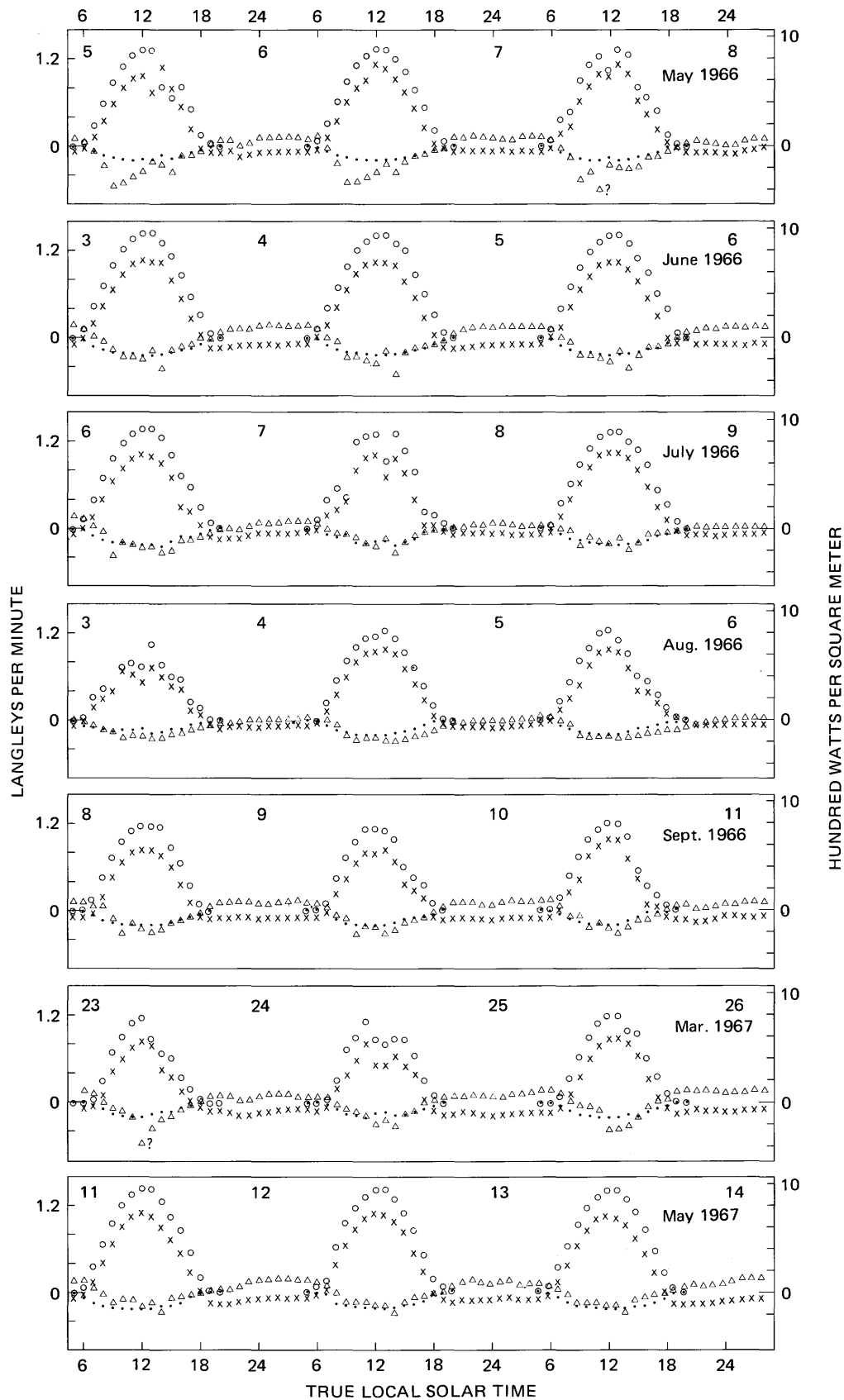
## SOIL HEAT FLUX

The soil heat-flux term appears in the energy budget because part of the incoming radiation is used to heat the soil during the daylight hours. Conversely, at night the soil loses heat by outgoing long-wave radiation and by conduction.

The soil heat flux is considered positive when heat moves through the soil toward the surface and negative when it moves from the surface into the soil. Figure 30 shows that the night-time flows are quite regular but during the day they are not. Some of this irregularity is undoubtedly due to a variation in shading, for instance the increase in flow at 1400 on all three days in June 1966 and also at 0700 on September 8, 9, and 10. Other sudden changes may well be due to temporary accumulations of moisture on the heat-flow plates.

Measuring this flux is troublesome because the sensing elements must be small in order to allow water and vapor movements which otherwise may affect the temperature of the elements and give wrong flux values. Heat flux through a small area, therefore, must represent the soil heat flux through a large area. At the Buckeye Project a measuring area of 0.00735 m<sup>2</sup> supposedly represented an area of 81 m<sup>2</sup>, which is the size

FIGURE 30.—March of radiation and heat flow at the Buckeye project for 3-day periods as indicated. Total short-wave radiation (direct plus diffuse): open circles (oooo); short-wave radiation reflected by soil and vegetation (albedo): dots (.....); net short plus long-wave radiation (incoming minus reflected and outgoing): xxx; heat flux into and out of the soil:  $\Delta\Delta\Delta$ .



of one evapotranspirometer. Measurements made on bare soil might actually be representative, but on vegetated soil, where sunlight and shade may alternate in unpredictable patterns, one can expect large variations which even show up in hourly averages. On the other hand, when the soil is vegetated and mostly shaded, the amounts of incoming and outgoing fluxes are very small compared to those of solar radiation; so they are often neglected (Penman, 1956).

If the density of the soil, its heat capacity, and moisture content are known, and if temperature records at different depths in the soil are available, it is possible to compute the heat flux. We start with the equation for heat flux derived from Fourier's conduction equation in one dimension:

$$\frac{\partial T}{\partial t} = \eta \frac{\partial^2 T}{\partial z^2} \quad \text{or} \quad \rho c \frac{\partial T}{\partial t} = \lambda \frac{\partial^2 T}{\partial z^2} \quad (34)$$

where  $T$  = temperature, in degrees Celsius,

$t$  = time, in seconds,

$z$  = depth, in meters,

$\eta = \lambda / \rho c$  = meters squared per second (thermal diffusivity),

$\lambda$  = thermal conductivity (watts per meter per degree Celsius),

$c$  = heat capacity (joules per kilogram per degree Celsius),

$\rho$  = density (kilogram per cubic meter).

At any given depth ( $z$ ) the heat flux ( $G_z$  in  $W m^{-2}$ ) is:

$$G_z = \lambda \frac{\partial T}{\partial z} \quad (35)$$

or

$$\rho c \frac{\partial T}{\partial t} = \frac{\partial G_z}{\partial z} \quad (36)$$

Following Portman (1954) we can now multiply both sides of equation 36 by  $\delta z$  and integrate from the surface where  $z = 0$  to a depth  $z$ :

$$\int_0^z \rho c \frac{\partial T}{\partial t} \delta z = G_0 - G_z \quad (37)$$

If, from temperature gradients, we can determine the depth where  $\partial T / \partial z$  approaches 0, we can determine  $G_0$  by evaluating the integral term from the surface to a depth where  $G_z = 0$ .

The term  $\rho c$  is the product of density and heat capacity, and both variables change with the moisture content of the soil. The moisture content was regularly measured and expressed as moisture percent by volume ( $M_v$ ); Moisture content by weight ( $M_w$ ) is then:

$$M_w = \frac{100 M_v}{140 + M_v} \quad (38)$$

where 140 is  $100 \times$  the density of the dry soil as determined by numerous weighings of Buckeye soils.

The specific heat, according to Kersten (1949), varies from 0.176 for Northway silt loam to 0.197 for Northway fine sand. Because the texture of the soils at the Buckeye Project is slightly sandier than that of Northway silt loam, a value of 0.18 calories  $gram^{-1} ^\circ C^{-1}$  ( $753.5 J kg^{-1} ^\circ C^{-1}$ ) was adopted for dry soil. Hence, considering the specific heat for water being unity for all practical purposes, the volumetric heat capacity is:

$$\rho c = 1.40 \left( 0.18 + \frac{M_w}{1 - M_w} \right) \text{ cal cm}^{-3} ^\circ C^{-1} \quad (39)$$

One can now plot two temperature profiles, say, 1 hour apart, on each of the layers of soil for which the moisture-dependent volumetric heat capacity can be considered uniform. The product of depth times a change in temperature can then be measured, for example, by planimeter, and this product multiplied by the  $\rho c$  for the particular depth gives the heat flux in calories per  $cm^2$  (or joules/ $m^2$ ) per hour. For the example shown in figure 31, the profiles were plotted on DI Form 213-F paper where  $1^\circ C$  was represented by 0.5 in. and 1 cm depth by 0.05 in. Because the planimeter measured areas in  $cm^2$ , an adjustment factor of 6.2 was necessary to convert the data to calories  $cm^{-2}$ .

Figure 32 shows the march of heat flow during one day computed from temperature measurements compared to that from heat-flow plates and also shows the 24-hour sinusoidal wave of these fluxes. It is immediately striking that these waves have roughly the

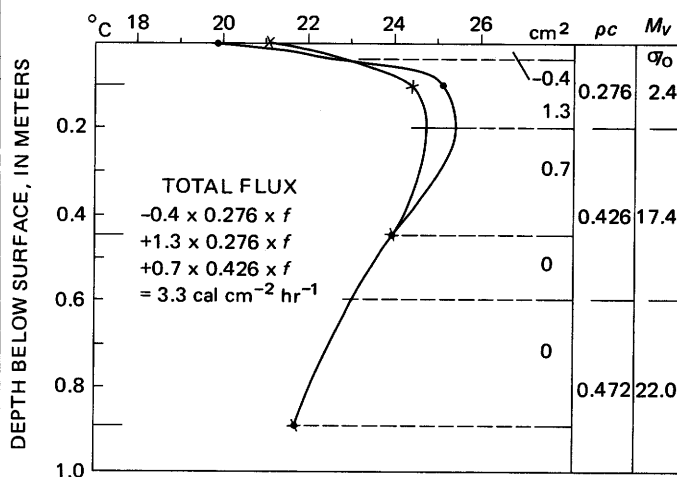


FIGURE 31.—Graphical computation of heat flow from 0500 (.) to 0600 (x) hours on May 5, 1966 in the soil of tank No. 6 at the Buckeye project.  $M_v$ : moisture content by volume (percent);  $\rho c$ : volumetric heat capacity (calories per cubic centimeter per degree Celsius); and  $f$ : factor to adjust units given by the planimeter to units used on the graph paper (see text).

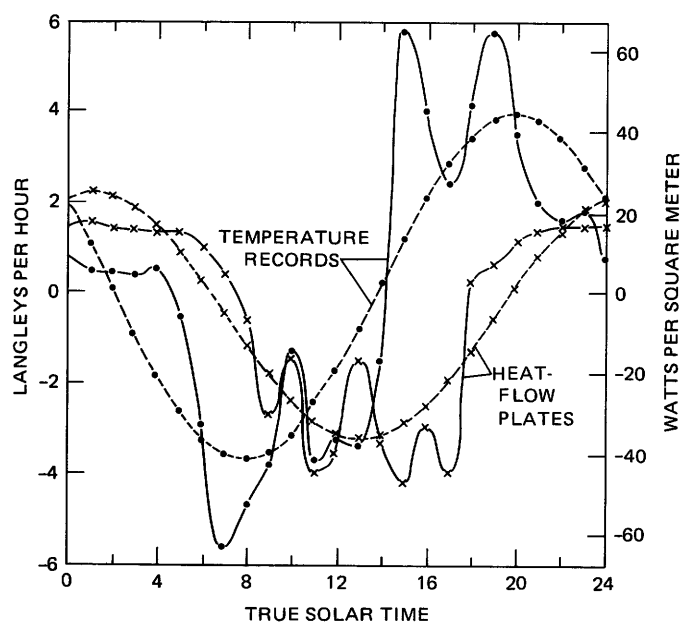


FIGURE 32.—Heat flow into (negative) and out of (positive) the soil in an evapotranspirometer near Buckeye, Ariz., recorded from heat-flow plates and computed from temperature records. The dashed lines are the curves of the first harmonics of the heat-flow and the temperature data, respectively.

same amplitude, but their phase angles are about 4.5 hours apart. The sinusoidal wave for the fluxes computed from temperature profiles peaks at a little before 0800 while the one computed from the heat-flow plates peaks, as could be expected, at about noon. This discrepancy was quite consistent for all the periods analyzed.

To find if more accurate or closely spaced thermometers could give closer agreement, a set of similar data, published by the Water Conservation Laboratory of the Agricultural Research Service in Tempe, Ariz. (van Bavel, 1967), was analyzed. The results, given in figure 33, show the close agreements between heat-flow data from heat-flow plates and those computed from temperature gradients. However, the temperatures were measured at depths 0.5, 1, 2, 4, 8, 16, 32, 64, and 128 cm whereas temperatures at the Buckeye site were only measured at 0, 10, 45, and 90 cm. Also the Tempe thermographs were reported to be accurate to at least  $0.1^{\circ}\text{C}$ , while the Buckeye ones were only accurate to  $0.5^{\circ}\text{C}$ . Notice further that the Tempe fluxes are an order of magnitude larger. The data refer not to flow into or out of vegetated soil but into or out of bare ground.

Especially the uncertainty as to what happens in the top 10 cm of the soil during the course of a day must lead to grave errors. Hence soil-temperature data, as collected at the Buckeye Project, could not be used to compute heat fluxes on an hourly or more frequent

basis. They could, however, be used on a daily basis because the sinusoidal waves were very similar in shape. Figure 34 shows four examples of waves computed from temperature profiles that have been shifted over to coincide in phase with the ones of the heat-flow plates.

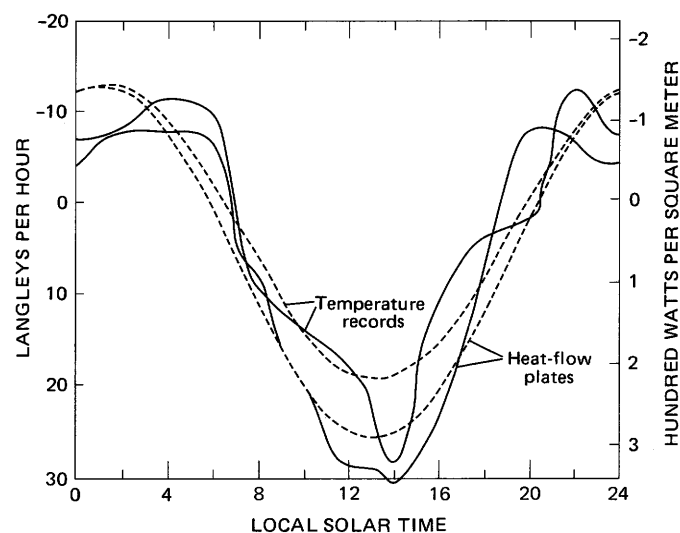


FIGURE 33.—Heat flow into (negative) and out of (positive) the soil in a lysimeter near Tempe, Ariz., recorded from heat-flow plates and computed from temperature records. The dashed lines are the curves of the first harmonics of the heat-flow and the temperature data, respectively. (Plate and temperature data from van Bavel, 1967.)

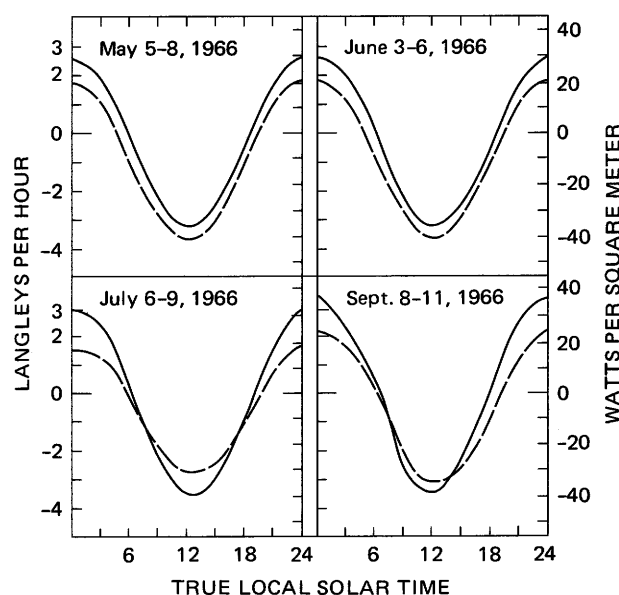


FIGURE 34.—Sinusoidal 24-hour waves of heat flow into (negative) and out of (positive) the soil computed by harmonic analysis of heat-flow plates data (dashed lines) and from data computed from soil-temperature gradients (solid lines).

More than 20 years ago McCulloch and Penman (1956, p. 279) ran into similar difficulties in their attempt to compute heat flow in soils. They emphasized the need for precise thermometers and concluded: "If only one set of observations is to be used, then phases are preferred to amplitudes, that is inaccurate thermometers with an accurate clock are better than good thermometers with a bad clock."

#### SOIL TEMPERATURES

We have seen that the soil-temperature data of the Buckeye Project usually were inadequate for the computation of heat fluxes into or out of the soil. They are, however, adequate for computing some soil characteristics, using data derived from the harmonic analyses of the temperature waves.

The method assumes that the data comprise only perfect sine curves of known periods  $P$  (in this case, days) or submultiples of  $P$ . Each curve explains a part of the variance of the data and it is possible to determine how large a part of the variance is expressed by a first, second, etc., sinusoidal curve after the amplitudes ( $a$ ) and phase angles ( $\alpha$ ) of each curve have been computed (see Panofsky and Brier, 1965).

Analyses of the temperature data of the Buckeye Project showed that nearly always more than 85 percent of the variance could be explained by the first harmonic, that is the sine waves with a 24-hour, or 86 400-second period. Using these phase angles and amplitude, one can compute thermal diffusivities ( $\eta$ ), timelags ( $t$ ), and other characteristics.<sup>9</sup> If  $a_z$  is the amplitude at a depth  $z$  and  $a_0$  the amplitude of the surface temperature wave, we have (van Wijk and de Vries, 1966):

$$a_z = a_0 \exp \left\{ -z \left[ \frac{\pi}{\eta P} \right]^{1/2} \right\} \quad (40)$$

where  $P$  is the length of the period (in this case 24 hours or 86 400 seconds.)

Once  $\eta$  is computed, the time lag between the occurrence of the maximum temperature at the surface and the maximum temperature at a distance below the surface can be computed using

$$t = z/2 \left( \frac{P}{\pi \eta} \right)^{1/2} \quad (41)$$

This time lag can then be compared with a time lag

<sup>9</sup>Thermal diffusivity ( $\eta$ ) is defined as  $K/\rho c$ , where  $K$  is the thermal conductivity ( $\text{cal cm}^{-1} \text{sec}^{-1} \text{C}^{-1}$ ),  $\rho$  ( $\text{g cm}^{-3}$ ) the density of the soil, and  $c$  ( $\text{cal g}^{-1} \text{C}^{-1}$ ) its heat capacity. It denotes the temperature change in any layer of the soil as heat flows into it from an adjacent layer (Baver and others, 1972).

observed between peaks of the sinusoidal graphs or actual curves at the two depths.

A similar procedure can be followed for other depths, such as between  $z_1 = 10$  cm and  $z_2 = 45$  cm. The term  $z$  in (40 and 41) then becomes  $\Delta z = z_2 - z_1$ .

Van Wijk and de Vries (1966) refer to the quantity

$$D_d = \left[ \frac{\eta P}{\pi} \right]^{1/2} \quad (42)$$

as the damping depth. It is the depth at which the amplitude is  $1/e$  or  $0.37 \times$  the amplitude at the surface. The quantity arises as a constant when integrating the heat-flux equation (34) under suitable boundary conditions. At a depth of  $4.61 D_d$ , the amplitude equals only  $0.01 a_0$  and the temperature (on a daily basis) can be considered constant.

Table 6 shows the results of harmonic analyses for two locations and two 3-day periods using temperature data at three depths. With a few exceptions, observational and computational data of the time lags agree quite well; this agreement gives some confidence in the computations of diffusivities and damping depths. The diffusivities increase as the moisture content increases with depth, and those computed for the three layers are in agreement with those given by van Wijk and de Vries (1966) and also by Baver, Gardner, and Gardner (1972).

Figure 35 illustrates how damping depth and depths of near-zero amplitude can be obtained graphically by plotting the amplitudes computed for 0, 10, and 45 cm depths on semilogarithmic paper. The short horizontal lines indicate the depth of  $D_d$  and the arrows are at the depth where the amplitude is about equal to  $0.05 \times$  the amplitude at the surface.

#### HEAT FLUX AND WATER USE

It follows from the first law of thermodynamics that if an evapotranspirometer for one reason or another uses less water, the energy of vaporization that becomes available has to be used somewhere else. Probably most of it is used to create turbulence in the air, and a certain amount will raise the temperature of the foliage, the branches, and the stems of the shrubs. Though the last three quantities are measureable, they were not determined at the Buckeye Project. The first quantity would be very difficult to distinguish from other turbulences. However, data were collected that showed an increase in the amount of heat stored in soils of evapotranspirometers using less water.

Figure 36 shows the heat flux in two tanks having identical vegetation covers. One tank used less water than the other because of a difference in depth to

TABLE 6.—Some results of harmonic analyses of soil-temperature fluctuations inside and outside tank 6 for means of two 3-day periods

[Diffusivity between 0 and 10, 0 and 45, and 10 and 45 cm, respectively. Damping depth ( $D_d$ ) =  $\left(\frac{\eta P}{\pi}\right)^{1/2}$  at which  $a = 0.37 a_0$ , between 0 and 10, 0 and 45, and 10 and 45 cm]

| Tank           | Depth<br>(cm) | Mean<br>temperature<br>(°C) | First harmonic (°C) |                                      | Phase<br>angles<br>(°C) | Time of highest<br>temperature<br>(hr; min) | Diffusivity<br>( $\eta$ ) mm <sup>2</sup> s <sup>-1</sup> | Time lag              |                       | Depth           |                                 |
|----------------|---------------|-----------------------------|---------------------|--------------------------------------|-------------------------|---------------------------------------------|-----------------------------------------------------------|-----------------------|-----------------------|-----------------|---------------------------------|
|                |               |                             | Amplitude<br>(a)    | Fluctuations<br>accounted for<br>(%) |                         |                                             |                                                           | Computed<br>(hr; min) | Observed<br>(hr; min) | Damping<br>(cm) | a ≈ 0.05 a <sub>0</sub><br>(cm) |
| May 3–6, 1966  |               |                             |                     |                                      |                         |                                             |                                                           |                       |                       |                 |                                 |
| Inside         | 0             | 30.3                        | 9.92                | 80                                   | 318                     | 13:49                                       | 0.21                                                      | 5:02                  | 4:19                  | 7.6             | 23                              |
|                | 10            | 27.4                        | 2.66                | 89                                   | 253                     | 18:08                                       | 0.45                                                      | 15:27                 | 12:05                 | 11.1            | 33                              |
|                | 45            | 24.0                        | 0.17                | 72                                   | 137                     | 01:54                                       | 0.59                                                      | 10:30                 | 7:46                  | 12.7            | 38                              |
| Outside        | 0             | 24.6                        | 6.11                | 79                                   | 308                     | 14:27                                       | 0.47                                                      | 3:22                  | 2:49                  | 11.4            | 34                              |
|                | 10            | 23.6                        | 2.55                | 89                                   | 266                     | 17:16                                       | 0.75                                                      | 11:58                 | 11:14                 | 14.4            | 43                              |
|                | 45            | 21.6                        | 0.27                | 89                                   | 140                     | 01:46                                       | 0.88                                                      | 8:59                  | 8:25                  | 15.6            | 47                              |
| July 6–9, 1966 |               |                             |                     |                                      |                         |                                             |                                                           |                       |                       |                 |                                 |
| Inside         | 0             | 32.4                        | 6.20                | 87                                   | 314                     | 14:06                                       | 0.32                                                      | 4:04                  | 3:47                  | 9.4             | 28                              |
|                | 10            | 30.2                        | 2.15                | 87                                   | 257                     | 17:53                                       | 0.68                                                      | 12:34                 | 12:36                 | 13.7            | 41                              |
|                | 45            | 27.4                        | 0.23                | 90                                   | 124                     | 02:42                                       | 0.89                                                      | 8:33                  | 8:49                  | 15.6            | 47                              |
| Outside        | 0             | 33.1                        | 8.53                | 85                                   | 323                     | 13:28                                       | 0.20                                                      | 5:09                  | 4:06                  | 7.4             | 22                              |
|                | 10            | 29.9                        | 2.24                | 90                                   | 262                     | 17:34                                       | 0.58                                                      | 13:37                 | 12:46                 | 12.6            | 38                              |
|                | 45            | 27.4                        | 0.25                | 91                                   | 132                     | 01:14                                       | 0.93                                                      | 8:22                  | 8:40                  | 16.0            | 48                              |

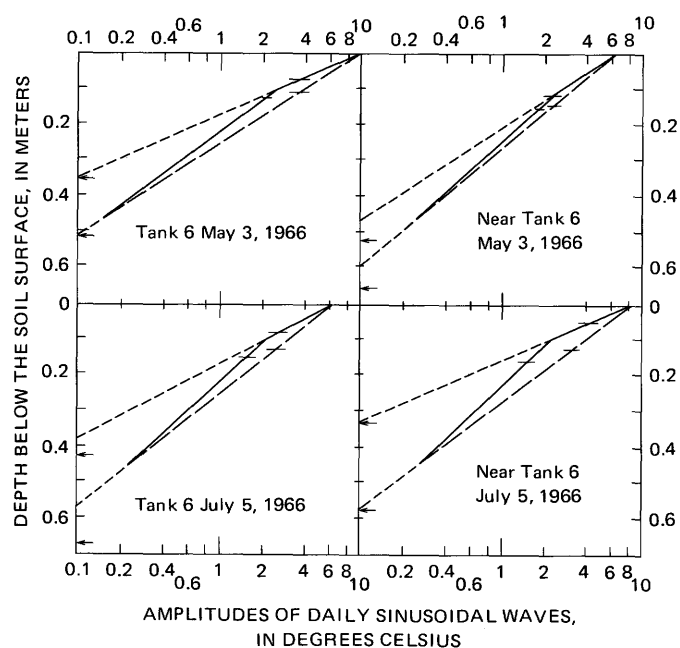


FIGURE 35.—Relations between amplitudes ( $a$ ) of daily temperature waves computed from data at 0, 10, and 45 cm depth, damping depths (—), and depths of  $0.05 a$  (←) for two locations and two dates near Buckeye, Arizona.

ground water. The heat flux in the tank using less water is larger than that in the other.

Note that for better comparison, the water use is expressed in calories per day per tank or joules per day per tank. The slopes of the lines connecting a tank with higher water use to one with lower water use indicate that each time the water use decreases, the soil heat flux increases. The dashed line, which is the mean slope of all curves, shows that an increase of  $10^8$

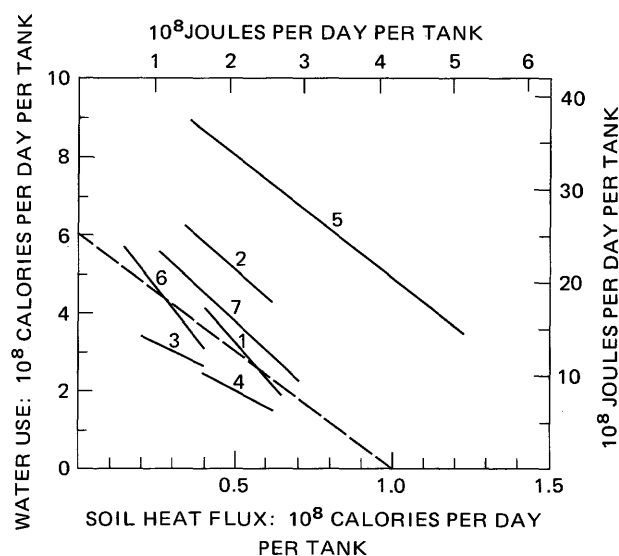


FIGURE 36.—Soil heat flux versus water use expressed as heat units. Two tanks using different amounts of water in each period are compared. 1 : May 1–6, 1963; 2 : June 5–10, 1963; 3 : September 8–13, 1963; 4 : October 8–13, 1963; 5 : May 5–8, 1966; 6 : August 3–6, 1966; 7 : September 8–11, 1966. Dashed line: mean slope of all curves.

calories per day per tank is the result of a decrease of water use of  $6 \times 10^8$  calories per day per tank. Obviously considerable energy is used elsewhere, but it was impossible to show this transfer inside the thickets at the Buckeye Project.

#### TURBULENT TRANSPORT

As noted earlier (see section on "Empirical Methods"), most of the theoretical and even some of the empirical equations to determine evapotranspiration

are based on the profile theory. We saw that at the Buckeye Project the vast majority of the wind profiles could be described by equation 31 with  $z_0$  being the "adjusted" roughness length and  $d$  (the zero displacement) suppressed. Also mentioned were the transport constants (see equations 12, 13, 14, and 15) for momentum, heat, vapor, and carbon dioxide which, depending on the type of turbulence, may or may not be the same. If they are the same, temperature and vapor-pressure values plotted against windspeeds at a number of elevations should fall on straight lines regardless of the shape of the profile (Penman and Long, 1960). Figure 37 shows examples for 6 of the periods used in figures 24 and 30. Note that 4-hour averages have been computed to avoid embarrassing anomalies. Nonetheless there are some glaring ones, for instance period 6 of September 10–11, 1966, which apparently can only be explained by instrumental or observational errors. Also, the data for March 23–26, 1967, are quite erratic. During that period the actual evapotranspiration is low and the transport constants for momentum, temperature, and vapor pressure might very well not be the same. Swinbank and Dyer (1967) showed that the transport constants for temperature and vapor pressure are often equal, but they are not equal to the momentum transport constant. If this is so, then the deviations from a straight line should be the same for temperature as well as vapor pressure. This actually seems to be the case as shown by the data for March 1967; wind profiles for that period deviate most from the logarithmic ones.

#### CARBON DIOXIDE

During the growing seasons of 1960–61 it was observed that the rate of growth and development of saltcedar grown in evapotranspirometers is correlated with the use of water by that plant. The less vigorous the growth, the less water was used. This raised the question whether the growth rate affected the rate of transpiration or whether other environmental factors affected both. In one attempt to explain the diminishing rates of growth and development, van Hylckama (1963) mentioned that maybe the carbon dioxide had become the limiting factor, especially at times of low windspeeds. If, during times of vigorous assimilation, the CO<sub>2</sub> content were to drop from a mean of about 300 ppm to 100 ppm, rates of growth and development would be diminished. Hence, the use of water might be diminished also. Such observations have been reported by Bonner and Galston (1952).

Also the fact that rates of photosynthesis and of transpiration are related is well known. Bierhuizen and Slatyer (1965) found that, under laboratory conditions, an increase in carbon dioxide content of the air to 0.10 percent or more results in less transpiration per

gram of carbon dioxide assimilated by cotton. One could say, therefore, that the plants become more efficient producers. But such conditions do not exist in the field, where the CO<sub>2</sub> content of the air rarely exceeds 0.02 to 0.04 percent (200 to 400 ppm). Pallas (1965), also under laboratory conditions, observed less transpiration when the CO<sub>2</sub> content of the ambient air is high. He noticed that the stomata of his plants closed when the CO<sub>2</sub> content went up to 4,000 ppm. One must assume that this impaired the passages of both CO<sub>2</sub> and vapor.

Therefore, the CO<sub>2</sub> content of the air within and above the saltcedar thickets was measured with an infrared gas analyzer (van Hylckama, 1969).

Figure 38 is an example of the results of such measurements. During the day, air turbulence caused mixing and the CO<sub>2</sub> content remained about the same in, as well as over, the thickets. During the night, sharp gradients occurred as the CO<sub>2</sub> content inside the thickets rose at times to more than 380 ppm. The figure also shows rather large fluctuations in CO<sub>2</sub> content at all levels and times. Much of this was undoubtedly due to turbulence and possibly also to shifts in calibration of the analyzer.

When photosynthesis takes place, one can expect to find smaller CO<sub>2</sub> contents inside, or near, the vegetation than above it. Diffusion and turbulence tend to equalize the CO<sub>2</sub> content of the air at all levels just as they equalize temperature, water-vapor content, and other properties of the atmosphere. These fluxes can be expressed as g m<sup>-2</sup> s<sup>-1</sup> or cal m<sup>-2</sup> s<sup>-1</sup>. There are several empirical methods for computing them, and the ones used here are:

$$F_c = \frac{k^2 (u_a - u_b) (C_a - C_b)}{[\ln \{ (a - z_0) / (b - z_0) \}]^2} \quad (43)$$

for CO<sub>2</sub> and

$$V = \frac{k^2 (u_a - u_b) (e_a - e_b)}{[\ln \{ (a - z_0) / (b - z_0) \}]^2} \quad (44)$$

for water vapor.  $F_c$  is the CO<sub>2</sub> flux,  $k$  the von Karman constant (here taken as 0.41),  $u_a$  and  $u_b$  (m/s) are the windspeeds at levels  $a$  and  $b$  (m), respectively,  $C_a$  and  $C_b$  the CO<sub>2</sub> contents (ppm),  $z_0$  is the roughness length (m); and  $V$  the vapor flux with  $e_a$  and  $e_b$  the vapor pressures (mb) (Lemon, 1960). To convert to g/m<sup>3</sup>, it was assumed that 1 ppm CO<sub>2</sub> at 985 mb (98.5 kPa) and 25°C equaled 1.77 mg/m<sup>3</sup> and 1 mb vapor equaled 724 mg/m<sup>3</sup>.

Figure 39 is an example of CO<sub>2</sub> fluxes during the day. Although short-time fluctuations resulting from those shown in figure 38 were somewhat smoothed out by averaging 3 days of data, there still are considerable irregularities.

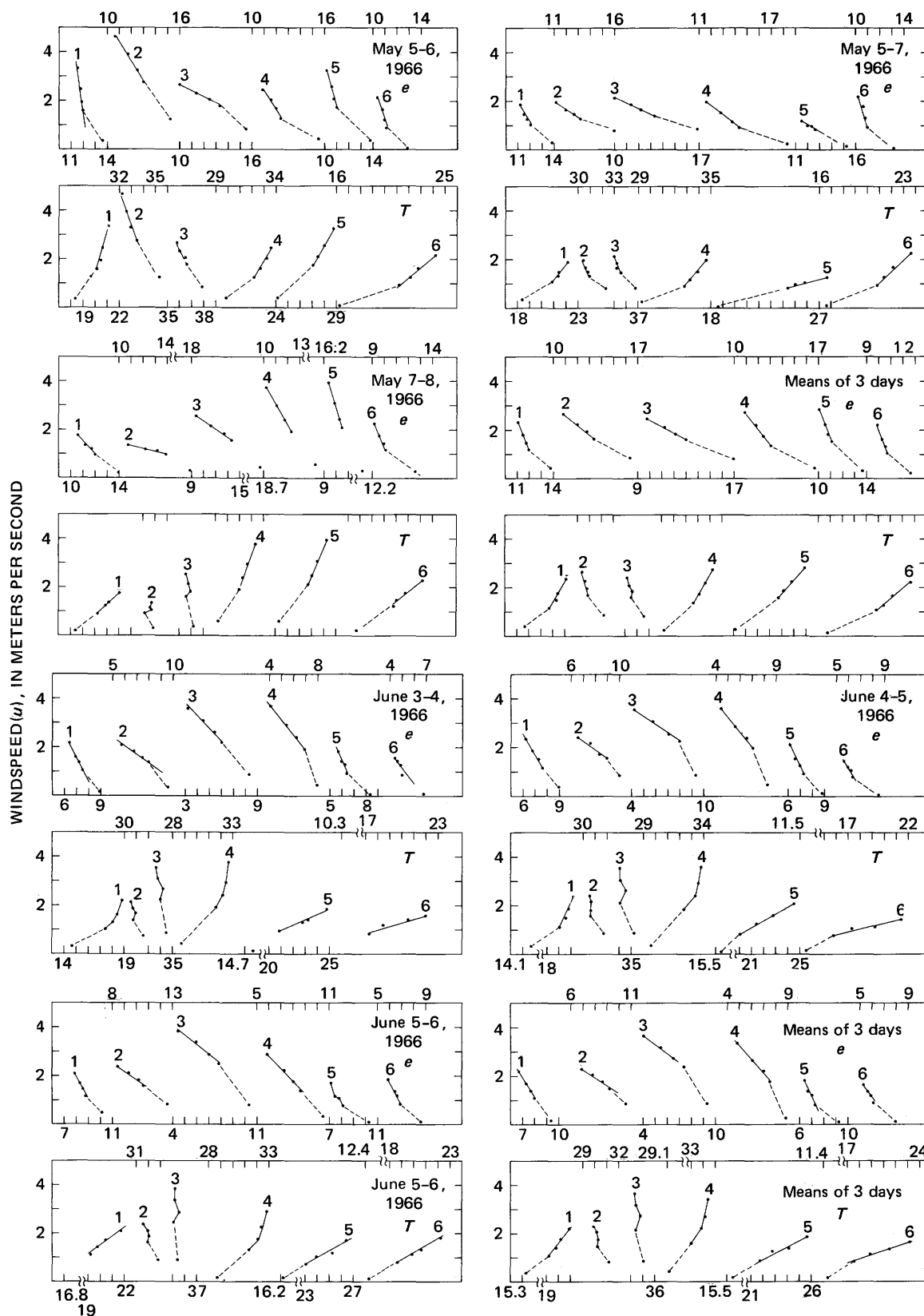


FIGURE 37.—Plots of windspeeds ( $u$ ) in meters per second versus vapor pressures ( $e$ ) in millibars and versus temperatures ( $T$ ) in degrees Celsius at the same levels. Data presented are 4-hour means: 1 = hours 5-8, 2 = hours 9-12, etc. Note:  $e$  and  $T$  scales on the abscissa are sometimes broken (SS) to save space. The windspeed scale (ordinate) does not change. The  $e$  (mb) and  $T$  ( $^{\circ}\text{C}$ ) values at the top of each box refer to time periods 2, 4 (1700-2000), and 6 (0100-0400), those at the bottom to 1, 3 (1300-1600), and 5 (2100-2400).

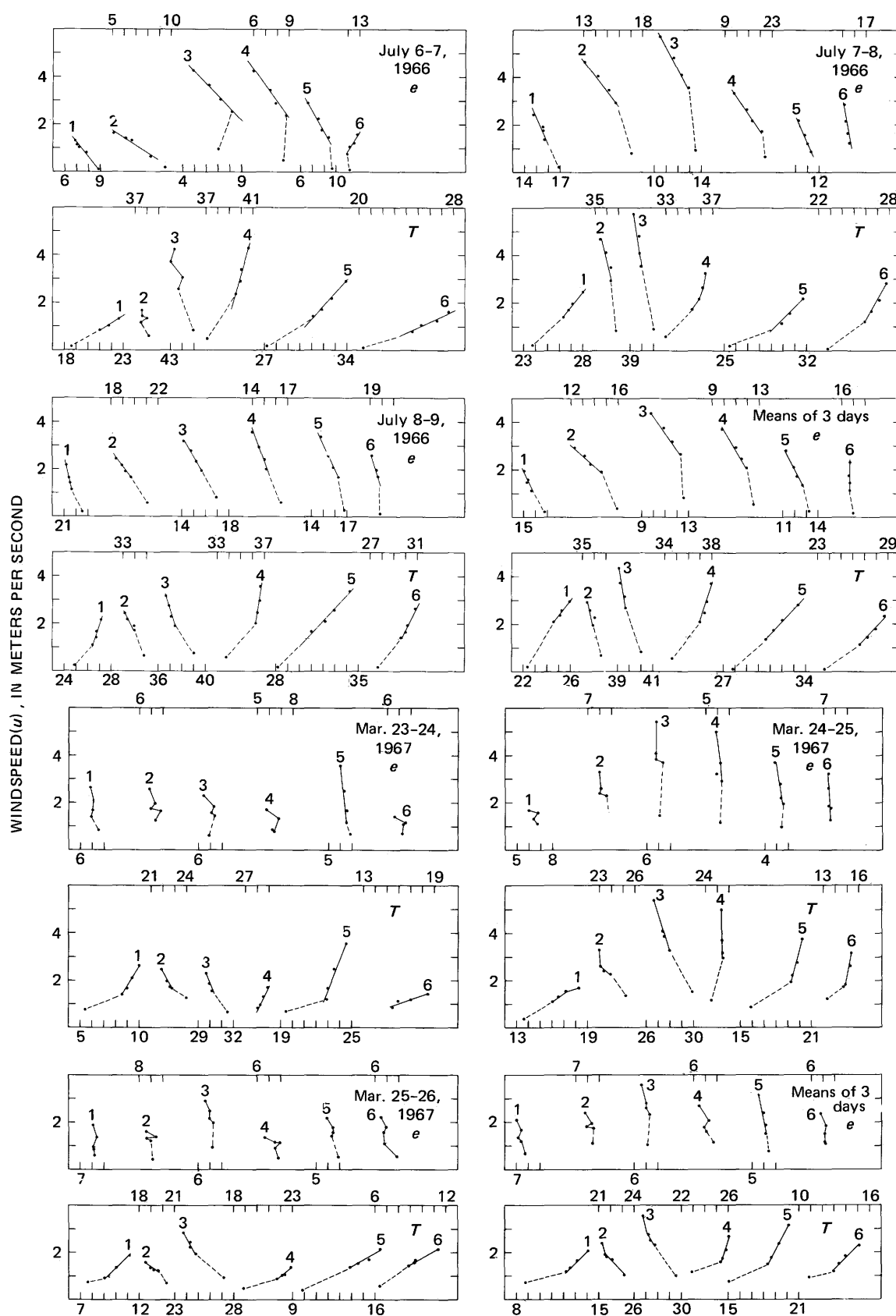


FIGURE 37.—Continued.

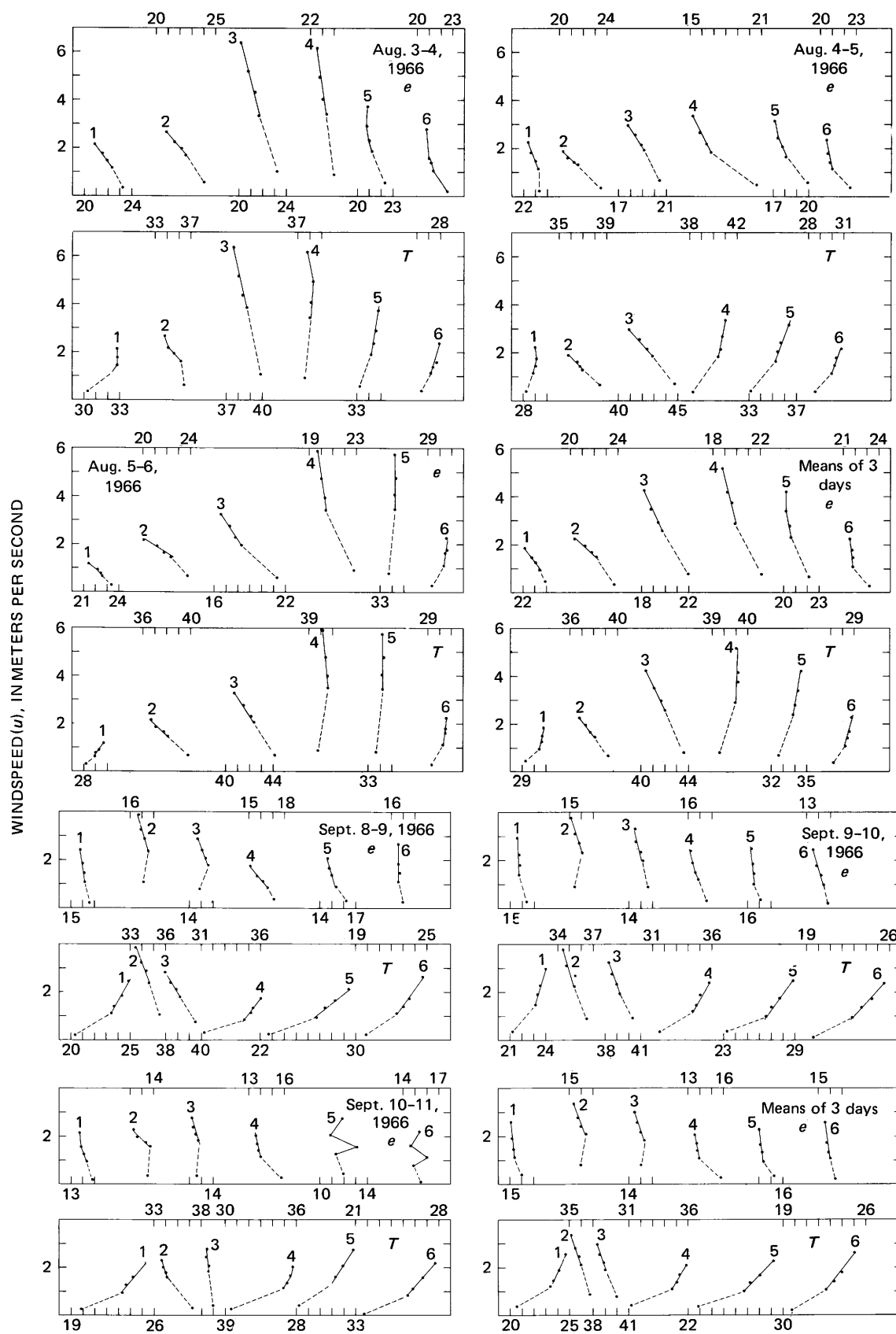


FIGURE 37.—Continued.

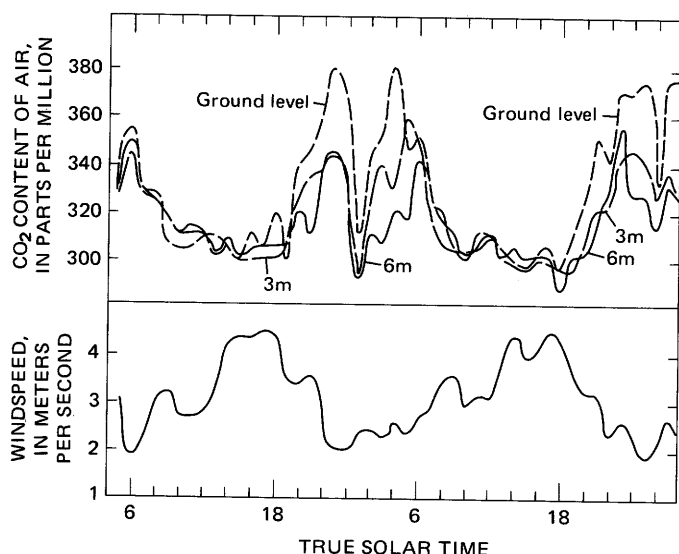


FIGURE 38.—Top. Fluctuation of carbon dioxide content (parts per million) in and over a stand of saltcedar near Buckeye, Ariz., June 3–5, 1966. Carbon dioxide content at 6 m, at the top of the vegetation, 3 m, and at ground level. Bottom: windspeed (meters/second) at 7 m above the ground.

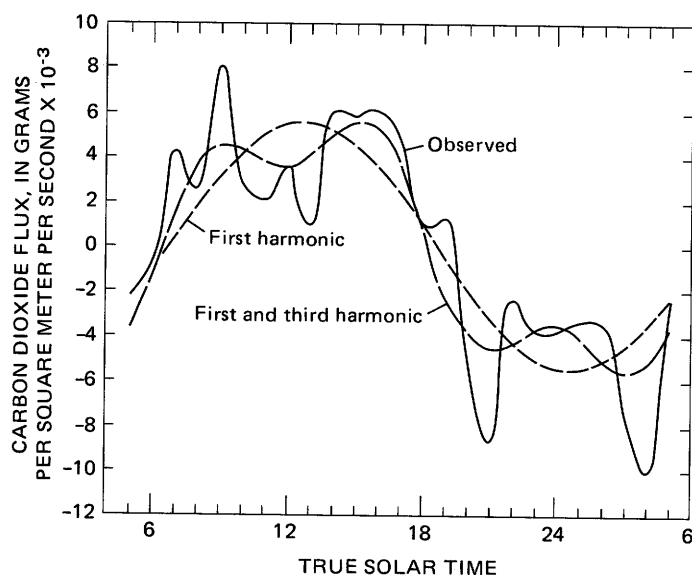


FIGURE 39.—Carbon dioxide fluxes in a saltcedar thicket near Buckeye, Ariz. Observed data, mean of June 3–5, 1966, compared with the computed first harmonic and with the combined first and third harmonic.

By applying harmonic analysis, the data can be smoothed out further. Figure 39 shows that the first harmonic alone represents the data rather well, although by adding the third (8 hour) harmonic a surprisingly faithful picture is obtained. The reason for this has yet to be explained.

Using first harmonics of both water vapor and  $\text{CO}_2$  fluxes an interesting curve is obtained showing the

correlation between the fluxes as exemplified in figure 40. The vapor flux, except during times of dew formation, would always be negative, but it is more negative during daylight hours, when the  $\text{CO}_2$  flux is positive and much less so during the night, when  $\text{CO}_2$  flux is also negative and large amounts of carbon dioxide are formed inside the thickets as was shown in figure 38.

Figure 40 also makes it possible to estimate the water-use efficiency (the amount of carbohydrate produced per unit of water) by considering the amount of water transpired per unit of  $\text{CO}_2$  absorbed. Ratios of over 600 occur in the early morning when light intensity is low, while values around 160 occur during the middle of the day and increase rapidly towards the evening. These values agree with data presented by Arkley (1963) and Bierhuizen and Slatyer (1965).

## PREDICTING WATER USE

### USE OF LONG-TERM MEANS

For the purpose of estimating how much water may be saved by managing riparian vegetation, it is usually and reasonably assumed that riparian vegetation transpires at the potential rate. For flood-plain vegetation less close to stream or lake, the situation grows

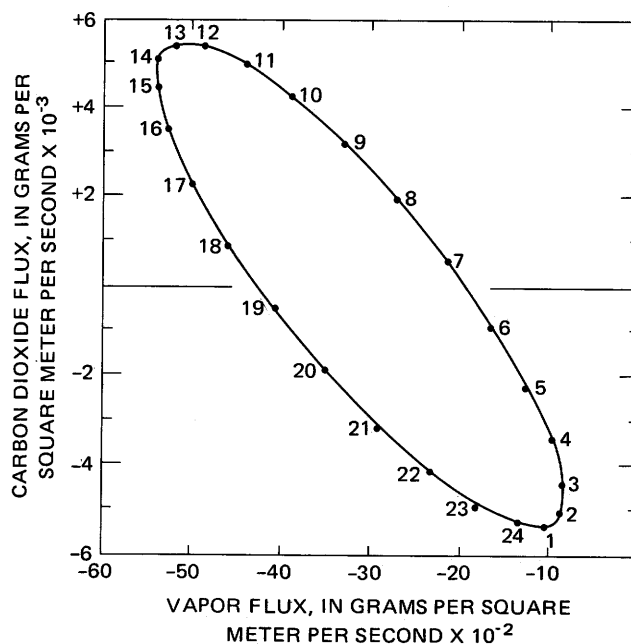


FIGURE 40.—Relation between carbon dioxide and water vapor fluxes during a day over a stand of saltcedar near Buckeye, Ariz., means of 3 days June 3–5, 1966. Ordinate:  $\text{CO}_2$  flux toward the vegetation positive; away from the plant negative. Abscissa: water vapor fluxes away from the vegetation negative. Numbers indicate hours of the days. Flux data are quantities resulting from harmonic analysis of the fluxes and represent first harmonics only.

more complex. Salinity of soil moisture, increasing depth to ground water, topography, and exposure affect, and usually diminish evapotranspiration. The presumption of potential evaporation is then no longer valid. However, in most cases, the approach to the estimation of actual evapotranspiration is through the potential. The main interest therefore remains to predict or be able to predict potential evapotranspiration.

The foregoing description of the microclimate of a saltcedar thicket shows it to be a very intricate phenomenon. If one wants to know how this "complicated mess we call a canopy" (Tanner, 1963, p. 148) affects evapotranspiration rates, all variables pertinent to the problem will have to be taken into account. However, models constructed for the prediction of water use often do not include a sufficient number, let alone all, of the variables that determine actual or potential evapotranspiration. Many models have been used, and even more proposed, that attempt to simplify the computation; often only one or two variables are used because of a lack of more information on the one hand and perhaps an overanxious desire to predict on the other.

A few examples will be presented, and the results compared with one another and with data from the analyses of water use by two Buckeye evapotranspirometers. No detailed description of the methods are given because they are readily available in the literature (see, for instance, the discussions by Cruff and Thompson (1967) and by Jensen (1973)). Table 7 lists the references and also the variables used by the various authors. Note that temperature ( $T$ ) and radiation ( $R_s$ ) are the most frequently chosen variables.  $R_s$ , when not measured, is supposed to be taken from climatic tables. Actual hours of sunshine relative to possible sunshine duration for that latitude and time are occasionally used instead of radiation. Vapor pressure ( $e$ )

can be computed from temperature and relative humidity records. Sometimes saturation vapor pressures are used; these are obtainable from temperature data and vapor-pressure tables.

Such models are incapable of depicting the (often sudden) changes in any of these and other variables in and over the vegetation. They are typically applied not to short-term periods (although some of their authors so do), but to average monthly data, preferably taken as means over a series of years. Figure 41 gives the mean potential evapotranspiration per year as computed by the models mentioned in table 7; the results are compared with measured data taken as the average from tanks 3 and 5. These tanks had, between 1961 and 1965, the smallest depth to water, and, without a doubt, evapotranspired at the potential rate, the more so, because the soil-moisture salinity was also low during that period. Effect of depth to ground water and of soil-moisture salinity will be discussed presently.

Another way of comparing models with measured data is by smoothing out the fluctuations throughout the year by using harmonic analyses. This is done for the year 1963 as shown in table 8. It is obvious from the percent column that the first harmonic describes the

TABLE 7.—Variables used in some models for predicting potential evapotranspiration

[ $T$ : mean temperature or maximum and minimum;  $e$ : vapor pressure, relative humidity, saturation vapor pressures (from  $T$ ), wet-bulb depression or saturation vapor density;  $R_s$ : solar radiation; Lat: latitude term to indicate duration of sunlight; and  $u$ : mean windspeed]

|                                           | $T$ | $e$ | $R_s$ | Lat | $u$ | Other       |
|-------------------------------------------|-----|-----|-------|-----|-----|-------------|
| Lowry-Johnson (1942)                      | X   |     |       |     |     |             |
| Eagelman (1967)                           | X   | X   |       |     |     |             |
| Jensen-Haise (1963)                       | X   |     | X     |     |     |             |
| Lane (1964)                               | X   |     | X     |     |     |             |
| Thornthwaite (1948)                       | X   |     |       | X   |     |             |
| Turc (1961)                               | X   | X   | X     |     |     |             |
| Blaney-Criddle (1962)                     | X   |     |       | X   |     | Crop Factor |
| Weather Bureau (Kohler and others (1955)) | X   | X   | X     |     | X   |             |
| Christiansen-Hargreaves (1969)            | X   | X   | X     |     | X   |             |
| Morton (1975)                             | X   | X   |       | X   |     | Albedo      |
| Papadakis (1966)                          | X   |     |       |     |     |             |
| Makkink (1957)                            | X   |     | X     |     |     |             |
| Hamon (1961)                              | X   |     | X     |     |     |             |
| Olivier (1961)                            | X   | X   | X     | X   |     |             |

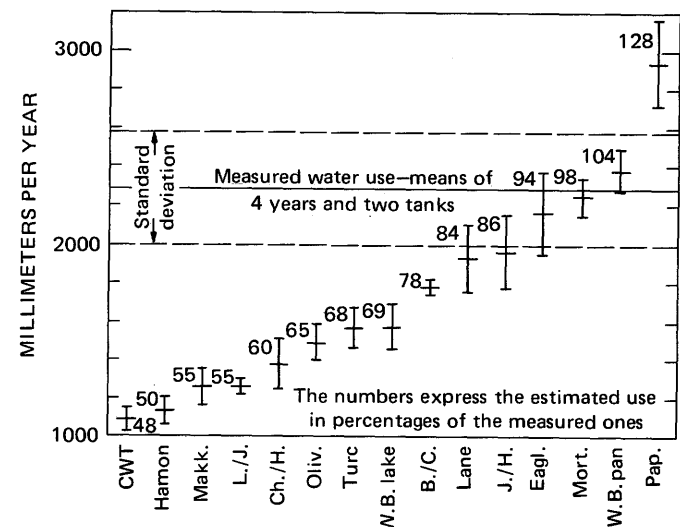


FIGURE 41.—Water use (millimeters per year) as measured and as computed by various models. The horizontal lines indicate the average use computed from 4 years of data and the vertical lines indicate the standard deviation. The measured use is computed from the means of tanks 3 and 5, which had, from 1961 to 1965, the smallest depth to water (1.5 m). The references are: CWT: Thornthwaite, 1948; Hamon, 1961; Makk.: Makkink, 1957; L./J.: Lowry-Johnson, 1942; Ch./H.: Christiansen-Hargreaves, 1969; Oliv.: Olivier, 1961; Turc, 1961; W. B. lake: Kohler and others, 1955, lake evaporation; B./C.: Blaney-Criddle, 1962; Lane, 1964; J./H.: Jensen-Haise, 1963; Eagl.: Eagelman, 1967; Mort.: Morton, 1975; W. B. pan: Kohler and others, 1955, pan evaporation; Pap.: Papadakis, 1966.

TABLE 8.—Comparison of different methods of estimating evapotranspiration for 1963 using the harmonic analysis data

[ $\bar{h}$  = mean and  $a_1$  = amplitude of first harmonic, both in millimeters.  $\phi_1$  = phase angle of first harmonic (in degrees); % = percent of all fluctuations accounted for by first harmonic and peak = approximate day of maximum use, computed from  $\phi_1$ ; total/year = total water use rounded to tens of millimeters. Measured use was taken as the mean of the use measured in tanks 3 and 5 which had the smallest depth to water (1.5 m)]

| Method                  | $\bar{h}$         | $a_1$ | %  | $\phi_1$ | Peak    | Total per year |
|-------------------------|-------------------|-------|----|----------|---------|----------------|
| Measured                | 190               | 104   | 82 | 277      | July 8  | 2280           |
| Thornthwaite            | 97                | 104   | 87 | 277      | 8       | 1170           |
| Hamon                   | 102               | 92    | 83 | 271      | 14      | 1230           |
| Makkink                 | 113               | 57    | 89 | 285      | June 30 | 1350           |
| Lowry-Johnson           | No monthly values |       |    |          |         | 1300           |
| Christiansen-Hargreaves | 130               | 77    | 90 | 287      | June 28 | 1560           |
| Olivier                 | 133               | 110   | 85 | 288      | 27      | 1590           |
| Turc                    | 141               | 84    | 86 | 288      | 27      | 1660           |
| Lake evaporation        |                   |       |    |          |         |                |
| Kohler and others       | 139               | 90    | 91 | 291      | 24      | 1660           |
| Blaney-Criddle          | 152               | 68    | 89 | 272      | July 13 | 1820           |
| Lane                    | 172               | 114   | 90 | 278      | 7       | 2070           |
| Jensen-Haise            | 177               | 128   | 90 | 276      | 9       | 2120           |
| Eagleman                | 195               | 141   | 76 | 264      | 21      | 2340           |
| Morton                  | 195               | 105   | 89 | 282      | 3       | 2350           |
| Pan evaporation         |                   |       |    |          |         |                |
| Kohler and others       | 204               | 126   | 91 | 286      | June 29 | 2450           |
| Papadakis               | 254               | 140   | 84 | 269      | July 16 | 3040           |

fluctuations accurately enough for all practical purposes. The second and third harmonics (not shown in the table) contribute from less than 1 to almost 5 percent to the fluctuations. Also the phase angles, and hence the time of maximum use, are quite similar for both measured and computed use, but there the similarity ends. The means ( $\bar{h}$ ) of the Eagleman and Morton models are closest to the measured means, but the amplitude ( $a_1$ ) of the Eagleman model is much larger than the measured  $a_1$ , while the Morton model shows an amplitude about equal to the measured one.

Russian authors are notably absent in table 8 and figure 41. There is good reason for this. Such methods as proposed by Budagovskii and Savina (1956); Ognev and Kozlov (1962); Konstantinov (1963a); and Bavina (1967) are all based on the one proposed by Budyko (1948; 1956). Budyko's method is basically a combination method similar to Penman's (See sections on "Bulk-Aerodynamic Methods" and "Energy-Budget Methods" in this report.) Since such methods are essentially models of instantaneous phenomena, they cannot successfully be used for daily or monthly averages, but one will be discussed in the section on "Short-Term Predictions."

#### USE OF DAILY AVERAGES

It was earlier explained (see section on "Water Use Measurements") how hourly water use could be obtained from the on-off recorders and the watermeters connected to the evapotranspirometers. These data, too, can then be smoothed out by harmonic analysis. An example is given in table 9. With one exception, all first harmonics account for more than 90 percent of the

fluctuations. Tank 4, which before 1966 had the same density of stand as tank 2, was thinned in March of that year to 50 percent of its original density, and the data show the slight effect of this treatment on water use, except in March 1967 when instrument failure was, if not the likeliest, the easiest explanation for the difference.

Table 10 shows some of the climatic data for the special observation periods mentioned in table 9. The daily mean temperatures ( $T_d$ ) did not vary much during each of the 3-day periods, but there are considerable differences in radiation ( $R_s$  and  $R_n$ ) and in windspeed. It is also of interest to note that, whereas the air temperature during the August period was by far the highest, the radiation was lower than in any of the earlier months. This explains in part the drastic decline in water use during August as compared to May, June, and July. Since most of the empirical models have mean temperature as their main input, one could expect a better fit between measured and computed data in that month than in any of the others.

Table 11 shows this to be the case. Six of the 15 models in table 8 have been used here to estimate evapotranspiration by days because only those models were used whose authors have applied them to estimate daily evapotranspiration values. As in table 8 and in figure 41, the fit is very poor, the least poor one being in August.

The reason for discussing some of the methods for estimating evapotranspiration was to emphasize the fact that a saltcedar thicket is a complicated entity. It is subject to (and reacting to) continuously and at times rapidly changing inputs. The three empirical models

TABLE 9.—Water use in tanks 2 and 4 during special observation periods with some results of harmonic analyses of the hourly data

[Means of three day, mm per hour.  $\bar{h}$  = mean;  $a_1$  = amplitude of the first harmonic (mm per hour); % = percent of total fluctuation due to first harmonic,  $\phi_1$  = phase angle of first harmonic, rounded to whole degrees. Peak = time of maximum use computed from  $\phi_1$ ]

| Period      | Tank | $\bar{h}$                  | $a_1$ | %  | $\phi_1$ | Peak  | Total per day (mm) |
|-------------|------|----------------------------|-------|----|----------|-------|--------------------|
| <b>1966</b> |      |                            |       |    |          |       |                    |
| May 5-8     | 2    | 0.70                       | 0.47  | 91 | 324      | 13:25 | 16.8               |
|             | 4    | N                          | O     | D  | A        | T     | A                  |
| June 3-6    | 2    | 0.80                       | 0.54  | 93 | 325      | 13:21 | 19.3               |
|             | 4    | 0.73                       | 0.43  | 94 | 324      | 13:25 | 17.5               |
| July 6-9    | 2    | 0.87                       | 0.65  | 93 | 341      | 12:17 | 21.0               |
|             | 4    | 0.86                       | 0.60  | 92 | 335      | 12:41 | 20.5               |
| Aug. 3-6    | 2    | 0.51                       | 0.34  | 90 | 334      | 12:45 | 12.2               |
|             | 4    | 0.46                       | 0.25  | 92 | 334      | 12:45 | 11.1               |
| Sept. 8-11  | 2    | 0.50                       | 0.44  | 88 | 342      | 12:13 | 11.9               |
|             | 4    | 0.51                       | 0.38  | 92 | 339      | 12:25 | 12.2               |
| <b>1967</b> |      |                            |       |    |          |       |                    |
| Mar 23-26   | 2    | No hourly values available |       |    |          |       | 2.3                |
|             | 4    |                            |       |    |          |       | 0.9                |
| May 11-14   | 2    | 0.36                       | 0.22  | 95 | 327      | 13:13 | 8.7                |
|             | 4    | 0.35                       | 0.24  | 94 | 343      | 12:09 | 8.4                |

TABLE 10.—Some climatic data pertaining to seven special observation periods of 3 days each

[ $R_s$ : total incoming short-wave radiation in langley's per day (ly/d), watts per m<sup>2</sup> (Wm<sup>-2</sup>) and millimeters water equivalent per day (mm/d);  $R_n$ : same but for net radiation;  $T_{d4}$  and  $T_{w4}$ : dry and wet bulb temperature at 4 m above the soil (°C, mean of 24 hours);  $e_4$ : vapor pressure at 4 m, determined with fig. 18 (1 kilopascal = 10 millibar);  $u_4$ : windspeed at 4 m (kilometer per day); rh: relative humidity (percent)]

| Period      |   | ly/d | $R_s$<br>Wm <sup>-2</sup> | mm/d | ly/d | $R_n$<br>Wm <sup>-2</sup> | mm/d | $T_{d4}$<br>°C | $T_{w4}$<br>°C | $e_4$<br>kPa | $u_4$<br>km/d | rh<br>% |
|-------------|---|------|---------------------------|------|------|---------------------------|------|----------------|----------------|--------------|---------------|---------|
| <b>1966</b> |   |      |                           |      |      |                           |      |                |                |              |               |         |
| May 5-8     | 1 | 593  | 287                       | 10.2 | 387  | 187                       | 6.7  | 28.6           | 17.0           | 1.21         | 144.6         | 31      |
|             | 2 | 641  | 310                       | 11.0 | 410  | 199                       | 7.0  | 27.7           | 17.2           | 1.28         | 93.2          | 34      |
|             | 3 | 596  | 289                       | 10.3 | 374  | 181                       | 6.4  | 28.9           | 16.7           | 1.13         | 123.0         | 28      |
| June 3-6    | 1 | 716  | 347                       | 12.3 | 414  | 200                       | 7.1  | 25.3           | 12.5           | 0.66         | 121.4         | 20      |
|             | 2 | 713  | 345                       | 12.2 | 415  | 201                       | 7.1  | 25.5           | 13.3           | 0.76         | 122.7         | 23      |
|             | 3 | 699  | 338                       | 12.0 | 416  | 201                       | 7.1  | 26.7           | 14.2           | 0.85         | 115.9         | 24      |
| July 6-9    | 1 | 668  | 323                       | 11.5 | 356  | 172                       | 6.1  | 32.6           | 16.7           | 0.91         | 130.4         | 18      |
|             | 2 | 579  | 280                       | 10.0 | 342  | 166                       | 5.9  | 31.8           | 19.1           | 1.42         | 169.7         | 30      |
|             | 3 | 655  | 317                       | 11.3 | 415  | 201                       | 7.1  | 32.4           | 21.0           | 1.77         | 140.9         | 36      |
| Aug. 3-6    | 1 | 417  | 202                       | 7.2  | 260  | 126                       | 4.5  | 35.1           | 23.6           | 2.19         | 193.6         | 39      |
|             | 2 | 580  | 281                       | 10.0 | 382  | 185                       | 6.6  | 35.6           | 22.8           | 1.97         | 176.7         | 34      |
|             | 3 | 525  | 254                       | 9.1  | 344  | 167                       | 5.9  | 35.1           | 23.6           | 2.18         | 170.2         | 39      |
| Sept. 8-11  | 1 | 539  | 261                       | 9.3  | 275  | 133                       | 4.7  | 30.2           | 19.4           | 1.57         | 115.2         | 37      |
|             | 2 | 482  | 233                       | 8.3  | 240  | 116                       | 4.1  | 30.3           | 19.1           | 1.50         | 126.3         | 35      |
|             | 3 | 480  | 232                       | 8.3  | 224  | 108                       | 3.9  | 31.4           | 18.7           | 1.37         | 101.1         | 30      |
| <b>1967</b> |   |      |                           |      |      |                           |      |                |                |              |               |         |
| Mar. 22-26  | 1 | 421  | 204                       | 7.2  | 179  | 87                        | 3.1  | 20.8           | 10.2           | 0.58         | 113.0         | 24      |
|             | 2 | 460  | 223                       | 7.8  | 178  | 86                        | 3.0  | 20.9           | 10.5           | 0.62         | 198.1         | 25      |
|             | 3 | 508  | 246                       | 8.7  | 251  | 122                       | 4.3  | 16.2           | 8.7            | 0.65         | 106.2         | 35      |
| May 11-14   | 1 | 685  | 332                       | 11.7 | 385  | 186                       | 6.6  | 20.2           | 10.8           | 0.71         | 133.7         | 30      |
|             | 2 | 662  | 321                       | 11.3 | 375  | 182                       | 6.4  | 20.5           | 10.7           | 0.67         | 162.3         | 28      |
|             | 3 | 685  | 332                       | 11.7 | 358  | 173                       | 6.1  | 19.9           | 9.9            | 0.60         | 187.5         | 26      |

using monthly mean values that give estimates close to the measured values were also the ones that used four instead of two or three variables as inputs (fig. 41), but these three models are not supposed to be valid for short-term periods; hence, they were not tested against daily water-use data.

#### SHORT-TERM PREDICTIONS

For short-term predictions the above mentioned empirical models have no fit. On the other hand, models capable of predicting water use for hourly or even shorter periods should not be applied to monthly or

TABLE 11.—Water use during special observation periods of 72 hours each as measured in tanks 2 and 4 and estimated according to various equations

[Water level in tanks 2.1 m below the surface. Means of 3 days, millimeters per day]

| Method                  | 1966       |             |             |             |               | 1967          |              |
|-------------------------|------------|-------------|-------------|-------------|---------------|---------------|--------------|
|                         | May<br>5-8 | June<br>3-6 | July<br>6-9 | Aug.<br>3-6 | Sept.<br>8-11 | Mar.<br>22-26 | May<br>11-14 |
| Measured in tank 2      | 16.8       | 19.3        | 21.0        | 12.2        | 11.9          | 2.3           | 8.7          |
| Measured in tank 4      |            | 17.5        | 20.5        | 11.1        | 12.2          | 0.9           | 8.4          |
| Olivier                 | 9.0        | 10.4        | 11.1        | 9.2         | 7.8           | 6.3           | 6.3          |
| Jensen-Haise            | 8.3        | 8.9         | 9.7         | 8.5         | 7.3           | 4.4           | 6.8          |
| Christiansen-Hargreaves | 5.5        | 6.1         | 6.5         | 5.9         | 4.7           | 3.5           | 5.4          |
| Thornthwaite            | 5.7        | 5.1         | 6.9         | 7.0         | 5.8           | 2.3           | 2.8          |
| Hamon                   | 5.1        | 4.8         | 6.9         | 7.2         | 4.8           | 2.4           | 3.2          |
| Makkink                 | 4.8        | 5.3         | 4.7         | 4.3         | 3.5           | 2.3           | 4.9          |

weekly periods by inserting into the equations mean monthly or weekly inputs such as mean temperature, mean windspeed, etc. They can, of course, give good results by adding 24 hourly values to give daily quantities of water use, and a compilation of 30 daily values will give a good monthly value.

The better a prediction equation represents the actual proceedings in and over a saltcedar thicket, the better the accuracy of prediction. The principles and theories of the eddy-diffusion, the aerodynamic, and the combination methods were discussed earlier (see the section on "Evapotranspiration and its Calculation"). Since no instrumentation for it was available, the eddy-diffusion method could not be tested at the Buckeye Project. Also energy-budget methods that do not include advective terms are omitted in the following discussion because, as was shown in the sections on "Climate" and "The Microclimate of a Saltcedar Thicket", advection is a very important and persistent part of the proceedings in and over any riparian or flood-plain vegetation in a dry and therefore usually windy climate. Finally, the Bowen ratio could not be tested because of its erratic nature, as was discussed in the section on the "Energy-Budget Method."

Three methods for predicting short-term water use will be discussed: one by Konstantinov (1963b), one by Rider (1957), and one by van Bavel (1966) which is modified by the inclusion of resistance terms as described by Monteith (1963; 1965).

Konstantinov's<sup>10</sup> method is based on aerodynamic approach including gradients of windspeed and vapor pressure and a Richardson number defined as

$$Ri = -0.078 \frac{T_{0.2} - T_{2.0}}{(u_{2.0} - u_{0.2})^2} \quad (45)$$

This is similar to the stability ratio of equation 27. The subscripts indicate the height (in meters) of the in-

struments above the soil. These heights are much too low for saltcedar studies, but Konstantinov gives instructions on how to reduce higher observations to lower ones. To compute windspeeds, for instance, we have

$$u_{2.0} - u_{0.2} = \frac{u_{z_2} - u_{z_1}}{\log(z_2/z_1)} \quad (46)$$

where  $z_2$  and  $z_1$ , are elevations other than 2.0 and 0.2 m. Of course, such a transform is only admissible if there exists a logarithmic wind profile throughout. Such a profile may not always exist over a saltcedar thicket.

The computations give results that, hour by hour, deviate considerably from the measured values. For 4-hour periods the outcome is a little better, but still leaves a lot to be desired. Figure 42 is a small example. The actual temperatures, windspeeds, and vapor pressures were taken from the 7 and 5 m levels and reduced, according to Konstantinov's instructions, to 2 and 0.2 m. This procedure may not be valid where tall vegetation is involved and may well be the reason for the poor fit. The daily totals for the day, illustrated in figure 42, are 24 mm for the Konstantinov model and 20 mm as measured. The correlation coefficient, 0.72, is only significant at the 5 percent level.

In 1957, Rider published a study of water losses from various land surfaces in which he used the aerodynamic method for predicting evapotranspiration. His model was based on the Thornthwaite-Holzman (1942) equation as modified by Pasquill (1949):

$$E_0 = \frac{3.46 \times 10^{-5} (e_1 - e_2) (u_2 - u_1)}{T \left[ \ln \frac{z_2 - d}{z_1 - d} \right]^2} \quad (47)$$

A comparison with equation 16 shows that the modification consists in the introduction of a zero-plane displacement,  $d$ , (discussed in the section on "Winds"), air temperature ( $T$ , in degrees Kelvin) instead of air density, and vapor pressure ( $e$ ) instead of specific humidity ( $q$ ).

<sup>10</sup> The reason for including this model in the present discussion is that Konstantinov considers his methods to be an improvement to be used with the official GGO manual of 1957 (Glavnaya Geofizicheskaya Observatoriya = Main Geophysical Laboratory) for making observations by the gradient method.

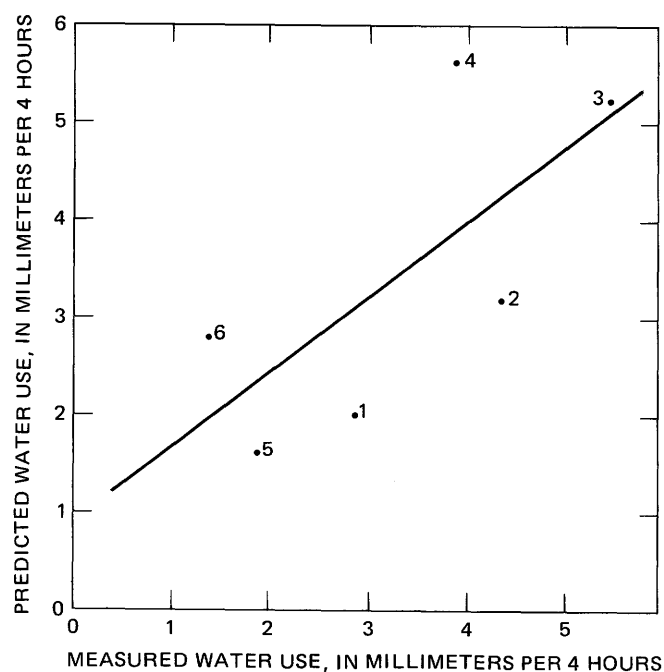


FIGURE 42.—Water use as predicted by the Konstantinov model (ordinate) versus the one measured in tank 2 on June 3–4, 1966. Correlation coefficient = 0.72\*. Regression  $y = 0.76 + 0.88x$ . The numbers at the dots give the 4-hour periods 1 = 5–8, 2 = 9–12, etc.

Rider determined hourly values for 18 days for which he had measured hourly water-use values available. The fits are only fair, the main reason being, by Rider's own admission, the quality of his records. Also equation 47 as well as equation 16 are strictly valid only under natural conditions of atmospheric stability.

The often successful method of smoothing out erraticism is to use sums of a certain number of values and (or) to use means of a certain number of days. This was done here for 4-hour sums and 3-day means. Two examples are presented at the top of figure 43. The correlation coefficients are at the 1 percent level of confidence and the regression lines show a close to 1 : 1 relationship.

The two curves at the bottom of figure 43 show the result of computations for only one day. On the right the air temperatures and humidity data are taken from instruments 7 and 4 m above the ground (4 and 1 m above the vegetation). On the left, the data at 11 and 5 m were used (8 and 2 m above the vegetation). The method is rather sensitive to the height at which the observations were taken, but both curves show a fairly good fit. Nonetheless, the instrumentation used at the Buckeye Project was not accurate or sensitive enough for a successful application of the aerodynamic model.

The combination method promised to give a better prediction, therefore, it was subjected to more elaborate testing. The model itself has been presented in the section on "Combination Methods" in this report.

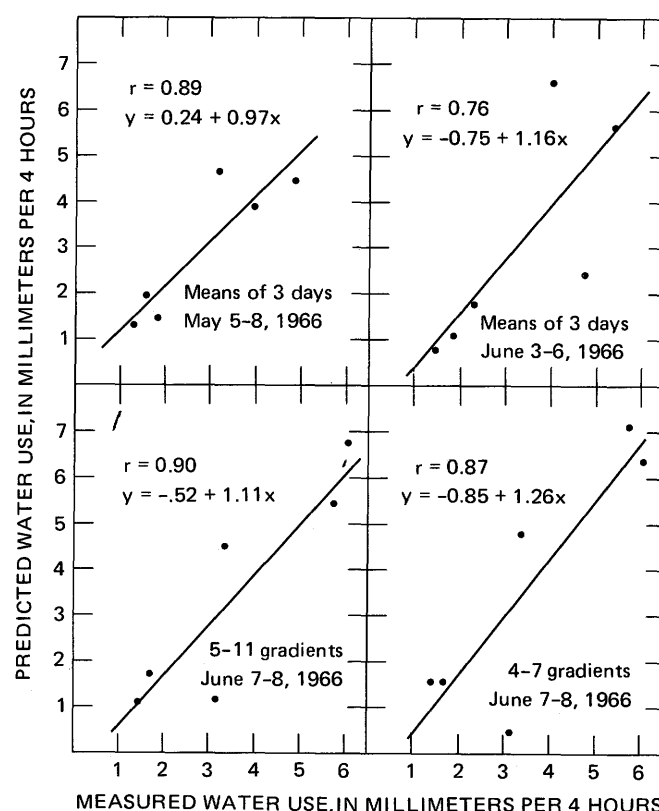


FIGURE 43.—Water use predicted by the Rider model versus that measured in tank 2. Gradients: the numbers indicate the elevation above ground from which the input data were taken.

Equations 22 to 26 are especially pertinent. A large part of the computations were done by longhand, using graphs and nomograms. Later a small programmable desk calculator was available. In both cases computations were simplified by assuming a constant air pressure of 98.3 kPa. In that case, the  $\Delta/\gamma$  term in equation 22 is dependent on air temperature alone and it was found that

$$\Delta/\gamma = \exp 0.045 T_a - 0.32 \quad (48)$$

was a very good approximation. Similarly, the first factor in equation 23 could be made dependent on air temperature alone and

$$\frac{\rho e k^2}{983} = 36.4 \times 10^{-6} \div (T_a + 273) \quad (49)$$

proved to be of excellent accuracy.

As van Bavel (1966) points out, the expression for  $B_e$  in equation (23) is based upon standard wind profile theory and applies strictly to adiabatic conditions only. Under such conditions logarithmic wind profiles obtain. Analyses of the wind data from the Buckeye Project revealed that within the limits of accuracy of the anemometers the profiles were nearly always

logarithmic but a variable modified roughness length had to be taken into account as was discussed in the section on "Winds." Inserting this modified roughness length, and using temperature and wind data from the 4-m level, gives computed values that are reasonably close to those measured.

The results of two computations, using the combination equation and covering 72-hour periods in May and June 1966, are displayed in figure 44 together with the water-use data. As can be seen, the computed potential evapotranspiration rate not only fluctuates much more than the one measured for tank 2 but, especially during the daylight hours, often seems excessively high. That the measured data do not fluctuate as much as the theoretical ones is partly due to the slow response of the vegetation to comparatively sudden changes in the ambient parameters and also due to the assumption under which the hourly water use in the tanks was computed; namely, a constant rate of water use between one filling and the next.

A perusal of these and other data shows clearly that large deviations occur when windspeeds are more than about 2 m/s and during periods of high temperature. This suggests the existence of a significant aerodynamic and stomatal or leaf resistance (see the sections on "Flow Resistance" and "Combination Methods" in this report, especially equations 24, 25, and 26).

The aerodynamic resistance ( $r_a$ ) can readily be computed if windspeeds and roughness lengths are known. The stomatal resistance, however, depends not only on  $r_a$  but also on  $\Delta/\gamma$  and on the ratio of potential over actual evapotranspiration. Stomatal resistance can be measured directly on broad-leaved plants with a porometer (Stiles, 1970; Byrne and others, 1970) but

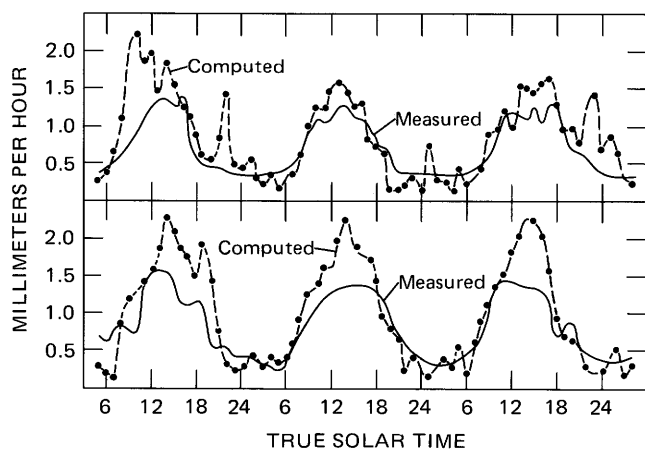


FIGURE 44.—Hourly rates of evapotranspiration for two 3-day periods near Buckeye, Ariz. Measured water use in tank No. 2, compared to that computed with equations 22 and 23.

these instruments cannot be used on the scalelike leaves of a saltcedar twig.<sup>11</sup> However,  $E_o$  can be computed with equation 22 and  $E_a$  can be measured. Thus values for the stomatal resistance ( $r_s$ ) can be obtained by the use of equation 25. This was done for one set of data, and it was found that  $r_s$  was highly correlated with windspeeds and also, but much less so, with temperatures and humidity.

Equation 25 shows that negative values appear when  $E_o < E_a$ . This can happen if (1) the graphical analysis of hourly water use results in a high  $E_a$ , (2) an erratic set of (say) temperature records gives a low  $E_o$ , or (3) if  $E_a$  is actually larger than the potential value. The data analysis showed that vapor pressure deficit affected  $r_s$  very little, the effect probably being overshadowed by that of temperature and wind. It was found that

$$r_s = -1.26 + 0.013 T_7 + 0.5 u_7 \quad (50)$$

It may seem strange that there is a negative constant in the equation but this is the result of the fact that  $T$  and  $u$  values were taken at 7 m above ground and not at the surface of the leaves where temperatures are higher (Gates, 1963) and windspeeds lower (Monteith, 1965). Thus, equation 50 is purely empirical, being derived from the 3-day data of August and then applied to other 3-day periods. Within the range of temperatures and windspeeds used in the regression analysis,  $r_s$  ranges from  $-0.7$  s/cm for  $T_7 = 8^\circ\text{C}$  and  $u_7 = 0.9$  m/s to  $2.9$  s/cm for  $T_7 = 42^\circ\text{C}$  and  $u_7 = 7.3$  m/s.

Hughes (1972), who used average monthly data, reports slightly higher  $r_s$  values and finds that  $r_s = 0.128 u_5^{1.92}/T_2^{2.73}$ , but restricts his analyses to temperatures between  $12^\circ$  and  $24^\circ\text{C}$  and windspeeds up to 3 m/s only. His relationship thus shows that  $r_s$  increases with increasing windspeed, as in the present study, but decreases with increasing temperatures (at least in the quoted temperature range) in contrast with the present findings.

Whether the use of porometer data or of data obtained by other means of actually measuring the resistance term would give better results is a matter of speculation, but the data computed by equations 26 and 50 and illustrated in figure 45 seem quite acceptable with the glaring exception of those from the period May 11–14, 1967, shown at the bottom of the figure. Here salinity had a decisive effect.

In 1974 van Hylckama discussed the effect of salinity on rate of water use and explained how some of the

<sup>11</sup>D. C. Davenport (oral and written commun., 1977) reported successful use of the porometer on saltcedar twigs by careful standardization of twig length and volume, but admits that the method is rather subjective and chances of discrepancies increase if different people use the method.

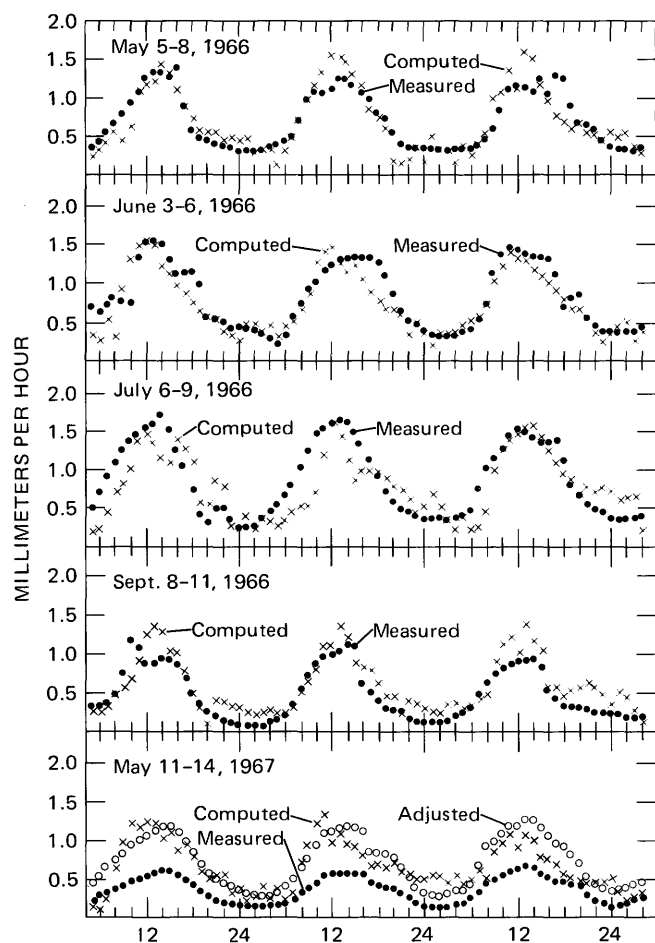


FIGURE 45.—Computed evapotranspiration, using equation 26, versus that measured in tank 2 at the Buckeye project in millimeters per hour for five periods of 3 days each. The ○○○○ (adjusted) line on the bottom graph compensates for salinity buildup (see text).

tanks were flushed in 1965 and 1966 to reduce the salinity of the soil moisture and the "ground water." In 1967 the tanks were given no such treatment. The records showed that the specific conductance in tank 2 increased between September 1966 and May 1967 from 18 to 32 millimhos per cm at 25°C. Such an increase would result in a decrease of water use by about 50 percent. Therefore the measured water use, indicated by the solid line in figure 45, was doubled as depicted by open circles. Although the corrected values do not fit ideally, they obviously compensate for drastic effects of soil-moisture salinity on water use.

It was mentioned (see section on "Short-Term Predictions") that models capable of predicting water use for hourly periods should not be applied to longer periods by inserting long-time means into the equations. An example of the result of such faulty procedure is given in table 12. Daily totals of evapotranspiration computed as sums of hourly values fit the measured ones quite well, whereas those computed using daily means of radiation, winds, etc., are much too large.

## DISCUSSION

A few important conclusions can be drawn from the foregoing.

Flood-plain vegetation in the arid and semi-arid southwest is characterized by a very complex set of interactions between inputs of ambient weather, soil, soil-moisture characteristics, and plant reactions to such inputs.

The instrumentation at the Buckeye Project had been used with adequate, if not excellent, results when applied to measuring evaporation from open water, but it was less adequate to cope successfully with the complexity of a riparian or flood-plain vegetation and its evapotranspiration.

For a rough estimate of yearly water use, the Weather Bureau's pan evaporation method (Kohler and others, 1955), and the Eagleman (1967) and the Morton (1975) models seem adequate. That Kohler's pan-evaporation, rather than lake-evaporation method, produced values closer to the measured quantities emphasizes the oasis characteristics of riparian vegetation where the advective term is very important, especially when, as is often the case, wind speeds are high and humidity is low.

For detailed estimates or predictions, the combination model (equations 22–26) gives the best results although such estimates often will be too high if aerodynamic and stomatal resistances are neglected. Riparian and flood-plain vegetation simply are not sets of wicks that release water on demand.

The disadvantages of the use of closed-bottom, plastic-lined tanks for measuring evapotranspiration rates have been discussed elsewhere (van Hylckama, 1974, p. E29). Better lysimeters would not only be flood-prone, if they were properly located, that is, within the riparian vegetation, but they would be very

TABLE 12.—Water use (millimeters/day) by saltcedar for 3 days in 1966

| Date     | Measured | Computed as the sum of 24 hourly values (eq. 26) | Deviation from measured | Computed with eq. 26 from mean daily values | Deviation from measured |
|----------|----------|--------------------------------------------------|-------------------------|---------------------------------------------|-------------------------|
| April 9  | 10.4     | 11.5                                             | +1.1                    | 14.4                                        | +4.0                    |
| April 28 | 15.4     | 15.6                                             | +0.2                    | 18.2                                        | +2.8                    |
| May 3    | 13.5     | 12.6                                             | −0.9                    | 15.8                                        | +2.3                    |

expensive. Moreover, like the plastic tanks, they would provide data that, strictly speaking, would be applicable only to areas quite similar in ecology. Such similarity is difficult to ascertain unequivocally.

The present studies have shown that even under the very complicated circumstances of riparian and floodplain vegetation, comparatively simple instrumentation can provide fairly adequate data for the purpose of estimating evapotranspiration using the combination-type model. Improved sensors and recorders, especially those of humidity and radiation, would undoubtedly provide more reliable results.

However, although not tested at the Buckeye Project, the eddy-correlation model and its instrumentation seems to be the most promising of all models and methods in use so far because of the fact that the method is independent of the height or exposure of the vegetation and independent of lapse rates or temperature and other profiles. By contrast, most aerodynamic or energy-budget models are valid only under adiabatic conditions.

In future evapotranspiration research, the eddy-correlation methods and its further instrumentation development should have the predominant attention of hydrologists, botanists, and other researchers in the Water Resources Division and, actually, in all other Federal, State, and private organizations studying plant-soil-water relationships.

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## **APPENDICES**

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TABLE A1-1.—Hourly averages of windspeeds and wind direction at the Buckeye Project during selected periods of 3 days each

[Windspeeds in meters per second ( $\text{m s}^{-1}$ ) at indicated levels (meters) above ground. Clocks set to true local solar time: 1200 (noon) when sun exactly at  $180^\circ$ ]

| 1-hr. period<br>beginning | 11m  | 7m   | 5m   | 4m   | 2m   | Wind<br>direction |
|---------------------------|------|------|------|------|------|-------------------|
| <b>5-6 May 1966</b>       |      |      |      |      |      |                   |
| 5                         | 2.97 | 2.15 | 1.54 | 1.01 | 0.13 | E                 |
| 6                         | 3.33 | 1.92 | 1.69 | 1.27 | 0.57 | E                 |
| 7                         | 3.33 | 2.62 | 2.04 | 1.79 | 0.72 | NE                |
| 8                         | 3.64 | 3.16 | 2.59 | 2.16 | 1.10 | NE                |
| 9                         | 5.45 | 4.90 | 3.80 | 3.06 | 1.31 | NE                |
| 10                        | 5.81 | 4.75 | 3.96 | 3.33 | 1.46 | NE                |
| 11                        | 3.64 | 3.09 | 2.66 | 2.29 | 1.16 | E                 |
| 12                        | 3.65 | 3.11 | 2.65 | 2.30 | 1.00 | E                 |
| 13                        | 2.53 | 2.28 | 2.00 | 1.79 | 0.86 | NE                |
| 14                        | 2.90 | 2.45 | 2.12 | 1.88 | 0.88 | SE                |
| 15                        | 2.53 | 2.28 | 1.95 | 1.69 | 0.88 | SE                |
| 16                        | 2.65 | 2.24 | 2.04 | 1.73 | 0.76 | SE                |
| 17                        | 2.94 | 2.41 | 2.11 | 1.73 | 0.61 | NE                |
| 18                        | 2.72 | 2.36 | 1.86 | 1.46 | 0.68 | NE                |
| 19                        | 2.23 | 1.73 | 1.33 | 0.90 | 0.40 | NE                |
| 20                        | 1.98 | 1.64 | 1.23 | 0.84 | 0.24 | NE                |
| 21                        | 3.09 | 2.53 | 2.07 | 1.75 | 0.46 | SW                |
| 22                        | 5.45 | 4.34 | 3.59 | 3.15 | 0.81 | SW                |
| 23                        | 2.11 | 1.77 | 1.51 | 1.25 | 0.28 | W                 |
| 24                        | 2.49 | 1.66 | 1.22 | 0.90 | 0.09 | W                 |
| 1                         | 3.06 | 2.17 | 1.60 | 1.19 | 0.12 | W                 |
| 2                         | 2.35 | 1.48 | 1.11 | 0.85 | 0.09 | W                 |
| 3                         | 1.18 | 1.05 | ---  | 0.88 | 0.07 | W                 |
| 4                         | 1.93 | 1.74 | 1.10 | 0.98 | 0.10 | N                 |
| <b>6-7 May 1966</b>       |      |      |      |      |      |                   |
| 5                         | 1.24 | 0.98 | 1.07 | 0.86 | 0.07 | N                 |
| 6                         | 2.48 | 1.84 | 1.38 | 1.08 | 0.28 | SE                |
| 7                         | 1.69 | 1.23 | 1.07 | 0.86 | 0.32 | SE                |
| 8                         | 2.12 | 1.87 | 1.56 | 1.35 | 0.73 | NE                |
| 9                         | 2.00 | 1.73 | 1.51 | 1.32 | 0.66 | NE                |
| 10                        | 2.12 | 1.86 | 1.69 | 1.41 | 0.90 | NE                |
| 11                        | 1.75 | 1.54 | 1.38 | 1.26 | 0.85 | NE                |
| 12                        | 1.92 | 1.63 | 1.42 | 1.30 | 0.88 | NE                |
| 13                        | 2.12 | 1.81 | 1.63 | 1.41 | 0.86 | NE                |
| 14                        | 2.04 | 1.78 | 1.60 | 1.41 | 0.93 | NE                |
| 15                        | 1.99 | 1.72 | 1.48 | 1.24 | 0.82 | NE                |
| 16                        | 2.47 | 2.17 | 1.88 | 1.60 | 0.76 | N                 |
| 17                        | 1.74 | 1.49 | 1.27 | 1.14 | 0.62 | N                 |
| 18                        | 2.30 | 1.79 | 1.48 | 1.20 | 0.32 | N                 |
| 19                        | 2.41 | 1.79 | 1.24 | 0.89 | 0.09 | N                 |
| 20                        | 1.27 | 0.92 | 0.72 | 0.55 | 0.09 | N                 |
| 21                        | 0.71 | 0.61 | 0.92 | 0.76 | 0.09 | N                 |
| 22                        | 0.85 | 0.88 | 0.90 | 0.68 | 0.09 | N                 |
| 23                        | 1.95 | 1.54 | 1.28 | 1.00 | 0.13 | W                 |
| 24                        | 1.33 | 1.06 | 0.88 | 0.72 | 0.13 | W                 |
| 1                         | 3.52 | 0.60 | 1.87 | 1.46 | 0.13 | W                 |
| 2                         | 1.93 | 1.52 | 1.20 | 0.93 | 0.09 | NE                |
| 3                         | 1.69 | 1.35 | 1.08 | 0.83 | 0.07 | NE                |
| 4                         | 1.69 | 1.28 | 0.98 | 0.63 | 0.07 | NE                |
| <b>7-8 May 1966</b>       |      |      |      |      |      |                   |
| 5                         | 2.65 | 1.94 | 1.54 | 1.19 | 0.08 | NE                |
| 6                         | 1.67 | 1.40 | 1.14 | 0.93 | 0.06 | SE                |
| 7                         | 1.28 | 0.95 | 0.98 | 0.75 | 0.23 | SE                |
| 8                         | 1.36 | 1.07 | 1.07 | 0.85 | 0.47 | SE                |
| 9                         | 1.80 | 1.51 | 1.36 | 1.10 | 0.72 | NE                |
| 10                        | 1.10 | 0.90 | 0.96 | 0.84 | 0.57 | NE                |
| 11                        | 1.38 | 1.21 | 1.08 | 0.96 | 0.64 | NE                |
| 12                        | 1.10 | 0.92 | 1.02 | 0.84 | 0.46 | N                 |
| 13                        | 1.76 | 1.51 | 1.36 | 1.24 | 0.72 | N                 |
| 13                        | 1.93 | 1.69 | 1.41 | 1.24 | 0.86 | NW                |
| 15                        | 2.88 | 2.40 | 2.00 | 1.73 | 0.77 | W                 |
| 16                        | 3.52 | 2.88 | 2.41 | 1.92 | 0.67 | W                 |
| 17                        | 4.37 | 3.58 | 2.73 | 2.18 | 0.75 | W                 |
| 18                        | 3.76 | 3.15 | 2.59 | 2.16 | 0.75 | W                 |
| 19                        | 3.41 | 2.72 | 2.16 | 1.73 | 0.51 | W                 |
| 20                        | 3.38 | 2.51 | 2.00 | 1.60 | 0.32 | W                 |

TABLE A1-1.—Hourly averages of windspeeds and wind direction at the Buckeye Project during selected periods of 3 days each—Continued

| 1-hr. period<br>beginning     | 11m  | 7m   | 5m   | 4m   | 2m   | Wind<br>direction |
|-------------------------------|------|------|------|------|------|-------------------|
| <b>7-8 May 1966—Continued</b> |      |      |      |      |      |                   |
| 21-----                       | 3.26 | 2.27 | 1.65 | 1.33 | 0.32 | W                 |
| 22-----                       | 4.48 | 3.54 | 2.91 | 2.48 | 0.55 | SW                |
| 23-----                       | 5.20 | 4.14 | 3.45 | 2.97 | 0.86 | SW                |
| 24-----                       | 2.86 | 2.30 | 1.89 | 1.53 | 0.67 | SW                |
| 1-----                        | 3.64 | 2.85 | 2.27 | 1.90 | 0.63 | SW                |
| 2-----                        | 2.65 | 1.99 | 1.52 | 1.17 | 0.12 | W                 |
| 3-----                        | 1.55 | 1.21 | 0.98 | 0.77 | 0.12 | NW                |
| 4-----                        | 1.33 | 1.08 | 0.88 | 0.77 | 0.12 | N                 |
| <b>3-4 June 1966</b>          |      |      |      |      |      |                   |
| 5-----                        | 2.79 | 2.05 | 1.54 | 1.12 | 0.12 | SE                |
| 6-----                        | 1.50 | 0.90 | 0.91 | 0.70 | 0.06 | SE                |
| 7-----                        | 1.95 | 1.35 | 1.16 | 0.91 | 0.38 | S                 |
| 8-----                        | 2.41 | 2.01 | 1.66 | 1.35 | 0.67 | NE                |
| 9-----                        | 2.59 | 2.23 | 1.86 | 1.51 | 0.79 | NE                |
| 10-----                       | 1.89 | 1.66 | 1.48 | 1.25 | 0.73 | NE                |
| 11-----                       | 1.92 | 1.66 | 1.51 | 1.25 | 0.79 | SE                |
| 12-----                       | 1.98 | 1.73 | 1.63 | 1.41 | 0.79 | V                 |
| 13-----                       | 2.59 | 2.29 | 1.98 | 1.79 | 0.85 | SW                |
| 14-----                       | 3.77 | 3.27 | 2.85 | 2.47 | 0.91 | SW                |
| 15-----                       | 3.84 | 3.33 | 2.85 | 2.41 | 0.98 | SW                |
| 16-----                       | 3.90 | 3.33 | 2.85 | 2.47 | 0.73 | SW                |
| 17-----                       | 4.34 | 3.45 | 3.03 | 2.59 | 0.64 | SW                |
| 18-----                       | 4.14 | 3.39 | 2.78 | 2.26 | 0.67 | W                 |
| 19-----                       | 3.15 | 2.53 | 2.07 | 1.60 | 0.55 | W                 |
| 20-----                       | 3.21 | 2.23 | 1.73 | 1.25 | 0.10 | W                 |
| 21-----                       | 3.45 | 2.41 | 1.82 | 1.41 | 0.11 | W                 |
| 22-----                       | 1.31 | 1.28 | 1.38 | 1.01 | 0.04 | W                 |
| 23-----                       | 1.35 | 1.10 | 1.10 | 0.79 | 0.04 | W                 |
| 24-----                       | 1.16 | 0.98 | 1.04 | 0.76 | 0.04 | W                 |
| 1-----                        | 1.60 | 1.38 | 1.23 | 0.83 | 0.05 | W                 |
| 2-----                        | 2.11 | 1.55 | 1.16 | 0.88 | 0.07 | S                 |
| 3-----                        | 0.98 | 1.23 | 1.09 | 0.76 | 0.06 | S                 |
| 4-----                        | 1.60 | 1.54 | 1.35 | 0.94 | 0.10 | S                 |
| <b>4-5 June 1966</b>          |      |      |      |      |      |                   |
| 5-----                        | 2.11 | 1.35 | 1.07 | 0.71 | 0.14 | S                 |
| 6-----                        | 2.17 | 1.63 | 1.41 | 1.09 | 0.14 | S                 |
| 7-----                        | 2.32 | 1.86 | 1.54 | 1.22 | 0.64 | NE                |
| 8-----                        | 2.85 | 2.41 | 1.98 | 1.60 | 0.79 | NE                |
| 9-----                        | 2.78 | 2.53 | 1.98 | 1.69 | 0.91 | NE                |
| 10-----                       | 2.04 | 1.86 | 1.60 | 1.38 | 0.85 | NE                |
| 11-----                       | 2.41 | 2.11 | 1.79 | 1.63 | 0.76 | V                 |
| 12-----                       | 2.35 | 2.01 | 1.69 | 1.48 | 0.83 | NW                |
| 13-----                       | 3.33 | 2.91 | 2.47 | 2.11 | 0.83 | SW                |
| 14-----                       | 3.96 | 3.39 | 2.91 | 2.50 | 0.90 | SW                |
| 15-----                       | 3.36 | 2.88 | 2.44 | 2.17 | 0.87 | SW                |
| 16-----                       | 3.54 | 3.06 | 2.53 | 2.17 | 0.79 | W                 |
| 17-----                       | 4.08 | 3.45 | 2.85 | 2.35 | 0.77 | W                 |
| 18-----                       | 3.77 | 3.24 | 2.72 | 2.32 | 0.61 | W                 |
| 19-----                       | 3.39 | 2.62 | 2.17 | 1.76 | 0.38 | W                 |
| 20-----                       | 3.12 | 2.17 | 1.66 | 1.21 | 0.10 | W                 |
| 21-----                       | 3.09 | 2.11 | 1.57 | 1.13 | 0.10 | W                 |
| 22-----                       | 1.98 | 1.16 | 0.99 | 0.66 | 0.06 | W                 |
| 23-----                       | 1.69 | 1.57 | 1.22 | 0.88 | 0.06 | V                 |
| 24-----                       | 1.66 | 1.25 | 1.14 | 0.90 | 0.06 | NE                |
| 1-----                        | 0.95 | 0.76 | 0.85 | 0.62 | 0.03 | W                 |
| 2-----                        | 1.16 | 1.05 | 1.10 | 0.76 | 0.04 | W                 |
| 3-----                        | 1.89 | 1.63 | 1.38 | 0.98 | 0.28 | NW                |
| 4-----                        | 1.73 | 1.20 | 1.04 | 0.75 | 0.13 | N                 |
| <b>5-6 June 1966</b>          |      |      |      |      |      |                   |
| 5-----                        | 2.56 | 1.95 | 1.48 | 1.10 | 0.21 | E                 |
| 6-----                        | 1.28 | 0.98 | 0.98 | 0.72 | 0.09 | NE                |
| 7-----                        | 2.04 | 1.69 | 1.48 | 1.16 | 0.63 | NE                |
| 8-----                        | 2.35 | 2.16 | 1.73 | 1.37 | 0.79 | NE                |
| 9-----                        | 2.11 | 1.98 | 1.60 | 1.37 | 0.76 | NE                |
| 10-----                       | 2.23 | 1.94 | 1.69 | 1.48 | 0.85 | NE                |
| 11-----                       | 2.23 | 1.98 | 1.70 | 1.51 | 0.85 | NE                |

TABLE A1-1.—Hourly averages of windspeeds and wind direction at the Buckeye Project during selected periods of 3 days each—Continued

| 1-hr. period<br>beginning      | 11m  | 7m   | 5m   | 4m   | 2m   | Wind<br>direction |
|--------------------------------|------|------|------|------|------|-------------------|
| <b>5-6 June 1966—Continued</b> |      |      |      |      |      |                   |
| 12                             | 2.91 | 2.53 | 2.29 | 1.98 | 0.91 | V                 |
| 13                             | 3.45 | 2.91 | 2.47 | 2.11 | 0.90 | SW                |
| 14                             | 3.84 | 3.45 | 2.91 | 2.59 | 0.87 | SW                |
| 15                             | 4.08 | 3.58 | 3.09 | 2.68 | 0.97 | SW                |
| 16                             | 3.96 | 3.54 | 3.03 | 2.53 | 0.91 | SW                |
| 17                             | 3.58 | 3.09 | 2.59 | 2.17 | 0.73 | W                 |
| 18                             | 2.85 | 2.23 | 1.73 | 1.41 | 0.34 | W                 |
| 19                             | 2.59 | 1.86 | 1.48 | 1.07 | 0.11 | W                 |
| 20                             | 2.59 | 1.66 | 1.16 | 0.76 | 0.11 | W                 |
| 21                             | 2.53 | 1.66 | 1.15 | 0.78 | 0.09 | W                 |
| 22                             | 1.69 | 1.13 | 0.98 | 0.71 | 0.09 | W                 |
| 23                             | 0.73 | 0.83 | 1.04 | 0.73 | 0.05 | W                 |
| 24                             | 1.19 | 1.01 | 1.00 | 0.71 | 0.05 | W                 |
| 1                              | 1.54 | 1.28 | 1.24 | 0.98 | 0.07 | V                 |
| 2                              | 2.50 | 1.86 | 1.48 | 1.01 | 0.13 | E                 |
| 3                              | 1.51 | 0.91 | 0.94 | 0.61 | 0.07 | E                 |
| 4                              | 1.95 | 1.38 | 1.03 | 0.66 | 0.09 | E                 |
| <b>6-7 July 1966</b>           |      |      |      |      |      |                   |
| 5                              | 1.24 | 0.86 | 0.98 | 0.71 | 0.06 | S                 |
| 6                              | 1.43 | 0.73 | 1.07 | 0.83 | 0.06 | S                 |
| 7                              | 1.35 | 1.08 | 1.08 | 0.89 | 0.24 | S                 |
| 8                              | 1.17 | 0.98 | 0.98 | 0.76 | 0.24 | V                 |
| 9                              | 1.23 | 1.00 | 1.06 | 0.89 | 0.32 | NE                |
| 10                             | 1.23 | 1.02 | 1.07 | 0.94 | 0.38 | V                 |
| 11                             | 1.80 | 1.57 | 1.48 | 1.24 | 0.62 | W                 |
| 12                             | 2.19 | 1.91 | 1.74 | 1.50 | 0.73 | V                 |
| 13                             | 3.13 | 2.68 | 2.38 | 2.04 | 0.78 | SW                |
| 14                             | 4.46 | 3.84 | 3.09 | 2.52 | 0.93 | W                 |
| 15                             | 4.95 | 4.17 | 3.45 | 2.86 | 0.93 | W                 |
| 16                             | 4.58 | 3.87 | 3.23 | 2.68 | 0.77 | SW                |
| 17                             | 4.14 | 3.49 | 2.97 | 2.47 | 0.70 | SW                |
| 18                             | 4.83 | 3.73 | 3.15 | 2.62 | 0.45 | W                 |
| 19                             | 4.58 | 3.71 | 3.15 | 2.66 | 0.52 | SW                |
| 20                             | 3.60 | 2.65 | 2.23 | 1.81 | 0.32 | SW                |
| 21                             | 4.08 | 2.99 | 2.44 | 2.03 | 0.24 | SW                |
| 22                             | 3.84 | 2.98 | 2.49 | 1.91 | 0.12 | W                 |
| 23                             | 1.22 | 1.06 | 0.83 | 0.73 | 0.06 | V                 |
| 24                             | 2.50 | 1.80 | 1.32 | 1.00 | 0.13 | NW                |
| 1                              | 1.93 | 1.33 | 1.03 | 0.81 | 0.10 | NW                |
| 2                              | 1.19 | 0.99 | 0.99 | 0.85 | 0.07 | NE                |
| 3                              | 1.40 | 1.31 | 1.13 | 0.76 | 0.08 | NE                |
| 4                              | 1.65 | 1.27 | 1.20 | 0.72 | 0.09 | NE                |
| <b>7-8 July ,1966</b>          |      |      |      |      |      |                   |
| 5                              | 1.24 | 1.04 | 0.95 | 0.78 | 0.07 | NE                |
| 6                              | 1.56 | 1.07 | 0.98 | 0.70 | 0.09 | NE                |
| 7                              | 1.53 | 1.24 | 1.14 | 0.88 | 0.09 | V                 |
| 8                              | 5.50 | 4.46 | 3.84 | 3.28 | 0.72 | SW                |
| 9                              | 5.28 | 4.48 | 3.75 | 3.17 | 0.70 | SW                |
| 10                             | 5.49 | 4.71 | 4.08 | 3.45 | 0.75 | SW                |
| 11                             | 4.74 | 4.18 | 3.67 | 3.00 | 0.98 | W                 |
| 12                             | 3.25 | 2.89 | 2.47 | 2.11 | 0.79 | SW                |
| 13                             | 3.64 | 3.21 | 2.73 | 2.37 | 0.72 | SW                |
| 14                             | 6.80 | 5.37 | 4.63 | 3.96 | 1.00 | SW                |
| 15                             | 7.25 | 6.03 | 5.12 | 4.50 | 1.05 | SW                |
| 16                             | 5.26 | 4.55 | 3.86 | 3.22 | 0.84 | W                 |
| 17                             | 4.24 | 3.45 | 2.78 | 2.24 | 0.58 | NW                |
| 18                             | 3.12 | 2.53 | 1.94 | 1.49 | 0.61 | NW                |
| 19                             | 2.93 | 2.39 | 2.02 | 1.60 | ---  | W                 |
| 20                             | 2.97 | 2.24 | 1.80 | 1.45 | ---  | W                 |
| 21                             | 2.60 | 1.87 | 1.49 | 1.19 | ---  | SW                |
| 22                             | 1.54 | 1.19 | 0.98 | 0.78 | ---  | SW                |
| 23                             | 2.11 | 1.41 | 1.20 | 0.85 | ---  | V                 |
| 24                             | 2.39 | 1.64 | 1.22 | 0.96 | ---  | NW                |
| 1                              | 3.15 | 2.20 | 1.63 | 1.22 | ---  | W                 |
| 2                              | 3.60 | 2.75 | 2.15 | 1.67 | ---  | W                 |
| 3                              | 2.02 | 1.50 | 1.13 | 0.85 | ---  | W                 |
| 4                              | 2.59 | 2.17 | 1.75 | 1.43 | ---  | SW                |

TABLE A1-1.—Hourly averages of windspeeds and wind direction at the Buckeye Project during selected periods of 3 days each—Continued

| 1-hr. period<br>beginning | 11m  | 7m   | 5m   | 4m   | 2m   | Wind<br>direction |
|---------------------------|------|------|------|------|------|-------------------|
| <b>8-9 July 1966</b>      |      |      |      |      |      |                   |
| 5                         | 1.86 | 1.32 | 1.10 | 0.82 | ---- | SW                |
| 6                         | 1.87 | 1.23 | 1.10 | 0.78 | ---- | W                 |
| 7                         | 2.06 | 1.73 | 1.51 | 1.20 | ---- | W                 |
| 8                         | 2.76 | 2.42 | 1.98 | 1.61 | ---- | W                 |
| 9                         | 2.24 | 1.95 | 1.76 | 1.52 | ---- | SW                |
| 10                        | 2.36 | 2.14 | 1.82 | 1.55 | 0.56 | SW                |
| 11                        | 2.72 | 2.32 | 2.05 | 1.77 | 0.48 | V                 |
| 12                        | 2.55 | 2.28 | 1.95 | 1.67 | 0.68 | SW                |
| 13                        | 3.25 | 2.78 | 2.25 | 2.00 | 0.78 | V                 |
| 14                        | 2.41 | 2.17 | 1.92 | 1.69 | 0.70 | SW                |
| 15                        | 3.33 | 2.91 | 2.43 | 2.05 | 0.73 | V                 |
| 16                        | 3.54 | 3.06 | 2.61 | 2.11 | 0.78 | SW                |
| 17                        | 4.08 | 3.45 | 2.94 | 2.49 | 0.64 | SW                |
| 18                        | 4.10 | 3.51 | 2.98 | 2.49 | 0.58 | SW                |
| 19                        | 3.18 | 2.60 | 2.18 | 1.76 | 0.78 | SW                |
| 20                        | 2.99 | 2.07 | 1.60 | 1.27 | 0.15 | W                 |
| 21                        | 2.87 | 2.07 | 1.54 | 1.21 | 0.15 | SW                |
| 22                        | 3.39 | 2.63 | 2.16 | 1.69 | 0.30 | W                 |
| 23                        | 3.64 | 2.97 | 2.42 | 1.98 | 0.40 | W                 |
| 24                        | 3.45 | 2.66 | 2.25 | 1.88 | ---- | W                 |
| 1                         | 2.98 | 2.14 | 1.75 | 1.40 | ---- | SW                |
| 2                         | 3.22 | 2.52 | 2.04 | 1.75 | ---- | SW                |
| 3                         | 3.21 | 2.49 | 2.12 | 1.78 | ---- | SW                |
| 4                         | 0.98 | 0.73 | 0.84 | 0.67 | ---- | SW                |
| <b>3-4 August 1966</b>    |      |      |      |      |      |                   |
| 5                         | 3.09 | 2.38 | 1.90 | 1.56 | 0.99 | W                 |
| 6                         | 2.79 | 2.07 | 1.74 | 1.35 | 0.44 | W                 |
| 7                         | 1.10 | 0.92 | 0.85 | 0.72 | 0.56 | W                 |
| 8                         | 1.75 | 1.61 | 1.33 | 1.07 | 0.46 | W                 |
| 9                         | 2.63 | 2.23 | 1.94 | 1.61 | 0.63 | W                 |
| 10                        | 2.50 | 2.00 | 1.66 | 1.41 | 0.50 | W                 |
| 11                        | 2.51 | 2.17 | 1.90 | 1.80 | 0.63 | SW                |
| 12                        | 2.91 | 2.53 | 2.18 | 1.92 | 0.57 | SW                |
| 13                        | 3.34 | 2.94 | 2.52 | 2.25 | 0.66 | SW                |
| 14                        | 3.97 | 3.33 | 2.85 | 2.47 | 0.71 | SW                |
| 15                        | 9.05 | 7.18 | 5.94 | 5.20 | 1.35 | SW                |
| 16                        | 9.17 | 7.31 | 6.06 | 5.32 | 1.35 | SW                |
| 17                        | 8.55 | 6.94 | 5.69 | 4.95 | 1.19 | SW                |
| 18                        | 7.06 | 5.57 | 4.58 | 3.96 | 0.99 | SW                |
| 19                        | 4.95 | 3.90 | 3.21 | 2.67 | 0.66 | SW                |
| 20                        | 4.21 | 3.31 | 2.72 | 2.30 | 0.74 | S                 |
| 21                        | 3.55 | 2.79 | 2.25 | 1.90 | 0.53 | S                 |
| 22                        | 3.26 | 2.57 | 2.11 | 1.69 | 0.47 | S                 |
| 23                        | 3.98 | 3.12 | 2.40 | 1.98 | 0.58 | SE                |
| 24                        | 4.08 | 3.14 | 2.51 | 2.04 | 0.58 | SE                |
| 1                         | 2.08 | 1.62 | 1.36 | 1.06 | 0.46 | E                 |
| 2                         | 2.62 | 2.06 | 1.61 | 1.22 | 0.57 | NE                |
| 3                         | 2.13 | 1.62 | 1.20 | 0.86 | 0.28 | NE                |
| 4                         | 2.42 | 1.64 | 1.43 | 1.05 | 0.30 | NE                |
| <b>4-5 August 1966</b>    |      |      |      |      |      |                   |
| 5                         | 2.21 | 1.65 | 1.19 | 0.83 | 0.27 | NE                |
| 6                         | 0.99 | 0.68 | 0.56 | 0.27 | 0.17 | NE                |
| 7                         | 1.55 | 1.28 | 1.07 | 0.90 | 0.32 | NE                |
| 8                         | 4.12 | 3.55 | 2.95 | 2.45 | 0.73 | SE                |
| 9                         | 2.45 | 1.99 | 1.69 | 1.45 | 0.67 | NE                |
| 10                        | 2.09 | 1.73 | 1.52 | 1.32 | 0.67 | V                 |
| 11                        | 1.62 | 1.38 | 1.29 | 1.19 | 0.61 | S                 |
| 12                        | 1.45 | 1.32 | 1.22 | 1.14 | 0.61 | S                 |
| 13                        | 1.96 | 1.70 | 1.51 | 1.40 | 0.62 | V                 |
| 14                        | 3.33 | 2.75 | 2.29 | 1.94 | 0.71 | NW                |
| 15                        | 3.58 | 2.99 | 2.50 | 2.13 | 0.66 | W                 |
| 16                        | 3.09 | 2.69 | 2.27 | 1.93 | 0.63 | W                 |
| 17                        | 3.58 | 3.03 | 2.59 | 2.27 | 0.64 | SW                |
| 18                        | 3.62 | 2.96 | 2.49 | 2.18 | 0.67 | W                 |
| 19                        | 3.21 | 2.50 | 1.89 | 1.54 | 0.40 | W                 |
| 20                        | 2.99 | 2.13 | 1.58 | 1.24 | 0.07 | SW                |
| 21                        | 3.06 | 2.35 | 1.87 | 1.55 | 0.46 | SW                |

TABLE A1-1.—Hourly averages of windspeeds and wind direction at the Buckeye Project during selected periods of 3 days each—Continued

| 1-hr. period<br>beginning        | 11m  | 7m   | 5m   | 4m   | 2m   | Wind<br>direction |
|----------------------------------|------|------|------|------|------|-------------------|
| <b>4-5 August 1966—Continued</b> |      |      |      |      |      |                   |
| 22                               | 3.11 | 2.49 | 2.05 | 1.64 | 0.58 | V                 |
| 23                               | 2.20 | 1.74 | 1.49 | 1.17 | 0.44 | NE                |
| 24                               | 4.22 | 3.31 | 2.69 | 2.21 | 0.73 | S                 |
| 1                                | 3.35 | 2.62 | 2.13 | 1.76 | 0.57 | S                 |
| 2                                | 2.11 | 1.63 | 1.23 | 0.99 | 0.46 | NE                |
| 3                                | 2.40 | 1.79 | 1.33 | 1.03 | 0.36 | NE                |
| 4                                | 1.49 | 1.05 | 0.93 | 0.67 | 0.21 | NE                |
| <b>5-6 August 1966</b>           |      |      |      |      |      |                   |
| 5                                | 1.23 | 0.76 | 0.65 | 0.28 | 0.21 | NE                |
| 6                                | 1.24 | 0.84 | 0.84 | 0.58 | 0.17 | N                 |
| 7                                | 1.00 | 0.88 | 0.82 | 0.74 | 0.24 | N                 |
| 8                                | 1.20 | 1.13 | 0.96 | 0.88 | 0.47 | NE                |
| 9                                | 1.76 | 1.50 | 1.23 | 1.07 | 0.55 | N                 |
| 10                               | 1.73 | 1.54 | 1.33 | 1.25 | 0.85 | V                 |
| 11                               | 3.08 | 2.48 | 2.05 | 1.73 | 0.66 | V                 |
| 12                               | 2.31 | 2.04 | 1.86 | 1.72 | 0.62 | V                 |
| 13                               | 2.18 | 1.93 | 1.74 | 1.63 | 0.61 | SW                |
| 14                               | 3.68 | 2.91 | 2.35 | 1.98 | 0.64 | NW                |
| 15                               | 3.75 | 3.03 | 2.54 | 2.11 | 0.63 | W                 |
| 16                               | 3.46 | 3.01 | 2.53 | 2.18 | 0.58 | W                 |
| 17                               | 3.15 | 2.69 | 2.28 | 2.10 | 0.55 | W                 |
| 18                               | 5.42 | 4.31 | 3.58 | 3.07 | 0.85 | SW                |
| 19                               | 7.26 | 5.63 | 4.62 | 3.98 | 1.04 | SW                |
| 20                               | 7.99 | 6.36 | 5.27 | 4.54 | 1.17 | SW                |
| 21                               | 6.55 | 5.39 | 4.54 | 3.88 | 0.90 | SW                |
| 22                               | 5.13 | 4.25 | 3.58 | 3.10 | 0.70 | SW                |
| 23                               | 5.94 | 4.95 | 4.21 | 3.64 | 0.82 | SW                |
| 24                               | 5.29 | 4.39 | 3.71 | 3.22 | 0.68 | SW                |
| 1                                | 2.85 | 2.23 | 1.89 | 1.52 | 0.47 | SW                |
| 2                                | 3.58 | 2.85 | 2.35 | 2.11 | 0.34 | SW                |
| 3                                | 1.07 | 0.75 | 0.92 | 0.45 | 0.21 | W                 |
| 4                                | 1.41 | 0.85 | 0.95 | 0.26 | 0.14 | W                 |
| <b>8-9 September 1966</b>        |      |      |      |      |      |                   |
| 5                                | 1.79 | 1.39 | 1.14 | 0.78 | 0.09 | E                 |
| 6                                | 2.05 | 1.55 | 1.15 | 0.85 | 0.09 | NE                |
| 7                                | 2.11 | 1.63 | 1.30 | 1.05 | 0.38 | NE                |
| 8                                | 3.75 | 2.81 | 2.13 | 1.67 | 0.77 | NE                |
| 9                                | 4.50 | 3.45 | 2.65 | 2.19 | 1.06 | NE                |
| 10                               | 4.73 | 3.74 | 3.03 | 2.59 | 1.18 | NE                |
| 11                               | 4.00 | 3.40 | 2.92 | 2.65 | 1.03 | NE                |
| 12                               | 2.89 | 2.47 | 2.15 | 1.89 | 0.81 | V                 |
| 13                               | 2.38 | 2.00 | 1.79 | 1.54 | 0.64 | V                 |
| 14                               | 2.70 | 2.21 | 1.93 | 1.62 | 0.75 | V                 |
| 15                               | 3.52 | 2.90 | 2.45 | 2.17 | 0.93 | NE                |
| 16                               | 2.87 | 2.49 | 2.06 | 1.82 | 0.73 | NE                |
| 17                               | 2.57 | 2.08 | 1.69 | 1.48 | 0.62 | NE                |
| 18                               | 2.04 | 1.51 | 1.22 | 0.95 | ---  | N                 |
| 19                               | 1.64 | 1.19 | 0.86 | 0.62 | ---  | N                 |
| 20                               | 0.60 | 0.48 | 0.68 | 0.34 | ---  | N                 |
| 21                               | 1.45 | 1.41 | 1.20 | 0.85 | ---  | NE                |
| 22                               | 1.57 | 1.41 | 1.21 | 0.84 | 0.17 | NE                |
| 23                               | 2.25 | 1.70 | 1.32 | 0.94 | 0.17 | V                 |
| 24                               | 2.76 | 1.93 | 1.54 | 1.17 | 0.66 | NE                |
| 1                                | 2.81 | 1.70 | 1.48 | 1.04 | 0.24 | NE                |
| 2                                | 2.81 | 1.81 | 1.49 | 1.07 | 0.17 | NE                |
| 3                                | 2.30 | 1.55 | 1.24 | 1.08 | 0.17 | E                 |
| 4                                | 2.63 | 1.76 | 1.43 | 1.03 | 0.36 | NE                |
| <b>9-10 September 1966</b>       |      |      |      |      |      |                   |
| 5                                | 3.11 | 2.01 | 1.73 | 1.27 | 0.76 | E                 |
| 6                                | 2.89 | 2.20 | 1.70 | 1.27 | 0.34 | NE                |
| 7                                | 2.92 | 2.25 | 1.70 | 1.38 | 0.52 | NE                |
| 8                                | 2.97 | 2.40 | 2.00 | 1.65 | 0.67 | NE                |
| 9                                | 3.58 | 2.95 | 2.40 | 2.06 | 0.89 | NE                |
| 10                               | 4.52 | 3.48 | 3.18 | 2.64 | 1.03 | NE                |
| 11                               | 3.33 | 2.88 | 2.45 | 2.11 | 0.89 | V                 |

TABLE A1-1.—Hourly averages of windspeeds and wind direction at the Buckeye Project during selected periods of 3 days each—Continued

| 1-hr. period<br>beginning            | 11m  | 7m   | 5m   | 4m   | 2m   | Wind<br>direction |
|--------------------------------------|------|------|------|------|------|-------------------|
| <b>9-10 September 1966—Continued</b> |      |      |      |      |      |                   |
| 12                                   | 3.75 | 3.04 | 2.54 | 2.17 | 0.79 | V                 |
| 13                                   | 2.53 | 2.23 | 1.98 | 1.80 | 0.76 | V                 |
| 14                                   | 3.10 | 2.57 | 2.27 | 1.95 | 0.78 | V                 |
| 15                                   | 3.60 | 2.92 | 2.36 | 1.99 | 0.85 | NE                |
| 16                                   | 3.88 | 3.20 | 2.69 | ---  | 1.04 | NE                |
| 17                                   | 3.09 | 2.55 | 2.08 | 1.82 | 0.77 | NE                |
| 18                                   | 2.76 | 2.08 | 1.54 | 1.20 | 0.42 | N                 |
| 19                                   | 1.88 | 1.44 | 1.04 | 0.86 | 0.17 | N                 |
| 20                                   | 1.82 | 1.42 | 1.10 | 0.89 | 0.11 | N                 |
| 21                                   | 1.87 | 1.17 | 1.05 | 0.72 | 0.11 | N                 |
| 22                                   | 2.95 | 1.77 | 1.52 | 1.02 | 0.11 | NE                |
| 23                                   | 2.29 | 1.70 | 1.36 | 1.02 | 0.48 | NE                |
| 24                                   | 2.80 | 2.04 | 1.54 | 1.18 | 0.66 | NE                |
| 1                                    | 2.27 | 1.51 | 1.32 | 0.92 | 0.11 | NE                |
| 2                                    | 1.57 | 1.31 | 1.03 | 0.90 | 0.11 | V                 |
| 3                                    | 2.45 | 2.05 | 1.28 | 0.85 | 0.11 | NE                |
| 4                                    | 3.30 | 2.08 | 1.74 | 1.22 | 0.11 | NE                |
| <b>10-11 September 1966</b>          |      |      |      |      |      |                   |
| 5                                    | 2.60 | 1.69 | 1.38 | 0.98 | 0.13 | E                 |
| 6                                    | 2.57 | 1.85 | 1.30 | 0.84 | 0.13 | E                 |
| 7                                    | 2.35 | 1.57 | 1.31 | 0.99 | 0.13 | NE                |
| 8                                    | 1.19 | 1.06 | 0.95 | 0.88 | 0.38 | NE                |
| 9                                    | 1.15 | 1.00 | 1.03 | 1.00 | 0.34 | NE                |
| 10                                   | 1.77 | 1.48 | 1.30 | 1.17 | 0.51 | SE                |
| 11                                   | 2.29 | 2.00 | 1.77 | 1.66 | 0.72 | V                 |
| 12                                   | 3.97 | 3.45 | 2.93 | 2.65 | 0.83 | SE                |
| 13                                   | 2.55 | 2.15 | 1.90 | 1.64 | 0.66 | SE                |
| 14                                   | 2.07 | 1.78 | 1.57 | 1.41 | 0.66 | V                 |
| 15                                   | 2.47 | 2.16 | 1.75 | 1.58 | 0.73 | NE                |
| 16                                   | 1.48 | 1.26 | 1.10 | 0.92 | 1.23 | NE                |
| 17                                   | 1.39 | 1.18 | 1.00 | 0.88 | 0.30 | N                 |
| 18                                   | 1.73 | 1.24 | 1.10 | 0.85 | 0.17 | N                 |
| 19                                   | 2.29 | 1.73 | 1.38 | 1.08 | 0.17 | NE                |
| 20                                   | 3.13 | 2.47 | 2.02 | 1.64 | 0.36 | V                 |
| 21                                   | 3.71 | 2.85 | 2.24 | 1.82 | 0.42 | SW                |
| 22                                   | 3.35 | 2.72 | 2.18 | 1.90 | 0.48 | SW                |
| 23                                   | 2.15 | 1.55 | 1.11 | 0.83 | 0.58 | W                 |
| 24                                   | 1.80 | 1.13 | 0.86 | 0.58 | 0.21 | W                 |
| 1                                    | 2.29 | 1.64 | 1.22 | 0.85 | 0.13 | W                 |
| 2                                    | 2.43 | 1.67 | 1.17 | 0.77 | 0    | W                 |
| 3                                    | 2.20 | 1.54 | 1.07 | 0.71 | 0    | NW                |
| 4                                    | 1.86 | 1.22 | 1.07 | 0.77 | 0    | V                 |
| <b>23-24 March 1967</b>              |      |      |      |      |      |                   |
| 5                                    | ---  | ---  | ---  | ---  | ---  | ---               |
| 6                                    | ---  | ---  | ---  | ---  | ---  | ---               |
| 7                                    | ---  | ---  | ---  | ---  | ---  | ---               |
| 8                                    | 2.62 | 2.07 | 1.63 | 1.40 | 0.75 | N                 |
| 9                                    | 2.97 | 2.53 | 2.29 | 2.04 | 1.74 | NE                |
| 10                                   | 3.14 | 2.60 | 2.21 | 1.95 | 1.60 | NE                |
| 11                                   | 1.60 | 1.30 | 1.04 | 1.38 | 0.90 | NE                |
| 12                                   | 1.59 | 1.45 | 1.31 | 1.26 | 0.76 | S                 |
| 13                                   | 1.48 | 1.32 | 1.20 | 1.17 | 0.70 | SE                |
| 14                                   | 2.07 | 1.76 | 1.54 | 1.43 | 0.57 | W                 |
| 15                                   | 3.09 | 2.35 | 1.89 | 1.52 | 0.71 | NW                |
| 16                                   | 2.47 | 2.00 | 1.73 | 1.51 | 0.56 | NW                |
| 17                                   | 1.60 | 1.21 | 0.99 | 0.80 | ---  | N                 |
| 18                                   | 1.51 | 1.05 | 0.84 | 0.63 | ---  | NW                |
| 19                                   | 1.81 | 1.42 | ---  | 0.85 | ---  | W                 |
| 20                                   | 1.89 | 1.48 | ---  | 0.95 | ---  | W                 |
| 21                                   | 3.30 | 2.44 | 1.76 | 1.42 | ---  | SW                |
| 22                                   | 4.55 | 3.06 | 1.99 | 1.25 | 0.67 | SW                |
| 23                                   | 4.11 | 2.85 | 1.54 | 1.00 | 0.61 | SW                |
| 24                                   | 2.20 | 1.60 | 1.14 | 0.80 | ---  | SW                |
| 1                                    | 1.79 | 1.48 | 1.18 | 1.07 | ---  | NW                |
| 2                                    | 1.28 | 1.10 | ---  | 0.93 | ---  | NW                |
| 3                                    | 1.17 | 1.10 | ---  | 0.89 | ---  | NE                |
| 4                                    | 1.36 | 1.13 | 1.05 | 0.94 | ---  | NE                |

TABLE A1-1.—Hourly averages of windspeeds and wind direction at the Buckeye Project during selected periods of 3 days each—Continued

| 1-hr. period<br>beginning | 11m  | 7m   | 5m   | 4m   | 2m   | Wind<br>direction |
|---------------------------|------|------|------|------|------|-------------------|
| <b>24-25 March 1967</b>   |      |      |      |      |      |                   |
| 5                         | 1.96 | 1.58 | 1.30 | 1.15 | ---- | V                 |
| 5                         | 1.96 | 1.58 | 1.30 | 1.15 | ---- | V                 |
| 6                         | 2.15 | 1.71 | ---- | 1.17 | ---- | SW                |
| 7                         | 1.59 | 1.30 | ---- | 0.85 | ---- | W                 |
| 8                         | 1.87 | 1.45 | ---- | 0.96 | ---- | NE                |
| 9                         | 1.60 | 1.30 | 1.08 | 0.96 | 0.84 | NE                |
| 10                        | 3.44 | 2.57 | 2.54 | 2.09 | 2.17 | SW                |
| 11                        | 4.58 | 3.04 | 2.96 | 3.02 | 1.14 | SW                |
| 12                        | 4.58 | 3.36 | 2.95 | 2.95 | 1.15 | SW                |
| 13                        | 4.34 | 2.97 | 3.06 | 2.95 | 1.20 | SW                |
| 14                        | 5.20 | 3.84 | 3.74 | 3.48 | 1.32 | SW                |
| 15                        | 5.57 | 4.76 | 4.24 | 3.90 | 1.57 | SW                |
| 16                        | 6.48 | 4.51 | 4.34 | 3.96 | 1.58 | SW                |
| 17                        | 5.69 | 3.69 | 3.90 | 3.65 | 1.32 | SW                |
| 18                        | 6.55 | 4.37 | 4.27 | 4.15 | 1.39 | W                 |
| 19                        | 4.70 | 3.50 | 2.96 | 2.75 | 0.79 | W                 |
| 20                        | 2.97 | 2.23 | 1.63 | 1.30 | ---- | W                 |
| 21                        | 2.85 | 2.12 | 1.70 | 1.40 | ---- | SW                |
| 22                        | 3.21 | 2.45 | 1.89 | 1.61 | ---- | SW                |
| 23                        | 3.77 | 2.98 | 2.35 | 2.05 | ---- | SW                |
| 24                        | 5.07 | 3.51 | 2.94 | 2.72 | 0.90 | SW                |
| 1                         | 5.51 | 4.21 | 2.65 | 3.10 | 1.22 | SW                |
| 2                         | 3.21 | 2.59 | 2.04 | 1.79 | ---- | SW                |
| 3                         | 2.23 | 1.83 | 1.55 | 1.35 | ---- | S                 |
| 4                         | 1.86 | 1.68 | 1.03 | 0.94 | ---- | SW                |
| <b>25-26 March 1967</b>   |      |      |      |      |      |                   |
| 5                         | 1.38 | 1.13 | 0.70 | 0.94 | ---- | SW                |
| 6                         | 2.48 | 1.69 | 1.03 | 0.95 | ---- | N                 |
| 7                         | 1.98 | 1.52 | 1.07 | 0.80 | ---- | NE                |
| 8                         | 1.58 | 1.13 | 1.07 | 1.07 | ---- | NE                |
| 9                         | 1.17 | 1.05 | 0.96 | 0.93 | 0.67 | NE                |
| 10                        | 1.35 | 1.28 | 1.22 | 1.18 | 0.67 | SW                |
| 11                        | 1.73 | 1.51 | 1.45 | 1.39 | 0.85 | S                 |
| 12                        | 2.12 | 1.69 | 1.73 | 1.60 | 0.64 | SW                |
| 13                        | 3.09 | 2.70 | 2.38 | 2.21 | 1.02 | SW                |
| 14                        | 3.21 | 2.75 | 2.33 | 2.17 | 1.06 | SW                |
| 15                        | 2.54 | 2.22 | 1.91 | 1.76 | 0.81 | SW                |
| 16                        | 2.62 | 2.14 | 1.86 | 1.66 | 0.84 | SW                |
| 17                        | 1.73 | 1.53 | 1.23 | 1.30 | ---- | W                 |
| 18                        | 1.48 | 1.17 | 0.98 | 0.86 | ---- | NW                |
| 19                        | 1.18 | 0.95 | ---- | 0.77 | ---- | W                 |
| 20                        | 0.84 | 0.68 | ---- | 0.67 | ---- | NW                |
| 21                        | 0.88 | 0.90 | ---- | 0.85 | ---- | W                 |
| 22                        | 2.23 | 1.84 | 1.46 | 1.18 | ---- | NE                |
| 23                        | 2.75 | 1.98 | 1.48 | 1.24 | ---- | E                 |
| 24                        | 2.92 | 2.24 | 1.77 | 1.41 | ---- | E                 |
| 1                         | 2.41 | 1.98 | 1.55 | 1.35 | ---- | E                 |
| 2                         | 2.26 | ---- | ---- | 1.03 | ---- | E                 |
| 3                         | 1.78 | ---- | ---- | 0.85 | ---- | E                 |
| 4                         | 2.18 | 1.58 | ---- | 0.99 | ---- | E                 |
| <b>11-12 May 1967</b>     |      |      |      |      |      |                   |
| 5                         | 2.11 | 1.28 | ---- | 0.78 | ---- | N                 |
| 6                         | 1.53 | 1.00 | ---- | 0.55 | ---- | N                 |
| 7                         | 0.77 | 0.62 | ---- | 0.42 | ---- | N                 |
| 8                         | 1.20 | 1.04 | ---- | 0.67 | 0.21 | N                 |
| 9                         | 2.38 | 2.04 | ---- | 1.54 | 0.46 | SW                |
| 10                        | ---- | 2.38 | ---- | 1.89 | 0.63 | SW                |
| 11                        | ---- | 2.85 | ---- | 1.78 | 0.73 | SW                |
| 12                        | ---- | 2.97 | ---- | 1.82 | 0.85 | SW                |
| 13                        | 3.99 | 3.30 | ---- | 2.38 | 0.78 | SW                |
| 14                        | 4.34 | 3.65 | ---- | 2.56 | 0.77 | W                 |
| 15                        | 3.71 | 3.05 | ---- | 2.23 | 0.76 | W                 |
| 16                        | 4.58 | 3.84 | ---- | 2.72 | 0.73 | W                 |

TABLE A1-1.—Hourly averages of windspeeds and wind direction at the Buckeye Project during selected periods of 3 days each—Continued

| 1-hr. period<br>beginning       | 11m  | 7m   | 5m    | 4m   | 2m    | Wind<br>direction |
|---------------------------------|------|------|-------|------|-------|-------------------|
| <b>11-12 May 1967—Continued</b> |      |      |       |      |       |                   |
| 17-----                         | 2.65 | 2.35 | ----- | 1.60 | 0.55  | W                 |
| 18-----                         | 2.94 | 2.41 | 1.99  | 1.76 | 0.44  | W                 |
| 19-----                         | 4.37 | 3.50 | 2.91  | 2.47 | 0.70  | SW                |
| 20-----                         | 4.88 | 3.96 | 3.28  | 2.78 | 0.77  | SW                |
| 21-----                         | 4.03 | 3.15 | 2.47  | 2.05 | 0.53  | SW                |
| 22-----                         | 2.85 | 2.24 | 1.71  | 1.45 | 0.21  | SW                |
| 23-----                         | 1.95 | 1.49 | 1.11  | 0.92 | 0.09  | NE                |
| 24-----                         | 2.11 | 1.73 | 1.44  | 1.24 | 0.13  | NE                |
| 1-----                          | 1.49 | 1.18 | 0.94  | 0.79 | 0.05  | NE                |
| 2-----                          | 1.15 | 1.10 | 0.92  | 0.85 | 0.09  | E                 |
| 3-----                          | 1.96 | 1.41 | 1.11  | 0.85 | ----- | E                 |
| 4-----                          | 1.60 | 1.25 | 0.94  | 0.82 | ----- | SE                |
| <b>12-13 May 1967</b>           |      |      |       |      |       |                   |
| 5-----                          | 2.95 | 2.05 | 1.52  | 1.15 | ----- | S                 |
| 6-----                          | 1.55 | 1.11 | 0.98  | 0.79 | ----- | SE                |
| 7-----                          | 1.89 | 1.80 | 1.60  | 1.22 | 0.46  | SE                |
| 8-----                          | 1.22 | 1.48 | 1.43  | 0.88 | 0.61  | SE                |
| 9-----                          | 1.04 | 1.15 | 1.03  | 0.93 | 0.62  | SE                |
| 10-----                         | 1.41 | 1.35 | 1.13  | 1.13 | 0.55  | V                 |
| 11-----                         | 2.68 | 2.35 | 2.03  | 1.90 | 0.73  | V                 |
| 12-----                         | 4.80 | 3.94 | 3.28  | 2.97 | 0.89  | SW                |
| 13-----                         | 4.50 | 3.64 | 3.21  | 2.78 | 0.88  | SW                |
| 14-----                         | 5.05 | 4.27 | 3.65  | 3.20 | 0.88  | SW                |
| 15-----                         | 5.12 | 4.27 | 3.58  | 3.27 | 0.90  | SW                |
| 16-----                         | 5.32 | 4.46 | 3.71  | 3.33 | 0.92  | SW                |
| 17-----                         | 5.87 | 4.88 | 4.12  | 3.51 | 0.90  | W                 |
| 18-----                         | 4.88 | 3.96 | 3.39  | 2.95 | 0.66  | W                 |
| 19-----                         | 4.95 | 3.88 | 3.16  | 2.72 | 0.61  | SW                |
| 20-----                         | 3.08 | 2.39 | 1.87  | 1.58 | 0.17  | SW                |
| 21-----                         | 2.60 | 1.76 | 1.21  | 0.88 | ----- | W                 |
| 22-----                         | 2.62 | 1.90 | 1.33  | 1.06 | ----- | W                 |
| 23-----                         | 3.37 | 2.42 | 1.79  | 1.28 | ----- | W                 |
| 24-----                         | 3.07 | 2.52 | 1.92  | 1.57 | ----- | SW                |
| 1-----                          | 2.76 | 2.03 | 1.57  | 1.23 | ----- | SW                |
| 2-----                          | 2.57 | 1.93 | 1.49  | 1.17 | ----- | W                 |
| 3-----                          | 3.77 | 2.79 | 2.24  | 1.87 | ----- | W                 |
| 4-----                          | 3.27 | 2.48 | 1.98  | 1.61 | ----- | W                 |
| <b>13-14 May 1967</b>           |      |      |       |      |       |                   |
| 5-----                          | 3.16 | 2.51 | 2.01  | 1.69 | ----- | W                 |
| 6-----                          | 3.08 | 2.40 | 1.95  | 1.63 | ----- | SW                |
| 7-----                          | 2.47 | 1.93 | 1.61  | 1.41 | ----- | SW                |
| 8-----                          | 4.78 | 3.87 | 3.25  | 2.78 | 0.66  | W                 |
| 9-----                          | 3.70 | 2.94 | 2.45  | 1.99 | 0.58  | W                 |
| 10-----                         | 3.71 | 3.21 | 2.85  | 2.58 | 0.66  | W                 |
| 11-----                         | 2.94 | 2.36 | 1.90  | 1.63 | 0.67  | SW                |
| 12-----                         | 5.57 | 4.34 | 3.71  | 3.08 | 1.06  | NW                |
| 13-----                         | 3.84 | 3.20 | 2.75  | 2.39 | 0.86  | NW                |
| 14-----                         | 5.50 | 4.14 | 3.19  | 2.60 | 0.93  | W                 |
| 15-----                         | 5.69 | 4.60 | 3.71  | 3.22 | 0.95  | W                 |
| 16-----                         | 5.20 | 4.40 | 3.84  | 3.45 | 0.92  | W                 |
| 17-----                         | 5.30 | 4.46 | 3.84  | 3.39 | 0.82  | W                 |
| 18-----                         | 5.05 | 4.60 | 3.88  | 3.33 | 0.82  | W                 |
| 19-----                         | 4.92 | 4.08 | 3.45  | 3.00 | 0.68  | W                 |
| 20-----                         | 3.98 | 3.27 | 2.82  | 2.44 | 0.45  | W                 |
| 21-----                         | 3.61 | 2.97 | 2.50  | 2.11 | 0.30  | W                 |
| 22-----                         | 3.80 | 3.08 | 2.54  | 2.16 | 0.32  | W                 |
| 23-----                         | 3.70 | 2.97 | 2.40  | 2.03 | 0.28  | W                 |
| 24-----                         | 3.33 | 2.47 | 1.83  | 1.53 | ----- | W                 |
| 1-----                          | 1.60 | 1.26 | 1.02  | 0.94 | ----- | W                 |
| 2-----                          | 1.73 | 1.39 | 1.13  | 0.92 | ----- | V                 |
| 3-----                          | 1.40 | 1.13 | 0.98  | 0.86 | ----- | E                 |
| 4-----                          | 1.41 | 1.35 | 1.05  | 0.92 | ----- | E                 |

TABLE A2-1. Hourly averages of air temperature and vapor pressure at the Buckeye Project during selected periods of 3 days each

[Air temperature in degrees Celsius (°C), vapor pressure in millibars (mb)\* at indicated levels (meters) above ground. 1 mb = 100 pascal (Pa)]

| 1-hr period<br>beginning | 11m  |      | 7m   |      | 5m   |      | 4m   |      | 2m   |      |
|--------------------------|------|------|------|------|------|------|------|------|------|------|
|                          | °C   | mb   | °C   | mb   | °C   | mb   | °C   | mb   | °C   | mb   |
| <b>5-6 May 1966</b>      |      |      |      |      |      |      |      |      |      |      |
| 5                        | 18.9 | 11.3 | 18.0 | 11.5 | 17.7 | 11.6 | 17.0 | 11.7 | 14.3 | 12.6 |
| 6                        | 20.8 | 11.0 | 19.5 | 11.3 | 19.1 | 11.5 | 18.5 | 11.6 | 15.5 | 13.3 |
| 7                        | 22.6 | 11.7 | 22.8 | 11.8 | 22.8 | 11.9 | 22.6 | 12.0 | 21.4 | 13.8 |
| 8                        | 26.2 | 12.1 | 26.3 | 12.4 | 26.4 | 12.6 | 26.4 | 12.7 | 26.4 | 14.8 |
| 9                        | 29.5 | 10.7 | 29.6 | 11.6 | 29.7 | 12.3 | 30.0 | 12.8 | 30.6 | 14.8 |
| 10                       | 31.6 | 10.6 | 32.0 | 11.3 | 32.5 | 11.8 | 33.0 | 12.1 | 34.7 | 14.8 |
| 11                       | 33.4 | 11.3 | 33.5 | 12.5 | 34.2 | 13.4 | 34.7 | 13.9 | 37.4 | 15.8 |
| 12                       | 34.4 | 10.0 | 35.1 | 11.4 | 35.3 | 12.5 | 36.4 | 13.2 | 38.6 | 15.5 |
| 13                       | 35.1 | 10.2 | 35.3 | 11.6 | 36.3 | 12.6 | 36.1 | 13.3 | 38.3 | 15.7 |
| 14                       | 35.8 | 9.2  | 35.6 | 11.0 | 36.2 | 12.5 | 36.7 | 13.5 | 37.3 | 16.4 |
| 15                       | 36.1 | 10.5 | 36.9 | 11.5 | 36.5 | 12.3 | 36.8 | 12.8 | 37.7 | 14.5 |
| 16                       | 36.4 | 10.3 | 36.4 | 11.6 | 37.0 | 12.6 | 36.7 | 13.5 | 38.2 | 15.4 |
| 17                       | 35.9 | 10.6 | 36.3 | 11.3 | 36.1 | 11.7 | 35.7 | 12.1 | 35.7 | 15.0 |
| 18                       | 34.7 | 11.0 | 34.2 | 11.6 | 33.7 | 12.1 | 33.2 | 12.3 | 32.3 | 15.1 |
| 19                       | 32.6 | 11.2 | 32.1 | 11.9 | 31.7 | 12.4 | 30.9 | 12.8 | 27.7 | 16.4 |
| 20                       | 31.2 | 10.8 | 30.5 | 11.5 | 29.3 | 12.0 | 28.6 | 12.3 | 23.8 | 15.9 |
| 21                       | 31.0 | 10.8 | 29.7 | 11.3 | 29.1 | 11.7 | 28.3 | 12.0 | 24.6 | 14.9 |
| 22                       | 31.1 | 9.2  | 30.8 | 9.5  | 30.4 | 9.7  | 30.6 | 9.8  | 28.5 | 12.4 |
| 23                       | 27.2 | 10.4 | 26.8 | 10.8 | 26.1 | 11.1 | 25.7 | 11.2 | 23.8 | 13.4 |
| 24                       | 25.9 | 10.6 | 24.8 | 10.8 | 24.0 | 10.9 | 23.8 | 11.0 | 19.0 | 14.4 |
| 1                        | 25.9 | 10.3 | 24.4 | 10.7 | 23.5 | 11.1 | 23.0 | 11.3 | 17.9 | 13.4 |
| 2                        | 24.4 | 10.4 | 22.8 | 10.6 | 22.0 | 10.8 | 21.5 | 10.9 | 16.3 | 13.2 |
| 3                        | 24.4 | 10.5 | 23.8 | 11.0 | 23.4 | 11.2 | 21.3 | 11.3 | 15.5 | 12.5 |
| 4                        | 22.3 | 10.6 | 20.2 | 10.8 | 19.4 | 10.9 | 19.0 | 11.0 | 14.9 | 12.6 |
| <b>6-7 May 1966</b>      |      |      |      |      |      |      |      |      |      |      |
| 5                        | 21.3 | 10.7 | 19.7 | 10.8 | 19.1 | 10.9 | 18.2 | 11.0 | 13.6 | 12.2 |
| 6                        | 19.8 | 9.9  | 19.3 | 10.1 | 18.8 | 10.2 | 18.5 | 10.3 | 14.8 | 12.0 |
| 7                        | 23.1 | 11.0 | 22.7 | 11.8 | 23.0 | 12.4 | 22.4 | 12.8 | 20.9 | 15.4 |
| 8                        | 24.3 | 12.8 | 24.1 | 13.4 | 24.5 | 13.9 | 23.9 | 14.2 | 24.3 | 16.1 |
| 9                        | 26.9 | 10.9 | 27.1 | 11.4 | 27.2 | 11.8 | 27.3 | 12.1 | 28.4 | 14.5 |
| 10                       | 29.2 | 10.7 | 29.7 | 11.6 | 29.4 | 12.3 | 30.3 | 12.7 | 31.2 | 15.0 |
| 11                       | 31.9 | 11.8 | 31.6 | 12.8 | 32.1 | 13.5 | 32.2 | 13.9 | 34.1 | 16.7 |
| 12                       | 33.8 | 11.0 | 34.2 | 12.2 | 34.4 | 13.2 | 33.8 | 13.9 | 35.9 | 18.0 |
| 13                       | 34.8 | 10.2 | 35.6 | 11.4 | 36.1 | 12.2 | 36.3 | 12.8 | 38.1 | 16.4 |
| 14                       | 36.3 | 10.4 | 35.7 | 11.9 | 35.7 | 12.4 | 36.5 | 13.7 | 38.0 | 17.9 |
| 15                       | 36.4 | 9.0  | 36.5 | 10.8 | 36.7 | 12.2 | 36.9 | 13.2 | 37.7 | 16.6 |
| 16                       | 36.5 | 10.5 | 36.8 | 11.7 | 36.5 | 12.2 | 36.1 | 13.4 | 37.2 | 16.8 |
| 17                       | 36.5 | 10.8 | 36.8 | 11.9 | 36.3 | 12.7 | 35.7 | 13.2 | 35.9 | 17.1 |
| 18                       | 35.6 | 11.5 | 35.5 | 13.1 | 35.1 | 14.4 | 34.3 | 15.2 | 32.4 | 20.0 |
| 19                       | 34.2 | 12.1 | 33.2 | 13.3 | 32.4 | 14.2 | 31.7 | 14.8 | 26.3 | 19.5 |
| 20                       | 31.9 | 12.1 | 30.0 | 13.1 | 29.3 | 14.0 | 29.0 | 14.4 | 22.4 | 17.0 |
| 21                       | 30.4 | 11.0 | 29.6 | 11.6 | 29.0 | 12.0 | 28.5 | 12.4 | 20.4 | 15.8 |
| 22                       | 29.2 | 11.3 | 27.1 | 11.9 | 25.7 | 12.3 | 24.3 | 12.6 | 18.9 | 15.4 |
| 23                       | 26.8 | 11.1 | 23.9 | 11.6 | 23.1 | 12.0 | 22.3 | 12.3 | 17.8 | 14.6 |
| 24                       | 23.9 | 12.5 | 22.8 | 13.0 | 22.2 | 13.3 | 22.3 | 13.5 | 17.3 | 14.8 |
| 1                        | 27.1 | 10.0 | 26.0 | 10.4 | 24.8 | 10.6 | 23.8 | 10.8 | 18.6 | 13.8 |
| 2                        | 23.6 | 10.3 | 21.9 | 10.8 | 21.8 | 11.2 | 22.9 | 11.4 | 18.1 | 13.3 |
| 3                        | 22.6 | 10.2 | 21.5 | 10.5 | 20.4 | 10.7 | 19.7 | 10.8 | 15.7 | 13.0 |
| 4                        | 21.1 | 10.4 | 19.1 | 10.6 | 18.6 | 10.8 | 16.9 | 10.9 | 14.1 | 12.5 |
| <b>7-8 May 1966</b>      |      |      |      |      |      |      |      |      |      |      |
| 5                        | 21.9 | 9.4  | 20.4 | 9.6  | 19.7 | 9.8  | 19.1 | 9.9  | 14.5 | 11.8 |
| 6                        | 21.3 | 9.4  | 19.4 | 10.0 | 19.2 | 10.4 | 18.0 | 10.7 | 15.2 | 12.7 |
| 7                        | 21.0 | 12.0 | 20.9 | 12.6 | 20.9 | 13.1 | 20.4 | 13.4 | 20.1 | 15.3 |
| 8                        | 23.6 | 11.8 | 23.8 | 12.8 | 23.9 | 13.6 | 23.5 | 14.1 | 23.6 | 16.3 |
| 9                        | 27.7 | 11.1 | 27.8 | 12.3 | 27.7 | 13.3 | 27.3 | 13.9 | 27.9 | 18.3 |
| 10                       | 30.7 | 10.5 | 31.2 | 12.0 | 30.9 | 13.1 | 30.4 | 13.8 | 31.2 | 18.7 |
| 11                       | 33.3 | 10.9 | 33.0 | 11.9 | 33.5 | 12.5 | 32.7 | 13.0 | 33.6 | 18.3 |
| 12                       | 35.0 | 10.5 | 34.2 | 12.5 | 34.8 | 14.0 | 33.9 | 15.0 | 35.0 | 16.5 |
| 13                       | 35.6 | 9.7  | 36.3 | 11.0 | 36.3 | 11.8 | 36.5 | 12.5 | 35.8 | 19.9 |
| 14                       | 36.4 | 9.3  | 37.6 | 10.5 | 37.9 | 11.4 | 37.0 | 12.0 | 39.3 | 18.0 |
| 15                       | 36.9 | 9.9  | 36.6 | 11.3 | 37.1 | 12.4 | 36.8 | 13.1 | 37.5 | 20.0 |
| 16                       | 37.3 | 8.6  | 36.6 | 10.1 | 36.8 | 11.3 | 36.0 | 12.1 | 36.3 | 16.8 |
| 17                       | 37.1 | 9.3  | 36.3 | 10.4 | 36.0 | 11.3 | 36.2 | 11.8 | 35.9 | 16.7 |
| 18                       | 35.6 | 9.3  | 35.1 | 10.6 | 34.8 | 11.6 | 34.3 | 12.3 | 33.2 | 16.4 |
| 19                       | 33.2 | 11.4 | 32.8 | 12.0 | 32.3 | 12.4 | 32.0 | 12.7 | 29.8 | 16.0 |
| 20                       | 31.3 | 10.8 | 30.3 | 11.4 | 30.0 | 11.9 | 29.5 | 12.3 | 26.4 | 15.6 |
| 21                       | 30.3 | 10.3 | 28.8 | 10.9 | 28.0 | 11.3 | 27.4 | 11.6 | 24.1 | 14.0 |

TABLE A2-1. Hourly averages of air temperature and vapor pressure at the Buckeye Project during selected periods of 3 days each.—Continued

| 1-hr period<br>beginning      | 11m  |      | 7m   |      | 5m   |      | 4m   |      | 2m   |      |
|-------------------------------|------|------|------|------|------|------|------|------|------|------|
|                               | °C   | mb   | °C   | mb   | °C   | mb   | °C   | mb   | °C   | mb   |
| <b>7-8 May 1966—Continued</b> |      |      |      |      |      |      |      |      |      |      |
| 22 -----                      | 31.2 | 7.9  | 30.9 | 8.3  | 30.2 | 8.6  | 30.1 | 8.8  | 27.7 | 11.6 |
| 23 -----                      | 30.7 | 7.5  | 30.4 | 8.0  | 30.3 | 8.4  | 30.0 | 8.7  | 28.2 | 11.5 |
| 24 -----                      | 28.5 | 7.9  | 27.9 | 8.4  | 27.6 | 8.7  | 27.3 | 9.0  | 25.3 | 11.5 |
| 1 -----                       | 28.0 | 8.1  | 27.3 | 8.4  | 27.0 | 8.7  | 26.6 | 8.8  | 24.3 | 11.0 |
| 2 -----                       | 26.7 | 8.2  | 25.5 | 8.7  | 24.7 | 9.1  | 24.5 | 9.3  | 21.0 | 12.0 |
| 3 -----                       | 24.5 | 9.7  | 23.1 | 9.9  | 22.4 | 10.0 | 22.7 | 10.1 | 19.1 | 12.8 |
| 4 -----                       | 25.4 | 11.0 | 23.1 | 11.6 | 21.8 | 12.0 | 21.3 | 12.3 | 18.4 | 14.4 |
| <b>3-4 June 1966</b>          |      |      |      |      |      |      |      |      |      |      |
| 5 -----                       | 18.8 | 6.1  | 17.2 | 6.4  | 16.5 | 6.6  | 15.4 | 6.7  | 8.8  | 8.0  |
| 6 -----                       | 16.4 | 6.0  | 16.0 | 6.4  | 15.5 | 6.7  | 14.6 | 6.9  | 10.9 | 8.4  |
| 7 -----                       | 18.1 | 6.8  | 18.3 | 7.3  | 18.3 | 7.7  | 17.7 | 8.0  | 16.9 | 9.3  |
| 8 -----                       | 21.7 | 6.6  | 22.0 | 7.4  | 22.0 | 8.0  | 21.8 | 8.4  | 22.2 | 10.2 |
| 9 -----                       | 25.3 | 6.6  | 25.6 | 7.5  | 25.7 | 8.1  | 25.6 | 8.5  | 26.2 | 9.5  |
| 10 -----                      | 28.7 | 6.3  | 29.0 | 7.4  | 28.9 | 8.3  | 29.0 | 8.8  | 29.6 | 9.6  |
| 11 -----                      | 31.2 | 5.4  | 31.3 | 6.2  | 31.7 | 6.8  | 31.4 | 7.2  | 31.9 | 9.4  |
| 12 -----                      | 33.1 | 4.9  | 33.0 | 6.0  | 33.5 | 6.8  | 33.2 | 7.4  | 34.6 | 10.1 |
| 13 -----                      | 34.3 | 3.3  | 34.1 | 4.6  | 34.5 | 5.5  | 34.6 | 6.2  | 35.3 | 8.7  |
| 14 -----                      | 34.5 | 3.2  | 34.5 | 4.4  | 34.6 | 5.1  | 34.9 | 5.7  | 35.4 | 8.5  |
| 15 -----                      | 34.9 | 3.3  | 35.3 | 4.3  | 35.7 | 5.1  | 35.2 | 5.6  | 35.8 | 7.8  |
| 16 -----                      | 35.0 | 3.1  | 35.2 | 4.6  | 35.8 | 5.7  | 35.5 | 6.4  | 35.4 | 8.1  |
| 17 -----                      | 35.2 | 3.0  | 35.6 | 4.1  | 35.4 | 5.1  | 35.3 | 5.6  | 34.5 | 7.0  |
| 18 -----                      | 34.7 | 3.5  | 34.9 | 4.9  | 34.8 | 5.9  | 34.1 | 6.5  | 32.4 | 7.4  |
| 19 -----                      | 32.5 | 4.6  | 32.2 | 5.9  | 32.1 | 6.9  | 31.0 | 7.5  | 28.0 | 8.0  |
| 20 -----                      | 28.5 | 5.2  | 27.4 | 6.5  | 26.6 | 7.5  | 25.9 | 8.1  | 20.5 | 9.8  |
| 21 -----                      | 27.3 | 5.6  | 25.7 | 6.0  | 25.0 | 6.3  | 24.2 | 6.4  | 17.9 | 8.7  |
| 22 -----                      | 24.3 | 5.6  | 23.0 | 6.1  | 21.6 | 6.5  | 20.8 | 6.7  | 15.9 | 8.1  |
| 23 -----                      | 23.9 | 6.1  | 22.3 | 6.3  | 20.4 | 6.5  | 19.7 | 6.6  | 13.8 | 7.8  |
| 24 -----                      | 23.5 | 5.4  | 21.8 | 5.6  | 20.4 | 5.8  | 18.8 | 5.9  | 11.3 | 9.1  |
| 1 -----                       | 22.7 | 4.3  | 22.0 | 4.5  | 20.8 | 4.7  | 19.3 | 4.8  | 10.0 | 7.4  |
| 2 -----                       | 22.7 | 4.3  | 20.1 | 4.4  | 18.8 | 4.5  | 18.5 | 4.6  | 11.0 | 6.2  |
| 3 -----                       | 21.4 | 4.4  | 20.0 | 4.6  | 18.2 | 4.8  | 16.8 | 4.9  | 9.8  | 6.4  |
| 4 -----                       | 21.2 | 4.4  | 19.8 | 4.7  | 16.2 | 5.5  | 14.6 | 5.8  | 10.0 | 7.3  |
| <b>4-5 June 1966</b>          |      |      |      |      |      |      |      |      |      |      |
| 5 -----                       | 19.5 | 4.9  | 18.3 | 5.3  | 17.3 | 5.6  | 16.4 | 5.8  | 8.8  | 8.4  |
| 6 -----                       | 17.7 | 5.7  | 16.7 | 6.4  | 16.8 | 6.9  | 16.2 | 7.3  | 10.6 | 8.2  |
| 7 -----                       | 18.1 | 7.3  | 18.2 | 7.9  | 18.1 | 8.3  | 17.7 | 8.6  | 17.6 | 9.6  |
| 8 -----                       | 21.7 | 7.0  | 22.0 | 7.7  | 22.0 | 8.3  | 21.8 | 8.7  | 22.1 | 9.6  |
| 9 -----                       | 25.6 | 6.9  | 25.9 | 7.5  | 25.8 | 8.0  | 25.5 | 8.3  | 26.7 | 9.9  |
| 10 -----                      | 28.7 | 6.2  | 29.1 | 7.7  | 29.1 | 8.8  | 29.0 | 9.6  | 29.9 | 10.9 |
| 11 -----                      | 31.2 | 6.9  | 31.4 | 8.3  | 30.8 | 9.2  | 31.0 | 9.9  | 32.5 | 10.1 |
| 12 -----                      | 32.5 | 6.2  | 32.1 | 7.1  | 32.8 | 7.7  | 32.7 | 8.2  | 34.2 | 9.1  |
| 13 -----                      | 33.6 | 4.8  | 34.0 | 6.2  | 34.7 | 7.3  | 34.4 | 8.0  | 35.9 | 8.4  |
| 14 -----                      | 34.8 | 4.4  | 34.7 | 6.0  | 35.7 | 7.2  | 35.1 | 8.0  | 36.5 | 10.4 |
| 15 -----                      | 36.0 | 3.8  | 35.6 | 5.4  | 35.9 | 7.1  | 35.3 | 8.1  | 36.4 | 8.1  |
| 16 -----                      | 35.7 | 3.7  | 36.1 | 5.5  | 36.3 | 6.8  | 35.7 | 7.7  | 36.0 | 10.3 |
| 17 -----                      | 35.5 | 3.3  | 36.4 | 5.0  | 36.3 | 6.4  | 35.5 | 7.3  | 35.1 | 7.9  |
| 18 -----                      | 35.2 | 4.4  | 35.5 | 5.5  | 35.4 | 6.4  | 34.5 | 6.9  | 32.8 | 8.0  |
| 19 -----                      | 33.2 | 5.3  | 32.9 | 6.1  | 32.7 | 6.8  | 31.7 | 7.1  | 28.3 | 8.4  |
| 20 -----                      | 31.3 | 4.8  | 29.8 | 5.8  | 28.7 | 6.7  | 27.6 | 7.2  | 22.1 | 8.9  |
| 21 -----                      | 28.3 | 5.4  | 26.5 | 6.3  | 25.3 | 7.0  | 23.9 | 7.4  | 18.2 | 9.6  |
| 22 -----                      | 25.1 | 7.2  | 23.4 | 7.4  | 22.8 | 7.5  | 21.5 | 7.6  | 15.6 | 9.2  |
| 23 -----                      | 24.9 | 5.3  | 24.2 | 5.9  | 21.1 | 6.4  | 20.0 | 6.7  | 14.8 | 8.3  |
| 24 -----                      | 24.2 | 6.7  | 20.9 | 7.0  | 19.9 | 7.1  | 19.0 | 7.4  | 13.5 | 8.5  |
| 1 -----                       | 23.2 | 6.3  | 20.5 | 6.9  | 19.0 | 7.3  | 17.6 | 7.4  | 12.3 | 9.0  |
| 2 -----                       | 23.1 | 4.3  | 21.6 | 4.8  | 18.5 | 5.2  | 17.1 | 5.5  | 11.1 | 9.0  |
| 3 -----                       | 21.5 | 6.0  | 18.1 | 6.2  | 16.7 | 6.4  | 15.3 | 6.5  | 11.9 | 7.8  |
| 4 -----                       | 21.9 | 5.7  | 20.7 | 6.0  | 19.3 | 6.2  | 17.4 | 6.3  | 10.7 | 8.7  |
| <b>5-6 June 1966</b>          |      |      |      |      |      |      |      |      |      |      |
| 5 -----                       | 23.0 | 6.4  | 20.7 | 6.6  | 19.3 | 6.7  | 18.4 | 6.8  | 10.6 | 8.8  |
| 6 -----                       | 20.6 | 8.1  | 17.0 | 8.3  | 16.1 | 8.5  | 15.5 | 8.6  | 11.8 | 9.8  |
| 7 -----                       | 20.5 | 8.6  | 20.4 | 9.2  | 20.3 | 9.7  | 19.7 | 10.0 | 19.2 | 11.5 |
| 8 -----                       | 23.3 | 8.4  | 23.6 | 9.1  | 23.5 | 9.6  | 23.1 | 9.9  | 23.6 | 10.8 |
| 9 -----                       | 27.4 | 8.3  | 27.7 | 9.4  | 27.4 | 10.2 | 27.2 | 10.7 | 28.0 | 12.8 |
| 10 -----                      | 29.7 | 9.1  | 29.8 | 10.0 | 30.0 | 10.1 | 30.1 | 11.0 | 30.7 | 12.1 |
| 11 -----                      | 31.3 | 8.0  | 32.0 | 9.4  | 31.7 | 10.4 | 31.6 | 11.0 | 33.0 | 14.4 |
| 12 -----                      | 33.7 | 8.2  | 34.1 | 9.0  | 34.8 | 9.5  | 34.7 | 9.9  | 35.6 | 11.1 |

TABLE A2-1. Hourly averages of air temperature and vapor pressure at the Buckeye Project during selected periods of 3 days each.—Continued

| 1-hr period<br>beginning | 11m  |      | 7m   |      | 5m   |      | 4m   |      | 2m   |      |
|--------------------------|------|------|------|------|------|------|------|------|------|------|
|                          | °C   | mb   | °C   | mb   | °C   | mb   | °C   | mb   | °C   | mb   |
| 5-6 June 1966—Continued  |      |      |      |      |      |      |      |      |      |      |
| 13 -----                 | 35.3 | 5.7  | 35.4 | 7.0  | 36.1 | 8.1  | 35.3 | 8.7  | 33.7 | 12.7 |
| 14 -----                 | 36.1 | 4.0  | 36.1 | 5.6  | 36.4 | 6.9  | 36.4 | 7.7  | 37.4 | 10.8 |
| 15 -----                 | 36.5 | 4.1  | 36.7 | 5.4  | 36.8 | 6.7  | 36.3 | 7.5  | 37.4 | 10.2 |
| 16 -----                 | 36.9 | 4.1  | 36.6 | 5.5  | 36.7 | 6.5  | 36.4 | 7.2  | 37.0 | 8.0  |
| 17 -----                 | 36.4 | 3.5  | 36.5 | 5.5  | 36.6 | 6.9  | 35.8 | 8.0  | 35.2 | 9.2  |
| 18 -----                 | 35.1 | 5.3  | 35.2 | 6.5  | 35.0 | 7.4  | 33.8 | 7.9  | 31.8 | 9.5  |
| 19 -----                 | 32.5 | 7.5  | 31.9 | 8.5  | 31.6 | 9.0  | 30.6 | 9.6  | 26.6 | 11.4 |
| 20 -----                 | 31.2 | 7.4  | 29.8 | 8.1  | 29.3 | 8.5  | 28.4 | 9.0  | 21.4 | 11.8 |
| 21 -----                 | 28.7 | 6.9  | 27.2 | 7.6  | 26.0 | 8.1  | 25.1 | 8.5  | 18.6 | 11.1 |
| 22 -----                 | 26.7 | 7.2  | 25.1 | 7.7  | 24.1 | 8.1  | 23.4 | 8.3  | 16.6 | 10.9 |
| 23 -----                 | 25.2 | 7.3  | 24.5 | 7.6  | 23.7 | 7.9  | 23.0 | 8.1  | 15.8 | 9.6  |
| 24 -----                 | 25.1 | 7.0  | 24.0 | 7.1  | 21.8 | 7.3  | 20.7 | 7.4  | 13.9 | 9.5  |
| 1 -----                  | 23.5 | 6.5  | 22.7 | 6.8  | 22.3 | 6.9  | 20.4 | 7.1  | 13.0 | 8.7  |
| 2 -----                  | 22.8 | 5.2  | 21.1 | 5.8  | 20.3 | 6.1  | 18.9 | 6.4  | 13.5 | 7.7  |
| 3 -----                  | 21.2 | 5.8  | 18.9 | 6.3  | 17.7 | 6.7  | 16.7 | 6.9  | 11.8 | 8.7  |
| 4 -----                  | 21.6 | 6.0  | 20.0 | 6.5  | 19.4 | 6.9  | 18.7 | 7.1  | 11.3 | 9.1  |
| 6-7 July 1966            |      |      |      |      |      |      |      |      |      |      |
| 5 -----                  | 20.6 | 5.3  | 18.3 | 6.2  | 18.7 | 5.2  | 16.9 | 6.2  | 12.2 | 7.5  |
| 6 -----                  | 19.7 | 6.6  | 18.7 | 6.6  | 18.5 | 6.8  | 17.6 | 7.3  | 14.4 | 8.1  |
| 7 -----                  | 22.5 | 8.7  | 22.4 | 8.3  | 22.3 | 8.4  | 22.0 | 8.9  | 21.2 | 10.1 |
| 8 -----                  | 27.8 | 7.1  | 27.6 | 7.9  | 27.8 | 7.9  | 27.3 | 9.3  | 26.8 | 10.0 |
| 9 -----                  | 32.0 | 5.9  | 31.7 | 6.4  | 32.3 | 6.5  | 31.0 | 8.3  | 31.5 | 9.6  |
| 10 -----                 | 35.5 | 7.3  | 35.5 | 8.0  | 35.8 | 8.2  | 35.5 | 9.0  | 35.5 | 10.2 |
| 11 -----                 | 38.6 | 4.8  | 38.6 | 5.9  | 38.9 | 6.6  | 38.4 | 8.4  | 39.2 | 9.7  |
| 12 -----                 | 40.4 | 2.5  | 40.6 | 4.5  | 40.8 | 5.6  | 40.9 | 7.6  | 42.3 | 8.6  |
| 13 -----                 | 42.2 | 5.0  | 40.2 | 6.0  | 42.5 | 6.7  | 41.9 | 7.5  | 43.9 | 6.9  |
| 14 -----                 | 41.8 | 4.4  | 42.0 | 5.7  | 42.7 | 7.0  | 43.1 | 7.8  | 45.3 | 6.2  |
| 15 -----                 | 42.5 | 4.2  | 42.8 | 5.8  | 43.3 | 7.0  | 43.1 | 8.5  | 44.7 | 6.8  |
| 16 -----                 | 42.6 | 6.0  | 42.8 | 7.2  | 43.2 | 8.0  | 42.7 | 9.0  | 42.2 | 8.0  |
| 17 -----                 | 42.2 | 6.4  | 42.5 | 7.4  | 42.4 | 7.5  | 42.3 | 8.7  | 41.1 | 8.6  |
| 18 -----                 | 41.4 | 5.9  | 41.2 | 7.6  | 41.0 | 8.0  | 40.9 | 9.4  | 38.5 | 9.3  |
| 19 -----                 | 40.1 | 5.8  | 39.8 | 7.1  | 39.4 | 8.0  | 38.9 | 8.7  | 36.0 | 8.3  |
| 20 -----                 | 38.7 | 5.7  | 37.4 | 7.3  | 36.7 | 7.9  | 36.2 | 8.6  | 32.7 | 8.1  |
| 21 -----                 | 37.4 | 6.7  | 36.0 | 7.8  | 35.4 | 8.1  | 34.8 | 8.6  | 30.2 | 8.8  |
| 22 -----                 | 37.1 | 6.6  | 35.8 | 7.5  | 35.2 | 7.9  | 34.7 | 8.6  | 30.8 | 9.1  |
| 23 -----                 | 30.6 | 8.0  | 29.6 | 9.0  | 28.5 | 9.4  | 27.9 | 10.1 | 25.0 | 10.4 |
| 24 -----                 | 30.4 | 9.0  | 28.9 | 9.7  | 27.9 | 9.8  | 27.0 | 10.1 | 21.9 | 10.6 |
| 1 -----                  | 28.7 | 11.2 | 27.5 | 11.3 | 26.5 | 11.4 | 26.0 | 11.6 | 22.4 | 12.1 |
| 2 -----                  | 28.0 | 13.4 | 26.9 | 13.0 | 26.0 | 12.8 | 25.7 | 12.4 | 20.8 | 12.0 |
| 3 -----                  | 27.1 | 13.5 | 26.6 | 12.7 | 25.4 | 12.0 | 23.6 | 11.6 | 19.5 | 12.1 |
| 4 -----                  | 26.9 | 12.8 | 25.3 | 12.5 | 23.4 | 12.3 | 22.9 | 12.1 | 18.8 | 12.8 |
| 7-8 July 1966            |      |      |      |      |      |      |      |      |      |      |
| 5 -----                  | 25.4 | 12.8 | 24.0 | 14.0 | 23.1 | 13.0 | 22.7 | 13.1 | 18.5 | 13.8 |
| 6 -----                  | 26.0 | 13.3 | 24.5 | 14.1 | 24.2 | 14.9 | 23.5 | 15.3 | 21.0 | 16.4 |
| 7 -----                  | 29.2 | 16.1 | 28.6 | 16.8 | 28.3 | 17.1 | 7.0  | 31.4 | 17.0 | 31.4 |
| 8 -----                  | 31.3 | 17.0 | 31.3 | 17.0 | 31.4 | 17.0 | 31.4 | 17.0 | 29.8 | 17.9 |
| 9 -----                  | 31.9 | 15.0 | 31.9 | 16.2 | 32.0 | 17.1 | 31.8 | 17.5 | 30.7 | 18.3 |
| 10 -----                 | 33.8 | 15.9 | 34.4 | 16.2 | 34.9 | 16.3 | 34.7 | 16.5 | 34.7 | 18.6 |
| 11 -----                 | 35.0 | 10.5 | 35.5 | 11.7 | 35.8 | 13.5 | 36.5 | 14.4 | 38.2 | 15.6 |
| 12 -----                 | 37.1 | 11.0 | 37.9 | 12.6 | 38.4 | 13.5 | 38.1 | 14.5 | 39.6 | 15.9 |
| 13 -----                 | 38.3 | 10.9 | 38.5 | 12.1 | 39.0 | 12.8 | 38.9 | 13.1 | 39.2 | 14.1 |
| 14 -----                 | 38.6 | 10.5 | 39.9 | 11.4 | 39.9 | 12.0 | 39.8 | 12.5 | 41.0 | 13.0 |
| 15 -----                 | 38.1 | 11.2 | 38.2 | 12.5 | 38.3 | 12.9 | 38.7 | 13.7 | 40.9 | 14.0 |
| 16 -----                 | 38.1 | 9.4  | 38.2 | 10.9 | 38.2 | 11.5 | 38.2 | 12.3 | 38.9 | 13.0 |
| 17 -----                 | 37.7 | 9.0  | 37.9 | 10.6 | 37.5 | 11.6 | 36.7 | 12.4 | 35.2 | 12.4 |
| 18 -----                 | 37.6 | 9.8  | 37.4 | 11.0 | 37.2 | 11.1 | 36.4 | 12.5 | 35.1 | 12.3 |
| 19 -----                 | 36.0 | 10.5 | 36.0 | 11.5 | 35.8 | 11.9 | 35.0 | 12.3 | 32.8 | 13.0 |
| 20 -----                 | 34.1 | 9.7  | 33.5 | 10.4 | 33.0 | 10.7 | 32.2 | 11.2 | 29.1 | 12.1 |
| 21 -----                 | 34.9 | 10.0 | 34.0 | 10.8 | 33.5 | 11.2 | 33.0 | 11.6 | 29.0 | 11.4 |
| 22 -----                 | 31.9 | 11.0 | 30.9 | 11.6 | 30.1 | 11.7 | 29.5 | 12.1 | 25.3 | 13.9 |
| 23 -----                 | 30.9 | 12.1 | 29.5 | 12.5 | 28.9 | 12.8 | 28.0 | 13.0 | 35.1 | 13.8 |
| 24 -----                 | 29.2 | 11.9 | 28.0 | 12.4 | 27.0 | 12.9 | 26.2 | 13.1 | 22.5 | 14.0 |
| 1 -----                  | 29.5 | 10.9 | 28.1 | 11.4 | 27.1 | 11.8 | 26.1 | 12.2 | 21.1 | 13.4 |
| 2 -----                  | 27.3 | 13.9 | 26.9 | 14.6 | 26.3 | 14.9 | 25.9 | 15.1 | 23.3 | 15.1 |
| 3 -----                  | 27.2 | 19.5 | 26.4 | 19.4 | 26.1 | 19.5 | 25.8 | 19.3 | 23.6 | 19.5 |
| 4 -----                  | 27.2 | 19.6 | 27.2 | 19.6 | 26.6 | 19.9 | 26.1 | 19.8 | 23.7 | 19.9 |

TABLE A2-1. Hourly averages of air temperature and vapor pressure at the Buckeye Project during selected periods of 3 days each.—Continued

| 1-hr period<br>beginning | 11m  |      | 7m   |      | 5m   |      | 4m   |      | 2m   |      |
|--------------------------|------|------|------|------|------|------|------|------|------|------|
|                          | °C   | mb   | °C   | mb   | °C   | mb   | °C   | mb   | °C   | mb   |
| <b>8-9 July 1966</b>     |      |      |      |      |      |      |      |      |      |      |
| 5 -----                  | 26.9 | 20.4 | 26.4 | 20.2 | 25.9 | 20.1 | 25.5 | 19.9 | 23.1 | 20.0 |
| 6 -----                  | 26.4 | 20.5 | 25.7 | 20.4 | 25.2 | 20.3 | 24.7 | 20.0 | 22.6 | 19.4 |
| 7 -----                  | 26.9 | 20.6 | 26.9 | 20.7 | 27.1 | 21.0 | 26.6 | 21.6 | 26.0 | 23.4 |
| 8 -----                  | 28.8 | 20.2 | 28.4 | 20.3 | 28.7 | 20.8 | 29.0 | 21.0 | 28.0 | 23.1 |
| 9 -----                  | 30.2 | 19.0 | 30.5 | 19.6 | 30.7 | 20.4 | 30.7 | 21.0 | 30.1 | 22.6 |
| 10 -----                 | 31.7 | 18.1 | 31.8 | 18.9 | 32.2 | 19.2 | 32.1 | 19.5 | 32.5 | 21.4 |
| 11 -----                 | 32.7 | 18.5 | 32.8 | 18.8 | 33.4 | 19.0 | 33.9 | 19.5 | 35.4 | 19.5 |
| 12 -----                 | 34.0 | 18.2 | 34.4 | 18.3 | 35.5 | 18.5 | 35.2 | 18.7 | 37.0 | 20.9 |
| 13 -----                 | 35.3 | 14.8 | 35.6 | 15.6 | 36.0 | 15.9 | 35.5 | 16.5 | 38.7 | 18.7 |
| 14 -----                 | 36.7 | 14.5 | 36.9 | 14.7 | 37.3 | 14.8 | 37.1 | 15.3 | 39.0 | 16.8 |
| 15 -----                 | 36.5 | 13.5 | 36.9 | 14.4 | 37.2 | 15.4 | 37.6 | 15.8 | 39.7 | 16.0 |
| 16 -----                 | 37.2 | 13.9 | 38.2 | 14.3 | 38.3 | 14.8 | 38.0 | 15.1 | 38.4 | 16.4 |
| 17 -----                 | 37.4 | 13.4 | 38.0 | 14.1 | 38.1 | 14.9 | 37.6 | 15.2 | 37.3 | 16.1 |
| 18 -----                 | 37.2 | 14.2 | 37.6 | 14.6 | 37.8 | 14.7 | 37.2 | 14.8 | 35.8 | 16.4 |
| 19 -----                 | 36.5 | 14.0 | 31.4 | 14.9 | 36.1 | 15.1 | 35.2 | 15.7 | 33.1 | 16.6 |
| 20 -----                 | 34.9 | 14.4 | 34.2 | 15.0 | 33.6 | 15.2 | 32.9 | 15.5 | 29.0 | 16.6 |
| 21 -----                 | 36.0 | 13.8 | 34.5 | 14.1 | 33.5 | 14.6 | 32.7 | 14.9 | 27.5 | 16.1 |
| 22 -----                 | 33.5 | 14.7 | 33.1 | 15.0 | 32.6 | 15.6 | 31.6 | 15.9 | 28.3 | 16.6 |
| 23 -----                 | 32.4 | 14.5 | 32.6 | 15.7 | 32.1 | 16.1 | 31.3 | 17.0 | 29.0 | 16.6 |
| 24 -----                 | 31.4 | 16.2 | 31.3 | 16.9 | 30.8 | 17.1 | 30.3 | 17.3 | 28.2 | 17.6 |
| 1 -----                  | 31.6 | 17.3 | 30.9 | 17.8 | 30.7 | 18.0 | 30.1 | 18.1 | 27.2 | 18.4 |
| 2 -----                  | 31.6 | 17.2 | 31.2 | 18.0 | 31.1 | 18.2 | 30.6 | 18.6 | 28.3 | 18.4 |
| 3 -----                  | 30.6 | 18.7 | 30.3 | 19.0 | 30.2 | 19.4 | 29.9 | 19.8 | 28.7 | 19.0 |
| 4 -----                  | 29.4 | 19.2 | 28.6 | 19.1 | 28.0 | 19.0 | 27.8 | 18.9 | 26.1 | 19.3 |
| <b>3-4 August 1966</b>   |      |      |      |      |      |      |      |      |      |      |
| 5 -----                  | 31.2 | 20.0 | 30.7 | 20.5 | 30.3 | 21.1 | 30.0 | 21.7 | 26.5 | 21.4 |
| 6 -----                  | 31.8 | 20.5 | 31.7 | 21.1 | 31.6 | 21.5 | 31.3 | 21.8 | 28.3 | 22.1 |
| 7 -----                  | 33.4 | 22.1 | 33.4 | 22.7 | 33.7 | 23.3 | 33.1 | 23.5 | 31.9 | 24.4 |
| 8 -----                  | 34.8 | 21.3 | 35.2 | 21.8 | 35.4 | 22.3 | 35.3 | 22.5 | 34.5 | 25.0 |
| 9 -----                  | 35.4 | 22.1 | 35.7 | 22.7 | 36.0 | 23.0 | 36.7 | 23.3 | 35.8 | 25.2 |
| 10 -----                 | 37.7 | 21.0 | 37.8 | 21.8 | 38.5 | 22.7 | 38.6 | 22.9 | 38.9 | 24.0 |
| 11 -----                 | 38.8 | 20.1 | 39.4 | 21.0 | 39.8 | 21.5 | 40.8 | 22.0 | 41.6 | 24.0 |
| 12 -----                 | 39.4 | 20.4 | 39.7 | 20.9 | 40.0 | 21.4 | 40.6 | 21.7 | 41.4 | 23.3 |
| 13 -----                 | 39.9 | 19.1 | 40.6 | 20.1 | 41.3 | 21.6 | 41.5 | 21.1 | 43.0 | 23.5 |
| 14 -----                 | 40.6 | 17.7 | 40.8 | 19.0 | 41.6 | 19.5 | 42.2 | 20.4 | 43.4 | 22.2 |
| 15 -----                 | 39.7 | 20.4 | 40.1 | 20.5 | 40.3 | 20.8 | 40.6 | 21.0 | 41.4 | 22.0 |
| 16 -----                 | 38.3 | 23.5 | 38.5 | 23.7 | 38.9 | 23.9 | 39.0 | 24.2 | 39.9 | 25.0 |
| 17 -----                 | 37.3 | 22.5 | 37.9 | 22.6 | 37.8 | 23.0 | 38.0 | 23.2 | 38.1 | 24.2 |
| 18 -----                 | 37.4 | 22.0 | 37.9 | 22.2 | 37.9 | 22.4 | 37.6 | 22.5 | 37.5 | 23.0 |
| 19 -----                 | 36.8 | 21.1 | 37.1 | 21.3 | 37.1 | 21.6 | 36.9 | 21.8 | 36.1 | 22.4 |
| 20 -----                 | 35.9 | 21.0 | 36.3 | 21.2 | 36.2 | 21.5 | 35.6 | 22.0 | 34.5 | 22.6 |
| 21 -----                 | 35.4 | 21.8 | 35.2 | 22.0 | 35.1 | 22.4 | 34.8 | 22.6 | 33.7 | 22.8 |
| 22 -----                 | 34.5 | 21.3 | 34.1 | 21.4 | 33.9 | 21.6 | 33.7 | 21.8 | 32.7 | 23.0 |
| 23 -----                 | 32.8 | 20.1 | 32.8 | 20.3 | 32.5 | 20.4 | 32.4 | 20.5 | 31.4 | 22.1 |
| 24 -----                 | 32.3 | 19.5 | 32.2 | 19.7 | 31.9 | 19.8 | 31.8 | 19.9 | 30.9 | 21.3 |
| 1 -----                  | 31.5 | 20.1 | 31.3 | 20.2 | 31.1 | 20.3 | 30.8 | 20.4 | 29.7 | 22.1 |
| 2 -----                  | 28.8 | 20.7 | 28.7 | 21.1 | 28.3 | 21.7 | 28.1 | 21.8 | 28.0 | 22.4 |
| 3 -----                  | 28.1 | 20.9 | 27.7 | 21.1 | 27.6 | 21.3 | 27.3 | 21.6 | 26.8 | 22.8 |
| 4 -----                  | 27.3 | 21.4 | 27.0 | 21.7 | 26.6 | 21.7 | 26.5 | 21.8 | 25.1 | 22.9 |
| <b>4-5 August 1966</b>   |      |      |      |      |      |      |      |      |      |      |
| 5 -----                  | 26.4 | 21.5 | 26.2 | 22.0 | 26.1 | 22.3 | 26.0 | 22.7 | 25.0 | 22.8 |
| 6 -----                  | 26.4 | 21.5 | 26.4 | 21.8 | 26.1 | 22.0 | 26.0 | 22.0 | 24.5 | 23.0 |
| 7 -----                  | 27.9 | 22.6 | 27.8 | 22.3 | 28.1 | 22.7 | 27.8 | 23.0 | 27.1 | 24.8 |
| 8 -----                  | 31.2 | 19.8 | 32.0 | 19.9 | 31.7 | 21.2 | 31.6 | 22.3 | 32.1 | 22.5 |
| 9 -----                  | 32.9 | 20.6 | 33.9 | 21.7 | 33.8 | 22.0 | 33.7 | 22.5 | 35.1 | 23.4 |
| 10 -----                 | 34.4 | 20.5 | 35.8 | 20.8 | 35.9 | 21.2 | 36.3 | 21.5 | 37.1 | 24.0 |
| 11 -----                 | 37.2 | 20.2 | 37.7 | 21.0 | 37.8 | 21.4 | 38.1 | 21.5 | 39.9 | 23.8 |
| 12 -----                 | 38.5 | 20.0 | 38.9 | 20.3 | 39.5 | 20.6 | 40.1 | 20.8 | 41.9 | 22.7 |
| 13 -----                 | 39.6 | 19.0 | 40.2 | 19.8 | 41.3 | 20.3 | 41.9 | 20.6 | 43.9 | 22.7 |
| 14 -----                 | 40.8 | 18.6 | 41.5 | 19.0 | 42.0 | 19.6 | 42.7 | 19.9 | 44.3 | 22.9 |
| 15 -----                 | 41.4 | 17.0 | 42.4 | 17.4 | 42.7 | 17.8 | 43.5 | 18.0 | 45.6 | 20.9 |
| 16 -----                 | 41.7 | 16.5 | 43.0 | 17.2 | 43.4 | 17.8 | 43.5 | 18.0 | 45.3 | 19.1 |
| 17 -----                 | 41.8 | 14.9 | 42.8 | 15.8 | 42.7 | 16.4 | 43.2 | 16.8 | 43.2 | 20.8 |
| 18 -----                 | 41.5 | 15.4 | 42.0 | 15.6 | 42.3 | 16.0 | 42.1 | 16.5 | 40.4 | 20.3 |
| 19 -----                 | 40.3 | 15.5 | 39.8 | 16.6 | 39.8 | 17.9 | 39.0 | 17.4 | 35.8 | 21.5 |
| 20 -----                 | 40.2 | 14.8 | 38.8 | 15.7 | 38.1 | 16.2 | 37.4 | 16.6 | 32.6 | 20.0 |
| 21 -----                 | 39.5 | 15.9 | 38.6 | 16.2 | 38.1 | 16.7 | 37.6 | 17.1 | 34.8 | 18.6 |

TABLE A2-1. Hourly averages of air temperature and vapor pressure at the Buckeye Project during selected periods of 3 days each.—Continued

| 1-hr period<br>beginning         | 11m  |      | 7m   |      | 5m   |      | 4m   |      | 2m   |      |
|----------------------------------|------|------|------|------|------|------|------|------|------|------|
|                                  | °C   | mb   | °C   | mb   | °C   | mb   | °C   | mb   | °C   | mb   |
| <b>4-5 August 1966—Continued</b> |      |      |      |      |      |      |      |      |      |      |
| 22 -----                         | 36.4 | 16.9 | 35.3 | 17.2 | 34.9 | 17.5 | 35.0 | 17.8 | 32.1 | 20.6 |
| 23 -----                         | 34.9 | 17.8 | 34.8 | 18.3 | 34.6 | 18.5 | 34.5 | 18.8 | 32.8 | 20.4 |
| 24 -----                         | 34.8 | 17.7 | 34.2 | 18.1 | 34.5 | 18.4 | 33.9 | 18.6 | 32.1 | 20.0 |
| 1 -----                          | 34.5 | 17.9 | 34.2 | 18.0 | 34.0 | 18.3 | 33.8 | 18.6 | 32.6 | 20.3 |
| 2 -----                          | 31.7 | 19.2 | 31.3 | 19.5 | 31.2 | 19.5 | 30.9 | 19.5 | 29.0 | 21.5 |
| 3 -----                          | 29.0 | 20.4 | 28.8 | 20.5 | 28.7 | 20.6 | 28.4 | 20.7 | 27.5 | 21.9 |
| 4 -----                          | 27.8 | 20.4 | 27.5 | 20.5 | 27.4 | 20.7 | 27.1 | 21.0 | 25.4 | 22.4 |
| <b>5-6 August 1966</b>           |      |      |      |      |      |      |      |      |      |      |
| 5 -----                          | 26.8 | 21.3 | 26.5 | 21.4 | 26.3 | 21.4 | 25.9 | 21.5 | 24.1 | 21.9 |
| 6 -----                          | 27.0 | 21.5 | 26.5 | 21.7 | 26.4 | 21.8 | 26.3 | 21.9 | 24.2 | 22.6 |
| 7 -----                          | 29.2 | 21.8 | 28.2 | 22.0 | 28.8 | 22.7 | 28.8 | 23.2 | 28.1 | 24.3 |
| 8 -----                          | 31.7 | 20.8 | 32.0 | 22.4 | 31.1 | 23.0 | 31.1 | 23.5 | 31.8 | 24.5 |
| 9 -----                          | 33.9 | 21.5 | 34.0 | 22.2 | 34.6 | 22.4 | 34.8 | 25.2 | 35.8 | 25.4 |
| 10 -----                         | 36.9 | 19.6 | 37.1 | 20.7 | 37.4 | 21.5 | 37.5 | 21.8 | 38.8 | 24.1 |
| 11 -----                         | 37.3 | 20.9 | 38.0 | 21.4 | 39.1 | 21.8 | 39.4 | 22.0 | 41.3 | 23.8 |
| 12 -----                         | 38.7 | 18.4 | 39.4 | 18.9 | 40.2 | 20.0 | 40.6 | 20.1 | 43.3 | 22.0 |
| 13 -----                         | 39.9 | 18.3 | 41.1 | 19.6 | 42.1 | 19.8 | 41.8 | 20.1 | 44.4 | 22.5 |
| 14 -----                         | 40.2 | 16.7 | 41.2 | 17.1 | 41.9 | 17.8 | 42.6 | 18.6 | 44.7 | 21.4 |
| 15 -----                         | 40.8 | 15.4 | 41.7 | 16.0 | 42.1 | 16.8 | 42.6 | 17.4 | 43.7 | 21.5 |
| 16 -----                         | 41.8 | 15.8 | 42.0 | 16.4 | 42.5 | 16.7 | 42.8 | 17.3 | 43.5 | 19.9 |
| 17 -----                         | 41.3 | 15.9 | 41.9 | 16.0 | 42.4 | 17.2 | 42.4 | 17.6 | 41.7 | 20.4 |
| 18 -----                         | 40.3 | 19.0 | 40.8 | 19.5 | 40.8 | 18.2 | 41.1 | 19.6 | 39.9 | 22.5 |
| 19 -----                         | 38.6 | 21.6 | 38.4 | 21.9 | 38.5 | 22.0 | 38.7 | 22.0 | 38.0 | 24.1 |
| 20 -----                         | 36.1 | 21.8 | 36.5 | 22.5 | 36.3 | 24.2 | 36.3 | 22.3 | 35.8 | 24.1 |
| 21 -----                         | 35.3 | 22.0 | 35.2 | 22.1 | 35.1 | 22.2 | 35.0 | 22.3 | 34.5 | 23.6 |
| 22 -----                         | 33.7 | 22.3 | 33.8 | 22.4 | 33.9 | 22.4 | 33.6 | 22.5 | 33.2 | 24.3 |
| 23 -----                         | 32.6 | 22.3 | 32.9 | 22.6 | 32.6 | 22.6 | 32.5 | 22.9 | 32.1 | 24.1 |
| 24 -----                         | 31.2 | 23.0 | 31.4 | 23.0 | 31.4 | 23.0 | 31.5 | 22.9 | 31.1 | 23.7 |
| 1 -----                          | 30.5 | 23.9 | 30.6 | 23.5 | 30.4 | 23.6 | 30.2 | 23.7 | 29.7 | 25.0 |
| 2 -----                          | 30.1 | 24.4 | 30.1 | 24.3 | 30.2 | 24.4 | 29.9 | 24.5 | 29.1 | 25.4 |
| 3 -----                          | 29.1 | 24.8 | 29.3 | 25.3 | 29.3 | 25.1 | 29.1 | 24.7 | 28.0 | 25.6 |
| 4 -----                          | 28.9 | 25.0 | 28.4 | 24.9 | 28.1 | 24.9 | 28.0 | 24.9 | 26.3 | 25.4 |
| <b>8-9 September 1966</b>        |      |      |      |      |      |      |      |      |      |      |
| 5 -----                          | 24.2 | 14.3 | 23.3 | 14.4 | 22.6 | 14.5 | 22.0 | 14.6 | 18.2 | 14.8 |
| 6 -----                          | 23.8 | 14.2 | 22.5 | 14.4 | 21.8 | 14.5 | 21.4 | 14.6 | 17.2 | 15.0 |
| 7 -----                          | 24.3 | 15.0 | 23.9 | 15.2 | 23.6 | 15.3 | 23.3 | 15.4 | 20.1 | 16.0 |
| 8 -----                          | 27.5 | 15.8 | 27.4 | 16.0 | 27.5 | 16.2 | 27.3 | 16.3 | 26.3 | 16.5 |
| 9 -----                          | 30.2 | 16.3 | 30.4 | 16.4 | 30.6 | 16.5 | 30.7 | 16.7 | 30.8 | 16.8 |
| 10 -----                         | 32.2 | 17.1 | 32.6 | 17.2 | 33.1 | 17.3 | 33.4 | 17.4 | 34.2 | 17.6 |
| 11 -----                         | 35.0 | 15.0 | 35.4 | 15.5 | 35.4 | 15.8 | 36.3 | 16.5 | 37.4 | 15.3 |
| 12 -----                         | 36.7 | 14.4 | 37.5 | 14.6 | 37.7 | 15.0 | 38.0 | 15.5 | 39.7 | 14.5 |
| 13 -----                         | 37.8 | 14.5 | 38.1 | 15.0 | 38.5 | 15.4 | 38.4 | 15.5 | 40.7 | 14.9 |
| 14 -----                         | 38.3 | 12.8 | 38.9 | 13.2 | 39.5 | 14.0 | 39.6 | 14.6 | 41.4 | 13.6 |
| 15 -----                         | 37.6 | 14.2 | 38.1 | 14.4 | 38.9 | 14.6 | 39.6 | 15.0 | 40.7 | 13.9 |
| 16 -----                         | 38.2 | 13.4 | 38.5 | 13.6 | 38.9 | 13.8 | 39.1 | 14.1 | 39.8 | 13.3 |
| 17 -----                         | 38.1 | 13.8 | 38.5 | 14.0 | 38.7 | 14.2 | 38.1 | 14.5 | 38.2 | 13.3 |
| 18 -----                         | 37.6 | 15.2 | 37.4 | 15.4 | 37.6 | 15.6 | 36.7 | 15.8 | 33.9 | 16.6 |
| 19 -----                         | 35.3 | 15.8 | 33.8 | 16.8 | 33.2 | 17.6 | 32.5 | 18.2 | 27.7 | 20.0 |
| 20 -----                         | 32.8 | 15.6 | 31.9 | 16.6 | 31.5 | 17.3 | 31.1 | 17.8 | 24.7 | 18.6 |
| 21 -----                         | 32.8 | 14.4 | 31.4 | 14.7 | 30.1 | 15.0 | 29.0 | 15.4 | 23.8 | 16.9 |
| 22 -----                         | 31.2 | 13.6 | 29.6 | 13.7 | 28.5 | 13.9 | 27.6 | 14.3 | 22.6 | 16.8 |
| 23 -----                         | 27.3 | 15.3 | 26.1 | 15.5 | 25.6 | 15.7 | 25.0 | 16.0 | 21.9 | 16.6 |
| 24 -----                         | 26.6 | 15.0 | 25.9 | 15.2 | 25.5 | 15.3 | 25.1 | 15.5 | 22.1 | 16.1 |
| 1 -----                          | 25.4 | 16.4 | 24.6 | 16.4 | 24.2 | 16.5 | 23.6 | 16.5 | 21.5 | 16.8 |
| 2 -----                          | 24.4 | 15.8 | 23.3 | 15.8 | 22.9 | 16.0 | 22.5 | 16.0 | 20.2 | 16.3 |
| 3 -----                          | 24.4 | 15.5 | 23.3 | 15.5 | 22.7 | 15.5 | 22.1 | 15.4 | 19.1 | 15.8 |
| 4 -----                          | 24.1 | 14.6 | 22.7 | 14.7 | 22.1 | 14.6 | 21.5 | 14.6 | 18.7 | 15.2 |
| <b>9-10 September 1966</b>       |      |      |      |      |      |      |      |      |      |      |
| 5 -----                          | 23.1 | 13.8 | 22.1 | 14.0 | 21.8 | 14.2 | 21.5 | 14.1 | 18.7 | 14.8 |
| 6 -----                          | 23.3 | 14.0 | 22.4 | 14.0 | 22.2 | 14.1 | 21.7 | 14.0 | 19.2 | 14.6 |
| 7 -----                          | 23.3 | 14.8 | 22.9 | 14.9 | 23.0 | 15.2 | 22.8 | 15.2 | 21.5 | 15.4 |
| 8 -----                          | 26.3 | 15.7 | 26.4 | 15.6 | 26.5 | 15.8 | 16.6 | 16.0 | 25.6 | 16.8 |
| 9 -----                          | 30.5 | 15.5 | 30.7 | 15.5 | 30.8 | 15.8 | 31.0 | 15.9 | 31.6 | 15.3 |
| 10 -----                         | 34.0 | 13.6 | 34.3 | 14.5 | 34.6 | 15.2 | 34.7 | 15.7 | 35.6 | 14.3 |
| 11 -----                         | 35.9 | 13.9 | 36.4 | 14.0 | 36.6 | 14.1 | 37.0 | 14.2 | 38.9 | 14.3 |

TABLE A2-1. *Hourly averages of air temperature and vapor pressure at the Buckeye Project during selected periods of 3 days each.*—Continued

| 1-hr period<br>beginning             | 11m  |      | 7m   |      | 5m   |      | 4m   |      | 2m   |      |
|--------------------------------------|------|------|------|------|------|------|------|------|------|------|
|                                      | °C   | mb   | °C   | mb   | °C   | mb   | °C   | mb   | °C   | mb   |
| <b>9-10 September 1966—Continued</b> |      |      |      |      |      |      |      |      |      |      |
| 12 -----                             | 37.5 | 13.3 | 37.8 | 13.8 | 38.0 | 14.1 | 38.4 | 14.3 | 40.0 | 13.6 |
| 13 -----                             | 38.6 | 13.0 | 39.0 | 13.0 | 39.3 | 13.2 | 39.8 | 13.4 | 41.4 | 13.5 |
| 14 -----                             | 39.2 | 13.5 | 39.3 | 13.5 | 39.9 | 13.6 | 40.0 | 13.6 | 41.7 | 13.2 |
| 15 -----                             | 38.5 | 13.5 | 38.6 | 13.8 | 39.2 | 14.0 | 39.0 | 14.5 | 39.7 | 14.7 |
| 16 -----                             | 37.5 | 14.1 | 37.6 | 14.8 | 37.8 | 15.2 | 38.2 | 15.5 | 38.6 | 15.0 |
| 17 -----                             | 37.7 | 14.9 | 38.0 | 15.0 | 38.3 | 15.2 | 38.4 | 15.5 | 38.6 | 15.0 |
| 18 -----                             | 37.3 | 15.1 | 36.7 | 15.4 | 37.0 | 15.6 | 36.5 | 15.8 | 35.0 | 16.0 |
| 19 -----                             | 34.8 | 15.5 | 34.1 | 15.6 | 33.6 | 15.8 | 33.2 | 16.0 | 28.0 | 17.6 |
| 20 -----                             | 33.5 | 15.2 | 31.1 | 15.4 | 29.9 | 15.8 | 29.5 | 16.1 | 24.9 | 17.5 |
| 21 -----                             | 30.6 | 15.0 | 28.7 | 15.2 | 28.1 | 15.4 | 27.5 | 15.5 | 23.1 | 16.6 |
| 22 -----                             | 29.5 | 15.1 | 27.9 | 15.2 | 27.3 | 15.3 | 26.8 | 15.3 | 22.2 | 16.4 |
| 23 -----                             | 29.1 | 15.5 | 28.2 | 15.5 | 28.0 | 15.6 | 27.3 | 15.6 | 24.0 | 15.6 |
| 24 -----                             | 26.3 | 15.8 | 25.9 | 15.7 | 25.7 | 15.7 | 25.3 | 15.6 | 23.5 | 16.0 |
| 1 -----                              | 24.7 | 15.6 | 24.0 | 15.8 | 23.7 | 15.8 | 23.2 | 15.8 | 21.2 | 16.0 |
| 2 -----                              | 26.2 | 13.7 | 25.4 | 14.0 | 24.3 | 14.6 | 23.0 | 15.0 | 19.2 | 15.6 |
| 3 -----                              | 26.1 | 12.5 | 24.2 | 13.0 | 23.6 | 13.6 | 22.8 | 13.8 | 19.0 | 14.4 |
| 4 -----                              | 25.1 | 12.3 | 24.0 | 12.4 | 23.4 | 12.6 | 22.6 | 12.8 | 18.8 | 13.4 |
| <b>10-11 September 1966</b>          |      |      |      |      |      |      |      |      |      |      |
| 5 -----                              | 23.6 | 12.5 | 22.2 | 12.5 | 21.6 | 12.6 | 21.0 | 12.7 | 17.8 | 13.7 |
| 6 -----                              | 25.0 | 12.0 | 23.1 | 12.1 | 22.0 | 12.2 | 21.7 | 12.2 | 16.8 | 13.3 |
| 7 -----                              | 25.1 | 12.5 | 24.2 | 12.5 | 24.3 | 12.6 | 23.7 | 12.8 | 19.8 | 13.8 |
| 8 -----                              | 27.7 | 14.1 | 27.5 | 14.5 | 27.8 | 14.9 | 27.1 | 15.7 | 25.3 | 15.0 |
| 9 -----                              | 32.0 | 13.4 | 31.5 | 14.0 | 31.4 | 14.3 | 31.3 | 14.7 | 29.3 | 14.6 |
| 10 -----                             | 33.9 | 12.9 | 34.4 | 12.9 | 34.5 | 15.0 | 34.3 | 15.1 | 32.9 | 14.9 |
| 11 -----                             | 35.3 | 13.4 | 36.1 | 13.5 | 36.8 | 14.3 | 37.0 | 14.6 | 36.6 | 14.0 |
| 12 -----                             | 36.6 | 13.6 | 37.0 | 14.0 | 37.5 | 14.2 | 37.9 | 14.5 | 39.8 | 14.4 |
| 13 -----                             | 38.3 | 12.0 | 38.0 | 12.4 | 38.2 | 13.0 | 38.9 | 13.4 | 41.0 | 13.8 |
| 14 -----                             | 38.7 | 13.3 | 38.4 | 13.5 | 39.7 | 13.8 | 39.5 | 14.0 | 40.6 | 13.7 |
| 15 -----                             | 38.9 | 13.5 | 38.2 | 13.6 | 38.3 | 14.0 | 37.8 | 14.1 | 38.1 | 12.9 |
| 16 -----                             | 38.3 | 13.0 | 37.8 | 13.1 | 38.5 | 13.3 | 38.0 | 13.7 | 36.5 | 13.8 |
| 17 -----                             | 38.0 | 13.0 | 38.1 | 13.5 | 37.8 | 13.7 | 37.7 | 13.8 | 34.6 | 15.3 |
| 18 -----                             | 37.7 | 13.8 | 37.1 | 14.0 | 36.8 | 13.8 | 36.5 | 14.3 | 32.4 | 16.0 |
| 19 -----                             | 35.6 | 13.9 | 34.6 | 13.8 | 34.2 | 13.9 | 33.6 | 14.1 | 27.8 | 16.8 |
| 20 -----                             | 33.8 | 13.6 | 32.8 | 13.6 | 32.1 | 13.8 | 31.8 | 13.8 | 27.2 | 14.9 |
| 21 -----                             | 35.2 | 12.0 | 34.6 | 12.3 | 33.7 | 12.6 | 33.6 | 11.0 | 31.4 | 10.5 |
| 22 -----                             | 33.6 | 11.6 | 32.8 | 10.0 | 32.2 | 12.5 | 31.9 | 10.4 | 29.2 | 11.0 |
| 23 -----                             | 32.0 | 11.5 | 31.4 | 10.9 | 31.0 | 13.0 | 30.7 | 11.3 | 27.2 | 13.0 |
| 24 -----                             | 30.4 | 12.5 | 28.9 | 12.5 | 28.3 | 14.5 | 28.0 | 12.6 | 24.3 | 13.4 |
| 1 -----                              | 30.5 | 12.2 | 29.5 | 11.6 | 28.7 | 13.8 | 28.8 | 12.0 | 24.1 | 14.0 |
| 2 -----                              | 27.4 | 14.9 | 26.8 | 13.5 | 26.2 | 15.1 | 25.6 | 14.4 | 22.1 | 15.2 |
| 3 -----                              | 27.3 | 17.5 | 25.9 | 16.5 | 24.8 | 17.8 | 24.1 | 16.7 | 20.6 | 16.1 |
| 4 -----                              | 25.6 | 17.1 | 24.0 | 16.6 | 23.3 | 17.5 | 23.0 | 16.5 | 20.0 | 16.7 |
| <b>23-24 March 1967</b>              |      |      |      |      |      |      |      |      |      |      |
| 5 -----                              | 8.5  | 4.5  | 7.8  | 5.0  | 6.5  | 5.0  | 5.8  | 4.8  | 2.8  | 5.3  |
| 6 -----                              | 9.5  | 4.5  | 8.5  | 4.8  | 8.2  | 4.4  | 8.0  | 4.5  | 4.8  | 5.6  |
| 7 -----                              | 12.0 | 5.5  | 12.0 | 5.6  | 12.0 | 5.5  | 12.0 | 5.4  | 10.5 | 6.0  |
| 8 -----                              | 16.5 | 6.1  | 16.8 | 6.4  | 16.8 | 5.9  | 16.8 | 6.4  | 17.0 | 6.5  |
| 9 -----                              | 20.0 | 6.0  | 20.8 | 6.2  | 21.0 | 6.1  | 21.2 | 7.1  | 22.5 | 6.3  |
| 10 -----                             | 24.0 | 5.3  | 24.5 | 6.6  | 24.5 | 6.2  | 25.2 | 6.6  | 26.5 | 6.2  |
| 11 -----                             | 27.0 | 5.9  | 27.5 | 6.2  | 28.0 | 5.9  | 27.8 | 7.0  | 30.2 | 6.2  |
| 12 -----                             | 29.0 | 5.8  | 30.0 | 6.8  | 30.0 | 5.9  | 30.2 | 5.8  | 32.0 | 5.0  |
| 13 -----                             | 30.0 | 4.3  | 30.5 | 5.6  | 30.8 | 5.8  | 30.5 | 5.3  | 32.0 | 4.6  |
| 14 -----                             | 29.5 | 6.3  | 29.8 | 6.9  | 30.0 | 6.8  | 30.8 | 7.6  | 31.5 | 7.0  |
| 15 -----                             | 30.0 | 5.1  | 29.8 | 6.1  | 30.0 | 6.0  | 30.2 | 6.7  | 30.5 | 7.0  |
| 16 -----                             | 29.5 | 6.0  | 29.8 | 6.5  | 29.8 | 6.0  | 29.8 | 6.5  | 29.2 | 6.9  |
| 17 -----                             | 29.0 | 5.0  | 29.0 | 6.3  | 28.8 | 5.8  | 28.5 | 6.0  | 25.8 | 8.2  |
| 18 -----                             | 26.5 | 6.2  | 26.2 | 7.5  | 26.0 | 6.8  | 25.5 | 6.9  | 21.2 | 7.5  |
| 19 -----                             | 26.5 | 5.8  | 25.2 | 7.0  | 24.5 | 6.6  | 24.2 | 6.4  | 18.5 | 8.5  |
| 20 -----                             | 26.0 | 5.0  | 24.2 | 5.6  | 23.5 | 5.7  | 23.2 | 5.9  | 17.5 | 7.6  |
| 21 -----                             | 25.8 | 5.1  | 25.0 | 5.2  | 24.8 | 5.3  | 24.5 | 5.5  | 22.2 | 5.4  |
| 22 -----                             | 24.2 | 4.6  | 23.8 | 4.8  | 23.2 | 5.2  | 23.0 | 5.3  | 20.5 | 5.4  |
| 23 -----                             | 22.0 | 5.1  | 21.0 | 5.6  | 20.5 | 5.7  | 21.0 | 5.1  | 17.2 | 5.3  |
| 24 -----                             | 18.2 | 5.4  | 15.8 | 7.0  | 15.2 | 6.5  | 15.0 | 6.6  | 13.2 | 6.5  |
| 1 -----                              | 18.5 | 5.9  | 17.0 | 6.3  | 15.5 | 6.4  | 14.5 | 6.6  | 12.5 | 6.6  |
| 2 -----                              | 19.2 | 5.8  | 18.0 | 6.2  | 16.2 | 6.3  | 16.0 | 6.0  | 12.8 | 6.4  |
| 3 -----                              | 18.0 | 6.2  | 17.0 | 6.5  | 16.5 | 6.5  | 16.5 | 6.1  | 13.5 | 6.6  |

TABLE A2-1. Hourly averages of air temperature and vapor pressure at the Buckeye Project during selected periods of 3 days each.—Continued

| 1-hr period<br>beginning | 11m  |     | 7m   |     | 5m   |     | 4m   |      | 2m   |      |
|--------------------------|------|-----|------|-----|------|-----|------|------|------|------|
|                          | °C   | mb  | °C   | mb  | °C   | mb  | °C   | mb   | °C   | mb   |
| <b>24-25 March 1967</b>  |      |     |      |     |      |     |      |      |      |      |
| 5 -----                  | 20.2 | 5.2 | 18.8 | 6.1 | 18.2 | 5.7 | 17.5 | 5.9  | 14.5 | 6.4  |
| 6 -----                  | 19.0 | 6.0 | 18.5 | 6.3 | 17.8 | 5.7 | 16.8 | 6.4  | 14.5 | 6.7  |
| 7 -----                  | 17.8 | 6.0 | 15.2 | 7.4 | 14.2 | 7.1 | 13.8 | 7.1  | 11.0 | 7.8  |
| 8 -----                  | 15.8 | 7.0 | 15.8 | 7.3 | 15.8 | 7.0 | 15.8 | 7.3  | 15.2 | 8.4  |
| 9 -----                  | 18.2 | 7.9 | 18.8 | 8.3 | 19.0 | 7.8 | 19.2 | 8.8  | 19.2 | 8.8  |
| 10 -----                 | 22.8 | 6.5 | 23.0 | 6.9 | 23.0 | 6.9 | 23.8 | 7.0  | 24.8 | 7.5  |
| 11 -----                 | 24.2 | 6.4 | 25.0 | 6.3 | 25.2 | 6.1 | 26.0 | 6.8  | 28.0 | 7.2  |
| 12 -----                 | 25.5 | 7.1 | 25.8 | 7.0 | 26.0 | 7.1 | 27.2 | 7.7  | 28.8 | 7.5  |
| 13 -----                 | 25.8 | 6.6 | 26.2 | 6.5 | 26.2 | 6.7 | 26.8 | 7.1  | 28.5 | 7.7  |
| 14 -----                 | 26.5 | 6.3 | 27.5 | 6.3 | 27.8 | 6.0 | 28.0 | 6.9  | 29.8 | 6.0  |
| 15 -----                 | 27.0 | 5.0 | 27.5 | 5.1 | 28.2 | 5.1 | 28.5 | 5.3  | 30.8 | 5.1  |
| 16 -----                 | 27.2 | 5.3 | 28.0 | 5.3 | 28.2 | 5.4 | 28.8 | 5.9  | 30.5 | 5.6  |
| 17 -----                 | 27.0 | 5.9 | 27.5 | 5.9 | 27.8 | 5.6 | 27.8 | 6.0  | 27.8 | 5.7  |
| 18 -----                 | 26.0 | 5.6 | 26.0 | 6.0 | 26.0 | 5.6 | 26.0 | 6.5  | 25.5 | 6.0  |
| 19 -----                 | 23.2 | 4.0 | 23.2 | 4.4 | 23.0 | 4.2 | 23.0 | 4.5  | 22.0 | 4.5  |
| 20 -----                 | 21.2 | 3.9 | 21.0 | 4.4 | 20.8 | 4.2 | 20.5 | 4.4  | 18.8 | 4.6  |
| 21 -----                 | 20.0 | 3.2 | 19.5 | 3.9 | 19.0 | 3.9 | 19.0 | 3.8  | 16.8 | 3.9  |
| 22 -----                 | 20.2 | 3.4 | 19.8 | 4.0 | 19.2 | 4.0 | 19.0 | 4.2  | 15.8 | 4.3  |
| 23 -----                 | 19.0 | 4.2 | 18.5 | 4.5 | 18.2 | 4.4 | 18.2 | 4.4  | 15.0 | 4.7  |
| 24 -----                 | 17.8 | 4.9 | 17.5 | 5.1 | 17.2 | 5.3 | 17.0 | 5.9  | 16.2 | 4.9  |
| 1 -----                  | 16.8 | 5.9 | 16.8 | 5.9 | 16.5 | 6.1 | 16.5 | 6.1  | 15.8 | 6.1  |
| 2 -----                  | 16.0 | 6.4 | 15.8 | 6.5 | 15.5 | 6.4 | 15.2 | 6.5  | 14.0 | 6.7  |
| 3 -----                  | 14.8 | 6.5 | 14.8 | 6.5 | 14.5 | 6.6 | 14.5 | 6.6  | 12.8 | 6.4  |
| 4 -----                  | 14.2 | 6.8 | 13.8 | 6.8 | 13.2 | 6.8 | 12.8 | 7.0  | 10.8 | 7.0  |
| <b>25-26 March 1967</b>  |      |     |      |     |      |     |      |      |      |      |
| 5 -----                  | 13.5 | 7.0 | 12.5 | 7.3 | 11.8 | 7.0 | 10.8 | 6.6  | 7.5  | 7.0  |
| 6 -----                  | 10.2 | 7.0 | 8.0  | 7.3 | 7.0  | 7.0 | 7.0  | 7.3  | 6.0  | 7.0  |
| 7 -----                  | 9.8  | 7.0 | 8.0  | 7.3 | 7.2  | 7.2 | 7.0  | 7.0  | 5.8  | 7.1  |
| 8 -----                  | 11.5 | 7.5 | 11.8 | 7.6 | 12.0 | 7.2 | 12.0 | 7.5  | 11.2 | 7.7  |
| 9 -----                  | 15.2 | 8.0 | 15.5 | 9.1 | 16.0 | 8.3 | 15.8 | 8.4  | 16.0 | 8.3  |
| 10 -----                 | 17.8 | 7.8 | 18.2 | 8.6 | 18.2 | 7.9 | 18.2 | 8.4  | 19.5 | 8.5  |
| 11 -----                 | 19.8 | 7.4 | 20.2 | 8.6 | 20.5 | 7.5 | 20.8 | 8.2  | 21.5 | 8.5  |
| 12 -----                 | 21.5 | 6.3 | 22.0 | 7.7 | 22.5 | 6.7 | 23.0 | 7.2  | 24.8 | 7.6  |
| 13 -----                 | 22.2 | 5.8 | 23.0 | 6.4 | 23.2 | 6.2 | 24.2 | 6.7  | 27.2 | 6.9  |
| 14 -----                 | 23.5 | 6.1 | 24.0 | 6.2 | 24.2 | 6.1 | 25.0 | 6.2  | 27.5 | 6.6  |
| 15 -----                 | 24.8 | 5.3 | 25.5 | 6.0 | 25.5 | 5.6 | 25.5 | 6.4  | 28.2 | 5.8  |
| 16 -----                 | 24.5 | 5.1 | 24.8 | 5.2 | 24.5 | 6.2 | 24.8 | 6.0  | 25.8 | 5.7  |
| 17 -----                 | 24.5 | 5.1 | 24.8 | 6.0 | 24.8 | 5.7 | 24.5 | 6.2  | 25.0 | 5.9  |
| 18 -----                 | 24.0 | 5.7 | 24.0 | 6.9 | 24.0 | 6.5 | 23.5 | 6.9  | 22.2 | 6.9  |
| 19 -----                 | 22.2 | 6.2 | 21.8 | 7.6 | 21.0 | 6.9 | 20.5 | 6.9  | 16.0 | 7.5  |
| 20 -----                 | 20.8 | 5.9 | 19.2 | 7.2 | 19.2 | 6.9 | 18.2 | 6.1  | 12.5 | 7.2  |
| 21 -----                 | 19.2 | 5.8 | 18.0 | 6.6 | 16.8 | 6.4 | 15.8 | 6.2  | 10.8 | 7.4  |
| 22 -----                 | 17.0 | 4.8 | 16.0 | 5.0 | 15.0 | 4.8 | 14.0 | 5.0  | 10.2 | 5.5  |
| 23 -----                 | 15.8 | 4.2 | 15.0 | 5.0 | 14.2 | 5.3 | 13.8 | 4.8  | 9.5  | 5.4  |
| 24 -----                 | 14.0 | 5.0 | 13.2 | 5.1 | 12.5 | 5.0 | 12.2 | 5.2  | 8.5  | 5.3  |
| 1 -----                  | 12.8 | 5.1 | 12.0 | 5.4 | 11.2 | 5.1 | 11.0 | 5.0  | 8.2  | 5.6  |
| 2 -----                  | 12.2 | 5.7 | 10.8 | 6.1 | 10.5 | 6.0 | 10.0 | 6.0  | 6.8  | 6.2  |
| 3 -----                  | 11.0 | 6.2 | 9.8  | 6.0 | 8.2  | 5.8 | 7.5  | 6.3  | 5.2  | 6.0  |
| 4 -----                  | 9.8  | 5.2 | 8.2  | 6.2 | 7.5  | 6.0 | 7.0  | 6.1  | 4.8  | 6.6  |
| <b>11-12 May 1967</b>    |      |     |      |     |      |     |      |      |      |      |
| 5 -----                  | 14.5 | 7.4 | 11.0 | 7.6 | 10.3 | 7.7 | 9.5  | 8.2  | 8.3  | 7.7  |
| 6 -----                  | 13.0 | 7.6 | 10.3 | 7.8 | 10.3 | 8.0 | 9.3  | 8.0  | 7.5  | 7.9  |
| 7 -----                  | 17.0 | 8.6 | 16.0 | 9.0 | 16.5 | 9.4 | 15.3 | 9.8  | 12.8 | 10.6 |
| 8 -----                  | 19.0 | 8.9 | 19.0 | 9.5 | 19.3 | 9.8 | 18.5 | 10.0 | 17.5 | 10.6 |
| 9 -----                  | 20.5 | 7.0 | 20.8 | 7.7 | 20.8 | 8.5 | 20.8 | 9.3  | 20.8 | 10.5 |
| 10 -----                 | 21.8 | 6.4 | 22.3 | 6.8 | 22.3 | 7.2 | 22.5 | 7.9  | 23.8 | 9.8  |
| 11 -----                 | 22.8 | 5.7 | 23.3 | 5.9 | 23.5 | 6.5 | 23.3 | 7.7  | 25.8 | 8.2  |
| 12 -----                 | 24.0 | 5.5 | 24.5 | 5.7 | 24.8 | 6.0 | 24.8 | 6.9  | 27.3 | 8.1  |
| 13 -----                 | 25.3 | 5.4 | 25.5 | 5.6 | 26.3 | 5.9 | 26.3 | 7.1  | 28.8 | 8.9  |
| 14 -----                 | 25.5 | 6.0 | 26.3 | 6.2 | 26.8 | 6.5 | 27.0 | 7.0  | 29.0 | 9.1  |
| 15 -----                 | 26.3 | 5.9 | 27.0 | 6.2 | 27.3 | 6.8 | 27.3 | 7.3  | 28.8 | 8.0  |
| 16 -----                 | 27.0 | 5.9 | 27.3 | 6.1 | 27.3 | 6.3 | 27.3 | 6.5  | 28.3 | 7.9  |
| 17 -----                 | 27.3 | 6.0 | 27.8 | 6.2 | 28.0 | 6.4 | 27.3 | 7.3  | 27.0 | 8.4  |

TABLE A2-1. Hourly averages of air temperature and vapor pressure at the Buckeye Project during selected periods of 3 days each.—Continued

| 1-hr period<br>beginning | 11m  |     | 7m   |     | 5m   |     | 4m   |     | 2m   |     |
|--------------------------|------|-----|------|-----|------|-----|------|-----|------|-----|
|                          | °C   | mb  | °C   | mb  | °C   | mb  | °C   | mb  | °C   | mb  |
| 11-12 May 1967—Continued |      |     |      |     |      |     |      |     |      |     |
| 18                       | 27.0 | 6.2 | 27.3 | 6.4 | 27.0 | 6.6 | 26.0 | 7.3 | 24.5 | 7.8 |
| 19                       | 26.0 | 6.1 | 25.8 | 6.2 | 25.5 | 6.3 | 24.8 | 6.5 | 23.5 | 5.8 |
| 20                       | 24.8 | 6.5 | 24.5 | 6.6 | 24.3 | 6.7 | 23.5 | 6.8 | 22.5 | 6.0 |
| 21                       | 23.8 | 6.4 | 23.5 | 6.2 | 23.3 | 6.0 | 22.3 | 6.0 | 21.3 | 5.2 |
| 22                       | 21.8 | 5.5 | 21.3 | 5.7 | 20.8 | 5.9 | 20.0 | 6.0 | 17.3 | 6.3 |
| 23                       | 16.0 | 6.8 | 14.8 | 6.9 | 15.0 | 7.0 | 14.0 | 7.0 | 13.0 | 6.9 |
| 24                       | 16.8 | 6.4 | 15.0 | 6.7 | 14.3 | 6.7 | 13.3 | 6.7 | 10.8 | 7.0 |
| 1                        | 15.5 | 6.0 | 14.0 | 6.2 | 12.0 | 6.3 | 11.8 | 6.4 | 8.3  | 7.1 |
| 2                        | 17.3 | 4.9 | 15.5 | 5.3 | 14.0 | 5.6 | 12.8 | 5.8 | 6.8  | 7.1 |
| 3                        | 15.8 | 4.9 | 14.8 | 5.1 | 14.0 | 5.4 | 13.5 | 5.8 | 6.5  | 7.0 |
| 4                        | 14.8 | 5.5 | 13.5 | 5.6 | 13.0 | 5.6 | 12.8 | 6.0 | 6.3  | 7.1 |
| 12-13 May 1967           |      |     |      |     |      |     |      |     |      |     |
| 5                        | 15.0 | 6.1 | 14.0 | 6.1 | 13.3 | 6.1 | 12.8 | 6.1 | 7.5  | 7.0 |
| 6                        | 13.5 | 5.7 | 11.5 | 5.9 | 11.0 | 6.2 | 10.5 | 6.3 | 7.8  | 7.5 |
| 7                        | 12.3 | 6.7 | 12.0 | 6.9 | 11.8 | 7.1 | 11.5 | 7.2 | 10.3 | 8.0 |
| 8                        | 15.5 | 6.7 | 15.5 | 6.9 | 15.5 | 7.1 | 15.3 | 8.0 | 15.5 | 8.2 |
| 9                        | 19.3 | 7.6 | 19.5 | 7.8 | 19.8 | 8.1 | 19.8 | 8.5 | 20.0 | 9.0 |
| 10                       | 22.3 | 7.6 | 22.3 | 7.8 | 22.8 | 8.1 | 22.5 | 8.6 | 23.3 | 9.4 |
| 11                       | 24.3 | 7.1 | 24.8 | 7.4 | 25.0 | 8.0 | 25.3 | 8.4 | 26.3 | 8.8 |
| 12                       | 26.0 | 6.5 | 26.5 | 6.6 | 26.5 | 7.0 | 27.0 | 8.4 | 28.8 | 8.9 |
| 13                       | 26.8 | 6.4 | 27.0 | 6.5 | 27.5 | 6.6 | 27.8 | 8.2 | 30.5 | 8.7 |
| 14                       | 28.3 | 6.2 | 28.5 | 6.5 | 28.5 | 6.9 | 28.8 | 7.5 | 31.0 | 8.4 |
| 15                       | 28.5 | 6.5 | 29.0 | 6.8 | 29.3 | 7.0 | 29.0 | 7.5 | 31.0 | 8.7 |
| 16                       | 28.8 | 6.7 | 29.0 | 6.8 | 29.3 | 6.9 | 29.0 | 5.0 | 30.0 | 7.6 |
| 17                       | 29.0 | 6.2 | 29.0 | 6.3 | 29.3 | 6.4 | 28.5 | 6.5 | 28.5 | 6.1 |
| 18                       | 28.0 | 6.0 | 28.0 | 4.0 | 28.0 | 4.8 | 27.3 | 6.0 | 26.3 | 5.5 |
| 19                       | 27.8 | 5.4 | 27.5 | 3.5 | 27.3 | 4.5 | 26.5 | 5.4 | 25.0 | 4.1 |
| 20                       | 26.3 | 5.1 | 25.5 | 3.8 | 25.0 | 4.1 | 24.0 | 5.0 | 21.3 | 4.5 |
| 21                       | 23.0 | 5.4 | 21.3 | 5.0 | 20.8 | 4.9 | 20.0 | 5.7 | 15.3 | 6.1 |
| 22                       | 20.5 | 5.5 | 19.0 | 5.0 | 17.8 | 5.0 | 17.0 | 5.5 | 11.5 | 6.4 |
| 23                       | 20.3 | 5.1 | 18.0 | 5.6 | 17.5 | 5.5 | 16.8 | 6.0 | 11.8 | 6.1 |
| 24                       | 20.0 | 5.7 | 18.3 | 5.4 | 17.8 | 5.3 | 17.0 | 5.8 | 13.0 | 6.0 |
| 1                        | 19.3 | 5.8 | 17.8 | 5.3 | 17.0 | 5.1 | 15.5 | 5.8 | 11.0 | 6.0 |
| 2                        | 17.3 | 5.3 | 15.8 | 5.2 | 14.5 | 6.5 | 13.5 | 5.7 | 9.0  | 6.6 |
| 3                        | 16.3 | 5.2 | 15.4 | 4.6 | 15.0 | 5.0 | 14.3 | 5.5 | 10.8 | 5.7 |
| 4                        | 15.3 | 5.1 | 17.0 | 3.5 | 14.0 | 5.0 | 13.3 | 5.4 | 10.3 | 5.8 |
| 13-14 May 1967           |      |     |      |     |      |     |      |     |      |     |
| 5                        | 14.8 | 5.1 | 14.0 | 5.2 | 13.3 | 5.3 | 12.8 | 5.5 | 9.0  | 6.3 |
| 6                        | 15.0 | 5.0 | 14.3 | 5.0 | 13.8 | 5.1 | 13.3 | 5.5 | 10.0 | 5.6 |
| 7                        | 17.0 | 5.5 | 16.8 | 5.6 | 16.8 | 5.6 | 16.3 | 6.6 | 14.0 | 7.4 |
| 8                        | 19.3 | 5.8 | 19.0 | 6.0 | 19.3 | 6.2 | 19.0 | 6.6 | 18.3 | 7.5 |
| 9                        | 21.0 | 6.6 | 21.0 | 6.6 | 21.3 | 6.7 | 21.3 | 7.9 | 21.5 | 9.4 |
| 10                       | 23.3 | 7.0 | 23.8 | 7.0 | 23.8 | 7.1 | 24.0 | 8.5 | 25.0 | 9.0 |
| 11                       | 25.3 | 6.5 | 25.5 | 6.5 | 25.8 | 6.6 | 26.0 | 8.5 | 27.8 | 9.5 |
| 12                       | 26.3 | 5.9 | 27.0 | 6.1 | 27.8 | 6.6 | 27.8 | 7.4 | 29.5 | 7.6 |
| 13                       | 26.8 | 5.5 | 27.3 | 5.7 | 28.3 | 6.2 | 29.0 | 6.6 | 30.8 | 6.8 |
| 14                       | 27.3 | 5.3 | 28.0 | 6.0 | 28.8 | 6.2 | 28.8 | 6.4 | 30.8 | 7.6 |
| 15                       | 27.3 | 6.0 | 28.0 | 6.1 | 28.5 | 6.4 | 28.5 | 6.5 | 30.5 | 6.1 |
| 16                       | 27.0 | 5.9 | 27.8 | 6.1 | 28.0 | 6.4 | 27.8 | 6.5 | 29.0 | 6.2 |
| 17                       | 27.5 | 6.4 | 27.5 | 4.4 | 27.5 | 5.1 | 27.5 | 5.9 | 27.5 | 5.9 |
| 18                       | 27.0 | 6.2 | 27.0 | 4.6 | 27.0 | 5.5 | 26.5 | 6.2 | 26.0 | 5.0 |
| 19                       | 24.8 | 6.5 | 24.8 | 5.0 | 24.8 | 5.3 | 24.0 | 6.2 | 23.0 | 5.3 |
| 20                       | 22.0 | 6.2 | 22.0 | 4.7 | 21.8 | 4.6 | 21.0 | 5.4 | 20.0 | 5.0 |
| 21                       | 19.5 | 5.6 | 19.3 | 4.7 | 19.0 | 5.0 | 18.5 | 5.3 | 16.8 | 5.0 |
| 22                       | 20.0 | 5.3 | 19.3 | 4.1 | 19.0 | 4.3 | 18.3 | 4.9 | 16.5 | 4.5 |
| 23                       | 16.8 | 5.2 | 16.3 | 4.6 | 16.0 | 4.8 | 15.5 | 5.1 | 15.0 | 4.4 |
| 24                       | 17.5 | 5.2 | 16.5 | 4.1 | 16.0 | 4.4 | 15.0 | 5.0 | 12.3 | 5.1 |
| 1                        | 17.3 | 4.6 | 15.3 | 4.5 | 14.3 | 4.5 | 13.3 | 4.8 | 9.5  | 5.4 |
| 2                        | 13.3 | 4.8 | 10.5 | 5.7 | 9.8  | 5.2 | 9.0  | 5.0 | 6.3  | 5.6 |
| 3                        | 12.8 | 4.3 | 11.0 | 4.2 | 9.0  | 4.5 | 8.0  | 4.5 | 4.3  | 5.6 |
| 4                        | 13.5 | 4.4 | 11.3 | 4.0 | 10.3 | 4.0 | 7.5  | 4.0 | 3.8  | 4.9 |

TABLE A3-1.—Total solar short-wave radiation, albedo, total long- and short-wave net radiation, and soil heatflow

[Solar radiation,  $R_s$ ; albedo,  $R_r$ ; net radiation,  $R_n$ ; and soil heatflow,  $S$ ; all in milliwatts per square centimeter]

| 1-hr. period<br>beginning | $R_s$  |        |        |        | $R_r$     |         |         |         | $R_n$     |        |        |        | $S$       |        |        |        |           |
|---------------------------|--------|--------|--------|--------|-----------|---------|---------|---------|-----------|--------|--------|--------|-----------|--------|--------|--------|-----------|
|                           | Day:   | 5/6    | 6/7    | 7/8    | $\bar{m}$ | 5/6     | 6/7     | 7/8     | $\bar{m}$ | 5/6    | 6/7    | 7/8    | $\bar{m}$ | 5/6    | 6/7    | 7/8    | $\bar{m}$ |
| 5-8 May 1966              |        |        |        |        |           |         |         |         |           |        |        |        |           |        |        |        |           |
| 5                         | 0      | 0      | 0      | 0      | 0         | 0       | 0       | 0       | 0         | -4.18  | -4.18  | -4.88  | -4.41     | 0.77   | 0.63   | 0.91   | 0.77      |
| 6                         | 4.18   | 5.58   | 5.58   | 5.11   | -1.39     | -1.39   | -1.39   | -1.39   | -1.39     | -0.70  | -2.79  | -2.09  | -1.86     | 0.42   | 0.91   | 0.63   | 0.65      |
| 7                         | 20.92  | 22.31  | 25.80  | 23.01  | -4.88     | -5.58   | -6.28   | -5.58   | -5.58     | 9.76   | 9.76   | 12.55  | 10.69     | -0.41  | -0.28  | -0.28  | 0.33      |
| 8                         | 41.84  | 41.84  | 33.47  | 39.05  | -9.06     | -9.06   | -7.67   | -8.60   | -8.60     | 25.10  | 25.00  | 20.22  | 23.71     | -1.81  | -1.74  | -1.12  | -1.56     |
| 9                         | 61.36  | 61.36  | 62.76  | 61.83  | -11.16    | -11.16  | -11.85  | -11.39  | -11.39    | 41.84  | 43.23  | 43.23  | 42.77     | -3.83  | -3.48  | -3.21  | -3.51     |
| 10                        | 76.70  | 77.40  | 77.40  | 77.17  | -12.55    | -12.55  | -13.25  | -12.78  | -12.78    | 57.18  | 56.48  | 57.18  | 56.95     | -3.48  | -3.48  | -2.44  | -3.13     |
| 11                        | 87.16  | 86.47  | 85.77  | 86.47  | -13.25    | -13.25  | -13.25  | -13.25  | -13.25    | 65.55  | 63.45  | 68.34  | 65.78     | -2.86  | -3.00  | -4.11  | -3.32     |
| 12                        | 92.74  | 92.74  | 92.74  | 92.74  | -12.55    | -12.55  | -13.25  | -11.85  | -12.55    | 68.33  | 78.79  | 52.99  | 66.94     | -2.37  | -2.58  | -1.88  | -2.30     |
| 13                        | 92.74  | 92.04  | 92.74  | 92.74  | -12.55    | -13.25  | -13.95  | -13.25  | -13.25    | 52.30  | 76.01  | 78.79  | 69.03     | -1.46  | -1.67  | -2.16  | -1.74     |
| 14                        | 57.18  | 83.68  | 87.86  | 76.01  | -8.37     | -12.55  | -13.25  | -11.16  | -11.16    | 76.70  | 64.15  | 69.03  | 69.73     | -1.74  | -2.44  | -2.23  | -2.16     |
| 15                        | 46.72  | 71.12  | 55.78  | 57.88  | -11.85    | -11.16  | -10.46  | -11.16  | -11.16    | 55.78  | 51.60  | 43.23  | 50.21     | -2.51  | -1.53  | -2.09  | -2.02     |
| 16                        | 57.18  | 53.69  | 46.02  | 52.30  | -9.76     | -9.76   | -9.06   | -9.76   | -9.76     | 38.35  | 36.26  | 29.98  | 34.87     | -1.04  | -0.98  | -1.18  | -1.04     |
| 17                        | 36.26  | 36.96  | 33.47  | 35.56  | -7.67     | -7.67   | -6.28   | -6.97   | -6.97     | 17.43  | 18.13  | 16.04  | 17.43     | -0.91  | -0.84  | -1.05  | -0.91     |
| 18                        | 11.16  | 15.34  | 11.16  | 12.55  | -2.09     | -4.18   | -1.39   | -2.79   | -2.79     | -1.39  | 2.79   | 2.79   | 1.39      | -0.48  | -0.42  | -0.56  | -0.49     |
| 19                        | 3.49   | 4.18   | 2.79   | 3.49   | -0.70     | -1.39   | -0.70   | -0.70   | -0.70     | -4.88  | -4.18  | -3.49  | -4.18     | 0.07   | 0.28   | -0.21  | 0.07      |
| 20                        | 0      | 0      | 0      | 0      | 0         | 0       | 0       | 0       | 0         | -5.58  | -5.58  | -6.28  | -5.58     | 0.49   | 0.77   | 0.07   | 0.42      |
| 21                        | 0      | 0      | 0      | 0      | 0         | 0       | 0       | 0       | 0         | -3.49  | -3.49  | -5.58  | -4.18     | 0.49   | 0.84   | 0.42   | 0.56      |
| 22                        | 0      | 0      | 0      | 0      | 0         | 0       | 0       | 0       | 0         | -9.06  | -4.18  | -6.28  | -6.28     | 0      | 0.91   | 0.28   | 0.42      |
| 23                        | 0      | 0      | 0      | 0      | 0         | 0       | 0       | 0       | 0         | -6.97  | -4.18  | -6.97  | -6.28     | 0.28   | 0.84   | 0.21   | 0.42      |
| 24                        | 0      | 0      | 0      | 0      | 0         | 0       | 0       | 0       | 0         | -4.88  | -4.18  | -8.37  | -5.58     | 0.77   | 0.84   | 0      | 0.56      |
| 1                         | 0      | 0      | 0      | 0      | 0         | 0       | 0       | 0       | 0         | -4.88  | -4.18  | -7.67  | -5.58     | 0.77   | 0.63   | 0.07   | 0.49      |
| 2                         | 0      | 0      | 0      | 0      | 0         | 0       | 0       | 0       | 0         | -4.18  | -4.88  | -4.88  | -4.88     | 0.84   | 0.56   | 0.42   | 0.63      |
| 3                         | 0      | 0      | 0      | 0      | 0         | 0       | 0       | 0       | 0         | -4.18  | -4.18  | -2.79  | -3.49     | 0.91   | 0.91   | 0.56   | 0.77      |
| 4                         | 0      | 0      | 0      | 0      | 0         | 0       | 0       | 0       | 0         | -4.18  | -4.18  | -0.70  | -2.79     | 0.84   | 0.91   | 0.63   | 0.77      |
| Total                     | 689.63 | 800.50 | 693.12 | 709.15 | -117.84   | -126.21 | -120.63 | -120.63 | -120.63   | 449.76 | 476.26 | 434.42 | 453.94    | -16.31 | -13.45 | -17.98 | -16.03    |

| 1-hr. period<br>beginning | $R_s$  |        |        |        | $R_r$     |         |         |         | $R_n$     |        |        |        | $S$       |       |       |       |           |
|---------------------------|--------|--------|--------|--------|-----------|---------|---------|---------|-----------|--------|--------|--------|-----------|-------|-------|-------|-----------|
|                           | Day:   | 3/4    | 4/5    | 5/6    | $\bar{m}$ | 3/4     | 4/5     | 5/6     | $\bar{m}$ | 3/4    | 4/5    | 5/6    | $\bar{m}$ | 3/4   | 4/5   | 5/6   | $\bar{m}$ |
| 4-6 June 1966             |        |        |        |        |           |         |         |         |           |        |        |        |           |       |       |       |           |
| 5                         | 0      | 0      | 0      | 0      | 0         | 0       | 0       | 0       | 0         | -5.58  | -5.58  | -5.58  | -5.58     | 1.25  | 1.25  | 1.05  | 1.18      |
| 6                         | 9.06   | 7.67   | 9.06   | 8.37   | -2.09     | -1.39   | -1.39   | -1.39   | -1.39     | -0.70  | 0      | 0      | 0         | 0.84  | 0.91  | 0.77  | 0.84      |
| 7                         | 29.98  | 27.89  | 27.89  | 28.59  | -7.67     | -6.97   | -6.97   | -6.97   | -6.97     | 13.95  | 12.55  | 13.25  | 13.25     | 0.14  | 0     | 0     | 0.07      |
| 8                         | 49.51  | 48.11  | 48.81  | 48.81  | -11.16    | -11.16  | -11.16  | -11.16  | -11.16    | 29.98  | 29.29  | 29.98  | 29.98     | -0.35 | -0.42 | -0.42 | -0.42     |
| 9                         | 69.03  | 68.34  | 67.64  | 68.34  | -13.25    | -13.25  | -13.25  | -13.25  | -13.25    | 46.02  | 46.02  | 46.02  | 46.02     | -1.25 | -1.81 | -1.81 | -1.60     |
| 10                        | 84.37  | 83.68  | 82.28  | 83.68  | -14.64    | -14.64  | -13.95  | -14.64  | -14.64    | 60.67  | 61.36  | 59.27  | 60.67     | -1.74 | -1.67 | -1.60 | -1.67     |
| 11                        | 94.14  | 92.74  | 92.04  | 92.74  | -15.34    | -15.34  | -15.34  | -15.34  | -15.34    | 70.43  | 70.42  | 70.42  | 70.43     | -1.74 | -2.16 | -2.02 | -1.95     |
| 12                        | 99.71  | 98.32  | 97.62  | 98.32  | -16.04    | -16.04  | -16.04  | -16.04  | -16.04    | 73.91  | 73.91  | 73.22  | 73.91     | -2.16 | -2.44 | -2.30 | -2.30     |
| 13                        | 99.71  | 98.32  | 98.32  | 99.02  | -16.04    | -16.04  | -16.04  | -16.04  | -16.04    | 73.22  | 72.52  | 73.22  | 73.22     | -1.25 | -1.25 | -1.39 | -1.32     |
| 14                        | 91.35  | 90.65  | 90.65  | 90.65  | -15.34    | -15.34  | -15.34  | -15.34  | -15.34    | 72.92  | 72.52  | 65.55  | 70.42     | -2.93 | -3.62 | -3.62 | -3.42     |
| 15                        | 78.79  | 83.68  | 76.01  | 79.49  | -13.95    | -13.95  | -13.95  | -13.95  | -13.95    | 55.09  | 53.69  | 54.39  | 54.39     | -1.25 | -1.39 | -1.60 | -1.39     |
| 16                        | 60.67  | 60.67  | 62.06  | 61.36  | -11.85    | -11.85  | -11.85  | -11.85  | -11.85    | 38.35  | 38.35  | 38.35  | 38.35     | -0.91 | -0.98 | -1.05 | -0.98     |
| 17                        | 39.75  | 41.84  | 41.84  | 41.14  | -9.76     | -9.76   | -9.76   | -9.76   | -9.76     | 20.22  | 19.52  | 20.22  | 20.22     | -0.63 | -0.77 | -0.91 | -0.77     |
| 18                        | 21.62  | 22.31  | 13.95  | 19.52  | -6.28     | -6.28   | -3.49   | -5.58   | -5.58     | 2.79   | 2.79   | 0      | 2.09      | 0     | -0.56 | -0.56 | -0.35     |
| 19                        | 4.88   | 4.88   | 4.18   | 4.88   | -1.39     | -1.39   | -0.70   | -1.39   | -1.39     | -9.06  | -9.06  | -4.18  | -7.67     | 0.07  | -0.21 | 0     | -0.07     |
| 20                        | 0      | 0      | 0      | 0      | 0         | 0       | 0       | 0       | 0         | -9.76  | -9.76  | -0.70  | -6.97     | 0.49  | 0.35  | 0.49  | 0.42      |
| 21                        | 0      | 0      | 0      | 0      | 0         | 0       | 0       | 0       | 0         | -8.37  | -7.67  | -6.28  | -7.67     | 0.77  | 0.70  | 0.70  | 0.70      |
| 22                        | 0      | 0      | 0      | 0      | 0         | 0       | 0       | 0       | 0         | -6.97  | -6.97  | -4.88  | -6.28     | 0.91  | 0.98  | 0.91  | 0.91      |
| 23                        | 0      | 0      | 0      | 0      | 0         | 0       | 0       | 0       | 0         | -6.28  | -6.28  | ----   | -4.18     | 0.77  | 1.05  | 0.91  | 0.91      |
| 24                        | 0      | 0      | 0      | 0      | 0         | 0       | 0       | 0       | 0         | -6.28  | -6.28  | -4.88  | -6.28     | 1.18  | 0.98  | 0.98  | 1.05      |
| 1                         | 0      | 0      | 0      | 0      | 0         | 0       | 0       | 0       | 0         | -5.58  | -4.88  | -5.58  | -5.58     | 1.25  | 1.05  | 1.05  | 1.12      |
| 2                         | 0      | 0      | 0      | 0      | 0         | 0       | 0       | 0       | 0         | -6.28  | -4.88  | -6.28  | -5.58     | 1.12  | 1.12  | 0.98  | 1.05      |
| 3                         | 0      | 0      | 0      | 0      | 0         | 0       | 0       | 0       | 0         | -4.88  | -5.58  | -4.88  | -4.88     | 1.12  | 1.05  | 1.05  | 1.05      |
| 4                         | 0      | 0      | 0      | 0      | 0         | 0       | 0       | 0       | 0         | -5.58  | -4.88  | -4.88  | -4.88     | 1.12  | 1.05  | 1.05  | 1.05      |
| Total                     | 832.58 | 829.09 | 812.35 | 824.91 | -154.80   | -154.10 | -149.22 | -152.71 | -152.71   | 481.83 | 481.14 | 495.78 | 487.41    | -3.35 | -6.83 | -7.39 | -5.92     |

TABLE A3-1.—Total solar short-wave radiation, albedo, total long- and short-wave net radiation, and soil heatflow—Continued

| 1-hr period<br>beginning | R <sub>s</sub> |        |        |        | R <sub>t</sub> |         |         |         | R <sub>n</sub> |        |        |        | S         |        |       |        |           |
|--------------------------|----------------|--------|--------|--------|----------------|---------|---------|---------|----------------|--------|--------|--------|-----------|--------|-------|--------|-----------|
|                          | Day:           | 6/7    | 7/8    | 8/9    | $\bar{m}$      | 6/7     | 7/8     | 8/9     | $\bar{m}$      | 6/7    | 7/8    | 8/9    | $\bar{m}$ | 6/7    | 7/8   | 8/9    | $\bar{m}$ |
| 7-9 July 1966            |                |        |        |        |                |         |         |         |                |        |        |        |           |        |       |        |           |
| 5                        | 0.70           | 0      | 0      | 0      | 0              | 0       | 0       | 0       | 0              | -4.88  | -3.49  | -5.58  | -4.88     | 1.12   | 0.63  | 0.21   | 0.63      |
| 6                        | 7.67           | 7.67   | 2.79   | 6.28   | -1.39          | -1.39   | -0.70   | -1.39   | -1.39          | -0.70  | -0.70  | -2.09  | -1.39     | 0.91   | 0.35  | 0.28   | 0.49      |
| 7                        | 26.50          | 26.50  | 23.71  | 25.80  | -6.97          | -6.28   | -5.58   | -6.28   | -6.28          | 11.16  | 12.55  | 11.85  | 11.85     | 0.14   | -0.14 | -0.07  | 0         |
| 8                        | 46.92          | 37.65  | 42.54  | 42.54  | -11.16         | -9.06   | -9.76   | -9.76   | -9.76          | 27.89  | 17.43  | 27.89  | 24.41     | -0.42  | -0.63 | -0.28  | -0.42     |
| 9                        | 65.55          | 29.29  | 60.67  | 51.60  | -13.25         | -6.28   | -11.85  | -13.95  | -13.95         | 43.93  | 25.10  | 43.93  | 37.65     | -2.65  | -0.63 | -1.74  | -1.67     |
| 10                       | 80.19          | 82.28  | 76.01  | 79.49  | -14.64         | -13.95  | -13.95  | -13.95  | -13.95         | 56.48  | 56.48  | 57.88  | 57.18     | -1.39  | -0.91 | -0.84  | -1.05     |
| 11                       | 89.29          | 87.16  | 86.47  | 87.86  | -16.04         | -15.34  | -15.34  | -15.34  | -15.34         | 65.55  | 66.94  | 69.03  | 66.94     | -1.67  | -1.53 | -1.32  | -1.53     |
| 12                       | 94.14          | 89.25  | 90.65  | 91.35  | -16.74         | -12.55  | -15.34  | -16.04  | -14.64         | 69.73  | 70.43  | 71.82  | 69.25     | -1.95  | -1.74 | -1.60  | -1.75     |
| 13                       | 94.14          | 63.45  | 91.35  | 82.98  | -16.04         | -12.55  | -16.04  | -14.64  | -14.64         | 68.34  | 48.81  | 71.82  | 62.76     | -1.60  | -1.05 | -0.98  | -1.18     |
| 14                       | 86.47          | 89.95  | 85.77  | 87.16  | -18.13         | -16.74  | -15.34  | -16.74  | -16.74         | 61.36  | 66.94  | 66.24  | 64.85     | -2.30  | -2.30 | -2.09  | -2.23     |
| 15                       | 70.43          | 73.91  | 74.61  | 73.22  | -12.55         | -13.95  | -13.95  | -13.95  | -13.95         | 47.42  | 52.99  | 55.78  | 52.30     | -2.16  | -1.32 | -1.46  | -1.67     |
| 16                       | 50.21          | 52.99  | 59.97  | 54.39  | -9.37          | -10.46  | -11.16  | -9.76   | -9.76          | 19.52  | 27.19  | 39.75  | 28.59     | -1.18  | -0.84 | -0.77  | -0.91     |
| 17                       | 39.75          | 15.34  | 36.26  | 30.28  | -9.06          | -3.49   | -8.37   | -6.97   | -6.97          | 16.03  | 2.79   | 19.52  | 12.55     | -1.12  | -0.42 | -0.63  | -0.70     |
| 18                       | 19.52          | 12.55  | 23.01  | 18.13  | -5.58          | -2.09   | -6.28   | -4.88   | -4.88          | 2.09   | 2.79   | 8.37   | 4.18      | -0.84  | -0.28 | -0.56  | -0.56     |
| 19                       | 5.58           | 4.88   | 6.97   | 5.58   | -1.39          | -0.70   | -2.09   | -1.39   | -1.39          | -7.67  | -2.79  | 8.37   | 4.18      | -0.49  | -0.28 | -0.28  | -0.35     |
| 20                       | 0              | 0      | 0      | 0      | 0              | 0       | 0       | 0       | 0              | -10.46 | -6.28  | -6.97  | -7.67     | -0.28  | -0.07 | 0      | -0.07     |
| 21                       | 0              | 0      | 0      | 0      | 0              | 0       | 0       | 0       | 0              | -9.76  | -4.18  | -5.58  | -6.28     | -0.07  | 0.07  | 0.14   | 0.07      |
| 22                       | 0              | 0      | 0      | 0      | 0              | 0       | 0       | 0       | -9.76          | -4.18  | -4.88  | -6.28  | -6.28     | -0.14  | 0.28  | 0.07   | 0.07      |
| 23                       | 0              | 0      | 0      | 0      | 0              | 0       | 0       | 0       | 0              | -6.97  | -3.49  | -6.97  | -5.58     | 0.14   | 0.28  | 0      | 0.14      |
| 24                       | 0              | 0      | 0      | 0      | 0              | 0       | 0       | 0       | 0              | -4.88  | -4.88  | -6.28  | -5.58     | 0.49   | 0.49  | 0.07   | 0.35      |
| 1                        | 0              | 0      | 0      | 0      | 0              | 0       | 0       | 0       | 0              | -4.88  | -4.18  | -4.88  | -4.88     | 0.42   | 0.49  | 0.07   | 0.35      |
| 2                        | 0              | 0      | 0      | 0      | 0              | 0       | 0       | 0       | 0              | -4.88  | -5.58  | -4.88  | -4.88     | 0.49   | 0.28  | 0.07   | 0.28      |
| 3                        | 0              | 0      | 0      | 0      | 0              | 0       | 0       | 0       | 0              | -4.88  | -5.58  | -5.58  | -5.58     | 0.63   | 0.14  | 0      | 0.28      |
| 4                        | 0              | 0      | 0      | 0      | 0              | 0       | 0       | 0       | 0              | -4.88  | -5.58  | -4.18  | -4.88     | 0.63   | 0.21  | 0.14   | 0.35      |
| Total                    | 776.79         | 672.89 | 760.75 | 737.05 | -151.31        | -124.82 | -145.74 | -142.95 | -142.95        | 414.89 | 399.55 | 483.23 | 450.46    | -13.59 | -8.78 | -11.57 | -11.08    |

| 1-hr period<br>beginning | R <sub>s</sub> |        |        |        | R <sub>r</sub> |         |         |        | R <sub>n</sub> |        |        |        | S         |        |        |        |           |
|--------------------------|----------------|--------|--------|--------|----------------|---------|---------|--------|----------------|--------|--------|--------|-----------|--------|--------|--------|-----------|
|                          | Day:           | 3/4    | 4/5    | 5/6    | $\bar{m}$      | 3/4     | 4/5     | 5/6    | $\bar{m}$      | 3/4    | 4/5    | 5/6    | $\bar{m}$ | 3/4    | 4/5    | 5/6    | $\bar{m}$ |
| 4-6 August 1966          |                |        |        |        |                |         |         |        |                |        |        |        |           |        |        |        |           |
| 5                        |                | 0      | 0      | 0      | 0              | 0       | 0       | 0      | 0              | -4.88  | -4.18  | -3.49  | -4.18     | 0.07   | 0.21   | 0.35   | 0.21      |
| 6                        |                | 2.79   | 2.09   | 2.79   | 2.79           | -5.58   | -0.70   | -2.09  | -2.09          | -1.39  | -0.70  | -1.39  | -1.39     | 0      | 0.28   | 0.28   | 0.21      |
| 7                        |                | 23.01  | 17.43  | 18.13  | 19.52          | -6.97   | -4.88   | -4.88  | -5.58          | 12.55  | 9.06   | 9.76   | 10.46     | -0.49  | 0      | -0.07  | -0.21     |
| 8                        |                | 30.68  | 38.35  | 36.26  | 34.87          | -8.37   | -9.76   | -8.37  | -9.06          | 20.92  | 25.10  | 21.62  | 22.31     | -0.77  | -0.49  | -0.42  | -0.56     |
| 9                        |                | 31.38  | 56.48  | 56.48  | 48.11          | -11.16  | -11.85  | -11.85 | -11.85         | 29.29  | 42.54  | 41.14  | 37.65     | -1.12  | -1.46  | -1.32  | -1.32     |
| 10                       |                | 50.90  | 70.43  | 68.34  | 63.45          | -9.06   | -13.25  | -12.55 | -11.85         | 48.81  | 56.48  | 52.30  | 52.30     | -1.60  | -1.88  | -1.60  | -1.67     |
| 11                       |                | 55.09  | 78.79  | 82.98  | 72.52          | -9.06   | -13.95  | -14.64 | -12.55         | 44.63  | 64.85  | 65.55  | 58.57     | -1.46  | -1.67  | -1.53  | -1.53     |
| 12                       |                | 51.60  | 80.19  | 85.77  | 72.52          | -7.67   | -14.64  | -15.34 | -12.55         | 36.26  | 66.24  | 68.35  | 57.18     | -1.53  | -1.67  | -1.60  | -1.60     |
| 13                       |                | 73.22  | 86.47  | 76.01  | 78.79          | -12.55  | -13.95  | -14.64 | -13.95         | 50.21  | 68.34  | 65.55  | 61.36     | -1.67  | -1.88  | -1.74  | -1.74     |
| 14                       |                | 52.99  | 78.79  | 63.45  | 65.85          | -11.16  | -12.55  | -11.85 | -11.85         | 42.54  | 63.45  | 49.51  | 51.60     | -1.67  | -1.95  | -1.67  | -1.74     |
| 15                       |                | 41.84  | 65.55  | 41.84  | 49.51          | -8.37   | -10.46  | -8.37  | -9.06          | 33.47  | 50.21  | 28.59  | 37.65     | -1.32  | -1.81  | -1.53  | -1.53     |
| 16                       |                | 39.75  | 50.90  | 36.96  | 42.54          | -8.37   | -7.67   | -7.67  | -7.67          | 29.98  | 35.56  | 26.50  | 30.68     | -1.18  | -1.53  | -1.32  | -1.32     |
| 17                       |                | 18.13  | 32.77  | 24.41  | 25.10          | -4.18   | -4.16   | -5.58  | -4.88          | 9.76   | 20.22  | 15.34  | 15.34     | -0.84  | -1.32  | -1.18  | -1.12     |
| 18                       |                | 12.55  | 14.64  | 14.64  | 13.95          | -3.47   | -0.70   | -3.49  | -2.79          | 4.88   | 4.18   | 6.28   | 4.88      | -0.63  | -0.98  | -0.84  | -0.84     |
| 19                       |                | 0.70   | 1.39   | 2.09   | 1.39           | -0.70   | 0       | -3.49  | -1.39          | -4.18  | -4.88  | 2.09   | -2.09     | -0.49  | -0.63  | -0.98  | -0.70     |
| 20                       |                | 0      | 0      | 0      | 0              | 0       | 0       | -0.70  | 0              | -6.97  | -5.58  | -4.18  | -5.58     | -0.28  | -0.14  | -0.70  | -0.35     |
| 21                       |                | 0      | 0      | 0      | 0              | 0       | 0       | 0      | 0              | -6.28  | -6.28  | -6.97  | -6.28     | -0.28  | -0.21  | -0.42  | -0.28     |
| 22                       |                | 0      | 0      | 0      | 0              | 0       | 0       | 0      | 0              | -5.58  | -4.88  | -6.97  | -5.58     | -0.14  | 0      | -0.28  | -0.14     |
| 23                       |                | 0      | 0      | 0      | 0              | 0       | 0       | 0      | 0              | -6.28  | m5.58  | -4.88  | -5.58     | 0      | -0.14  | -0.14  | -0.07     |
| 24                       |                | 0      | 0      | 0      | 0              | 0       | 0       | 0      | 0              | -6.28  | -6.97  | -4.88  | -6.28     | 0      | 0      | -0.07  | 0         |
| 1                        |                | 0      | 0      | 0      | 0              | 0       | 0       | 0      | 0              | -4.88  | -6.97  | -4.88  | -5.58     | 0.07   | -0.07  | 0      | 0         |
| 2                        |                | 0      | 0      | 0      | 0              | 0       | 0       | 0      | 0              | -4.88  | -5.97  | -4.88  | -4.88     | 0.14   | 0.07   | 0.07   | 0.07      |
| 3                        |                | 0      | 0      | 0      | 0              | 0       | 0       | 0      | 0              | -4.18  | -4.88  | -4.88  | -4.88     | 0.21   | 0.21   | 0.07   | 0.14      |
| 4                        |                | 0      | 0      | 0      | 0              | 0       | 0       | 0      | 0              | 0      | -4.18  | -4.18  | -4.88     | 0.21   | 0.21   | 0.07   | 0.14      |
| Total                    |                | 484.62 | 674.29 | 610.14 | 589.92         | -106.69 | -118.54 | 123.42 | -117.15        | 302.63 | 444.88 | 400.95 | 383.52    | -14.92 | -17.01 | -16.73 | -16.03    |

WEATHER AND EVAPOTRANSPIRATION STUDIES IN A SALT CEDAR THICKET, ARIZONA

TABLE A3-1.—Total solar short-wave radiation, albedo, total long- and short-wave net radiation, and soil heatflow—Continued

| 1-hr period<br>beginning | R <sub>s</sub> |        |        |        | R <sub>t</sub> |         |         |         | R <sub>n</sub> |        |        |        | S      |       |       |       |       |
|--------------------------|----------------|--------|--------|--------|----------------|---------|---------|---------|----------------|--------|--------|--------|--------|-------|-------|-------|-------|
|                          | Day:           | 8/9    | 9/10   | 10/11  | m              | 8/9     | 9/10    | 10/11   | m              | 8/9    | 9/10   | 10/11  | m      | 8/9   | 9/10  | 10/11 | m     |
| 9-11 September 1966      |                |        |        |        |                |         |         |         |                |        |        |        |        |       |       |       |       |
| 5                        | 0              | 0      | 0      | 0      | 0              | 0       | 0       | 0       | 0              | -5.58  | -6.28  | -6.97  | -6.27  | 0.91  | 0.77  | 0.98  | 0.91  |
| 6                        | 1.39           | 0.70   | 0.70   | 0      | 0              | 0       | 0       | 0       | 0              | -4.88  | -5.58  | -6.28  | -5.58  | 0.91  | 0.70  | 1.05  | 0.91  |
| 7                        | 11.85          | 6.97   | 11.85  | 10.46  | -4.18          | -2.09   | -4.18   | -3.49   | -2.79          | -2.79  | -1.39  | 2.09   | -2.09  | 0.42  | 0.42  | 0.56  | 0.49  |
| 8                        | 32.77          | 30.68  | 32.77  | 32.08  | -9.06          | -8.37   | -9.06   | -9.06   | -9.06          | 16.04  | 16.74  | 18.13  | 16.74  | 0.49  | -0.42 | -0.56 | -0.14 |
| 9                        | 52.30          | 50.21  | 51.60  | 51.60  | -11.85         | -11.85  | -11.85  | -11.85  | -11.85         | 32.08  | 30.68  | 36.96  | 33.47  | -0.84 | -0.70 | -0.56 | -0.70 |
| 10                       | 67.64          | 66.24  | 67.64  | 66.94  | -13.25         | -13.25  | -13.25  | -13.25  | -13.25         | 46.02  | 46.02  | 52.30  | 48.11  | -2.16 | -2.23 | -1.60 | -2.02 |
| 11                       | 78.10          | 78.10  | 77.40  | 78.10  | -13.95         | -13.95  | -13.95  | -13.95  | -13.95         | 55.09  | 55.78  | 62.06  | 57.88  | -1.32 | -1.46 | -1.25 | -1.32 |
| 12                       | 82.98          | 78.10  | 82.98  | 81.58  | -13.95         | -13.95  | -13.95  | -14.64  | -13.95         | 58.57  | 55.09  | 68.34  | 60.67  | -1.67 | -1.53 | -1.60 | -1.60 |
| 13                       | 82.28          | 75.31  | 82.28  | 80.19  | -13.95         | -13.95  | -13.95  | -14.64  | -13.95         | 59.27  | 58.57  | 68.34  | 62.06  | -2.02 | -2.16 | -2.23 | -2.16 |
| 14                       | 73.22          | 68.34  | 70.43  | 70.43  | -13.25         | -11.85  | -11.16  | -11.85  | -11.85         | 52.99  | 47.42  | 49.51  | 50.21  | -1.81 | -1.81 | -1.60 | -1.74 |
| 15                       | 62.06          | 41.84  | 37.65  | 47.42  | -11.85         | -8.27   | -7.67   | -7.67   | -9.06          | 42.84  | 25.80  | 31.38  | 32.77  | -1.18 | -1.12 | -0.98 | -1.12 |
| 16                       | 67.72          | 32.08  | 22.31  | 33.47  | -9.76          | -6.97   | -3.49   | -6.97   | -6.97          | 25.80  | 19.52  | 5.58   | 16.74  | -0.91 | -0.84 | -0.91 | -0.91 |
| 17                       | 24.41          | 24.41  | 15.34  | 21.62  | -6.97          | -7.67   | -3.49   | -6.28   | -6.28          | 7.67   | 12.55  | 3.49   | 7.67   | -0.56 | -0.63 | -0.28 | -0.49 |
| 18                       | 8.37           | 7.67   | 4.88   | 6.97   | -2.39          | -2.79   | -2.09   | -2.79   | -2.79          | -4.18  | -4.18  | -4.88  | -4.18  | -0.14 | -0.14 | 0.07  | -0.14 |
| 19                       | 0              | 0      | 0      | 0      | 0              | 0       | 0       | 0       | 0              | -6.97  | -8.37  | -7.67  | -7.67  | 0.42  | 0.35  | 0.49  | 0.42  |
| 20                       | 0              | 0      | 0      | 0      | 0              | 0       | 0       | 0       | 0              | -6.28  | -6.97  | -8.37  | -6.97  | 0.77  | 0.77  | 0.63  | 0.70  |
| 21                       | 0              | 0      | 0      | 0      | 0              | 0       | 0       | 0       | 0              | -6.28  | -6.28  | -11.16 | -7.67  | 0.84  | 0.84  | 0.14  | 0.63  |
| 22                       | 0              | 0      | 0      | 0      | 0              | 0       | 0       | 0       | 0              | -5.58  | -6.97  | -10.46 | -7.67  | 0.91  | 0.84  | 0.21  | 0.63  |
| 23                       | 0              | 0      | 0      | 0      | 0              | 0       | 0       | 0       | 0              | -5.58  | -7.67  | -8.37  | -6.97  | 0.91  | 0.63  | 0.35  | 0.63  |
| 24                       | 0              | 0      | 0      | 0      | 0              | 0       | 0       | 0       | 0              | -6.97  | -8.37  | -4.88  | -6.97  | 0.77  | 0.56  | 0.56  | 0.63  |
| 1                        | 0              | 0      | 0      | 0      | 0              | 0       | 0       | 0       | 0              | -6.28  | -6.97  | -4.88  | -6.28  | 0.70  | 0.77  | 0.56  | 0.70  |
| 2                        | 0              | 0      | 0      | 0      | 0              | 0       | 0       | 0       | 0              | -6.97  | -6.28  | -6.28  | -6.28  | 0.84  | 0.98  | 0.77  | 0.84  |
| 3                        | 0              | 0      | 0      | 0      | 0              | 0       | 0       | 0       | 0              | -6.28  | -6.28  | -6.97  | -6.28  | 0.98  | 0.91  | 0.84  | 0.91  |
| 4                        | 0              | 0      | 0      | 0      | 0              | 0       | 0       | 0       | 0              | -6.28  | -6.97  | -6.28  | 6.28   | 0.91  | 0.91  | 0.84  | 0.91  |
| Total                    | 624.08         | 560.63 | 557.84 | 581.55 | -124.82        | -115.05 | -109.48 | -116.45 | 314.48         | 279.62 | 304.72 | 299.84 | 299.84 | -1.88 | -3.62 | -3.55 | -3.07 |

| 1-hr period<br>beginning | R <sub>s</sub> |        |        |        | R <sub>t</sub> |         |         |        | R <sub>n</sub> |        |        |        | S      |       |       |       |       |
|--------------------------|----------------|--------|--------|--------|----------------|---------|---------|--------|----------------|--------|--------|--------|--------|-------|-------|-------|-------|
|                          | Day            | 23/24  | 24/25  | 25/26  | m              | 23/24   | 24/25   | 25/26  | m              | 23/24  | 24/25  | 25/26  | m      | 23/24 | 24/25 | 25/26 | m     |
| 24-26 March 1967         |                |        |        |        |                |         |         |        |                |        |        |        |        |       |       |       |       |
| 5                        | 0              | 0      | 0      | 0      | 0              | 0       | 0       | 0      | 0              | -----  | -4.88  | -7.67  | -6.28  | ----- | 0.56  | 1.25  | 0.91  |
| 6                        | 0              | 0      | 0      | 0      | 0              | 0       | 0       | 0      | 0              | -6.28  | -6.97  | -7.67  | -6.97  | 1.18  | 0.63  | 1.18  | 0.98  |
| 7                        | 3.49           | 3.49   | 6.28   | 4.18   | -1.39          | -0.70   | -1.39   | -1.39  | -1.39          | -3.49  | -2.79  | -2.79  | -2.79  | 0.77  | 0.63  | 0.98  | 0.77  |
| 8                        | 20.92          | 21.62  | 23.71  | 22.31  | -5.58          | -6.28   | -6.97   | -6.28  | -6.97          | 13.95  | 8.37   | 9.76   | 9.76   | 0     | -0.14 | -0.14 | 0     |
| 9                        | 48.81          | 51.60  | 44.63  | 48.11  | -10.46         | -110.46 | -11.16  | -10.46 | -10.46         | 29.29  | 27.19  | 25.80  | 27.19  | -0.56 | -0.63 | -0.21 | -0.49 |
| 10                       | 62.76          | 62.76  | 62.76  | 62.76  | -12.55         | -11.85  | -12.55  | -12.55 | -12.55         | 41.14  | 41.84  | 42.54  | 41.84  | -0.84 | -0.77 | -0.35 | -0.63 |
| 11                       | 76.01          | 78.79  | 76.01  | 76.70  | -13.95         | -13.95  | -13.95  | -13.95 | -13.95         | 52.99  | 57.18  | 54.39  | 55.09  | -1.32 | -1.25 | -0.77 | -1.12 |
| 12                       | 81.58          | 60.67  | 82.98  | 75.31  | -13.95         | -9.76   | -13.95  | -13.95 | -12.55         | 58.57  | 36.26  | 60.67  | 51.60  | -3.83 | -1.95 | -2.51 | -2.79 |
| 13                       | 61.36          | 56.48  | 83.68  | 66.94  | -11.16         | -9.06   | -13.95  | -13.95 | -11.16         | 40.44  | 36.26  | 62.06  | 46.02  | -2.44 | -1.67 | -2.44 | -2.16 |
| 14                       | 47.42          | 61.36  | 67.64  | 58.57  | -9.06          | -11.85  | -11.85  | -11.16 | -11.16         | 32.08  | 44.63  | 57.18  | 44.63  | -1.74 | -2.23 | -2.16 | -2.02 |
| 15                       | 43.23          | 61.36  | 66.24  | 57.18  | -8.37          | -11.16  | -12.55  | -10.46 | -10.46         | 24.41  | 35.56  | 45.32  | 34.87  | -1.32 | -1.32 | -1.39 | -1.32 |
| 16                       | 24.41          | 46.02  | 41.84  | 37.65  | -4.18          | -9.06   | -9.06   | -7.67  | -7.67          | 10.46  | 27.89  | 22.31  | 20.22  | -0.70 | -0.77 | -0.42 | -0.63 |
| 17                       | 13.95          | 22.31  | 24.41  | 20.22  | -2.79          | -5.58   | -5.58   | -4.88  | -4.88          | 2.79   | 3.49   | 5.58   | 4.18   | -0.28 | 0.07  | 0.14  | 0     |
| 18                       | 4.88           | 7.67   | 9.06   | 6.97   | -0.70          | -2.79   | -2.79   | -2.09  | -2.09          | -3.49  | -6.28  | -4.18  | -4.88  | 0.21  | 0.28  | 0.35  | 0.28  |
| 19                       | 0              | 0      | 0.70   | 0      | 0              | 0       | 0       | 0      | 0              | -6.97  | -11.16 | -9.76  | -9.06  | 0.63  | 0.56  | 1.05  | 0.77  |
| 20                       | 0              | 0      | 0      | 0      | 0              | 0       | 0       | 0      | 0              | -6.28  | -9.76  | -8.37  | -8.37  | 0.70  | 0.70  | 1.25  | 0.91  |
| 21                       | 0              | 0      | 0      | 0      | 0              | 0       | 0       | 0      | 0              | -9.06  | -6.97  | -5.58  | -6.97  | 0.70  | 0.70  | 1.12  | 0.84  |
| 22                       | 0              | 0      | 0      | 0      | 0              | 0       | 0       | 0      | 0              | -11.85 | -9.06  | -6.97  | -9.06  | 0.21  | 0.77  | 1.18  | 0.70  |
| 23                       | 0              | 0      | 0      | 0      | 0              | 0       | 0       | 0      | 0              | -11.16 | -10.46 | -6.97  | -9.76  | 0.28  | 0.70  | 1.12  | 0.70  |
| 24                       | 0              | 0      | 0      | 0      | 0              | 0       | 0       | 0      | 0              | -9.06  | -11.16 | -7.67  | -9.06  | 0.63  | 0.63  | 0.98  | 0.77  |
| 1                        | 0              | 0      | 0      | 0      | 0              | 0       | 0       | 0      | 0              | -7.67  | -11.16 | -7.67  | -9.06  | 0.91  | 0.63  | 0.98  | 0.84  |
| 2                        | 0              | 0      | 0      | 0      | 0              | 0       | 0       | 0      | 0              | -5.58  | -9.76  | -6.28  | -6.97  | 0.84  | 0.77  | 0.98  | 0.84  |
| 3                        | 0              | 0      | 0      | 0      | 0              | 0       | 0       | 0      | 0              | -4.88  | -9.06  | -6.28  | -6.97  | 0.77  | 0.91  | 1.18  | 0.98  |
| 4                        | 0              | 0      | 0      | 0      | 0              | 0       | 0       | 0      | 0              | -4.88  | -8.37  | -5.58  | -6.28  | 0.56  | 0.98  | 1.12  | 0.91  |
| Total                    | 488.81         | 534.13 | 589.92 | 536.92 | -94.14         | -102.50 | -115.75 | 104.60 | 208.49         | 206.40 | 290.77 | 232.90 | 232.90 | -4.67 | -1.25 | -4.75 | 0.07  |

TABLE A3-1.—Total solar short-wave radiation, albedo, total long- and short-wave net radiation, and soil heatflow—Continued

| 1-hr period<br>beginning | R <sub>s</sub> |        |        |        | R <sub>t</sub> |         |         |         | R <sub>n</sub> |        |        |        | S         |       |       |       |           |
|--------------------------|----------------|--------|--------|--------|----------------|---------|---------|---------|----------------|--------|--------|--------|-----------|-------|-------|-------|-----------|
|                          | Day            | 11/12  | 12/13  | 13/14  | $\bar{m}$      | 11/12   | 12/13   | 13/14   | $\bar{m}$      | 11/12  | 12/13  | 13/14  | $\bar{m}$ | 11/12 | 12/13 | 13/14 | $\bar{m}$ |
| 12-14 May 1967           |                |        |        |        |                |         |         |         |                |        |        |        |           |       |       |       |           |
| 5                        | -----          | 0      | 0      | 0      | 0              | 0       | 0       | 0       | 0              | -6.27  | -6.97  | -7.67  | -6.97     | 1.12  | 1.05  | 0.77  | 0.98      |
| 6                        | -----          | 4.88   | 4.88   | 4.88   | 4.88           | -1.39   | -0.70   | -1.39   | -1.39          | -2.09  | -2.79  | -4.18  | -2.79     | 1.12  | 0.91  | 0.63  | 0.91      |
| 7                        | -----          | 24.41  | 10.46  | 23.71  | 19.52          | -6.28   | -2.09   | -6.28   | -4.88          | 9.76   | 1.39   | 9.06   | 6.97      | 0.42  | 0.56  | 0.14  | 0.35      |
| 8                        | -----          | 46.02  | 43.23  | 43.93  | 42.93          | -11.16  | -12.55  | -11.16  | -11.85         | 28.59  | 25.10  | 25.80  | 26.50     | -0.21 | -0.14 | -0.35 | -0.21     |
| 9                        | -----          | 66.24  | 66.24  | 64.85  | 65.55          | -14.64  | -14.64  | -14.64  | -14.64         | 46.72  | 44.63  | 43.93  | 45.32     | -1.05 | -1.12 | -1.12 | -1.12     |
| 10                       | -----          | 83.68  | 80.89  | 80.89  | 81.58          | -15.34  | -15.34  | -15.34  | -15.34         | 62.76  | 59.97  | 58.57  | 60.67     | -0.70 | -1.05 | -1.05 | -0.91     |
| 11                       | -----          | 94.14  | 91.35  | 91.35  | 92.04          | -16.04  | -16.04  | -16.04  | -16.04         | 71.82  | 69.73  | 69.03  | 70.43     | -0.77 | -1.05 | -1.05 | -0.98     |
| 12                       | -----          | 100.41 | 98.32  | 98.32  | 99.02          | -17.43  | -17.43  | -17.43  | -17.43         | 76.01  | 74.61  | 71.82  | 73.91     | -1.39 | -1.46 | -1.39 | -1.39     |
| 13                       | -----          | 99.71  | 98.32  | 98.32  | 99.02          | -17.43  | -17.43  | -17.43  | -17.43         | 73.22  | 73.91  | 70.43  | 72.52     | -1.05 | -1.39 | -1.32 | -1.25     |
| 14                       | -----          | 87.86  | 89.25  | 89.95  | 89.25          | -16.74  | -16.04  | -16.74  | -16.74         | 62.02  | 66.24  | 64.15  | 64.15     | -1.95 | -2.09 | -1.95 | -2.02     |
| 15                       | -----          | 73.22  | 76.01  | 77.40  | 75.31          | -14.64  | -14.64  | -15.34  | -14.64         | 50.21  | 57.18  | 51.60  | 52.99     | -0.63 | -1.12 | -0.84 | -0.84     |
| 17                       | -----          | 59.97  | 58.57  | 59.97  | 59.27          | -13.95  | -13.25  | -13.95  | -13.95         | 37.65  | 36.96  | 36.26  | 36.96     | -0.49 | -0.63 | -0.49 | -0.56     |
| 18                       | -----          | 38.35  | 34.87  | 39.75  | 37.65          | -11.16  | -10.46  | -11.16  | -11.16         | 18.83  | 18.83  | 18.13  | 18.83     | -0.35 | -0.49 | -0.48 | -0.35     |
| 18                       | -----          | 14.64  | 12.55  | 18.83  | 15.34          | -5.58   | -3.49   | -6.97   | -5.58          | 0.70   | -2.09  | 0      | -0.70     | -0.70 | -0.14 | -0.14 | -0.14     |
| 19                       | -----          | 2.09   | 4.88   | 3.49   | 3.49           | -1.39   | -2.09   | -1.39   | -1.39          | -10.46 | -8.37  | -11.16 | -9.76     | 0.14  | -0.07 | 0.21  | 0.07      |
| 20                       | -----          | 0      | 0      | 0      | 0              | 0       | 0       | 0       | 0              | -11.85 | -10.46 | -12.55 | -11.85    | 0.21  | 0.28  | 0.49  | 0.35      |
| 21                       | -----          | 0      | 0      | 0      | 0              | 0       | 0       | 0       | 0              | -11.85 | -8.37  | -11.16 | -10.46    | 0.28  | 0.84  | 0.70  | 0.63      |
| 22                       | -----          | 0      | 0      | 0      | 0              | 0       | 0       | 0       | 0              | -9.76  | -7.67  | -11.16 | -9.76     | 0.35  | 1.12  | 0.56  | 0.70      |
| 23                       | -----          | 0      | 0      | 0      | 0              | 0       | 0       | 0       | 0              | -7.67  | -8.37  | -10.46 | -9.06     | 0.91  | 0.91  | 0.70  | 0.84      |
| 24                       | -----          | 0      | 0      | 0      | 0              | 0       | 0       | 0       | 0              | -6.97  | -8.37  | -9.06  | -8.37     | 1.12  | 0.70  | 0.77  | 0.84      |
| 1                        | -----          | 0      | 0      | 0      | 0              | 0       | 0       | 0       | 0              | -6.28  | -6.97  | -7.67  | -6.97     | 1.18  | 0.91  | 1.05  | 1.05      |
| 2                        | -----          | 0      | 0      | 0      | 0              | 0       | 0       | 0       | 0              | -5.58  | -6.28  | -6.28  | -6.28     | 1.25  | 1.05  | 1.32  | 1.18      |
| 3                        | -----          | 0      | 0      | 0      | 0              | 0       | 0       | 0       | 0              | -6.28  | -7.67  | -6.28  | -6.97     | 1.25  | 0.63  | 1.39  | 1.12      |
| 4                        | -----          | 0      | 0      | 0      | 0              | 0       | 0       | 0       | 0              | -6.28  | -7.67  | -5.58  | -6.28     | 1.18  | 0.70  | 1.39  | 1.12      |
| Total                    | -----          | 795.62 | 769.92 | 795.62 | 785.86         | -163.87 | -156.20 | -165.26 | -162.47        | 446.97 | 436.51 | 415.59 | 433.02    | 2.02  | -1.12 | 0.14  | 0.35      |

TABLE A4-1.—*Windspeed, temperature, and vapor pressure at five elevations above ground during seven periods of 3 days each at the Buckeye Project*[Windspeed,  $u$  in  $\text{m s}^{-1}$ ; temperature,  $T$  in  $^{\circ}\text{C}$ ; vapor pressure,  $e$  in  $\text{kPa}$ ; and elevations,  $z$  in  $\text{m}$ ]

| Hrs           | Day 1 |      |      | Day 2 |      |      | Day 3 |      |      | Mean |      |      | z  |
|---------------|-------|------|------|-------|------|------|-------|------|------|------|------|------|----|
|               | u     | T    | e    | u     | T    | e    | u     | T    | e    | u    | T    | e    |    |
| 5-8 May 1966  |       |      |      |       |      |      |       |      |      |      |      |      |    |
| 5-8           | 3.32  | 2.21 | 1.15 | 1.88  | 22.1 | 1.11 | 1.74  | 22.0 | 1.06 | 2.31 | 22.1 | 1.11 | 11 |
|               | 2.46  | 21.6 | 1.18 | 1.48  | 21.4 | 1.15 | 1.34  | 21.1 | 1.12 | 1.76 | 21.4 | 1.15 | 7  |
|               | 1.96  | 21.5 | 1.19 | 1.27  | 21.4 | 1.18 | 1.18  | 20.9 | 1.17 | 1.47 | 21.3 | 1.18 | 5  |
| 9-12          | 1.56  | 21.1 | 1.20 | 1.04  | 20.8 | 1.21 | 0.93  | 20.2 | 1.20 | 1.18 | 20.7 | 1.20 | 4  |
|               | 0.63  | 19.4 | 1.36 | 0.35  | 18.4 | 1.39 | 0.21  | 18.4 | 1.40 | 0.40 | 18.7 | 1.38 | 2  |
|               | 4.64  | 32.2 | 1.06 | 1.95  | 30.4 | 1.11 | 1.34  | 31.7 | 1.08 | 2.64 | 31.4 | 1.08 | 11 |
|               | 3.96  | 32.6 | 1.17 | 1.69  | 30.6 | 1.20 | 1.14  | 31.6 | 1.22 | 2.26 | 31.6 | 1.20 | 7  |
|               | 3.27  | 32.9 | 1.25 | 1.50  | 30.8 | 1.27 | 1.10  | 31.7 | 1.32 | 1.96 | 31.8 | 1.28 | 5  |
| 13-16         | 2.74  | 33.5 | 1.30 | 1.32  | 30.9 | 1.32 | 0.94  | 31.1 | 1.39 | 1.67 | 31.8 | 1.34 | 4  |
|               | 1.23  | 35.3 | 1.52 | 0.82  | 32.4 | 1.60 | 0.60  | 31.9 | 1.80 | 0.88 | 33.2 | 1.64 | 2  |
|               | 2.65  | 35.8 | 1.00 | 2.16  | 36.0 | 1.00 | 2.52  | 36.6 | 0.94 | 2.44 | 36.1 | 0.98 | 11 |
|               | 2.31  | 36.0 | 1.14 | 1.87  | 36.2 | 1.14 | 2.12  | 36.8 | 1.07 | 2.10 | 36.3 | 1.12 | 7  |
|               | 2.03  | 36.5 | 1.25 | 1.65  | 36.2 | 1.22 | 1.80  | 37.0 | 1.17 | 1.83 | 36.6 | 1.21 | 5  |
| 17-20         | 1.77  | 36.6 | 1.33 | 1.42  | 36.4 | 1.33 | 1.53  | 36.6 | 1.24 | 1.57 | 36.5 | 1.30 | 4  |
|               | 0.84  | 37.9 | 1.55 | 0.84  | 37.8 | 1.69 | 0.76  | 37.2 | 1.87 | 0.81 | 37.6 | 1.70 | 2  |
|               | 2.47  | 33.6 | 1.09 | 1.93  | 34.6 | 1.16 | 3.73  | 34.3 | 1.02 | 2.71 | 34.2 | 1.09 | 11 |
|               | 2.05  | 33.3 | 1.16 | 1.50  | 33.9 | 1.28 | 2.99  | 33.7 | 1.11 | 2.18 | 33.6 | 1.18 | 7  |
|               | 1.63  | 32.7 | 1.20 | 1.18  | 33.3 | 1.38 | 2.37  | 33.3 | 1.18 | 1.73 | 33.1 | 1.25 | 5  |
| 21-24         | 1.23  | 32.1 | 1.24 | 0.94  | 32.7 | 1.44 | 1.92  | 33.0 | 1.23 | 1.36 | 32.6 | 1.30 | 4  |
|               | 0.48  | 29.9 | 1.56 | 0.28  | 29.2 | 1.84 | 0.58  | 31.3 | 1.62 | 0.45 | 30.1 | 1.67 | 2  |
|               | 3.28  | 28.8 | 1.02 | 1.21  | 27.6 | 1.15 | 3.95  | 30.2 | 0.84 | 2.81 | 28.9 | 1.00 | 11 |
|               | 2.58  | 28.0 | 1.06 | 1.02  | 25.8 | 1.20 | 3.06  | 29.5 | 0.89 | 2.22 | 27.8 | 1.05 | 7  |
|               | 2.10  | 27.4 | 1.08 | 1.00  | 25.0 | 1.24 | 2.48  | 29.0 | 0.92 | 1.86 | 27.1 | 1.08 | 5  |
| 1-4           | 1.76  | 27.1 | 1.10 | 0.79  | 24.4 | 1.27 | 2.08  | 28.7 | 0.95 | 1.54 | 26.7 | 1.11 | 4  |
|               | 0.41  | 24.0 | 1.38 | 0.11  | 18.6 | 1.52 | 0.60  | 26.3 | 1.22 | 0.37 | 23.0 | 1.37 | 2  |
|               | 2.13  | 24.2 | 1.04 | 2.21  | 23.6 | 1.02 | 2.29  | 26.2 | 0.92 | 2.21 | 24.7 | 0.99 | 11 |
|               | 1.61  | 22.8 | 1.08 | 1.69  | 22.1 | 1.06 | 1.78  | 24.8 | 0.96 | 1.69 | 23.2 | 1.03 | 7  |
|               | 1.22  | 22.1 | 1.10 | 1.28  | 21.4 | 1.08 | 1.41  | 24.0 | 1.00 | 1.30 | 22.5 | 1.06 | 5  |
|               | 0.98  | 2.12 | 1.11 | 0.96  | 20.8 | 1.10 | 1.15  | 23.8 | 1.01 | 1.03 | 21.9 | 1.07 | 4  |
|               | 0.10  | 16.2 | 1.29 | 0.09  | 16.6 | 1.32 | 0.25  | 20.7 | 1.26 | 0.15 | 17.8 | 1.29 | 2  |
| 3-6 June 1966 |       |      |      |       |      |      |       |      |      |      |      |      |    |
| 5-8           | 2.16  | 18.8 | 0.64 | 2.36  | 19.2 | 0.62 | 2.06  | 21.8 | 0.79 | 2.19 | 19.9 | 0.68 | 11 |
|               | 1.58  | 18.4 | 0.69 | 1.81  | 18.8 | 0.68 | 1.70  | 20.4 | 0.83 | 1.70 | 19.2 | 0.73 | 7  |
|               | 1.32  | 18.1 | 0.72 | 1.50  | 18.6 | 0.73 | 1.42  | 19.8 | 0.86 | 1.41 | 18.8 | 0.77 | 5  |
| 9-12          | 1.02  | 17.4 | 0.75 | 1.16  | 18.0 | 0.76 | 1.09  | 19.2 | 0.88 | 1.09 | 18.2 | 0.80 | 4  |
|               | 0.31  | 14.7 | 0.90 | 0.43  | 14.8 | 0.90 | 0.43  | 16.3 | 1.02 | 0.39 | 15.3 | 0.94 | 2  |
|               | 2.10  | 29.6 | 0.58 | 2.40  | 29.5 | 0.66 | 2.37  | 30.5 | 0.84 | 2.29 | 29.9 | 0.69 | 11 |
|               | 1.82  | 29.7 | 0.68 | 2.13  | 29.6 | 0.76 | 2.11  | 30.9 | 0.94 | 2.02 | 30.1 | 0.79 | 7  |
|               | 1.62  | 30.0 | 0.75 | 1.76  | 29.6 | 0.84 | 1.82  | 31.0 | 1.02 | 1.73 | 30.2 | 0.87 | 5  |
| 13-16         | 1.36  | 29.8 | 0.80 | 1.54  | 29.6 | 0.90 | 1.58  | 30.9 | 1.06 | 1.49 | 30.1 | 0.92 | 4  |
|               | 0.78  | 30.6 | 0.96 | 0.84  | 30.8 | 1.00 | 0.84  | 31.8 | 1.26 | 0.82 | 31.1 | 1.07 | 2  |
|               | 3.52  | 34.7 | 0.32 | 3.55  | 35.0 | 0.42 | 3.83  | 36.2 | 0.45 | 3.63 | 35.3 | 0.40 | 11 |
|               | 3.06  | 34.8 | 0.45 | 3.06  | 35.1 | 0.58 | 3.37  | 36.2 | 0.59 | 3.16 | 35.4 | 0.54 | 7  |
|               | 2.63  | 35.2 | 0.54 | 2.59  | 35.6 | 0.71 | 2.88  | 36.5 | 0.70 | 2.70 | 35.8 | 0.65 | 5  |
| 17-20         | 2.28  | 35.0 | 0.60 | 2.24  | 35.1 | 0.80 | 2.48  | 36.1 | 0.78 | 2.33 | 35.4 | 0.73 | 4  |
|               | 0.87  | 35.5 | 0.83 | 0.85  | 36.2 | 0.93 | 0.91  | 36.4 | 1.04 | 0.88 | 36.0 | 0.93 | 2  |
|               | 3.71  | 32.7 | 0.41 | 3.59  | 33.8 | 0.44 | 2.90  | 33.8 | 0.59 | 3.40 | 33.4 | 0.48 | 11 |
|               | 2.90  | 32.5 | 0.54 | 2.87  | 33.6 | 0.56 | 2.21  | 33.4 | 0.72 | 2.66 | 33.2 | 0.61 | 7  |
|               | 2.40  | 32.2 | 0.64 | 2.35  | 33.3 | 0.66 | 1.74  | 33.1 | 0.80 | 2.16 | 32.9 | 0.70 | 5  |
| 21-24         | 1.92  | 31.6 | 0.69 | 1.91  | 32.3 | 0.71 | 1.35  | 32.2 | 0.86 | 1.73 | 32.0 | 0.75 | 4  |
|               | 0.49  | 28.8 | 0.80 | 0.46  | 29.6 | 0.83 | 0.32  | 28.8 | 1.05 | 0.42 | 29.1 | 0.89 | 2  |
|               | 1.82  | 24.8 | 0.57 | 2.10  | 25.6 | 0.62 | 1.54  | 26.4 | 0.71 | 1.82 | 25.6 | 0.63 | 11 |
|               | 1.44  | 23.2 | 0.60 | 1.52  | 23.8 | 0.66 | 1.16  | 25.2 | 0.75 | 1.37 | 24.1 | 0.67 | 7  |
|               | 1.34  | 21.8 | 0.63 | 1.23  | 22.3 | 0.70 | 1.07  | 23.9 | 0.78 | 1.21 | 22.7 | 0.70 | 5  |
| 1-4           | 0.99  | 20.9 | 0.64 | 0.89  | 21.1 | 0.73 | 0.73  | 23.0 | 0.81 | 0.87 | 21.7 | 0.73 | 4  |
|               | 0.06  | 14.7 | 0.84 | 0.07  | 15.5 | 0.89 | 0.07  | 16.2 | 1.03 | 0.07 | 15.5 | 0.92 | 2  |
|               | 1.57  | 22.0 | 0.44 | 1.43  | 22.4 | 0.56 | 1.88  | 22.3 | 0.59 | 1.63 | 22.2 | 0.53 | 11 |
|               | 1.42  | 20.5 | 0.46 | 1.16  | 20.2 | 0.60 | 1.36  | 20.7 | 0.64 | 1.31 | 20.5 | 0.57 | 7  |
|               | 1.21  | 18.5 | 0.49 | 1.09  | 18.4 | 0.63 | 1.17  | 19.9 | 0.66 | 1.16 | 18.9 | 0.59 | 5  |
|               | 0.85  | 17.3 | 0.50 | 0.78  | 16.8 | 0.64 | 0.82  | 18.7 | 0.69 | 0.82 | 17.6 | 0.61 | 4  |
|               | 0.07  | 10.2 | 0.68 | 0.12  | 11.5 | 0.86 | 0.09  | 12.4 | 0.86 | 0.09 | 11.4 | 0.80 | 2  |
| 6-9 July 1966 |       |      |      |       |      |      |       |      |      |      |      |      |    |
| 5-8           | 1.30  | 22.6 | 0.69 | 2.46  | 28.0 | 1.48 | 2.14  | 27.1 | 2.02 | 1.97 | 25.9 | 1.40 | 11 |
|               | 1.02  | 21.8 | 0.72 | 1.95  | 27.1 | 1.55 | 1.68  | 26.8 | 2.04 | 1.55 | 25.2 | 1.44 | 7  |
|               | 1.03  | 21.8 | 0.71 | 1.73  | 26.8 | 1.55 | 1.42  | 26.7 | 2.05 | 1.39 | 25.1 | 1.43 | 5  |
|               | 0.80  | 21.9 | 0.79 | 1.41  | 26.4 | 1.57 | 1.10  | 26.4 | 2.06 | 1.10 | 24.6 | 1.47 | 4  |
|               | 0.15  | 18.6 | 0.89 | 0.24  | 23.8 | 1.70 | 0.20  | 24.9 | 2.15 | 0.20 | 22.4 | 1.58 | 2  |

TABLE A4-1.—Windspeed, temperature, and vapor pressure at five elevations above ground during seven periods of 3 days each at the Buckeye Project.—Continued

| Hrs                     | Day 1 |      |      | Day 2 |      |      | Day 3 |      |      | Mean |      |      | z  |
|-------------------------|-------|------|------|-------|------|------|-------|------|------|------|------|------|----|
|                         | u     | T    | e    | u     | T    | e    | u     | T    | e    | u    | T    | e    |    |
| 6-9 July 1966—Continued |       |      |      |       |      |      |       |      |      |      |      |      |    |
| 9-12                    | 1.61  | 36.6 | 0.51 | 4.69  | 34.4 | 1.31 | 2.47  | 32.2 | 1.84 | 2.92 | 34.4 | 1.22 | 11 |
|                         | 1.42  | 36.6 | 0.62 | 4.06  | 34.9 | 1.42 | 2.17  | 32.4 | 1.89 | 2.55 | 34.6 | 1.31 | 7  |
|                         | 1.34  | 37.0 | 0.67 | 3.49  | 35.3 | 1.51 | 1.90  | 33.0 | 1.92 | 2.24 | 35.1 | 1.36 | 5  |
|                         | 1.14  | 36.4 | 0.83 | 2.93  | 35.3 | 1.57 | 1.63  | 33.0 | 1.97 | 1.90 | 34.9 | 1.46 | 4  |
|                         | 0.51  | 37.1 | 0.95 | 0.80  | 35.8 | 1.71 | 0.57  | 33.8 | 2.11 | 0.63 | 35.6 | 1.59 | 2  |
| 13-16                   | 4.28  | 42.3 | 0.49 | 5.74  | 38.3 | 1.05 | 3.13  | 36.6 | 1.41 | 4.38 | 39.1 | 0.98 | 11 |
|                         | 3.64  | 42.0 | 0.62 | 4.79  | 38.7 | 1.17 | 2.73  | 36.9 | 1.48 | 3.72 | 39.2 | 1.09 | 7  |
|                         | 3.04  | 43.0 | 0.72 | 4.08  | 38.8 | 1.23 | 2.30  | 37.1 | 1.52 | 3.14 | 39.6 | 1.16 | 5  |
|                         | 2.52  | 42.7 | 0.82 | 3.51  | 38.9 | 1.29 | 1.96  | 37.4 | 1.57 | 2.66 | 39.7 | 1.23 | 4  |
|                         | 0.85  | 44.0 | 0.70 | 0.90  | 40.0 | 1.35 | 0.75  | 39.0 | 1.70 | 0.83 | 41.0 | 1.25 | 2  |
| 17-20                   | 4.29  | 40.6 | 0.60 | 3.32  | 36.4 | 0.98 | 3.59  | 36.7 | 1.40 | 3.73 | 37.9 | 0.99 | 11 |
|                         | 3.40  | 40.0 | 0.74 | 2.65  | 36.2 | 1.09 | 2.91  | 36.6 | 1.46 | 2.99 | 37.6 | 1.10 | 7  |
|                         | 2.88  | 39.9 | 0.79 | 2.14  | 35.9 | 1.13 | 2.42  | 36.4 | 1.50 | 2.48 | 37.4 | 1.15 | 5  |
|                         | 2.39  | 39.6 | 0.88 | 1.70  | 35.2 | 1.21 | 2.00  | 36.3 | 1.52 | 2.03 | 37.0 | 1.20 | 4  |
|                         | 0.50  | 37.1 | 0.86 | 0.60  | 33.0 | 1.24 | 0.54  | 33.8 | 1.64 | 0.55 | 34.6 | 1.25 | 2  |
| 21-24                   | 2.91  | 33.9 | 0.76 | 2.16  | 31.7 | 1.12 | 3.34  | 34.2 | 1.48 | 2.80 | 33.3 | 1.12 | 11 |
|                         | 2.21  | 32.6 | 0.85 | 1.53  | 30.6 | 1.18 | 2.58  | 32.9 | 1.54 | 2.11 | 32.0 | 1.19 | 7  |
|                         | 1.77  | 31.8 | 0.88 | 1.22  | 29.9 | 1.20 | 2.09  | 32.2 | 1.59 | 1.69 | 31.3 | 1.22 | 5  |
|                         | 1.42  | 31.1 | 0.94 | 0.94  | 29.2 | 1.24 | 1.69  | 31.5 | 1.63 | 1.35 | 30.6 | 1.27 | 4  |
|                         | 0.14  | 27.0 | 0.97 | 0.21  | 25.5 | 1.33 | 0.28  | 28.2 | 1.67 | 0.21 | 26.9 | 1.32 | 2  |
| 1-4                     | 1.54  | 27.7 | 1.28 | 2.84  | 27.8 | 1.61 | 2.60  | 30.8 | 1.81 | 2.33 | 28.8 | 1.57 | 11 |
|                         | 1.22  | 26.6 | 1.25 | 2.16  | 27.2 | 1.62 | 1.97  | 30.2 | 1.85 | 1.78 | 28.0 | 1.57 | 7  |
|                         | 1.09  | 25.3 | 1.21 | 1.66  | 26.5 | 1.65 | 1.69  | 30.0 | 1.86 | 1.48 | 27.3 | 1.57 | 5  |
|                         | 0.78  | 24.6 | 1.20 | 1.29  | 26.0 | 1.66 | 1.40  | 29.6 | 1.88 | 1.16 | 26.7 | 1.58 | 4  |
|                         | 0.11  | 20.4 | 1.22 | 0.11  | 22.9 | 1.70 | 0.11  | 27.6 | 1.88 | 0.11 | 23.6 | 1.60 | 2  |
| 3-6 August 1966         |       |      |      |       |      |      |       |      |      |      |      |      |    |
| 5-8                     | 2.18  | 32.8 | 2.09 | 2.22  | 28.0 | 2.14 | 1.17  | 28.7 | 2.14 | 1.86 | 29.8 | 2.12 | 11 |
|                         | 1.74  | 32.8 | 2.15 | 1.79  | 28.1 | 2.16 | 0.90  | 28.3 | 2.22 | 1.48 | 29.7 | 2.18 | 7  |
|                         | 1.45  | 32.8 | 2.20 | 1.44  | 28.0 | 2.20 | 0.74  | 28.0 | 2.24 | 1.21 | 29.6 | 2.21 | 5  |
|                         | 1.18  | 32.4 | 2.24 | 1.11  | 27.8 | 2.22 | 0.62  | 28.0 | 2.25 | 0.97 | 29.4 | 2.24 | 4  |
|                         | 0.61  | 30.3 | 2.32 | 0.37  | 27.2 | 2.23 | 0.27  | 27.0 | 2.33 | 0.42 | 28.2 | 2.29 | 2  |
| 9-12                    | 2.63  | 37.8 | 2.09 | 1.90  | 35.8 | 2.03 | 2.22  | 36.7 | 2.01 | 2.25 | 36.8 | 2.04 | 11 |
|                         | 2.23  | 38.1 | 2.16 | 1.60  | 36.6 | 2.07 | 1.89  | 37.1 | 2.12 | 1.91 | 37.3 | 2.12 | 7  |
|                         | 1.92  | 38.6 | 2.22 | 1.43  | 36.8 | 2.13 | 1.62  | 37.8 | 2.18 | 1.66 | 37.7 | 2.18 | 5  |
|                         | 1.68  | 39.2 | 2.25 | 1.28  | 37.0 | 2.16 | 1.44  | 38.1 | 2.24 | 1.47 | 38.1 | 2.22 | 4  |
|                         | 0.58  | 39.4 | 2.41 | 0.64  | 38.5 | 2.35 | 0.67  | 39.8 | 2.38 | 0.63 | 39.2 | 2.38 | 2  |
| 13-16                   | 6.38  | 39.6 | 2.02 | 2.99  | 40.9 | 1.78 | 3.27  | 40.7 | 1.66 | 4.21 | 40.4 | 1.82 | 11 |
|                         | 5.19  | 40.0 | 2.08 | 2.53  | 41.8 | 1.84 | 2.72  | 41.5 | 1.73 | 3.48 | 41.1 | 1.88 | 7  |
|                         | 4.34  | 40.5 | 2.14 | 2.14  | 42.4 | 1.89 | 2.29  | 42.1 | 1.78 | 2.92 | 41.7 | 1.94 | 5  |
|                         | 3.81  | 40.8 | 2.17 | 1.85  | 42.9 | 1.91 | 1.98  | 42.4 | 1.84 | 2.55 | 42.0 | 1.97 | 4  |
|                         | 1.02  | 41.9 | 2.32 | 0.66  | 44.8 | 2.14 | 0.62  | 44.1 | 2.13 | 0.77 | 43.6 | 2.20 | 2  |
| 17-20                   | 6.19  | 36.8 | 2.16 | 3.35  | 41.0 | 1.52 | 5.96  | 39.1 | 1.97 | 5.17 | 39.0 | 1.88 | 11 |
|                         | 4.93  | 37.3 | 2.18 | 2.66  | 40.8 | 1.59 | 4.75  | 39.4 | 2.00 | 4.11 | 39.2 | 1.92 | 7  |
|                         | 4.05  | 37.2 | 2.21 | 2.14  | 40.7 | 1.64 | 3.94  | 39.6 | 2.03 | 3.71 | 39.2 | 1.96 | 5  |
|                         | 3.47  | 37.0 | 2.24 | 1.81  | 40.4 | 1.68 | 3.42  | 39.6 | 2.04 | 2.90 | 39.0 | 1.99 | 4  |
|                         | 0.90  | 36.6 | 2.30 | 0.44  | 38.0 | 2.06 | 0.90  | 38.8 | 2.28 | 0.75 | 37.8 | 2.21 | 2  |
| 21-24                   | 3.72  | 33.8 | 2.09 | 3.15  | 36.4 | 1.71 | 5.73  | 33.2 | 2.25 | 4.20 | 34.5 | 2.02 | 11 |
|                         | 2.90  | 33.6 | 2.08 | 2.47  | 35.7 | 1.74 | 4.74  | 33.3 | 2.25 | 3.37 | 34.2 | 2.02 | 7  |
|                         | 2.32  | 33.4 | 2.10 | 2.02  | 35.5 | 1.78 | 4.01  | 33.2 | 2.26 | 2.78 | 34.0 | 2.05 | 5  |
|                         | 1.90  | 33.2 | 2.12 | 1.64  | 35.2 | 1.81 | 3.46  | 33.2 | 2.26 | 2.33 | 33.9 | 2.06 | 4  |
|                         | 0.54  | 32.2 | 2.23 | 0.55  | 33.0 | 1.99 | 0.78  | 32.7 | 2.42 | 0.62 | 32.6 | 2.21 | 2  |
| 1-4                     | 2.31  | 28.9 | 2.08 | 2.34  | 30.8 | 1.95 | 2.23  | 29.6 | 2.45 | 2.29 | 29.8 | 2.16 | 11 |
|                         | 1.58  | 28.7 | 2.10 | 1.77  | 30.4 | 1.96 | 1.67  | 29.6 | 2.45 | 1.67 | 29.6 | 2.17 | 7  |
|                         | 1.40  | 28.4 | 2.12 | 1.40  | 30.3 | 1.98 | 1.53  | 29.5 | 2.45 | 1.44 | 29.4 | 2.18 | 5  |
|                         | 1.05  | 28.2 | 2.14 | 1.11  | 30.0 | 2.00 | 1.08  | 29.3 | 2.44 | 1.08 | 29.1 | 2.19 | 4  |
|                         | 0.40  | 27.4 | 2.26 | 0.40  | 28.6 | 2.15 | 0.29  | 28.3 | 2.54 | 0.36 | 28.1 | 2.32 | 2  |
| 8-11 September 1966     |       |      |      |       |      |      |       |      |      |      |      |      |    |
| 5-8                     | 2.42  | 24.9 | 1.48 | 2.97  | 24.0 | 1.46 | 2.18  | 25.3 | 1.28 | 2.52 | 24.7 | 1.41 | 11 |
|                         | 1.87  | 24.4 | 1.50 | 2.22  | 23.5 | 1.48 | 1.54  | 24.3 | 1.29 | 1.88 | 24.1 | 1.42 | 7  |
|                         | 1.43  | 23.6 | 1.51 | 1.78  | 23.4 | 1.48 | 1.24  | 23.9 | 1.31 | 1.48 | 23.6 | 1.43 | 5  |
|                         | 1.09  | 23.5 | 1.52 | 1.39  | 23.2 | 1.48 | 0.92  | 23.4 | 1.34 | 1.13 | 23.4 | 1.44 | 4  |
|                         | 0.33  | 20.4 | 1.56 | 0.57  | 21.2 | 1.54 | 0.19  | 19.9 | 1.39 | 0.36 | 20.5 | 1.50 | 2  |
| 9-12                    | 3.88  | 33.5 | 1.57 | 3.79  | 34.5 | 1.41 | 2.29  | 34.7 | 1.33 | 3.32 | 34.2 | 1.44 | 11 |
|                         | 3.27  | 34.0 | 1.59 | 3.09  | 34.8 | 1.44 | 1.98  | 34.8 | 1.36 | 2.78 | 34.5 | 1.46 | 7  |
|                         | 2.89  | 34.4 | 1.62 | 2.64  | 35.5 | 1.48 | 1.76  | 35.0 | 1.44 | 2.43 | 34.9 | 1.50 | 5  |
|                         | 2.33  | 34.6 | 1.65 | 2.25  | 35.4 | 1.50 | 1.60  | 35.1 | 1.47 | 2.06 | 35.0 | 1.54 | 4  |
|                         | 1.02  | 35.5 | 1.61 | 0.89  | 36.5 | 1.44 | 0.60  | 37.2 | 1.45 | 0.84 | 35.8 | 1.50 | 2  |
| 13-16                   | 2.87  | 38.0 | 1.37 | 3.28  | 38.4 | 1.35 | 2.77  | 38.5 | 1.32 | 2.97 | 38.3 | 1.35 | 11 |
|                         | 2.40  | 38.4 | 1.41 | 2.73  | 38.6 | 1.36 | 2.39  | 38.4 | 1.33 | 2.51 | 38.5 | 1.37 | 7  |
|                         | 2.06  | 38.9 | 1.44 | 2.33  | 39.0 | 1.40 | 2.04  | 38.7 | 1.35 | 2.14 | 38.9 | 1.40 | 5  |

TABLE A4-1.—Windspeed, temperature, and vapor pressure at five elevations above ground during seven periods of 3 days each at the Buckeye Project—Continued

| Hrs                           | Day 1          |      |      | Day 2 |      |      | Day 3 |      |      | Mean |      |      | z  |
|-------------------------------|----------------|------|------|-------|------|------|-------|------|------|------|------|------|----|
|                               | u              | T    | e    | u     | T    | e    | u     | T    | e    | u    | T    | e    |    |
| 8-11 September 1996—Continued |                |      |      |       |      |      |       |      |      |      |      |      |    |
| 17-20                         | 1.79           | 39.2 | 1.48 | 1.99  | 39.2 | 1.42 | 1.82  | 38.6 | 1.38 | 1.87 | 39.0 | 1.43 | 4  |
|                               | 0.76           | 40.6 | 1.39 | 0.86  | 40.3 | 1.46 | 0.72  | 39.0 | 1.36 | 0.78 | 40.0 | 1.40 | 2  |
|                               | 1.71           | 36.0 | 1.51 | 2.39  | 35.8 | 1.52 | 2.01  | 35.8 | 1.36 | 2.04 | 35.9 | 1.46 | 11 |
|                               | 1.32           | 35.4 | 1.57 | 1.87  | 35.0 | 1.54 | 1.66  | 35.6 | 1.37 | 1.62 | 35.3 | 1.49 | 7  |
|                               | 1.11           | 35.2 | 1.62 | 1.44  | 34.7 | 1.56 | 1.37  | 35.2 | 1.38 | 1.31 | 35.1 | 1.52 | 5  |
| 21-24                         | 0.85           | 34.6 | 1.66 | 1.19  | 34.4 | 1.59 | 1.11  | 34.9 | 1.40 | 1.05 | 34.6 | 1.55 | 4  |
|                               | 0.62           | 31.1 | 1.71 | 0.37  | 31.6 | 1.65 | 0.25  | 30.5 | 1.58 | 0.41 | 31.1 | 1.65 | 2  |
|                               | 2.01           | 29.4 | 1.47 | 2.48  | 28.9 | 1.53 | 2.75  | 32.8 | 1.19 | 2.25 | 29.2 | 1.50 | 11 |
|                               | 1.61           | 28.2 | 1.48 | 1.70  | 27.7 | 1.54 | 2.06  | 31.9 | 1.09 | 1.65 | 28.0 | 1.51 | 7  |
|                               | 1.32           | 27.4 | 1.50 | 1.37  | 27.0 | 1.55 | 1.60  | 31.3 | 1.31 | 1.35 | 27.2 | 1.52 | 5  |
| 1-4                           | 0.95           | 26.7 | 1.54 | 0.98  | 26.7 | 1.55 | 1.28  | 31.0 | 1.13 | 1.97 | 26.7 | 1.54 | 4  |
|                               | 0.33           | 22.6 | 1.66 | 0.34  | 23.2 | 1.61 | 0.42  | 28.0 | 1.20 | 0.33 | 22.9 | 1.63 | 2  |
|                               | 2.64           | 24.6 | 1.56 | 2.40  | 25.5 | 1.35 | 2.20  | 27.7 | 1.54 | 2.52 | 25.0 | 1.46 | 11 |
|                               | 1.71           | 23.5 | 1.56 | 1.74  | 24.4 | 1.38 | 1.52  | 26.6 | 1.46 | 1.72 | 24.0 | 1.47 | 7  |
|                               | 1.41           | 23.0 | 1.57 | 1.34  | 23.6 | 1.42 | 1.13  | 25.8 | 1.60 | 1.38 | 23.3 | 1.49 | 5  |
|                               | 1.06           | 22.4 | 1.56 | 0.97  | 22.9 | 1.44 | 0.78  | 25.4 | 1.49 | 1.01 | 22.7 | 1.50 | 4  |
|                               | 0.24           | 19.9 | 1.60 | 0.11  | 19.6 | 1.48 | 0.03  | 21.7 | 1.55 | 0.18 | 19.7 | 1.54 | 2  |
| 23-26 March 1967              |                |      |      |       |      |      |       |      |      |      |      |      |    |
| 5-8                           | 2.62           | 10.0 | 0.48 | 1.69  | 18.2 | 0.60 | 1.86  | 11.2 | 0.71 | 2.06 | 13.1 | 0.60 | 11 |
|                               | 2.07           | 9.4  | 0.51 | 1.51  | 17.1 | 0.68 | 1.37  | 10.1 | 0.74 | 1.65 | 12.2 | 0.64 | 7  |
|                               | 1.63           | 8.9  | 0.50 | 1.30  | 16.5 | 0.64 | 0.98  | 9.5  | 0.71 | 1.30 | 11.6 | 0.61 | 5  |
|                               | 1.40           | 8.6  | 0.49 | 1.03  | 16.0 | 0.67 | 0.94  | 9.2  | 0.71 | 1.12 | 11.3 | 0.62 | 4  |
|                               | 0.75           | 5.2  | 0.56 | ----- | 13.6 | 0.73 | ----- | 7.6  | 0.72 | 0.75 | 8.8  | 0.67 | 2  |
| 9-12                          | 2.42           | 21.9 | 0.58 | 3.30  | 23.0 | 0.70 | 1.59  | 18.6 | 0.76 | 2.40 | 21.2 | 0.68 | 11 |
|                               | 1.97           | 22.4 | 0.63 | 2.55  | 23.1 | 0.71 | 1.38  | 19.0 | 0.85 | 1.97 | 21.5 | 0.73 | 7  |
|                               | 1.71           | 22.6 | 0.60 | 2.38  | 23.3 | 0.70 | 1.34  | 19.3 | 0.76 | 1.81 | 21.7 | 0.69 | 5  |
|                               | 1.66           | 22.8 | 0.68 | 2.26  | 24.0 | 0.76 | 1.22  | 19.7 | 0.80 | 1.71 | 22.2 | 0.75 | 4  |
|                               | 1.22           | 24.0 | 0.63 | 1.32  | 25.2 | 0.78 | 0.71  | 20.4 | 0.82 | 1.98 | 23.2 | 0.74 | 2  |
| 13-16                         | 2.28           | 29.6 | 0.54 | 5.40  | 26.6 | 0.58 | 2.86  | 23.8 | 0.56 | 3.51 | 26.7 | 0.56 | 11 |
|                               | 1.86           | 30.0 | 0.63 | 4.02  | 27.3 | 0.58 | 2.45  | 24.3 | 0.60 | 2.78 | 27.2 | 0.60 | 7  |
|                               | 1.59           | 30.2 | 0.61 | 3.84  | 27.6 | 0.58 | 2.12  | 24.3 | 0.60 | 2.52 | 27.4 | 0.60 | 5  |
|                               | 1.41           | 30.4 | 0.63 | 3.57  | 28.0 | 0.63 | 1.95  | 24.9 | 0.63 | 2.31 | 27.8 | 0.63 | 4  |
|                               | 0.64           | 31.5 | 0.59 | 1.42  | 29.9 | 0.61 | 0.93  | 27.2 | 0.62 | 1.00 | 29.5 | 0.61 | 2  |
| 17-20                         | 1.70           | 27.9 | 0.58 | 4.98  | 24.3 | 0.49 | 1.31  | 22.9 | 0.57 | 2.66 | 25.0 | 0.55 | 11 |
|                               | 1.29           | 27.5 | 0.68 | 3.70  | 24.4 | 0.52 | 1.08  | 22.4 | 0.69 | 2.03 | 24.8 | 0.63 | 7  |
|                               | 0.92           | 27.3 | 0.63 | 3.19  | 24.4 | 0.49 | 1.10  | 22.2 | 0.65 | 1.74 | 24.5 | 0.59 | 5  |
|                               | 0.81           | 27.0 | 0.64 | 2.96  | 24.3 | 0.54 | 0.90  | 21.7 | 0.65 | 1.56 | 24.3 | 0.61 | 4  |
|                               | -----          | 26.2 | 0.79 | 1.17  | 23.5 | 0.52 | ----- | 18.9 | 0.69 | 1.17 | 22.9 | 0.67 | 2  |
| 21-24                         | 3.54           | 24.5 | 0.50 | 3.72  | 19.2 | 0.39 | 2.19  | 16.5 | 0.49 | 3.15 | 20.1 | 0.46 | 11 |
|                               | 2.49           | 23.5 | 0.53 | 2.77  | 18.8 | 0.44 | 1.74  | 15.5 | 0.54 | 2.33 | 19.3 | 0.50 | 7  |
|                               | 1.61           | 23.0 | 0.55 | 2.22  | 18.4 | 0.44 | 1.57  | 14.6 | 0.54 | 1.80 | 18.7 | 0.51 | 5  |
|                               | 1.12           | 22.9 | 0.55 | 1.95  | 18.3 | 0.46 | 1.42  | 13.9 | 0.53 | 1.50 | 18.4 | 0.51 | 4  |
|                               | 0.64           | 19.4 | 0.59 | 0.90  | 15.9 | 0.45 | ----- | 9.8  | 0.59 | 0.77 | 15.0 | 0.54 | 2  |
| 1-4                           | 1.40           | 18.5 | 0.56 | 3.20  | 15.4 | 0.64 | 2.16  | 11.4 | 0.55 | 2.29 | 15.1 | 0.58 | 11 |
|                               | 1.20           | 17.0 | 0.65 | 2.58  | 15.3 | 0.64 | 1.78  | 9.4  | 0.59 | 1.85 | 13.9 | 0.63 | 7  |
|                               | 1.12           | 15.9 | 0.64 | 1.82  | 14.9 | 0.65 | 1.55  | 9.3  | 0.57 | 1.50 | 13.4 | 0.62 | 5  |
|                               | -----          | 13.0 | 0.65 | 1.22  | 13.3 | 0.66 | ----- | 6.2  | 0.59 | 1.12 | 10.8 | 0.63 | 2  |
|                               | 11-14 May 1967 |      |      |       |      |      |       |      |      |      |      |      |    |
| 5-8                           | 1.40           | 15.9 | 0.81 | 1.90  | 14.1 | 0.63 | 3.37  | 16.5 | 0.53 | 2.22 | 15.5 | 0.66 | 11 |
|                               | 0.98           | 14.1 | 0.85 | 1.61  | 13.2 | 0.64 | 2.68  | 16.0 | 0.54 | 1.76 | 14.4 | 0.68 | 7  |
|                               | 0.80           | 14.1 | 0.87 | 1.38  | 12.9 | 0.66 | 2.21  | 15.8 | 0.55 | 1.46 | 14.3 | 0.69 | 5  |
|                               | 0.61           | 13.2 | 0.90 | 1.01  | 12.5 | 0.69 | 1.88  | 15.3 | 0.61 | 1.17 | 13.7 | 0.73 | 4  |
|                               | 0.21           | 11.5 | 0.92 | 0.53  | 10.3 | 0.77 | 0.66  | 12.8 | 0.67 | 0.47 | 11.5 | 0.79 | 2  |
| 9-12                          | 3.04           | 22.3 | 0.62 | 2.48  | 23.0 | 0.72 | 3.98  | 24.0 | 0.63 | 3.17 | 23.1 | 0.66 | 11 |
|                               | 2.56           | 22.7 | 0.65 | 2.20  | 23.4 | 0.74 | 3.21  | 24.3 | 0.65 | 2.66 | 23.5 | 0.68 | 7  |
|                               | 2.16           | 22.8 | 0.70 | 1.87  | 23.5 | 0.78 | 2.73  | 24.4 | 0.68 | 2.25 | 23.6 | 0.72 | 5  |
|                               | 1.76           | 23.2 | 0.80 | 1.73  | 23.6 | 0.84 | 2.32  | 24.8 | 0.81 | 1.94 | 23.9 | 0.82 | 4  |
|                               | 0.67           | 24.4 | 0.92 | 0.70  | 24.6 | 0.90 | 0.74  | 26.0 | 0.89 | 0.70 | 25.0 | 0.90 | 2  |
| 13-16                         | 4.15           | 26.0 | 0.58 | 5.00  | 28.1 | 0.64 | 5.06  | 27.1 | 0.57 | 4.74 | 27.1 | 0.60 | 11 |
|                               | 3.46           | 26.5 | 0.60 | 4.16  | 28.4 | 0.66 | 4.08  | 27.8 | 0.60 | 3.90 | 27.6 | 0.62 | 7  |
|                               | 2.84           | 26.9 | 0.64 | 3.54  | 28.7 | 0.69 | 3.37  | 28.4 | 0.63 | 3.25 | 28.0 | 0.65 | 5  |
|                               | 2.47           | 27.0 | 0.72 | 3.14  | 28.7 | 0.75 | 2.92  | 28.5 | 0.65 | 2.84 | 28.1 | 0.71 | 4  |
|                               | 0.76           | 28.7 | 0.85 | 0.90  | 30.6 | 0.84 | 0.92  | 30.3 | 0.67 | 0.86 | 29.9 | 0.79 | 2  |
| 17-20                         | 3.71           | 26.3 | 0.62 | 4.70  | 27.8 | 0.57 | 4.81  | 25.4 | 0.63 | 4.41 | 26.5 | 0.61 | 11 |
|                               | 3.05           | 26.4 | 0.64 | 3.58  | 27.5 | 0.44 | 4.10  | 25.4 | 0.47 | 3.58 | 26.4 | 0.52 | 7  |
|                               | 2.46           | 26.2 | 0.65 | 3.16  | 27.4 | 0.50 | 3.50  | 25.3 | 0.54 | 3.04 | 26.3 | 0.56 | 5  |
|                               | 2.15           | 25.4 | 0.70 | 2.69  | 26.6 | 0.57 | 3.04  | 24.8 | 0.59 | 2.63 | 25.6 | 0.62 | 4  |
|                               | 0.62           | 24.4 | 0.70 | 0.59  | 25.3 | 0.51 | 0.69  | 24.1 | 0.53 | 0.63 | 24.6 | 0.58 | 2  |
| 21-24                         | 2.74           | 19.6 | 0.63 | 2.92  | 21.0 | 0.54 | 3.61  | 18.4 | 0.53 | 3.09 | 19.7 | 0.57 | 11 |
|                               | 2.15           | 18.7 | 0.64 | 2.15  | 19.2 | 0.52 | 2.87  | 17.8 | 0.44 | 2.39 | 18.6 | 0.53 | 7  |

TABLE A4-1.—Windspeed, temperature, and vapor pressure at five elevations above ground during seven periods of 3 days each at the Buckeye Project —Continued

| Hrs                      | Day 1 |      |      | Day 2 |      |      | Day 3 |      |      | Mean |      |      | z  |
|--------------------------|-------|------|------|-------|------|------|-------|------|------|------|------|------|----|
|                          | u     | T    | e    | u     | T    | e    | u     | T    | e    | u    | T    | e    |    |
| 11-14 May 1967—Continued |       |      |      |       |      |      |       |      |      |      |      |      |    |
| 1-4                      | 1.68  | 18.0 | 0.64 | 1.56  | 18.5 | 0.52 | 2.32  | 17.5 | 0.46 | 1.85 | 18.0 | 0.54 | 5  |
|                          | 1.42  | 17.4 | 0.64 | 1.18  | 17.7 | 0.58 | 1.96  | 16.8 | 0.51 | 1.55 | 17.3 | 0.58 | 4  |
|                          | 0.24  | 15.9 | 0.63 | ----  | 12.9 | 0.62 | 0.30  | 15.2 | 0.48 | 0.27 | 14.7 | 0.58 | 2  |
|                          | 1.55  | 15.8 | 0.53 | 3.09  | 17.0 | 0.54 | 1.54  | 14.2 | 0.45 | 2.06 | 15.7 | 0.51 | 11 |
|                          | 1.24  | 14.4 | 0.56 | 2.31  | 16.0 | 0.46 | 1.28  | 12.0 | 0.46 | 1.61 | 14.1 | 0.49 | 7  |
|                          | 0.98  | 13.2 | 0.57 | 1.82  | 15.1 | 0.54 | 1.04  | 11.1 | 0.46 | 1.28 | 13.1 | 0.52 | 5  |
|                          | 0.83  | 12.7 | 0.60 | 1.47  | 14.2 | 0.56 | 0.91  | 9.4  | 0.46 | 1.07 | 12.1 | 0.54 | 4  |
|                          | 0.07  | 7.0  | 0.71 | ----  | 10.3 | 0.60 | ----  | 6.0  | 0.54 | 0.07 | 7.8  | 0.62 | 2  |

<sup>1</sup> Estimated from mean of other days.

## APPENDIX B

## EXPLANATION OF THE NOMOGRAM OF FIGURE 20

Whenever the energy-balance method is used, heat flow is often measured by means of a thermopile voltage as in heat-flow plates and net radiometers.

The voltage needs a correction for temperature of the plate, and the instrument has a calibration factor ( $K$ ) so that:

$$H = E F_t K^{-1} \quad (\text{A-1})$$

where  $H$  is the heat flow,

$E$  is the voltage,

$F_t$  is the correction factor for temperature.

When records are analysed nonautomatically the process of converting voltage into heat-flow units becomes quite tedious, especially if data are recorded on strip charts.

Equation (A-1) suggests the possibility of a nomogram to convert voltage directly into heat flow. Taking logarithms,

$$\log H = \log E + \log F_t - \log K. \quad (\text{A-2})$$

The graphs for temperature correction are usually identical for sets of instruments used in any one heat flow study, which makes it possible to draw a scale converting thermocouple voltage directly into  $F_t$ . The calibration factor,  $K$ , varies from instrument to instrument.

Choosing the geometric logarithmic moduli,  $m$ ,  $n$ , and  $k$  for the variables  $\log E$ ,  $\log F_t$ , and  $\log H + \log K$ , the geometry of the nomogram can be expressed by the determinant:

$$\begin{vmatrix} -m & km \log E & 1 \\ n & kn \log F_t & 1 \\ 0 & [kmn (\log H + \log K)] & m + n \end{vmatrix} = 0. \quad (\text{A-3})$$

A nomogram is possible if we can insert the correction factor,  $K$ , conveniently. This can be accomplished by shifting the  $H$  scale up or down according to size of  $K$ .

Trial shows that a convenient modulus for the  $F_t$  line is 125 cm, but the  $E$  and  $H$  lines need two moduli each to accommodate the range of readings, namely 12.5 and 25 cm for  $E$  and 11.375 and 20.833 cm for the  $H$ . The distances between  $E$  and  $H$  are 2.727 and 5 cm, respectively, and between  $H$  and  $F_t$ , 27.273 and 25 cm.

The  $H$  scales, which slide in grooves, can be set according to the size of  $K$  (which has the same modulus as  $H$ ). A rack and pinion slides a transparent arm along the  $F_t$  scale on the right, (fig. 20). Sliding the other end of the arm over the  $E$  scale at the left, the heat flow in proper units can be read immediately on the  $H$  scales which are the second and third lines from the left. The  $H$  scales are pasted on steel strips held in place by magnets. The nomogram is mounted on a drawing board standing upright behind the data pad of the analyst.

## APPENDIX C

## SYMBOLS AND DIMENSIONS

The numbers in parentheses refer to the equations where the symbol first appeared.

Dimensions:  $H$  = heat,  $L$  = length,  $M$  = mass,  $T$  = time,  $\Theta$  = temperature,  $0$  = dimensionless.

| Symbol | Dimensions                                               | Description                                  |
|--------|----------------------------------------------------------|----------------------------------------------|
| $a$    | $0$                                                      | empirical constant (9)                       |
| $a$    | $L$                                                      | amplitude (page 20)                          |
| $b$    | $0$                                                      | empirical constant (9)                       |
| $c$    | $0$                                                      | empirical constant (10)                      |
| $c$    | $L^2 T^{-2} \Theta^{-1}$<br>(or $H M^{-1} \Theta^{-1}$ ) | specific heat (34)                           |
| $c_p$  | do                                                       | specific heat at<br>constant pressure (13)   |
| $d$    | $L$                                                      | zero-plane displacement (33)                 |
| $d_a$  | $M L^{-1} T^{-2}$                                        | vapor-pressure deficit (22)<br>= $e_s - e_a$ |
| $e$    | do                                                       | vapor pressure (8)                           |

| Symbol  | Dimensions              | Description                                                  | Symbol           | Dimensions                     | Description                                                                                   |
|---------|-------------------------|--------------------------------------------------------------|------------------|--------------------------------|-----------------------------------------------------------------------------------------------|
| $e_a$   | do                      | $e$ in the air above the surface (8)                         | $K$              | $L^2 T^{-1}$                   | eddy transfer coefficient                                                                     |
| $e_0$   | do                      | $e$ at the water surface (8)                                 | $K_A$            | do                             | K for sensible heat (13)                                                                      |
| $e_s$   | do                      | saturation vapor pressure, See $d_a$                         | $K_c$            | do                             | K for carbon dioxide (15)                                                                     |
| $k$     | O                       | von Karman constant (16)                                     | $K_m$            | do                             | K for momentum (12)                                                                           |
| $p$     | $M L^{-1} T^{-2}$       | atmospheric pressure (18)                                    | $K_v$            | do                             | K for water vapor (13)                                                                        |
| $q$     | $M M^{-1}$              | humidity of the air (3)                                      | $L$              | $L^2 T^{-2}$                   | latent heat of vaporization (17)                                                              |
| $q'$    | do                      | deviation from mean humidity (4)                             | $M$              | L                              | moisture in the atmosphere (2)                                                                |
| $r$     | $T L^{-1}$              | evapotranspiration resistance (24)                           | $\nabla \cdot M$ | L                              | divergence or convergence of M (2)                                                            |
| $r_a$   | do                      | external $r$ (24)                                            | $M_v$            | $M L^{-3}$                     | moisture content of the soil by volume (38)                                                   |
| $r_s$   | do                      | stomatal $r$ (25)                                            | $M_w$            | $M M^{-1}$                     | moisture content of the soil by weight (38)                                                   |
| $r$     | O                       | correlation coefficient (fig. 43)                            | $N$              | O                              | empirical constant (11 c)                                                                     |
| $t$     | T                       | time (34)                                                    | $P$              | L                              | precipitation (1)                                                                             |
| $u$     | $L T^{-1}$              | horizontal windspeed (8)                                     | $P$              | T                              | period (40)                                                                                   |
| $u_*$   | do                      | friction velocity (30)                                       | $R_i$            | $L^2 T^{-2}$                   | Richardson number (45), stability ratio in equation 45                                        |
| $w$     | do                      | vertical speed of air movement (3)                           | $R_n$            | $M T^{-3}$                     | net radiation (17)                                                                            |
| $w'$    | do                      | eddy component of $w$ (4)                                    |                  | (or $M L^{-2} T^{-1}$ )        |                                                                                               |
| $z$     | L                       | vertical height or depth (12, 35)                            | $RO$             | L                              | runoff (1)                                                                                    |
| $z_a$   | do                      | $z$ in the air above the surface (23)                        | $S$              | L                              | soil moisture (1)                                                                             |
| $z_0$   | do                      | roughness length (23)                                        | $\Delta S$       | L                              | change in $S$ (1)                                                                             |
| $A$     | $M T^{-3}$              | flux of sensible heat (13)                                   | $SR$             | $\Theta L^{-2} T^{-2}$         | stability ratio (27)                                                                          |
|         | (or $H L^{-2} T^{-1}$ ) |                                                              | $T$              | $\Theta$                       | temperature (13)                                                                              |
| $B_v$   | $M T^{-3}$              | the advective energy part in equation 22 (23)                | $V$              | $M L^{-2} T^{-1}$              | water-vapor flux (14)                                                                         |
| $C$     | $M L^{-3}$              | carbon dioxide content (15)                                  | $W$              | L                              | precipitable water in the atmosphere (2)                                                      |
| $D_d$   | L                       | damping depth (42)                                           | $\Delta W$       | L                              | change in $W$ (2)                                                                             |
| $E$     | L                       | evaporation (1)                                              | $\alpha$         | angle                          | phase angle (page 20)                                                                         |
| $E$     | $M L^{-2} T^{-1}$       | evaporative flux (16)                                        | $\beta$          | O                              | Bowen ratio (18)                                                                              |
| $E_a$   | L                       | actual or measured evapotranspiration (25)                   | $\gamma$         | $M L^{-1} T^{-2} \Theta^{-1}$  | psychrometer constant (19)                                                                    |
| $E_a^*$ | L                       | $f(u) (e_0 - e_a)$ (21)                                      | $\Delta$         | $M L^{-1} T^{-2} \Theta^{-1}$  | slope of the saturation vapor pressure versus the temperature curve ( $de_s/d^\circ C$ ) (21) |
| $E_0$   | L                       | evaporation from open water (8)                              | $\epsilon$       | O                              | water-air molecular ratio (23)                                                                |
| $F$     | $M L^{-2} T^{-1}$       | flux (3)                                                     | $\eta$           | $L^2 T^{-1}$                   | thermal diffusivity of soils (34)                                                             |
| $F_c$   | do                      | flux of carbon dioxide (15)                                  | $\lambda$        | $H L^{-1} \Theta^{-1} T^{-1}$  | Thermal conductivity of soils (34)                                                            |
| $G$     | $H L^{-2} T^{-2}$       | heat flow into or out of the ground (17)                     |                  | (or $M L \Theta^{-1} T^{-3}$ ) |                                                                                               |
| $G_z$   | do                      | heat flow at depth $z$ (35)                                  | $\rho$           | $M L^{-3}$                     | density                                                                                       |
| $H$     | $H L^{-2} T^{-2}$       | sum of energy input at the surface, except $A$ and $LE$ (22) | $\rho_a$         | do                             | density of air (3)                                                                            |
|         | (or $M T^{-3}$ )        |                                                              | $\rho'_a$        | do                             | deviations from mean density (4)                                                              |
| $H_0$   | do                      | net gain of radiation at the water surface (21)              | $\tau$           | $M L^{-1} T^{-2}$              | shearing stress or momentum transfer (12, 20)                                                 |