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EVAPORATION STUDY IN
GRAND RIVER BASIN

Thesis for the Degree of B. S.
H. R. Hamilton
1935

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Evaporation Study
in
Grand River Basin

A Thesis Submitted to

The Faculty of
MICHIGAN STATE COLLEGE
of
AGRICULTURE AND APPLIED SCIENCE

By

H. R. Hamilton

Candidate for the Degree of

Bachelor of Science

June 1935

THESIS

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PREFACE

Purpose and Scope:

This thesis problem was begun in the Spring of 1935 by H. R. Hamilton. It was the desire to gain some knowledge of the evaporation rate in the Grand River Basin from water surfaces. Before this time such an experiment had not been attempted in this area, so the purpose was to obtain results that would give those interested in this field a practical application to base future experiments on.

Comparable observations were taken over a period of time. The results of this experiment are considered of great value by the author and the hope exists that the work will be carried further on.

Acknowledgement:

The author wishes to acknowledge the help and very helpful suggestions of Mr. C. M. Cade of the Civil Engineering staff and his readiness at any time to give advice. The author is also indebted to the Board of Water and Electric Light Commissioners for the use of their equipment and their source of data prior to the beginning of this experiment. Also many helpful suggestions were given by the Engineering staff of the Board of Water and Electric Light Commissioners.

INTRODUCTION

Since there had not been any experiments made on this problem before in the Grand River Easin, all results had to be compared with areas outside of the Grand River Basin. A systematic study was begun of methods as to how to determine the various effects of the different variables. There is a great amount of literature on various phases of evaporation but not a great deal has been compiled on evaporation rate from water surfaces.

Considerable difficulty was experienced in obtaining the observations by the floating pan method. This study should really be made in an isolated area where the observer does not have the problem of watching his experiment all of the timme to keep the various sources of error from disturbing the recordings of data.

GENERAL DISCUSSION

A great deal of work has been done in connection with evaporation from water surfaces, but the literature is quite limited on this phase of evaporation. In late years however, more attention has been given to the study of rates of evaporation and an effort has been made to evaluate these factors so they could be used in practical manner by those interested in this particular field.

In the different regions evaporation varies because of precipitation rates are greater or lower, that is in the East where it is humid, precipitation depth equals or exceeds the evaporation, where in the arid West evaporation may exceed precipitation greatly. It has been shown from a number of experiments that the evaporation in the West may exceed that in the East from two to four times in the months of May to September. Therefore, it can be said that climatic conditions must be considered in the study of evaporation.

THEORETICAL CONSIDERATIONS

In the theoretical considerations evaporation from a water surface consists of two distinct processes; the transferring of the molecules of water from a liquid to a vaporous state and the removal of the water vapor from proximity to the water surface. The molecules of liquid water are in a state of constant movement which is very rapid, the rate of a movement depending upon the temperature of the water which in turn depends upon the amount of heat energy received from the sun and atmosphere. The rapid rate of vibration of the molecules located near the water surface causes them to break through the surface film of the water. They do not return by continue to remain in the air as water vapor. The molecules continue to vibrate at a rapid rate, pounding on the walls of any enclosing medium which results in a pressure upon the walls of the medium, this pressure is known as vapor pressure. Increase in the temperature of the air containing water vapor, or increase in the amount of water vapor will increase the vapor pressure.

At any given temperature of the air there exists a maximum amount of water vapor which the air can hold, when this amount is reached the air becomes saturated. If temperature is increased further the vapor holding capacity is increased also; whereas a decrease will reduce the vapor holding capacity and, if the air has been saturated, will cause condensation. As the water temperature increases to-

ward the surface the rapidity of movement of the water molecules increases and more of them leave the water surface.

The fewer the number of water molecules in the air near the water surface the less the resistance will be to those leaving the surface, so more molecules will leave the surface under this condition. It then becomes evident that any factor which reduces the number of water molecules near the water surface, such as wind movement or rise of temperature of water at the surface, will naturally increase the rate of evaporation.

EXPERIMENTAL CONSIDERATIONS

Experimental evidence as well as theory indicate that, everything else being equal, the rate of evaporation from a water surface varies directly with the difference in vapor pressure of saturated air corresponding to the temperature of the water at the surface of the body, and the actual vapor pressure of the air in contact with such a surface, and also with the rate of removal of the moist air from the water surface. Vapor pressure is a function of temperature and, temperature being constant, of the amount of vapor contained in the air; and temperature is likewise a function of the amount of radiant energy received by the water surface from the sun and atmosphere less the amount lost through various agencies. Barometric pressure also affects evaporation, as the latter is a measure of the combined pressure exerted by all of the gases included in the atmosphere, and a decrease in this pressure results in fewer molecules of air to impede the departure of the molecules from the water surface. An increase in density of the water, due to various types of matter in the water, will slow down the movement of the molecules in the water and cause greater difficulty in leaving the water. Basically speaking, it may be said that four factors govern the rate of evaporation from a water surface. These four factors are:

1. Difference in temperature of the water and of the surrounding air, which influences the dif-

ference in vapor pressure.

2. Amount of water vapor in the air in proximity to the water surface, which also influences the difference in vapor pressure.
3. Barometric pressure of the air.
4. Density of the water.

The pressure of saturated vapor at ordinary temperatures which occur, doubles for every increase of approximately 20 degrees fahrenheit. Due to this fact a temperature differential of a given amount between water and air, when a constant vapor content exists in the air, will cause much greater evaporation at high than at low temperatures. Little evaporation will occur with cool air in proximity to cool water, but with air of same vapor content, a considerable amount will occur with both the water and air warmed a few degrees. In regions of fairly high temperatures the vapor pressure differences are considerable and evaporation is high. The effect of wind in increasing evaporation rate is primarily to remove the overlying moist air from the water surface from which it is constantly receiving water vapor, and replace it with air of smaller moisture content. Were the overlying air to remain still it would soon become saturated and evaporation would cease. The greater the velocity of the wind the greater will be the rate at which the moisture laden air is removed from the water surface and dry air introduced. Therefore, differences in vapor pressures are maintained, and evaporation is a function of wind velocity.

Variations in barometric pressure at a given elevation and their effect upon evaporation are relatively small. With increase in altitude, while the decrease in barometric pressure is marked, the decrease in temperature has so much greater effect that for all practical purposes barometric pressure is a negligible factor.

FORMULAS - GENERAL FORM

Many formulas have been developed for computing the rate of evaporation from other known factors through experimental research and other theoretical considerations. Those most frequently used are based on Daltons' law and follow the general form of

$$E = (e_w - e_d) (1 + CK)$$

where E = the rate of evaporation

e_w = vapor pressure of saturated vapor corresponding to temperature of water surface.

e_d = vapor pressure of atmosphere at water surface.

K = wind velocity.

C = Constant.

The values of the constant depend upon the units used in expressing the other factors in the formula.

Meyer modified this formula into the following result:

$$E_m = 15(e_w - e_d) \left(1 + \frac{K}{10}\right)$$

this giving evaporation in inches per month.

Bigelow's formula which is expressed in English units:

$$E_m = 75.8 \left(\frac{e_w}{e_d} \frac{de_w}{de_d} \right) \left(1 + \frac{K}{9}\right)$$

where $\frac{de_w}{de_d}$ is the rate of change with temperature of maximum vapor pressure at the temperature of water surface. The constant 75.8 being a factor introduced to take care of small water surface areas. When getting the data together to in-

troduce into these formulas, the following things must be gathered and considered: air temperature, water temperature, 1" above water, 1" above pan water temperature, pan water temperature, air velocity and relative humidity.

For expressing the rate of evaporation over a relatively short period of time, such as a few hours, these formulas are quite satisfactory, but to the research man who is primarily interested in monthly or annual rate of evaporation, they are of little practical use. This is due to the variations of the factors in the equations when used over longer periods of time and the difficulty in evaluating these, for if such evaluation is attempted it would take considerable time, during which actual evaporation experiments could be run which would yield more complete and satisfactory results.

METHODS OF OBSERVATION

Much work has been done on evaporation experiments to determine the rates of evaporation through field experiments carried on by the United States Weather Bureau, Bureau of Reclamation and many other private agencies during recent years and a great deal of discussion has followed these experiments and their results in the technical press. Most of the work has been carried on by use of evaporation pans, either situated on land or floating in water such as a pond, lake, or reservoir. The results of these experiments show that there exists a substantial difference in the evaporation rate so determined, depending on the way the pan is exposed, its size, shape and setting. The problem then involves the finding of a correlation between the surface area of pan and some large surface area from this experimental work.

The location of the evaporation pan should be given careful consideration; otherwise comparable and reliable data can not be obtained. The emplacement of land pans should be on a level area on which there are no trees or obstructing buildings, and if the observations are for the purpose of determining the equivalent reservoir evaporation the location for the pan should be representative of conditions at the reservoir. Isolated places where there is no satisfactory water supply available or where a competent observer cannot be had, should be avoided. The standard pan used at Class A

stations of the United States Weather Bureau is made of galvanized iron and is circular in shape, 4 feet in diameter and 10 inches in depth, set somewhat above the surface of the ground upon a wooden support so that the sides and bottom are exposed to the air. The other pans used for land observations range from 3 to 4 feet in diameter for circular pans to the same side dimensions for square pans, and in depths from 2 to 3 feet. They are set in the ground the entire depth.

Floating pans are not recommended; if it is necessary to install one the location should be carefully chosen. The location should be in an area protected from wave action. The exposure to the wind should be representative of the average conditions of the reservoir or body of water that is under observation. Floating pans also vary in shape, size and depth and are supported by metal floats attached to the pans so as to keep the lip of the pan a few inches above the water surface. Protection from splashing by wave action in the case of floating pans can be obtained by placing a wooden float around the outside of the pan. A suitable float may be made from 4"x 4" timbers or by setting on edge planking 1"x 12", 16" long, forming a square with cross members so arranged as to form an opening in which the pan may be located and cross braced to make float rigid.

A vertical rod with a sharp pointed top is attached to the bottom of the pan, which must be braced so as to make it rigid, and the water surface is maintained at the top of

the rod which must be near the top of the pan. Every few days or once a week, water is added to the pan to bring the water level to the top of the rod and make up for the water evaporated. The added water may be measured by using a small cup of such a size that each cupful of water is equivalent to 0.01 in depth on the surface of the pan. The use of the calibrated cup simplifies the work of keeping notes and making computations.

The rain gauge for evaporation stations should be of the Weather Bureau type and should be located adjacent to the pan in order to determine the amount of precipitation caught by it. This amount should be added to the observed evaporation to give the actual quantity. The evaporation gauges used in connection with the different pans are usually of special forms, but any gauge giving readings within 0.001 feet should be satisfactory.

The evaporation from different types of pans is dependent to some extent on the color of the pan. With this in view it is recommended that no paint, tar or other coatings be used. To reduce the growth of Algae and other plants in the water, the pans should be cleaned once a month and oftener if necessary. The cleaning of the tanks also removes the salts, thus lowering the concentration of the water which would otherwise occur due to the evaporation.

In order to obtain comparable evaporation data the

floating pan record should be checked by installing a land pan as near to it as possible, because even when protected by a float, waves may sometimes splash into the pan and cause erroneous results. Where pan cannot be kept under constant observation it should be covered by a covering of chicken mesh and surrounded by a fence. Instances have been known to occur where unprotected pans have been used as bathing pools by birds, resulting in a loss of water by splashing. A complete meteorological record should be kept and a standardized procedure followed in taking observations. The meteorological record should include the air and water temperatures, the humidity, the wind movement, the precipitation and the evaporation loss. Other added items might be the temperature 1.0 inch above water, pan water temperature and 1.0 inch above pan water surface. The following instruments are required:

- 2 - Sets of "maximum and minimum" thermometers for determining the mean air and water temperature, or
- 2 - Ordinary thermometers where observations can be taken at 12 hour intervals or often-er,
- 1 - Psychrometer for determining the humidity of the air,
- 1 - Anemometer for recording the wind movement,
- 1 - Rain gauge for measuring the precipitation,
- 1 - Gauge for measuring the evaporation, and
- 1 - Instrument shelter for the air thermometers and psychrometer.

PROCEDURE OF GATHERING DATA

The standard method used by the Weather Bureau should be used in taking observations on the pan. This is, the readings on the instruments are taken twice daily at approximately 7:00 A.M. and 7:00 P.M. The mean temperature of the water may be determined either by readings of "maximum-and-minimum" thermometers floating in the water with their bulbs immersed 1/4 inch below the surface of the water, or by readings on an ordinary thermometer similarly exposed. The "maximum-and-minimum" thermometers require only one reading per day to obtain a fair average of the temperature while the ordinary thermometer requires two readings a day at 12 hour intervals to get similar accuracy. Maximum thermometers are easily broken and so for this reason it should not be used by an observer not accustomed to using this type of thermometer. If possible, the sling or rotating psychrometer should be used for determining humidity, but where readings cannot be taken at regular intervals a hair hygrometer may be used to obtain approximate results.

The velocity of the wind varies with the elevation above the ground surface. With this fact in consideration, a standard anemometer setting should be adopted for each type of evaporation pan in order to obtain comparable results. The standard practice at Class A Weather Bureau stations is to mount the anemometer on the grillage of timbers which sup-

port the evaporation pan so that the cups of the anemometer are 6.0 inches above the top of the pan. At some places in the United States the practice has been to mount the anemometer so that the cups are 24.0 inches above the top of the pan. When in doubt as to what distance to set anemometer above pans that are not of a standard type, it is suggested for uniformity that the cups of the anemometer be set 13.0 inches above the top of the surface of the ground or water. Either the 3-cup or the 4-cup anemometers, of the Weather Bureau pattern, may be used. The 3-cup type are more accurate at high velocities, but near the ground the velocities are never so high that the 4-cup anemometer is not sufficiently accurate. When considering this variable, that is wind velocity and its effect on evaporation rate, most evaporation formulas contain an expression relative to some of the general form

$$(1 + CK)$$

where C is a coefficient depending in magnitude upon the elevation above the ground and decreasing with increase in elevation above the surface at which the wind velocity was recorded, and K is the wind velocity expressed in suitable units. Very often velocities of wind given by Weather Bureau or other agencies are observed at elevations ranging from 50 to 150 feet above the ground surface where the ground records were taken from 2 to 3 feet above the surface. A value of C of 0.10 may be taken as a fair average provided the velocity of the wind is expressed in miles per hour as observed at regu-

lar Weather Bureau Stations. If wind velocity is taken near the ground this value should be increased from two to four times. It was found from experiment that in the Grand River Basin that the best value for C was 0.20.

The wind factor should be used only as a guide to judgment, in comparing evaporation at a location under consideration. In such cases the ratio

$$\frac{1 + CK}{1 + C^1 K^1}$$

should be applied to the observed records; CK and $C^1 K^1$ being quantities at the location under consideration and at the location where the records were obtained, respectively.

VARIABLES AND THEIR EFFECTS ON EVAPORATION RATE

Wind effect is less on water areas of large extent than on smaller bodies of water. Wind serves merely to remove water vapor from the water surface and replace it with dry air. It may be said then that when the wind sweep over a water surface is great, the vapor content becomes large before the leeward side is reached and the drying effect of the wind is lessened.

The effect of size and shape of the pan upon evaporation rate may be shown through experiments carried on in connection with this subject. The results show that with an increase in size of the pan used the recorded evaporation is reduced and from this it may be assumed that this condition more closely approaches that of a large open water surface. This is probably due to the fact that the larger and deeper pans hold the heat better and maintain a more constant temperature than the smaller pans, which causes a higher rate of evaporation. The thin capillary film creeping up the sides of the pan has a higher temperature than the water in the pan and evaporation occurs from it also at a much higher rate than from the cool water surface. With larger pans, the ratio of this area around the water's edge to the total exposed area of water surface becomes smaller and the effect is reduced.

- Experiments having to do with the effect of size and shape of pan upon evaporation rate indicated quite clearly the effect of these factors upon the result. Data gathered showed a decreasing rate of evaporation in relationship to an increasing size of pan until pan surface area reaches 100 square feet, then the evaporation rate does not further increase. Although these experiments are not conclusive of the fact that the rate from pans of 100 square feet in surface area is equal to that from a large open water surface such as a reservoir or lake, and confirmatory experiments are necessary before this fact can be generally accepted and a relationship established, they do quite clearly bring out the fact that such a distinct relationship exists and it is essential in using results of evaporation experiments that careful consideration be made of such factors as size and shape of pan, exposure, location and similar effects.

The relationship between rate of evaporation from land and floating pans shown by both experimental results and theoretical considerations indicate that the rate of evaporation from pans floating in a body of water is less than from same pans set upon the surface of the ground or in the ground. A floating pan is covered with a blanket of water vapor which reduces the evaporation rate, and the temperature of the surrounding water serves to maintain a lower temperature in the water in the pan. Land pans are not so likely to be covered by a vapor blanket and the wat-

er will attain a higher temperature than that in a floating pan. Pans set upon the surface of the ground or upon boards attain a higher temperature than those set in the ground and therefore show a higher evaporation rate than those insulated by surrounding soil.

The conclusions that are drawn as to the results from the different types of pans, as far as the gathering of comparable data is concerned, are, that the records from floating are not as consistent or reliable as land-pan records, nor is the evaporation from a floating pan any nearer the evaporation from a large water surface than that from a sunken pan of the same size and shape. Comparison of the evaporation from different types of pans with that from large water surfaces of different sizes, shows that the size of the pan has a proportionately smaller effect on evaporation as the size of the surface increases, and that when the diameter is greater than 12 feet, the size of the pan has practically no effect on the evaporation. In order to obtain comparable evaporation results, standard equipment installed under representative conditions should be used, and a standard procedure should be followed in making the observations.

The relationship between mean temperature and the rate of evaporation may be developed. When an attempt is made to determine the rate of evaporation at a given locality for the use in water supply studies, the only physical data usually available are the mean daily or monthly temperature

records as given by the U. S. Weather Bureau, and it is often necessary to combine these with experimental data of nearby stations to attain the result desired. A relationship between evaporation and mean temperature may be developed which will be sufficiently accurate for use as a guide, particularly when other factors such as wind velocity, relative humidity, and others are known. These figures, though, should be used only as a guide in aiding judgment, in cases where local data are not available.

DAILY MONTHLY AND ANNUAL VARIATION IN EVAPORATION RATE

The daily variation in rate of evaporation, as a general proposition, includes all factors tending to cause an increase in the evaporation rate are subject to increase during the daylight hours and decrease during the night. Temperature, wind, and relative humidity are usually greater during the daylight hours. The great decrease in the rate of evaporation at high altitudes, even though the daytime temperatures may reach fairly high figures, is due to the fact that the low night temperatures reduce the average temperature to such a degree that the mean evaporation is small.

When making a study of the monthly variation in rate of evaporation, it will be found that those stations which have a mean monthly temperature around the freezing point, indicate a monthly rate of evaporation during the winter periods to be from $\frac{1}{4}$ to $\frac{3}{4}$ of an inch per month for land pans, and from 1 to 2 inches per month from floating pans. The latter pans give higher figures due to the insulating effect of the surrounding water upon the contents of the pan. Monthly variation of evaporation should be studied in areas such as the Arid West where evaporation rate is greater than the precipitation rate. In northern areas, the freezing weather prevents securing of records during the winter months, but because of the fact that the total rate of evaporation is so small during this period, the evaporation during these

months may be disregarded.

Annual variation of evaporation rate, like most meteorological and hydrological data, little thought usually is given to obtaining experimental data relative to evaporation until the time it is needed, and then usually it is possible to obtain records of only one or two seasons. It, therefore, becomes of great importance to determine whether the annual variation in evaporation rate is great enough to render a short record of doubtful value as an indication of mean rate, and also whether the use of mean values when determined will greatly affect the results desired. In regions where large annual variations are indicated, it is advisable to develop a relationship between mean annual temperature and rate of evaporation for the location, and use the resulting figures for each year, rather than to use the mean value of evaporation throughout any computations of water supply.

VARIATION DUE TO GEOGRAPHICAL LOCATION

Due to the effect upon evaporation rate of the size of the pan, exposure temperature and wind velocity, it is impossible to obtain an idea of the variation of evaporation in different localities by comparing results of observations at different stations. A factor has to be applied to reduce to a common denominator the observations from other stations. This factor is due to the locality of the station. In general it may be said that in the United States the rate of evaporation decreases with increase of latitude.

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EVAPORATION FROM SNOW AND ICE

It is very difficult to make year-round observations of evaporation at stations where sub freezing weather occurs during several months of the year. For that reason, records at such stations are very often incomplete. When an attempt is made to keep a record of evaporation during this freezing period, it will be found that the average monthly rate of evaporation is so small that it cannot be considered a factor in the losses from a large body of water.

Evaporation from snow surfaces is also difficult to derive, and because of the greater area exposed to the air, the losses are greater than those from an ice surface. It very often happens that a warm, dry wind blowing over snow fields for several days will result in their complete disappearance. This is often credited to the evaporation of the snow, but this theory is generally in error and the fact is the warm air causes the snow to melt and be absorbed by the ground.

VARIATION OF EVAPORATION DUE TO SPECIFIC GRAVITY

Specific gravity of water and its effect upon the rate of evaporation must also be considered as a factor. When water is heavily charged with mineral substances, the internal motion of the molecules is decreased and their rate of escape from the solution is retarded. When the mineral content reaches such a point that crystallization or the formation of a film of crystals at the water surface occurs, the rate is reduced to practically zero. The specific gravity at which crystallization commences will vary with the chemical composition of the mineral constituents.

The importance of this phenomenon from a water supply standpoint develops from the use of evaporation rate to determine the water supply of areas tributary to lake or moist areas.

Many lakes in the Arid West are saline in character, with no outlets, and, based upon their fluctuations, area and an assumed or observed rate of evaporation, the annual inflow is sought. Also in areas where a stream may be highly polluted and a great portion of this water is held in a reservoir, it can readily be seen that an allowance should be made for the specific gravity of the water content in determining the evaporation rate from the surfaces of water of this nature.

DISCUSSION OF GRAND RIVER EXPERIMENT

With the theoretical and practical application mentioned before, this problem of the evaporation rate in the Grand River Basin was studied and results noted. The equipment that was used was a 4 foot diameter floating pan and the other standard equipment already mentioned. A floating pan was used so as to get the most nearly ideal conditions necessary to make a study of this kind. Observations were taken over a period of three years and were found to be comparable to other observations taken at various points in other areas.

Variation of evaporation rate with temperature was noted and results may be noted on Chart I. All the variables such as wind movement, temperature, and relative humidity were included in Chart II. These results may be considered as the most complete because of the fact that all variables were included. A curve cannot be made of one of these effects and have the curve be of any practical value, because the actual evaporation rate recorded includes all of the variables. Recordings were not taken in the freezing months because these values may be neglected for the reason that evaporation is so low during this period. Mean daily evaporation during the three years was $\frac{1}{4}$ inch per day. This value fluctuated very little and the reason for this was the fact that during the seasonal changes, both temperature and wind movement varied so as to cause little change in the daily evaporation rate.

Using this 4 foot pan, a coefficient of reduction to apply to the open water surface was used. The value of the coefficient was 9. This was applied to the total evaporation recorded daily.

COEFFICIENTS OF REDUCTION; PAN EVAPORATION
RECORDS TO OPEN WATER SURFACES

Table I

Depth of Tank or Pan in Feet	Depth of Water in Tank or Pan in Feet	Dimensions of Pan or Bank in Feet	Coefficient of Reduction to Open Water Surfaces	Remarks
1.5	1.25	3x3, sg.	0.91	Pan set in water pro- tected by raft to re- duce wave action.
0.83	0.58	circular 4.0	0.92	Pan set in water sub- merged to a depth of 7".
1.83	1.50	3.5	0.91	

The general equation derived by Dalton may be used in the Grand River Basin

$$E = (e_u - e_d) (1 / C K)$$

This formula having been discussed before, there is no need of further explanation of its use. The reason that this formula serves the purpose of getting the evaporation rate is that it entails all of the variables and it also deals with the vapor pressures of the air and water vapor. Vapor pressure has a marked effect on evaporation rate in this area due to the slight mists that hang over water surfaces during certain months of the year. These mists cause a vaporous state of the air conditions close to the water surface. The molecular action of the water particles is reduced by the steaming surface to such an extent that there is a marked reduction in the evaporation rate.

One thing in particular was noticed as to water temperatures, that is that evaporation rate has a cooling effect on the body of water. This was noted when making a study of River temperature below Moores Park Power Plant. As the discharge of cooling water came into the river, the water in the stream increased in temperature, and as the flow went downstream, the water gradually cooled.

On days when evaporation was the greatest, the river cooled more rapidly, therefore making evaporation a major factor in the location of future power stations downstream.

Comparison of observations was made with the U. S. Weather Bureau at East Lansing, and in this way a check was kept on recordings at experimental station on the river. Difficulties constantly come up with an experiment of this kind such as, the station can't be constantly watched so interference comes from intruders who some of the time disturb the setup.

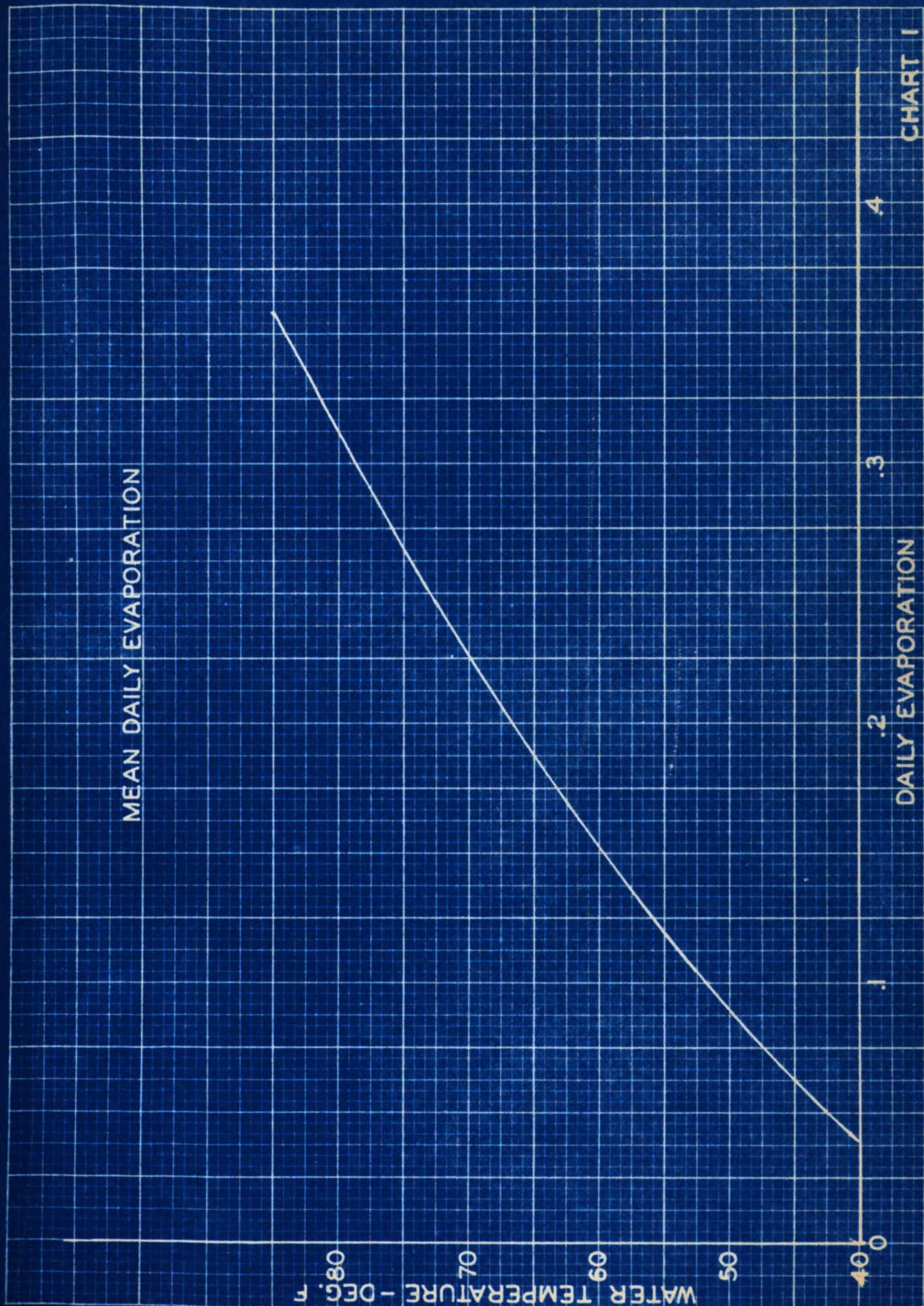
Loss of equipment is another item that must be watched closely.

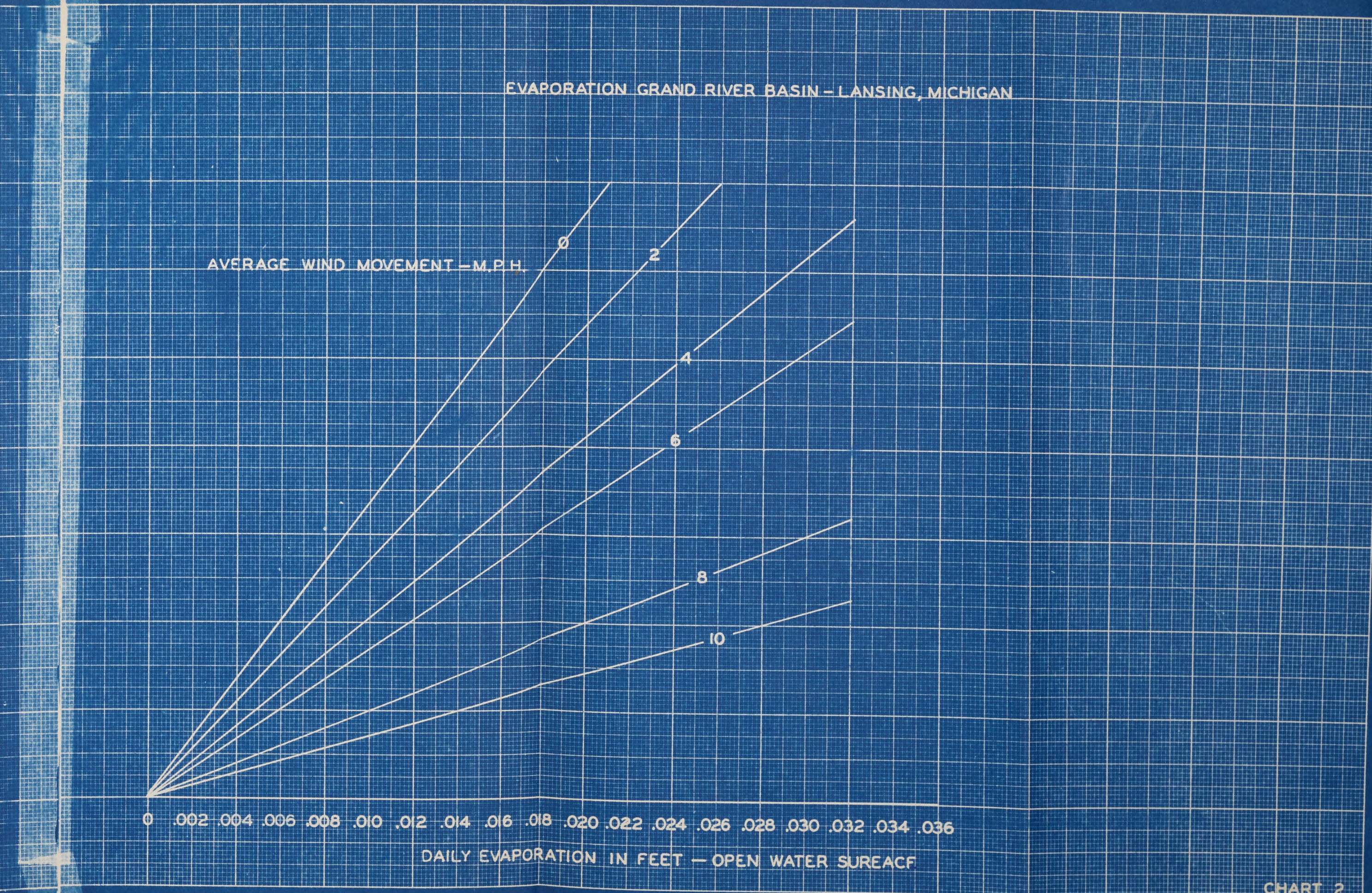
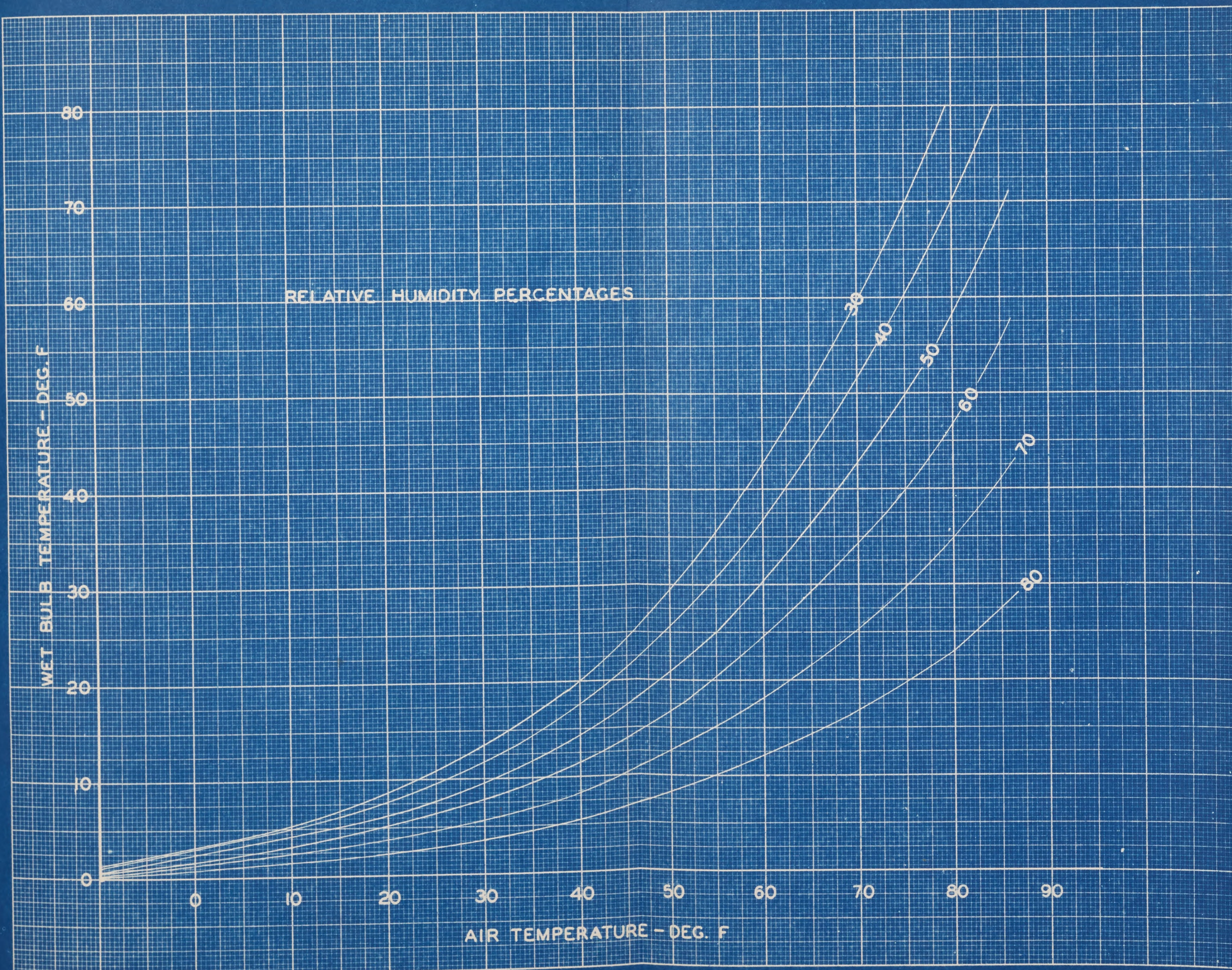
When considering the specific gravity of the Grand River, it may be considered high. The reason for this is that the stream is highly polluted causing a density somewhat higher than that of ordinary water. Although in this particular case this higher specific gravity doesn't affect evaporation greatly because of the stream flow. A crust cannot form on this moving surface and impede evaporation. The water in the pan, though, has to be changed every three days so as to have a solution under comparable conditions, under observation.

The accompanying charts will show the results of the observations gathered and give reason for the foregoing conclusions. Chart I was compiled from observations taken over a period of three years, 1931, 1932, 1933, and the spring of 1935. A direct variation in evaporation may be noted with the temperature. Chart II was compiled from the same observations and that in itself gives a more complete description of what taken place under conditions set up by

the variable effects on evaporation rate. The purpose of this chart is to give a basis for judgment and computations on evaporation rate from a water surface. Chart III will show a factor that exists between the rate of evaporation and the area of the water surface. This curve can be used to apply to any size of pan that is used for the experiment, when doing this the results from the pan may be changed into terms of a large water surface. Chart IV shows the effect of humidity on evaporation rate from a water surface. The one difficulty that arises in compiling a humidity effect curve lies in the fact that the effect of wind movement causes the humidity to give a widely different effect at the same conditions of humidity. Chart V shows the effect of wind movement on the evaporation rate. This curve very nearly gives a direct result of evaporation because of the direct effect that the wind movement has on the evaporation rate. All of these results are to be considered as mean values, however, because observations extended over a period of 24 hours each.

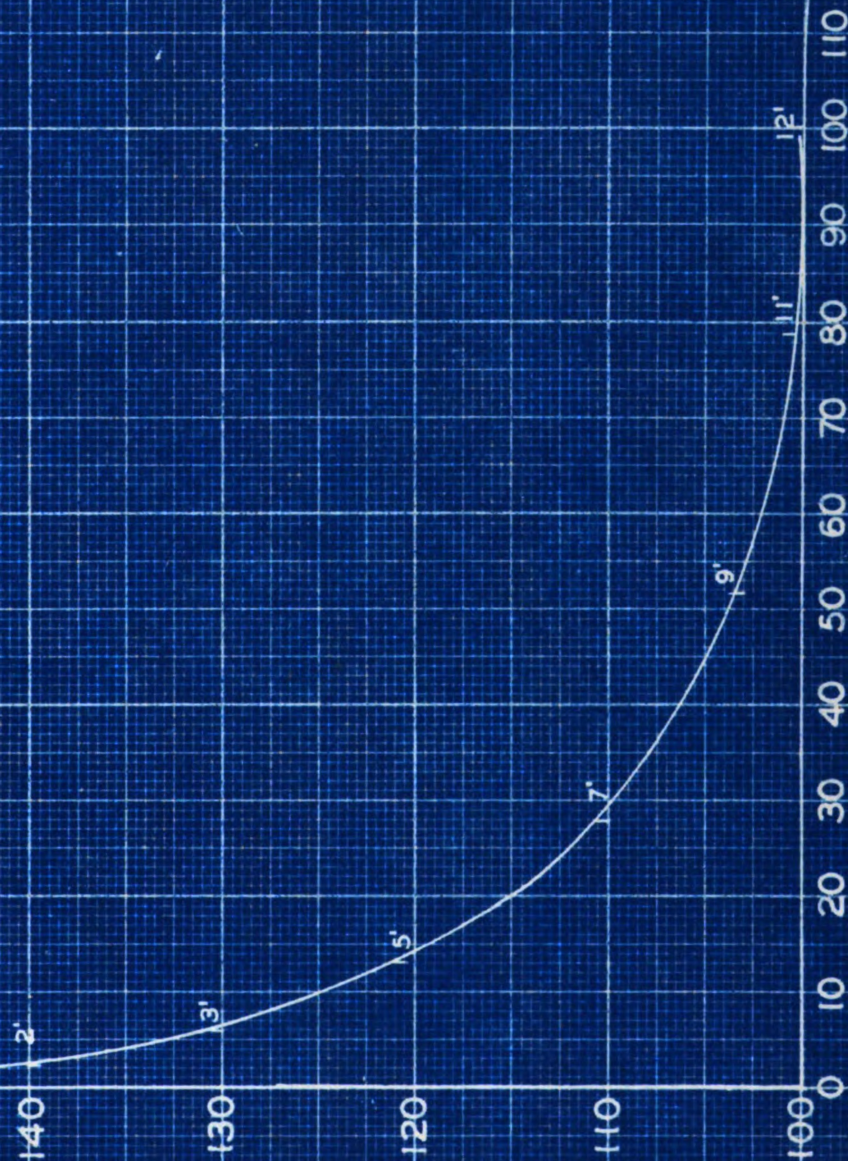
This fact may be noted from data sheet. Again too much stress cannot be laid on the fact that extreme carefulness must be followed in taking observations by the floating pan method.





RELATION BETWEEN RATE OF EVAPORATION & AREA OF SURFACE OF EVAPORATION PAN

EVAPORATION - PERCENT
12' TANK TAKEN AS 100 %



AREA OF EXPOSED SURFACE - SQ FT

DIAMETER INDICATED

HUMIDITY EFFECT ON MEAN DAILY EVAPORATION

RELATIVE HUMIDITY %

DAILY EVAPORATION — INCHES

CHART 4

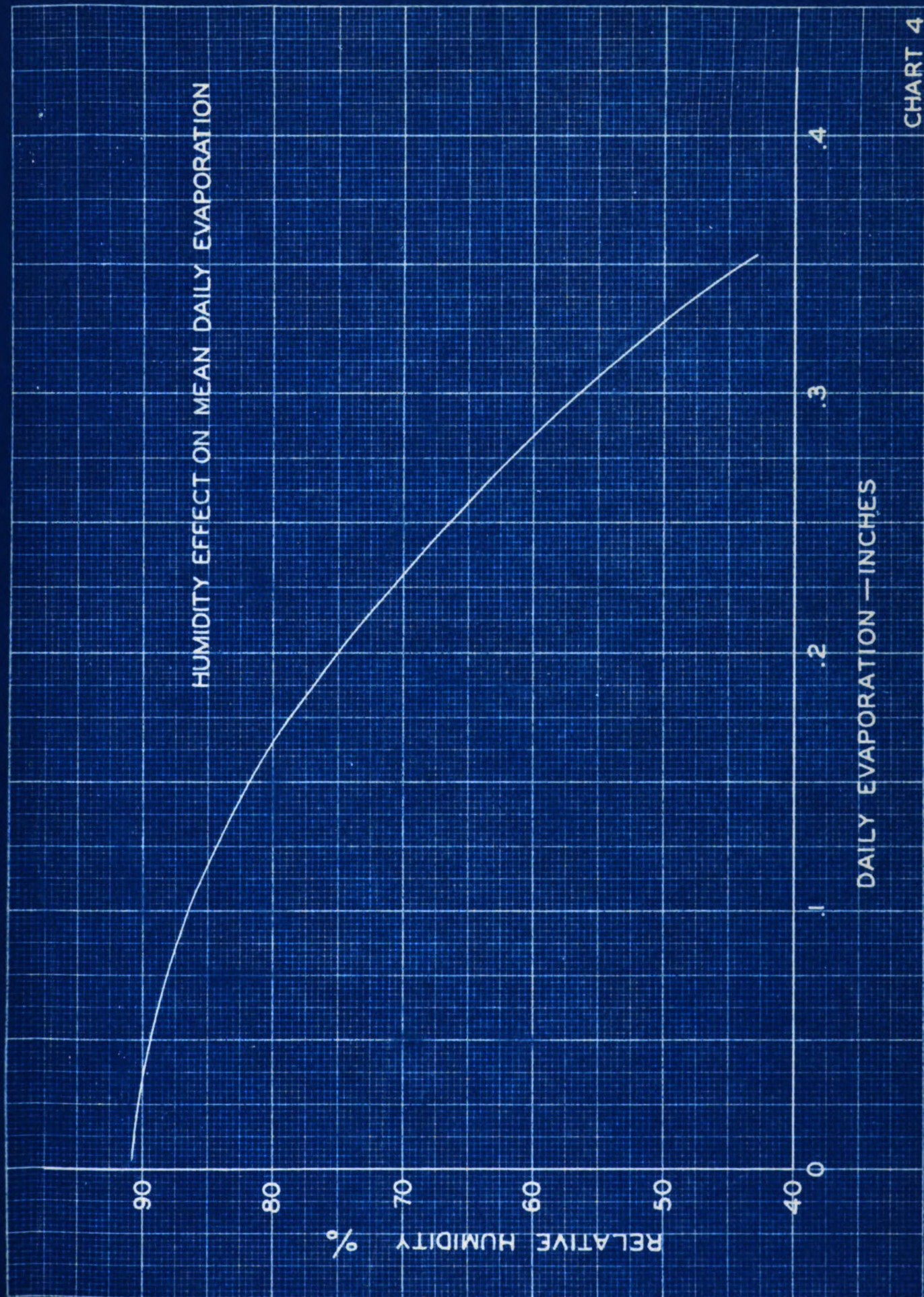
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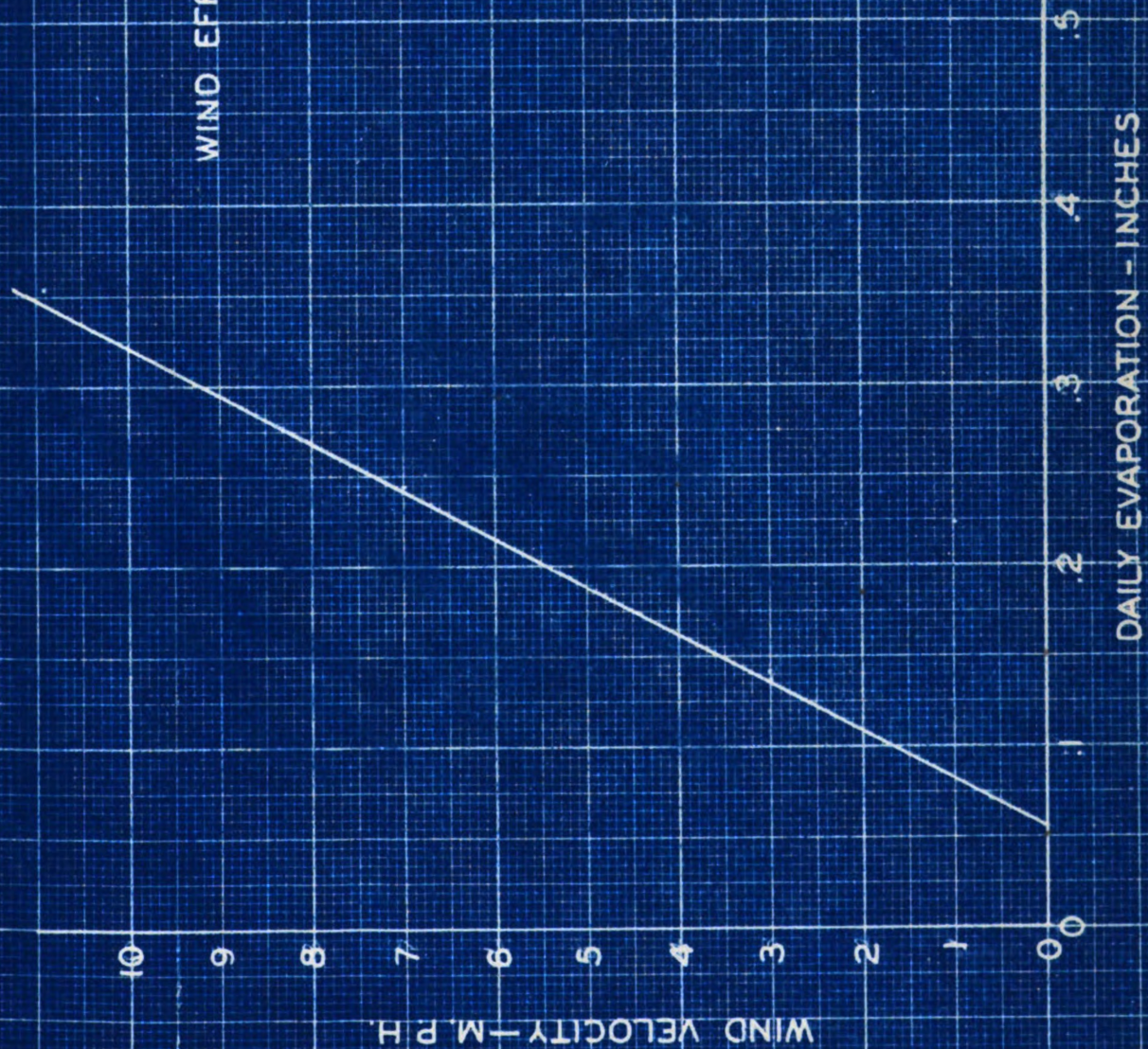
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.1



WIND EFFECT ON MEAN DAILY EVAPORATION



IDENTITY		TIME	OBSERVER	CHARACTER	TEMPERATURE					
12 P.M.	AVERAGE				RIVER			PAN		
					WATER 1" ABOVE	AVG. DAILY	WATER 1" ABOVE			
		12.00			6 45			47 45	0 = 3.1 Hook GAUGE	rans.
		"			6 42			45 41		
		"			5 40			45 40		
		"			3 38			44 38	0 = 2.7 Hook GAUGE	s. Am.
		"			4 49			45 49		
		"			5 47			46 47		. Am.
		"			5 47			45 47		
		"			6 39			45 39		
		"			5 51			55 52	0 = 10.35 Hook GAUGE	ions,
		"			7 61			58 61		
		"			7 61			58 61		
		"			0 64			61 64		e Gradient
		"			2 71			62 71		ther
		"			2 62			62 62	0 = 4.2 Hook GAUGE	
		"			8 54			58 54	0 = 4.1 " "	Stations
		"			4 50			54 50		News,
		"			0 46			60 46		
		"			7 40			47 40		ops,
		"			6 46			47 46	0 = 5.0 Hook GAUGE	. D.
		"			6 60			56 60		
		"			6 60			56 60		
		"			54 62			54 62		
		"			4 62			54 62	Observations taken	
		"			4 60			54 60	during April and May	now Sur-
		"			7 62			57 62	1935	1917, p. 363.
		"			7 62			57 62	0 = 3.8 Hook GAUGE	hen Used
		"			7 61			60 61		review,
		"			8 55			59 55		
		"			6 53			55 53		
		"			7 62			60 62		Michigan.
		"			4 69			65 69		daho.
		"			8 70			69 70		
		"			7 65			69 65		
		"			5 60			66 60		

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