MAPPING OF SALINE SOILS AND VEGETATION

BY REMOTE SENSING TECHNIQUES

By

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1968

Submitted to the Faculty of the Graduate College
of the Oklahoma State University
in partial fulfillment of the requirements
for the Degree of
MASTER OF SCIENCE
May, 1970

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## BY REMOTE SENSING TECHNIQUES

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# ACKNOWLEDGMENTS

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CHAPTER I

INTRODUCTION

General

Less than one hundred years ago physicists abandoned the view that
heat is a substance and agreed that it is a form of energy transferable
from one body to another by radiation, conduction or convection - or a
combination of these three processes.  Radiation of heat is the process
of importance in remote sensing.

Earth scientists, space scientists and life scientists frequently
have to detect and identify various objects and conditions in the physi-
cal universe solely from information collected by sensors that are re-
motely situated with respect to the area being investigated.  This is
called remote sensing.  Energy that is either emitted or reflected from
the objects of interest is recorded by the sensors, either in photo-
graphic form or in a form which can be readily reconstituted into a
photo-like image.

The energy which is detected by the sensors moves with the constant
velocity of light in a harmonic wave pattern and is defined to be in the
electromagnetic spectrum.  Distinguished by the methods used to produce
and detect radiation, this spectrum has been divided historically into
various regions called spectrum bands.  Effectively differentiated by
their interaction with matter, these bands are radio waves, microwaves,

infrared, visible, ultraviolet, x-rays, and gamma rays. This spectrum is shown in Figure 1.

Forasmuch as the intensity of radiation is simply the number of photons per unit time and area, various interactions may occur when a photon hits solid matter. According to basic physical principles, energy and mass are conserved, and energy is (1) transmitted, that is propagated through the solid matter, (2) reflected, that is returned unchanged to the medium, (3) absorbed, giving up its energy largely into heating matter, (4) emitted, or more commonly re-emitted by the matter as a function of temperature and structure, at the same or different wavelength, (5) scattered, that is deflected to one side and lost ultimately to absorption or further scattered (5).

<div align="center">Problem</div>

Many soils in arid areas of the world are affected by high water tables and resultant soil salinity. Detection of the saline areas and the degree of salinity in the rooting zones is one of considerable interest to agricultural workers and engineers. The detection of these saline soils in early stages, in a precise and economical way, has been a problem which has been partially solved by the use of remote sensing techniques. It has been proved that obtaining information in more than one portion of the electromagnetic spectrum is sometimes advantageous. This method of reconnaissance is known as "multiband spectral reconnaissance" by means of which two or more remotely situated cameras or other sensing devices, each specially suited for the sensing of energy in its own spectral band, can be used together to provide information of the area that no single sensor can provide.

TEMPERATURE OF PEAK RADIATED ENERGY

| 7000 | 3000 | | 500 | 212 °F |
| 3871 | 1649 | | 260 | 0 °C |

ULTRA-VIOLET | VISIBLE LIGHT | NEAR IR | MIDDLE IR | FAR IR | MICROWAVES

0.3   0.72   1.5      5.6   8        1,000   WAVELENGTH, $\mu$

$1 \mu = 10^{-6} M$
$1 A = 10^{-10} M$
$FREQUENCY, MC = \dfrac{300}{WAVELENGTH, M}$

WAVELENGTH, $10^N$ ANGSTROMS

N= -6  -5  -4  -3  -2  -1  0  1  2  3  4  5  6  7  8  9  10  11  12  13  14  15

ELECTRON WAVES          INFRARED          RADIO WAVES

ULTRAVIOLET

X RAYS          VISIBLE

COSMIC RAYS   GAMMA RAYS          MICROWAVES

N= -16  -15  -14  -13  -12  -11  -10  -9  -8  -7  -6  -5  -4  -3  -2  -1  0  1  2  3  4  5

WAVELENGTH, $10^N$ METERS

Figure 1.  Position of Infrared Radiation in the Electromagnetic Spectrum

## Purpose and Scope of Investigation

It is the general purpose of the research described herein to de-termine the type of remote sensing devices for which the problem of detecting saline soils can best be solved. This objective is to be obtained by: (1) using vegetation as indicators of salinity and deter-mining the best film-filter combination for showing maximum contrasts in photographs of vegetation grown in different levels of salinity, and (2) directly measuring emitted energy from soils as they are affected by variations in moisture content, salt content and changing depth to free water table.

In this investigation wheat and salt grass were used as indicators and were grown in the greenhouse in soil at different levels of salinity. Wheat represents the major type of economic crop and salt grass is the major type of natural vegetation in the area under investigation. The wheat was grown in silty clay with salinity ranging from 0 ppm to 10,000 ppm, while the salt grass was grown in sand and silty clay with salinity ranging from 0 ppm to 160,000 ppm. Samples taken from the vegetation were tested in a DU-2 spectrophotometer with a reflectance attachment. Reflectance was recorded in the ultra-violet, visible and near infrared regions of the electromagnetic spectrum.

Silty clay and sand were used for determining the influence of salt content, moisture content, and changing water table on emissivity of soil. The soils, with salinity varying from 0 to 160,000 ppm, were placed in one-foot square panels and kept outdoors in the sunlight. The emissivity was measured at different periods of the day with a Precision Radiation Thermometer (PRT-5) radiometer, manufactured by Barnes Engineering Com-pany, which measures the emitted radiation in the 8 to 14 micron window.

Silty clay and sand were also placed in an apparatus specially devised to simulate changing in water table, for saline and non-saline water, from 0 to 4 feet. The emissivity was measured for these soils in the same manner as for the soils in the panels.

CHAPTER II

REVIEW OF LITERATURE

Nature and Characteristics of Infrared Radiation

Infrared is that portion of the electromagnetic spectrum bounded on one side by the visible portion of the spectrum and the other side by micro wavelengths used for high resolution regions (Figure 1). Human eyes respond to light in the visible portion of the electromagnetic spectrum. However, to a scientist, one of the most useful regions on the spectrum is beyond that of the human eyes response - that is, the infrared region. Within this region, it has been established that all matter with temperature above absolute zero continuously emits and absorbs electromagnetic radiation. This emission is a result of the continual motion of the elementary charged particles within the substance. Whereas the thermal motion of the electrons and protons increases with temperature, it follows that the continuous radiation from a particular sample must increase with temperature. Consequently, almost everything in man's surroundings, and man himself, radiate energy in the infrared portion of the electromagnetic spectrum (10) (20).

The primary source of natural radiation is the sun; and, as solar energy impinges upon the surface of the earth, it is either absorbed or reflected. Objects with temperatures above absolute zero which absorb radiation tend to increase in temperature, then re-emit this energy

mostly in the infrared portion of the spectrum. Objects which absorb all incident radiation and emit more radiation than any other object at the same temperature are termed blackbodies; however, since a perfect black-body does not exist, all materials are considered in terms of degree of "blackness", as gray bodies.

Today infrared, or IR, is recognized as electromagnetic energy of wavelengths between 0.7 and 1,000 $\mu$ (0.7 to 1,000 x $10^{-4}$ cm). Its realm in the electromagnetic spectrum is further divided into three specific regions - near, middle, and far - with each region having radiation de-tectors peculiar to its location in the pattern of wavelengths. In the near infrared region, wavelengths from 0.72 to 1.5 $\mu$ , radiation can be detected by photoemissive cells, photoconductive cells, photovoltaic cells and infrared photographic emulsions. Photoconductive and photo-voltaic cells, together with thermal detectors at the longer wavelengths, are commonly used detectors in the middle infrared region or wavelengths from 1.5 to 20 $\mu$ . Detection in the far infrared region, wavelengths from 20 to 1,000 $\mu$ , is usually made by thermal detectors which measure the variation of some physical parameter with temperature.

Dictated by its domain in the electromagnetic spectrum, infrared exhibits some of the characteristics of both visible light and micro-wave radio waves. Infrared wavelengths near the visible light region can be optically focused and directed by lenses and mirrors or dispersed by prisms, whereas, infrared near the radio wave region can be propagated through some materials that are opaque to visible light (8).

# Laws of Radiation

Since all objects with temperature above absolute zero radiate electromagnetic energy, the total amount of emitted radiation increases as the object's absolute temperature increases. This is shown by the Stefan-Boltzmann Law which states that the total energy (of all wavelengths) radiated from an object is given by the equation $E = \sigma(T^4 - T_o^4) e_t$

where     $E$ = energy radiated, in watts per sq cm

$T$ = absolute temperature of the radiating body, in deg. K

$T_o$ = absolute temperature of the radiating surrounding surfaces, in deg. K

$e_t$ = total emissivity (unit of blackbody source)

$\sigma = 5.673 \times 10^{-12}$ watt cm$^{-2}$ °K$^{-4}$

If $T$ is greater than $T_o^4$ the error introduced by neglecting $T_o$ is less than .5 percent and the equation becomes

$$E = \sigma T^4 e_t = 5.673 \times 10^{-12} T^4 e_t \text{ (8) (11)}.$$

The emissivity factor ($e_t$) in the Stefan-Boltzmann Law is the ratio of an object's total radiant emittance to that of the total radiant emittance of a blackbody at the same absolute temperature. For instance mirrors have emissivity of approximately .05 while a lamp black is approximately .95. Therefore, the smoother and shinier the surface of an object, the amount of radiation which will be absorbed is smaller.

The Stefan-Boltzmann Law shows how much energy is radiated at a given temperature, but it does not give any information about the distribution of energy. This is given by Planck's Law (8) (11)

$$E\lambda d\lambda = C_1 \lambda^{-5} (e^{(C_2/\lambda T)} - 1)^{-1}$$

where    $C_1 = 3.732 \times 10^{-12}$ watt $cm^2$

$C_2 = 1.436$ cm °K

$e = 2.718$

$E\lambda d\lambda$ = energy radiated in wavelength

$\lambda$ = wavelength, in cm

$T$ = absolute temperature, in °K

Planck's Law for any temperature may be represented by a curve giving the relationship between energy radiated and wavelength as shown in Figure 2. The area under the curve is total energy radiated and graphically represents the Stefan-Boltzmann Law.

In nature, objects are not perfect radiators throughout the entire spectrum and therefore will reflect or transmit as well as absorb some portion of incident radiation. The total amount of emitted radiation reaches a peak at certain wavelengths. This is shown through Wien's Displacement Law which states that the wavelength at which peak radiation power occurs equals a constant ($K = 2.89 \mu$ °K) divided by the object's absolute temperature in degrees Kelvin ($\lambda = K/T$). This peak radiation power shifts toward the shorter wavelength as the temperature of the radiator is increased, as shown in Figure 2 (9). The well known variation in the color of hot objects with temperature is explained by these curves in Figure 2. At room temperature virtually all the radiation is in the infrared region of the electromagnetic spectrum, while as the temperature increases more and more of the radiation appears in the visible range. At first it is in the red end of the spectrum, with
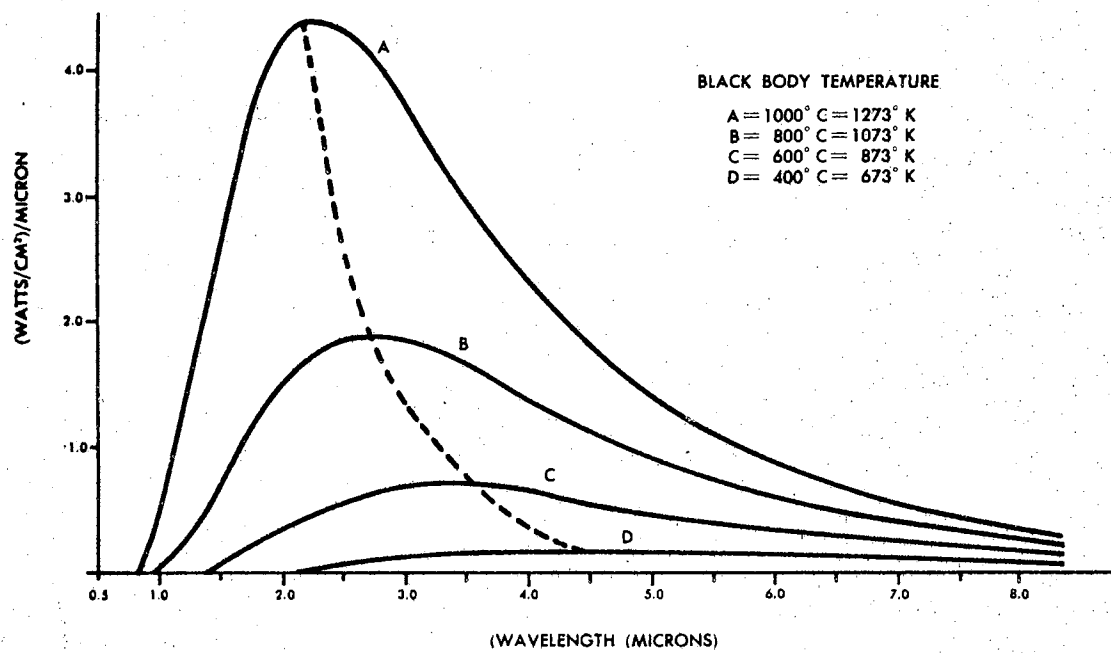
Figure 2. Blackbody Radiation Curves

the result that the object appears red. When its temperature is of the magnitude of the temperature of the sun's surface (6000°K) the radiation is distributed throughout the visible region to produce the color sensation which we call white. The earth has an average temperature of 300°K which is shown to have its peak radiation emittance power at 9.6 $\mu$ (Figure 2). This radiant energy is an excellent energy source and permits the detection of terrestrial objects by the use of emitted energy in the infrared spectrum band. Since the sun is an excellent energy source it permits the detection of terrestrial objects by reflected energy in visible and near infrared spectrum bands by use of panchromatic and infrared sensitive film (17).

<div align="center">Atmospheric Absorption and Scattering</div>

Due to the passage of radiation through the atmosphere, it is necessary to consider the atmospheric constituents and their effects on radiation. These constituents, such as gasses, smoke and dust particles, water vapor, and water droplets, cause losses by scattering and/or reflecting and absorbing the radiation. Particles in the atmosphere of approximately .25 $\mu$ in size greatly scatter radiation of ultraviolet and blue violet frequency with scattering decreasing toward the longer wavelengths in the visible portion of the spectrum. Likewise fog particles of approximately 4 $\mu$ radii will completely attenuate by scattering radiation in the near and much of the middle infrared region.

A typical transmission spectrum of the atmosphere, as shown in Figure 3, depicts the transparency of the atmosphere at different wavelengths along the spectrum. At certain wavelengths it is nearly opaque. Wavelength ranges for which the atmosphere is transparent to radiation
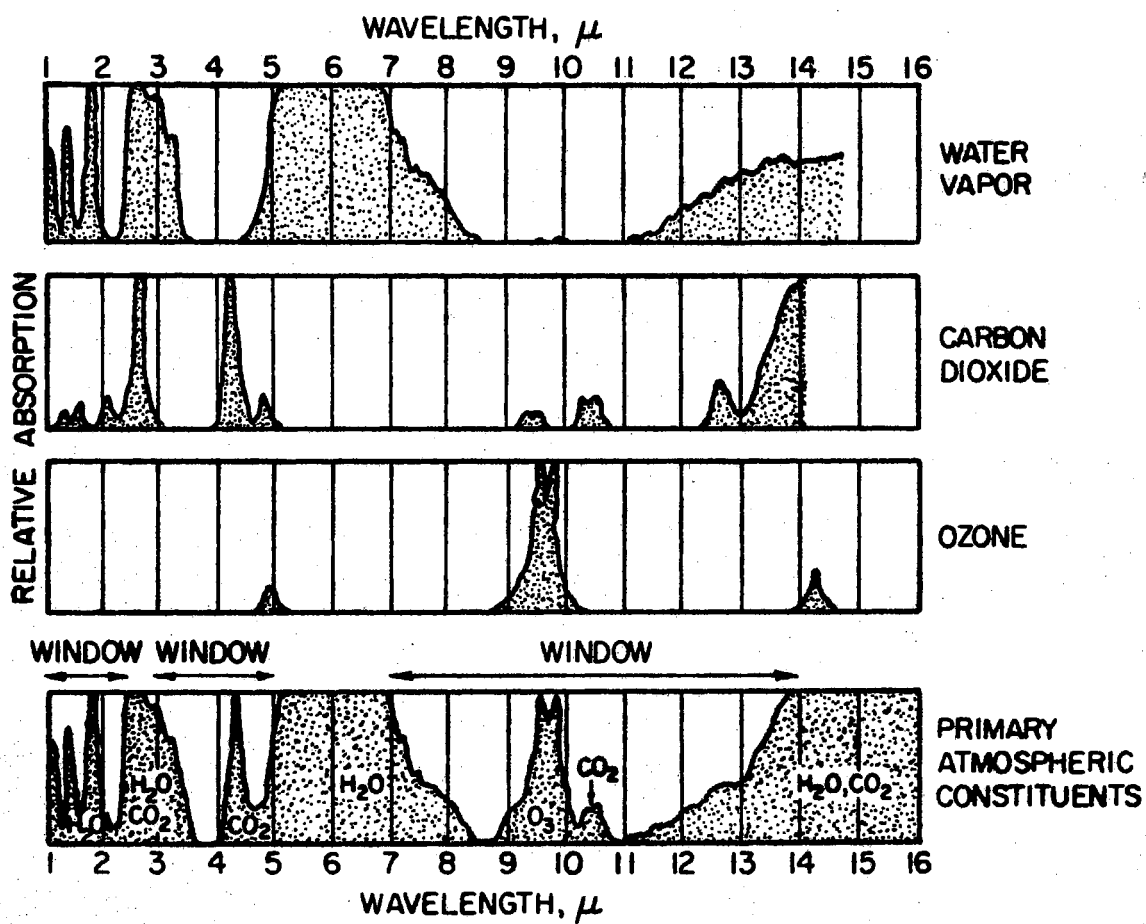
Figure 3. Infrared Absorption Bands of Primary Atmospheric
Constituents

are called "windows". "Windows", however, are not perfectly transparent,
80% transmission would more nearly represent their transparency.

The amount of atmospheric absorption and scattering is a function
of pathlength, the amount of scattering and absorbing constituents with-
in this pathlength, and the wavelength particle size relationship. A
number of different atmospheric constituents attenuate an infrared beam
as it passes through the atmosphere. Most of the absorption of the ra-
diation in the beam is due to molecules of water vapor ($H_2O$), carbon
dioxide ($CO_2$), and ozone ($O_3$). However, ozone is limited to a layer at
an altitude of approximately 80,000 feet and for most purposes the effect
of it on infrared transmission below this altitude can be neglected. The
effect of minor atmospheric constituents such as methane ($CH_4$), nitrous
oxide ($N_2O$) and carbon monoxide (CO) may be observed over long paths.
Two oxygen absorption bands occur at 1.06 u and 1.27 u in the infrared
portions of the spectrum. The absorption of the electromagnetic energy
by water vapor virtually closes the atmosphere beyond the 25 micron wave-
length to the start of the microwave region (11) (8).

## Remote Sensing

Today's modern aircraft and earth satellites make it possible to
survey the earth from a vantage point heretofore unobtainable. By this
method of remote sensing the identification of an object or determina-
tion of some properties of the object can be done in two ways. The
identification may be obtained on the basis of shape, size, color or
other criteria; or it can be obtained by duplicating our visual senses
by photography. In many cases the measurement we wish to make is one of
quantity, i.e., the absolute value of the radiation; while on the other

hand, we may wish to measure qualitative aspects, i.e., the relative value of the radiation and thus acquire the information that this conveys in the light of our knowledge of some of the physical properties of the object.

There are two types of remote sensing, active and passive systems. The active system is one that actually illuminates the object under investigation with radiation of a particular wavelength and then samples the portion reflected back to the detecting device. Radar is the best example of an active system among the radiation sensors. Night photography, where an artificial illumination system is required, would be another example (17).

The passive system is one that samples emitted and reflected radiation from a source. Radiometers and scanners that measure emitted and reflected radiation in the infrared and microwave regions are examples of passive systems (17).

Due to the fact that matter which is struck by photons either transmits, reflects, emits, absorbs or scatters electromagnetic energy at different magnitudes is the principle by which different types of matter are identified by measuring these differences with some type of remote sensor (5).

In selecting the type of sensor to be used, one should consider these three aspects, (1) what atmospheric window is to be used, (2) in what part of the electromagnetic spectrum will best detection be possible, and (3) what properties are to be detected. For example, if the reflectance properties are to be detected by a sensor these are best disclosed in the atmospheric window between .4 to .9 microns by photography. The photography is usually obtained by an Itek nine lens multiband camera shown in Figure 4.
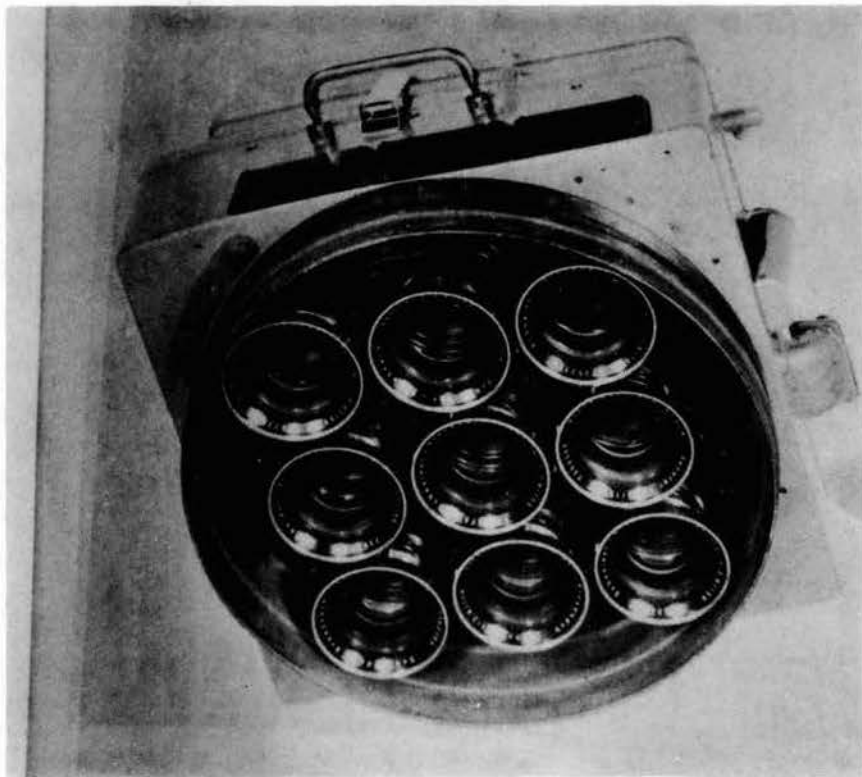
Figure 4.    Itek Nine Lens Multiband Camera

The camera consists of nine matched lenses with different filters to take nine simultaneous exposures of the same identical ground area. By using different filters it is possible to filter out different portions of the spectrum to show which part of the spectrum will detect the particular property of the object which is of interest to the viewer (13).

If the emitted energy is the property which is to be investigated by a sensor, the atmospheric windows between 3.5 to 5.5 and 8 to 14 microns are used. Futhermore, since approximately 30% of the radiation emitted by terrestrial objects falls within the 8 to 14 micron range, it is a good range of the spectrum for detecting emitted energy. The measuring of emitted energy by sensors is usually done by use of an electronic instrument which measures emitted energy in degrees centigrade or Fahrenheit and is called a radiometer. See Figure 10.

## Effects of Salinity on Plants

Plants grown in soils having excessive soluble salt concentrations in the root zone are affected in many ways. The increased osmotic pressure of saline solutions restricts uptake of water by plant roots which affects the growth of plants. Specific ion toxicity can also affect plant growth and appearance. Since the behavior of plants is a good index of their environment, plants are frequently used as indicators of conditions that occur below the soil surface. These are manifested in the plants' appearance and spectral reflectance from the leaf surfaces. Since the root systems of plants explore a rather large soil volume, a plant sample is more representative of the site conditions than is a single soil sample (14).

Because of a leaf's physiological structure light of different wavelengths is reflected from different portions of the leaf's cross-section (Figure 5). The chloroplasts which are used in photosynthesis affects the electromagnetic spectrum between .3 - .6 microns. The blue and red lights are largely absorbed by the chloroplasts while the green light is largely reflected. Chloroplasts, being transparent to the infrared portion of the spectrum, have little effect on infrared radiation striking it, however, the spongy mesophyll affects the infrared by highly transmitting and reflecting it (4) (15).

A leaf's reflectance changes as it matures because its spectral properties are closely associated with cell structure. Due to an increase in chlorophyll with maturity, the reflectance of leaves increases in the visible region of the spectrum with maturity. Reflectance also increases with maturity in the near infrared region. It is probable that the near infrared reflectance is a function of the cell shape and size as well as the amount of intercellular space. Initially, the mesophyll of the vary young leaf consists primarily of spongy parenchyma with considerable air spaces which are favorable to the mechanism of internal reflection. Then as the leaf matures these cells enlarge, crowding together, reducing the intercellular space and increasing the reflectance. It would then appear that during the final maturing the cell structure and intercellular space relationship become favorable for increased reflectance. In order to establish this relationship, careful experiments will need to be done relating the reflectance to the leaf morphology (21).

The relative turgidity, which is a measure of field moisture content of plants expressed as a percentage of their turgid water content, does not have much effect on the reflectance of leaves in the visible
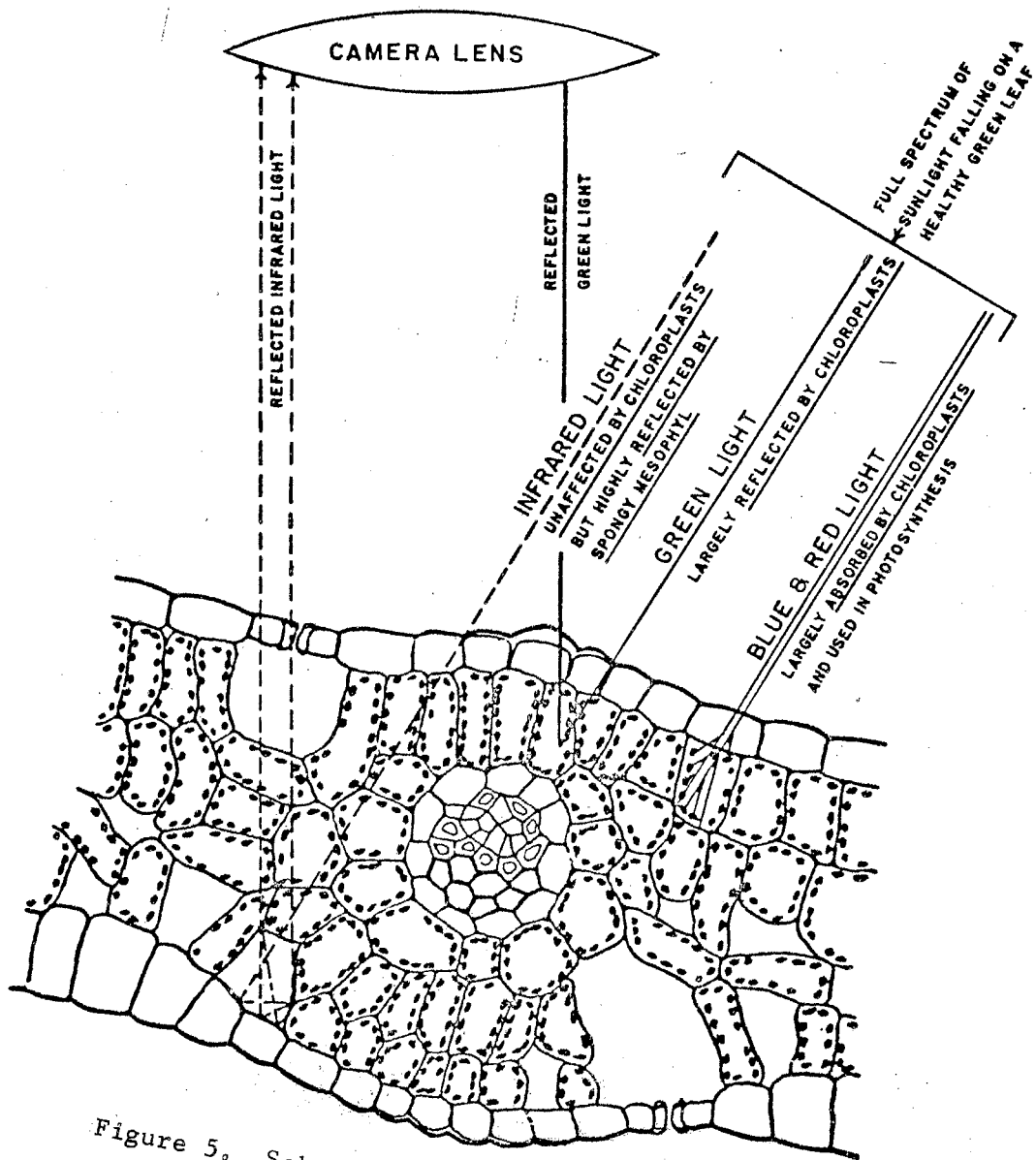
Figure 5. Schematic Drawing of Cross-Section of Healthy Leaf

range of the spectrum. While reflectance does increase as relative tur-
gidity decreases, it must be less than 80% to affect reflectance.

Reflectance of leaves in the infrared region of the electromagnetic
spectrum increases when leaves are stacked on each other, while no effect
in magnitude of reflectance occurs in the visible region. This shows
that the reflectance in the visible region is a surface phenomenon and
that in the infrared portion it depends on thickness of leaves. Thus a
spectrophotometer study of single leaves can be very misleading in terms
of the magnitude of reflectance of the infrared region of vegetation in
the field (16).

A study by Myers, et. al. (1963) predicted the expected tonal con-
trasts on the basis of single leaf thickness spectrophotometer studies.
The study showed that the differences in reflectance between cotton
leaves affected by salinity and non-affected leaves to be only 2 percent.
On the other hand, infrared photographs taken of the area showed quite a
contrast in the tone of the affected and non-affected plants. This is
believed to be due to the reinforcement of reflectance by multiple leaf
layers (16).

Since the materials of the leaf that affect spectral reflectance
are common to all agricultural plants, all foilage exhibits the same
general pattern of reflectance. But it is important to recognize that
other factors such as crop geometry and background soil conditions af-
fect the reflectance measured in the field.

Numerous factors influence the timing of the picture taking mission
and the photo interpretation. Experience has shown that physiological
drought caused by salinity is most apparent in the morning hours. In
the afternoon hours leaves lose turgidity as a result of high ambient

temperature, an effect that makes part of the evidence of physiological drought predominant (15).

## Detection of Saline Soils

Many areas of the United States are plagued with the problem of saline soils with a high water table. The detection of these saline soil areas is of special significance to agricultural scientists, agronomists and civil engineers. Remote sensing has been considered by some scientists as an effective approach to the detection and mapping of such areas.

The detection of salinity through the atmospheric window 8 - 14 microns is done through the temperature characteristics of the soil. Therefore, the emitted energy is a function not only of the physical characteristics of the surface but of the surface temperature as well. Since the surface temperature is dependent upon factors which are affecting the soil temperature at depth it is possible to detect such things as water table by use of these longer wavelengths.

The ability of soil to radiate thermal energy is dependent upon many factors, such as emissivity, thermal conductivity, tone, specific heat, and thermal diffusivity of the soil. All of these factors are raised as the moisture content rises in the soil due to water replacing air voids (2). Therefore water has a large effect on the rate at which thermal energy is emitted from the soil. Since different concentrations of salt in the soil change the rate of evaporation in the soil's moisture content, it is possible to detect its amount of salinity.

Due to the rate of differential heating and cooling of the soil, there are times during the day when maximum differences in emitted

energy will be observed. These differences depend upon the climate and type of soil. There is also a time of day when there will be no difference in emitted thermal energy (7). Thus, the best time for detection has to be found by trial and error.

CHAPTER III

MATERIALS AND LABORATORY PROCEDURES USED IN INVESTIGATION

General

The soils used in this investigation were silty clay and sand.
Both types are found in the Salt Plains area. Since such large amounts
of soils were needed during the investigation, the samples to be used
were taken from the area surrounding Stillwater, Oklahoma and not from
the Salt Plains.

The types of vegetation grown in the greenhouse during the investi-
gation were wheat and salt grass. The choice of these types of vegeta-
tion was made on the basis of salt grass being a native grass which can
be grown in soils having high saline content; and, wheat being the most
prominent crop grown in the Salt Plains area.

Properties of Soils

Sand

The sand used in the investigation was river sand having a specific
gravity for particles passing a No. 10 sieve of 2.69. A sieve analysis
of the sand is shown in Figure 6. All sand used in the investigation
was sieved through a No. 10 sieve. Table I shows the results of the
chemical analysis of the sand.

**U.S. STANDARD SIEVE OPENING IN INCHES    U.S. STANDARD SIEVE NUMBERS           HYDROMETER**

GRAIN SIZE IN MILLIMETERS

Unified Soil Classification System – Corp of Engineers, U.S. Army
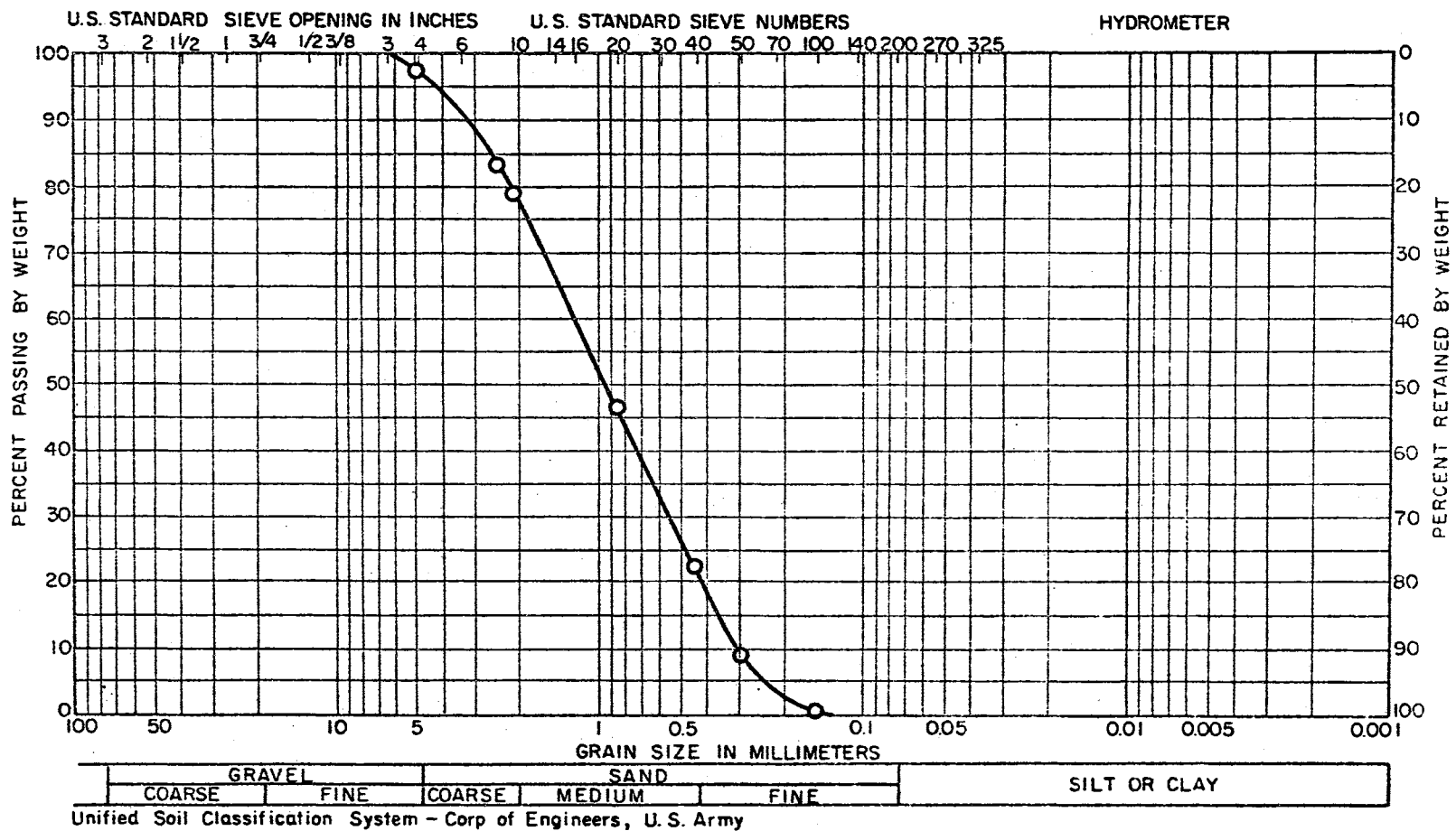
Figure 6.    Grain Size Distribution Curve for Sand

TABLE I

CHEMICAL ANALYSIS OF SAND

| Soil Test Results | Reading | Adjective Rating |
|---|---|---|
| Organic Matter (Nitrogen %) | 0.07 | Very low |
| Phosphorous #/A (lbs/acre) | 9.40 | Very low |
| Potash #/A (lbs/acre) | 35.00 | Very low |
| PH (Acidity or Alkalinity) | 7.20 | Neutral to very slightly alkalinity |

## Silty Clay

Standard sieve and hydrometer analyses on samples of the silty clay yielded the grain size distribution curve shown in Figure 7. The specific gravity, determined on samples passing a standard No. 16 sieve, was 2.77. All silty clay used in this investigation was sieved through a No. 16 sieve. The Atterberg Limits of the soil were:

Liquid Limit . . . 28.5

Plastic Limit . . 17.9

Table II shows the results of a chemical analysis of the silty clay.
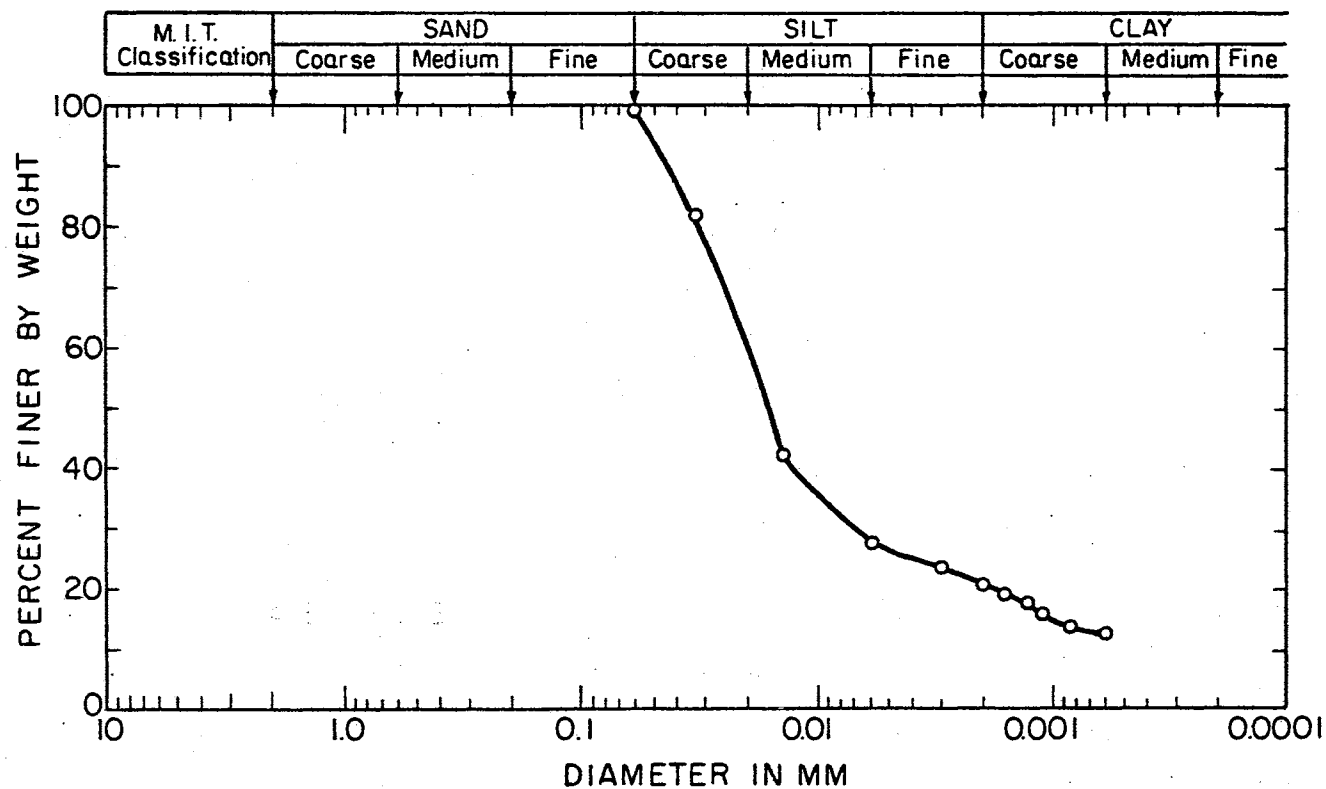
Figure 7.   Grain Size Distribution Curve for Silty Clay

TABLE II

CHEMICAL ANALYSIS OF SILTY CLAY

| Soil Test Results | Reading | Adjective Rating |
|---|---|---|
| Organic Matter (Nitrogen %) | 1.35 | Very low |
| Phosphorous #/A (lbs/acre) | 105.60 | Very low |
| Potash #/A (lbs/acre) | 375.00 | Very high |
| PH (Acidity or Alkalinity) | 5.95 | Moderately Acid |

Water Holding Capacity

The ability of soils to hold water depends on the grain size and the amount of organic matter present in the soil. Water holding capacity of a soil is determined by placing a sample of soil in water until it is saturated and then draining it for 24 hours. During this period most of the excess of non-capillary water is drained away by gravity, and the soil attains the water holding capacity (22).

Procedure

Two-inch square brass containers with screened bottoms were used for soil samples. Filter paper was placed in the screened bottoms, and the containers were filled with soil to two-thirds capacity. The containers were then placed in a water bath one-half immersed. After remaining in the water bath for 24 hours, they were taken out and allowed to drain for another 24-hour period. Having drained, they were weighed and placed in an oven at 110° C. for 24 hours, then reweighed. The

percent of water holding capacity is $(\frac{X - Y}{Y - Z})$ x 100, where,

weight of drained sample . . . . . . . . . X grams

weight of oven-dried sample . . . . . . . Y grams

weight of containers . . . . . . . . . . . Z grams

content of water . . . . . . . . . . . . . (X - Y) grams

The water holding capacities of the silty clay, sand and sandy clay mix-
ture were found to be 45, 18 and 20, respectively.

## Relative Turgidity and Water Content of Leaves

Water content of the leaves is simply the amount of water by weight
which is in the leaves. Relative turgidity is the amount of water by
weight which the leaves can hold. The method used in determining the
relative turgidity was to weigh three or four leaves and placing them
in a dish of distilled water in a refrigerator at the temperature of
7° C. for 24 hours. Leaf cuts were then blotted dry with tissue paper,
weighed immediately, and oven-dried at 85° C. for 24 hours. After this
period, the leaf cuts were then reweighed (19).

The relative turgidity of leaves was expressed as a percentage and
evaluated according to the equation:

$$R.T. \% = (\frac{X}{Y}) \text{ x } 100$$

The water content of leaves was expressed on a fresh weight basis and
calculated as follows:

$$W.C. \% = (\frac{A - B}{A}) \text{ x } 100$$

where,

leaf tissue fresh weight . . . . . . . . A

leaf tissue oven-dried . . . . . . . . . B

leaf tissue saturated weight . . . . . C

water content of the fresh leaf tissue $X = (\dfrac{A - B}{A})$

water content of the same leaf tissue at full saturation $Y = (\dfrac{C - B}{C})$

CHAPTER IV

INVESTIGATIVE PROCEDURES FOR REFLECTANCE

General

Since vegetation is affected by chemicals present in the soil, it
has been proved to be one of the best indicators of salinity in soil
profiles. Therefore, a reflection study was made of vegetation native
to the Salt Plains area to determine if these types of vegetation could
be used as indicators of salinity in soils of that area.

The vegetation was grown in the greenhouse under controlled climate.
Samples were contained in two-gallon buckets. By growing the vegetation
under controlled conditions it was possible to eliminate some of the
variables which could affect the growth of the plants. The salt grass
was grown at five levels of salinity, that is 0, 20,000, 60,000, 80,000,
100,000 and 160,000 ppm and in two types of soil -- silty clay and sandy
clay mixture. The wheat was also grown at five levels of salinity -- 0,
2,000, 4,000, 6,000, 8,000 and 10,000 ppm, but only in one type of soil,
silty clay. The wheat was grown at much lower levels of salinity since
the salts become toxic to wheat at lower levels than salt grass.

Determination of Salt Contents

The determination of the levels of salinity at which the vegetation
should be grown was made by the osmotic values found to be present in

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the soils of the Salt Plains area by Dr. Elsharkawi (6). The predomi-
nant salts found in the area were sodium chloride and calcium chloride.
In calculating the amounts of both sodium chloride and calcium chloride
which when dissolved in one litre of water give a solution of particular
osmotic pressure, the equation followed by Lagerwerff and Holland (1960)
was used (12).

The amount of salts to be used at different osmotic values is de-
pendent upon the level of the sodium absorption ratio (SAR) at which the
sodium becomes toxic to the plant. Dr. Elsharkawi found an SAR value of
1/8 to be low enough to avoid sodium toxicity in wheat and salt grass.

$$\text{SAR} = \frac{\text{Na}^+}{(\text{Mg}^{++} + \text{Ca}^{++})} \quad \text{m moles}^{1/2} \text{ litre}^{-1/2}$$

However since the amount of magnesium in the soils is negligible com-
pared to that of calcium (usual in soils with high calcium content) the
equation can be written as

$$\text{SAR} = \frac{\text{Na}^+}{(\text{Ca}^{++})} \quad \text{m moles}^{1/2} \text{ litre}^{-1/2}$$

The amount of sodium chloride and calcium chloride for a solution of
one atmosphere at an SAR of 1/8 is

$$\text{SAR} = \frac{\text{Na}^+}{(\text{Ca}^{++})1/2} = 1/8 \quad \therefore \quad 8\text{Na}^{++} = (\text{Ca}^{++})^{1/2}$$

or

$$64(\text{Na}^+)^2 = \text{Ca}^{++} \text{ m moles litre}^{-1} \tag{1}$$

And since 32 me $CaCl_2$ per litre and 24 me NaCl per litre constitute a
solution of one atmosphere osmotic pressure

$$\therefore \quad \frac{me\ NaCl}{24} + \frac{me\ CaCl_2}{32} = 1\ atm \qquad (2)$$

Thus substituting for Ca in equation (2) its value in equation (1)

$$NaCl + 48(NaCl)^2 = 24 \qquad (3)$$

Equation (3) is a quadratic equation of the form

$$Ax^2 + Bx = C$$

where x can be determined from the solution of the equation

$$x = \frac{-B \pm (B^2 + 4AC)^{1/2}}{2A}$$

$$\therefore \quad NaCl = \frac{-1 \pm [1 - 4 \times 48 \times (-24)]^{1/2}}{2 \times 48} = \frac{-1 \pm (4609)^{1/2}}{96}$$

$$= \frac{66.89}{96}\ me\ litre^{-1}$$

or

$$CaCl_2 = 64 \times (\frac{66.89}{96})^2\ me\ litre^{-1}$$

$$CaCl_2 = 64 \times (\frac{66.89}{96})^2 \times 55.49 = 1723.83\ mg\ litre^{-1}$$

The amounts of sodium chloride and calcium chloride to be dissolved in one litre to give osmotic pressures from 0 to 170 atmospheres were calculated and are shown in Table III and Figure 8.

TABLE III

CALCULATED AMOUNTS OF NaCl AND CaCl$_2$ PER LITRE

WHICH GIVE DIFFERENT VALUES OF OSMOTIC

PRESSURE IN SOLUTION AT FIXED

SAR OF 1/8

| Osmotic Pressure in Atm. | NaCl(g) | CaCl$_2$(g) | Total Salt in ppm |
|---|---|---|---|
| 0.5 | 0.02865 | 0.8525 | 880 |
| 1.0 | 0.0407 | 1.723 | 1764 |
| 1.5 | 0.0501 | 2.610 | 2660 |
| 2.0 | 0.0570 | 3.480 | 3537 |
| 2.5 | 0.0645 | 4.340 | 4405 |
| 3.0 | 0.0712 | 5.250 | 5321 |
| 3.5 | 0.0768 | 6.118 | 6194 |
| 4.0 | 0.0821 | 6.997 | 7079 |
| 4.5 | 0.0871 | 7.882 | 7969 |
| 5.0 | 0.0918 | 8.760 | 8852 |
| 10.0 | 0.1300 | 17.58 | 17710 |
| 15.0 | 0.1592 | 26.35 | 26509 |
| 20.0 | 0.1842 | 35.28 | 35464 |
| 25.0 | 0.2060 | 43.81 | 44016 |
| 30.0 | 0.2257 | 52.98 | 53206 |
| 40.0 | 0.2607 | 70.69 | 70951 |
| 50.0 | 0.2916 | 87.35 | 87612 |
| 60.0 | 0.3195 | 99.75 | 100069 |
| 90.0 | 0.3914 | 159.31 | 159701 |
| 110.0 | 0.436 | 198.75 | 199186 |
| 130.0 | 0.4708 | 250.24 | 250711 |

Method of Growing Vegetation

In preparing the soil in which the vegetation was to be grown, the silty clay and sandy clay mixture was dried, sieved and placed in buckets. Buckets for the wheat and one-half of the salt grass were filled with thirty pounds of silty clay. The remaining half of salt grass buckets
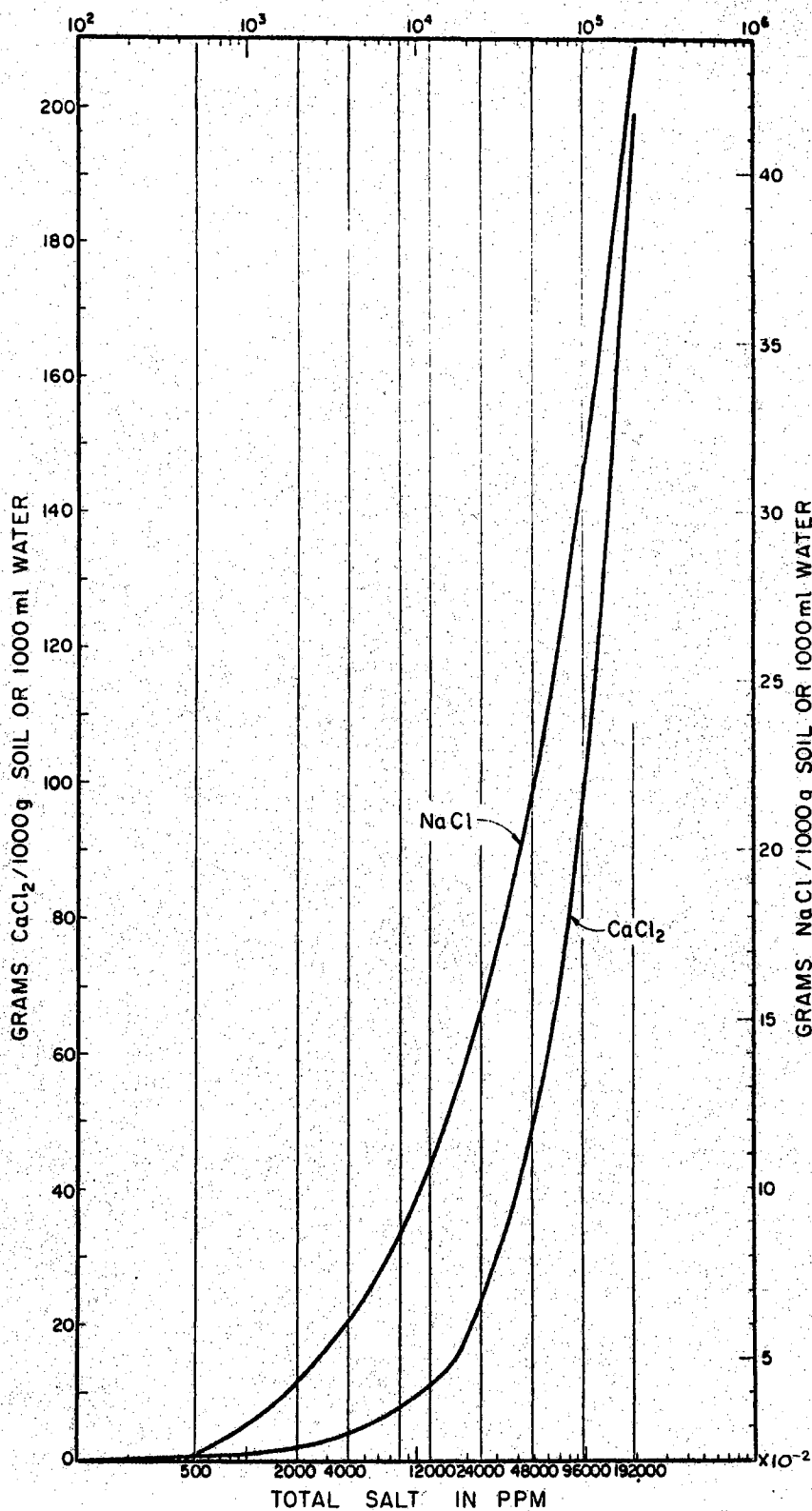
Figure 8. Amounts of NaCl and CaCl₂ that Give
Concentrations up to 192,000 ppm
at Fixed SAR of 1/8

were filled with thirty-five pounds of sandy clay mixture. Salts for the
different levels of salinity were determined and are given in Tables IV,
V, and VI.

The amounts of salts to be added to the soil were based on ppm in
solution. Therefore the amount of water which can be held by the soil,
or its water holding capacity, under saturated conditions had to be de-
termined. For example, the amount of water required to saturate thirty
pounds of silty clay at loose state is

$$30 \text{ lbs} \times 453 \text{ gm/lb} = 13{,}590 \text{ grams}$$

$$13{,}590 \text{ gm} \times .45 = 6{,}115 \text{ gm} \approx 6.1 \text{ litres}$$

where water holding capacity of silty clay = 45%. Therefore the total
salts to be added to thirty pounds of silty clay is

total $CaCl_2$ = $CaCl_2$ (gm/litres for particular ppm

        solution) x (number of litres to saturate

        thirty pounds of silty clay)

total NaCl = NaCl (gm/litres for particular ppm

        solution) x (number of litres to saturate

        thirty pounds of silty clay)

Salts were added and mixed thoroughly to the soils in the amounts given
in the tables.

The salt grass and wheat were then planted in the buckets and the
soil was saturated. The salt grass was planted from roots taken from
the Salt Plains area and the wheat was planted with seeds. The soil was
kept saturated throughout the growing period of the vegetation. The

TABLE IV

AMOUNT OF SALTS FOR TREATMENT OF WHEAT
GROWN IN 30 LBS. OF SILTY CLAY

| ppm | $CaCl_2$ gm/litre | NaCl gm/litre | litres | $CaCl_2$ gm | NaCl gm |
|------|------|------|------|------|------|
| 2000 | 1.96 | .043 | 6.1 | 11.9 | .26 |
| 4000 | 3.94 | .0615 | 6.1 | 24.03 | .37 |
| 6000 | 5.73 | .074 | 6.1 | 34.95 | .45 |
| 8000 | 7.72 | .086 | 6.1 | 47.09 | .52 |
| 10000 | 9.90 | .097 | 6.1 | 60.40 | .59 |

TABLE V

AMOUNT OF SALTS FOR TREATMENT OF SALT GRASS
GROWN IN 30 LBS. OF SILTY CLAY

| ppm | $CaCl_2$ gm/litre | NaCl gm/litre | litres | $CaCl_2$ gm | NaCl gm |
|------|------|------|------|------|------|
| 20000 | 19.85 | .138 | 6.1 | 121.08 | .84 |
| 60000 | 59.70 | .237 | 6.1 | 364.17 | 1.44 |
| 80000 | 79.70 | .277 | 6.1 | 486.00 | 1.68 |
| 100000 | 99.70 | .307 | 6.1 | 608.10 | 1.87 |
| 160000 | 159.30 | .391 | 6.1 | 971.00 | 2.38 |

TABLE VI

AMOUNT OF SALTS FOR TREATMENT OF SALT GRASS
GROWN IN 35 LBS. OF SANDY CLAY

| ppm | $CaCl_2$ gm/litre | NaCl gm/litre | litres | $CaCl_2$ gm | NaCl gm |
|---|---|---|---|---|---|
| 20000 | 19.85 | .138 | 3.2 | 63.52 | .44 |
| 60000 | 59.70 | .237 | 3.2 | 191.04 | .76 |
| 80000 | 79.70 | .277 | 3.2 | 255.00 | .88 |
| 100000 | 99.70 | .307 | 3.2 | 319.00 | .98 |
| 160000 | 159.30 | .391 | 3.2 | 509.76 | 1.25 |

vegetation was irrigated through one-inch plastic tubes which were punc-
tured with 1/8 holes all around them. These tubes were placed down
through the soils to the bottom of the buckets in order to prevent the
salts from being leached out of the top of the soil when water was added.
The soil was irrigated everyday to keep it completely saturated through-
out the growing period.

Procedure for Measuring Reflectance

In order to measure reflectance of the vegetation, it was grown for
one month allowing a suitable growth of leaves and time for the salts to
affect the plants. At the end of this growing period, leaves which ap-
peared to be healthy to the visible eye, were harvested for reflectance
investigation. These leaves were then placed on 2-inch by 1.5-inch

metal strips which had been prepared with double adhesive tape to hold the leaves in place. Care was taken in placing the samples on the metal strips, making a uniform cover of leaves with no overlapping or gapping between the leaves.

The reflectance was measured on a DU-2 Spectrophotometer with reflectance attachment connected to chart recorder shown in Figure 9. Four samples of each level of salinity were tested in this investigation. To guard against the leaves losing their freshness, only one sample was prepared at a time. Only twenty minutes elapsed from the time the leaves for one sample were harvested and reflectance measured from 200 to 1000 millimicrons. The four samples of each level of salinity were run on the same chart so the high and low values could be determined and plotted on graphs given in Chapter VI.

The reflectance measurements cannot be read directly from the chart; they must be calculated. The reflectance is equal to the ratio of the reference sample to the vegetation sample, using a piece of magnesium carbonate as the reference sample. The relative turgidity for the different levels of salinity were also determined and are given in Appendix A.

### Description of DU-2 Spectrophotometer

The spectrophotometer is an instrument which measures the radiant energy reflected or transmitted by a specimen. It then compares these measurements to those of radiant energy reflected or transmitted by another substance, such as magnesium carbonate, taken as a reference standard. The following is a list and brief description of the essential spectrophotometer components:
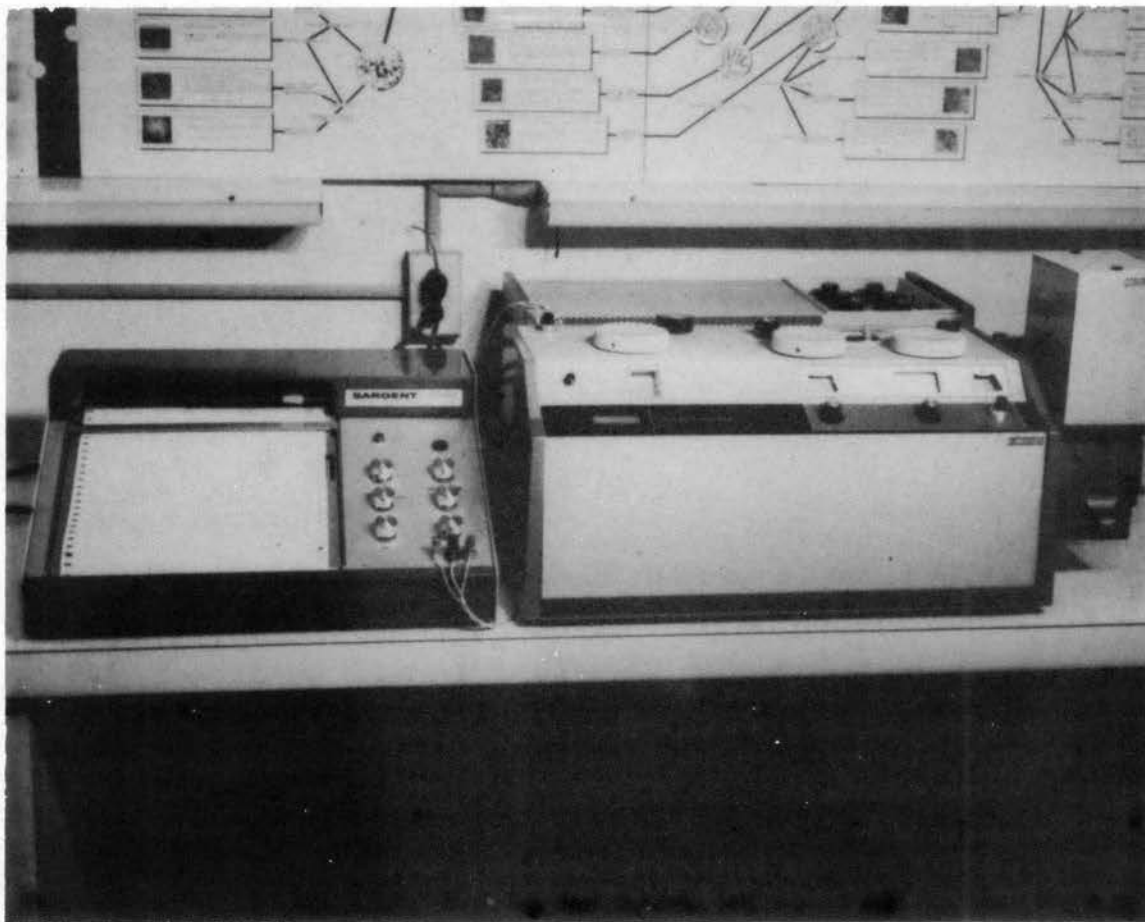
Figure 9.  Spectrophotometer Attached to a Chart Recorder

(1) <u>Radiation sources</u> - usually hydrogen arc for ultraviolet range, the incandescent tungsten filament for the visible range, and nernst glower for the infrared range.

(2) <u>Intensity control</u> - a variable slit controlling the intensity of radiant energy falling onto the specimen and the standard.

(3) <u>Wavelength control (Monochromator)</u> - a grating or prism which isolates a narrow spectral band from a continuous source.

(4) <u>Sample holder</u> - container for the sample and the reference standard.

(5) <u>Receptor</u> - a detector, such as a photocell, which measures the radiant energy reflected by the sample and the reference.

(6) <u>Indicator</u> - a recorder or simple galvanometer.

Reflectance data is obtained with a spectrophotometer by directing radiant energy of various portions of the electromagnetic spectrum to strike a specimen and then determine what portion of energy is reflected by the specimen. The radiant energy is provided by a hydrogen lamp in the 190 to 350 millimicrons wavelength region, while a tungsten lamp provides the energy in the wavelength range extending from 350 to 1000 millimicrons (9).

CHAPTER V

INVESTIGATIVE PROCEDURE FOR EMITTANCE OF SOIL

General

Soils with different chemical compositions would be expected to emit radiant energy at different magnitudes depending upon their compositions. Since the emittance of a substance is best measured at the higher wavelengths of the electromagnetic spectrum, a PRT-5 Radiometer was used in this portion of the investigation.

The measuring of emissivity of soils consisted of two tests. Both tests were run on silty clay and on sand. The first test determined the effect of salinity on soils as moisture is evaporated by solar energy. The second test, consisting of two parts, determined the effect of changing levels of water table on emissivity of soils (a) with non-saline water, and (b) with saline water.

Description of Radiometer

The PRT-5 Radiometer measures the emissivity of a substance between 8 to 14 micron wavelengths. It is a completely portable, non-contact, direct-reading, temperature-measuring instrument which consists of an optical unit and electronic unit (Figure 10). The optical unit continuously compares the amount of energy emitted by the target with that emitted by an internal, controlled, reference environment. The
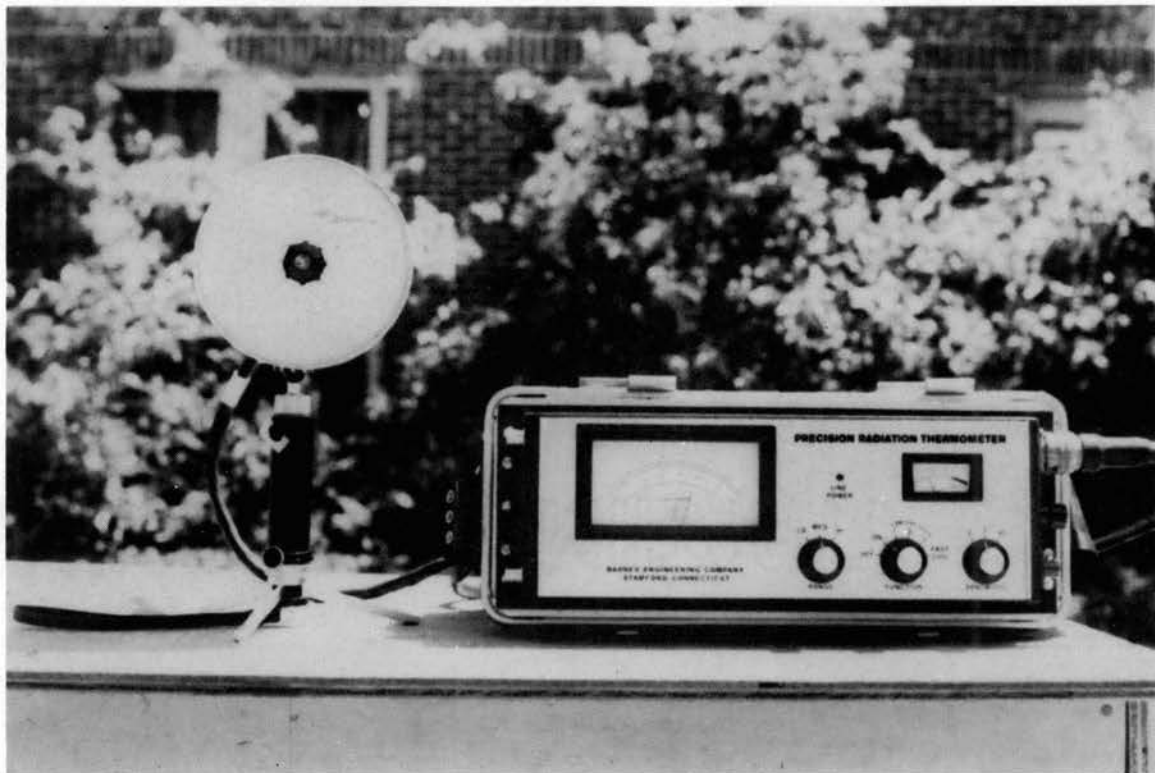
Figure 10. PRT-5 Radiometer

electronic unit processes this comparison into a voltage which is di-
rectly related to the energy difference between the target and the
reference (1).

The PRT-5 gives precise readings of equivalent blackbody temperature
from -20° C. to +75° C. Readings are accurate down to .5° C. The opti-
cal unit has a field view of 2° and a spectral filter which limits the
measurement to the 8 to 14 micron atmospheric window.

### Preparation of Panels

Panels, one-foot square by one-half foot deep, were made from 3/8-
inch plyboard to contain the soils for the first test. The panels were
sealed on the inside with epoxy to make sure the plyboard would not soak
up any moisture from the soil. Soils used for testing were dried, sieved
and placed in thirty-gallon galvanized barrels for storage. The salts to
be used in this investigation were calculated, using the same procedure
as described in Chapter IV, for the levels of salinity of 0, 20,000,
40,000, 60,000, 80,000, 100,000, 130,000 and 160,000 ppm in solution.
These amounts of salts were then weighed and dissolved in the proper
amounts of water and stored in five-gallon plastic containers. The
panels were first weighed empty, then eight of them were filled with 25
pounds of silty clay in each panel. Another eight panels were filled
with 30 pounds each of sand. The different levels of salt solutions
were then added to each panel of soil and mixed into the soils by hand.
The panels were then reweighed and placed outdoors on tables (Figure 11).
The weights of the panels were recorded in order to determine the amount
of moisture in the soils.
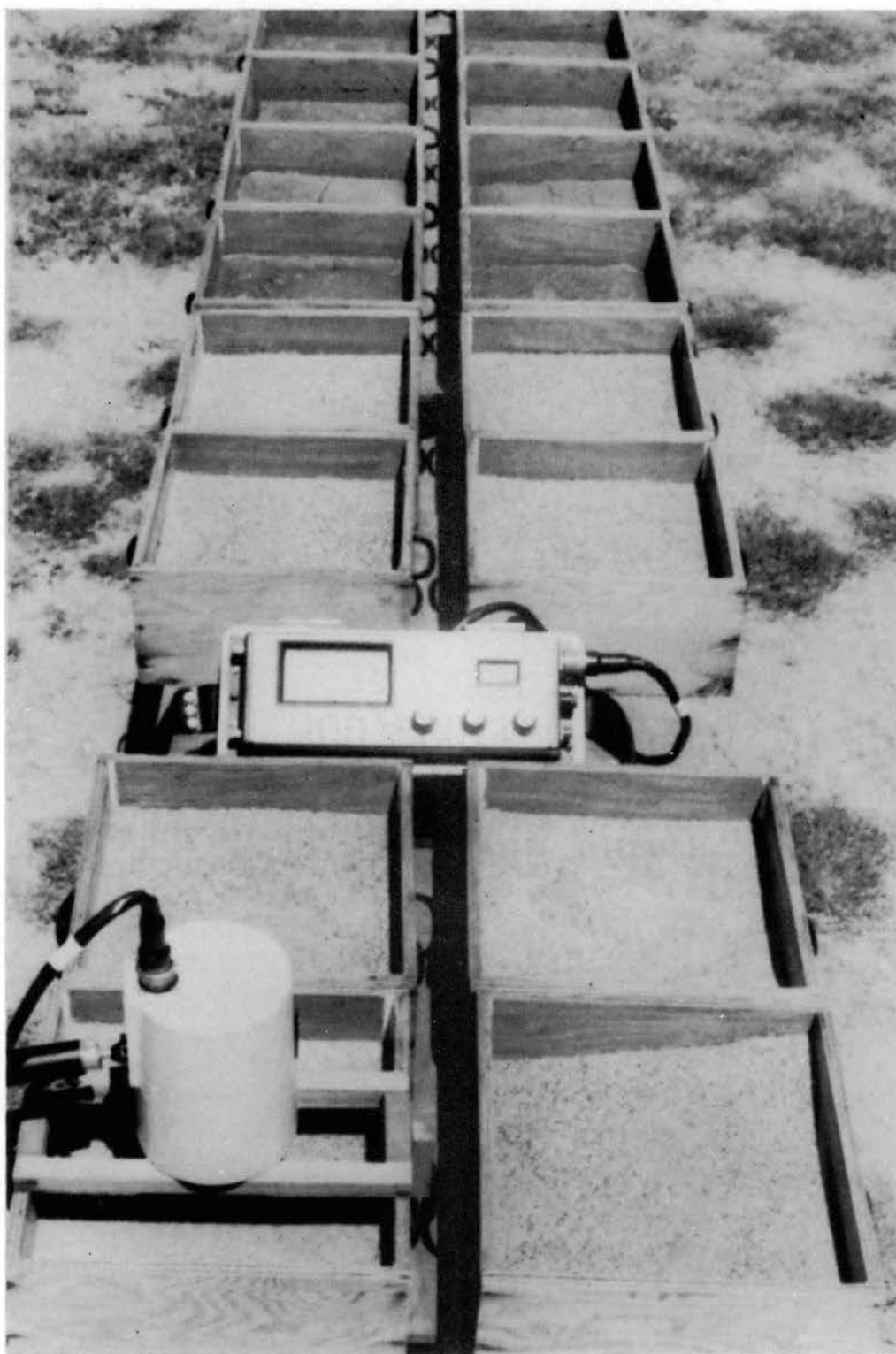
Figure 11. Soil Panels

## Procedure for Measuring Emittance

The panels were left outdoors overnight before readings were begun allowing the soils temperature to come into equilibrium with the ambient temperature. Readings were taken with the radiometer for at least one week with eight readings taken during every 24-hour period. The ambient temperature and meteorological changes were also noted and recorded at every time of reading. Each day at 4:00 p.m. the panels were reweighed in order to determine the change in moisture. Care was taken to keep the optical unit of the radiometer at the same distance from the soils for each reading.

The PRT-5 Radiometer gives readings in equivalent blackbody temperature. From the graph shown in Figure 12 the emitted energy was determined and is given in the results of Chapter VI.

## Description of Water Table Apparatus

Since the surface temperature of soils is affected by the temperature of soils beneath them, the changing water table was thought to affect the emissivity of the soil. Therefore, an apparatus was designed and built to simulate changing water table in a laboratory test. The apparatus consisted of a 10-inch square inner box, 4 ft.-2 in. high, to hold the soil, and a 17½-inch square outer box, 4-feet high, to hold the water (Figure 13).

The outer box had a 20-inch square base plate affixed to the bottom with built-up strips 10-inches square for the inner box to rest in. The inner box was made in 1-foot sections for ease of cleaning and tearing down after each experiment was completed. The inner box had 12 quarter-inch holes, three on each side, at every one foot level to allow passage
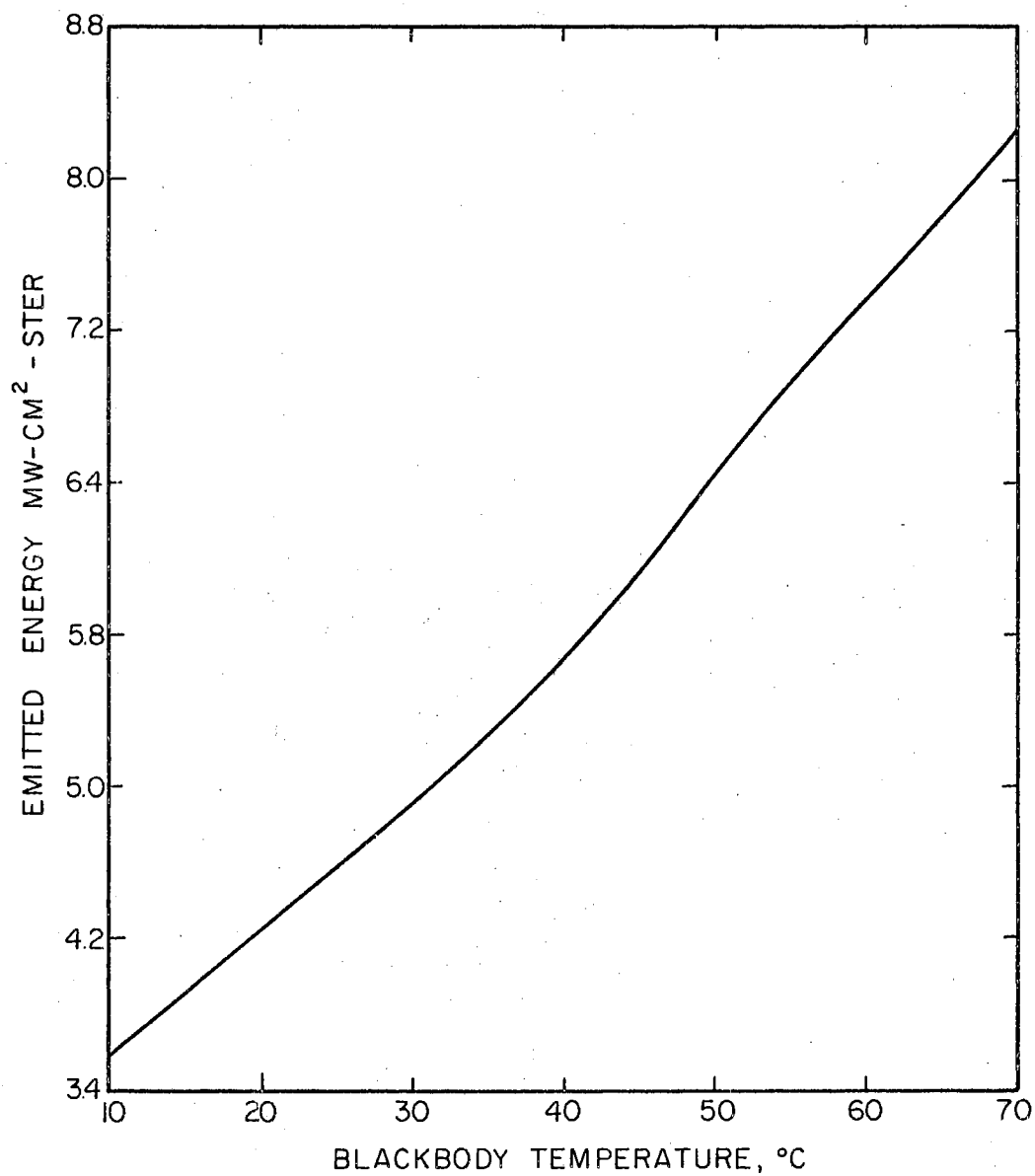
Figure 12. Effective Emitted Energy for
Standard PRT-5 Radiometer
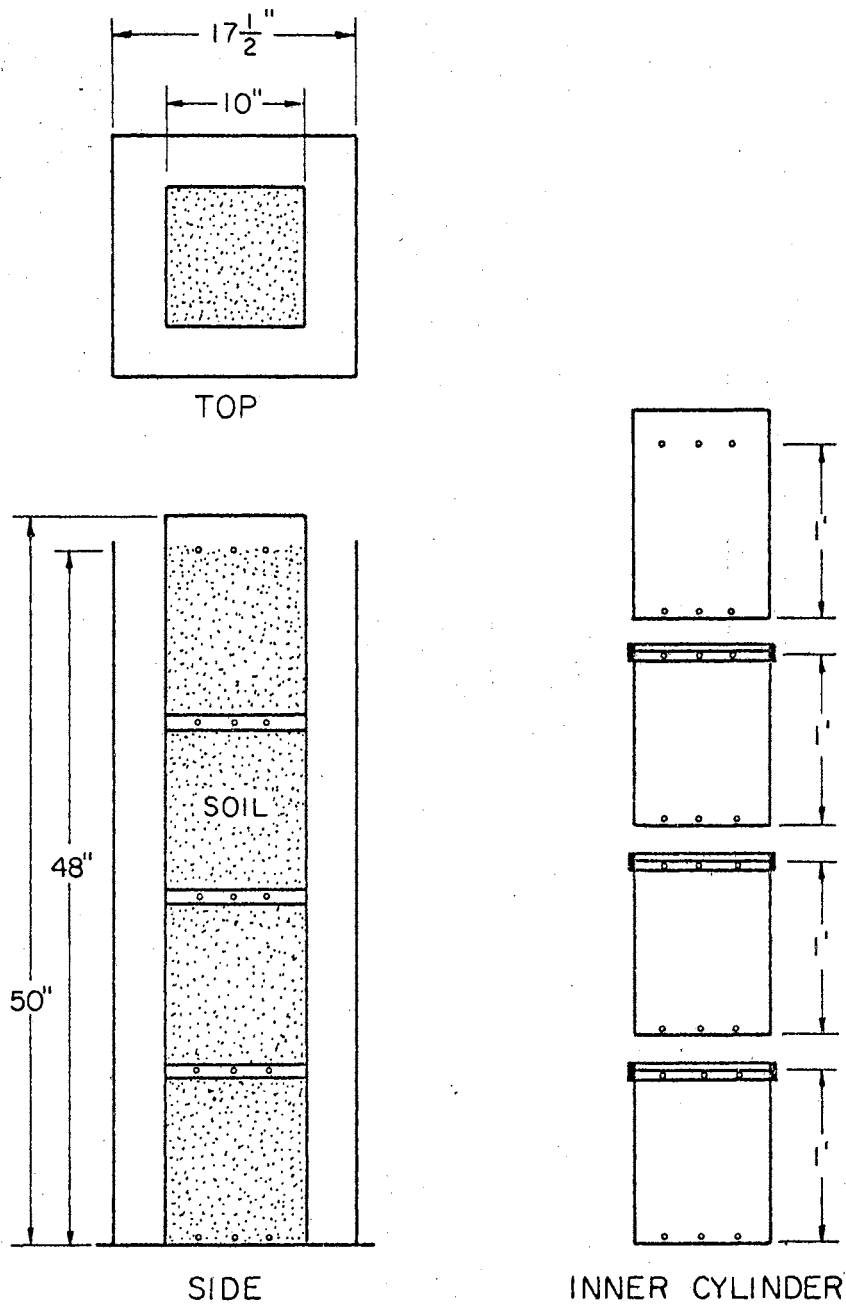
Figure 13. Water Table Apparatus

of the water into the soil as the water level changed. The apparatus was constructed from Plexiglas for ease of making and having a water tight system.

### Preparation of Test for Effect of Water Table

A. Non-Saline Water

The soils were again dried, sieved and stored in 30-gallon galvanized barrels. The boxes were placed outdoors and the inner boxes were filled with soil. When placing the soil in the inner box it was tamped every six-inch lift in order for all five boxes to have approximately the same density. This was done to eliminate the variable of density of soil on its emissivity. The outer boxes were then filled with tap water to the 0 ft., 1 ft., 2 ft., 3 ft., and 4 ft. levels (Figure 14).

This same procedure was followed with both sand and silty clay soil. The sand was dried and used again in part B of the investigation. The silty clay was dried, pulverized and sieved again to be reused in part B.

B. Saline Water

Salt solutions for 0, 20,000, 60,000, 100,000 and 160,000 ppm were prepared and stored in five-gallon containers. Forty litres of each level of salinity were prepared at a time. The soil was placed in the inner boxes in the same manner as was done in part A. The salt solutions were then put in the outer boxes. Only enough salt solution was put in all five boxes to have the depth to water table at the 4 ft. level.

O FT       I FT       2 FT       3 FT       4 FT
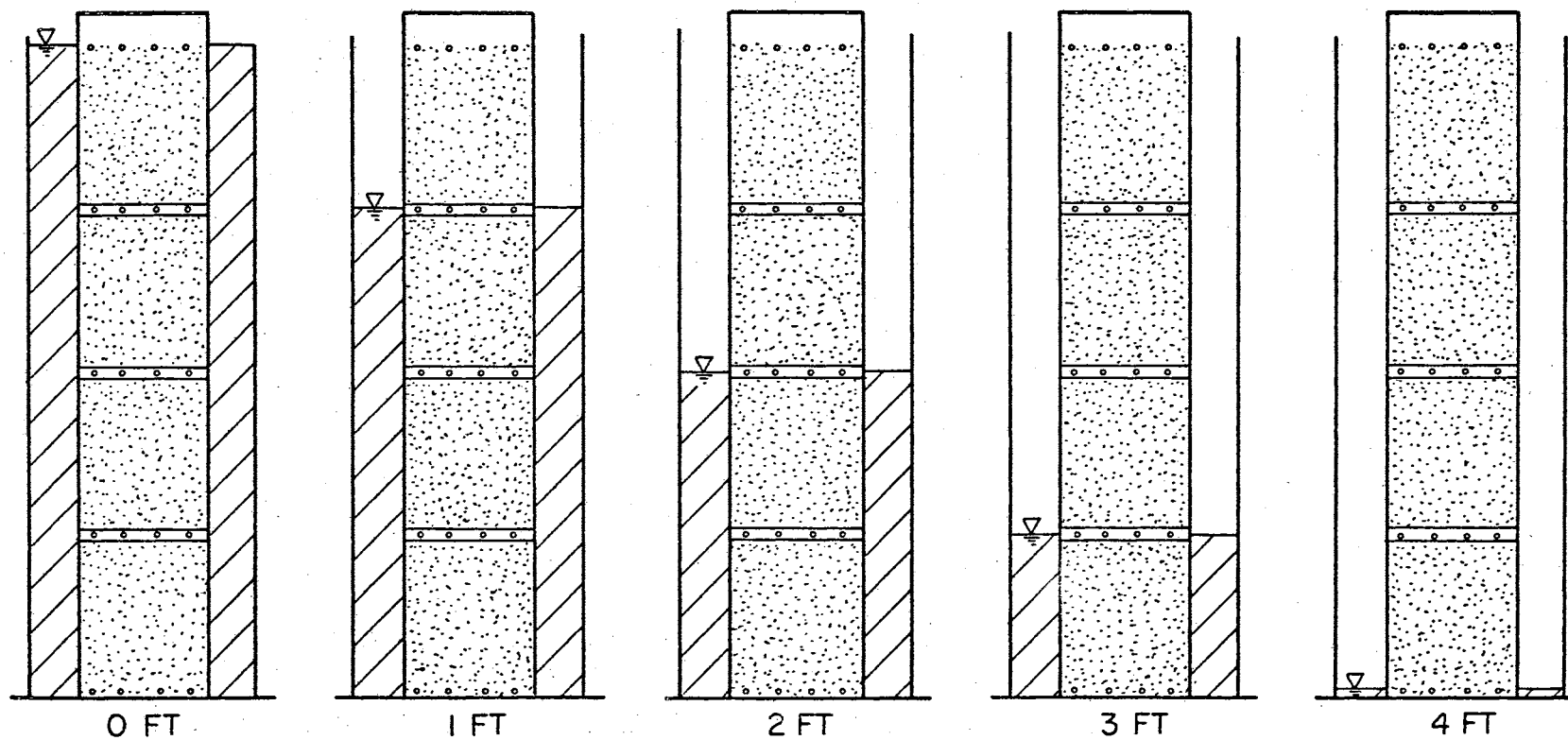
WATER TABLE

Figure 14. Water Table Levels for Non-Saline Water Table Test

## Procedure for Measuring Emittance

The boxes were left outdoors overnight before readings were begun to allow the soil temperature to come into equilibrium with the ambient temperature and all the capillary rise to occur. The readings were taken in the same manner as was used in measuring the emittance of soils in the panels (Figure 15).

When evaporation of the water brought the water level below the desired level, water was added to the outer box. The water table for the non-saline water test was kept at the same level as shown in Figure 14 throughout the test. The water table for the saline water test was raised one foot every two days. When raising the water level, the saline solutions were added at 12:00 midnight so soils could become saturated before readings were taken again at 6:00 a.m. The boxes were covered with plastic sheets when it rained to keep the soils from becoming wetter than would be natural from the levels of the water table and diluting the saline water.
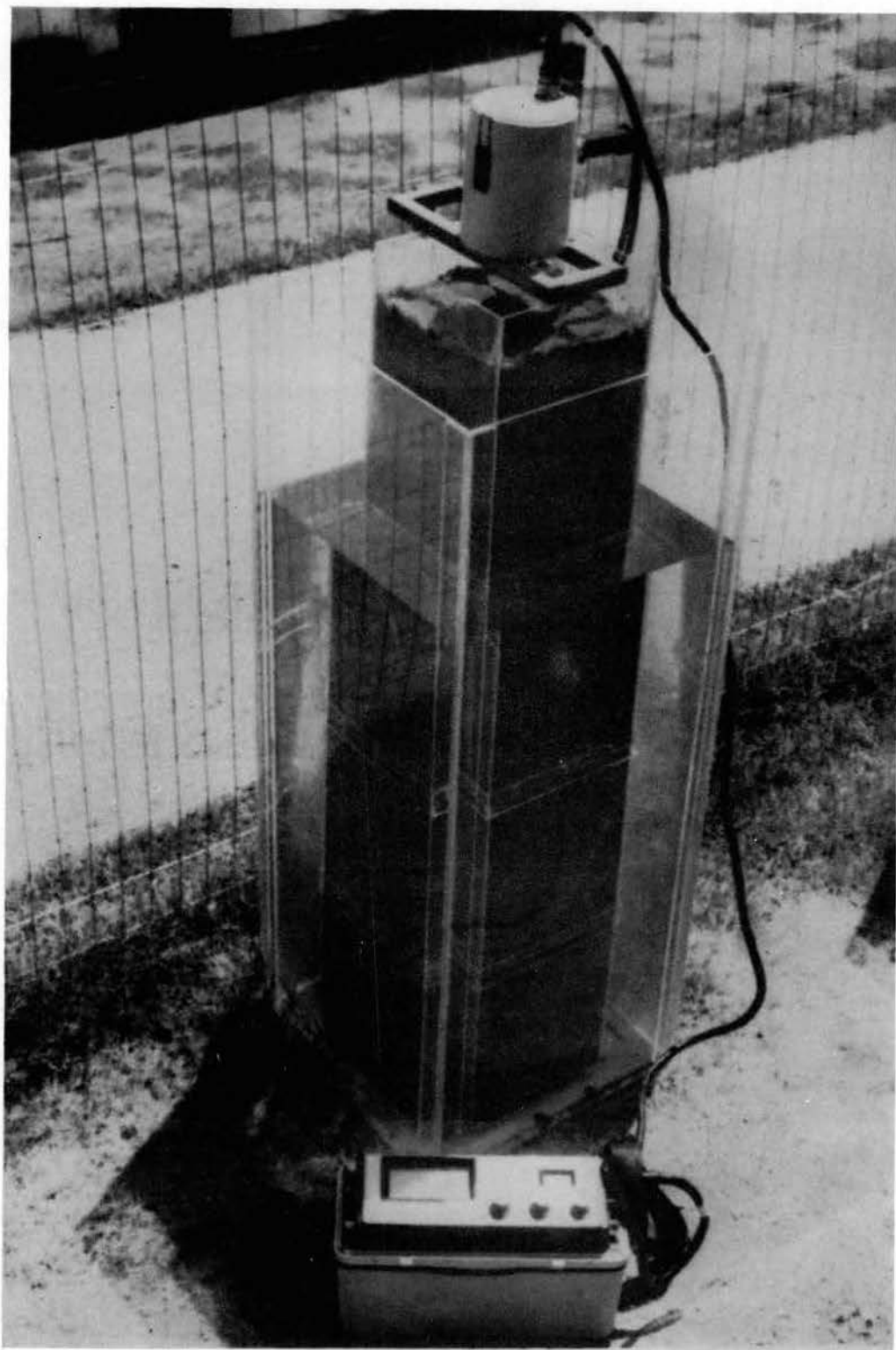
Figure 15. Water Table Apparatus

CHAPTER VI

DISCUSSION AND RESULTS

Effect of Salinity on Reflectance of Vegetation

For testing the effects of salinity on reflectance of vegetation, the wheat and salt grass were grown in soils containing varied salt concentrations. These test results are shown in Figures 16 through 19 and Appendix A. Since there are certain materials in both the wheat and salt grass leaves which affect spectral reflectance in the same manner, they have the same general pattern of reflectance throughout the electromagnetic spectrum tested in this study (15). Both types of vegetation had their lowest reflectance at the end of the ultraviolet portion of the spectrum, that is at 350 millimicrons. This is the violet and blue light portion of the spectrum which is largely absorbed by chloroplasts and used in the photosynthesis process. The chloroplasts of the leaves were unaffected by the salts to the point that the reflectance for any one wavelength did not change for the different levels of salinity.

Between 200 and 650 millimicrons the reflectance for both types of vegetation remained approximately the same, with only a slight variance at 550 millimicrons. At this point, the reflectance for both types had increased, but the variance due to the effect of different levels of salinity was greater for the wheat than that for the salt grass. This

51
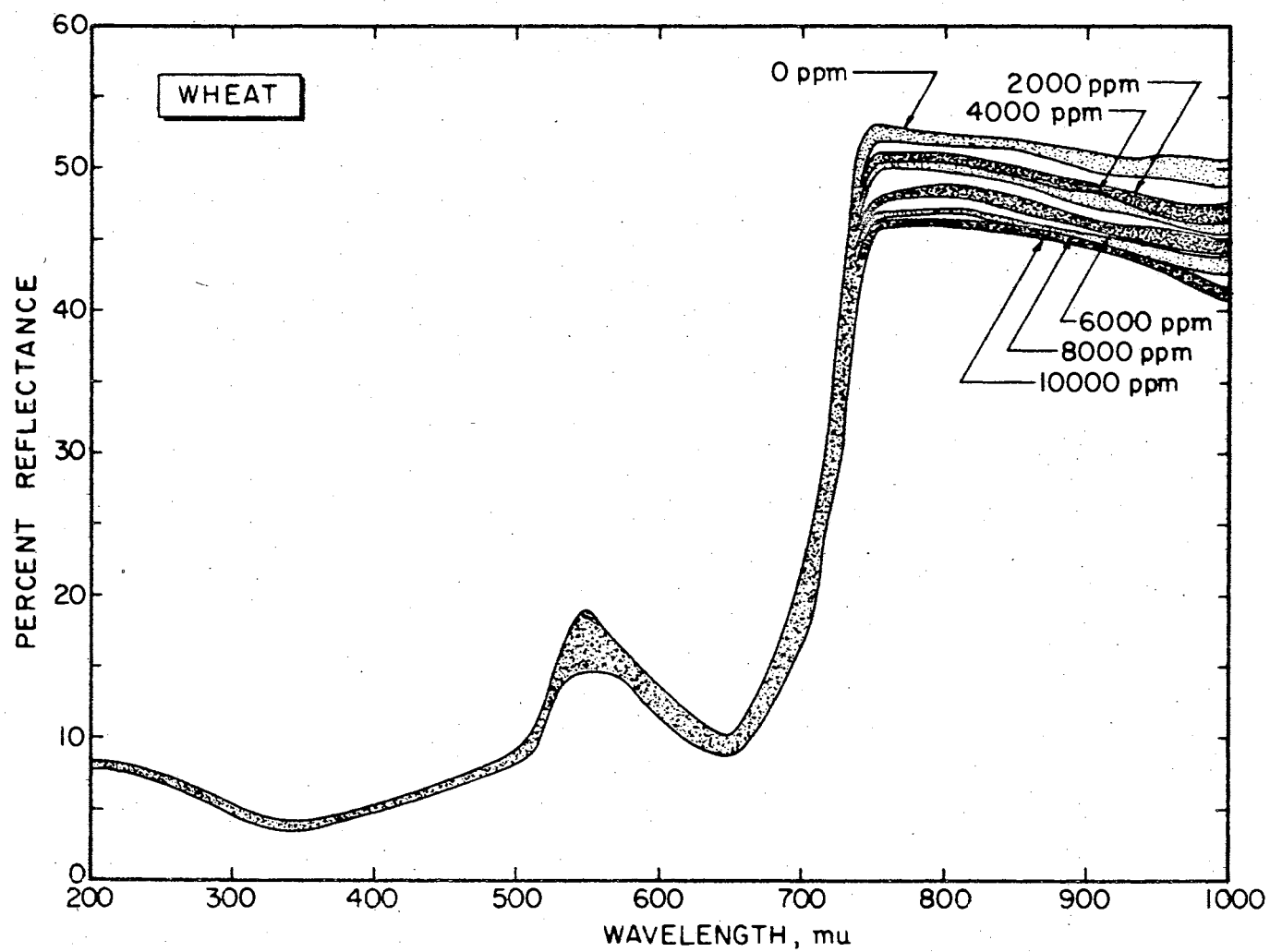
Figure 16. Plot of High and Low Reflectance of Wheat Grown in Varied Salt Concentrations
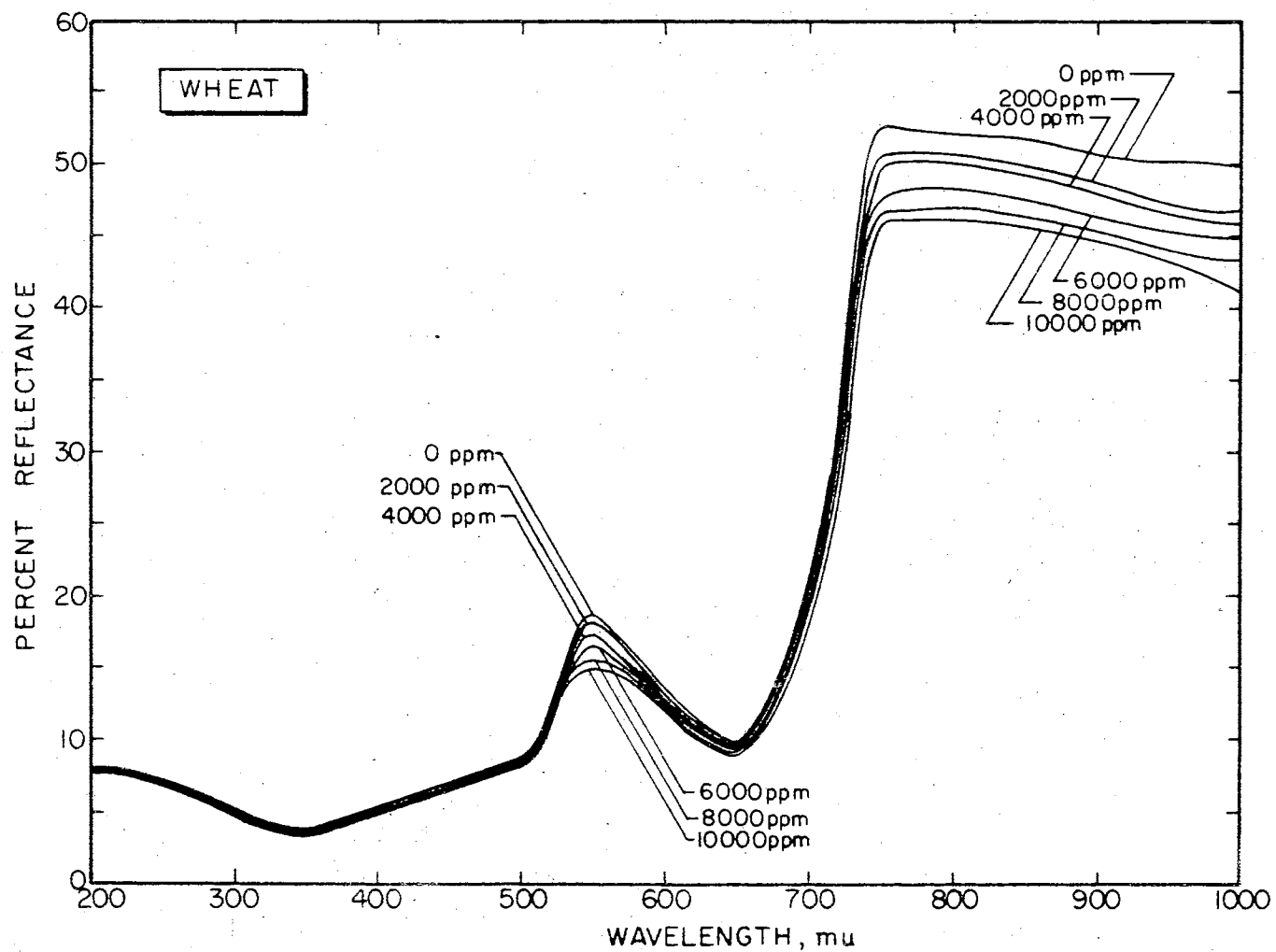
Figure 17. Average of High and Low Reflectance for Wheat

increase in reflectance occurred in the green light portion of the spec-

trum where it is largely reflected by chloroplasts.

At 750 millimicrons the near infrared portion of the spectrum

begins, at which point the infrared light is highly reflected by the

spongy mesophyll of a leaf's structure. For this reason, between 650

and 750 millimicrons both the salt grass and wheat reflectances sharply

increased.

From 720 to 1000 millimicrons the reflectance stayed fairly con-

stant, between 40% and 50%. It was within this region that the maximum

difference for the varied levels of salinity was attained for both the

salt grass and wheat. This is believed to have occurred when the spongy

mesophyll of the leaf structures began collapsing due to the salts in

the soils causing the leaves to reflect less near infrared energy (18).

It could then be seen that the greater the salt concentrations, the

greater the collapse of the mesophyll and more absorbent the leaves be-

came to the near infrared light.

The relative turgidity for the leaves grown at different levels of

salinity was determined for both types of vegetation. These results are

given in Appendix A. The variance is from 90% to 98.5%. Since it would

have to be less than 80% to affect the reflectance of the leaves, rela-

tive turgidity was not a factor in determining the reflectance of the

vegetation used in this investigation (21).

As can be seen from Figures 18 and 19, the vegetation did not grow

in soils containing high salt concentrations. The salt grass would not

grow in silty clay having salt concentrations above 60,000 ppm, nor in

sand having salt concentrations above 100,000 ppm. At these levels the

salts became toxic to the plants.

SALT GRASS GROWN IN CLAY

O PPM

20,000 PPM

60,000 PPM
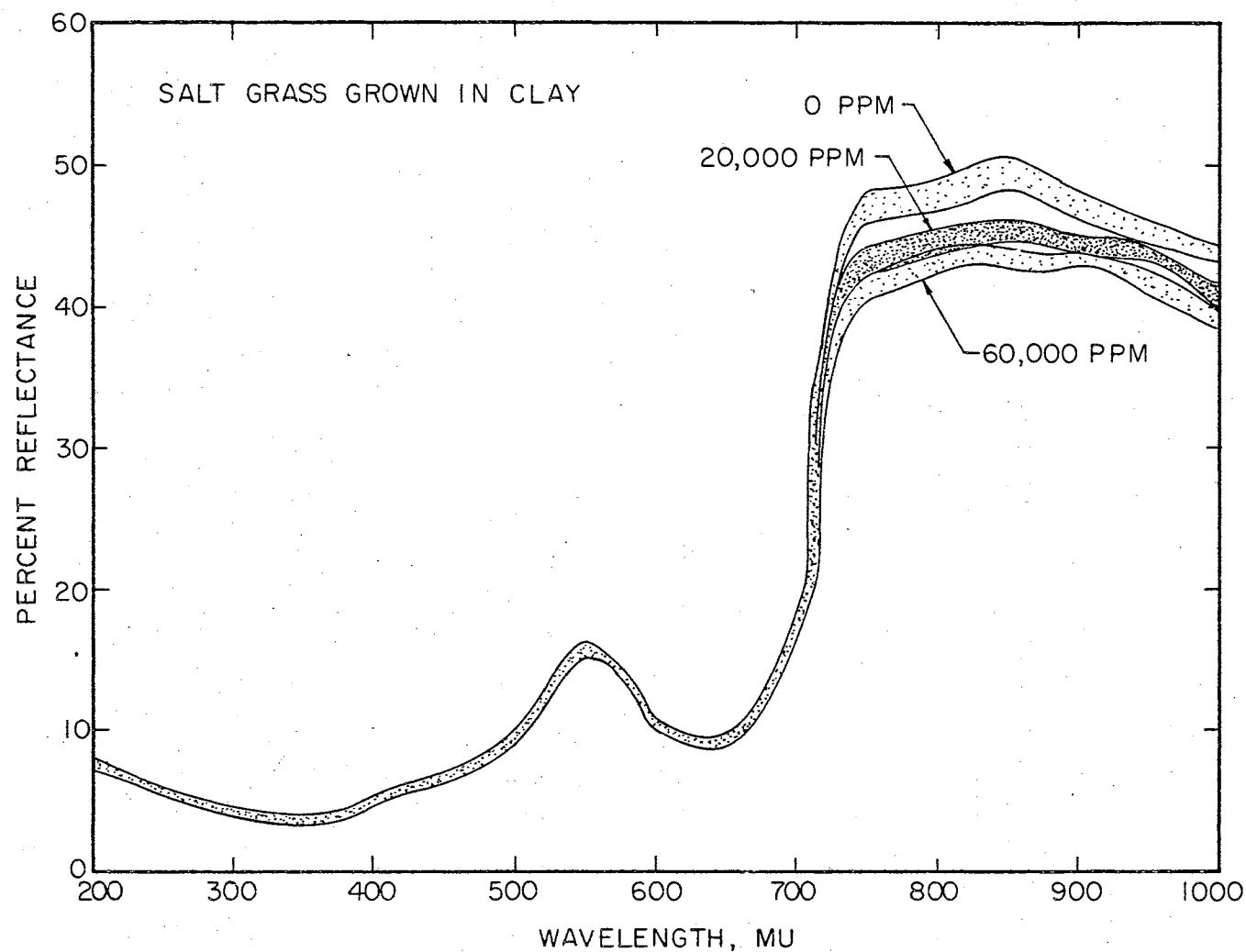
Figure 18.   Plot of High and Low Reflectance of Salt Grass Grown in
Silty Clay at Varied Salt Concentrations
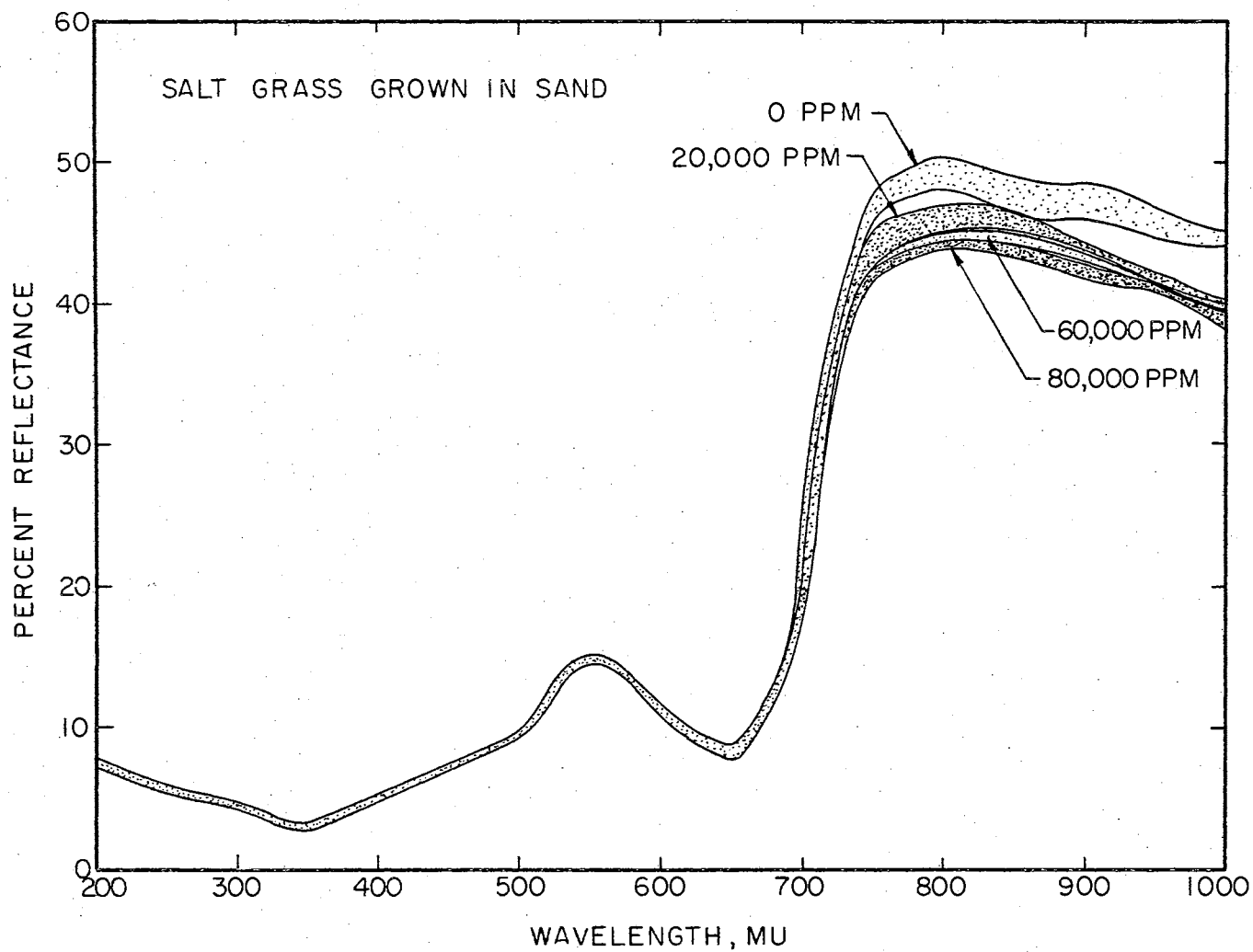
Figure 19. Plot of High and Low Reflectance of Salt Grass Grown in
Sand at Varied Salt Concentrations

Infrared photographs were taken of samples of wheat leaves with a Kodak Retina IV camera, using an Ektachrome IR film with No. 12 and No. 25 wratten filters. The Ektachrome IR film is sensitive to light beginning with the visible light up to 860 millimicron wavelengths. The wratten filters block out all of the electromagnetic energy for certain portions of the electromagnetic spectrum; at the same time, they are transparent to the rest of the spectrum and electromagnetic energy passes through the filters unaffected. The portion of the spectrum which is filtered out depends upon the type of filter used. The No. 25 filter filters out all light throughout the spectrum up to 590 millimicrons, the No. 12 filter filters out all light up to 500 millimicrons, except for a small window between 300 and 320 millimicrons. Therefore, with these particular film-filter combinations, the photographs measured the magnitude of reflectance of the wheat primarily between 500 to 860 millimicron wavelengths with the No. 12 filter and between 590 to 860 millimicrons with the No. 25 filter.

Photographs were taken indoors with two 300 watt tungsten lamps as energy sources. These photographs were taken with different focal lengths and exposure times with best results obtained at a focal length of f/16 and exposure time of 1/60 for the No. 12 filter, and at a focal length of f/16 and exposure time 1/125 for the No. 25 filter. The photographs depicted a difference in color for the varied levels of salinity at which the wheat was grown. Since Ektachrome IR film is a false color film, the leaves photographed were varying shades of red. The wheat grown in the higher salt concentrations had the lightest shade of red, and the wheat grown in lesser salt concentrations had darker shades of red.

## Emitted Energy of Soils with Variance
## in Moisture and Salinity

Since the temperature of soil is greatly affected by the amount of moisture it contains, and salts retard the evaporation of that moisture, a test was run to determine these effects on the emitted energy of sand and silty clay. The test was run from September 20 through 27, 1968. The data for the test are given in Appendix B. Figures 20 through 31 show plots for September 21-26. This same test was run in May 1969, and gave the same results as shown in these data.

The general trend for both silty clay and sand was for the highest emitted energy of the different levels of salinity to be in the 160,000 ppm salt concentrations and then decrease accordingly down to 0 ppm. Although some readings were erratic, this trend was predominant between 12:00 to 16:00 hours. The soils having higher salt concentrations emitted more radiant energy since the salts retarded evaporation of moisture in the soil. Therefore, the lesser salt concentrations allowed more evaporation of moisture causing the soils to be slightly cooled by the process (3). This was further verified by the moisture content in the soils which was determined each day of the investigation. (See Appendix B.) Since the soils were air dried they had small amounts of moisture in them before the salt solutions were added. The moisture content for Sept. 20 is the amount of moisture added to the soil with the salt solutions. However, the actual moisture content is greater than that shown, due to the small amount of moisture retained by soils when air dried and existent in them when testing began. The moisture content decreased about 26% for the 0 ppm in the silty clay and only about 9% for the 160,000 ppm. A similar occurrence took place in the sand with the
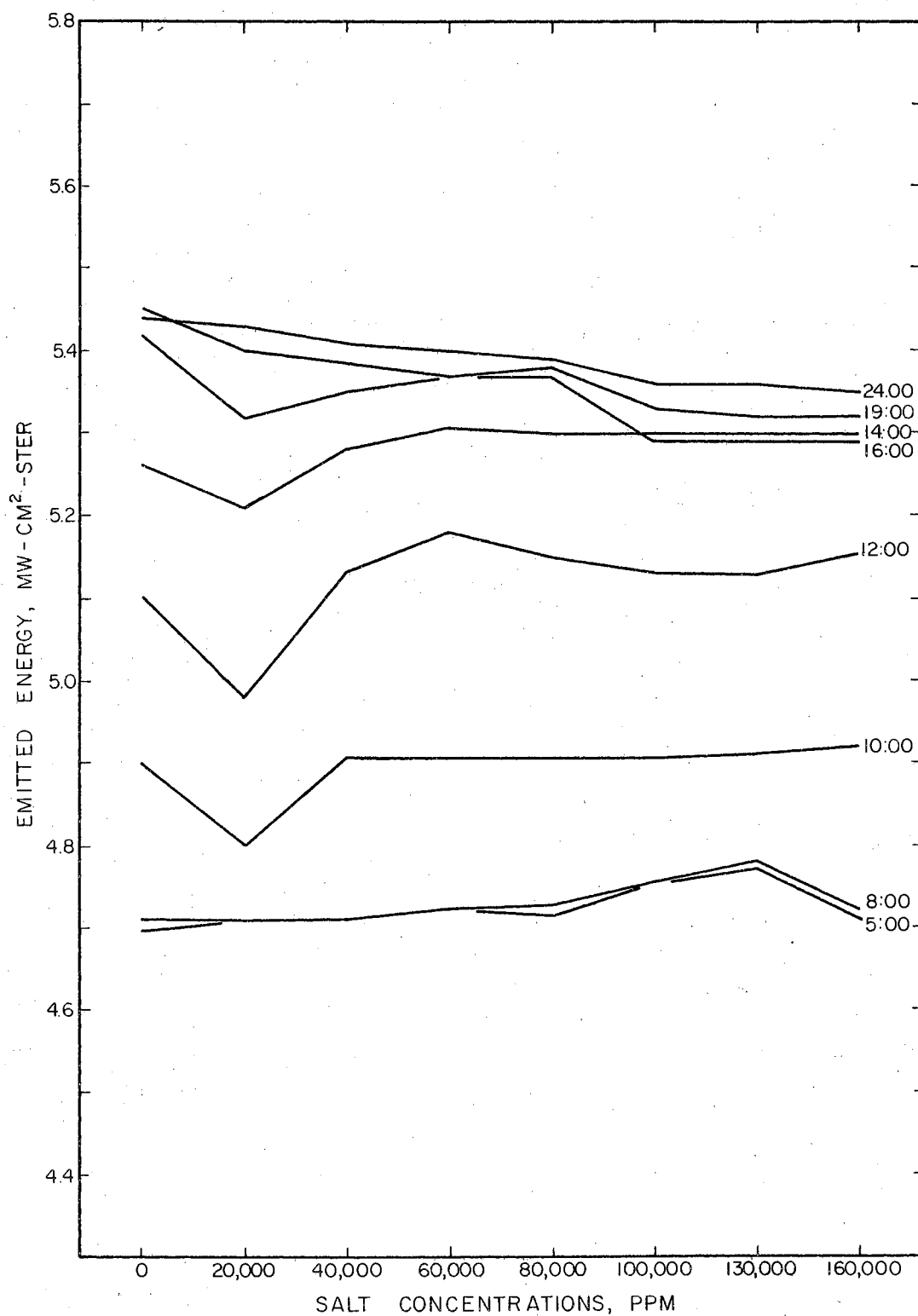
Figure 20. Emitted Energy of Sand with Variance in Moisture and Salinity for September 21
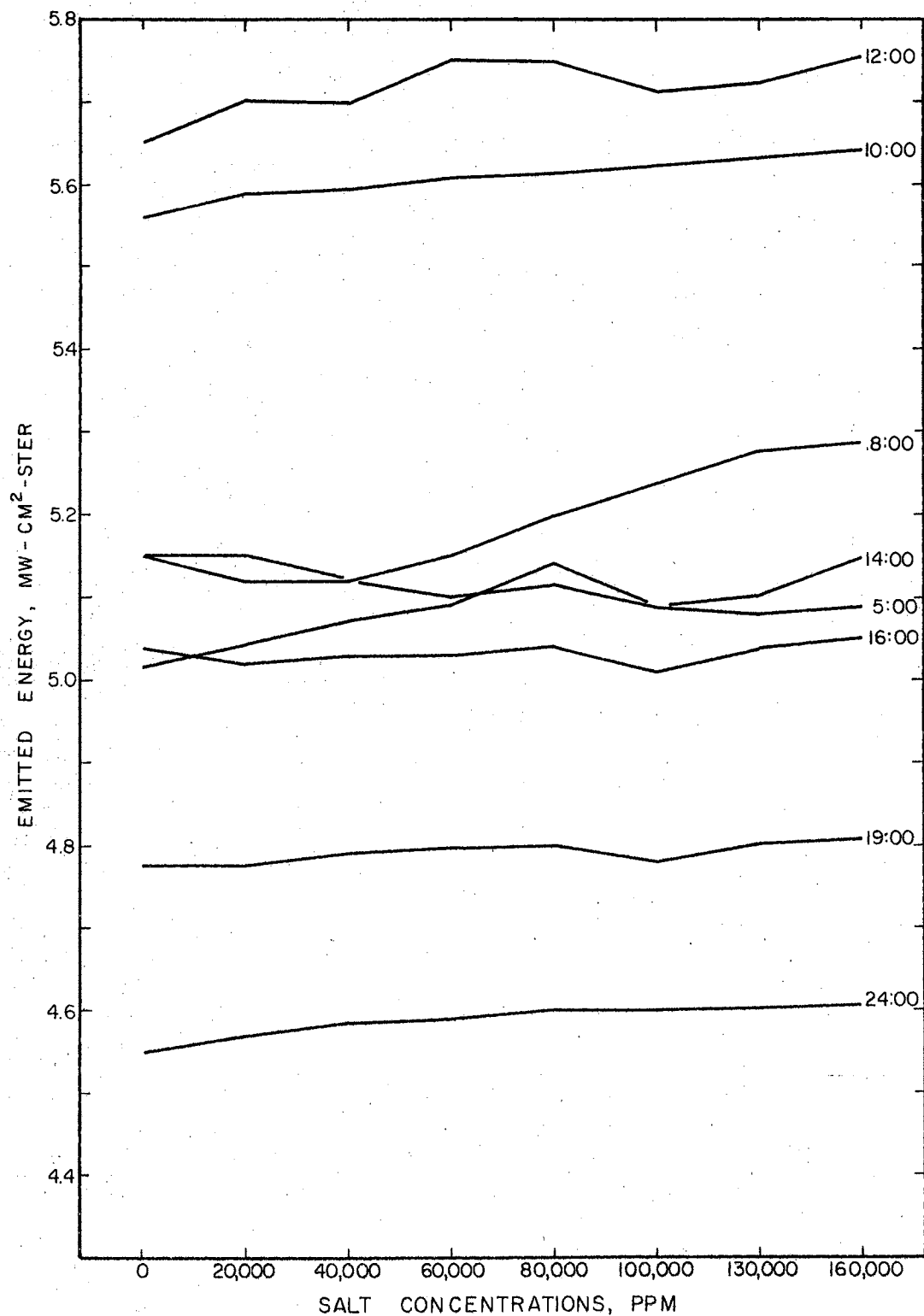
Figure 21. Emitted Energy of Sand with Variance in Moisture
and Salinity for September 22
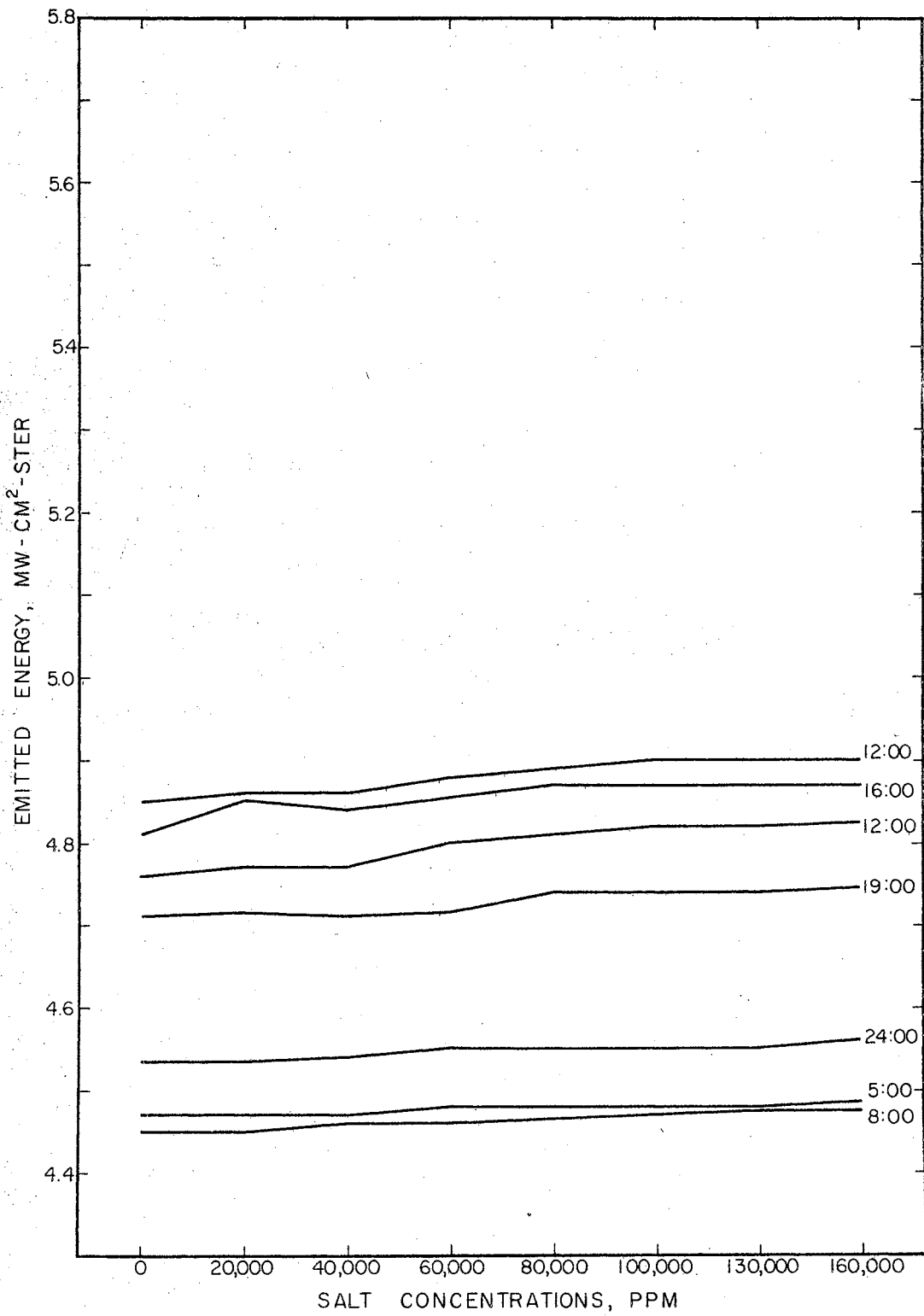
Figure 22. Emitted Energy of Sand with Variance in Moisture and Salinity for September 23
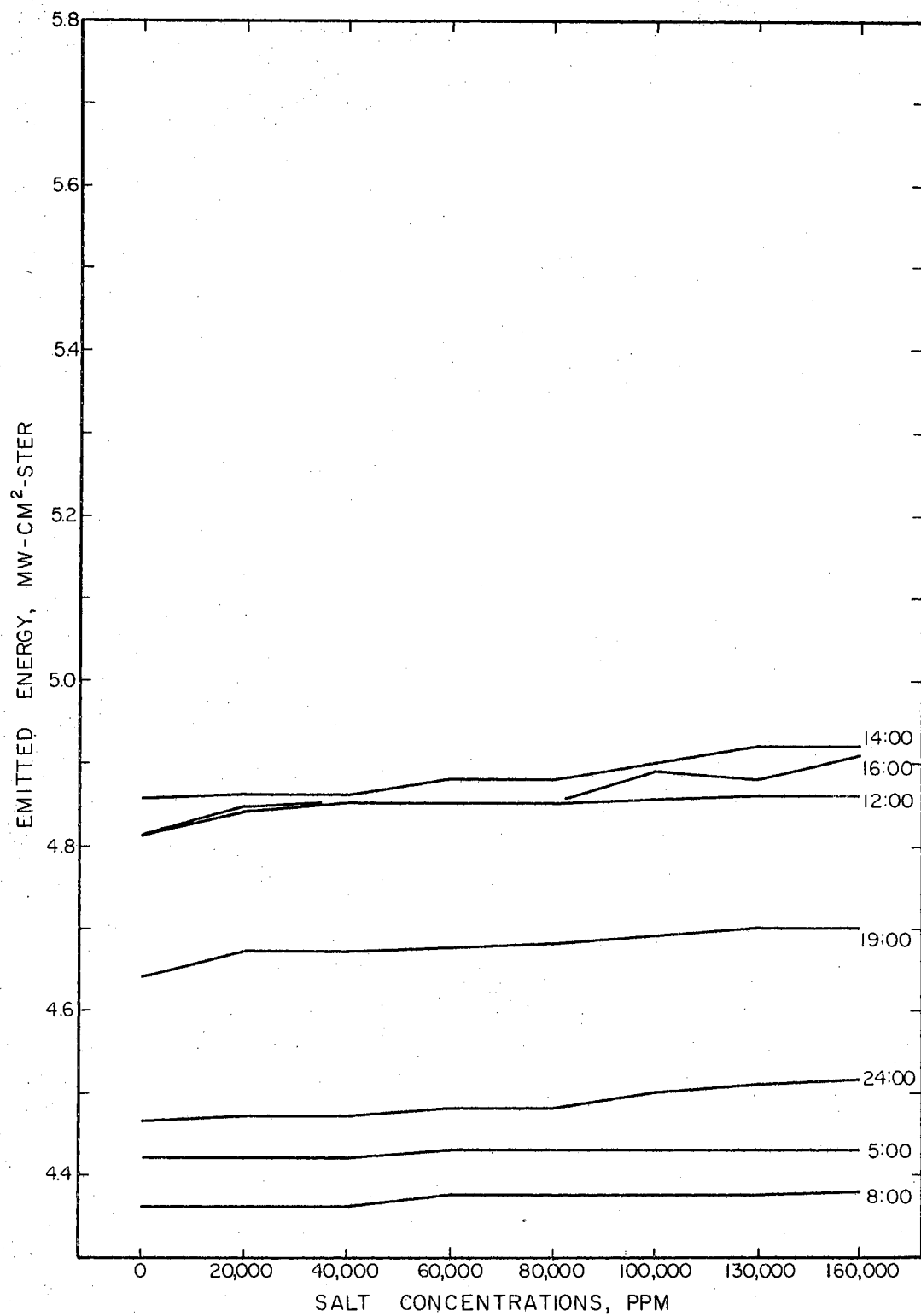
Figure 23. Emitted Energy of Sand with Variance in Moisture and Salinity for September 24
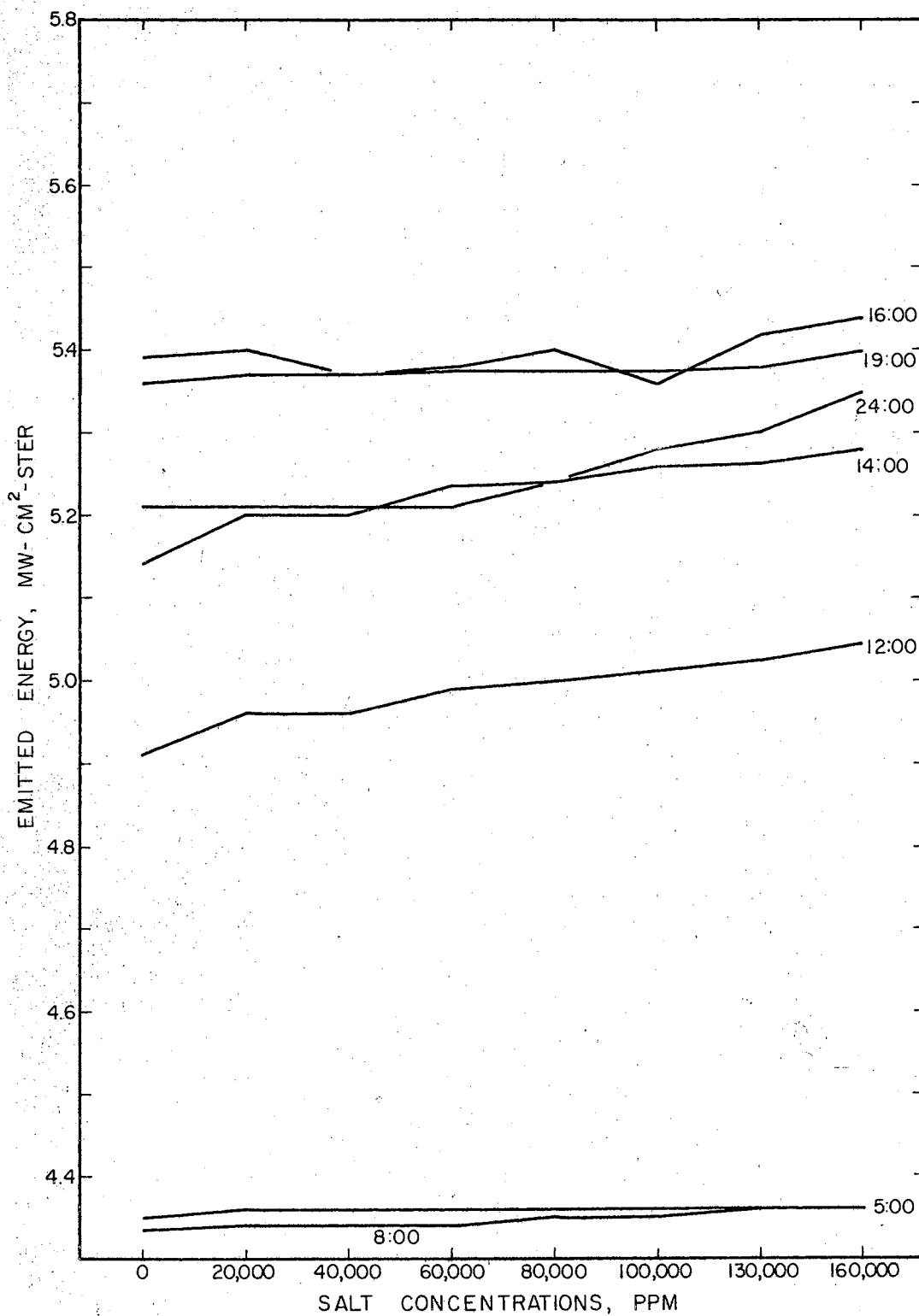
Figure 24. Emitted Energy of Sand with Variance in Moisture
and Salinity for September 25
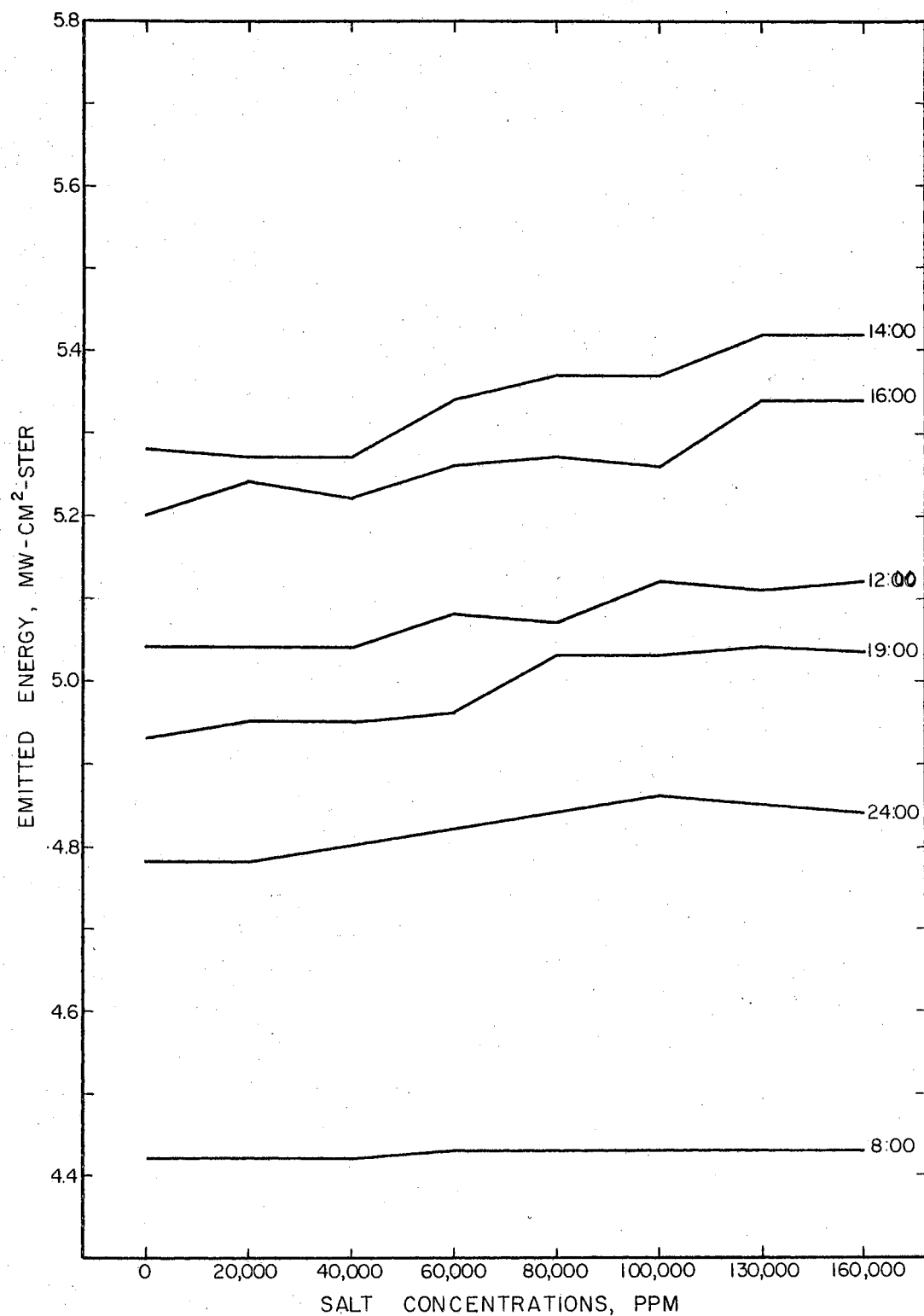
Figure 25. Emitted Energy of Sand with Variance in Moisture and Salinity for September 26
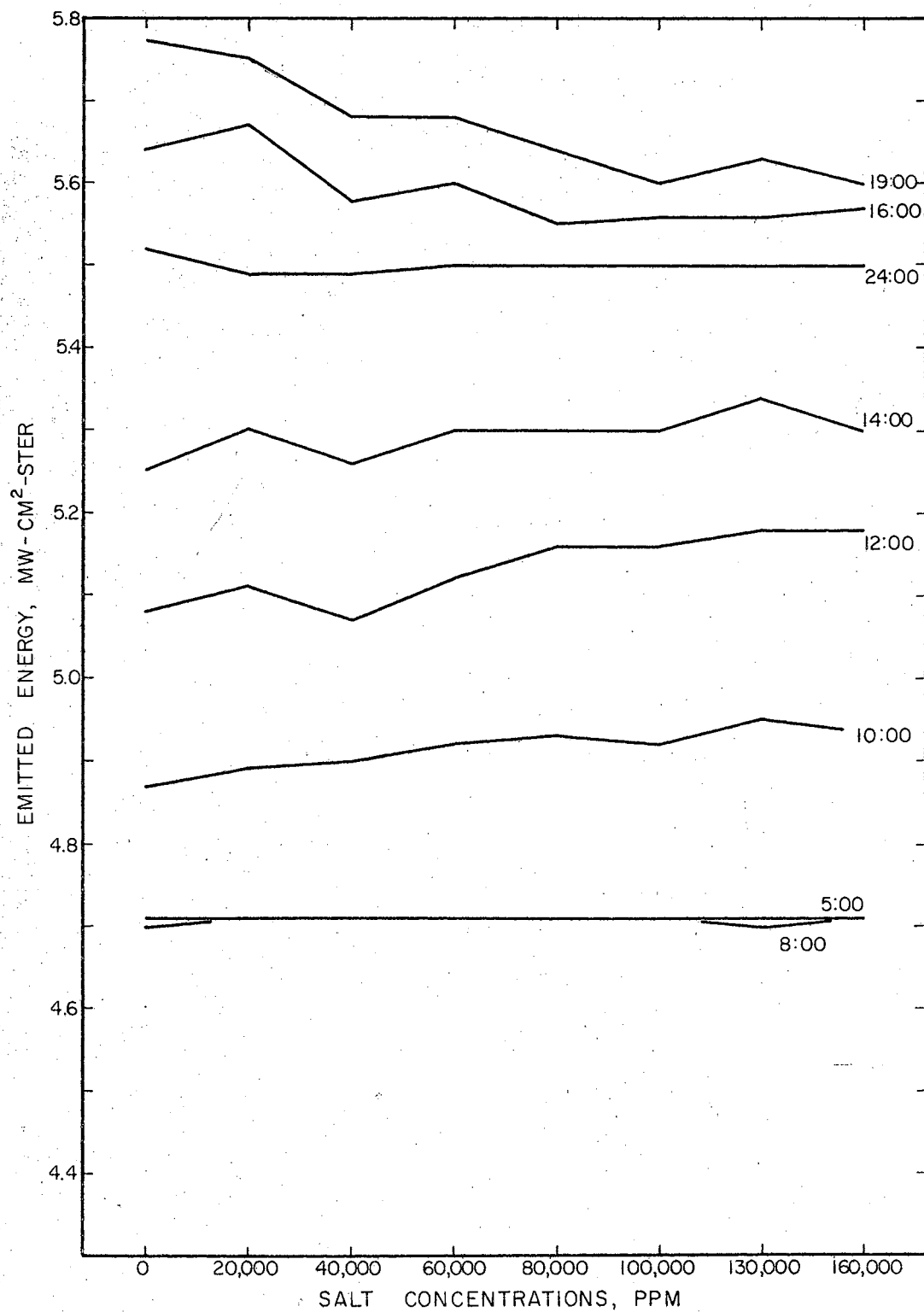
Figure 26. Emitted Energy of Silty Clay with Variance in
Moisture and Salinity for September 21
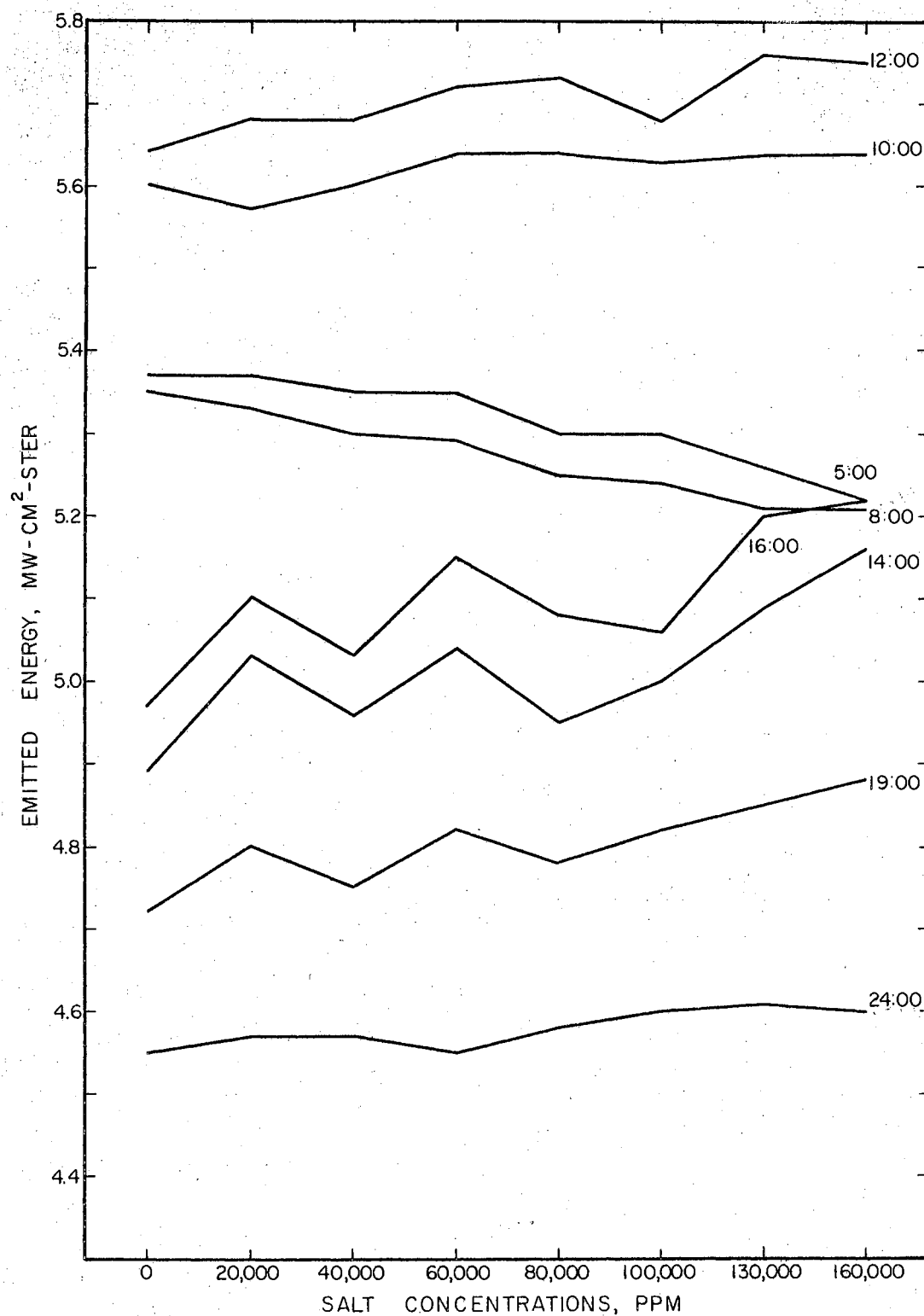
Figure 27. Emitted Energy of Silty Clay with Variance in
Moisture and Salinity for September 22
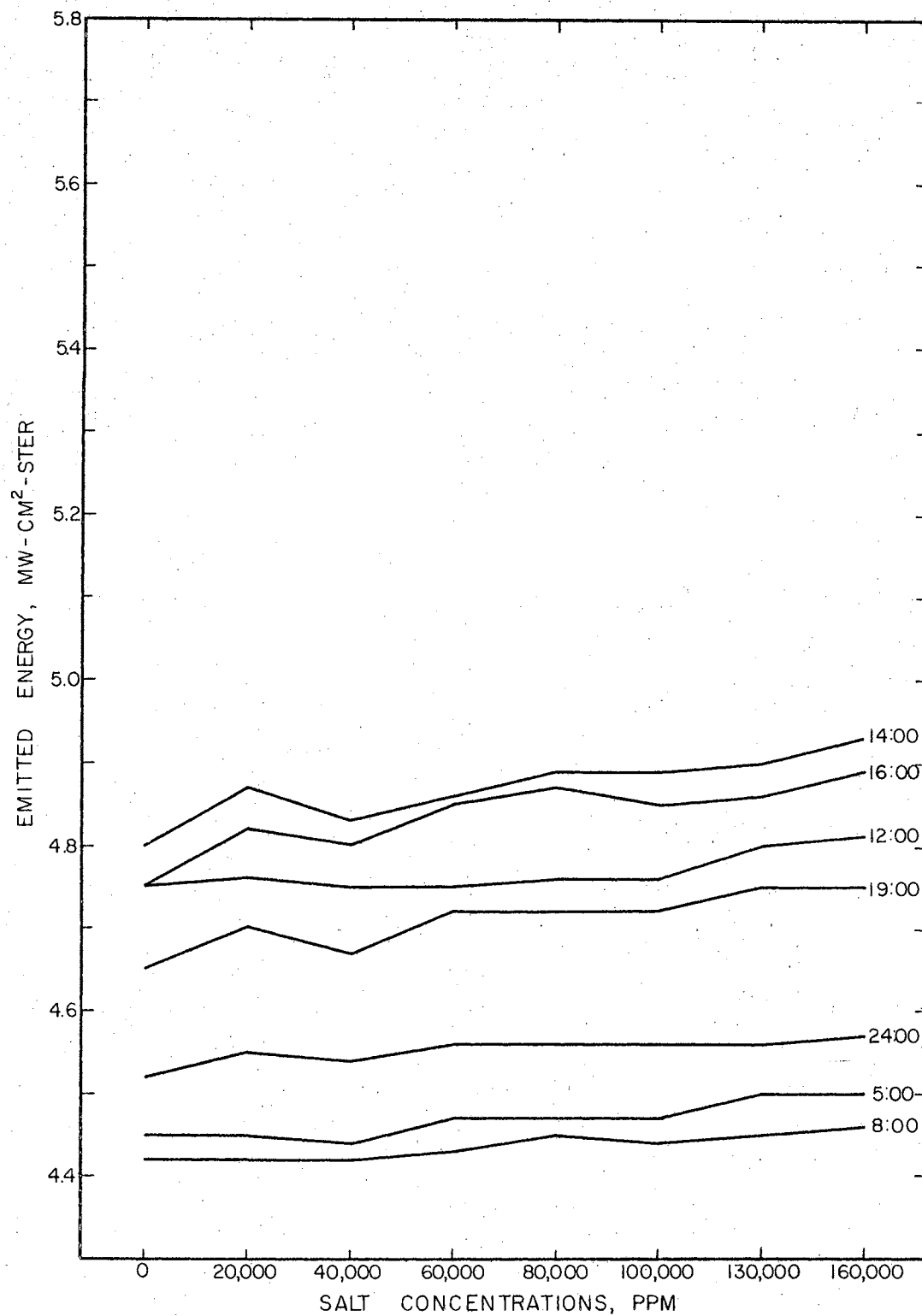
Figure 28. Emitted Energy of Silty Clay with Variance in
Moisture and Salinity for September 23
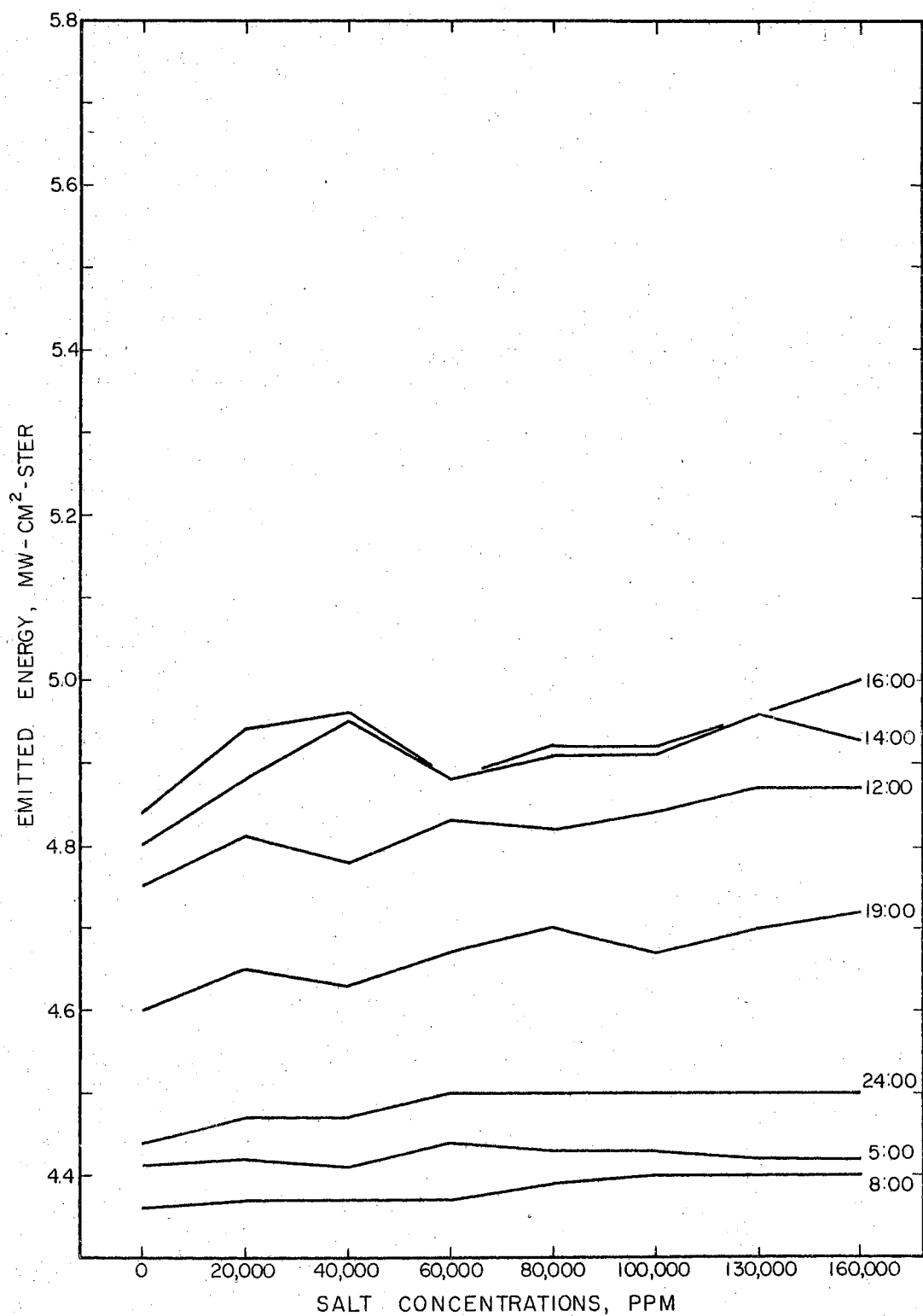
Figure 29. Emitted Energy of Silty Clay with Variance in
Moisture and Salinity for September 24
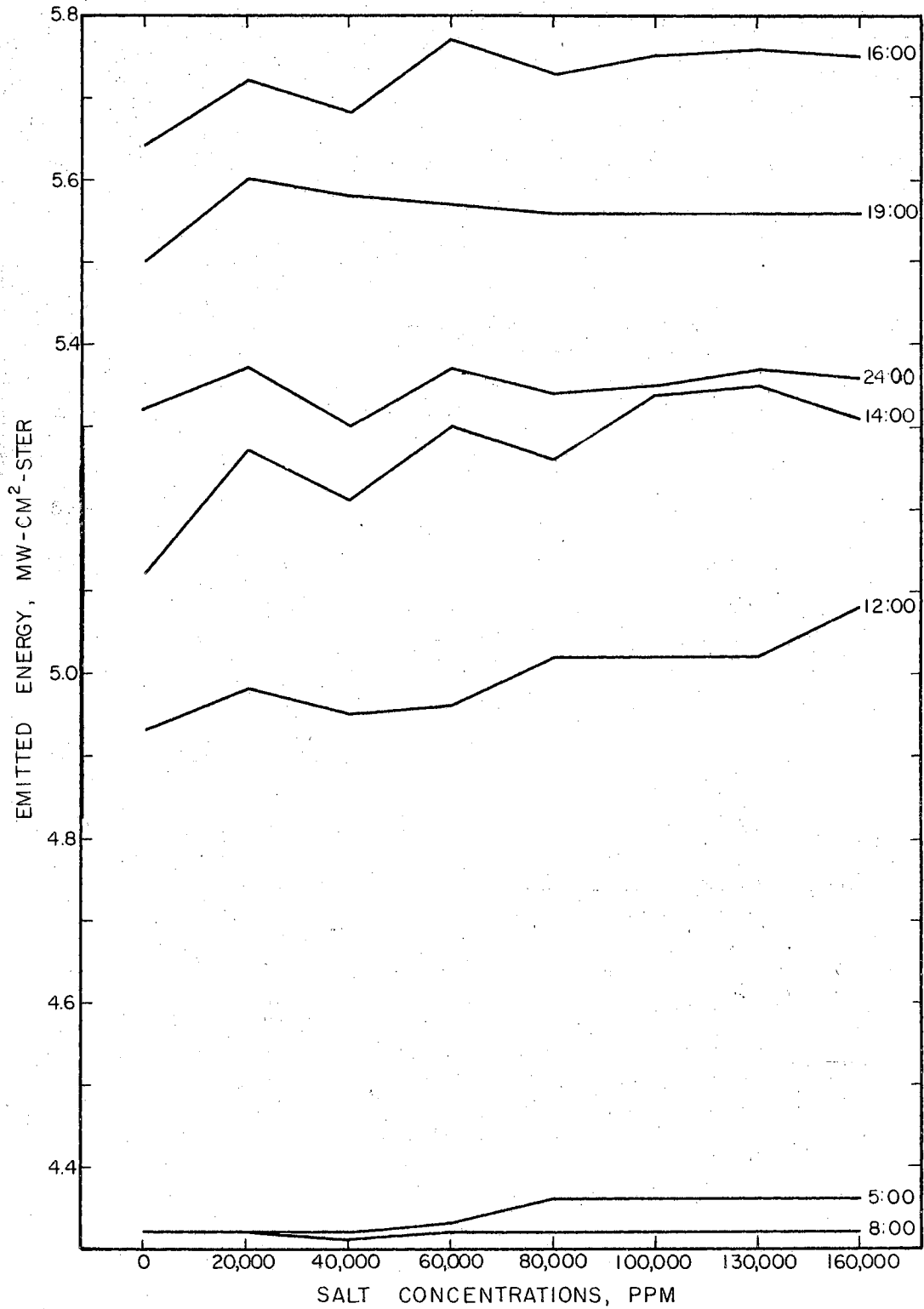
Figure 30. Emitted Energy of Silty Clay with Variance in
Moisture and Salinity for September 25
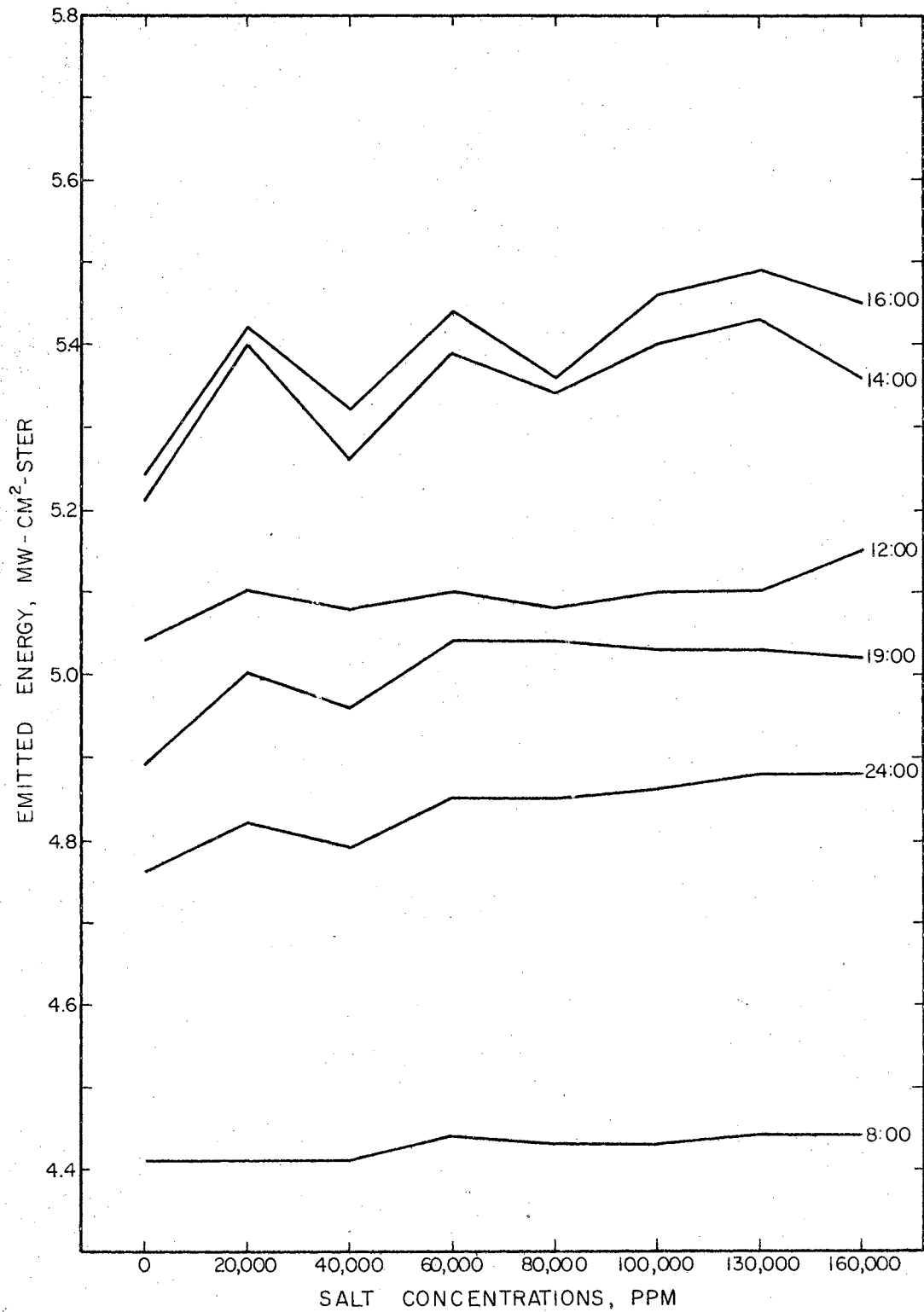
Figure 31. Emitted Energy of Silty Clay with Variance in Moisture and Salinity for September 26

0 ppm moisture content decreasing 9.5% and 5.5% for the 160,000 ppm. As can be seen the silty clay had a great deal more variance in the amount of moisture it contained at its different levels of salinity than that contained by the sand. For this reason, the emitted energy of the silty clay was much more erratic than that given off by the sand.

This trend of emittance occurred throughout the experiment except on Sept. 21. On this particular day the highest emittances were given off by the soils containing the lowest salt concentrations. This occurred for both soil types at 16:00, 19:00 and 24:00 hours. (See Figures 20 and 26.) There is no explanation for this occurrence either theoretically or experimentally.

Emitted Energy of Soils for Changing

Non-Saline Ground Water Table

The emitted energy was taken from the surfaces of both silty clay and sand in different levels of non-saline water. This test was to determine the effect of water table on the emitted energy of the soils. Figures 32 through 36 show the plots of emitted energy taken of the silty clay from May 9 through 13. Figures 37 through 42 show the plots of emitted energy taken of the sand from May 19 through 24. Appendix C denotes the emitted energy and meteorological conditions taken for these plots.

The test results indicated that both silty clay and sand have the same pattern of emittance over a 24-hour period. Their peak emittances occurred between 2:00 and 4:00 in the afternoon, and their lowest emittances occurred about 6:00 a.m., shortly before sunrise. The maximum variance in the emittances of the different levels of the water table
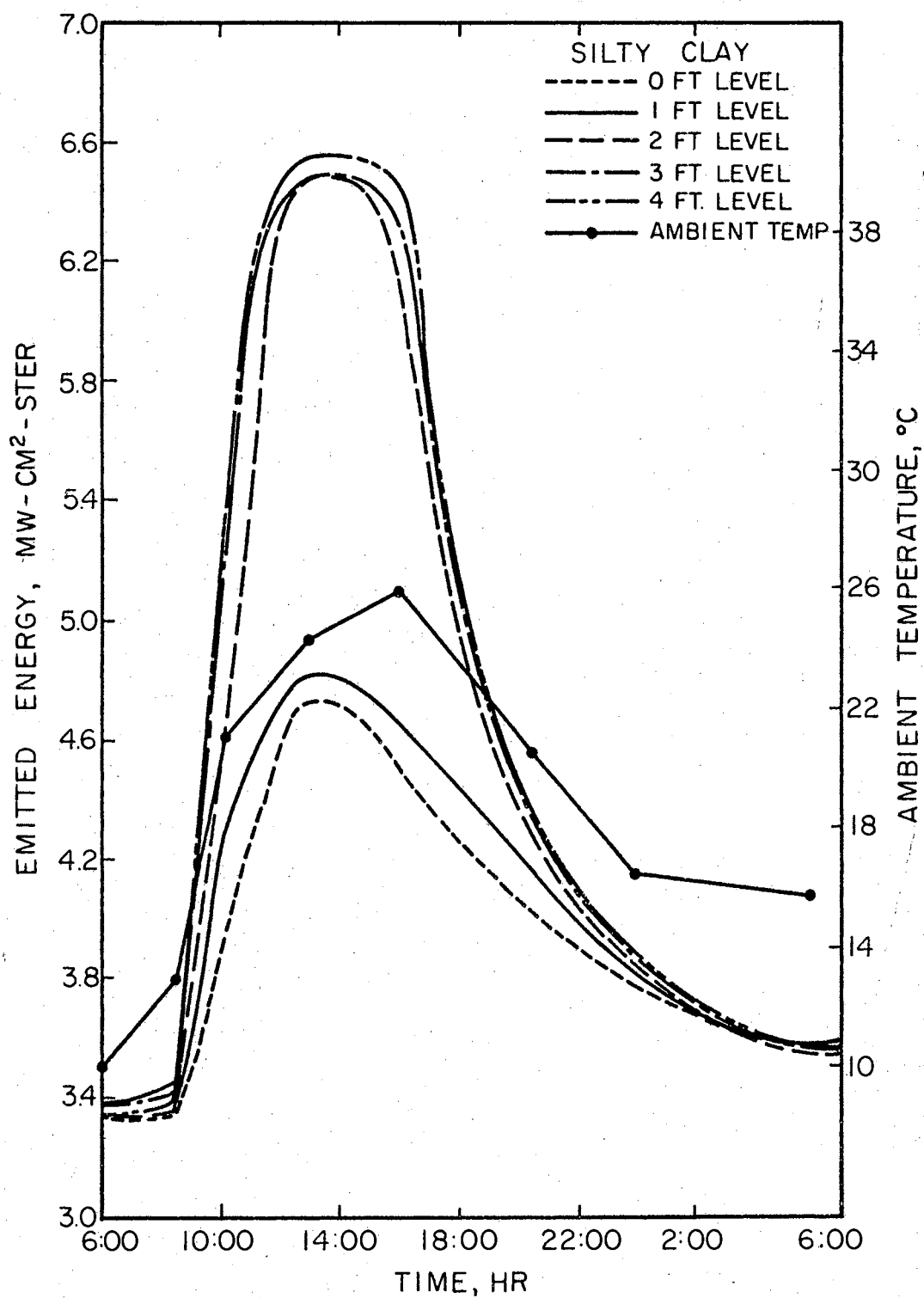
Figure 32. Emitted Energy of Silty Clay for Changing
Non-Saline Water Table on May 9
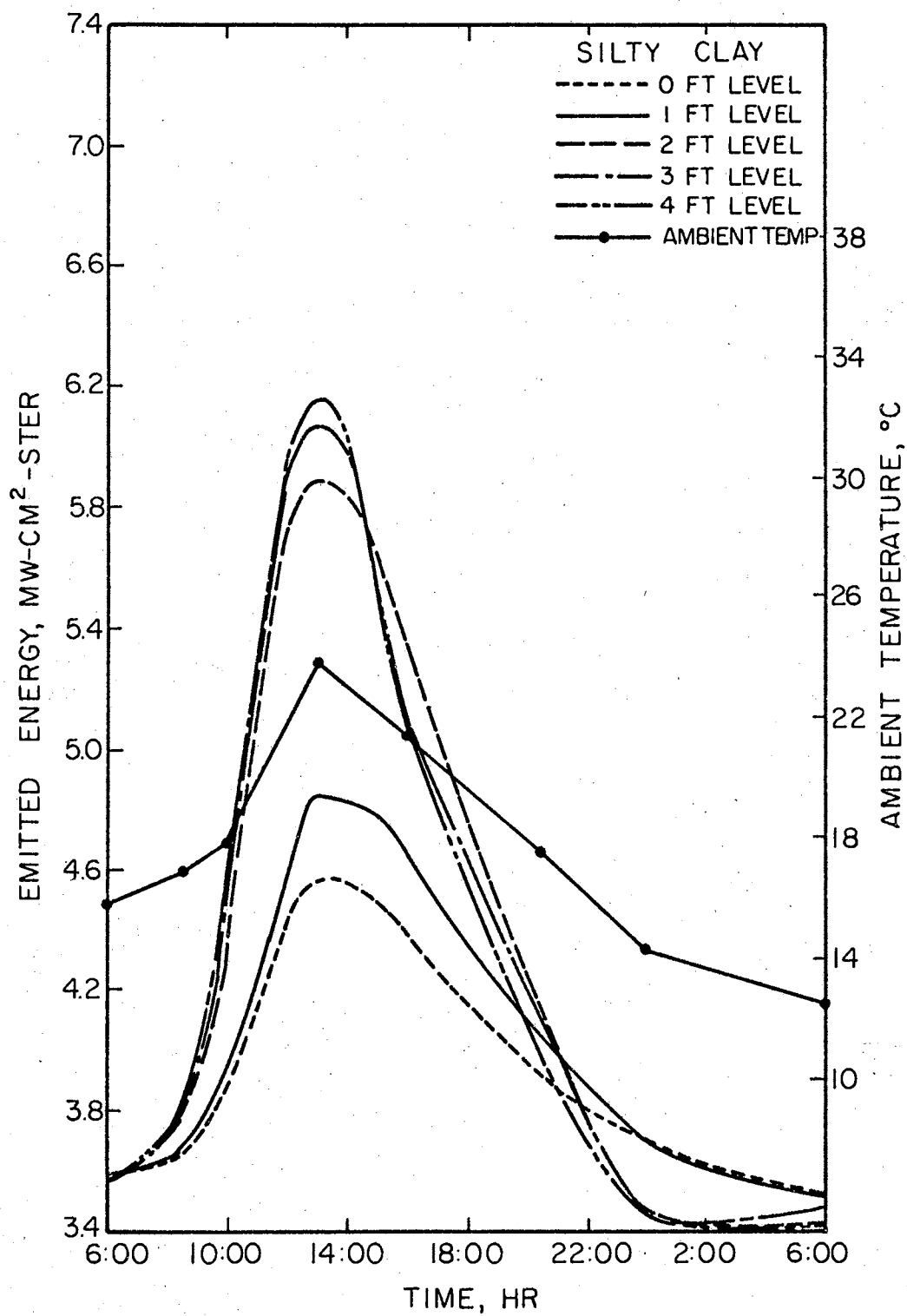
Figure 33. Emitted Energy of Silty Clay for Changing
Non-Saline Water Table on May 10
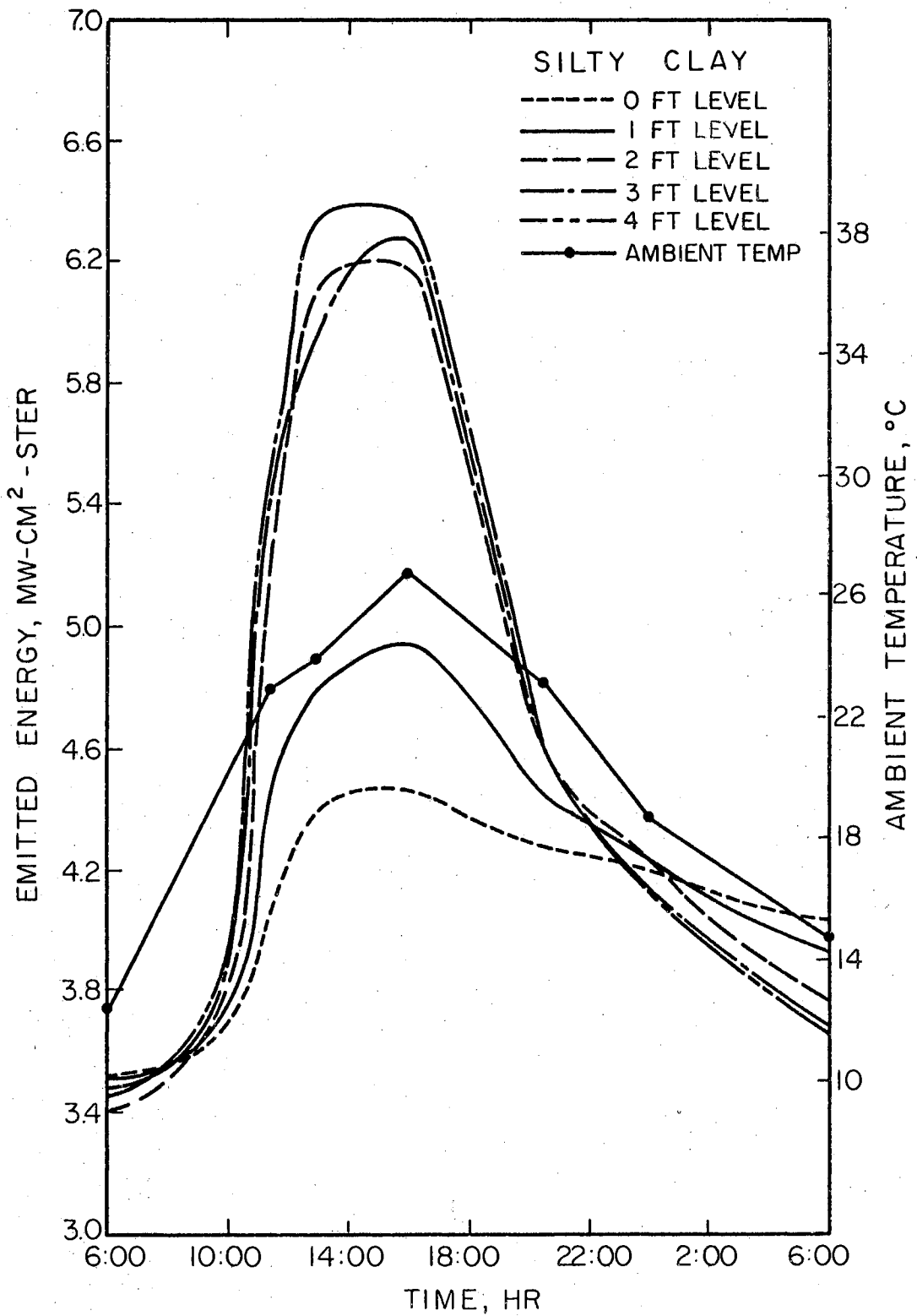
Figure 34. Emitted Energy of Silty Clay for Changing
Non-Saline Water Table on May 11
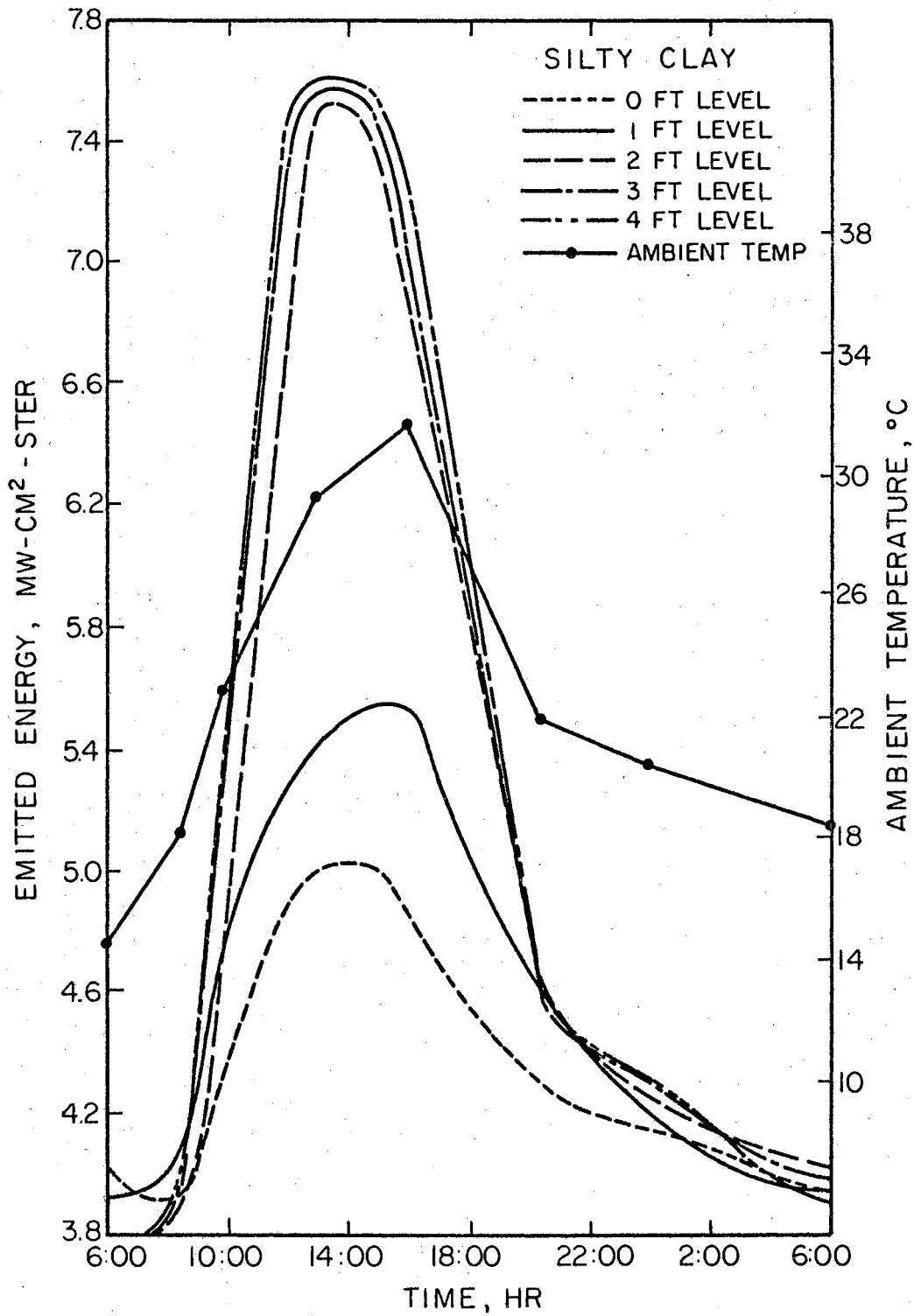
Figure 35. Emitted Energy of Silty Clay for Changing
Non-Saline Water Table on May 12
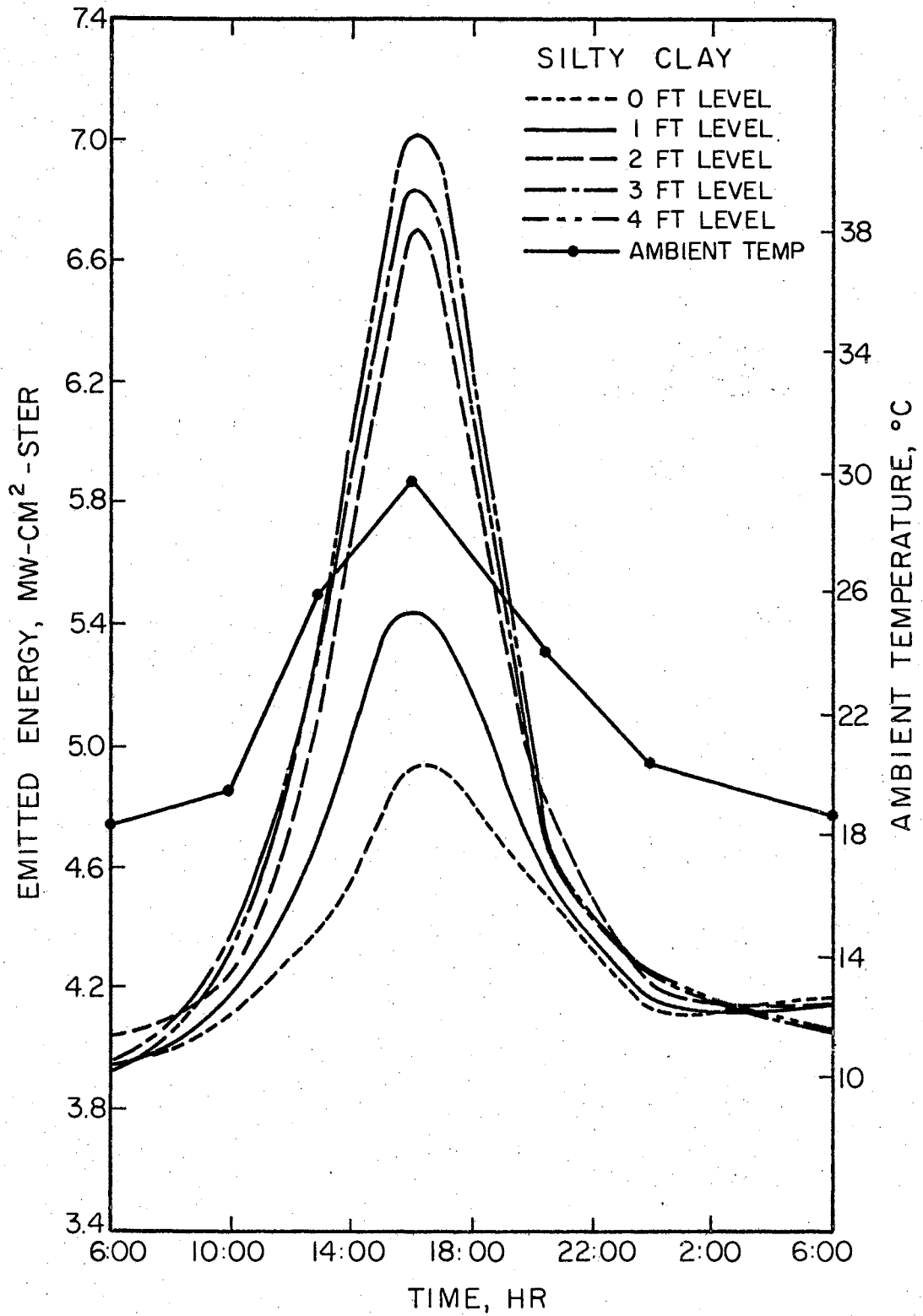
Figure 36. Emitted Energy of Silty Clay for Changing
Non-Saline Water Table on May 13
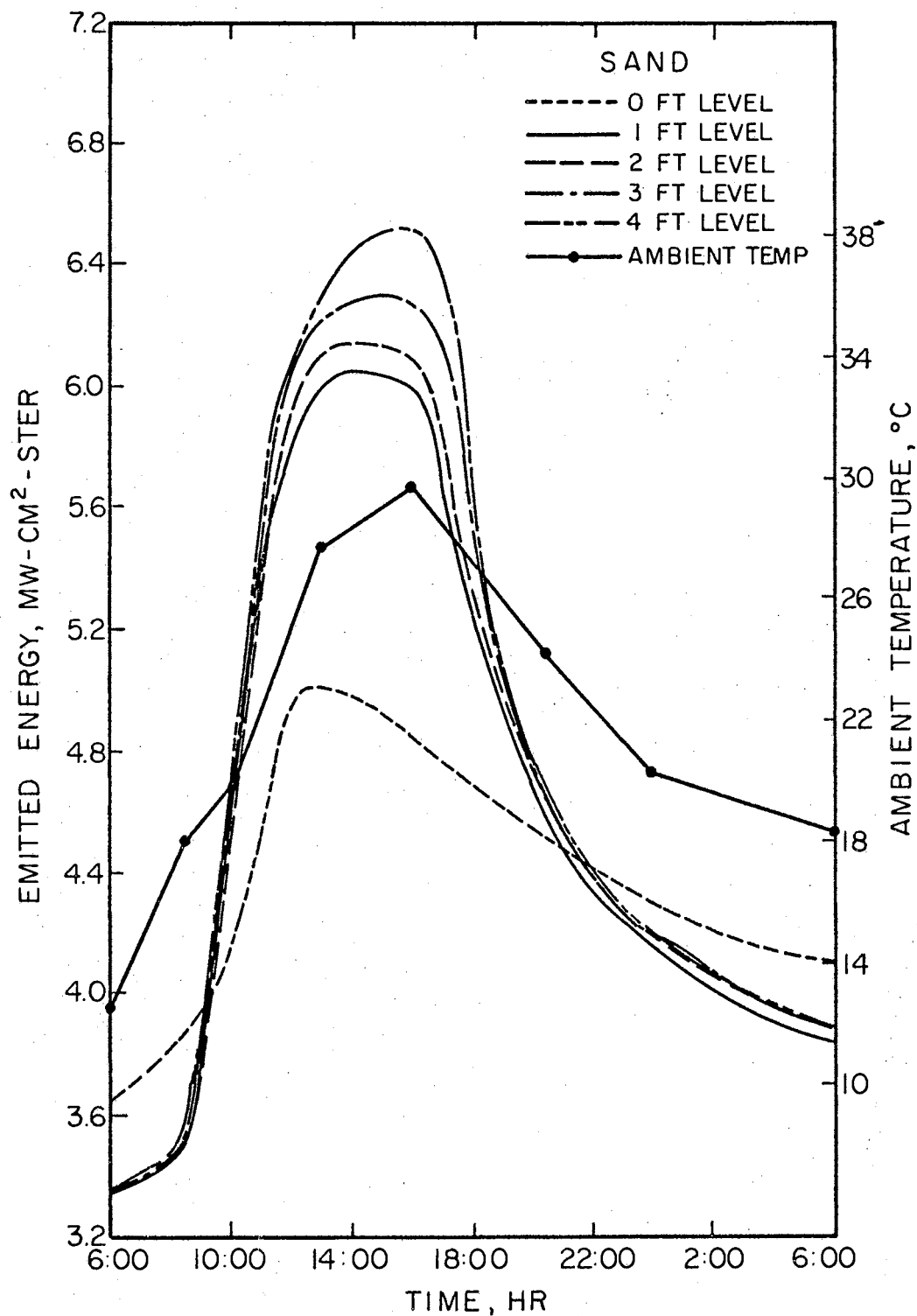
Figure 37. Emitted Energy of Sand for Changing
Non-Saline Water Table on May 19
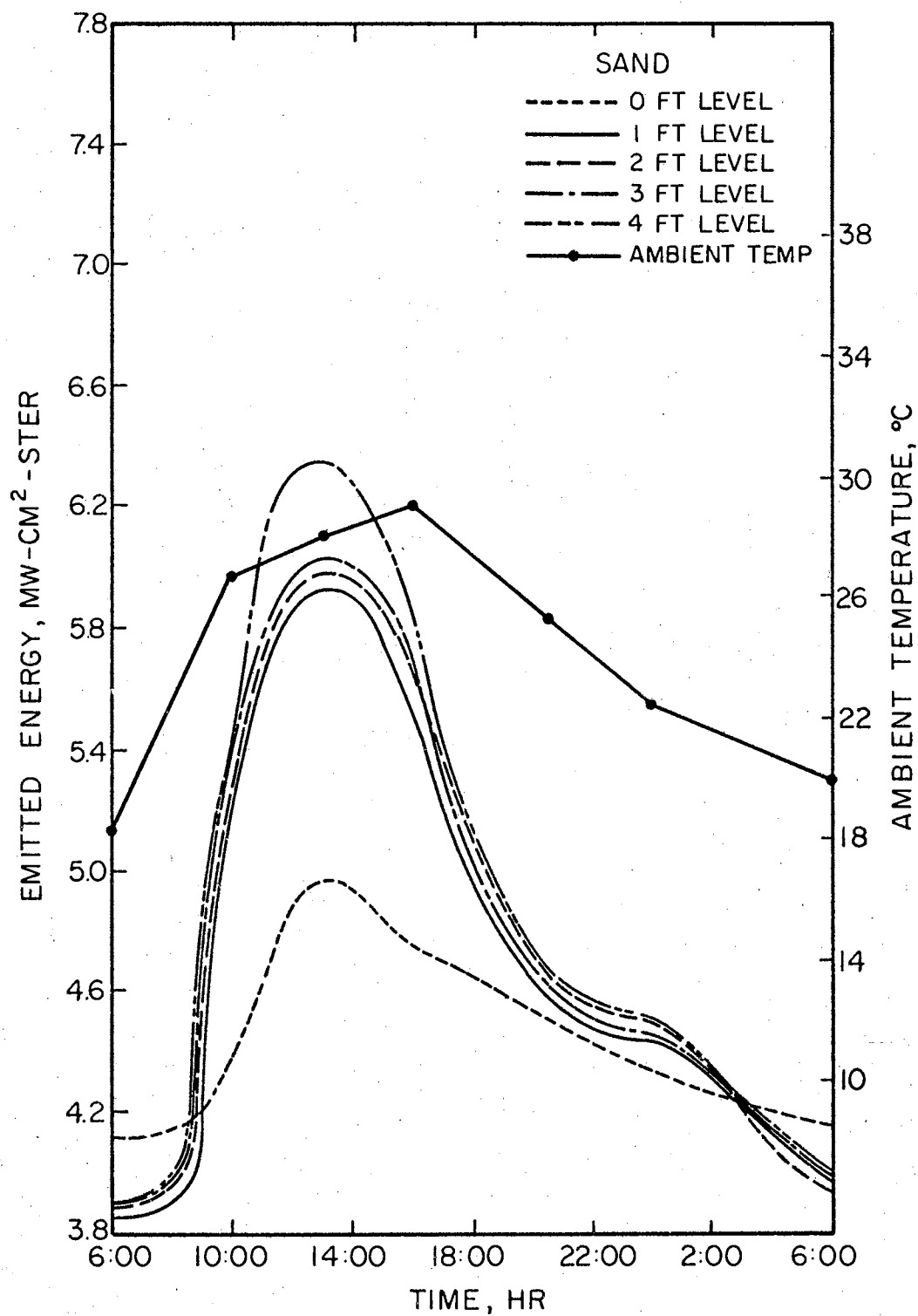
Figure 38. Emitted Energy of Sand for Changing
Non-Saline Water Table on May 20
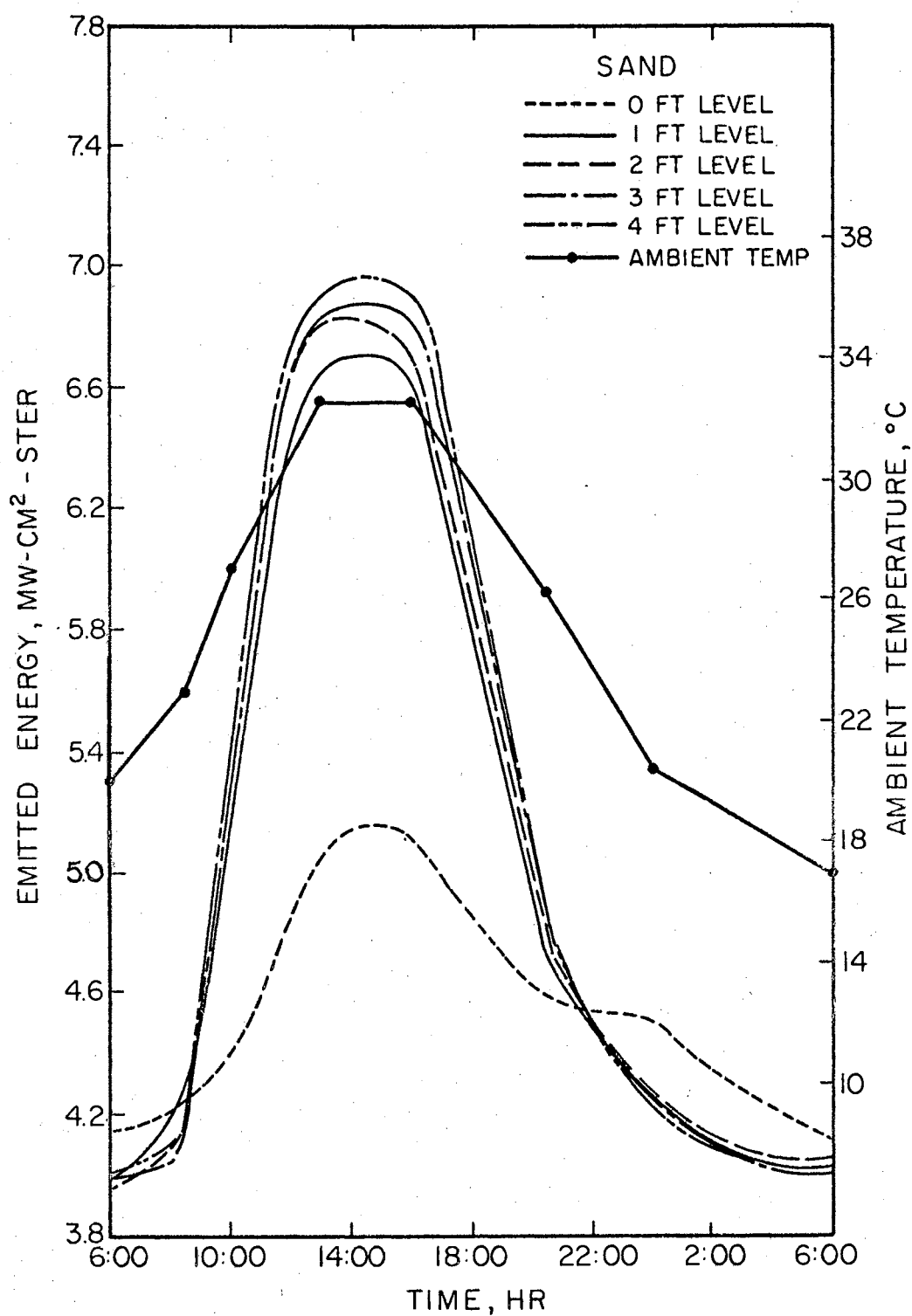
Figure 39. Emitted Energy of Sand for Changing
Non-Saline Water Table on May 21
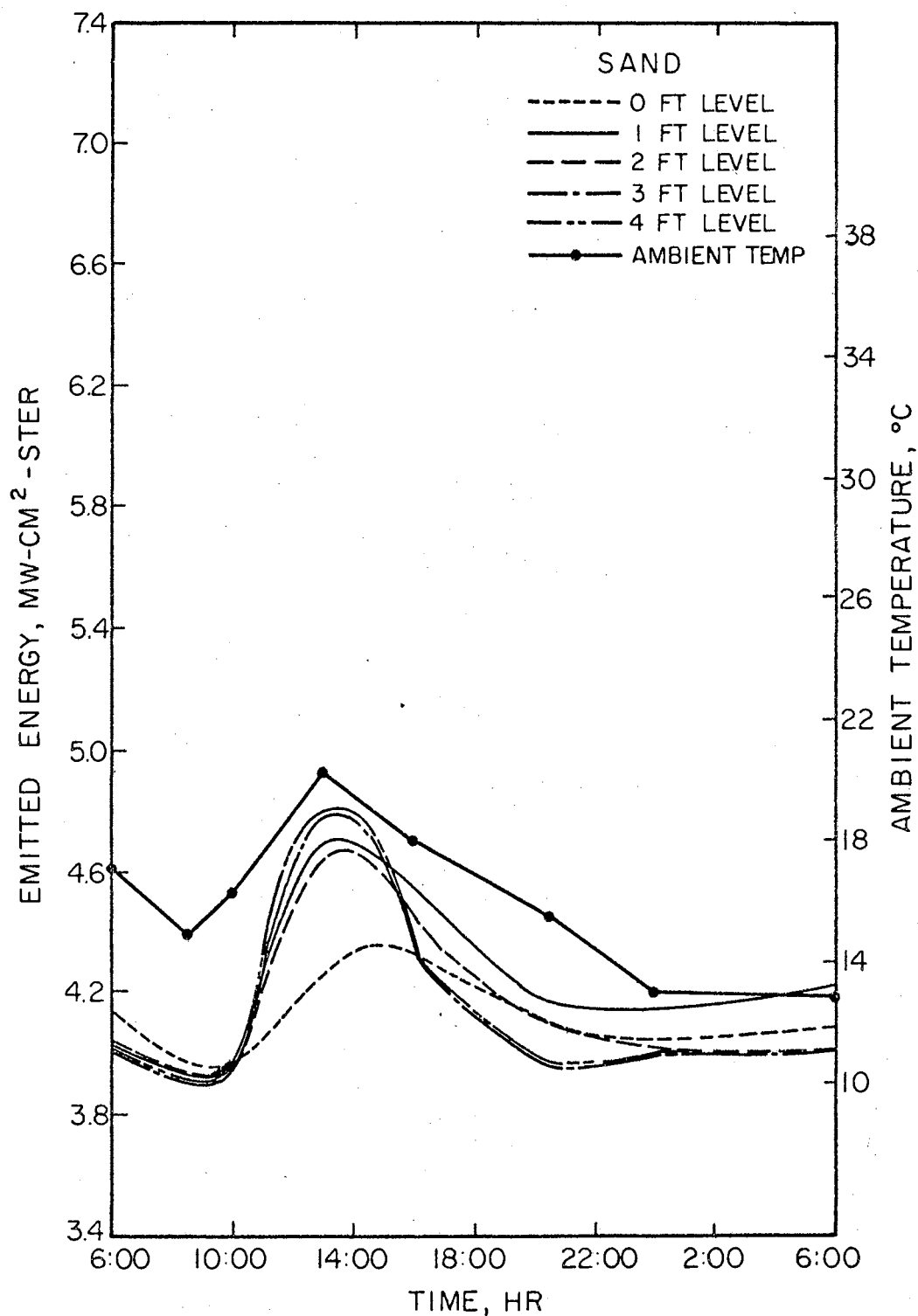
Figure 40.  Emitted Energy of Sand for Changing
Non-Saline Water Table on May 22
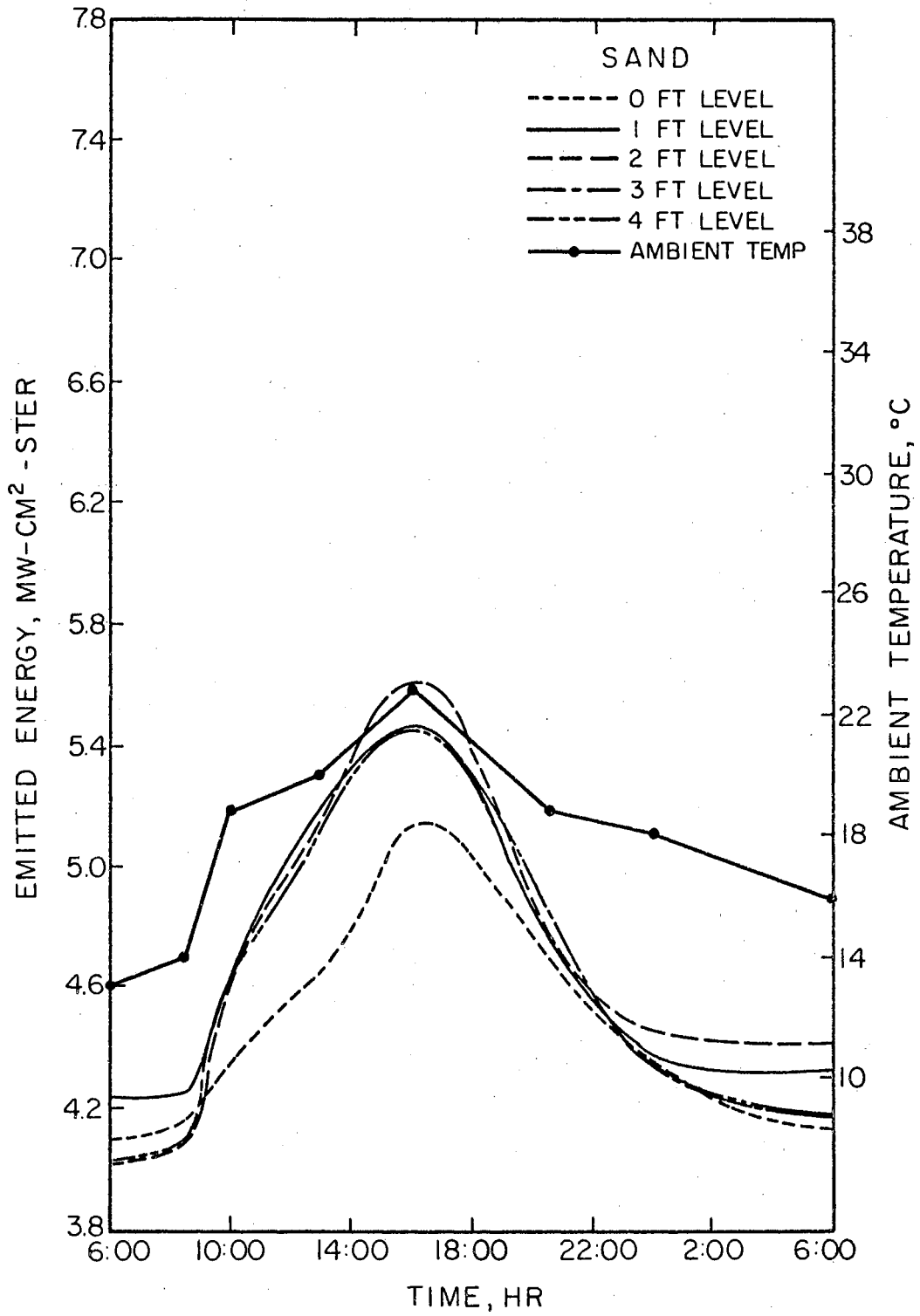
Figure 41. Emitted Energy of Sand for Changing
Non-Saline Water Table on May 23
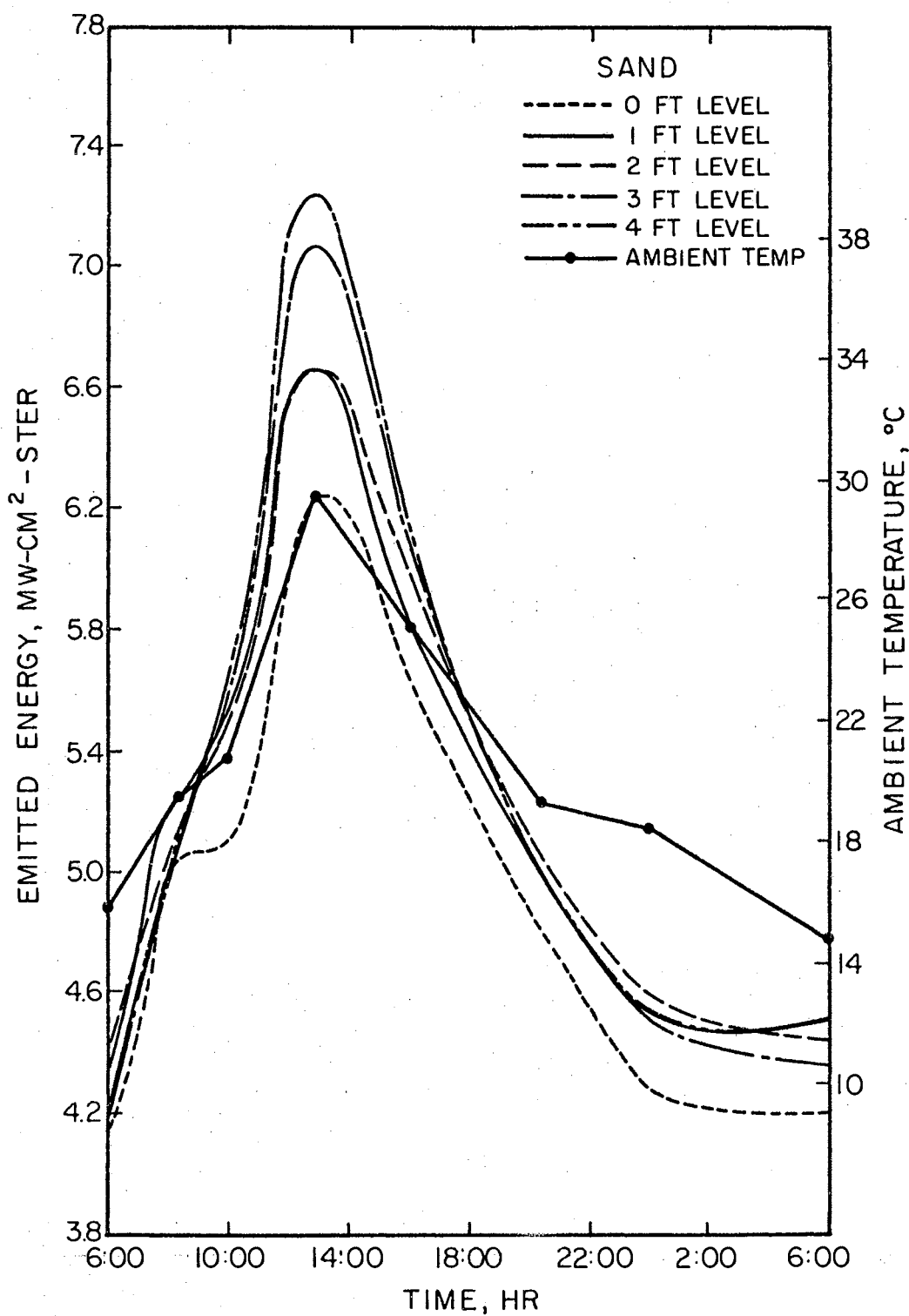
Figure 42. Emitted Energy of Sand for Changing
Non-Saline Water Table on May 24

also took place between 2:00 and 4:00 p.m. for both soil types, with the 4 ft. level having the highest emittance and 0 ft. level (water level at surface of soil) having the least emittance of radiant energy. There was an inversion in the amounts of emittances given off by the soils between 12:00 midnight and 6:00 a.m., with the highest energy being emitted by the 0 ft. level (water level at surface of soil) and the least energy being emitted by the 4 ft. level of both soil types.

These variations in emittances between the different levels of the water table are due to the diverse thermal characteristics of air and water. Water takes the place of air in soil voids as the soil becomes moist. Since water has a specific heat of 1.0 and air has only .000306, water has great influence on the ability of the soil to be heated and cooled (2) (3). Thus, the emitted energy varies according to the moisture content of the soil. For this reason, the maximum variance in emittance between the different levels of the water table occurs during the hottest portion of the day, since more solar energy is needed to raise the temperature of water than is needed to raise that of the soil. This fact further explains the inversion of emittances which occurred at night. The more moisture contained in the soil results in a higher heat capacity due to the higher specific heat of water. Since heat capacity is the ability of a material to hold heat, the wetter the soil is, the longer it will hold heat. Furthermore, the drier soils cool faster than the wet soils, therefore the emitted energy is less (3). This resulted in the inversion of emittances at night.

Emitted Energy of Soils for Changing

Saline Ground Water Table

Test results for the changing saline water table are given in Appendix D for silty clay and sand. These results are also shown in Figures 43 through 53 for sand and Figures 54 through 63 for silty clay. The emitted energy for silty clay was taken from June 13 through June 23. The emitted energy for the sand was taken from May 30 through June 9. Test results for both the silty clay and sand show that there was a slight difference in emitted energy from the soils having variance in concentrations of saline water table.

The sand had the greater variance of emitted energy from the changing levels of its saline water table due to its higher thermal conductivity. The highest emittance for the sand occurred between 2:00 and 4:00 in the afternoon with the 0 ppm solution giving the highest emitted energy. This took place at the 4 ft., 3 ft., 2 ft. and 1 ft. levels of water table, as shown in Figures 43 through 50. The reason for this is that the higher the salt concentrations added to the soils, the higher the specific heat of these soils becomes, therefore the less its temperature can be raised with the same amount of solar energy. Since these water table levels were below the surface, evaporation was lessened and did not affect the surface temperature.

Figures 52 and 53 are plots of the emitted energy for sand at the 0 ft. level. As can be seen, there was an inversion of the emittance at this level, compared to the 4 ft., 3 ft., 2 ft., and 1 ft. levels, with the highest emitted energy being given off by the soils containing the highest salt concentrations. These same results were found in the

soils tested in the panels as well, and are due to the same reason. At the 0 ft. level the surface was wet and evaporation of the moisture had a cooling effect on the soil. The soils containing the least amount of salt concentrations had the greatest amount of evaporation, therefore, emitted less energy. This inversion of emitted energy also occurred on the second day of the test at the 1 ft. water table level, as shown in Figure 51. This occurrence was also due to evaporation of water from the soil. A possible reason this did not occur on the first day the water table was at the 1 ft. level could be the difference in temperature on the two days. The temperature on June 6 (Figure 50) was not as high as that on June 7 (Figure 51), therefore, on June 6 enough evaporation may not have taken place to cause an inversion of emittance.

The 4 ft. and 3 ft. water table levels for the silty clay had the same trend of emittance as that of the sand at the 4 ft., 3 ft., 2 ft. and 1 ft. levels, with the soil containing 0 ppm giving off the highest emittance. (Figures 53 through 56) This is also due to the difference in specific heat for the varied salt concentrations. The readings for the silty clay were more erratic than those for the sand and there was not as great a difference between the varied salt concentrations as in the sand. An inversion of the emitted energy by the silty clay occurred at the 2 ft., 1 ft. and 0 ft. water table levels. Therefore it could be seen that the evaporation of the moisture in the soil at these water levels was controlling the temperature instead of the difference in the specific heat, as at the 4 ft. and 3 ft. water levels. The reason for this inversion of emittance for silty clay at a lower water table than that of the sand is the difference in capillary rise in these soils. The silty clay was moist within six inches of the surface when the water

table was at the 2 ft. level, while the water table for the sand had to

be at the 1 ft. level to moisten the soil within six inches of the sur-

face. Therefore, the amount of emitted energy given off by both soil

types is controlled by the difference in specific heat for the different

salt concentrations until the water table is raised to a point where the

capillary rise is high enough for evaporation of moisture from the soil

to cause a cooling effect on the soil. At this point an inversion of

emittance occurs. In this test, inversions of emittances occurred at

the 2 ft. level and 1 ft. level for silty clay and sand, respectively.
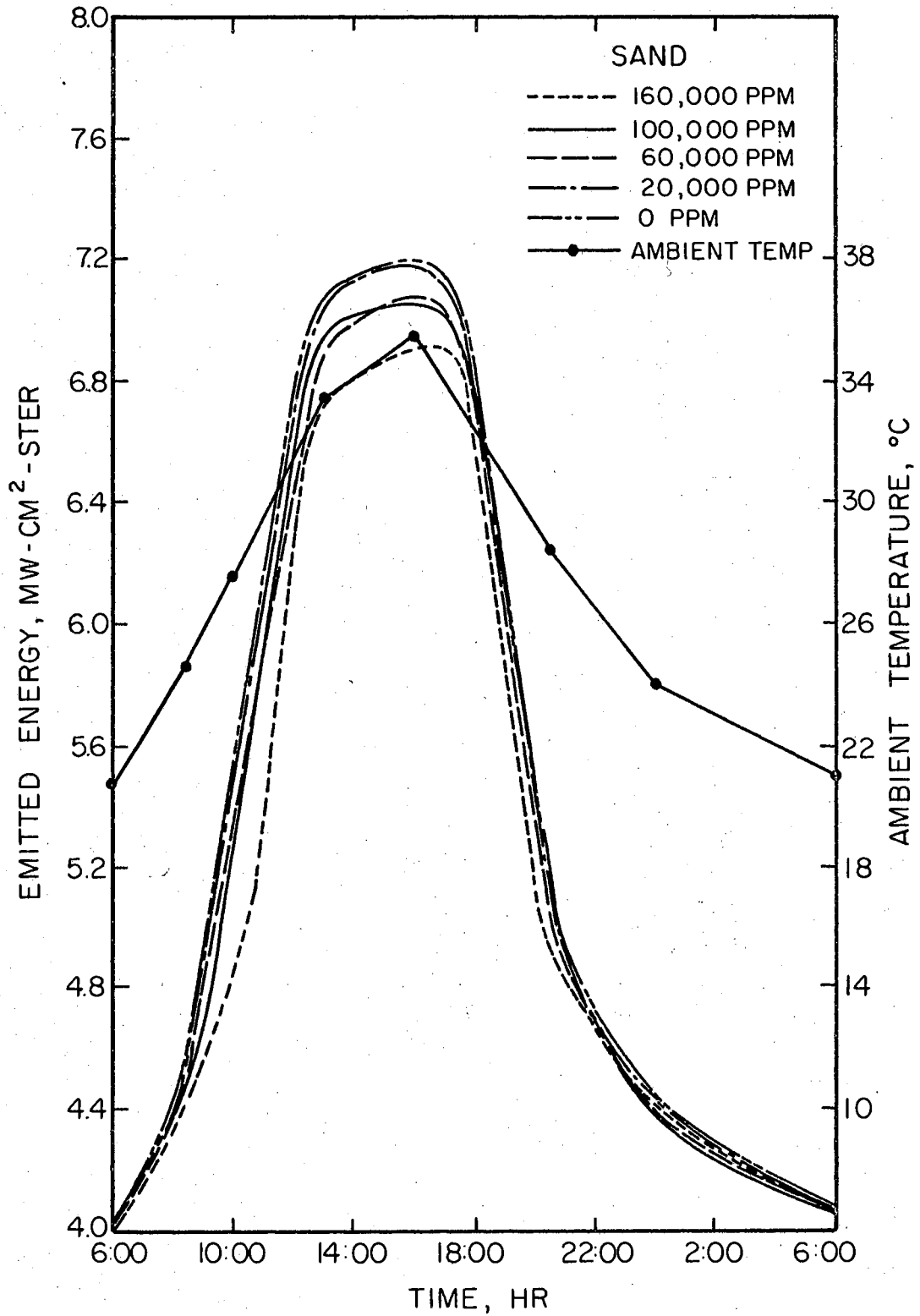
Figure 43. Emitted Energy for May 30 for Saline
Water Table at 4 ft. in Sand
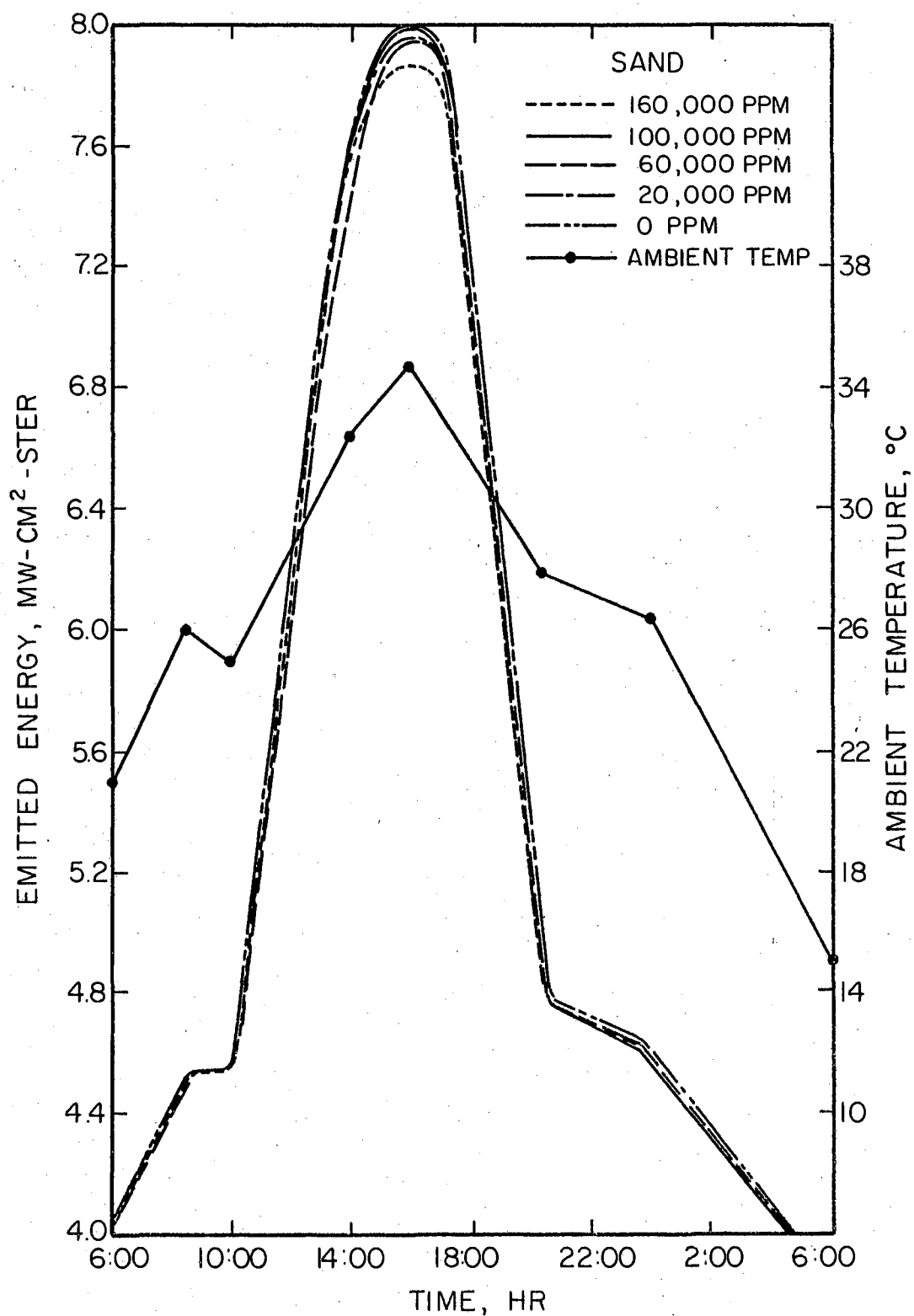
Figure 44. Emitted Energy for May 31 for Saline
Water Table at 4 ft. in Sand
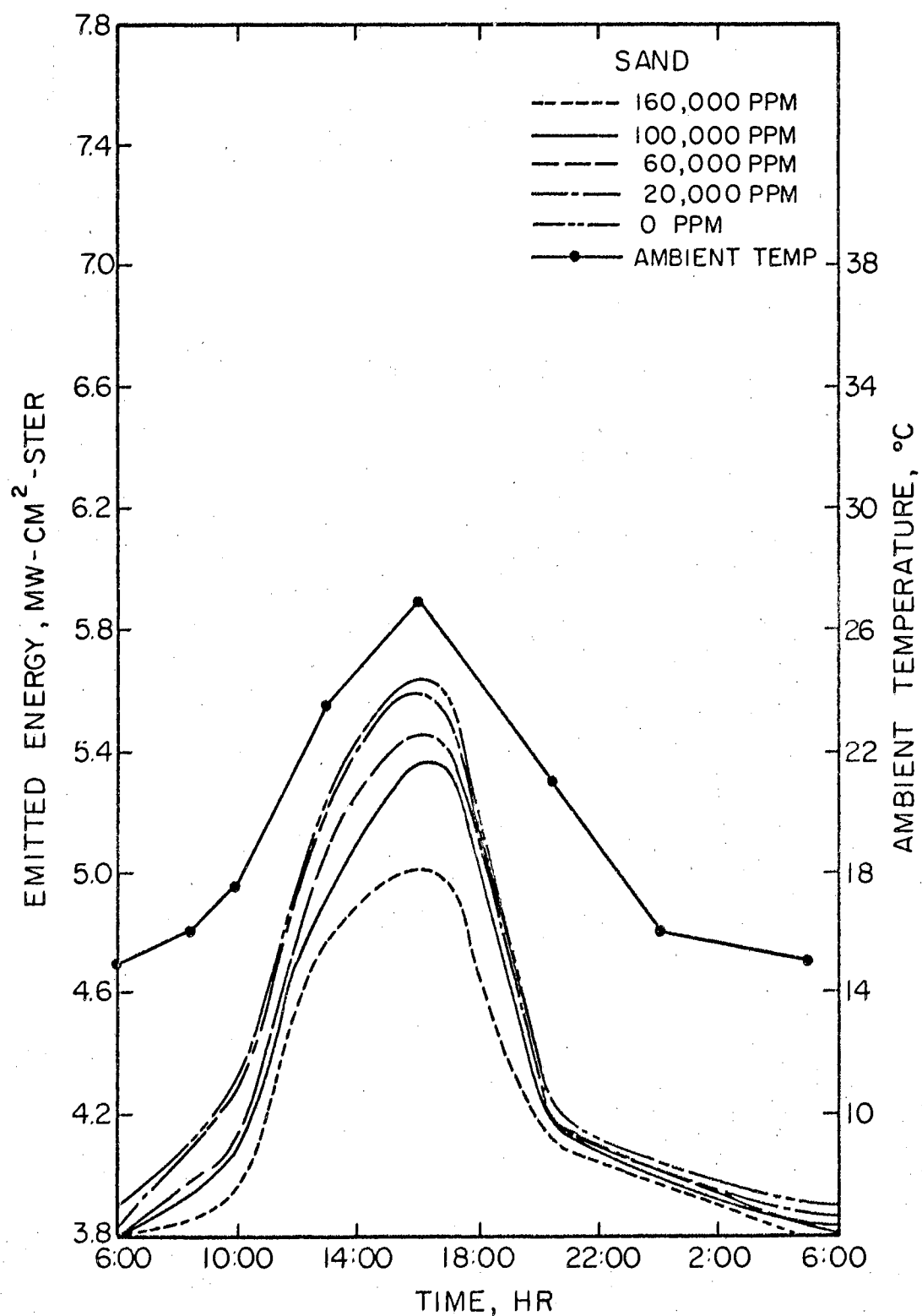
Figure 45. Emitted Energy for June 1 for Saline
Water Table at 3 ft. in Sand
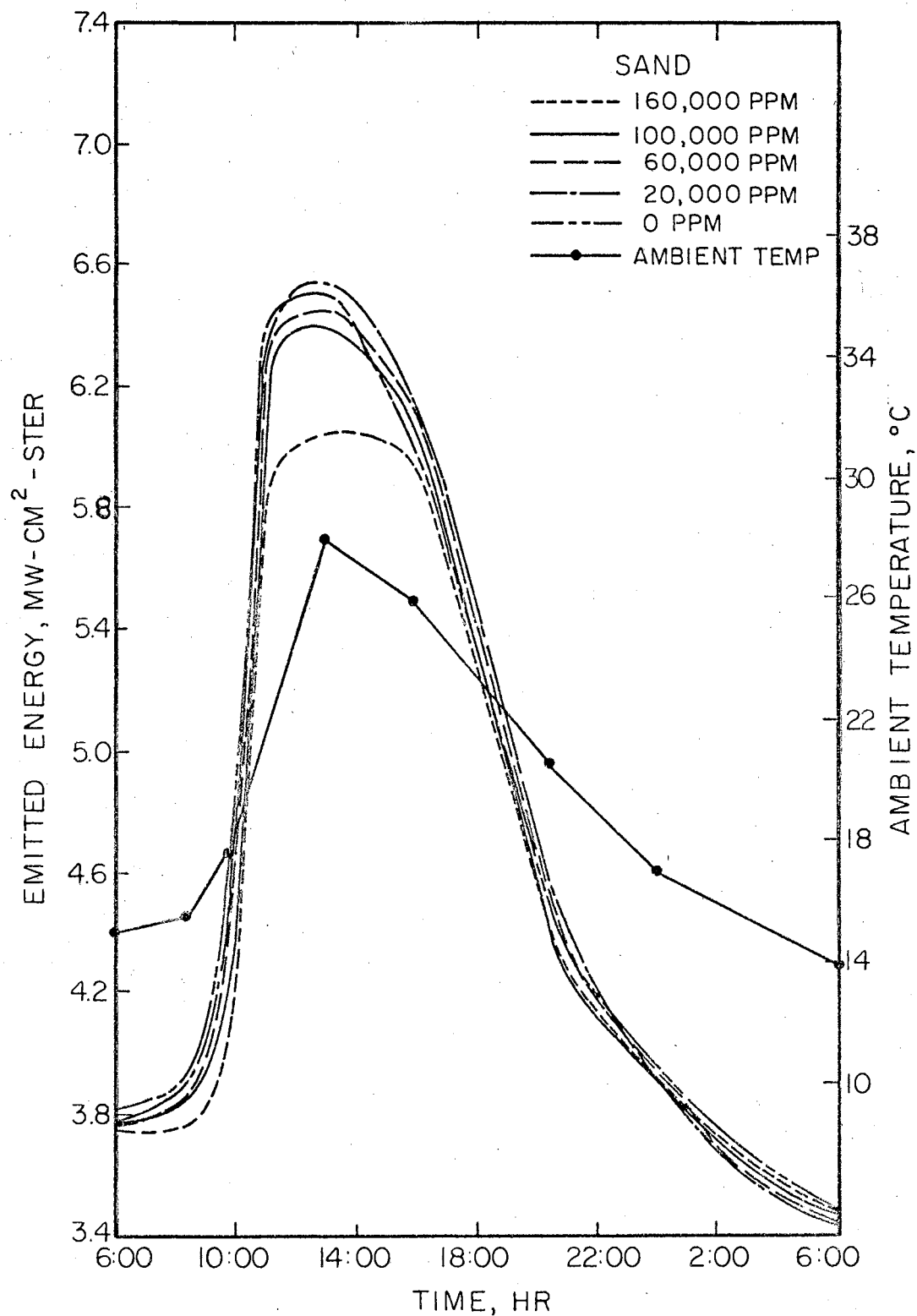
Figure 46. Emitted Energy for June 2 for Saline
Water Table at 3 ft. in Sand
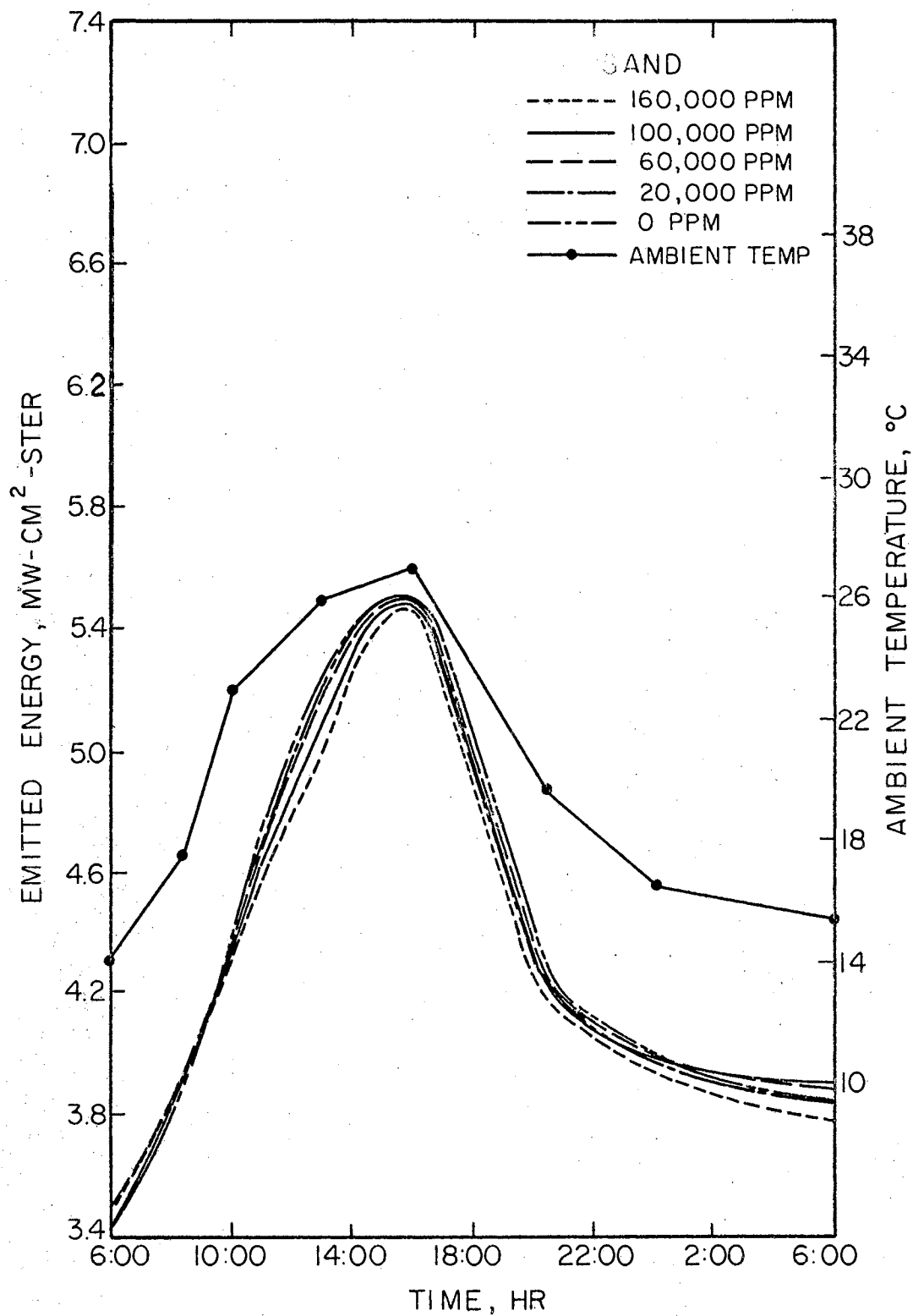
Figure 47. Emitted Energy for June 3 for Saline
Water Table at 2 ft. in Sand
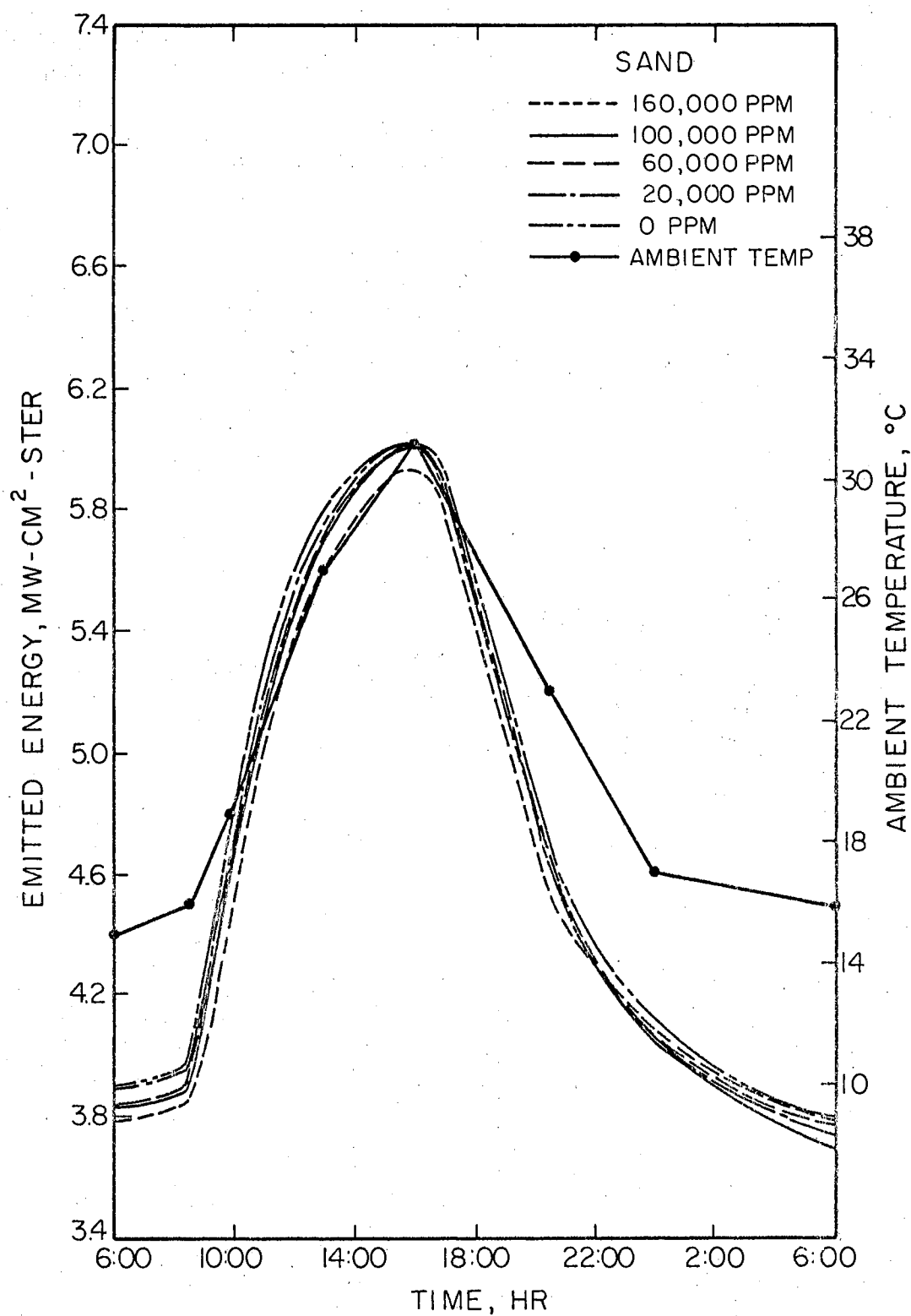
Figure 48. Emitted Energy for June 4 for Saline
Water Table at 2 ft. in Sand
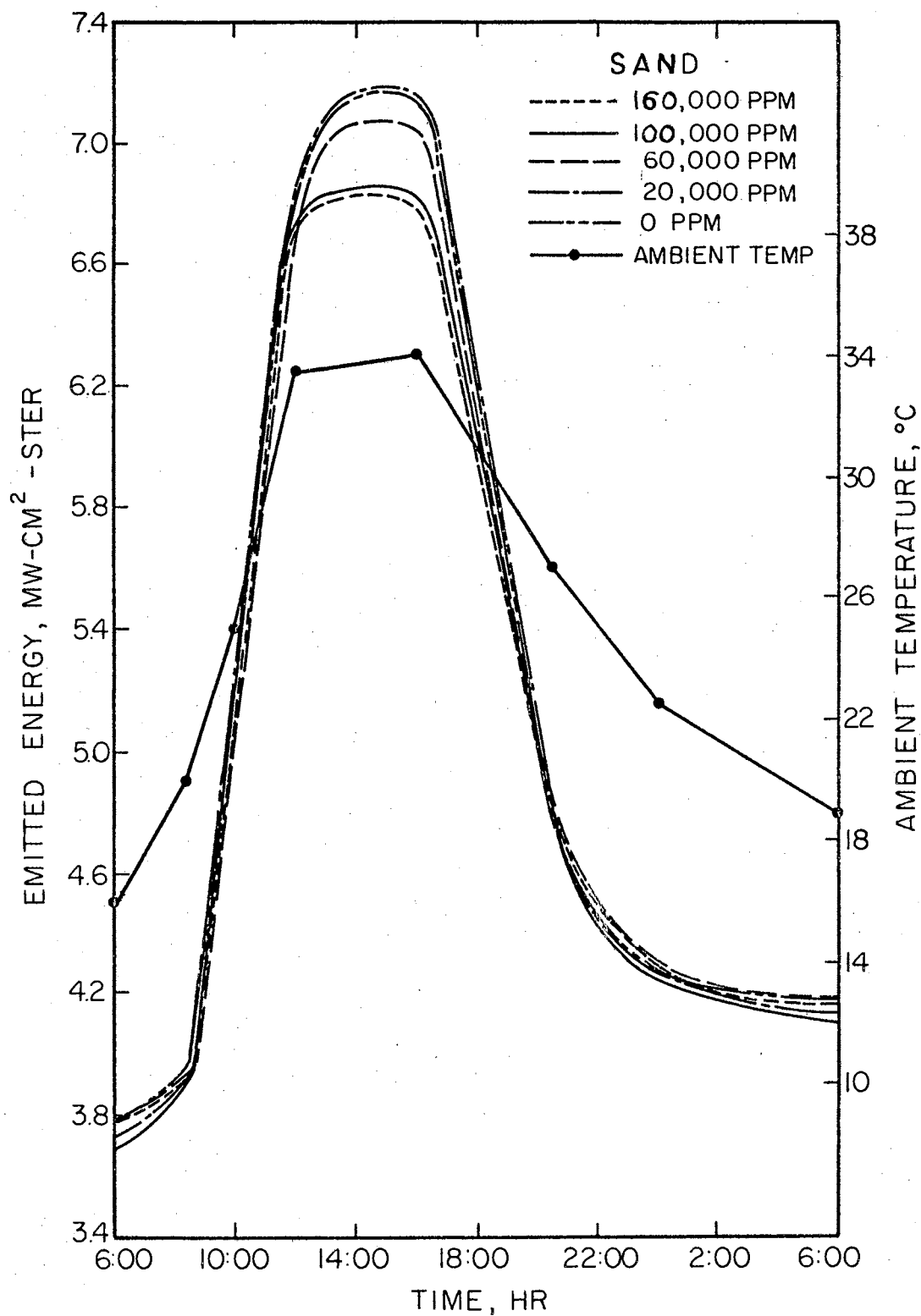
Figure 49. Emitted Energy for June 5 for Saline
Water Table at 2 ft. in Sand
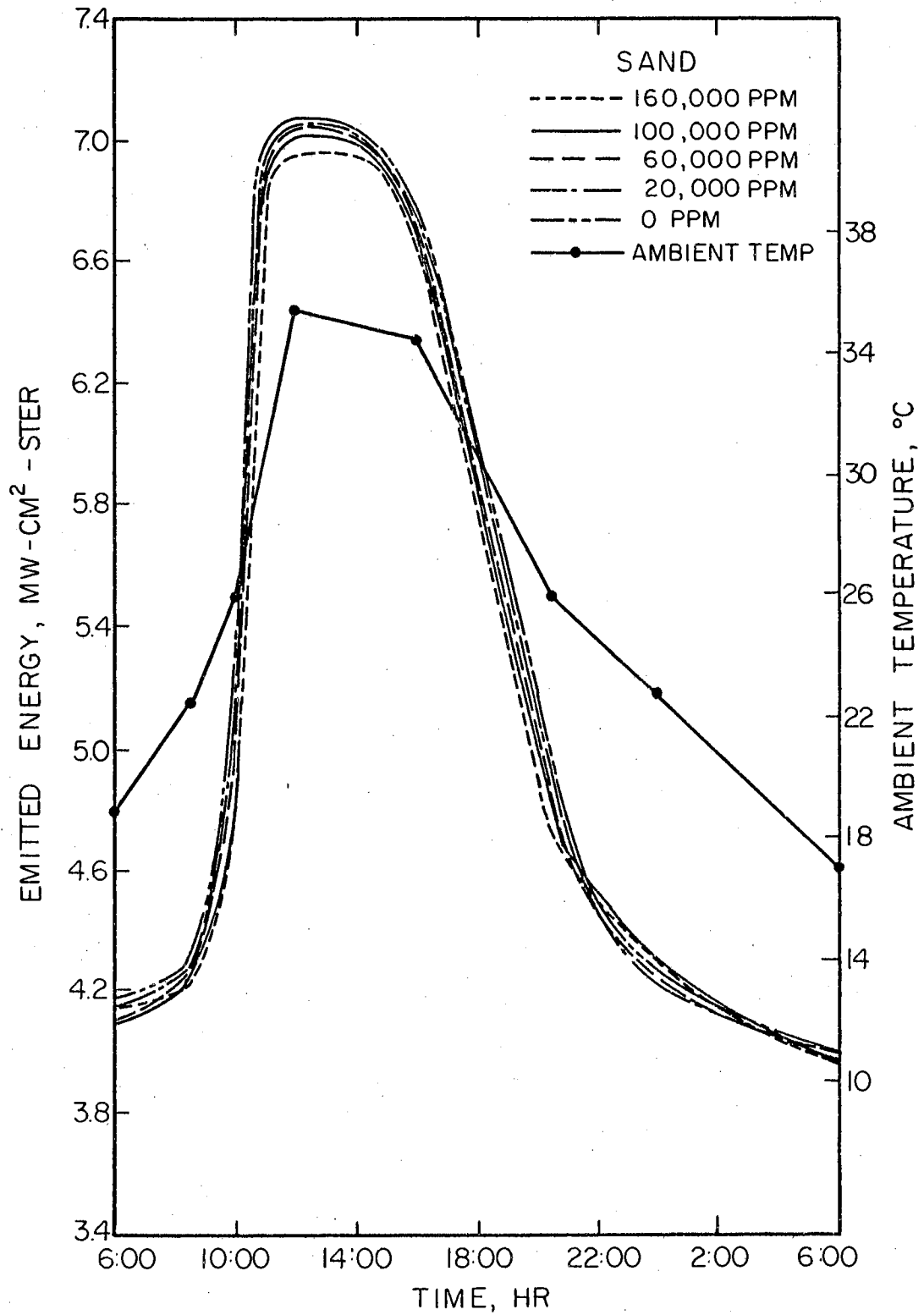
Figure 50. Emitted Energy for June 6 for Saline
Water Table at 1 ft. in Sand
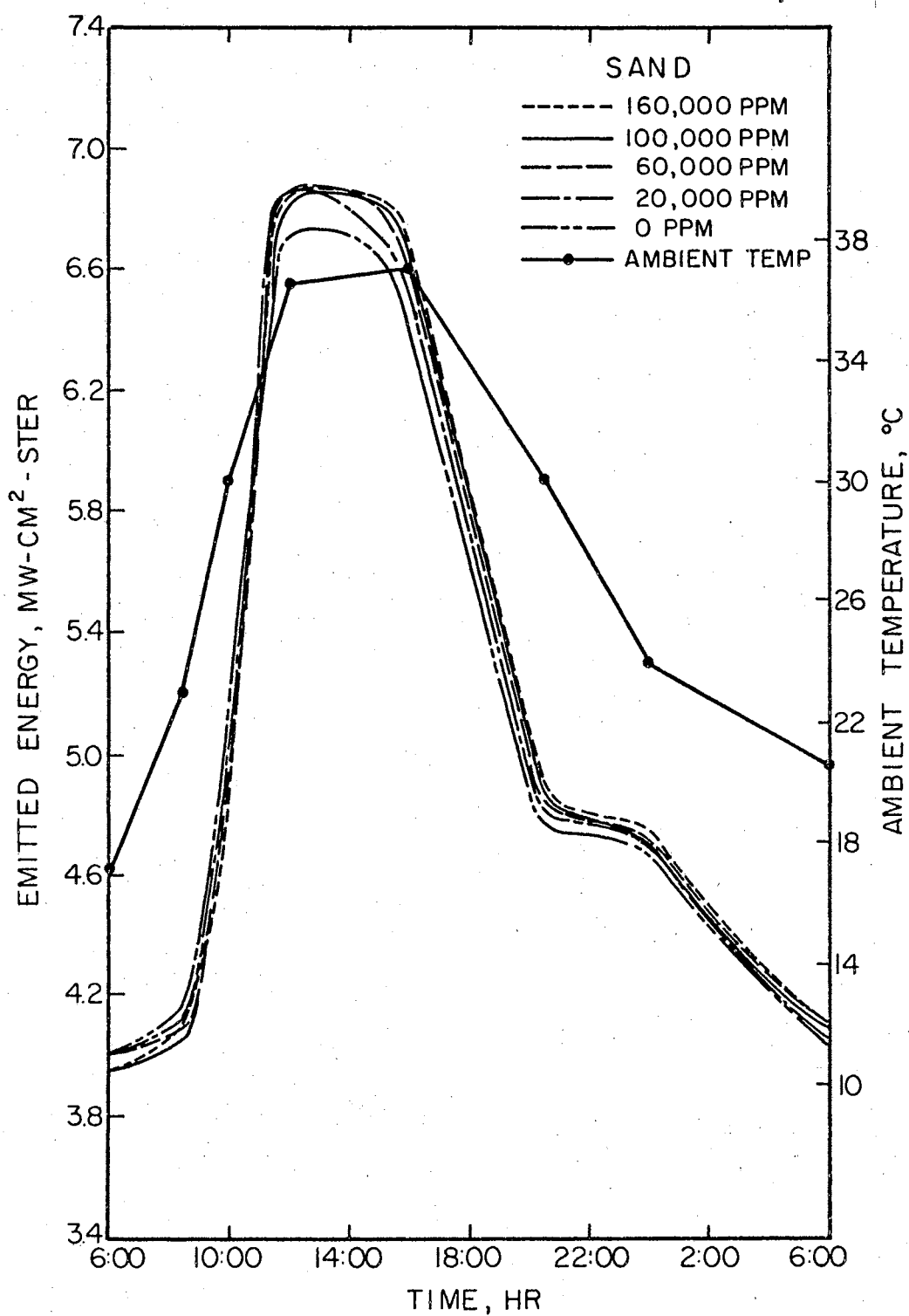
Figure 51. Emitted Energy for June 7 for Saline
Water Table at 1 ft. in Sand
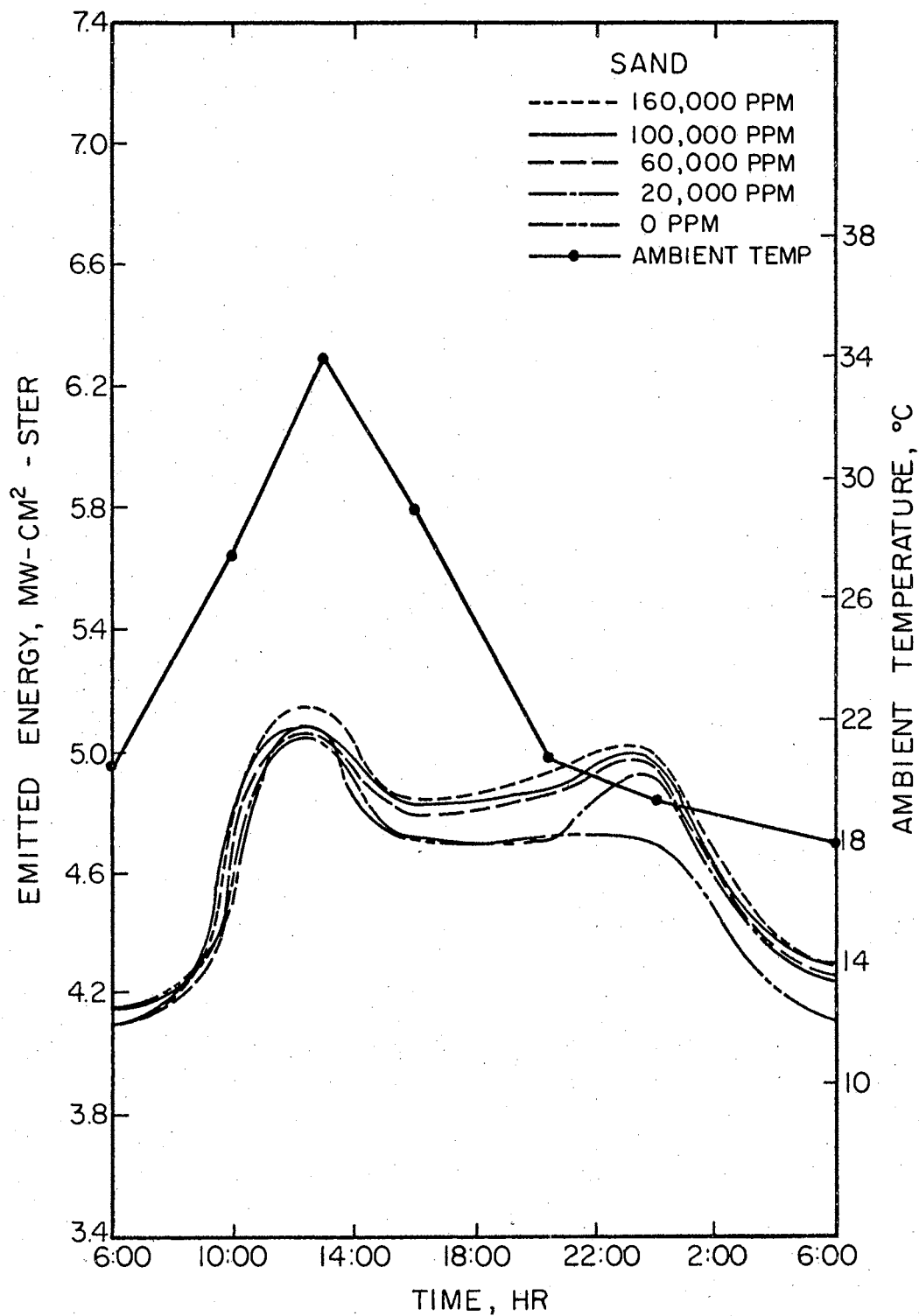
Figure 52. Emitted Energy for June 8 for Saline
Water Table at 0 ft. in Sand
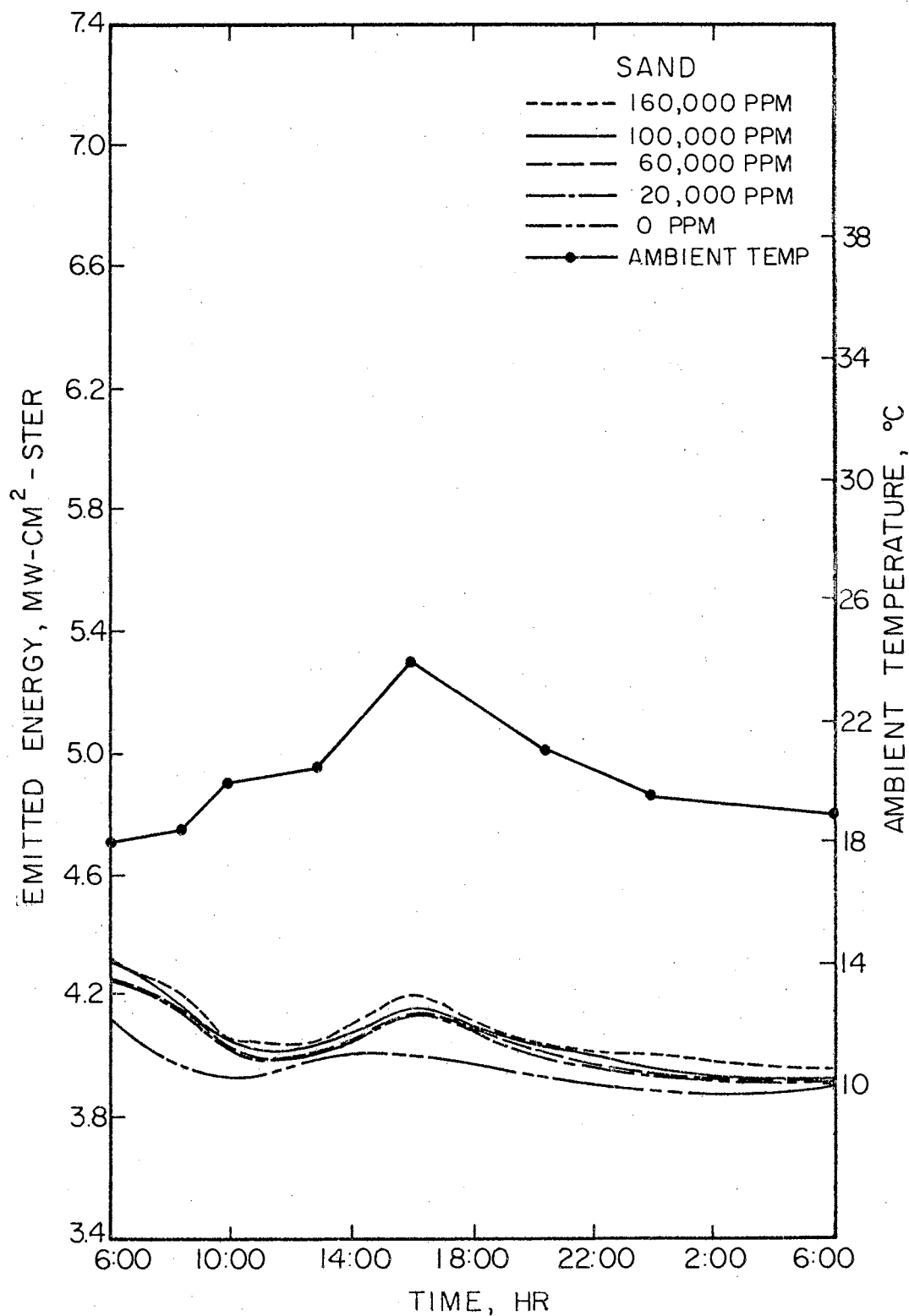
Figure 53. Emitted Energy for June 9 for Saline
Water Table at 0 ft. in Sand
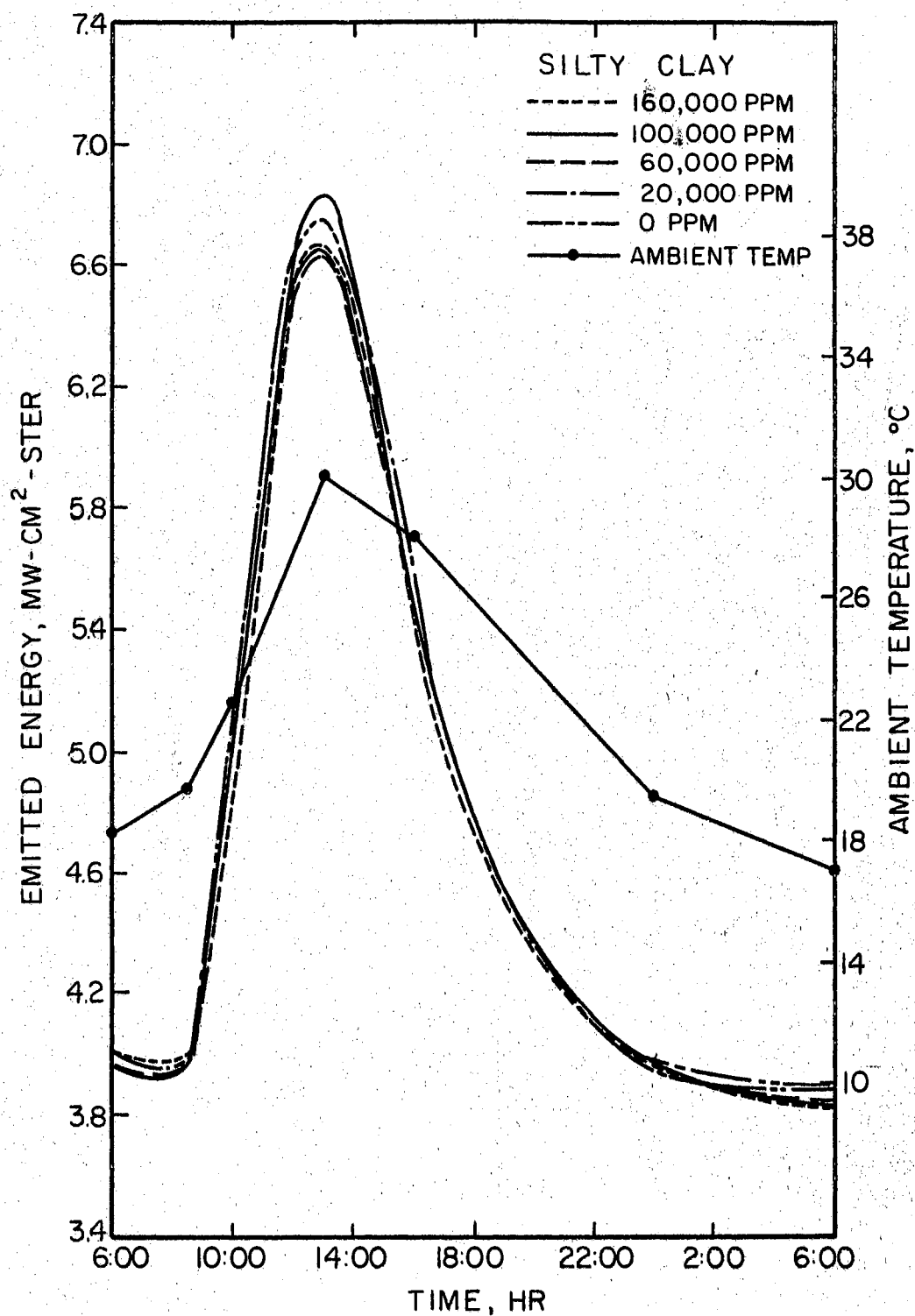
Figure 54. Emitted Energy for June 13 for Saline Water
Table at 4 ft. in Silty Clay
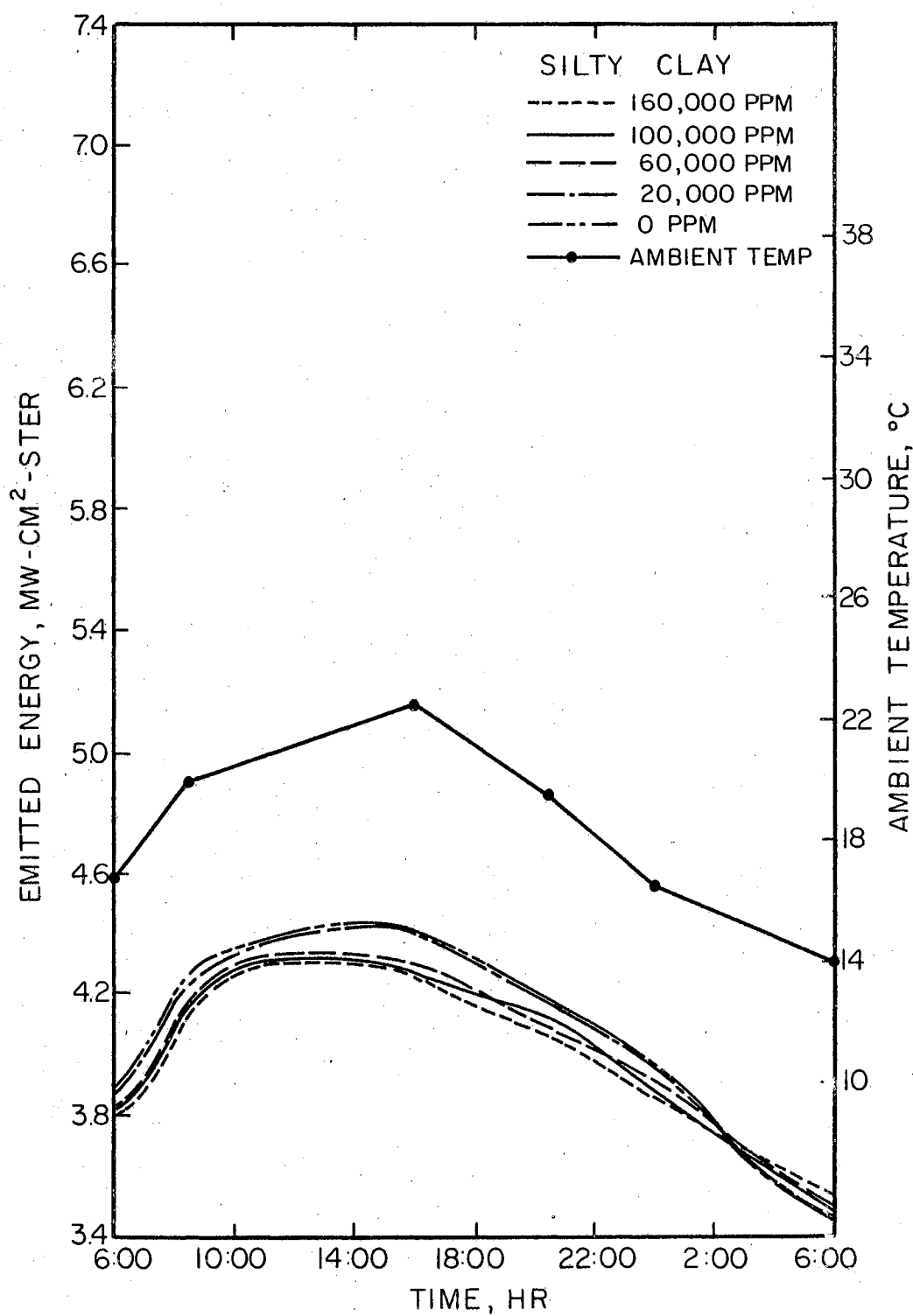
Figure 55. Emitted Energy for June 14 for Saline Water
Table at 4 ft. in Silty Clay
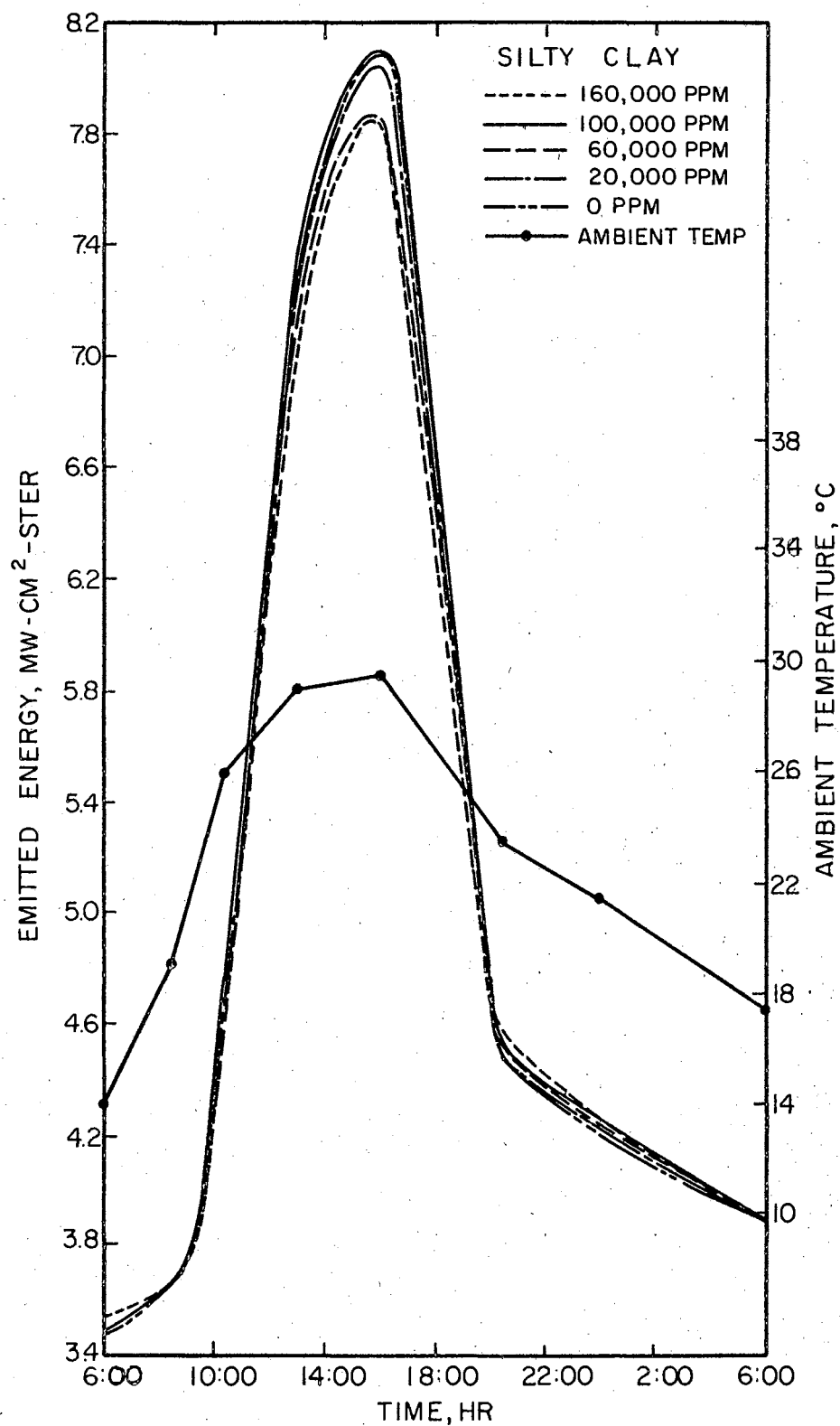
Figure 56. Emitted Energy for June 15 for Saline
Water Table at 3 ft. in Silty Clay
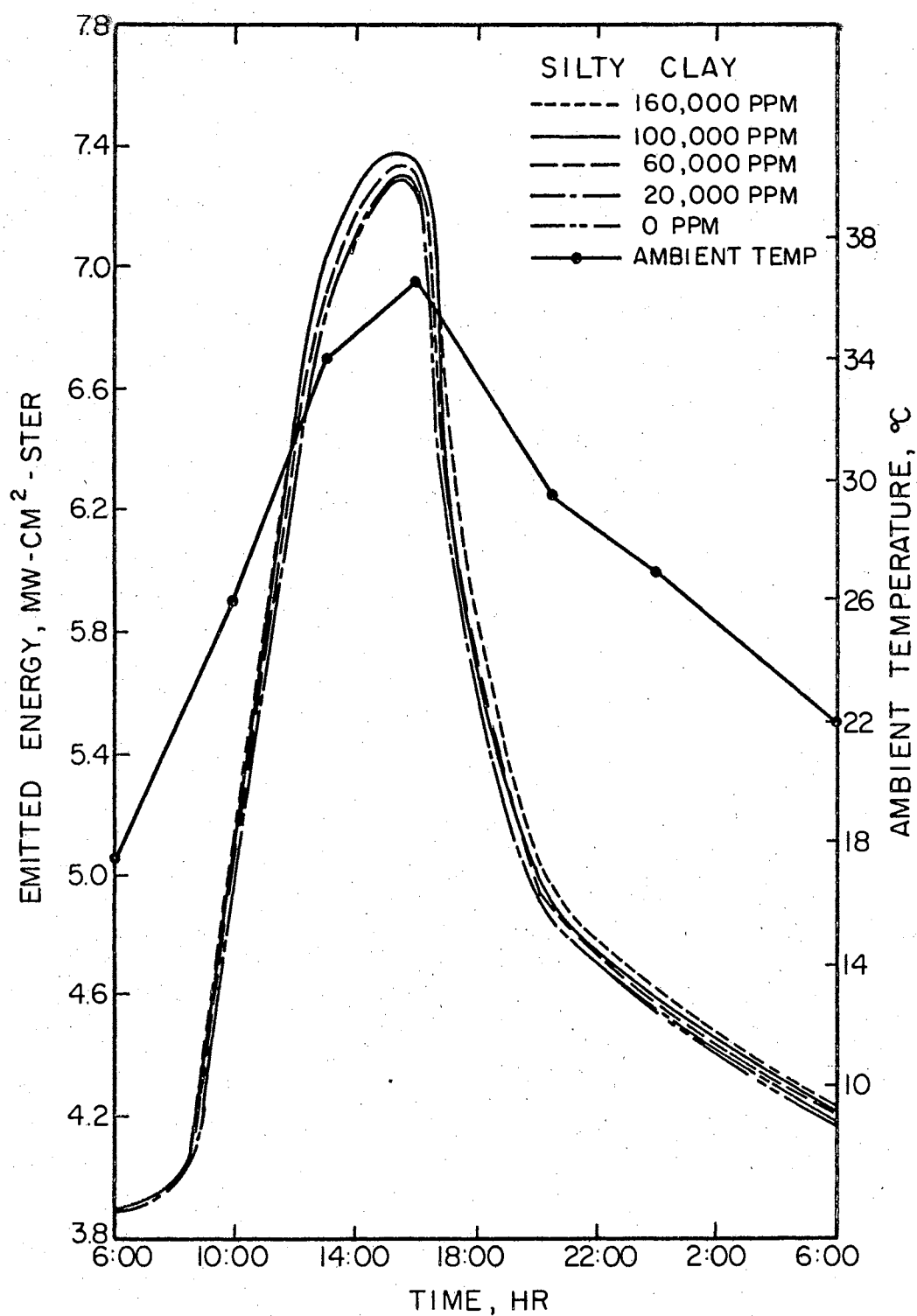
Figure 57.  Emitted Energy for June 16 for Saline Water
Table at 3 ft. in Silty Clay
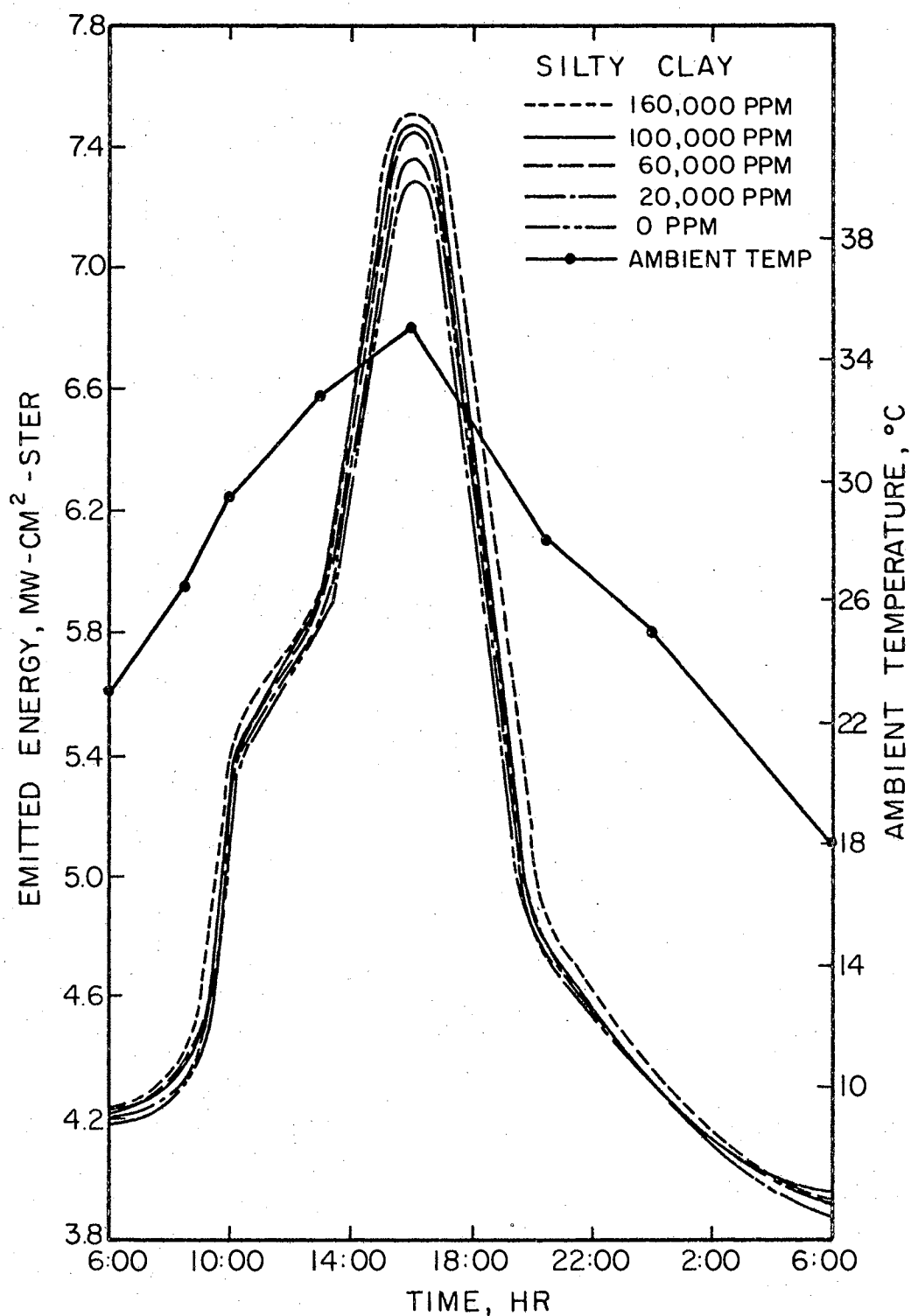
Figure 58. Emitted Energy for June 17 for Saline Water
Table at 2 ft. in Silty Clay
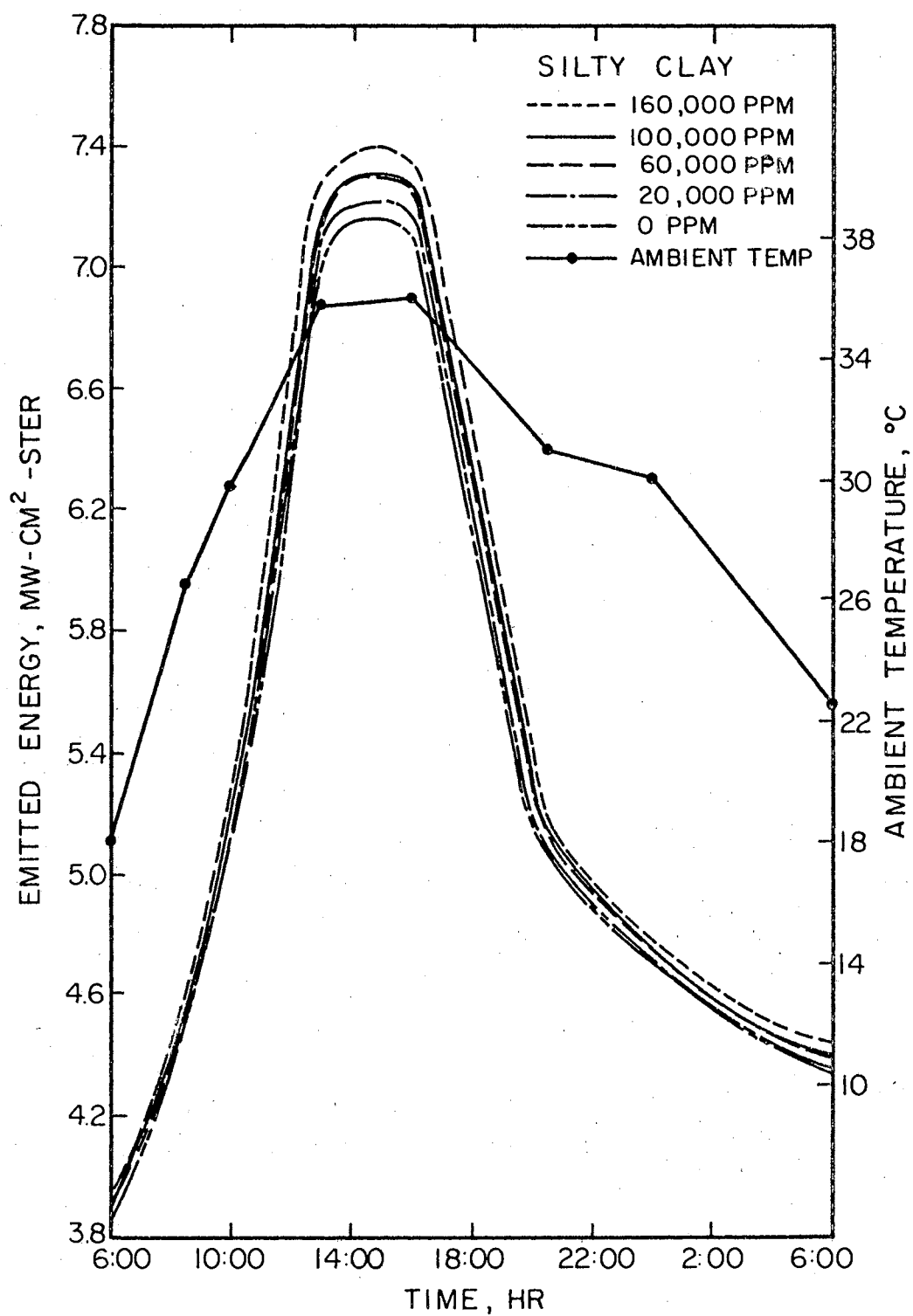
Figure 59. Emitted Energy for June 18 for Saline Water
Table at 2 ft. in Silty Clay
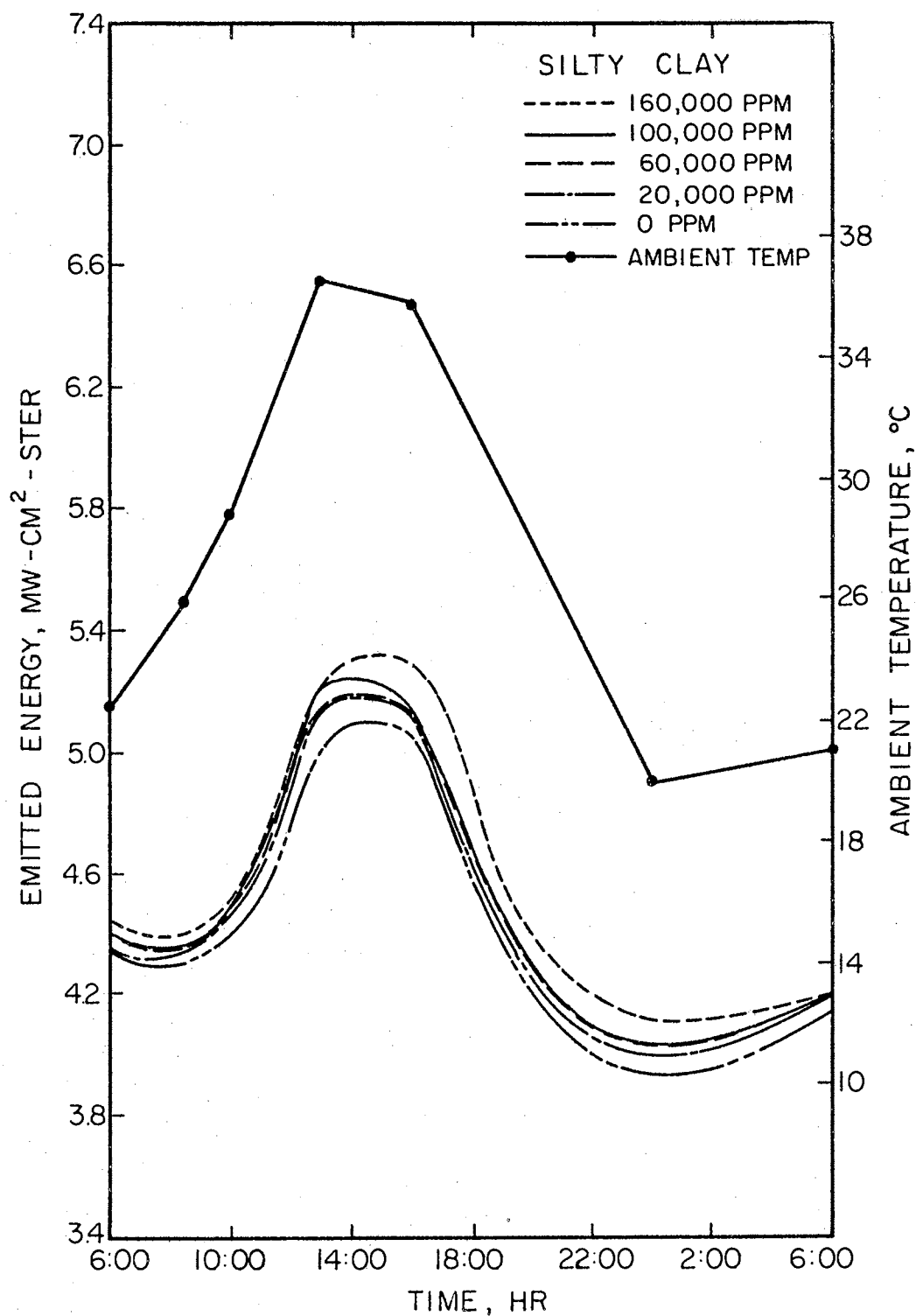
Figure 60. Emitted Energy for June 19 for Saline Water
Table at 1 ft. in Silty Clay
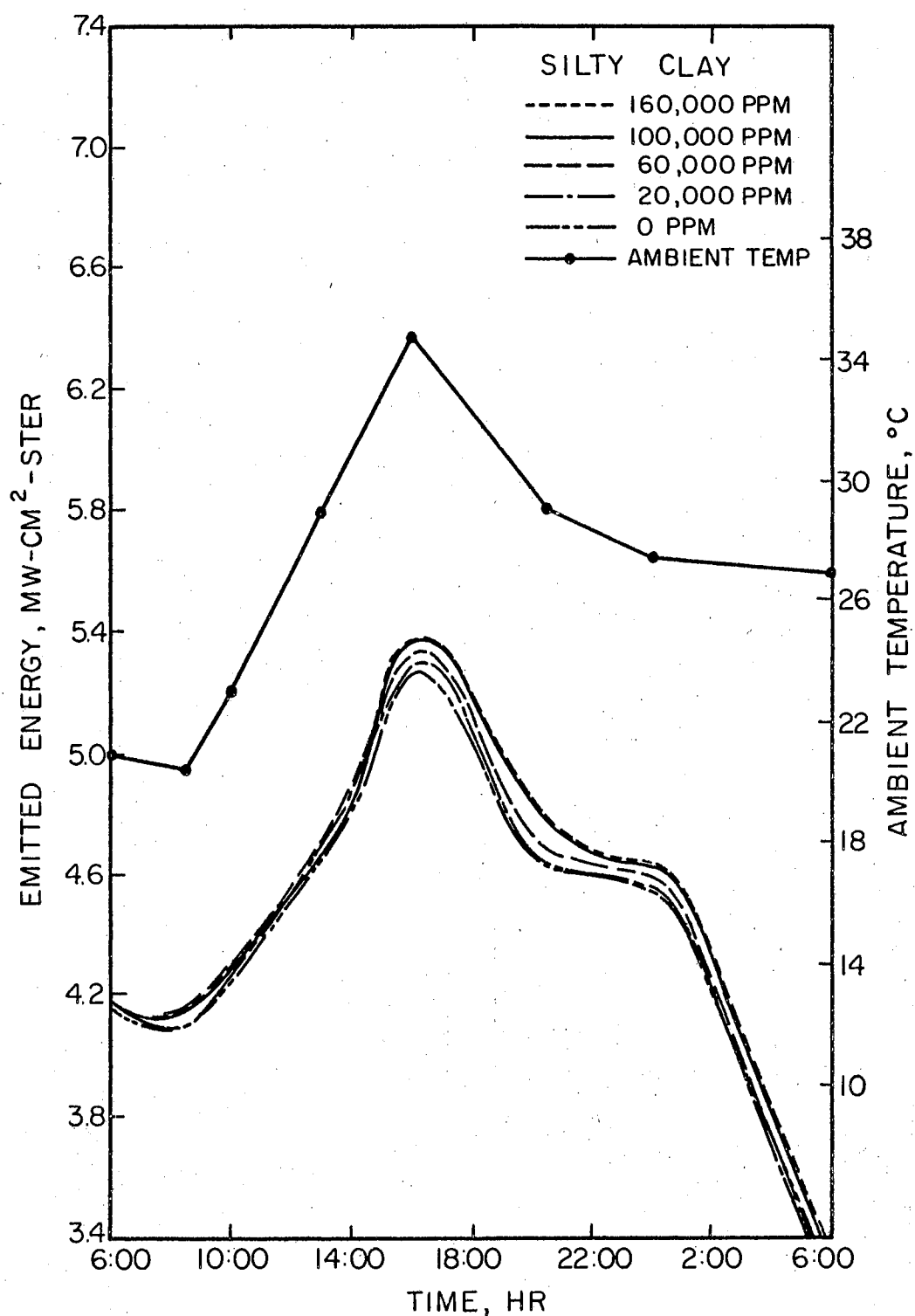
Figure 61. Emitted Energy for June 20 for Saline Water
Table at 1 ft. in Silty Clay
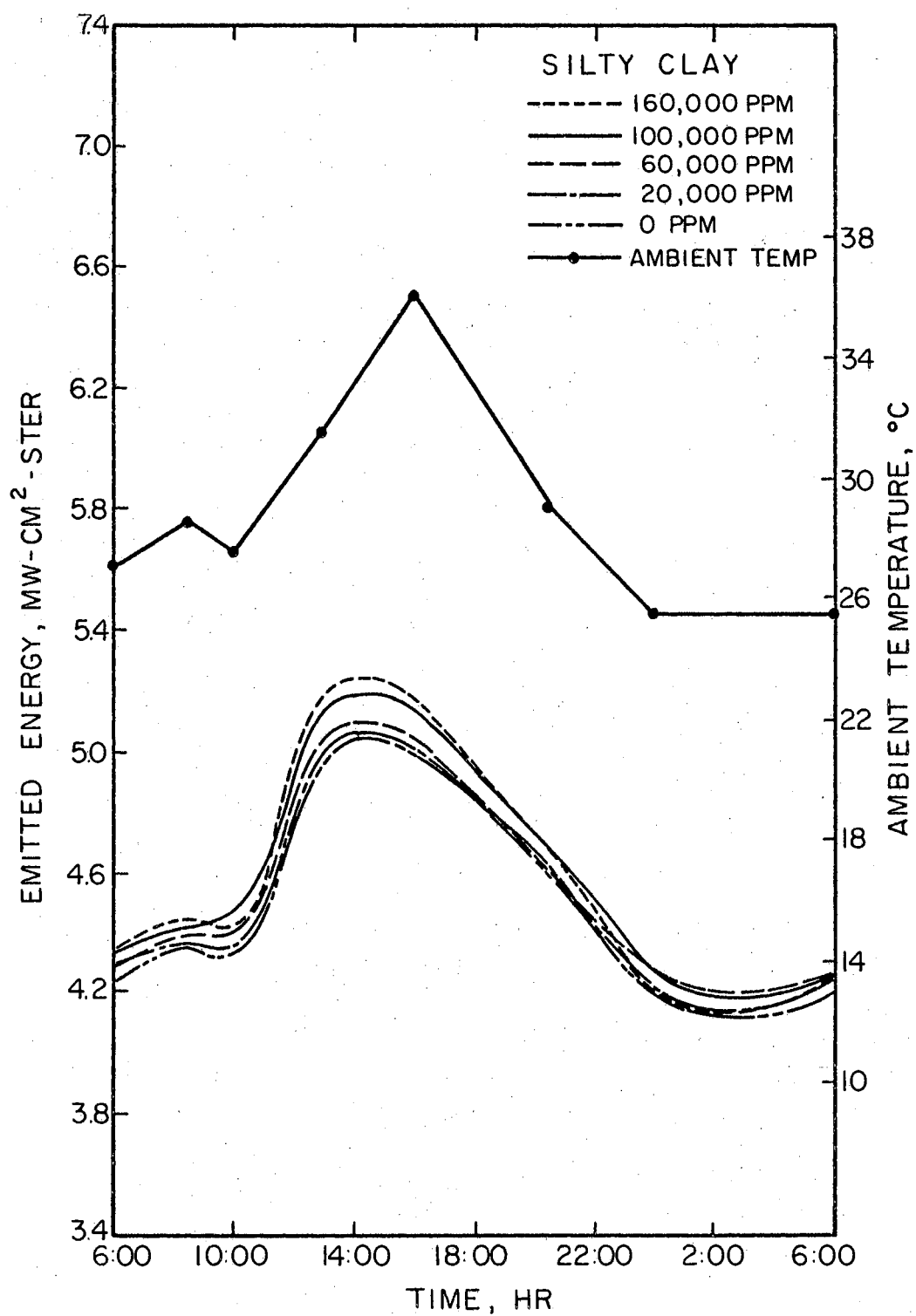
Figure 62. Emitted Energy for June 21 for Saline Water
Table at 0 ft. in Silty Clay
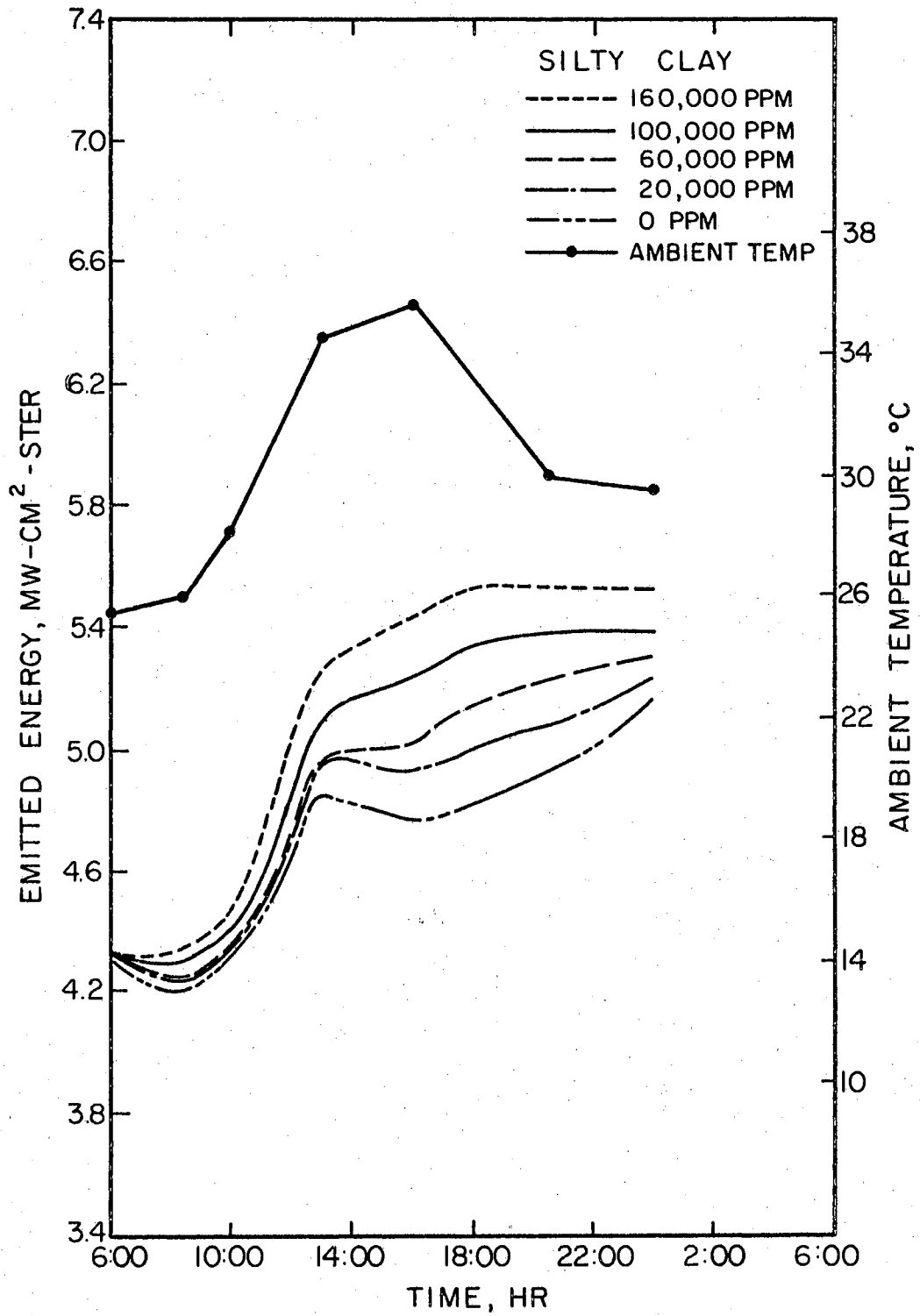
Figure 63. Emitted Energy for June 22 for Saline Water Table at 0 ft. in Silty Clay

CHAPTER VII

CONCLUSIONS AND RECOMMENDATIONS

Conclusions

This investigation was conducted (a) to study the emittance quali-
ties of sand and silty clay containing varying salt concentrations and
changing ground water tables, and (b) to study the reflectance variances
of wheat and salt grass grown in soils containing varied salt concentra-
tions. The main objects of this research were (a) to determine the best
film-filter combination for measuring reflectance variances of vegeta-
tion grown in soils containing varied amounts of salt; (b) to determine
if soils containing varied salt concentrations and soils with changing
ground water tables could be detected by emittance measurements, and if
so (c) to determine the best time to take an imagery for measuring emit-
ted energy of soils.

From the analysis of the data discussed in the preceeding chapter
the following conclusions can be drawn:

(1) The maximum difference in reflectance of both soil types of
vegetation grown in soils containing veried salt concentrations occurred
primarily in the near infrared region, 720-1000 millimicron wavelengths,
of the electromagnetic spectrum. Therefore, Ektachrome IR film with
No. 12 and No. 25 filters were used to take photographs of wheat sam-
ples. The variances in reflectance were detectable in the photographs

taken of samples in the lab. However, since a larger area and more than one layer of leaves will be photographed of vegetation in the field, these reflectance variances should be magnified. Also, the energy source for field photography will be solar energy which will result in a change of exposure time and focal length settings. Photographs for detection of salinity in soils by measuring reflectance of vegetation is best done when there is a good canopy of leaves on the plants in order to minimize ground detection. Results showed maturity to be quite instrumental in obtaining favorable reflectance qualities, however, the photographs will give best color contrasts if taken before leaves enter stages of yellowing. For this reason, detection of salinity in soils in which wheat is grown will give best results if wheat is photographed shortly before heading occurs. Aerial photography should be taken in the morning at a low altitude flight to incur a minimal amount of atmospheric haze interferring with reflectance.

(2) The maximum difference in emittances of both soil types with varied salt concentrations occurred between 2:00 and 4:00 in the afternoon. These results show the measuring of emitted energy between the atmospheric window 8 - 14 micron wavelengths by remote sensing techniques will give best detection when testing is conducted at this time. Although some of the readings taken during this investigation were erratic, the emittance variances of soils with varied salt concentrations in the field may be detectable by imagery. The field area of soil emitting the energy will be much larger and should lessen the amount of erratic readings which were detected in the soil panels. Although imagery will not give the amount of salt concentration in the soil, quantitatively, it will give the boundary of each change in salt concentration in the soil

by changing shades. After an imagery has been taken and the boundaries
for the different salt concentrations have been determined, samples of
soils can be taken within these particular boundaries to determine the
amount of salt contained by the soil. In the field, as the soil types
change so will the emitted energy change; therefore, the boundary of the
soil types will also have to be determined.

(3) The maximum difference in emittance for changing non-saline
water tables also occurred between 2:00 and 4:00 p.m. Therefore, detec-
tion of emittance of changing water tables by imagery may be conducted
during this time. The changes in emitted energy for the different levels
of water table depend upon how close the water level is to the surface
and how much capillary rise will occur in the particular soil from which
emittance measurements are taken. In other words, the greater the capil-
lary rise, the greater the depth of water table that can be detected by
the difference in emitted energy. An imagery will not give the depth
to water table, quantitatively, but it will show the change in water
table if the water level is close enough to the surface to effect the
emitted energy of the soil.

(4) Differences in emittance for varied saline water tables were
slight and some readings were erratic. There was an inversion of emit-
tance when the water table reached a point where evaporation controlled
the emitted energy given off by the surface. Water tables at the same
level, containing different concentrations of salt, may give better de-
tection by remote sensing techniques when the water table is closer to
the surface.

(5) It should be taken into consideration that the four variables
under investigation were tested separately. However, in measuring the

emittance of soils in the field, all four variables may be affecting the emittance measurements simultaneously.

## Recommendations for Future Research

The following are suggestions for further research:

(1) Different types of vegetation should be tested since the reflectance changes with different types of vegetation.

(2) Photographs should be taken in the field to determine how well vegetation grown under field conditions can be used as detectors for salinity in soils.

(3) Imagery should be taken of soils in the field to determine how the emitted energy of soils is affected when more than one of the variables studied in this investigation is present under field conditions.

SELECTED BIBLIOGRAPHY

(1)  Barnes Engineering Company.  "Infra-Red and Electro-Optics."
         Instruction Manual for Model PRT-5 Precision Radiation Ther-
         mometer, Rev. April 1968, pp. 1-2.

(2)  Baver, Leonard D.  Soil Physics, 3rd ed.  New York:  Wiley, 1956,
         pp. 362-384.

(3)  Bouyoucos, George J.  "Soil Temperature."  Technical Bulletin,
         No. 26, Michigan Agricultural Experiment Station, East Lans-
         ing, Mich., January 1916, pp. 1-133.

(4)  Colwell, R. N.  "Determining the Prevalence of Certain Cereal Crop
         Diseases by Means of Aerial-Photography."  Hilgardia, Vol. 26,
         November 1956, pp. 223-286.

(5)  Colwell, R. N.  "Uses and Limitations of Multispectral Remote Sen-
         sing."  Proceedings of the Fourth Symposium on Remote Sensing
         of Environment, The University of Michigan, December 1966,
         pp. 71-100.

(6)  Elsharkawi, E. M.  "Water Relations of Some Grasses with Phrea-
         tophytic Properties."  Doctoral Thesis, Oklahoma State
         University, July 1968, pp. 55-71.

(7)  Estes, John E.  "Some Geographic Applications of Aerial Infrared
         Imagery."  Proceedings of the Fourth Symposium on Remote
         Sensing of Environment, The University of Michigan,
         December 1966, pp. 173-181.

(8)  Hackforth, L. M.  Infrared Radiation.  New York:  McGraw-Hill,
         1960, pp. 3-288.

(9)  Hammond, H. K. III and I. Nimeroff.  "Minimizing Anomalies in
         Reflectance Measurements with the Beckman Quartz Spectro-
         photometer."  Journal of the Optical Society of America,
         Vol. 42, No. 6, June 1952, pp. 367-372.

(10)  Harris, David E. and Caspar L. Woodbridge.  "Terrain Mapping by
         Use of Infrared Radiation."  Photogrammetric Engineering,
         Vol. 30, 1964, pp. 134-139.

(11)  Jamieson, John A., R. H. McFee, G. N. Plass, R. H. Grube and
         R. G. Richards.  Infrared Physics and Engineering.  New
         York:  McGraw-Hill, 1963, p. 673.

(12) Lagerwerff, J. V. and J. P. Holland. "Growth and Mineral Content
of Carrots and Beans as Related to Varying Osmotic and Ionic
Composition Effects in Saline and Sodic Sand Cultures."
Agron. Journal, Vol. 52, No. 10, October 1960, pp. 603-608.

(13) Molineux, C. E. "Aerial Reconnaissance of Surface Features with
the Multiband Spectral System." Proceedings of the Third
Symposium on Remote Sensing of Environment, The University
of Michigan, February 1965, pp. 399-421.

(14) Myers, V. I., D. L. Carter, and W. J. Rippert. "Remote Sensing
for Estimating Soil Salinity." Proceedings of American So-
ciety of Civil Engineers, Vol. 92, IR 4, December 1966,
pp. 59-68.

(15) Myers, V. I., L. R. Ussery, and W. J. Rippert. "Photogrammetry
for Detailed Detection of Drainage and Salinity Problems."
Transactions: American Society of Agricultural Engineers,
Vol. 6, 1963, pp. 332-334.

(16) Myers, V. I., C. L. Wiegand, M. D. Heilman, and J. R. Thomas.
"Remote Sensing in Soil and Water Conservation Research."
Proceedings of the Fourth Symposium on Remote Sensing of
Environment, The University of Michigan, December 1966,
pp. 801-813.

(17) Parker, Dana C. "Some Basic Considerations Related to the Prob-
lem of Remote Sensing." Proceedings of the First Symposium
on Remote Sensing of Environment, The University of Michigan,
February 1962, pp. 7-18.

(18) Pestrong, Raymond. "Multiband Photos for a Tidal Marsh." Photo-
grammetric Engineering, Vol. 35, No. 5, May 1969, pp. 453-470.

(19) Slayter, R. O. "Evapotranspiration in Relation to Soil Moisture."
Netherlands Journ. Agric. Sci., 1956, pp. 73-76.

(20) Suits, G. H. "The Nature of Infrared Radiation and Ways to Photo-
graph It." Photogrammetric Engineering, Vol. 26, 1960,
pp. 763-772.

(21) Thomas, J. R., V. I. Myers, M. D. Heilman, and C. L. Wiegand.
"Factors Affecting Light Reflectance of Cotton." Proceedings
of the Fourth Symposium on Remote Sensing of Environment, The
University of Michigan, December 1966, pp. 305-312.

(22) Wilde, S. A. and G. K. Woigt. Analysis of Soils and Plants for
Forestors and Horticulturists. Ann Arbor: J. W. Edwards
Publishers, Inc., 1955, p. 13.

APPENDIX A

## REFLECTANCE READINGS OF WHEAT GROWN IN SILTY CLAY AT VARIED LEVELS OF SALINITY

| Wave-length (mµ) | 0 ppm Level | | 2,000 ppm Level | | 4,000 ppm Level | | 6,000 ppm Level | | 8,000 ppm Level | | 10,000 ppm Level | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Max.% | Min.% | Max.% | Min.% | Max.% | Min.% | Max.% | Min.% | Max.% | Min.% | Max.% | Min.% |
| 200 | 7.8 | 7.7 | 7.9 | 7.7 | 7.8 | 7.5 | 7.9 | 7.6 | 7.5 | 7.8 | 7.5 | 7.5 |
| 250 | 7.3 | 7.0 | 7.3 | 7.4 | 7.2 | 7.1 | 7.2 | 7.0 | 7.3 | 7.1 | 7.2 | 7.1 |
| 300 | 4.6 | 4.5 | 4.6 | 4.5 | 4.6 | 4.7 | 4.5 | 4.5 | 4.5 | 4.4 | 4.5 | 4.4 |
| 350 | 3.5 | 3.4 | 3.5 | 3.5 | 3.6 | 3.5 | 3.5 | 3.6 | 3.5 | 3.5 | 3.3 | 3.4 |
| 400 | 4.7 | 5.1 | 4.5 | 4.6 | 4.7 | 4.5 | 4.5 | 4.9 | 4.6 | 4.9 | 4.8 | 4.4 |
| 450 | 6.5 | 7.1 | 6.4 | 7.1 | 6.4 | 7.1 | 6.4 | 6.9 | 6.8 | 6.4 | 6.9 | 6.3 |
| 500 | 8.5 | 8.3 | 8.5 | 8.5 | 8.4 | 8.5 | 8.5 | 8.3 | 8.4 | 8.4 | 8.4 | 8.6 |
| 550 | 19.0 | 18.5 | 17.5 | 17.7 | 17.5 | 17.0 | 16.7 | 16.0 | 15.4 | 15.1 | 14.9 | 15.1 |
| 600 | 14.7 | 14.1 | 14.2 | 14.1 | 14.1 | 13.8 | 14.0 | 13.9 | 13.9 | 13.7 | 13.5 | 13.0 |
| 650 | 16.0 | 9.2 | 9.1 | 9.1 | 9.0 | 8.7 | 8.7 | 8.9 | 8.6 | 8.4 | 8.5 | 8.4 |
| 700 | 21.0 | 21.6 | 18.0 | 17.8 | 17.9 | 17.2 | 17.5 | 16.9 | 17.1 | 16.7 | 16.7 | 16.0 |
| 750 | 53.0 | 51.9 | 51.0 | 50.6 | 50.1 | 50.0 | 47.0 | 47.2 | 46.5 | 46.8 | 46.5 | 46.1 |
| 800 | 52.4 | 51.7 | 50.9 | 50.6 | 50.7 | 50.1 | 49.0 | 48.0 | 47.0 | 47.0 | 46.6 | 46.0 |
| 850 | 52.0 | 51.3 | 50.1 | 49.7 | 49.7 | 49.2 | 48.0 | 47.1 | 46.3 | 46.1 | 46.0 | 45.4 |
| 900 | 51.2 | 49.7 | 48.9 | 48.6 | 48.1 | 47.4 | 46.5 | 46.0 | 45.8 | 45.0 | 45.3 | 44.7 |
| 950 | 51.0 | 49.2 | 47.9 | 46.0 | 47.0 | 47.0 | 46.0 | 44.7 | 44.4 | 43.7 | 43.9 | 43.0 |
| 1000 | 50.4 | 48.6 | 47.5 | 46.0 | 46.1 | 45.6 | 45.1 | 44.0 | 43.8 | 42.6 | 41.6 | 40.5 |

## REFLECTANCE READINGS OF SALT GRASS GROWN
## AT VARIED LEVELS OF SALINITY

| Wavelength (mμ) | Grown in Sand | | | | | | | | Grown in Silty Clay | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | 0 ppm Level | | 20,000 ppm Level | | 60,000 ppm Level | | 80,000 ppm Level | | 0 ppm Level | | 20,000 ppm Level | | 60,000 ppm Level | |
| | Max.% | Min.% | Max.% | Min.% | Max.% | Min.% | Max.% | Min.% | Max.% | Min.% | Max.% | Min.% | Max.% | Min.% |
| 200 | 7.1 | 7.2 | 7.2 | 7.4 | 7.4 | 7.7 | 7.1 | 7.3 | 7.4 | 7.1 | 7.3 | 7.1 | 7.4 | 7.6 |
| 250 | 5.6 | 6.0 | 5.8 | 6.2 | 6.1 | 6.6 | 6.5 | 6.8 | 6.0 | 5.4 | 5.8 | 5.3 | 5.2 | 5.5 |
| 300 | 4.5 | 4.1 | 4.3 | 4.1 | 4.6 | 4.5 | 4.5 | 4.1 | 4.4 | 4.2 | 4.4 | 4.0 | 4.1 | 4.3 |
| 350 | 3.2 | 3.0 | 3.5 | 3.1 | 3.5 | 3.0 | 3.6 | 3.2 | 3.4 | 3.1 | 3.2 | 3.0 | 3.5 | 3.1 |
| 400 | 5.1 | 4.6 | 4.8 | 5.1 | 5.0 | 4.7 | 5.5 | 5.2 | 5.5 | 4.5 | 5.7 | 5.4 | 5.9 | 5.4 |
| 450 | 7.0 | 6.4 | 7.0 | 6.2 | 6.5 | 6.2 | 6.8 | 7.0 | 7.0 | 6.2 | 7.1 | 6.5 | 7.3 | 7.5 |
| 500 | 9.3 | 9.0 | 8.9 | 8.6 | 8.5 | 8.0 | 8.9 | 9.1 | 9.4 | 9.1 | 8.8 | 9.0 | 9.0 | 8.7 |
| 550 | 15.3 | 15.0 | 14.9 | 14.7 | 15.1 | 14.8 | 14.2 | 14.6 | 16.2 | 16.4 | 15.5 | 16.0 | 15.1 | 15.8 |
| 600 | 10.7 | 10.0 | 9.8 | 9.7 | 10.0 | 9.6 | 10.0 | 9.5 | 10.1 | 10.5 | 10.2 | 10.3 | 10.1 | 10.3 |
| 650 | 8.6 | 8.5 | 7.7 | 7.7 | 7.8 | 7.2 | 7.5 | 7.4 | 8.7 | 8.9 | 8.6 | 8.1 | 8.5 | 8.7 |
| 700 | 18.3 | 18.0 | 15.2 | 14.5 | 15.0 | 14.1 | 15.0 | 14.6 | 17.8 | 17.5 | 17.2 | 17.5 | 17.5 | 17.1 |
| 750 | 48.0 | 46.5 | 45.9 | 43.3 | 44.0 | 43.2 | 42.5 | 42.0 | 48.2 | 46.0 | 43.9 | 42.4 | 41.9 | 40.7 |
| 800 | 50.4 | 48.3 | 46.8 | 44.8 | 45.0 | 44.5 | 44.0 | 44.3 | 48.9 | 46.5 | 45.5 | 43.5 | 43.7 | 42.5 |
| 850 | 49.3 | 45.7 | 46.6 | 45.0 | 45.5 | 44.7 | 43.1 | 43.4 | 50.5 | 48.1 | 46.4 | 44.6 | 44.3 | 42.6 |
| 900 | 48.5 | 46.0 | 44.0 | 43.8 | 43.7 | 43.0 | 42.2 | 42.5 | 48.4 | 46.3 | 45.3 | 44.0 | 43.2 | 42.5 |
| 950 | 46.8 | 44.6 | 42.2 | 41.7 | 42.0 | 41.1 | 41.0 | 41.2 | 46.2 | 44.7 | 44.0 | 43.2 | 42.5 | 41.0 |
| 1000 | 45.4 | 44.2 | 39.7 | 40.1 | 40.0 | 39.2 | 37.7 | 37.0 | 44.4 | 43.0 | 41.7 | 40.0 | 39.0 | 38.1 |

# RELATIVE TURGIDITY OF VEGETATION

## Wheat Grown in Silty Clay

| Salt in ppm | Relative Turgidity |
|---|---|
| 0 | 98.5% |
| 2,000 | 96.3% |
| 4,000 | 94.0% |
| 6,000 | 93.5% |
| 8,000 | 92.3% |
| 10,000 | 90.3% |

## Salt Grass Grown in Sand Mixture

| Salt in ppm | Relative Turgidity |
|---|---|
| 0 | 97.2% |
| 20,000 | 95.2% |
| 60,000 | 92.0% |
| 100,000 | 90.1% |

## Salt Grass Grown in Silty Clay

| Salt in ppm | Relative Turgidity |
|---|---|
| 0 | 97.2% |
| 20,000 | 93.5% |
| 60,000 | 91.0% |

APPENDIX B

APPENDIX TERMS

Salt in ppm . . . . . . . . . . . . . . . . Parts Per Million

Ambient Temperature . . . . . . . . . . . . Degrees Centigrade

Meteorological Conditions . . . . . . . . . PC - Partly Cloudy
                                            R  - Rain
                                            C  - Clear
                                            O  - Overcast

Emitted Energy . . . . . . . . . . . . . . . $(mw\text{-}cm^2\text{-}ster)$

EMITTED ENERGY OF SAND WITH VARIANCE
IN MOISTURE AND SALINITY

| Date | Time | Ambient Temp. | Met. Cond. | EMITTED ENERGY Salt Content in ppm | | | | | | | |
|------|------|---------------|------------|-----|--------|--------|--------|--------|---------|---------|---------|
| | | | | 0 | 20,000 | 40,000 | 60,000 | 80,000 | 100,000 | 130,000 | 160,000 |
| 9-21-68 | 5:00 | 14.3 | C | 4.70 | 4.71 | 4.71 | 4.71 | 4.72 | 4.77 | 4.77 | 4.71 |
| | 8:00 | 14.3 | C | 4.71 | 4.71 | 4.71 | 4.72 | 4.72 | 4.77 | 4.78 | 4.72 |
| | 10:00 | 24.1 | C | 4.90 | 4.80 | 4.90 | 4.91 | 4.91 | 4.91 | 4.91 | 4.93 |
| | 12:00 | 25.5 | PC | 5.10 | 4.98 | 5.14 | 5.18 | 5.15 | 5.14 | 5.14 | 5.16 |
| | 14:00 | 27.2 | C | 5.26 | 5.21 | 5.29 | 5.31 | 5.30 | 5.30 | 5.30 | 5.31 |
| | 16:00 | 27.4 | C | 5.42 | 5.32 | 5.35 | 5.37 | 5.37 | 5.29 | 5.29 | 5.29 |
| | 19:00 | 22.2 | C | 5.45 | 5.40 | 5.39 | 5.37 | 5.38 | 5.32 | 5.33 | 5.32 |
| | 24:00 | 17.0 | R | 5.44 | 5.43 | 5.41 | 5.40 | 5.39 | 5.36 | 5.36 | 5.35 |
| 9-22-68 | 5:00 | 10.8 | C | 5.15 | 5.15 | 5.12 | 5.10 | 5.12 | 5.08 | 5.09 | 5.09 |
| | 8:00 | 10.6 | C | 5.15 | 5.12 | 5.12 | 5.15 | 5.20 | 5.24 | 5.28 | 5.29 |
| | 10:00 | 17.8 | C | 5.56 | 5.60 | 5.60 | 5.61 | 5.61 | 5.62 | 5.63 | 5.64 |
| | 12:00 | 19.8 | C | 5.65 | 5.70 | 5.70 | 5.76 | 5.76 | 5.72 | 5.72 | 5.76 |
| | 14:00 | 20.2 | C | 5.02 | 5.04 | 5.03 | 5.09 | 5.14 | 5.09 | 5.09 | 5.15 |
| | 16:00 | 20.2 | C | 5.04 | 5.02 | 5.01 | 5.02 | 5.07 | 5.01 | 5.04 | 5.05 |
| | 19:00 | 14.8 | C | 4.78 | 4.78 | 4.79 | 4.80 | 4.80 | 4.78 | 4.80 | 4.81 |
| | 24:00 | 8.2 | C | 4.55 | 4.57 | 4.59 | 4.60 | 4.60 | 4.60 | 4.60 | 4.61 |
| 9-23-68 | 5:00 | 7.2 | C | 4.47 | 4.47 | 4.47 | 4.48 | 4.48 | 4.48 | 4.48 | 4.48 |
| | 8:00 | 8.0 | C | 4.45 | 4.45 | 4.46 | 4.46 | 4.46 | 4.46 | 4.47 | 4.47 |
| | 12:00 | 19.4 | O | 4.76 | 4.77 | 4.77 | 4.80 | 4.81 | 4.81 | 4.82 | 4.84 |
| | 14:00 | 19.0 | O | 4.85 | 4.86 | 4.86 | 4.88 | 4.89 | 4.90 | 4.90 | 4.91 |
| | 16:00 | 16.4 | O | 4.81 | 4.85 | 4.84 | 4.85 | 4.87 | 4.85 | 4.86 | 4.87 |
| | 19:00 | 12.4 | C | 4.71 | 4.71 | 4.71 | 4.71 | 4.74 | 4.74 | 4.74 | 4.73 |
| | 24:00 | 8.9 | C | 4.53 | 4.53 | 4.53 | 4.53 | 4.53 | 4.53 | 4.53 | 4.53 |
| 9-24-68 | 5:00 | 5.8 | C | 4.42 | 4.42 | 4.42 | 4.42 | 4.44 | 4.44 | 4.44 | 4.44 |
| | 8:00 | 5.1 | C | 4.36 | 4.36 | 4.36 | 4.37 | 4.37 | 4.38 | 4.37 | 4.40 |
| | 12:00 | 13.0 | PC | 4.81 | 4.84 | 4.85 | 4.85 | 4.85 | 4.81 | 4.82 | 4.84 |
| | 14:00 | 14.5 | PC | 4.86 | 4.86 | 4.86 | 4.88 | 4.90 | 4.92 | 4.91 | 4.92 |
| | 16:00 | 16.0 | C | 4.81 | 4.85 | 4.85 | 4.85 | 4.90 | 4.87 | 4.91 | 4.92 |
| | 19:00 | 11.4 | C | 4.64 | 4.67 | 4.67 | 4.68 | 4.68 | 4.67 | 4.68 | 4.68 |
| | 24:00 | 5.8 | C | 4.47 | 4.47 | 4.48 | 4.48 | 4.50 | 4.51 | 4.51 | 4.52 |
| 9-25-68 | 5:00 | 3.3 | C | 4.35 | 4.36 | 4.36 | 4.36 | 4.36 | 4.36 | 4.36 | 4.36 |
| | 8:00 | 4.4 | C | 4.34 | 4.34 | 4.34 | 4.34 | 4.34 | 4.34 | 4.35 | 4.34 |
| | 12:00 | 21.0 | C | 4.91 | 4.96 | 4.96 | 5.00 | 5.01 | 5.05 | 5.04 | 5.05 |
| | 14:00 | 23.0 | C | 5.14 | 5.20 | 5.20 | 5.24 | 5.26 | 5.26 | 5.28 | 5.28 |
| | 16:00 | 24.6 | C | 5.39 | 5.40 | 5.37 | 5.38 | 5.40 | 5.36 | 5.35 | 5.44 |
| | 19:00 | 17.0 | C | 5.36 | 5.39 | 5.37 | 5.37 | 5.37 | 5.37 | 5.36 | 5.40 |
| | 24:00 | 10.4 | C | 5.21 | 5.21 | 5.21 | 5.24 | 5.28 | 5.30 | 5.31 | 5.34 |
| 9-26-68 | 8:00 | 6.2 | C | 4.42 | 4.42 | 4.42 | 4.43 | 4.43 | 4.43 | 4.43 | 4.43 |
| | 12:00 | 26.0 | C | 5.04 | 5.04 | 5.04 | 5.08 | 5.07 | 5.12 | 5.11 | 5.12 |
| | 14:00 | 28.2 | C | 5.28 | 5.27 | 5.27 | 5.34 | 5.37 | 5.37 | 5.42 | 5.42 |
| | 16:00 | 30.0 | C | 5.20 | 5.24 | 5.22 | 5.26 | 5.27 | 5.26 | 5.34 | 5.34 |
| | 19:00 | 20.0 | C | 4.93 | 4.95 | 4.95 | 4.96 | 5.03 | 5.03 | 5.04 | 5.05 |
| | 24:00 | 17.8 | C | 4.78 | 4.78 | 4.80 | 4.82 | 4.84 | 4.86 | 4.85 | 4.84 |

EMITTED ENERGY OF SILTY CLAY WITH VARIANCE
IN MOISTURE AND SALINITY

| Date | Time | Ambient Temp. | Met. Cond. | EMITTED ENERGY Salt Content in ppm | | | | | | | |
|------|------|------|------|------|------|------|------|------|------|------|------|
| | | | | 0 | 20,000 | 40,000 | 60,000 | 80,000 | 100,000 | 130,000 | 160,000 |
| 9-21-68 | 5:00 | 14.3 | C | 4.70 | 4.71 | 4.71 | 4.71 | 4.71 | 4.71 | 4.71 | 4.72 |
| | 8:00 | 14.3 | C | 4.71 | 4.71 | 4.71 | 4.71 | 4.71 | 4.70 | 4.71 | 4.72 |
| | 10:00 | 24.1 | C | 4.87 | 4.89 | 4.90 | 4.92 | 4.93 | 4.92 | 4.95 | 4.94 |
| | 12:00 | 25.5 | PC | 5.08 | 5.10 | 5.07 | 5.12 | 5.16 | 5.16 | 5.18 | 5.18 |
| | 14:00 | 27.2 | C | 5.25 | 5.30 | 5.26 | 5.30 | 5.30 | 5.30 | 5.34 | 5.30 |
| | 16:00 | 27.4 | C | 5.64 | 5.69 | 5.58 | 5.60 | 5.55 | 5.56 | 5.56 | 5.60 |
| | 19:00 | 22.2 | C | 5.77 | 5.75 | 5.68 | 5.68 | 5.64 | 5.60 | 5.63 | 5.57 |
| | 24:00 | 17.0 | R | 5.52 | 5.49 | 5.49 | 5.50 | 5.50 | 5.50 | 5.40 | 5.50 |
| 9-22-68 | 5:00 | 10.8 | C | 5.37 | 5.37 | 5.35 | 5.35 | 5.30 | 5.30 | 5.26 | 5.21 |
| | 8:00 | 10.6 | C | 5.35 | 5.33 | 5.30 | 5.29 | 5.25 | 5.24 | 5.21 | 5.22 |
| | 10:00 | 17.8 | C | 5.60 | 5.57 | 5.60 | 5.64 | 5.64 | 5.63 | 5.64 | 5.64 |
| | 12:00 | 19.8 | C | 5.64 | 5.68 | 5.68 | 5.72 | 5.73 | 5.68 | 4.76 | 5.75 |
| | 14:00 | 20.2 | C | 4.89 | 5.03 | 4.96 | 5.04 | 4.95 | 5.00 | 5.09 | 5.16 |
| | 16:00 | 20.2 | C | 4.97 | 5.10 | 5.03 | 5.15 | 5.08 | 5.06 | 5.20 | 5.22 |
| | 19:00 | 14.8 | C | 4.72 | 4.80 | 4.75 | 4.82 | 4.78 | 4.82 | 4.85 | 4.88 |
| | 24:00 | 8.2 | C | 4.55 | 4.57 | 4.57 | 4.55 | 4.58 | 4.60 | 4.61 | 4.60 |
| 9-23-68 | 5:00 | 7.2 | C | 4.45 | 4.45 | 4.44 | 4.47 | 4.47 | 4.47 | 4.50 | 4.50 |
| | 8:00 | 8.0 | C | 4.42 | 4.43 | 4.42 | 4.43 | 4.45 | 4.44 | 4.45 | 4.46 |
| | 12:00 | 19.4 | O | 4.75 | 4.76 | 4.75 | 4.75 | 4.76 | 4.76 | 4.80 | 4.81 |
| | 14:00 | 19.0 | O | 4.80 | 4.87 | 4.83 | 4.86 | 4.89 | 4.89 | 4.90 | 4.93 |
| | 16:00 | 16.4 | O | 4.75 | 4.82 | 4.80 | 4.85 | 4.87 | 4.85 | 4.86 | 4.89 |
| | 19:00 | 12.4 | C | 4.65 | 4.70 | 4.67 | 4.72 | 4.72 | 4.72 | 4.75 | 4.75 |
| | 24:00 | 8.9 | C | 4.52 | 4.55 | 4.54 | 4.56 | 4.56 | 4.56 | 4.56 | 4.57 |
| 9-24-68 | 5:00 | 5.8 | C | 4.41 | 4.42 | 4.41 | 4.44 | 4.45 | 4.43 | 4.42 | 4.42 |
| | 8:00 | 5.1 | C | 4.36 | 4.37 | 4.37 | 4.37 | 4.39 | 4.44 | 4.40 | 4.40 |
| | 12:00 | 13.0 | PC | 4.75 | 4.81 | 4.78 | 4.83 | 4.82 | 4.84 | 4.87 | 4.87 |
| | 14:00 | 14.5 | PC | 4.80 | 4.88 | 4.95 | 4.88 | 4.91 | 4.91 | 4.96 | 4.93 |
| | 16:00 | 16.0 | C | 4.84 | 4.94 | 4.96 | 4.96 | 4.88 | 4.92 | 4.92 | 5.00 |
| | 19:00 | 11.4 | C | 4.60 | 4.65 | 4.63 | 4.67 | 4.70 | 4.67 | 4.70 | 4.72 |
| | 24:00 | 5.8 | C | 4.44 | 4.47 | 4.47 | 4.50 | 4.50 | 4.50 | 4.50 | 4.50 |
| 9-25-68 | 5:00 | 3.3 | C | 4.32 | 4.32 | 4.32 | 4.33 | 4.36 | 4.36 | 4.36 | 4.36 |
| | 8:00 | 4.4 | C | 4.32 | 4.32 | 4.31 | 4.32 | 4.32 | 4.32 | 4.32 | 4.32 |
| | 12:00 | 21.0 | C | 4.93 | 4.98 | 4.95 | 4.96 | 5.02 | 5.02 | 5.02 | 5.08 |
| | 14:00 | 23.0 | C | 5.12 | 5.27 | 5.21 | 5.30 | 5.26 | 5.34 | 5.35 | 5.31 |
| | 16:00 | 24.6 | C | 5.64 | 5.72 | 5.68 | 5.77 | 5.73 | 5.75 | 5.76 | 5.75 |
| | 19:00 | 17.0 | C | 5.50 | 5.60 | 5.58 | 5.57 | 5.56 | 5.56 | 5.56 | 5.56 |
| | 24:00 | 10.4 | C | 5.32 | 5.37 | 5.30 | 5.37 | 5.34 | 5.35 | 5.37 | 5.36 |
| 9-26-68 | 8:00 | 6.2 | C | 4.41 | 4.41 | 4.41 | 4.44 | 4.43 | 4.43 | 4.44 | 4.44 |
| | 12:00 | 26.0 | C | 5.04 | 5.10 | 5.08 | 5.10 | 5.09 | 5.10 | 5.10 | 5.15 |
| | 14:00 | 28.2 | C | 5.21 | 5.40 | 5.26 | 5.39 | 5.34 | 5.40 | 5.43 | 5.36 |
| | 16:00 | 30.0 | C | 5.24 | 5.42 | 5.32 | 5.44 | 5.36 | 5.46 | 5.49 | 5.45 |
| | 19:00 | 20.0 | C | 4.89 | 5.00 | 5.32 | 5.04 | 5.06 | 5.08 | 5.08 | 5.07 |
| | 24:00 | 17.8 | C | 4.76 | 4.82 | 4.79 | 4.85 | 4.85 | 4.86 | 4.88 | 4.87 |

# MOISTURE VARIATION IN SOILS

## Silty Clay

| Salt in ppm | PERCENT OF MOISTURE CONTENT | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| | Sept. 20 | Sept. 21 | Sept. 22 | Sept. 23 | Sept. 24 | Sept. 25 | Sept. 26 | Sept. 27 |
| 0 | 36.10 | 26.0 | 21.5 | 18.24 | 15.748 | 13.2 | 11.248 | 9.748 |
| 20,000 | 36.00 | 27.752 | 24.25 | 21.00 | 19.748 | 18.2 | 15.748 | 14.248 |
| 40,000 | 36.25 | 29.0 | 26.748 | 25.0 | 23.748 | 21.5 | 19.248 | 17.8 |
| 60,000 | 36.12 | 30.248 | 28.748 | 27.0 | 25.75 | 24.3 | 21.748 | 20.0 |
| 80,000 | 36.00 | 31.748 | 29.0 | 28.5 | 27.25 | 26.5 | 23.75 | 22.25 |
| 100,000 | 35.88 | 33.248 | 32.0 | 29.248 | 28.248 | 26.748 | 24.5 | 22.5 |
| 130,000 | 36.05 | 34.248 | 32.248 | 31.248 | 30.748 | 30.248 | 28.748 | 26.5 |
| 160,000 | 36.12 | 34.0 | 33.0 | 32.0 | 31.20 | 30.0 | 28.5 | 27.0 |

## Sand

| Salt in ppm | PERCENT OF MOISTURE CONTENT | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| | Sept. 20 | Sept. 21 | Sept. 22 | Sept. 23 | Sept. 24 | Sept. 25 | Sept. 26 | Sept. 27 |
| 0 | 18.05 | 15.625 | 14.061 | 13.194 | 12.321 | 11.283 | 9.89 | 8.53 |
| 20,000 | 18.05 | 15.8 | 14.408 | 13.366 | 12.50 | 11.458 | 10.009 | 9.76 |
| 40,000 | 18.23 | 16.319 | 14.933 | 14.063 | 13.369 | 12.675 | 11.458 | 10.51 |
| 60,000 | 18.12 | 16.75 | 15.277 | 14.411 | 13.88 | 12.847 | 11.630 | 10.76 |
| 80,000 | 18.05 | 17.013 | 15.625 | 14.583 | 14.063 | 13.019 | 12.327 | 11.286 |
| 100,000 | 18.25 | 17.361 | 15.80 | 14.933 | 14.411 | 13.369 | 12.5 | 11.286 |
| 130,000 | 18.00 | 17.42 | 16.147 | 15.452 | 14.758 | 14.063 | 13.194 | 11.98 |
| 160,000 | 18.05 | 17.5 | 16.4 | 15.625 | 15.105 | 14.408 | 13.54 | 12.5 |

APPENDIX C

EMITTANCE MEASUREMENTS OF CHANGING WATER TABLE
FOR SILTY CLAY WITH NON-SALINE WATER

| | | | | EMITTED ENERGY | | | | |
| | | | | | | Water Level | | |
| Date | Time | Ambient Temp. | Met. Cond. | 0 ft. | 1 ft. | 2 ft. | 3 ft. | 4 ft. |
|------|------|---------------|------------|-------|-------|-------|-------|-------|
| 5-9-69 | 5:30 | 10.2 | C | 3.36 | 3.39 | 3.36 | 3.39 | 3.37 |
| | 8:30 | 13.0 | C | 3.36 | 3.46 | 3.36 | 3.42 | 3.38 |
| | 10:00 | 21.0 | C | 3.90 | 4.18 | 4.54 | 5.04 | 5.08 |
| | 13:00 | 24.4 | C | 4.72 | 4.82 | 6.48 | 6.48 | 6.55 |
| | 16:00 | 26.0 | C | 4.51 | 4.67 | 6.16 | 6.36 | 6.49 |
| | 20:30 | 20.6 | C | 4.03 | 4.18 | 4.30 | 4.34 | 4.27 |
| | 24:00 | 16.4 | C | 3.78 | 3.81 | 3.87 | 3.85 | 3.85 |
| 5-10-69 | 5:30 | 15.8 | C | 3.58 | 3.58 | 3.57 | 3.57 | 3.57 |
| | 8:30 | 16.8 | O | 3.64 | 3.64 | 3.78 | 3.78 | 3.78 |
| | 10:00 | 17.8 | C | 3.90 | 3.93 | 4.30 | 4.36 | 4.36 |
| | 13:00 | 23.8 | C | 4.57 | 4.85 | 5.89 | 6.08 | 4.16 |
| | 16:00 | 21.4 | C | 4.37 | 4.64 | 5.30 | 5.07 | 5.08 |
| | 20:30 | 17.5 | C | 3.90 | 4.06 | 4.09 | 4.10 | 3.94 |
| | 24:00 | 14.2 | C | 3.69 | 3.68 | 3.46 | 3.43 | 3.42 |
| 5-11-69 | 5:30 | 12.6 | C | 3.52 | 3.52 | 3.40 | 3.48 | 3.38 |
| | 11:30 | 23.0 | PC | 4.10 | 4.50 | 5.30 | 5.39 | 5.49 |
| | 13:00 | 24.0 | C | 4.40 | 4.80 | 6.11 | 6.07 | 6.36 |
| | 16:00 | 26.8 | C | 4.48 | 4.96 | 6.19 | 6.28 | 6.36 |
| | 20:30 | 23.1 | PC | 4.27 | 4.44 | 4.56 | 4.56 | 4.56 |
| | 24:00 | 18.8 | C | 4.20 | 4.22 | 4.22 | 4.14 | 4.13 |
| 5-12-69 | 6:00 | 14.7 | C | 4.04 | 3.92 | 3.74 | 3.68 | 3.64 |
| | 8 30 | 18.3 | C | 3.90 | 4.08 | 3.84 | 3.88 | 3.84 |
| | 10:00 | 23.0 | C | 4.32 | 4.76 | 4.78 | 5.38 | 5.42 |
| | 13:00 | 29.4 | C | 5.00 | 5.42 | 7.50 | 7.55 | 7.60 |
| | 16:00 | 31.7 | C | 4.88 | 5.54 | 6.82 | 6.95 | 7.28 |
| | 20:30 | 22.0 | C | 4.30 | 4.58 | 4.60 | 4.56 | 4.56 |
| | 24:00 | 20.5 | C | 4.16 | 4.20 | 4.27 | 4.31 | 4.31 |
| 5-13-69 | 6:00 | 18.5 | C | 3.96 | 3.96 | 4.04 | 3.96 | 3.91 |
| | 8:30 | -- | R | -- | -- | -- | -- | -- |
| | 10:00 | 19.5 | O | 4.10 | 4.16 | 4.23 | 4.34 | 4.30 |
| | 13:00 | 26.0 | O | 4.40 | 4.72 | 5.15 | 3.30 | 5.35 |
| | 16:00 | 29.9 | C | 4.92 | 5.44 | 6.70 | 6.85 | 7.02 |
| | 20:30 | 24.1 | C | 4.50 | 4.58 | 4.70 | 4.66 | 4.66 |
| | 24:00 | 20.4 | O | 4.12 | 4.16 | 4.29 | 4.26 | 4.26 |

EMITTANCE MEASUREMENTS OF CHANGING WATER TABLE
FOR SAND WITH NON-SALINE WATER

| Date | Time | Ambient Temp. | Met. Cond. | EMITTED ENERGY Water Level | | | | |
| | | | | 0 ft. | 1 ft. | 2 ft. | 3 ft. | 4 ft. |
|------|------|---------------|------------|-------|-------|-------|-------|-------|
| 5-19-69 | 6:00 | 12.6 | C | 3.64 | 3.36 | 3.36 | 3.36 | 3.36 |
| | 8:30 | 18.0 | C | 3.84 | 3.50 | 3.50 | 3.50 | 3.50 |
| | 10:00 | 19.9 | C | 4.16 | 4.60 | 4.51 | 4.51 | 4.58 |
| | 13:00 | 27.7 | C | 5.00 | 6.00 | 6.12 | 6.20 | 6.24 |
| | 16:00 | 29.7 | C | 4.84 | 6.00 | 6.08 | 6.28 | 6.52 |
| | 20:30 | 24.1 | C | 4.50 | 4.54 | 4.58 | 4.58 | 4.58 |
| | 24:00 | 20.2 | C | 4.30 | 4.16 | 4.20 | 4.20 | 4.20 |
| 5-20-69 | 6:20 | 18.3 | C | 4.10 | 3.84 | 3.88 | 3.88 | 3.88 |
| | 10:00 | 26.7 | C | 4.40 | 5.22 | 5.22 | 5.30 | 5.30 |
| | 13:00 | 28.0 | C | 4.95 | 5.92 | 6.08 | 6.12 | 6.36 |
| | 16:00 | 29.0 | PC | 4.75 | 5.53 | 5.70 | 5.70 | 5.78 |
| | 20:30 | 25.2 | C | 4.50 | 4.58 | 4.63 | 4.60 | 4.65 |
| | 24:00 | 22.5 | C | 4.32 | 4.44 | 4.50 | 4.46 | 4.50 |
| 5-21-69 | 6:00 | 20.0 | C | 4.16 | 3.97 | 3.94 | 3.99 | 4.00 |
| | 8:30 | 23.0 | C | 4.23 | 4.16 | 4.12 | 4.09 | 4.11 |
| | 10:00 | 27.0 | C | 4.40 | 5.15 | 5.18 | 5.22 | 5.31 |
| | 13:00 | 32.6 | C | 5.04 | 6.66 | 6.82 | 6.82 | 6.90 |
| | 16:00 | 32.6 | C | 5.11 | 6.61 | 6.70 | 6.82 | 6.90 |
| | 20:30 | 26.2 | C | 4.58 | 4.71 | 4.80 | 4.80 | 4.78 |
| | 24:00 | 20.4 | C | 4.41 | 4.28 | 4.27 | 4.27 | 4.23 |
| 5-22-69 | 6:00 | 17.0 | PC | 4.12 | 4.02 | 4.04 | 4.00 | 4.01 |
| | 8:30 | 15.0 | O | 3.97 | 3.93 | 3.94 | 3.90 | 3.90 |
| | 10:00 | 16.2 | O | 3.97 | 3.97 | 3.97 | 3.93 | 3.94 |
| | 13:00 | 20.2 | O | 4.27 | 4.70 | 4.65 | 4.69 | 4.70 |
| | 16:00 | 18.0 | PC | 4.32 | 4.54 | 4.42 | 4.32 | 4.32 |
| | 20:30 | 15.6 | C | 4.09 | 4.16 | 4.09 | 3.96 | 3.96 |
| | 24:00 | 13.0 | C | 4.05 | 4.16 | 4.01 | 4.01 | 4.01 |
| 5-23-69 | 6:30 | 13.0 | C | 4.09 | 4.28 | 4.01 | 4.01 | 4.01 |
| | 8:30 | 14.0 | C | 4.16 | 4.23 | 4.09 | 4.09 | 4.09 |
| | 10:00 | 18.8 | C | 4.36 | 4.64 | 4.64 | 4.62 | 4.62 |
| | 13:00 | 19.0 | C | 4.64 | 5.19 | 5.15 | 5.15 | 5.15 |
| | 16:00 | 22.8 | C | 5.15 | 5.46 | 5.60 | 5.46 | 5.46 |
| | 20:30 | 18.8 | C | 4.71 | 4.77 | 4.78 | 4.85 | 4.77 |
| | 24:00 | 18.0 | C | 4.36 | 4.36 | 4.44 | 4.32 | 4.32 |
| 5-24-69 | 6:30 | 15.8 | C | 4.12 | 4.31 | 4.40 | 4.16 | 4.16 |
| | 8:30 | 19.4 | C | 5.03 | 5.26 | 5.15 | 5.15 | 5.15 |
| | 10:00 | 20.8 | C | 5.07 | 5.52 | 5.52 | 5.60 | 5.60 |
| | 13:00 | 29.4 | C | 6.23 | 6.66 | 6.66 | 7.08 | 7.24 |
| | 16:00 | 25.0 | C | 5.66 | 5.85 | 6.00 | 6.15 | 6.23 |
| | 20:30 | 19.2 | C | 4.81 | 5.00 | 5.04 | 5.00 | 5.00 |
| | 24:00 | 18.4 | C | 4.28 | 4.50 | 4.58 | 4.50 | 4.50 |

APPENDIX D

EMITTANCE MEASUREMENTS OF CHANGING WATER TABLE
FOR SAND WITH SALINE WATER

| Water Level | Date | Time | Ambient Temp. | Met. Cond. | EMITTED ENERGY Salt Content in ppm | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | | | | | 160,000 | 100,000 | 60,000 | 20,000 | 0 |
| 4 ft. | 5-30-69 | 6:00 | 20.6 | PC | 4.00 | 3.96 | 4.03 | 3.96 | 4.02 |
| | | 8:30 | 24.6 | PC | 4.44 | 4.44 | 4.47 | 4.49 | 4.54 |
| | | 10:00 | 27.6 | C | 4.84 | 5.22 | 5.32 | 5.46 | 5.56 |
| | | 13:00 | 33.4 | C | 6.74 | 6.96 | 6.90 | 7.08 | 7.08 |
| | | 16:00 | 35.4 | C | 6.90 | 7.05 | 7.08 | 7.18 | 7.18 |
| | | 20:30 | 28.4 | C | 4.96 | 5.01 | 5.00 | 5.00 | 5.13 |
| | | 24:00 | 24.0 | C | 4.40 | 4.36 | 4.39 | 4.37 | 4.39 |
| 4 ft. | 5-31-69 | 6:00 | 21.0 | PC | 4.08 | 4.06 | 4.07 | 4.06 | 4.06 |
| | | 8:30 | 26.0 | PC | 4.54 | 4.55 | 4.53 | 4.54 | 4.54 |
| | | 10:00 | 25.0 | O | 4.54 | 4.54 | 4.54 | 4.58 | 4.55 |
| | | 13:00 | 32.6 | C | 7.05 | 6.96 | 6.90 | 7.00 | 6.88 |
| | | 16:00 | 34.8 | C | 7.87 | 8.00 | 7.96 | 7.96 | 8.00 |
| | | 20:30 | 28.0 | C | 4.78 | 4.74 | 4.75 | 4.78 | 4.77 |
| | | 24:00 | 26.5 | C | 4.58 | 4.56 | 4.58 | 4.58 | 4.58 |
| 3 ft. | 6-1-69 | 6:00 | 15.0 | PC | 3.80 | 3.80 | 3.90 | 3.94 | 3.90 |
| | | 8:30 | 16.0 | C | 3.84 | 3.94 | 3.98 | 4.10 | 4.10 |
| | | 10:00 | 17.5 | C | 3.96 | 4.09 | 4.10 | 4.30 | 4.30 |
| | | 13:00 | 23.5 | C | 4.78 | 4.92 | 5.08 | 5.22 | 5.22 |
| | | 16:00 | 26.0 | C | 5.00 | 5.38 | 5.46 | 5.60 | 5.64 |
| | | 20:30 | 24.0 | C | 4.10 | 4.15 | 4.15 | 4.14 | 4.14 |
| | | 24:00 | 16.0 | C | 3.90 | 3.94 | 3.90 | 3.94 | 3.94 |
| 3 ft. | 6-2-69 | 6:00 | 15.0 | C | 3.76 | 3.80 | 3.80 | 3.86 | 3.90 |
| | | 8:30 | 15.5 | C | 3.76 | 3.84 | 3.84 | 3.90 | 3.90 |
| | | 10:00 | 17.5 | C | 4.10 | 4.36 | 4.50 | 4.58 | 4.58 |
| | | 13:00 | 28.0 | C | 6.04 | 6.40 | 6.48 | 6.56 | 6.52 |
| | | 16:00 | 26.0 | C | 5.96 | 6.00 | 5.98 | 5.98 | 5.92 |
| | | 20:30 | 20.5 | C | 4.36 | 4.36 | 4.44 | 4.48 | 4.46 |
| | | 24:00 | 17.0 | C | 3.90 | 3.90 | 3.95 | 3.90 | 3.98 |
| 2 ft. | 6-3-69 | 6:00 | 14.0 | O | 3.48 | 3.46 | 3.44 | 3.44 | 3.48 |
| | | 8:30 | 17.5 | O | 3.96 | 3.96 | 3.94 | 3.96 | 3.93 |
| | | 10:00 | 23.0 | O | 4.32 | 4.40 | 4.40 | 4.40 | 4.27 |
| | | 13:00 | 26.0 | PC | 5.01 | 5.12 | 5.18 | 5.22 | 5.22 |
| | | 16:00 | 27.0 | C | 5.46 | 5.47 | 5.49 | 5.52 | 5.48 |
| | | 20:30 | 19.8 | C | 4.18 | 4.19 | 4.22 | 4.20 | 4.20 |
| | | 24:00 | 16.5 | C | 3.92 | 3.96 | 3.96 | 3.98 | 4.00 |
| 2 ft. | 6-4-69 | 6:00 | 15.0 | C | 3.78 | 3.84 | 3.84 | 3.90 | 3.90 |
| | | 8:30 | 16.0 | C | 3.88 | 3.88 | 3.88 | 3.93 | 3.93 |
| | | 10:00 | 19.0 | C | 4.51 | 4.57 | 4.64 | 4.71 | 4.71 |
| | | 13:00 | 27.0 | C | 5.60 | 5.70 | 5.70 | 5.74 | 5.79 |
| | | 16:00 | 31.0 | C | 5.92 | 6.00 | 6.00 | 6.00 | 6.00 |
| | | 20:30 | 23.0 | C | 4.51 | 4.57 | 4.57 | 4.48 | 4.57 |
| | | 24:00 | 17.0 | C | 4.10 | 4.03 | 4.03 | 4.03 | 4.10 |

| Water Level | Date | Time | Ambient Temp. | Met. Cond. | EMITTED ENERGY Salt Content in ppm 160,000 | 100,000 | 60,000 | 20,000 | 0 |
|---|---|---|---|---|---|---|---|---|---|
| 2 ft. | 6-5-69 | 6:00 | 16.0 | C | 3.78 | 3.68 | 3.78 | 3.74 | 3.78 |
| | | 8:30 | 20.0 | C | 3.93 | 3.92 | 3.94 | 3.96 | 3.96 |
| | | 10:00 | 25.0 | C | 5.03 | 5.07 | 5.03 | 5.00 | 4.98 |
| | | 13:00 | 33.4 | C | 6.82 | 6.82 | 6.70 | 6.74 | 6.70 |
| | | 16:00 | 34.0 | C | 6.78 | 6.82 | 7.04 | 7.14 | 7.14 |
| | | 20:30 | 27.0 | C | 4.81 | 4.92 | 4.84 | 4.73 | 4.77 |
| | | 24:00 | 22.5 | C | 4.26 | 4.26 | 4.30 | 4.20 | 4.22 |
| 1 ft. | 6-6-69 | 6:00 | 19.0 | C | 4.14 | 4.09 | 4.14 | 4.15 | 4.18 |
| | | 8:30 | 22.5 | C | 4.22 | 4.22 | 4.26 | 4.25 | 4.26 |
| | | 10:00 | 26.0 | C | 4.85 | 4.92 | 4.92 | 5.07 | 5.07 |
| | | 13:00 | 35.5 | C | 6.96 | 7.00 | 7.03 | 7.03 | 7.07 |
| | | 16:00 | 34.5 | C | 6.65 | 6.65 | 6.70 | 6.74 | 6.79 |
| | | 20:30 | 26.0 | C | 4.68 | 4.71 | 4.76 | 4.80 | 4.81 |
| | | 24:00 | 22.8 | C | 4.29 | 4.29 | 4.24 | 4.24 | 4.26 |
| 1 ft. | 6-7-69 | 6:00 | 17.0 | C | 3.94 | 3.96 | 4.00 | 4.00 | 4.00 |
| | | 8:30 | 23.0 | C | 4.10 | 4.02 | 4.07 | 4.10 | 4.14 |
| | | 10:00 | 29.0 | C | 4.96 | 4.92 | 4.96 | 5.00 | 5.04 |
| | | 13:00 | 35.5 | C | 6.86 | 6.82 | 6.86 | 6.82 | 6.70 |
| | | 16:00 | 36.0 | C | 6.70 | 6.66 | 6.63 | 6.56 | 6.39 |
| | | 20:30 | 29.0 | C | 4.88 | 4.84 | 4.83 | 4.80 | 4.76 |
| | | 24:00 | 24.0 | C | 4.75 | 4.72 | 4.72 | 4.70 | 4.67 |
| 0 ft. | 6-8-69 | 6:00 | 20.6 | C | 4.10 | 4.10 | 4.10 | 4.14 | 4.14 |
| | | 10:00 | 27.5 | C | 4.84 | 4.82 | 4.68 | 4.68 | 4.58 |
| | | 13:00 | 34.0 | C | 5.12 | 5.08 | 5.08 | 5.04 | 5.08 |
| | | 16:00 | 29.0 | PC | 4.82 | 4.82 | 4.78 | 4.70 | 4.70 |
| | | 20:30 | 20.8 | PC | 4.92 | 4.84 | 4.86 | 4.70 | 4.72 |
| | | 24:00 | 19.5 | 0 | 5.04 | 5.00 | 5.00 | 4.96 | 4.70 |
| 0 ft. | 6-9-69 | 6:00 | 18.0 | 0 | 4.30 | 4.30 | 4.26 | 4.26 | 4.10 |
| | | 8:30 | 18.5 | 0 | 4.20 | 4.16 | 4.16 | 4.14 | 3.96 |
| | | 10:00 | 20.0 | PC | 4.06 | 4.02 | 4.02 | 4.00 | 3.92 |
| | | 13:00 | 20.5 | PC | 4.06 | 4.02 | 4.02 | 4.02 | 4.00 |
| | | 16:00 | 24.0 | C | 4.20 | 4.16 | 4.16 | 4.14 | 4.00 |
| | | 20:30 | 21.0 | C | 4.02 | 4.02 | 4.00 | 4.00 | 3.93 |
| | | 24:00 | 19.5 | C | 4.00 | 3.96 | 3.96 | 3.96 | 3.88 |
| | | 6:00 | 19.0 | 0 | 3.95 | 3.92 | 3.92 | 3.91 | 3.91 |

EMITTANCE MEASUREMENTS OF CHANGING WATER TABLE
FOR SILTY CLAY WITH SALINE WATER

| Water Level | Date | Time | Ambient Temp. | Met. Cond. | EMITTED ENERGY Salt Content in ppm | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | | | | | 160,000 | 100,000 | 60,000 | 20,000 | 0 |
| 4 ft. | 6-13-69 | 6:00 | 18.2 | C | 3.98 | 3.96 | 3.96 | 4.00 | 4.00 |
| | | 8:30 | 19.8 | C | 4.00 | 3.96 | 3.96 | 3.96 | 4.00 |
| | | 10:00 | 22.5 | C | 4.78 | 4.89 | 4.93 | 5.12 | 5.12 |
| | | 13:00 | 30.0 | C | 6.66 | 6.82 | 6.61 | 6.75 | 6.64 |
| | | 16:00 | 28.0 | C | 5.46 | 5.56 | 5.56 | 5.60 | 5.50 |
| | | 20:30 | -- | R | -- | -- | -- | -- | -- |
| | | 24:00 | 19.5 | PC | 3.93 | 3.96 | 3.96 | 3.93 | 3.96 |
| 4 ft. | 6-14-69 | 6:00 | 17.0 | PC | 3.80 | 3.80 | 3.82 | 3.88 | 3.88 |
| | | 8:30 | 20.0 | PC | 4.12 | 4.16 | 4.16 | 4.22 | 4.28 |
| | | 10:00 | -- | R | -- | -- | -- | -- | -- |
| | | 13:00 | -- | R | -- | -- | -- | -- | -- |
| | | 16:00 | 22.5 | PC | 4.26 | 4.26 | 4.30 | 4.40 | 4.40 |
| | | 20:30 | 19.5 | C | 4.04 | 4.12 | 4.08 | 4.16 | 4.16 |
| | | 24:00 | 16.5 | C | 3.84 | 3.88 | 3.92 | 3.96 | 3.96 |
| 3 ft. | 6-15-69 | 6:00 | 14.0 | C | 3.52 | 3.48 | 3.48 | 3.46 | 3.44 |
| | | 8:30 | 19.1 | C | 3.66 | 3.66 | 3.66 | 3.64 | 3.64 |
| | | 10:00 | 26.0 | C | 4.74 | 4.74 | 4.74 | 4.70 | 4.68 |
| | | 13:00 | 29.0 | C | 7.04 | 7.36 | 7.24 | 7.24 | 7.14 |
| | | 16:00 | 29.5 | C | 7.76 | 8.00 | 7.76 | 7.96 | 8.00 |
| | | 20:30 | 23.5 | C | 4.56 | 4.51 | 4.48 | 4.48 | 4.46 |
| | | 24:00 | 21.5 | C | 4.26 | 4.26 | 4.26 | 4.22 | 4.21 |
| 3 ft. | 6-16-69 | 6:00 | 17.5 | C | 3.90 | 3.90 | 3.90 | 3.90 | 3.86 |
| | | 8:30 | 22.5 | C | 4.10 | 4.06 | 4.06 | 4.06 | 4.06 |
| | | 10:00 | 26.0 | C | 5.12 | 5.12 | 5.08 | 5.08 | 5.00 |
| | | 13:00 | 34.0 | C | 7.00 | 7.00 | 6.90 | 6.86 | 6.86 |
| | | 16:00 | 36.5 | C | 7.36 | 7.36 | 7.32 | 7.28 | 7.28 |
| | | 20:30 | 29.3 | C | 4.92 | 4.88 | 4.88 | 4.84 | 4.84 |
| | | 24:00 | 27.0 | C | 4.64 | 4.60 | 4.60 | 4.56 | 4.56 |
| 2 ft. | 6-17-69 | 6:00 | 22.0 | C | 4.22 | 4.22 | 4.19 | 4.19 | 4.17 |
| | | 8:30 | 25.5 | C | 4.40 | 4.36 | 4.36 | 4.32 | 4.32 |
| | | 10:00 | 28.5 | C | 5.42 | 5.38 | 5.38 | 5.34 | 5.30 |
| | | 13:00 | 31.8 | PC | 5.92 | 5.92 | 5.88 | 5.84 | 5.80 |
| | | 16:00 | 34.0 | C | 7.50 | 7.48 | 7.44 | 7.36 | 7.28 |
| | | 20:30 | 27.0 | 0 | 4.83 | 4.74 | 4.74 | 4.71 | 4.73 |
| | | 24:00 | 24.0 | C | 4.36 | 4.34 | 4.34 | 4.36 | 4.34 |
| 2 ft. | 6-18-69 | 6:00 | 18.0 | C | 3.96 | 3.96 | 3.92 | 3.90 | 3.86 |
| | | 8:30 | 26.5 | C | 4.60 | 4.60 | 4.56 | 4.54 | 4.54 |
| | | 10:00 | 29.8 | C | 5.12 | 5.08 | 5.08 | 5.00 | 5.00 |
| | | 13:00 | 35.8 | PC | 7.28 | 7.14 | 7.14 | 7.10 | 7.00 |
| | | 16:00 | 36.0 | C | 7.36 | 7.28 | 7.28 | 7.18 | 7.10 |
| | | 20:30 | 31.0 | C | 5.18 | 5.14 | 5.12 | 5.08 | 5.08 |
| | | 24:00 | 30.0 | C | 4.78 | 4.77 | 4.74 | 4.68 | 4.68 |

| Water Level | Date | Time | Ambient Temp. | Met. Cond. | EMITTED ENERGY Salt Content in ppm | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | | | | | 160,000 | 100,000 | 60,000 | 20,000 | 0 |
| 1 ft. | 6-19-69 | 6:00 | 22.5 | C | 4.44 | 4.40 | 4.40 | 4.36 | 4.36 |
| | | 8:30 | 26.0 | C | 4.40 | 4.35 | 4.35 | 4.36 | 4.36 |
| | | 10:00 | 28.9 | PC | 4.50 | 4.48 | 4.44 | 4.44 | 4.40 |
| | | 13:00 | 36.5 | PC | 5.22 | 5.22 | 5.14 | 5.12 | 5.00 |
| | | 16:00 | 35.8 | PC | 5.30 | 5.14 | 5.14 | 5.12 | 5.06 |
| | | 20:30 | -- | R | -- | -- | -- | -- | -- |
| | | 24:00 | 20.0 | PC | 4.10 | 4.04 | 4.04 | 4.00 | 3.93 |
| 1 ft. | 6-20-69 | 6:00 | 21.0 | O | 4.20 | 4.20 | 4.20 | 4.20 | 4.16 |
| | | 8:30 | 20.5 | O | 4.14 | 4.14 | 4.14 | 4.10 | 4.10 |
| | | 10:00 | 23.0 | O | 4.30 | 4.30 | 4.30 | 4.30 | 4.27 |
| | | 13:00 | 29.0 | O | 4.66 | 4.66 | 4.68 | 4.68 | 4.68 |
| | | 16:00 | 34.8 | PC | 5.38 | 5.38 | 5.34 | 5.30 | 5.26 |
| | | 20:30 | 29.0 | C | 4.74 | 4.74 | 4.68 | 4.64 | 4.64 |
| | | 24:00 | 27.5 | C | 4.62 | 4.62 | 4.60 | 4.56 | 4.54 |
| 0 ft. | 6-21-69 | 6:00 | 27.0 | O | 4.36 | 4.33 | 4.30 | 4.30 | 4.26 |
| | | 8:30 | 28.5 | C | 4.44 | 4.40 | 4.40 | 4.36 | 4.36 |
| | | 10:00 | 27.5 | O | 4.40 | 4.44 | 4.39 | 4.34 | 4.30 |
| | | 13:00 | 31.5 | PC | 5.18 | 5.12 | 5.04 | 5.00 | 4.96 |
| | | 16:00 | 36.0 | PC | 5.18 | 5.14 | 5.04 | 5.00 | 5.00 |
| | | 20:30 | 29.0 | C | 4.68 | 4.68 | 4.64 | 4.64 | 4.64 |
| | | 24:00 | 25.5 | C | 4.30 | 4.26 | 4.26 | 4.20 | 4.20 |
| 0 ft. | 6-22-69 | 6:00 | 25.5 | C | 4.34 | 4.34 | 4.34 | 4.34 | 4.30 |
| | | 8:30 | 26.0 | C | 4.34 | 4.30 | 4.26 | 4.22 | 4.20 |
| | | 10:00 | 28.0 | C | 4.44 | 4.40 | 4.36 | 4.36 | 4.34 |
| | | 13:00 | 34.5 | C | 5.26 | 5.08 | 4.96 | 4.96 | 4.84 |
| | | 17:00 | 35.5 | C | 5.42 | 5.22 | 5.00 | 4.92 | 4.78 |
| | | 20:30 | 30.0 | C | 5.52 | 5.38 | 5.22 | 5.08 | 4.92 |
| | | 24:00 | 29.5 | C | 5.52 | 5.38 | 5.30 | 5.22 | 5.16 |

VITA

Harlan Elliott Karbs

Candidate for the Degree of

Master of Science

Thesis: MAPPING OF SALINE SOILS AND VEGETATION BY REMOTE SENSING
TECHNIQUES

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