THE DEVELOPMENT OF A BORDER STRIP IRRIGATION SYSTEM IN THE NICOLA VALLEY

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ABSTRACT

The research reported has been carried out to develop a border irrigation system for the semi-arid region in the Nicola Valley in British Columbia.

To develop a border irrigation system in the Valley a 60 acre field was surveyed and the design of land grading prepared. A small section of the larger prepared field was selected for this study and three border strips, each having the same length with different widths, were constructed.

Formulas and curves were used for the design calculation of slope, discharge, depth of water to be applied, required amount of water, and the time of application for each strip.

Infiltration rates, soil moisture capacities and soil classification are reported.

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I. INTRODUCTION

Irrigation is the controlled application of water to agricultural land to supply crop requirements not satisfied by normal rainfall. In arid and semi-arid lands, crop growth may be entirely dependent on the supply of supplementary water; a depth of up to 48 inches or more per season may be required depending on the climatic and growing conditions (26).

Numerous irrigation methods are applied the world over. These differ in different places from the most primitive "wild" or uncontrolled flooding to very sophisticated sprinkler irrigation systems.

Irrigation water application is commonly designated according to the manner in which water is applied to the soil. Irrigation water is applied to land by three general methods (15); namely (a) surface irrigation, in which water is applied by complete flooding, or in furrows, wetting part of the surface; (b) subsurface irrigation, in which water is applied beneath the surface, wetting the surface little if at all; and (c) sprinkler irrigation, in which the soil surface is wetted as much as it is by rainfall.

Methods of applying irrigation water vary with topography, soil condition, amount of land preparation necessary, crop to be grown, value of crops, cultural practices, and available water supply (24). The social conditions also play a role in selection of irrigation methods. The social conditions include the type of government in power, people's level of consciousness, motives for production (that is, profits, self sufficiency), availability of technology to the average farmers, and mode of production (that is, collective or individual).

Each method has certain limitations. On some sites several methods of water application are suitable. In some areas farmers have become accustomed to particular methods of applying water and continue to use them even though others are more efficient. Factors such as initial capital cost, labor, the cost and ease of installation, maintenance required, skill of operator, flexibility of the system, and the irrigator's preferences must be considered in selecting the best method of irrigation.

In the sub-irrigation method water is applied through open ditches or tile drains. A sub-irrigation sytem is very expensive and generally is used only for high value crops and in glass houses. The sub-irrigation method is suited to soil having reasonably uniform texture and permeable enough for water to move rapidly both horizontally and vertically. The soil profile must also contain a barrier against excessive losses through deep percolation. Water having a high salt content cannot be used for sub-irrigation because it raises salinity problems and deteriorates the soil structure. In some arid areas soils become saline unless adequately drained. Choice of crops is limited in some areas. Deep rooted crops generally cannot be sub-irrigated because of a high water table. Since this method of applying water requires an unusual combination of natural conditions, it can be used in only a few areas (24).

Sprinkler methods use pipes to distribute water to various parts of the field where it is sprayed into the air and falls more or less uniformly (if the system is properly designed) on all parts of the surface. The design of a sprinkler irrigation system requires detailed analysis of soil, crop, topography, and weather. Although this system of applying water is very sophisticated, MacDonald (17) indicates this system usually requires the highest initial investment and higher annual cost than any other method in British Columbia. Also according to the Soil Conservation Service Bulletin (24), wind distorts sprinkler patterns and causes uneven distribution of water which reduces crop production. The water must be clean and free of sand, debris, and large amounts of dissolved salts in order to avoid clogging of the pipes, pressure fall, and salinization of the soil. More special equipment is needed and power requirements are usually high since sprinklers operate with a water pressure of 15 to more than 100 pounds per square inch (24). A stable water supply is needed for the most economical use of the equipment. Adding to the above limitations, it should be noted that the energy requirements for this type of irrigation method renders it unsuitable for some farmers.

In surface methods water is applied directly to the soil surface by three important methods (15); namely, (a) uncontrolled or "wild" flooding, (b) furrow method, and (c) border strip method.

In the early irrigation of centuries past, water was applied by "wild flooding". It is practiced largely where irrigation water is abundant and inexpensive. It is an important and difficult problem to apply water efficiently by uncontrolled methods. The disadvantages of wild flooding are high irrigation labor requirements, low water application efficiency, and uneven water distribution. Where land and water are expensive it is not generally economical to use uncontrolled irrigation methods.

In furrow irrigation water is applied through narrow channels having a continuous slope in the direction of irrigation. The furrow irrigation method cannot be applied on the sandy soils because of high water intake rate. Again here extensive irrigation labor is required, some runoff usually is necessary for uniform water application and erosion hazards occur on steep slopes (24).

The border strip method is a form of controlled surface flooding (Figure 1). As Bishop et al. (2) describe it, although the border strip method of irrigation has some

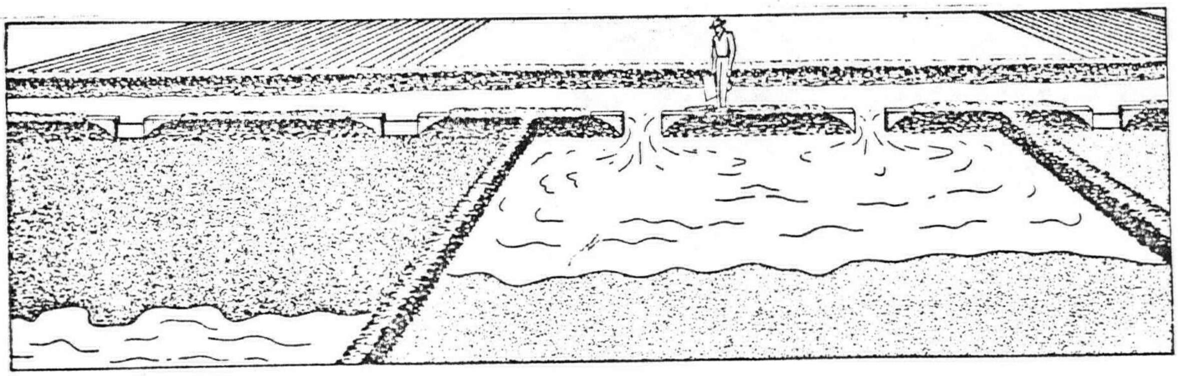


Figure 1. Graded-border irrigation.

(U.S.D.A. Soil Conservation Service) (24).

limitations such as extensive land grading and engineering cost, but if the system is properly designed then high water application efficiency, and efficient use of irrigation labor is achieved.

The border strip method is applicable on most soil types and it has low maintenance costs, and positive control over irrigation water will be obtained. Labor requirements are among the lowest for all application methods (24). The strip width can be designed to accommodate the farm machinery used for tillage, planting and harvesting (24). If surface drainage is critical the method is an excellent means for rapid disposal of excess surface water, because the excess water can be carried away in the form of tail water from the end of the border strip (if there is no dike or stoppage of waterflow at the end of the border strip).

The purpose of this study was to develop an irrigation system for a field in the Nicola Valley of British Columbia, Canada. Considering the limitations of each method, the condition of the area, funding available, and consulting with the co-operative farmer, it was felt that the border strip method would be the most suitable and efficient one for the above area. Therefore this study has been carried out to develop a border strip irrigation system to determine:

1) The amount and depth of water required for each strip, the rate of flow of water for each strip, the irrigation intervals, and the time of application of irrigation water to each strip.
2) The best length and width of each strip.
3) The uniformity of water distribution in border strip method and compare it with that of the wild flooding method.
4) The water application efficiency of the border strip method and compare it with that of the wild flooding method.

II. BORDER STRIP METHOD

The border strip method is one of the most common types of irrigation systems and is among the best methods for irrigating many crops in gentle slopes. It is simple, economical, and an efficient way to irrigate (6).

In the border irrigation water is applied on the ground at the ground level and it flows by gravity over the surface of the field. It is a controlled flooding process.

The area to be irrigated is divided into strips by constructing border dikes or levees. The border strips are wide, shallow channels in which the water flows from the head ditch to the end of the strip, moistening the soil as it flows down the slope. Each strip is irrigated by "turning in" a stream of water at the upper end. The stream must be large enough to spread over the entire width between the border dikes without overtopping them (23). The dikes restrict the lateral movement of water, causing it to flow to the end of the field between the dikes. The dikes must be higher for the gentle slopes than for the steeper ones. The base of the dikes should also be broad, so that farming operations can be carried on also over the constructed dikes (20).

As the Soil Conservation Service Bulletin (24) indicates, the border strips should have little or no cross slope, but should have some slope in the direction of irrigation. The amount of slope that is required depends mainly on the available water supply, the soil, the climate, and the crops. Therefore, the best type of land preparation for border irrigation is a uniform slope in the direction of irrigation with no cross slope (1). The border strip method is commonly used when slopes in the direction of irrigation (parallel to the dikes) ranges from 0.1 to 1% for most crops to as much as 6% for pasture lands (2). Therefore, extensive grading is usually required for the border strip method of irrigation.

The border irrigation method is suitable for most close-growing crops such as grain and alfalfa and some row crops such as cotton and some orchards (6). It cannot be used on soils that have very low or very high intake rates.

The limitations of the border strip method are extensive land grading, engineering designs are necessary for high efficiencies, relative large flows are required, shallow soils cannot be economically graded, and dikes hinder cultivation and harvesting.

Well planned, adequately constructed, and on adapted land, the border strip method makes possible efficient and economical irrigation.

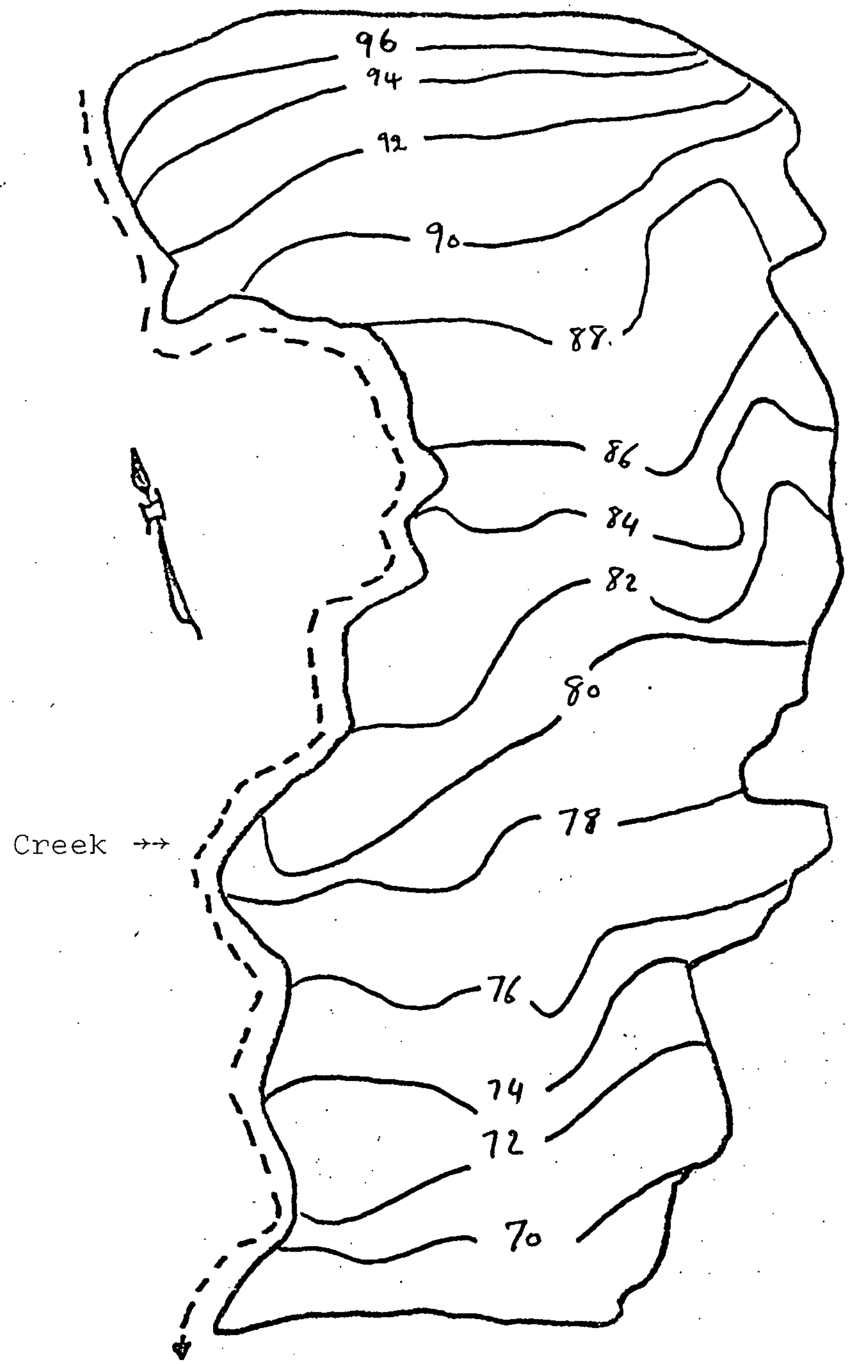
III DESCRIPTION OF THE AREA

The Nicola Valley area is located between Merritt and Kamloops in the Province of British Columbia. The land ranges in elevation from 1000 to 6000 feet, consisting mainly of plateau areas intersected by small alluvial valleys. Willcocks (26) has reviewed and determined that most of the agriculture is carried on below the 2500 feet level. He also has indicated that the rock underlying the land surface of the Nicola Valley varies from limestone to igneous intrusions of granite. Generally the soils are calcareous in nature. For agricultural purposes they are deficient in Nitrogen and Phosphorous (26).

The Nicola Valley area receives 10 inches of precipitation annually (4). The cumulative evapotranspiration at Merritt adjusted for the length of the growing season is taken as 31.9" (26). During the growing season the average total precipitation from April to October inclusive, is 4.7" (26). This decreases the irrigation requirement for evapotranspiration to 27.2". Therefore, it is obvious that irrigation is required for the valley to satisfy crop requirements.

In the Nicola Valley area the main crops are oats, alfalfa, red and alsike clover, and some grasses. The majority of irrigation in the area (about 80%) (26) is carried out by surface methods which have received little attention from the Provincial Government. Most of the area is irrigated by wild flooding which has poor water application efficiency and water distribution.

For this study, a 60 acre field (Figure 2) was chosen in the Valley and it was surveyed by S.R. Leggett and Associates. A design of land levelling was prepared and the border strips for controlled flood surface irrigation were constructed by a local contractor in the Nicola Valley.



NICOLA LAKE

Scale: 1" = 400'

Figure 2. Site of Experiment

IV. REVIEW OF LITERATURE

On many farms some of the irrigation water is wasted. To prevent such waste fields should be properly prepared before they are irrigated. The preparation of land for irrigation, or land grading as it is commonly called, is the reshaping of the land surface to facilitate or improve the distribution of the water.

Givan (12) found the application of the least squares method (which is a statistical procedure for obtaining the best fit to a group of points) to the problem of fitting a plane to the different elevations delineating an uneven land surface of a rectangular tract. Then Chugg (8) extended the application of the least squares method to include land areas of any shape, but the method does not necessarily provide the best slope for irrigation (21). Marr (18) indicated that the least squares and average profiles method is another adaptation of the same principle of the least squares method to the problem. The method proposed by Marr appears to be sufficiently easy to follow, practical to use and warrants wide acceptance. The Soil Conservation Service (25) suggested the plane method for land grading. The plane method assumes that the field is to be graded to a true plane. The average elevation of the field is determined, and this elevation is assigned to the centroid of the area.

In all the methods mentioned above, the slope of the land is dependent on the general topography of the land, and the "cut-fill" ratio is greater than one. The "cut-fill" ratio is the amount of cut divided by the amount of fill. Experience has shown that this ratio should be greater than one (21). Compaction from equipment in the cut area which reduces the volume of cut and also compaction in the fill area which increases the fill volume needed are believed to be the principal reasons for this effect. It would be a serious problem, as far as erosion is concerned, if the calculated slope became more than 2% for border strip method. A variation of the plan method is proposed. In the method the irrigator will choose the slope of the land both G_{NS}* and G_{WE}** (Figure 3). Besides the amount of fill in this method would be equal to the amount of cut.

In the border irrigation method an attempt is made to adjust the size of the irrigation stream to the intake characteristics of the soil, the slope of the border strip, and the area to be covered so as to provide a nearly uniform time of water coverage (intake opportunity time) at all points along the length of the border strip.

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* G_{NS} = slope of the line which best fits the points which present the average land slope in a north to south direction across the field.

** G_{WE} = slope of the line which best fits the points which present the average land slope in a west to east direction across the field.

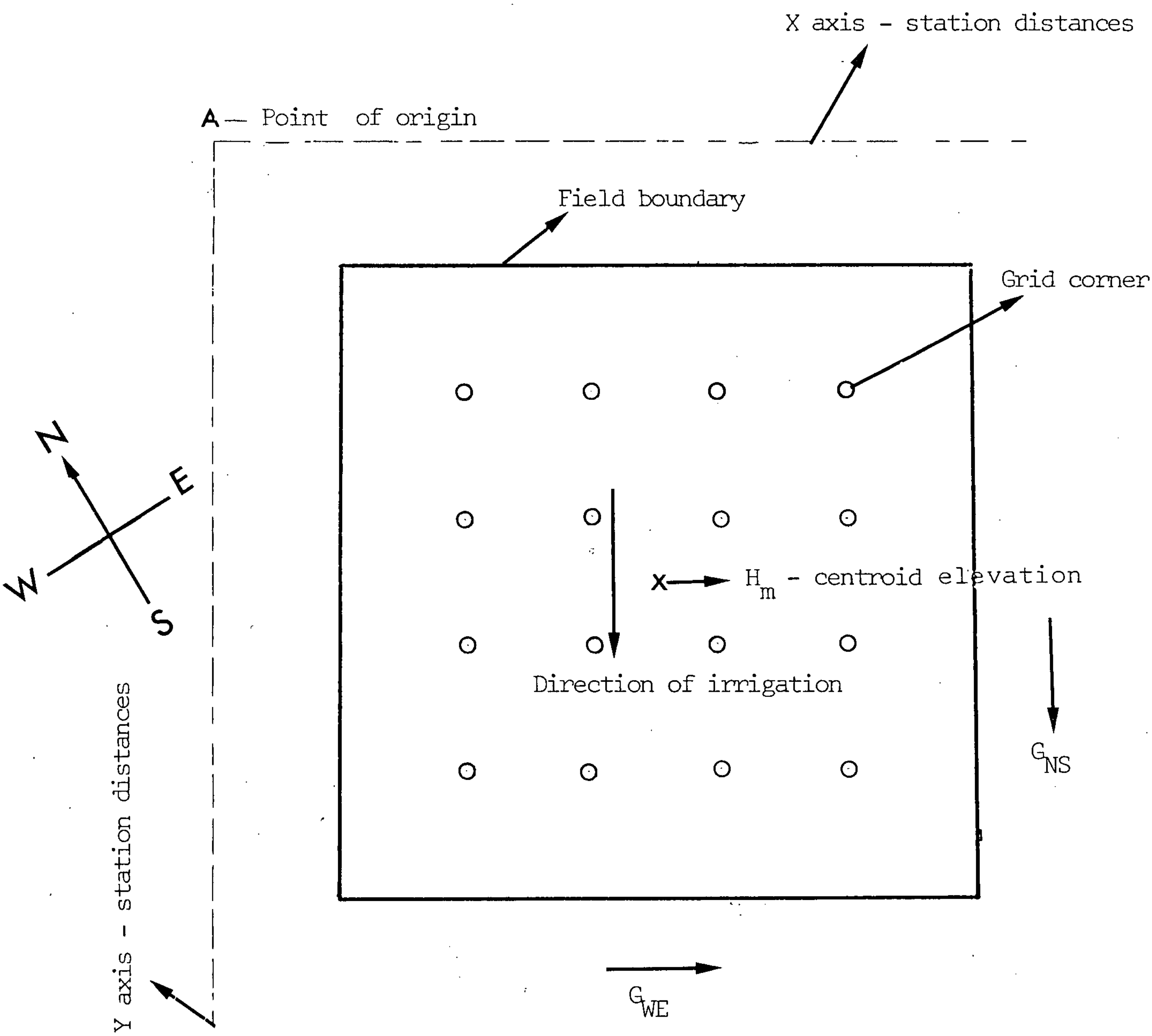

Figure 3. An example of a rectangular area which is to be graded.

A general knowledge of the hydraulics of border irrigation system is basic to border system planning and design. This includes the discharge, width of border, length of run, slope, water intake, depth of flow, time of irrigation, the total quantity of water to be applied, and water movement into soil and water advance over the land. Since some of the variables involved in the border irrigation system have not been evaluated and their relationships have not been determined, empirical procedures are currently employed in the design of surface irrigation systems. Shockley et al. (22) indicate that the completely rational method of border irrigation design demands that the designer should be able to predict the intake characteristics of the soil, the rate of advance of the water* front moving down the border strip, and the rate of recession of water** from the border strip after the irrigating stream has been turned off. Intake characteristics can be determined from cylinder infiltrometers (13), and approximate methods of predicting the advance curve have been prepared by Hall (14), and Christiansen, Bishop and Fok (7). However, no satisfactory method has been developed for predicting the rate of

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* The rate of advance of water is calculated from the time for the advancing sheet to reach various distances down the field.

** The rate of recession is calculated from the time that the water recedes past each station after the water is turned off.

recession. Therefore, Shockley et al. (22) proposed a quasi-rational method for designing a border strip irrigation. They emphasized that irrigation would be most uniform if intake opportunity time was the same for the entire length of the border.

There are a number of variables which should be considered when designing a border strip method. These variables are; size of stream, rate of advance and recession, length of run, border width, depth of flow, intake rate, slope of land surface, erosion hazard, and depth of water to be applied (21). Among the variables size of stream, slope of land surface, length of run, border width and intake rate are very important and should be considered carefully. Marr (19) has propsoed a table which can be used for estimation of these variables. In this table for each soil texture best length, slope, width and discharge have been suggested. The United States Department of Agriculture in Leaflet No. 297 (6) suggested another table for estimating these variables. Phelan and Criddle (20) have given a table which gives the border irrigation relationships for various soils, slopes, and depth of application. The tables discussed are tentative for estimating the border irrigation variables because they are of a temporary nature.

Lewis and Milne (16) described the advancing front of the border irrigation stream mathematically and pointed out that parallel advance and recession provides uniform intake opportunity time and may be obtained by stopping the inflow before the advancing front reaches the end of the border. Criddle and Davis (10) proposed a method for designing the border irrigation system. They have prepared a chart on which one could design a border strip irrigation if the data on intake rate, soil, the depth of applied water, and the slope are available. The border strip irrigation has been evaluated by Criddle et al. (9) and they have proposed a method for this evaluation. Hall (14) presented a practical method for predicting the rate of water advance moving down an irrigation border which simplifies the design of a border strip irrigation system. As Criddle et al. (9) indicated, border irrigation should be evaluated after designing and constructing in order to obtain high water application efficiency and water distribution.

From the foregoing discussion, it is concluded that for designing a border strip irrigation system one should estimate the advance of the water front as a function of time, the rate of flow, the slope, the depth of water in the border, the infiltration characteristics of the soil, and the depth of rooting zone to be replenished, that is, the total quantity of water to be applied.

V. INFORMATION REQUIRED

For developing a border irrigation system some information on climate, soils, crops and other variables is required in order to obtain a well designed system.

1) Climate

Some climatic variables such as wind, temperature, relative humidity, etc. determine the evapotranspiration which is used along with the precipitation, which is also a climatic variable, to determine the depth of water to be applied to a crop during a season. Therefore, the irrigation regime is governed by climatic variables.

Rain and snow which fall on irrigated lands are valuable as a source of water. The data on precipitation will show how much water might be available during an irrigation season.

Where irrigation water is applied by flooding methods, large amounts of water are lost by direct evaporation from the soil surface without having passed through roots, stems, and leaves of the plants. When planning irrigation projects data on both evaporation and transpiration should be available so that the designer will be able to predict the depth of application of water.

Several methods have been suggested for measuring precipitation and evapotranspiration. All forms of precipitation are measured in the basis of the vertical depth of water that would accumulate on a level surface if the precipitation remained where it fell (21). The best records are obtained at stations which are equipped with continuous rainfall records. Not only the total amount of precipitation is given, but also the intensity of each storm can be recorded. Usually for measuring the amount of precipitation and intensity a weighing or tipping bucket type gauge is used (21). If only the amount of precipitation is required, the United States Weather Bureau non-recording (standard) rain gauge (8 inches in diameter) is used.

In order to determine seasonal and peak crop water needs, a means of measuring or estimating seasonal and peak evapotranspiration is necessary.

The most direct method of measurement of evapotranspiration is by lysimeter (15). A lysimeter is a container in which plants are grown under simulated natural conditions. The container and contents are weighed at regular intervals to determine water loss by evapotranspiration. However, conditions and facilities will not always permit the weighing of the container. Also the method is a slow and laborious process.

Many empirical formulas (15) have been developed for estimating potential evapotranspiration* based on climatological measurements.

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* Potential evapotranspiration is the amount of water that could be evapotranspired in a unit time by a short green crop of uniform height completely shading the ground and never lacking for water.

If there are no data on weather measurements, the evaporation may be obtained from an evaporation pan. The Standard Weather Bureau Class A Pan (21) is normally used for determining evaporation which could be converted to evapotranspiration by considering a crop factor. This factor varies with the crop variety, the crop's stage of maturity, and the fraction of soil surface covered by the crop.

2) Soil

Knowledge of soil and water relationships is valuable to all who have the opportunity to develop irrigation systems, to obtain the best use of water available for their lands.

Soil texture is the term commonly used to designate the size or sizes of the mineral particles in a given soil. The relative proportions of sand, silt, and clay determine the soil texture. This property of soil can play an important part in the design of an irrigation system. It affects the soil-water intake rate, soil-water holding capacity, and moisture content of the soil. Although there are several principles that could be employed to determine a soil's texture, the most widely used is based upon changes in density of the soil particles suspended in water with time at a given depth. The pipette and hydrometer methods (11) are classical examples of this principle. Summation percentage curves of the different separates from particle-size analyses can be plotted as a continuous function of diameter. Then by using textural classification chart (21), one could determine the soil texture.

Soil structure implies an arrangement of the primary and secondary particles into certain structural patterns. It necessarily follows that such patterns include the accompanying pore space. Pore space plays an important role in irrigation practices because it affects water content of the soil.

The rate of entry of water into the soil under field conditions is called intake rate (15). It varies with many factors including depth of water on the surface, soil structure and moisture content of the soil. Soil intake characteristics can be determined satisfactorily from border trials (22) or from cylinder infiltrometer tests (13).

The water holding capacity of the soil is the amount of water it can hold. Coarse textured soils, such as sandy soils, hold less water than fine textured soils such as clay soils. This means that if the soil is a coarse textured soil the irrigation system must be designed to apply water more frequently than if it is a fine textured soil.

Soil moisture content is one of the most important factors that should be determined because it affects the depth of water which should be applied to the soil. There are several methods (15) for determining the soil moisture.

Among them, the neutron moisture meter is much used in the field for measuring water content. It is a non-destructive method and in this method moisture content on a volume basis can be determined in the field.

When working with irrigated soils, it is necessary to know their apparent specific gravity (15) -- or sometimes called "bulk density" -- in order to account for the water applied in irrigation. The bulk density of the soil is influenced by structure, texture, and compactness of the soil particles. The usual method for determining this property of the soil is to obtain an uncompacted and undisturbed soil sample using 7.3 cm (diameter) cores. Another method for measuring bulk density is by the gamma-ray absorption technique (15). This is a measurement of bulk density in the field.

Other information such as geographical location, size and area of the field, crops to be grown on the field, slope, available surface and sub-surface drainage systems, source of water, and the depth of rooting of the crop should be available in order to obtain a more efficient and economical border irrigation system.

VI. DEVELOPING A BORDER STRIP IRRIGATION SYSTEM

For developing a border strip irrigation system four factors should be considered. These factors are: (a) slope, (b) stream size, (c) border width, and (d) length of run.

Because the water is required to flow the length of the border, some grade is usually provided in the direction of irrigation flow. This slope is commonly understood to be the amount of fall per unit of length of the strip, expressed in feet of fall per 100 feet of length or in percent.

Before constructing the border strips, the land should be graded in order to obtain a uniform slope.

According to the least squares and average profiles method (18), the stakes are set and elevations are obtained at 100 foot intervals, 50 feet in from the property lines, thus forming a grid with the elevation known at each grid corner. For grade calculation purposes, the grid corners are located by a system of coordinates. In this case, the point of origin "A" is located 50 feet north and 50 feet west of the north-west corner of the field. The locations of the grid corners are designated in stations (number of 100 foot intervals) southward along the Y-axis and eastward along the X-axis from "A" (Figure 3).

The first step in the calculations consists of adding the elevations along each line and in each column and computing the average elevation of each line and column.

The second step consists of locating the centroid and determining its elevation, "H_m". The location of the centroid is given by the average station distances from "A" on the X and Y axes, or X_m and Y_m, so:

$$X_m = \frac{\text{sum of station distances in X direction}}{\text{number of stations in X direction}}$$

$$Y_m = \frac{\text{sum of station distances in Y direction}}{\text{number of stations in Y direction}}$$

The third step consists of determining slopes of the lines which most nearly fit the average profiles in the two coordinate directions. According to the least squares method, the slope of the line which best fits the points on each of these two profiles is:

$$G_{NS} = \frac{\sum_{i=1}^{n} (S_{y_i} H_i) - \frac{(\sum_{i=1}^{n} S_{y_i})(\sum_{i=1}^{n} H_i)}{n}}{\sum_{i=1}^{n} (S_{y_i})^2 - \frac{(\sum_{i=1}^{n} S_{y_i})^2}{n}} \qquad (1)$$

and

$$G_{WE} = \frac{\sum_{i=1}^{n} (S_{x_i} H_i) - \frac{(\sum_{i=1}^{n} S_{x_i})(\sum_{i=1}^{n} H_i)}{n}}{\sum_{i=1}^{n} (S_{x_i})^2 - \frac{(\sum_{i=1}^{n} S_{x_i})^2}{n}} \qquad (2)$$

where G_{NS} = slope of the line which best fits the points which represent the average land slope in a north to south direction across the field.

G_{WE} = slope of the line which best fits the points which represent the average land slope in a west to east direction across the field.

$\sum_{i=1}^{n}$ = sum of n values.

$\sum_{i=1}^{n} (S_i H_i)$ = the sum of the product of the station distance and elevation of each of the plotted points.

$(\sum_{i=1}^{n} S_i)(\sum_{i=1}^{n} H_i)$ = The product of the sums of the station distances and the elevation of each of the plotted points.

n = the number of plotted points.

$\sum_{i=1}^{n} (S_i)^2$ = the sum of squares of the station distances of each of the plotted points.

$(\sum_{i=1}^{n} S_i)^2$ = the square of the sum of the station distance of each of the plotted points.

The fourth step consists of using slopes G_{NS} and G_{WE} and the elevation of the centroid to delineate the plane which best fits all of the grid corner elevations. The elevation of the point "A", a, is found by:

$$a = H_m - (G_{WE})(X_m) - (G_{NS})(Y_m) \qquad (3)$$

In this equation the only unknown element is "a" which could be determined. The new elevations which would correspond with the old elevations would be found from:

$$H_{new} = a + (G_{WE})(X) + (G_{NS})(Y). \qquad (4)$$

Then the amount of cut or fill would be determined for each grid corner. An example of this method is represented in Appendix I.

In this equation, G_{WE} and G_{NS} are dependent on the general topography of the land and the amount of cut is not usually equal to the amount of fill. It will be found in some instances that slopes calculated by this method are either too flat or too steep to suit the crop or preferred method of irrigation. This difficulty could be solved if G_{NS} and G_{WE} are given. It is represented in the Appendix II.

The most desirable size of stream can be determined by a series of curves (9). These curves are used in estimation of the unit stream size as a function of basic intake rate, slope, and depth of water to be applied.

The depth of water to be applied is determined by:

$$d = \frac{P_w \text{ X B.D. X D}}{100} \quad \text{or} \quad d = \frac{P_v \text{ X D}}{100} \qquad (5)$$

where

d = depth of water to be applied (cm)

P_w = available water storage capacity of the soil on dry weight basis (percentage)

B.D. = bulk density of the soil

D = depth of the rooting zone which is irrigated

P_v = available water storage capacity of the soil in volume basis (percentage).

The actual irrigation stream needed for any given border strip irrigation can be determined by (10):

$$Q = q \times \frac{L}{100} \times W \qquad (6)$$

where

Q = required irrigating stream (cfs)

q = unit stream size* (cfs)

L = length of run (ft)

W = width of border strip (ft)

The above formula can be transposed to provide a direct solution for the length of run (L) and the width of the border strip (W) by:

$$L = \frac{100 \times Q}{q \times W} \qquad (7)$$

and

$$W = \frac{100\ Q}{q \times L} \qquad (8)$$

Sometimes the size of the field dictates the desired length of run and width of a border strip. In such a case, the existing size of the field must be considered to measure the discharge and the time of application**.

After designing the border strip irrigation system, it should be evaluated in order to obtain maximum efficiency. The evaluation process has been proposed by Criddle et al.(9).

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* The unit stream size is defined as the stream in ft^3/sec required for each 100 foot length of border strip one foot wide.

** Time of application = time of spread of water + time required to fill the root zone of the soil to field capacity from the initial moisture content.

Experiment

For developing a border strip irrigation system, a 60 acre field in the Nicola Valley area was chosen. The field was surveyed with a 100 foot grid system of levels. The least squares and average profiles method was used for calculating the land grading. The procedure for land grading has been described in Chapter VI. There are two ditches in the field (Figure 4) separating it into three different sections; therefore the 60 acres of land was divided into three sections for land grading. Each section was graded independently. For each section G_{NS} and G_{WE} and the amount of cut and fill were calculated. The left top section of the field was chosen for the construction of border strips.

Three border strips each having a length of 600 feet were constructed with different widths (two strips having the width of 25 and one of 50 feet). The reasons for this selection were due to the limitations of the field and farmer's preferences. In each border strip 3 aluminum tubes (2" diameter) were installed into the soil in order to measure the soil moisture content and bulk density of the different depths of the soil by means of nuclear probes.

The first step in developing a border strip irrigation is to determine the basic intake rate of the soil. The double ring infiltrometer was used to measure the basic intake rate. Double rings consist of two metal cylinders,

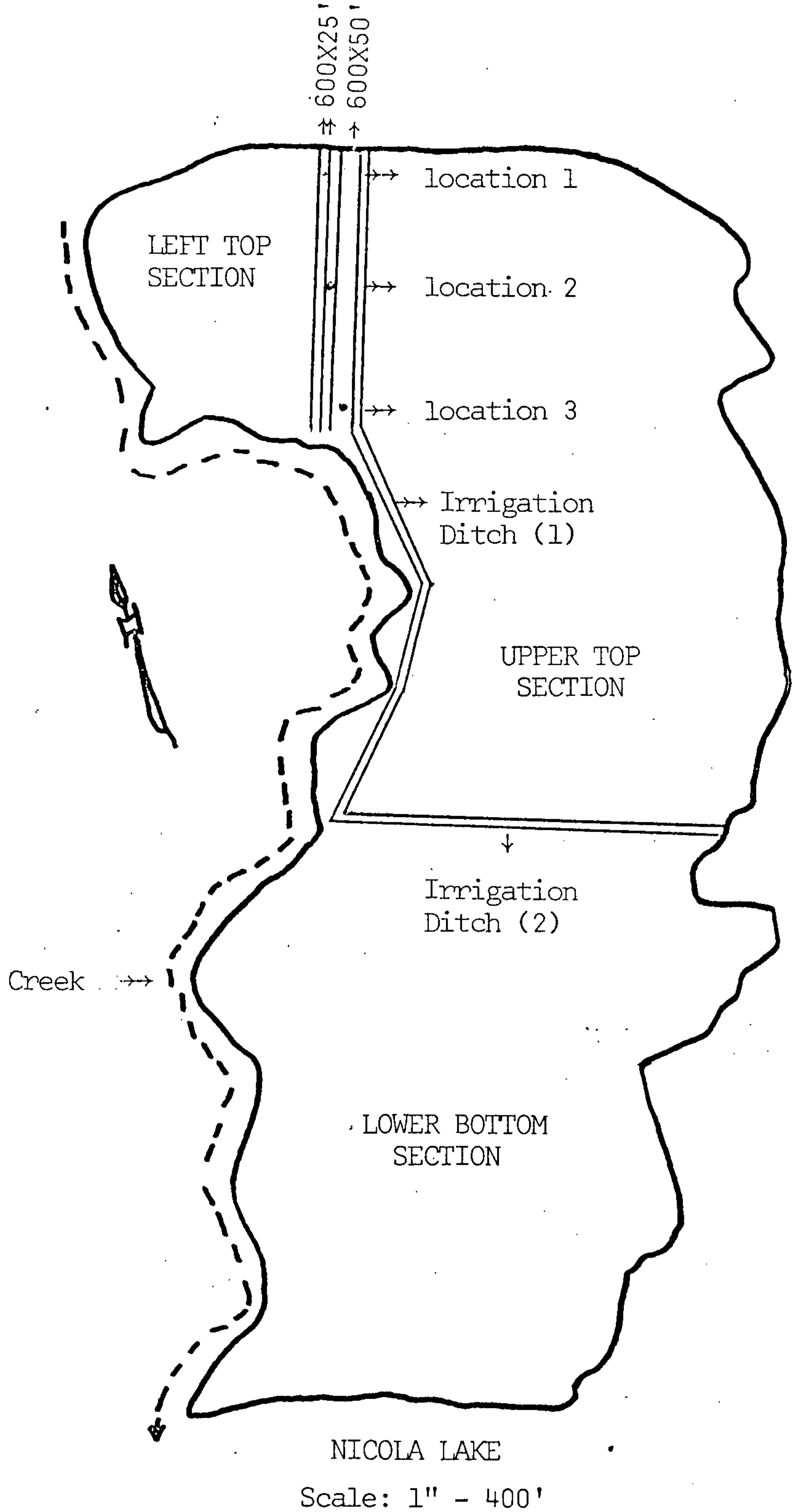

Figure 4. Irrigation ditches 1 and 2 divide the field into 3 sections. The locations of holes for soil sampling are indicated in each border strip.

one slightly larger than the other. The diameters of the cylinders were 10 and 8 inches respectively. The length of each cylinder was 18 inches in which 4 inches of each cylinder was driven into the soil. Water was added to these cylinders and the rate of which it was absorbed during recorded time periods was determined. Two infiltrometers were installed in the soil, both in the middle strip, one 100 feet from the upper end and the other 100 feet from the lower end of the strip. The basic intake rate (which is the rate at which water would enter the soil after a period of several hours, when the change in the rate becomes very slow) was determined.

Core samples as well as bulk soil samples were taken at 3 locations (Figure 4, location 1, 2 and 3). Both core and bulk samples were taken at approximately the same depth at which soil moisture measurements were estimated, to a depth of 36 inches (the average rooting zone of alfalfa, clover and oats is 36 inches).

In order to measure the soil texture, the bulk samples from different depths (0-6", 6"-12", 12"-18", 18"-24", 24"-30", and 30"-36") were taken at the 3 locations. All of the 18 samples were sieved through a 2 mm sieve to separate the gravel from the "fine earth". Approximately 40 grams of each sample was mixed with 30 ml of water and 100 ml of 6% of H_2O_2 (H_2O_2 is used to remove the organic matter in the sample). Each mixture was heated on a hot plate and 5 ml of 30% H_2O_2 was added to remove all organic matter. Each mixture was transferred to an agitator and agitated for 15 minutes. Then each mixture was transferred to a one liter cylinder. Water was added to make the volume up to one liter and it was kept at 20°C for 24 hours. Using the hydrometer method (11) the change in the density of the solution with time at a different depth was measured. Summation percentage curves of the different separates from particle size analysis were plotted as a continuous function of diameter. Then, the texture of the soil was determined by textural classification chart (21).

Laboratory experiments were carried out on the core samples and bulk samples to determine the soil water characteristics at the different depths (0-6", 6"-12", 12"-18", 18"-24", 24"-30", and 30"-36"), soil bulk density, available water storage capacity, and porosity for the 3 locations.

The soil water tension, the tenacity with which the soil holds water against a pull, as a function of volumetric water content was defined for the soils from the various depths over a range of zero to 15 atmospheres. This was accomplished in three stages (3). From zero to 100 cm H_2O tension, a hanging column water manometer was used. From 100 to 1000 cm H_2O tension, the pressure plate with the hanging column mercury manometer equipment and for tensions ranging from one atmosphere to 15 atmospheres, the high pressure membrane apparatus were used.

After the first stage, core samples were put in the oven and kept at 105°C for 24 hours. The bulk density at each depth was determined by (15):

$$\text{B.D.} = \frac{\text{weight of dry soil}}{\text{total volume of soil*}}$$

Two parameters, field capacity and the permanent wilting point (5) are important in terms of available water holding capacity. "Field capacity" is the soil water content retained by the soil following an irrigation or heavy rain, after downward movement of water has materially decreased. It is the upper limit of soil water available for plant use. It usually occurs at about 0.3 bars of soil moisture tension. "Permanent wilting point" is the water content of the soil when plants growing in it are wilted to the point where they will not recover when placed in a humid cabinet for 12 hours in an atmosphere of 100% relative humidity. It usually occurs at about 15 bars of soil moisture tension. The available water storage capacity is the range in the soil water between field capacity and permanent wilting point and it is found from the soil moisture characteristics curves by determining the field capacity which is selected at 0.3 bars and permanent wilting

* Total volume of the soil is equal to the volume of the core. The diameter and the length of the core are 7.3 and 7.6 cm respectively.

point which is selected at 15 bars. From these curves the porosity of the soil at each depth for the 3 locations were also determined.

VII. RESULTS AND DISCUSSION

1. Land Grading

The G_{NS} and G_{WE} for each section of the field were calculated and are shown in Tables 1, 2, and 3. Since the left top section of the field was chosen for the construction of the border strips. The land grading of this section of the field will be discussed here (Table 1).

According to the least squares and average profiles method, the land grading calculations for the left top section are as follows:

H_m = elevation of the centroid = 92.53

$$X_m = \frac{1 + 2 + 3 + 4 + 5}{5} = 3$$

$$Y_m = \frac{1 + 2 + 3 + 4 + 5 + 6}{6} = 3.5$$

Computation for G_{NS}:

ΣS = 21

$(\Sigma S)^2$ = 441

$\Sigma (S)^2$ = 91

(ΣH) = 555.18

(ΣSH) = 1921.74

$$G_{NS} = \frac{\Sigma(SH) - \dfrac{(\Sigma S)(\Sigma H)}{n}}{\Sigma(S)^2 - \dfrac{(\Sigma S)^2}{n}}$$

$$G_{NS} = \frac{1921.74 - \dfrac{21 \times 555.18}{6}}{91 - \dfrac{441}{6}} = -1.22 \text{ ft/100 ft}$$

(Minus sign indicates slope is southward from "A").

TABLE 1 LEFT TOP SECTION - ORIGINAL ELEVATIONS

						Line Totals	Line Average
	97.70	96.20	96.40	95.50	95.70	481.50	96.30
	95.50	95.10	94.10	93.30	93.30	471.30	94.26
	93.50	92.80	92.40	91.90	91.80	462.40	92.48
	92.40	92.30	91.30	90.70	90.50	457.20	91.44
	91.70	91.60	90.20	89.60	89.30	452.40	90.48
	92.30	92.00	89.90	88.70	88.20	451.10	90.22
Column Totals	563.10	560.00	554.30	549.70	548.80	2775.90	92.54
Column Average	93.85	93.33	92.38	91.62	91.47		↑ Elevation of Centroid (Hm)

G_{NS} = -1.2222' PER 100 FEET

G_{WE} = -0.6482' PER 100 FEET

NEW ELEVATIONS/CUTS AND FILLS FOR LEFT TOP SECTION

Positive numbers signify fills — Negative numbers signify cuts

96.882	96.234	95.585	94.937	94.289
(-0.818)	(0.034)	(-0.815)	(-9.563)	(-1.411)
95.660	95.011	94.363	93.715	93.067
(0.160)	(-0.089)	(0.263)	(0.415)	(-0.233)
94.437	93.789	93.141	92.493	91.845
(0.937)	(0.989)	(0.741)	(0.593)	(0.045)
93.215	92.567	91.919	91.271	90.622
(0.815)	(0.267)	(0.619)	(0.571)	(0.122)
91.993	91.345	90.697	90.048	89.400
(0.293)	(-0.255)	(0.498)	(0.448)	(0.100)
90.771	90.123	89.474	88.826	88.178
(-1.529(	(-1.877)	(-0.426)	(0.126)	(-0.022)

TABLE 2. TOP SECTION - ORIGINAL ELEVATIONS

									Line Totals	Line Average
	94.80	94.30	93.70	94.00	94.40	93.20	92.50	91.90	748.80	93.60
	92.70	92.50	92.40	91.80	91.60	91.30	91.60	89.20	733.10	91.64
	90.80	91.20	91.00	90.60	90.30	87.60	87.60	89.20	718.30	89.79
	90.30	90.30	90.30	89.80	89.50	86.30	89.80	89.80	716.10	89.51
	89.20	89.10	88.80	89.20	88.30	85.90	86.00	88.10	704.60	88.07
	87.90	88.10	88.00	88.30	87.30	85.70	84.60	85.40	695.30	86.91
	86.90	86.60	87.00	87.50	87.90	87.30	87.00	83.50	693.70	86.71
	86.40	86.20	86.70	86.90	86.90	86.90	85.40	82.80	688.20	86.02
	85.70	85.60	85.10	85.60	86.40	86.10	82.10	82.10	678.70	84.84
	83.30	84.60	84.10	83.80	84.30	84.89	84.30	80.80	670.00	83.75
	82.60	83.80	83.20	82.60	81.90	83.10	83.00	79.80	660.00	82.50
	82.90	82.20	81.90	81.40	81.60	82.40	81.90	79.60	653.90	81.74
	83.50	82.70	79.10	78.30	79.60	76.50	78.30	78.70	636.70	79.59
Column Totals	1137.00	1137.20	1131.30	1129.80	1130.00	1117.10	1114.10	1100.90	8997.38	86.51
Column Average	87.46	76.48	87.02	86.91	86.92	85.93	85.70	84.68		↑ Elevation of Centroid (Hm)

G_{NS} = -1.0295' PER 100 FEET

G_{WE} = -0.3759' PER 100 FEET

TABLE 2 (Continued)

NEW ELEVATIONS/ CUTS AND FILL FOR TOP SECTION

POSITIVE NUMBERS SIGNIFY FILLS NEGATIVE NUMBERS SIGNIFY CUTS

94.006 (-0.794)	93.630 (-0.670)	93.254 (-0.446)	92.878 (-1.122)	92.502 (-1.898)	92.126 (-1.074)	91.750 (-0.750)	91.375 (-0.525)
92.977 (0.277)	92.601 (0.101)	92.225 (-0.175)	91.849 (0.049)	91.473 (-0.127)	91.097 (-0.203)	90.721 (-0.879)	90.345 (1.145)
91.947 (1.147)	91.571 (0.371)	91.195 (0.195)	90.819 (0.219)	90.443 (0.143)	90.067 (2.467)	89.691 (2.091)	89.315 (0.115)
90.918 (0.618)	90.542 (0.242)	90.166 (-0.134)	89.790 (-0.010)	89.414 (-0.086)	89.038 (2.738)	88.662 (-1.138)	88.286 (-1.514)
89.888 (0.688)	89.512 (0.412)	89.136 (0.336)	88.760 (-0.440)	88.384 (0.084)	88.008 (2.108)	87.632 (1.632)	87.256 (-0.844)
88.859 (0.959)	88.483 (0.383)	88.107 (0.107)	87.731 (-0.569)	87.355 (0.055)	86.979 (1.279(	86.603 (2.003)	86.227 (0.827)
87.829 (0.929)	87.453 (0.853)	87.077 (0.077)	86.701 (-0.799)	86.325 (-1.575)	85.949 (-1.351)	85.573 (-1.427)	85.197 (1.697)
86.800 (0.400)	86.424 (0.224)	86.048 (-0.652)	85.672 (-1.228)	85.296 (-1.604)	84.920 (-1.980)	84.544 (-0.856)	84.168 (1.368)
85.770 (0.070)	85.394 (-0.206)	85.018 (-0.082)	84.642 (-0.958)	84.266 (-2.134)	83.890 (-2.210)	83.514 (1.414)	83.138 (1.038)
84.741 (1.441)	84.365 (-0.235)	83.989 (-0.111)	83.613 (-0.187)	83.237 (-1.063)	82.861 (-1.939)	82.485 (-1.815)	82.109 (1.309)
83.711 (1.111)	83.335 (-0.465)	82.959 (-0.241)	82.583 (-0.017)	82.207 (0.307)	81.831 (-1.269)	81.455 (-1.545)	81.079 (1.279)
82.682 (-0.218)	82.306 (0.106)	81.930 (0.030)	81.554 (0.154)	81.178 (-0.422)	80.802 (-1.598)	80.426 (-1.474)	80.050 (0.450)
81.652 (-1.848)	81.276 (-1.424)	80.900 (1.800)	80.524 (2.224)	80.148 (0.548)	79.772 (3.272)	79.396 (1.096)	79.020 (0.320)

TABLE 3. BOTTOM SECTION - ORIGINAL ELEVATIONS

									Line Totals	Line Average
	82.50	82.20	82.50	82.00	80.60	80.40	77.20	80.80	648.20	81.20
	82.00	81.40	80.50	80.10	79.40	78.60	73.50	79.40	634.90	79.36
	80.50	80.70	80.10	78.80	77.10	76.80	78.40	78.40	630.80	78.85
	80.20	80.00	80.60	79.50	77.40	78.90	74.30	74.90	625.80	78.22
	77.40	76.90	77.70	77.30	75.40	76.30	74.30	73.00	608.30	76.04
	76.90	76.10	76.80	77.00	76.50	76.50	73.50	73.30	606.60	75.82
	75.00	75.20	75.90	75.70	73.40	75.50	75.40	72.50	598.60	74.82
	74.10	74.30	74.60	74.50	73.10	73.70	75.20	72.70	592.20	74.02
	73.90	73.30	73.30	73.40	73.80	72.30	74.30	74.90	589.20	73.65
	72.40	72.50	72.30	72.00	71.30	71.60	72.80	69.80	574.70	71.84
	71.70	72.10	71.70	70.70	71.00	70.00	70.30	69.50	567.00	70.87
	68.50	68.80	68.90	71.50	69.20	69.00	68.50	68.00	552.40	69.05
	69.70	68.80	68.30	68.20	69.50	69.90	70.10	70.30	554.80	69.35
Column Totals	984.80	982.30	983.20	980.70	967.70	969.50	957.80	957.50	7783.48	74.84 ↑
Column Average	75.75	75.56	75.63	75.44	74.44	74.58	73.68	73.65		Elevation of Centroid (Hm)

G_{NS} = 0.9849' PER 100 FEET

G_{WE} = 0.3367' PER 100 FEET

TABLE 3 (Continued) NEW ELEVATIONS/ CUT AND FILL FOR BOTTOM SECTION

POSITIVE NUMBERS SIGNIFY FILLS NEGATIVE NUMBERS SIGNIFY CUTS

81.929 (-0.571)	81.592 (-0.608)	81.256 (-1.244)	80.919 (-1.081)	80.582 (-0.018)	80.246 (-0.154)	79.909 (2.709)	79.572 (-1.228)
80.944 (-1.056)	80.607 (-0.793)	80.271 (-0.229)	79.934 (-0.166)	79.597 (0.197)	79.261 (0.661)	78.924 (5.424)	78.587 (-0.813)
79.959 (-0.541)	79.622 (-1.078)	79.286 (-0.814)	78.949 (0.149)	78.612 (1.512)	78.276 (1.476)	77.939 (-0.461)	77.602 (-0.798)
78.974 (-1.226)	78.638 (-1.362)	78.301 (-2.299)	77.964 (-1.536)	77.628 (0.228)	77.291 (-1.609)	76.954 (2.654)	76.618 (1.718)
77.989 (0.589)	77.653 (0.753)	77.316 (-0.384)	76.979 (-0.321)	76.643 (1.243)	76.306 (0.006)	75.969 (1.669)	75.633 (2.633)
77.004 (0.104)	76.668 (0.568)	76.331 (-0.469)	75.994 (-1.006)	75.658 (-0.842)	75.321 (-1.179)	74.984 (1.484)	74.648 (1.348)
76.020 (1.020)	75.683 (0.483)	75.346 (-0.554)	75.010 (-0.690)	74.673 (1.273)	74.336 (-1.164)	73.999 (-1.400)	73.663 (1.163)
75.035 (0.935)	74.069 (0.398)	74.361 (-0.239)	74.025 (-0.475)	73.688 (0.588)	73.351 (-0.349)	73.015 (-2.185)	72.678 (-0.022)
74.050 (0.150)	73.713 (0.413)	73.376 (0.076)	73.040 (-0.360)	72.703 (-1.097)	72.366 (0.066)	72.030 (-2.270)	71.693 (-3.207)
73.065 (0.665)	72.728 (0.228)	72.392 (0.092)	72.055 (0.055)	71.718 (0.418)	71.382 (-0.219)	71.045 (-1.755)	70.708 (0.908)
72.080 (0.380)	71.743 (-0.357)	71.407 (-0.293)	71.070 (0.370)	70.733 (-0.267)	70.397 (0.397)	70.060 (-0.240)	69.723 (0.223)
71.095 (2.595)	70.758 (1.958)	70.422 (1.522)	70.085 (-1.415)	69.748 (0.548)	69.412 (0.412)	69.075 (0.575)	68.738 (0.738)
70.110 (0.410)	69.774 (0.974)	69.437 (1.137)	69.100 (0.900)	68.764 (-0.736)	69.427 (-1.473)	68.090 (-2.010)	67.753 (-2.547)

Computation for G_{WE}:

$(\Sigma S) = 15$

$(\Sigma S)^2 = 225$

$\Sigma(S)^2 = 55$

$(\Sigma H) = 462.5$

$\Sigma(SH) = 1381.48$

$$G_{WE} = \frac{1381.48 - \frac{15 \times 462.65}{5}}{55 - \frac{225}{5}} = -0.65$$

(Minus sign indicates slope is eastward from "A").

$H_m = a + (G_{WE})(X_m) + (G_{NS})(Y_m)$

$92.53 = a + (-0.65)(3) + (-1.22)(3.5)$

$a = 98.75$

The new elevations that would correspond with the original elevations would be found from:

$H_{new} = a + (G_{WE})(X) + (G_{NS})(Y).$

For example, the new elevation for the station 1.1 will be:

$H_{new} = 98.75 + (-0.65)(1) + (-1.22)(1)$

$H_{new} = 96.88$

The amount of cut or fill will be calculated from substracting the original elevation from the new elevation. For example, for the station (1,1) the amount of cut will be $H_{new} - H_{original} = 96.88 - 97.70 = -0.82$. In Table 1, the positive and negative numbers designate fills and cuts respectively. This was given as an example of the data shown in

Table 1. Other data in this table were calculated in the same manner. These are calculated values which are carried in 3 significant figures, but the practical values should be considered in one significant figure.

The "cut-full" ratio of this section is approximately one. It means that the amount of cut is equal to the amount of fill. Because the border strips should have no cross slopes, the G_{WE} for each strip was adjusted.

2. Soil Properties

All data on soil properties is shown in Table 4. The average soil texture of the soil is loam and the bulk density varies from 1.27 to 1.40 gm/cm^3. The field capacity, permanent wilting point, and available water storage capacity for each depth are derived from the soil moisture retention curves which are shown in the Appendix III.

The average available water storage capacity for the field is the sum of the field capacity values of the different depth of the soil minus the average permanent wilting points. This value is equal to:

$$\text{A.W.S.C.} = \frac{5.58 + 7.72 + 7.94}{3} = 7.08 \text{ inch/3ft}$$

3. Irrigation Design

Water is not equally available to plants over the available water content range (5). The availability coefficient, which is the maximum fraction of available water storage capacity to be removed before irrigation is required, is 0.5

TABLE 4. DATA ON SOIL PROPERTIES

Location No.	Depth Inches	Bulk Density gr/cm^3	Textural Class	Porosity	Moisture Content cm^3/cm^3 at tension of 0 cm	25 cm	50 cm	75 cm	0.3 Bars	3 Bars	15 Bars	AWSC cm^3/cm^3	Average AWSC inch/3ft
1	0- 6	1.35	Loam	0.49	0.45	0.434	0.415	0.398	0.232	0.128	0.121	0.111	
"	6-12	1.36	Loam	0.49	0.45	0.439	0.426	0.419	0.2435	0.145	0.137	0.1065	
"	12-18	1.38	Sandy loam	0.48	0.45	0.43	0.424	0.413	0.185	0.1090	0.1035	0.0815	
"	18-24	1.38	Sandy loam	0.48	0.45	0.43	0.424	0.413	0.181	0.1085	0.1009	0.0801	5.58
"	24-30	1.40	Loamy sand	0.47	0.44	0.425	0.404	0.375	0.135	0.097	0.0897	0.0453	
"	30-36	1.40	Loamy sand	0.47	0.44	0.425	0.404	0.375	0.138	0.1010	0.097	0.041	
2	0- 6	1.27	Silt loam	0.52	0.48	0.463	0.449	0.439	0.2822	0.1590	0.1463	0.136	
"	6-12	1.29	Silt loam	0.51	0.47	0.431	0.420	0.412	0.2739	0.151	0.1404	0.1335	
"	12-18	1.30	Loam	0.51	0.47	0.45	0.442	0.431	0.234	0.131	0.121	0.113	
"	18-24	1.30	Loam	0.51	0.47	0.45	0.492	0.431	0.2475	0.156	0.142	0.1055	7.72
"	24-30	1.32	Sandy loam	0.50	0.45	0.434	0.41	0.392	0.169	0.095	0.0899	0.0791	
"	30-36	1.40	Sandy loam	0.47	0.44	0.425	0.404	0.375	0.165	0.0976	0.089	0.076	
3	0- 6	1.30	Loam	0.51	0.47	0.43	0.425	0.418	0.245	0.136	0.122	0.123	
"	6-12	1.30	Loam	0.51	0.47	0.458	0.453	0.447	0.236	0.129	0.117	0.119	
"	12-18	1.35	Loam	0.49	0.45	0.443	0.432	0.417	0.235	0.134	0.122	0.113	
"	18-24	1.38	Loam	0.48	0.45	0.93	0.424	0.413	0.234	0.130	0.119	0.115	7.94
"	24-30	1.38	Loam	0.47	0.45	0.43	0.424	0.413	0.2375	0.139	0.124	0.1135	
"	30-36	1.40	Sandy loam	0.47	0.44	0.418	0.415	0.393	0.170	0.1010	0.0915	0.0785	

for alfalfa (5). Therefore, the available water storage capacity would be equal to 0.5 X 7.08 = 3.54 inches per 3 feet of the soil.

The peak evapotranspiration rate for the Nicola Valley is about 0.25 inches per day (5) at the season's peak and therefore the irrigation intervals are equal to:

$$\frac{3.54}{0.25} = 14.16 \text{ days (use 14 days).}$$

Taking the irrigation efficiency at about 70 percent (22), then the depth of applied water would be calculated as:

$$\text{Depth of applied water} = \frac{14 \text{ X } 0.25}{0.70} = 5.00 \text{ inches.}$$

The average basic intake rate for the soil is about 0.75 inches per hour as shown in Figure 5 and 6.

Considering Figure 7 (10), the unit stream size (10) would be calculated by knowing the depth of applied water and basic intake rate. Therefore, the unit stream size (q) will be equal to 0.0042 ft^3/sec. However, the slope of the strip is 1.22 percent, therefore, referring to Table 5 (21), the slope factor for 1.22 percent would be calculated as 0.82. Thus, the actual unit stream size would be as follows:

$$q = 0.82 \text{ X } 0.0042 = 0.003444 \text{ cfs/ft of width.}$$

Table 6 shows the summary of the above discussion and also the actual discharge, Q, the total volume of water, and the time of application for 2 different strips.

According to the land grading calculations, G_{NS} for the left top section, where the border strips were

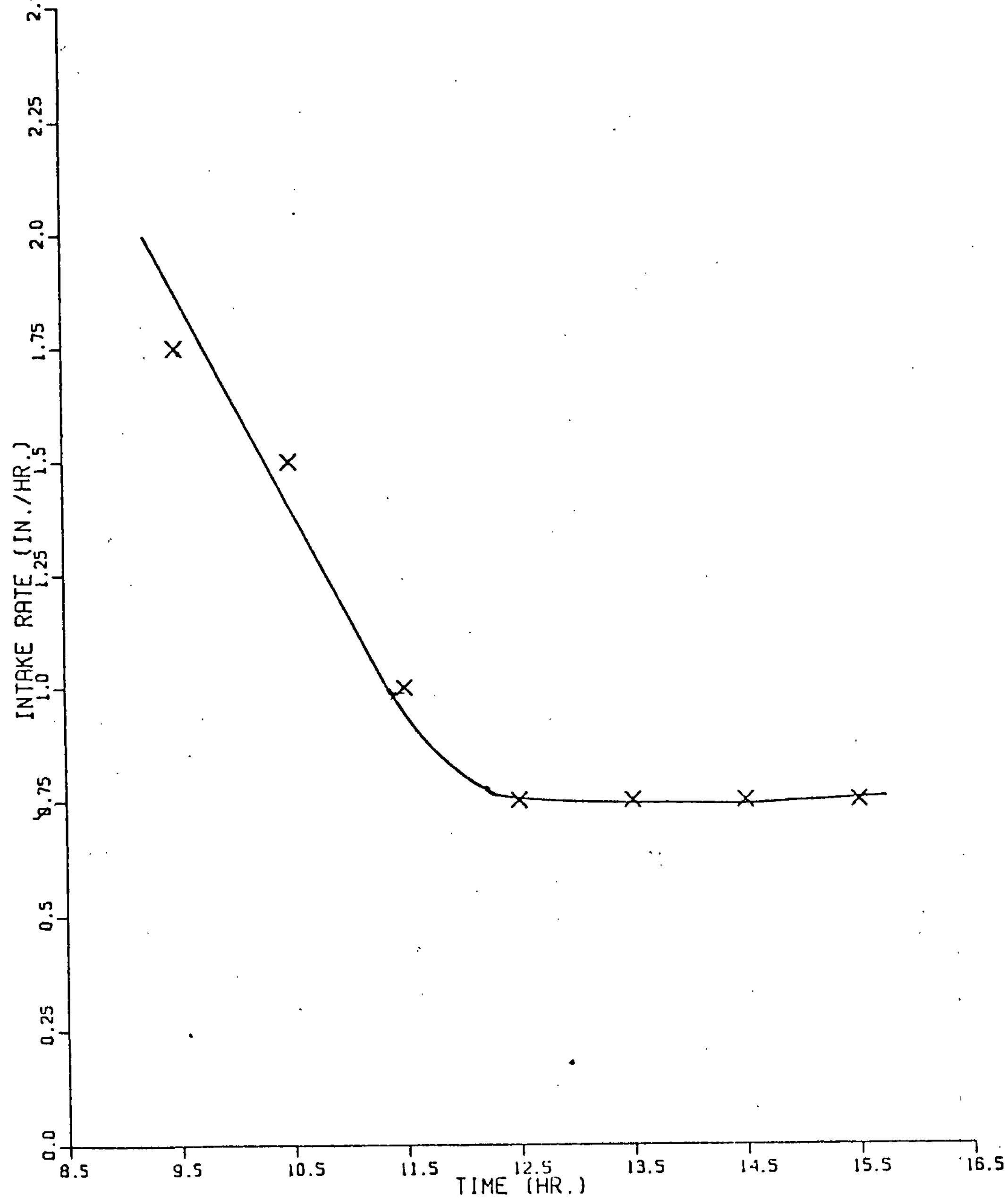

Figure 5. Intake rate curve developed from infiltrometer data.

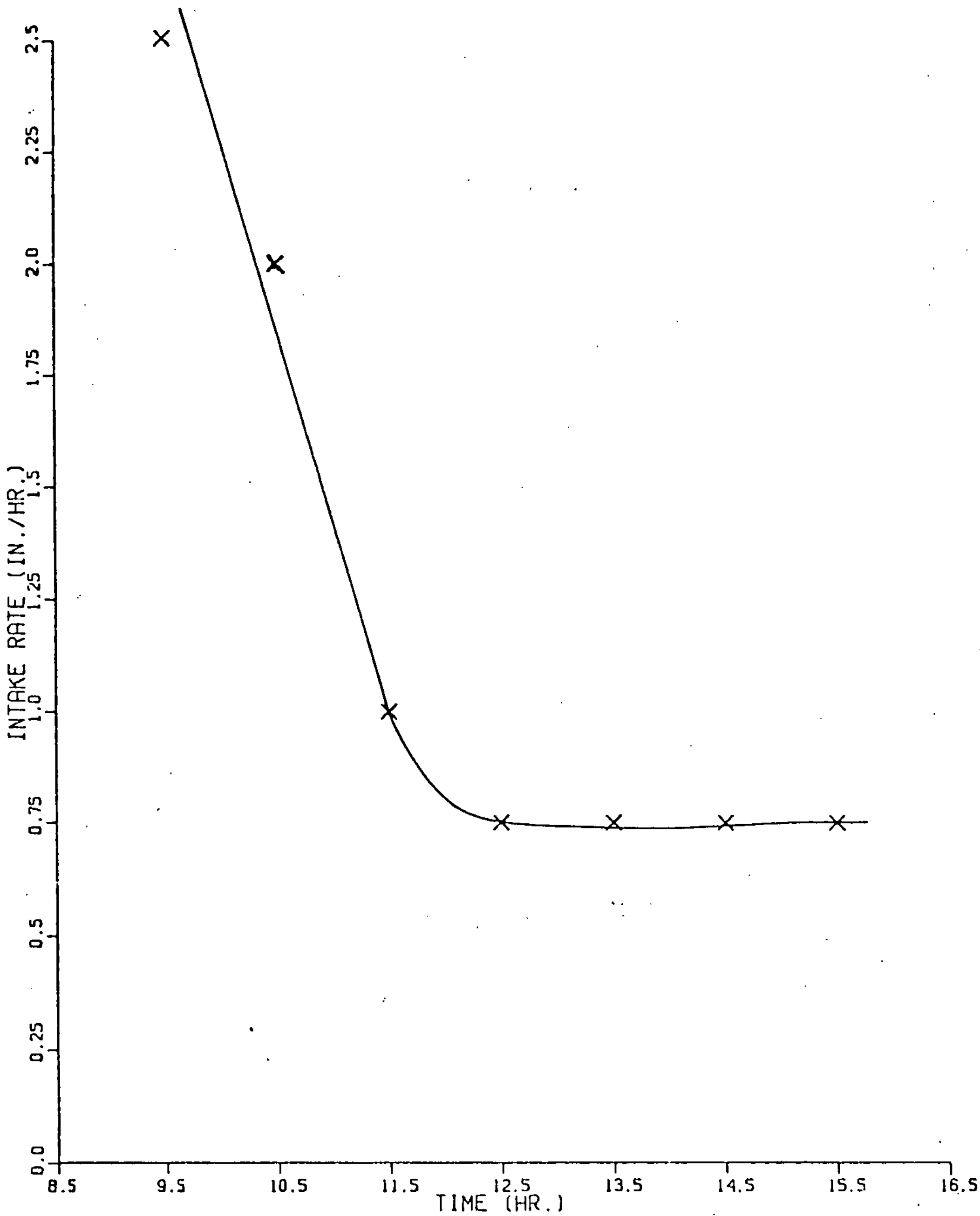

Figure 6. Intake rate curve developed from infiltrometer data.

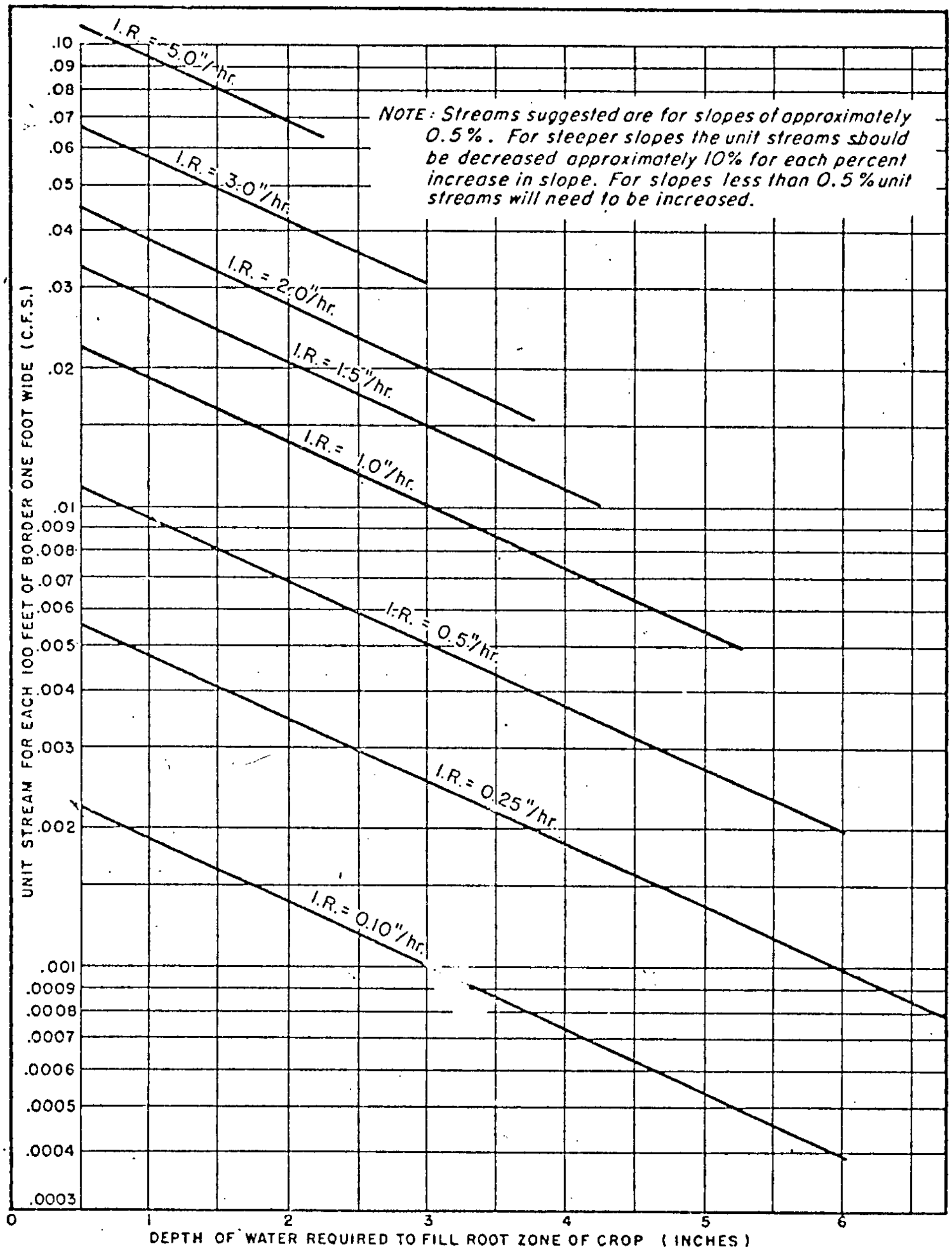

Figure 7. Curves for determining desirable size of streams to use on a border strip 1' wide and 100' long for soils having different basic intake rates (I.R.). Taken from reference (10).

TABLE 5. FACTORS FOR USE IN ADJUSTING UNIT STREAMS FROM FIGURE 7 FOR SLOPES OTHER THAN 0.5 PERCENT. Taken from reference (21).

Slope %	Slope Factor	Slope %	Slope Factor
Level	2.00	2.5	0.70
0.1	1.43	3.0	0.67
0.2	1.23	4.0	0.63
0.3	1.13	5.0	0.60
0.4	1.04	6.0	0.58
0.5	1.00	7.0	0.56
0.6	0.96	8.0	0.54
0.7	0.93	9.0	0.53
0.8	0.90	10.0	0.52
0.9	0.88	11.0	0.51
1.0	0.85	12.0	0.50
1.5	0.78		
2.0	0.74		

TABLE 6. SUMMARY OF BORDER IRRIGATION RELATIONSHIPS

Depth of Applied Water (Inch)	Peak Evapo-transpiration (inch/day)	Basic Intake Rate (inch/hr)	Unit Stream Size (ft^3/sec)	Width (ft)	Length of run (ft)	Discharge (ft^3/sec)	Volume of Water ft^3	Time of Application hrs	Irrigation Interval days
5.00	0.25	0.75	0.003444	50	600	$\frac{0.003444 X 600 X 50}{100}$ = 1.03	$\frac{50 X 600 X 5}{12}$ = 12500	$t=\frac{12500}{1.03 X 3600}$ = 3.37	14
5.00	0.25	0.75	0.003444	25	600	0.52	6250	t=3.34	14

constructed, is equal to 1.22 percent. This land is supposed to be used for cultivation of alfalfa. The slope limitations for border irrigated alfalfa are 0.15 percent minimum and approximately 1.5 percent maximum, but a uniform slope ranging from 0.2 to 0.3 percent is usually ideal for alfalfa (19). Therefore, it is obvious that 1.22 percent is not satisfactory for alfalfa but it is possible.

The following steps trace the procedures followed and indicate the conditions which impeded completion of planned research.

1) The land loaned for this project was levelled crosswise by a local contractor.
2) Three controlled flooding strips were constructed and a corresponding uncontrolled flooding area was set aside to be used for comparison.
3) At lengthwise intervals of 50 feet, the cross slope of each strip was checked transversley. Each strip was found to have a variation from side to side of less than one inch per 25 feet.
4) Water was released to each strip by rectangular weirs.
5) At this stage, contrary to expectations, the water did not flow evenly to the end of each strip. Instead, in both 25 and 50 foot widths about 2/5 had full flow of water but 3/5 of each strip remained dry.
6) Since the uneven flow condition was not satisfactory for continuing research as planned, the water was turned off.

7) On each strip the cross slope was now rechecked and revealed that the land levelling (of step 1) had not been maintained. Instead, the land settling process had resulted in as much as one foot variation instead of the maximum 1 or 2 inches per 25 feet of variation allowable for proper experiment.

This extreme variation of cross slope across the width of each strip thus made it impossible to irrigate the strips to establish proper border strip parameters.

CONCLUSIONS

This study has been carried out to develop a border strip irrigation system in a field in the Nicola Valley in British Columbia. From the foregoing results and discussion, the following conclusions are made:

1) The depth of water required for replenishment of the soil moisture is 5 inches per irrigation.
2) The 600 X 50 foot strip should be irrigated every 14 days with the discharge of 1.03 ft^3/sec. The time of application would be 3.37 hours.
3) The 600 X 25 foot strip should also be irrigated every 14 days with the discharge 0.52 ft^3/sec. The time of application would be 3.34 hours.
4) Further development of a border strip irrigation system such as designed by this study requires these supplementary steps:
   a) First - focus further experiment on establishing stable maintenance of cross slope of less than one inch per 25 feet.
   b) Next - proceed with the comparison between the water application efficiency of border strip irrigation and uncontrolled flooding.
   c) Similarly - proceed with the comparison between the uniformity of water distribution of border strip irrigation and of uncontrolled flooding.

This study is a beginning effort to face the challenge of developing a viable alternative irrigation needs of areas such as the Nicola Valley. The unavailability of funds for research aborted the thorough implementation of planned development of border strip irrigation under optimum conditions of time, materials and co-operation. Nevertheless, the review of literature and the resulting research design outlined in this study and conclusions 1, 2 and 3 above are offered as a basic frame of reference for further study whenever funds become available.

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APPENDIX I.

An example for the least squares and average profiles method.

Field size = 132m X 99m.

Station distance = 33m corner stations.

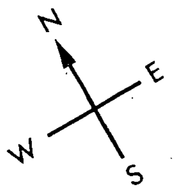
Located 33/2 = 16.5m inside

Station elevation along axis = 10,9,7,8, for Y_1.

and 9,8,8,9, for Y_2

and 9,10,9,10, for Y_3.

A



Station distance (across); Station distance (down)

	1	2	3	4	Line Totals	Line Average
1	10	9	7	8	36	8.5
2	9	8	8	9	34	8.5
3	9	10	9	10	38	9.5
Column Totals	28	27	24	27	106	
Column Average	9.33	9	8	9		H_m = 8.83

$$X_m = \frac{1 + 2 + 3 + 4}{4} = 2.5$$

$$Y_m = \frac{1 + 2 + 3}{3} = 2.0$$

$$H_m = \frac{10 + 9 \;.......\; + 9 + 10}{12} = 8.33m$$

$$G_{WE} = \frac{\Sigma(SH) - \frac{(\Sigma S)(\Sigma)}{n}}{\Sigma(S)^2 - \frac{(\Sigma S)^2}{n}} = \frac{87.33 - \frac{(10 \times 35.33)}{4}}{30 - \frac{100}{4}} = -0.199$$

Because:

$$\Sigma(SH) = (1 \times 9.33) + (2 \times 9) + (3 \times 8) + (4 \times 9)$$

$$= 87.33$$

$$\Sigma S = 1 + 2 + 3 + 4 = 10$$

$$\Sigma H = 9.33 + 9 + 8 + 9 = 35.33$$

$$\Sigma(S)^2 = 1^2 + 2^2 + 3^2 + 4^2 = 30$$

$$(\Sigma S)^2 = 100$$

$$n = 4$$

$$G_{NS} = \frac{54 - \frac{(6 \times 26.5)}{3}}{14 - \frac{36}{3}} = 0.5$$

Because:

$$\Sigma(SH) = (1 + 8.5) + (2 \times 8.5) + (3 \times 9.5) = 54$$

$$\Sigma S = 1 + 2 + 3 = 6$$

$$\Sigma(S)^2 = 1^2 + 2^2 + 3^2 = 14$$

$$(\Sigma S)^2 = 36$$

$$\Sigma H = 8.5 + 8.5 + 9.5 = 26.5$$

$$H_m = a + (G_{WE})(X_m) + (G_{NS})(Y_m)$$

$$H_m = 8.83, \quad X_m = 2.5, \quad Y_m = 2$$

$$a = 8.83 - (-0.199 \times 2.5) - (0.5 \times 2) = 8.33$$

a is the elevation of the point of origin in the plane and the new elevation, H, of each grid point corresponding to the old elevation is found by:

$$H = a + (G_{WE})(X) + (G_{NS})(Y)$$

10	9	7	8
o	o	o	o
8.63	8.43	8.23	8.03
9	8	8	9
o	o	o	o
9.13	8.93	8.73	8.53
9	10	9	10
o	o	o	o
9.63	9.43	9.23	9.03

The figures above the points show the original elevations, whereas the figures below the points are new elevations which are found by the above equation. If the figures above the points are less than the figures below the points, the rest is fill. Otherwise it should be cut. In this example the "cut-fill" ratio is 1.08.

APPENDIX II

A Variation of Plane Method

The equation, if the plane is

$$H = a + (G_{WE})(n) + (G_{NS})\, y$$

Assumption
(G_{NS} and G_{WE}: are given
(Cut = fill
(Variation between the points is linear
(H^* = original elevation
(H = new elevation

$$\sum_{i=1}^{n} (H_i^* - H_i) = 0$$

$$\sum_{i=1}^{n} (H_i^* - (G_{NS})(Y_i) - (G_{WE})(X_i) - a) = 0$$

$$\sum_{i=1}^{n} H_i^* - G_{NS} \sum_{i=1}^{n} Y_i - G_{WE} \sum_{i=1}^{n} X_i - ma = 0$$

$$a = \frac{\sum_{i=1}^{n} H_i^* - G_{NS} \sum_{i=1}^{n} Y_i - G_{WE} \sum_{i=1}^{n} X_i}{n}$$

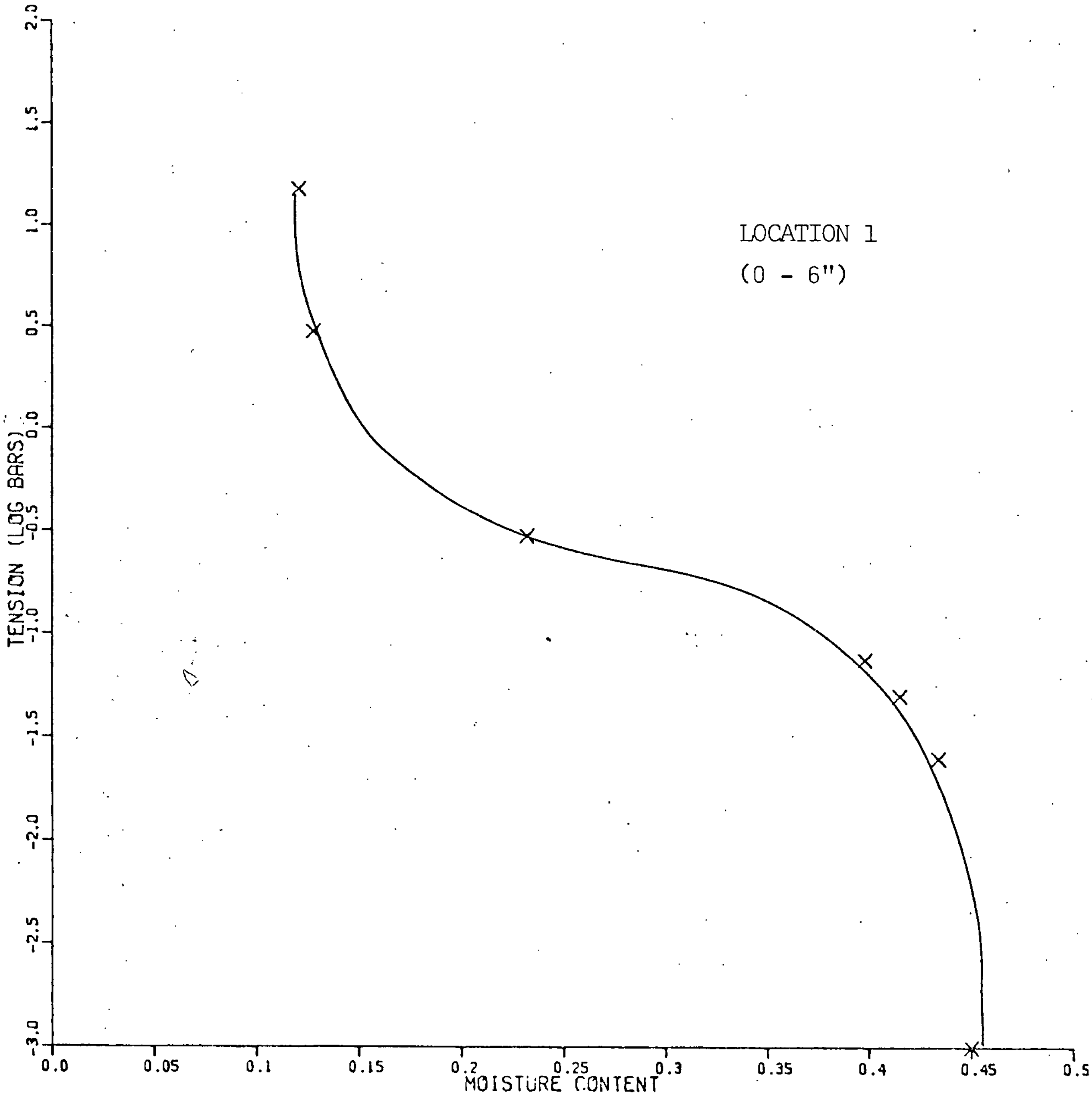
In the equation of the plane G_{WE} and G_{NS} are given, "a" will be found from the above equation and X and Y are the station numbers. Therefore, the new elevation of each point will be determined.

In this method G_{WE} and G_{NS} are not dependent on the general topography of the area and consequently there will be no problem as far as slope is concerned.

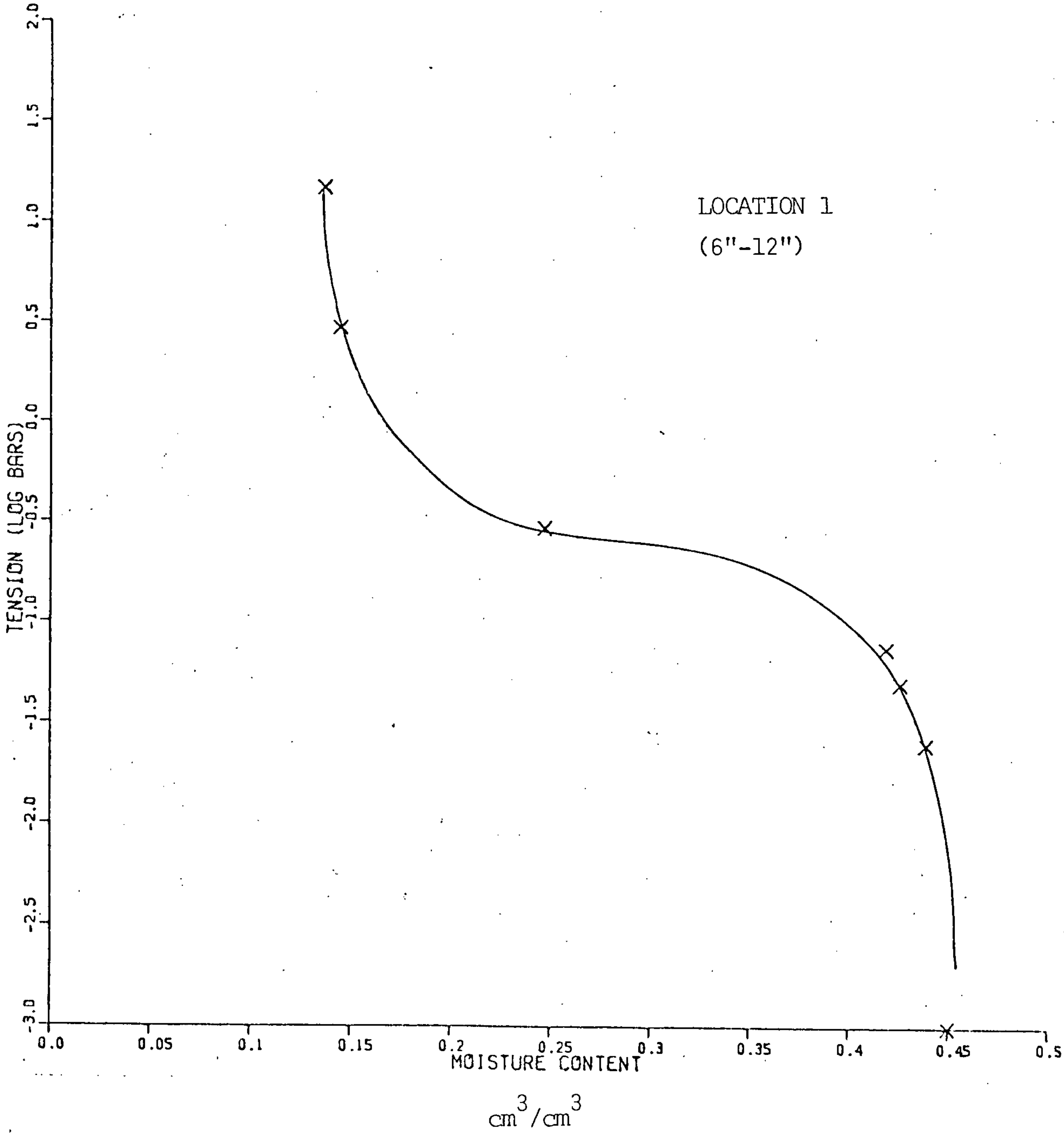
The problem with this method is that the amount of earth movement may be too great.

APPENDIX III

SOIL MOISTURE RETENTION CURVES FOR 18 SAMPLES.



cm^3/cm^3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-2.5
-3.0
0.0
0.05
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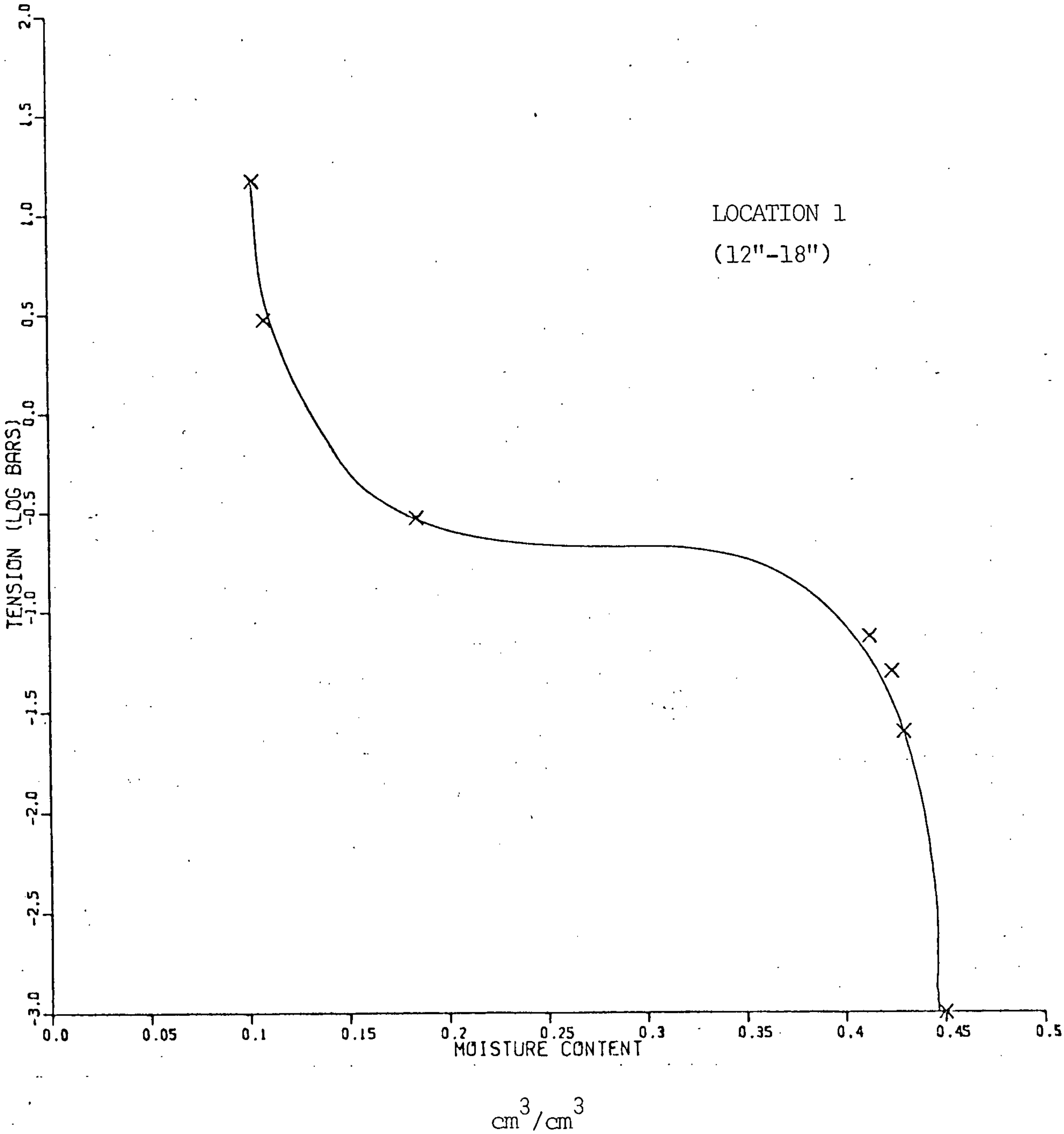
0.25
0.3
0.35
0.4
0.45
0.5
MOISTURE CONTENT
cm³/cm³



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0.0
0.05
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0.25
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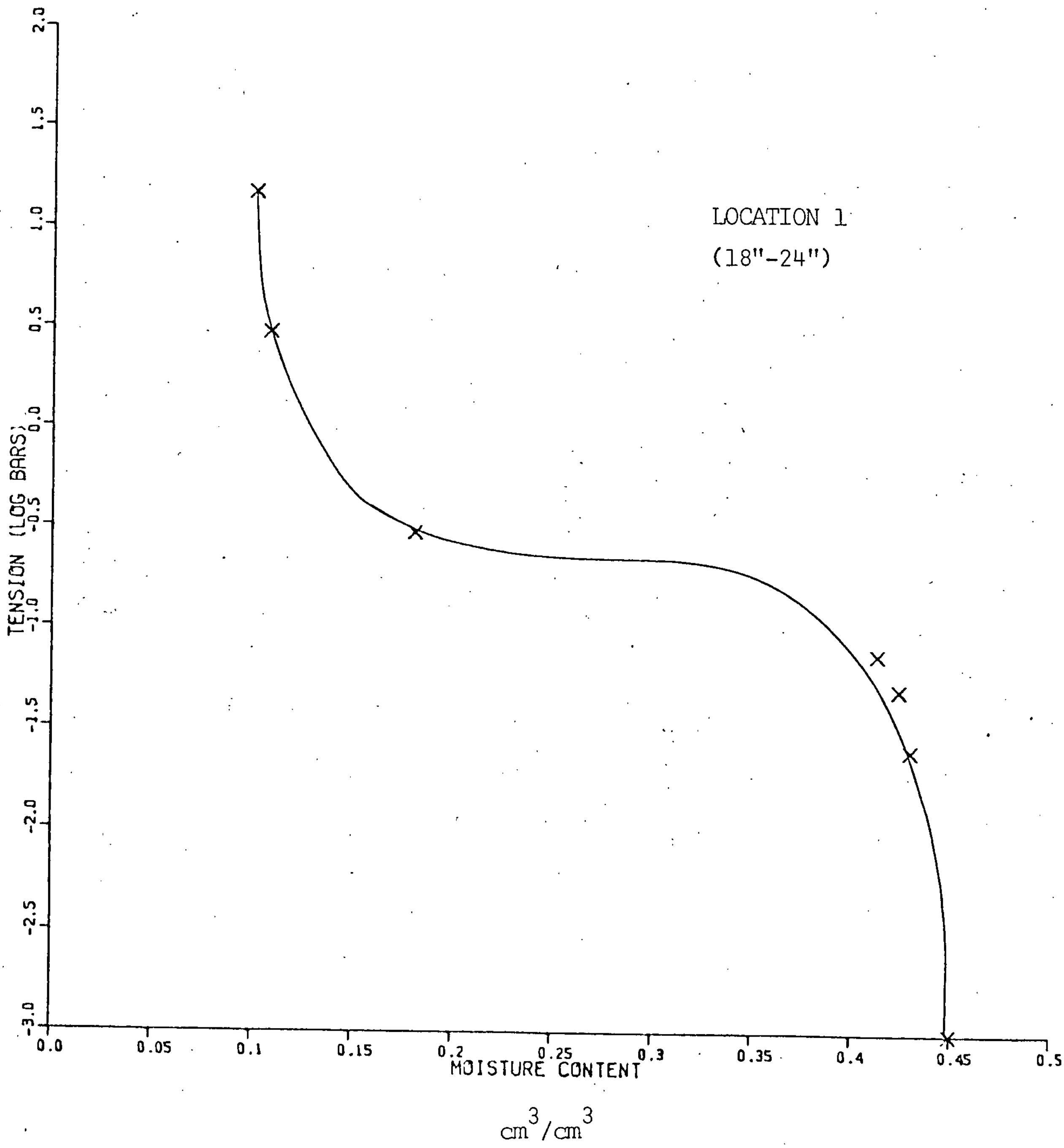
cm3/cm3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-3.0
0.0
0.05
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0.2
0.25
0.3
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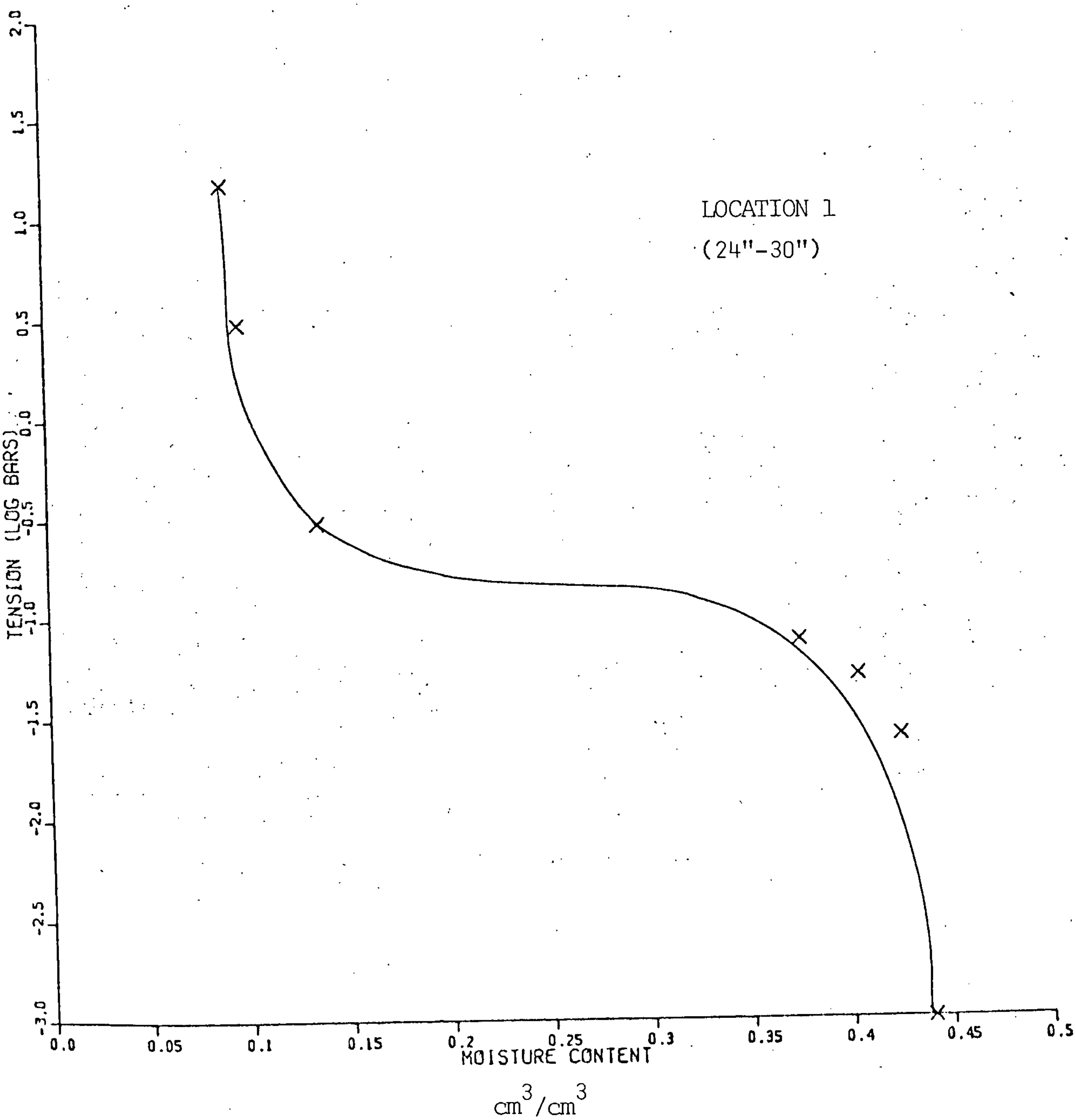
0.4
0.45
0.5
MOISTURE CONTENT
cm3/cm3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-1.5
-2.0
-2.5
-3.0
0.0
0.05
0.1
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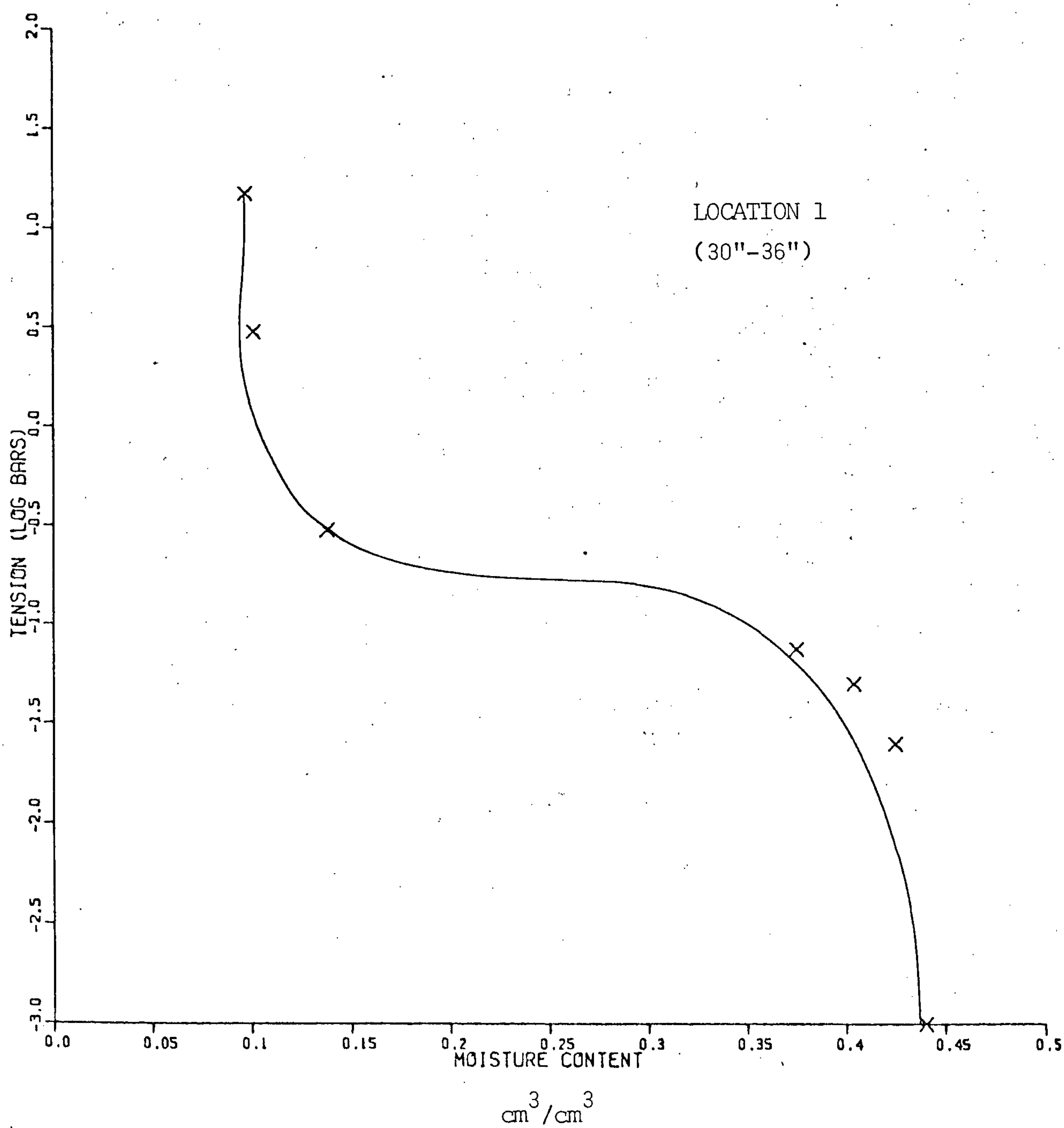
0.2
0.25
0.3
0.35
0.4
0.45
0.5
MOISTURE CONTENT
cm3/cm3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0.05
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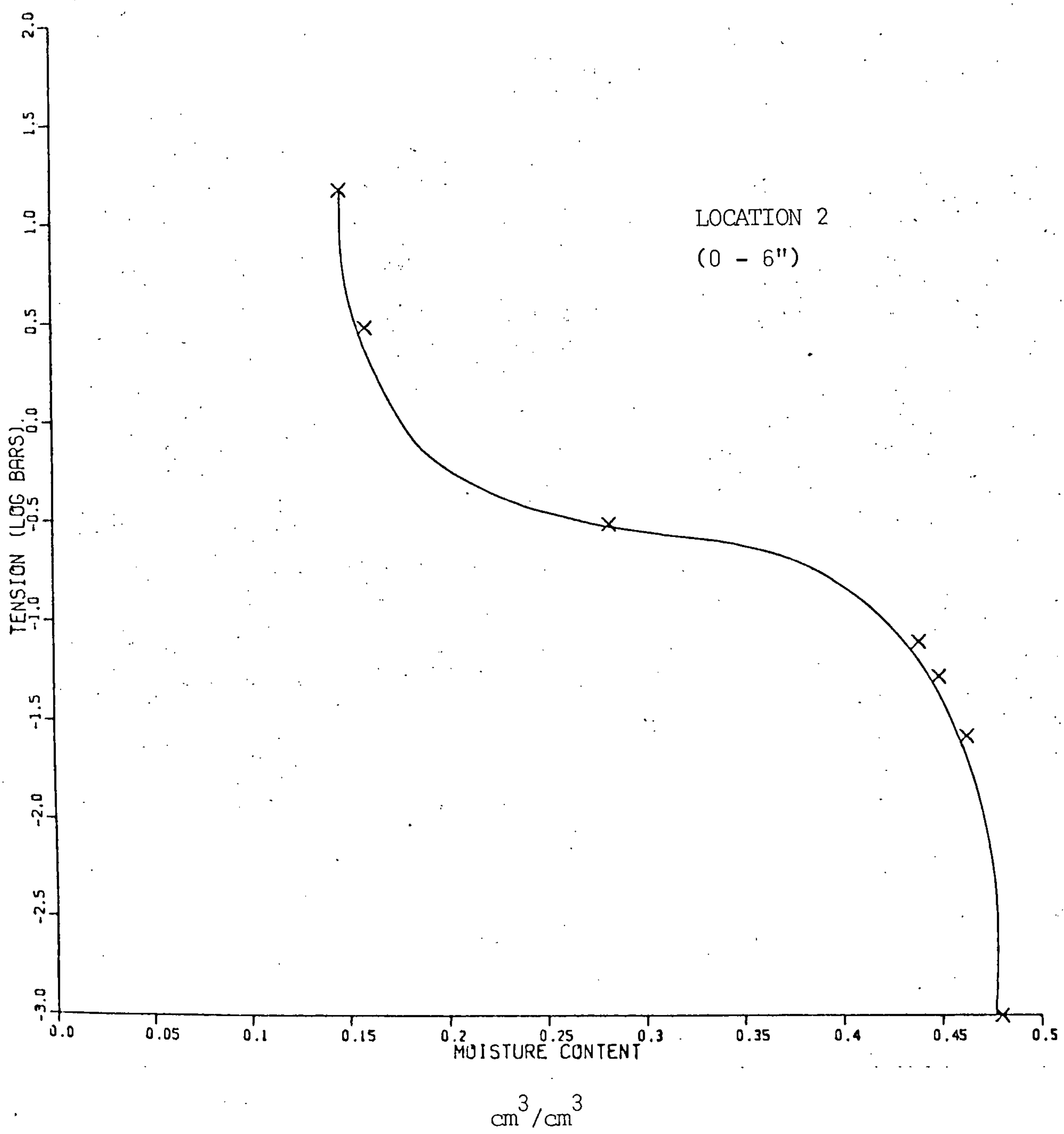
MOISTURE CONTENT
cm³/cm³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0.05
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0.2
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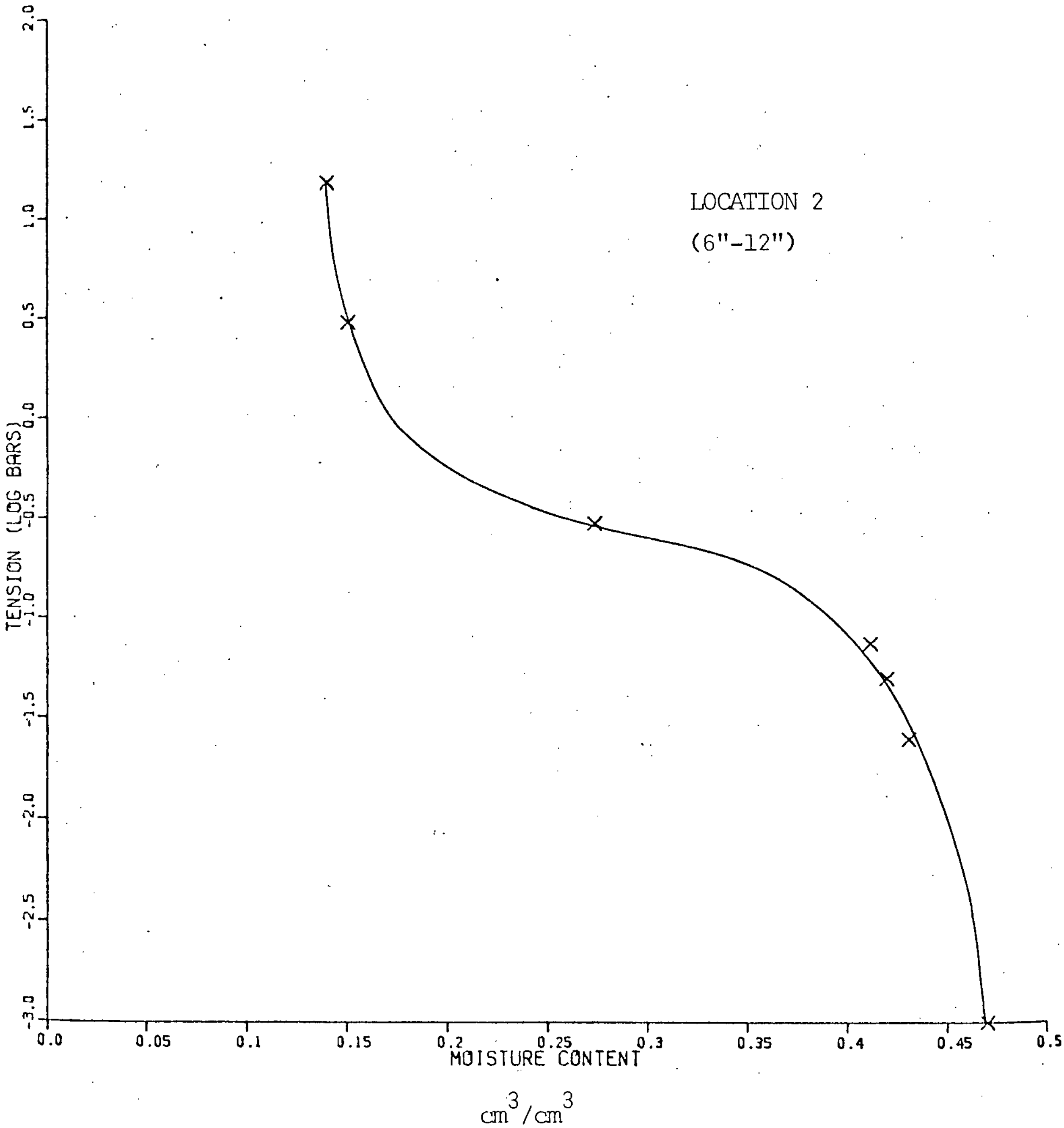
MOISTURE CONTENT
cm3/cm3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0.0
0.05
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0.2
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0.4
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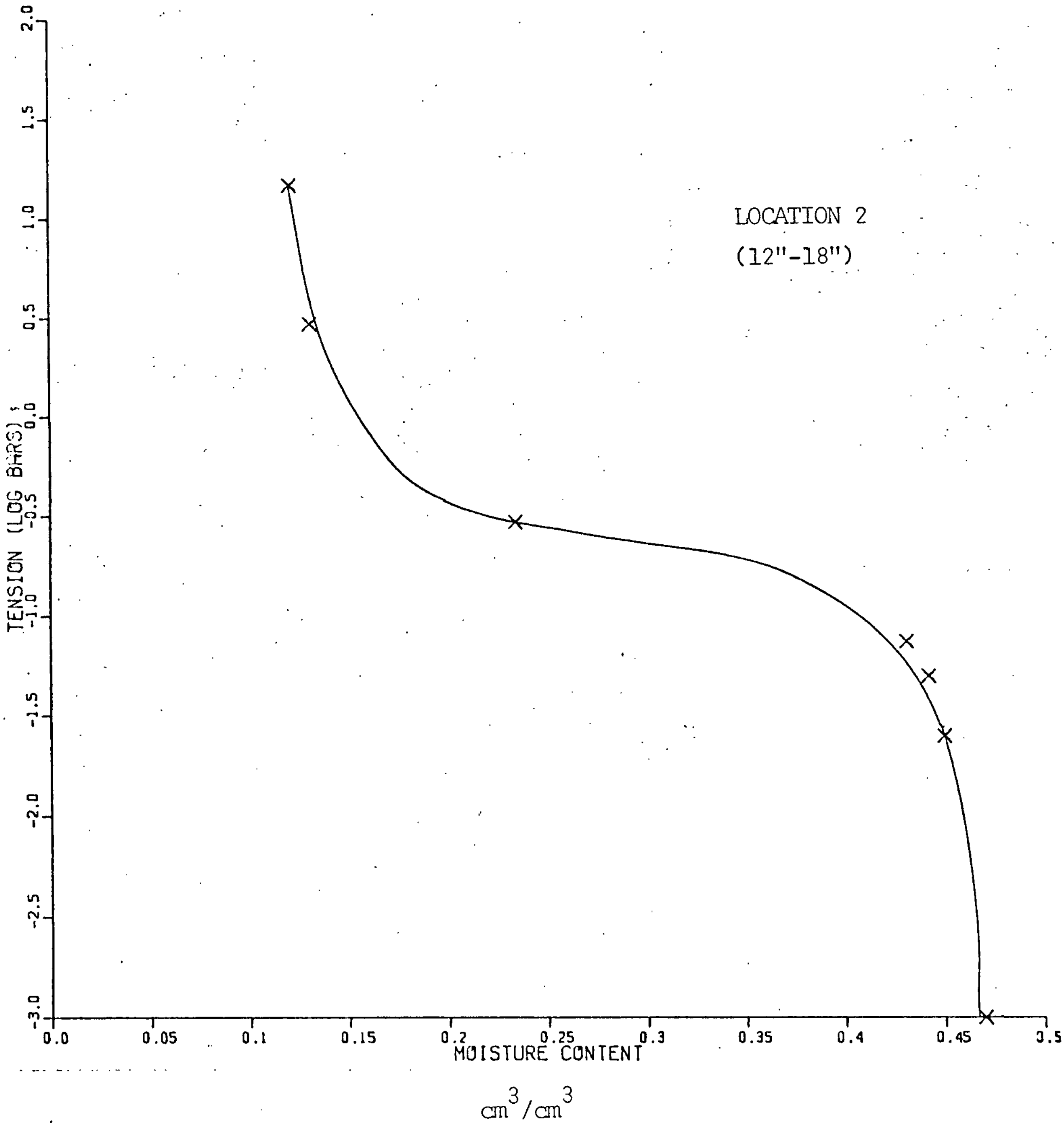
0.5
MOISTURE CONTENT
cm3/cm3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0.05
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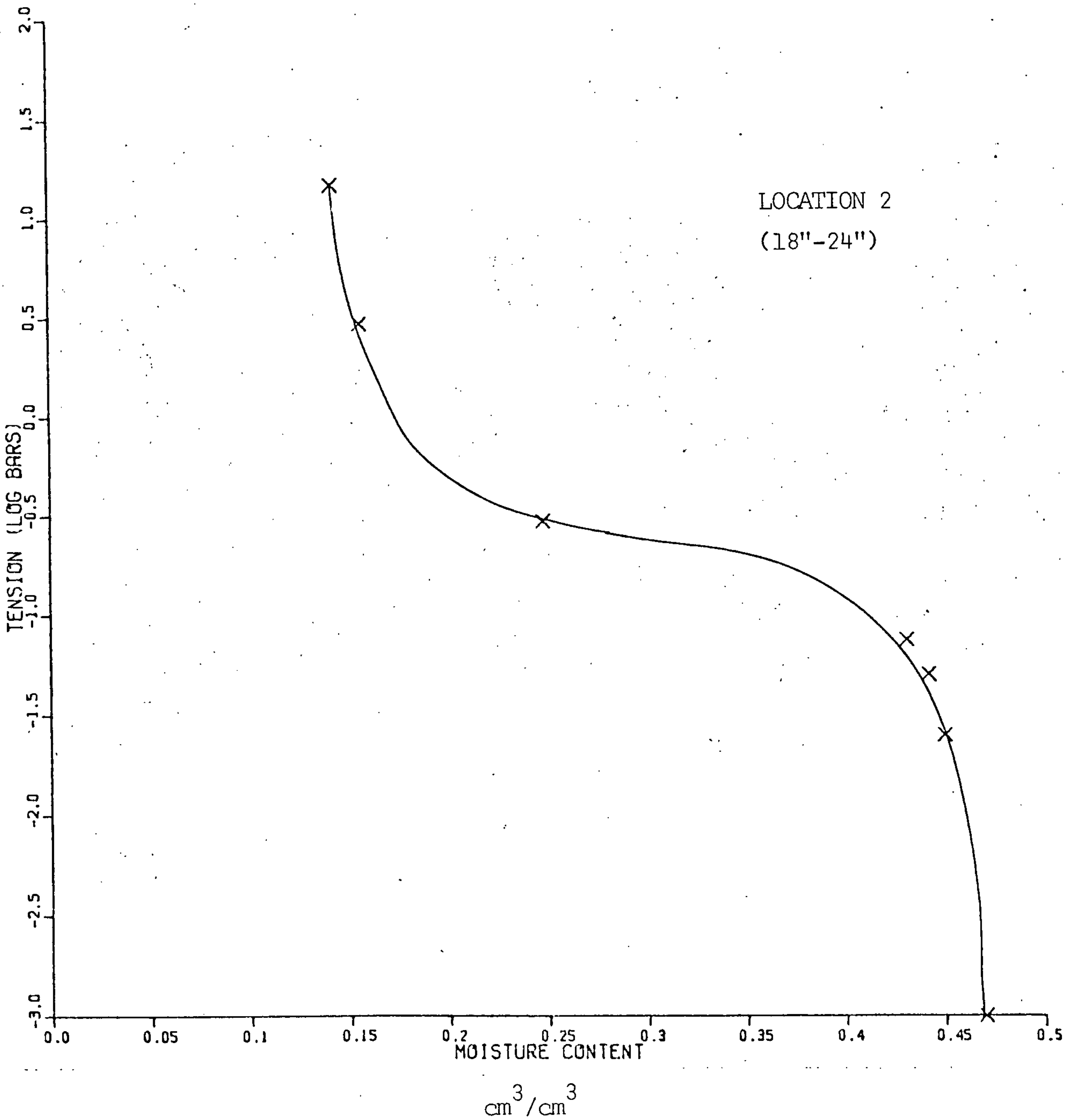
cm3/cm3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0.05
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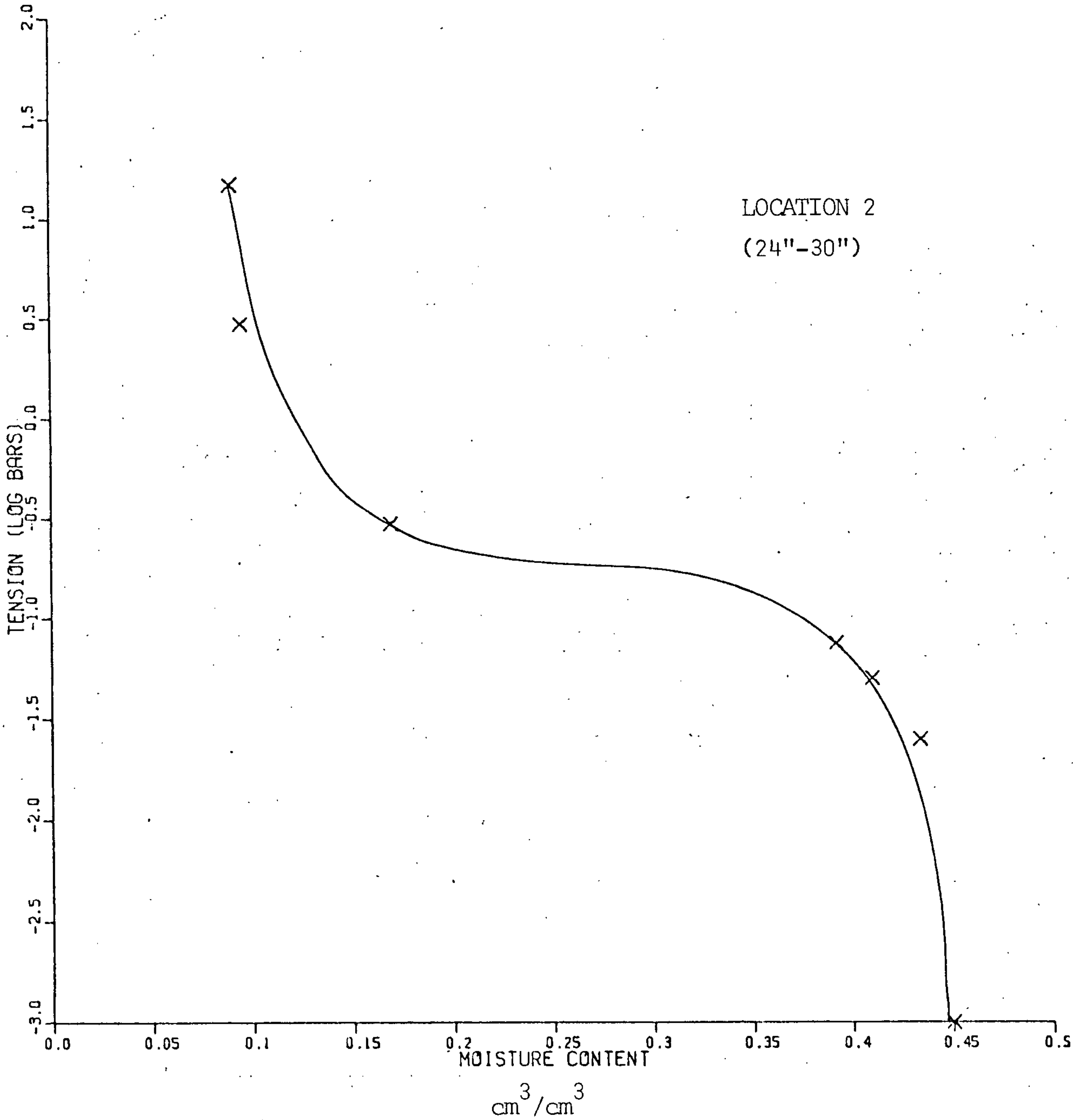
cm3/cm3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0.0
0.05
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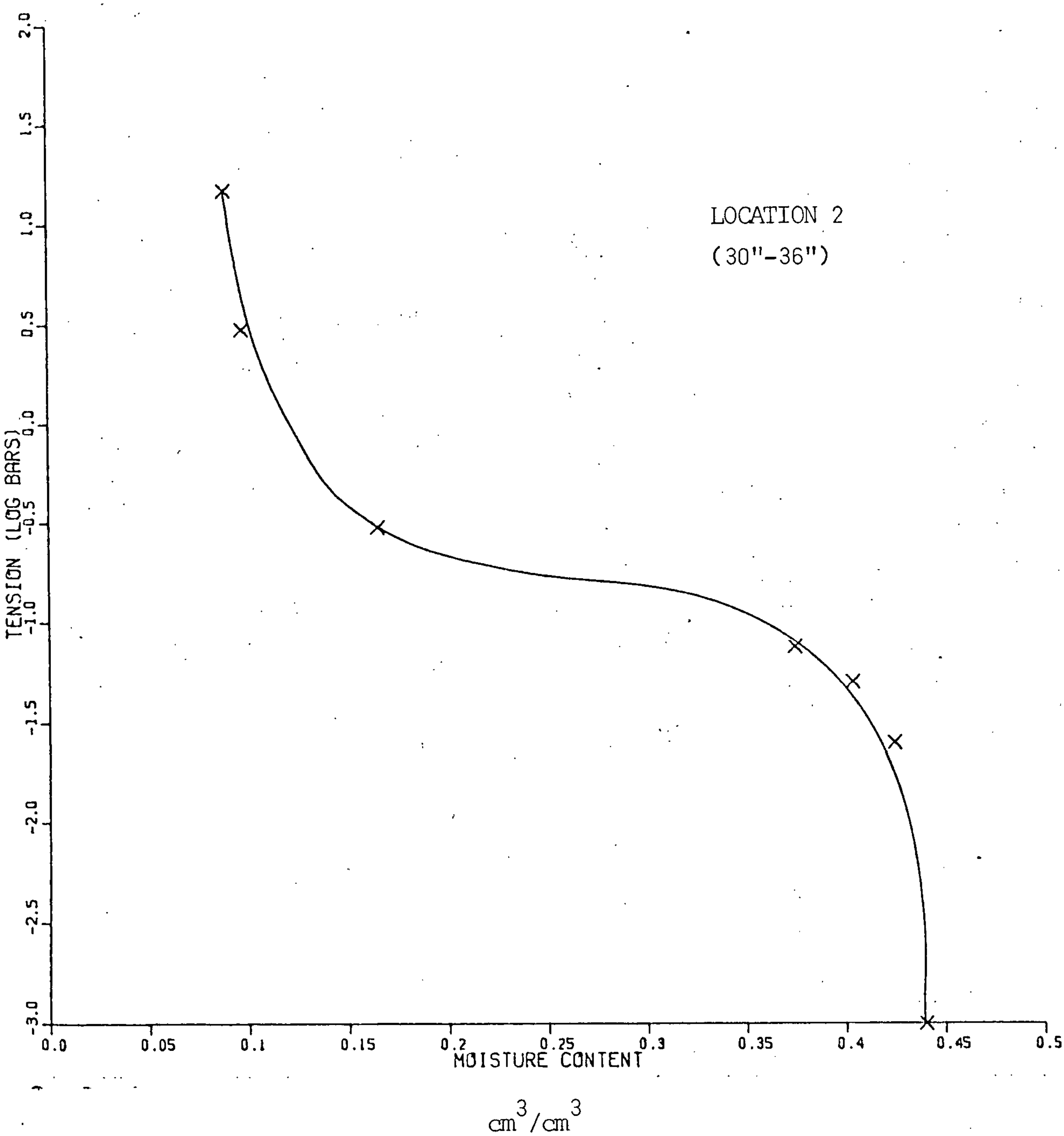
MOISTURE CONTENT
cm3/cm3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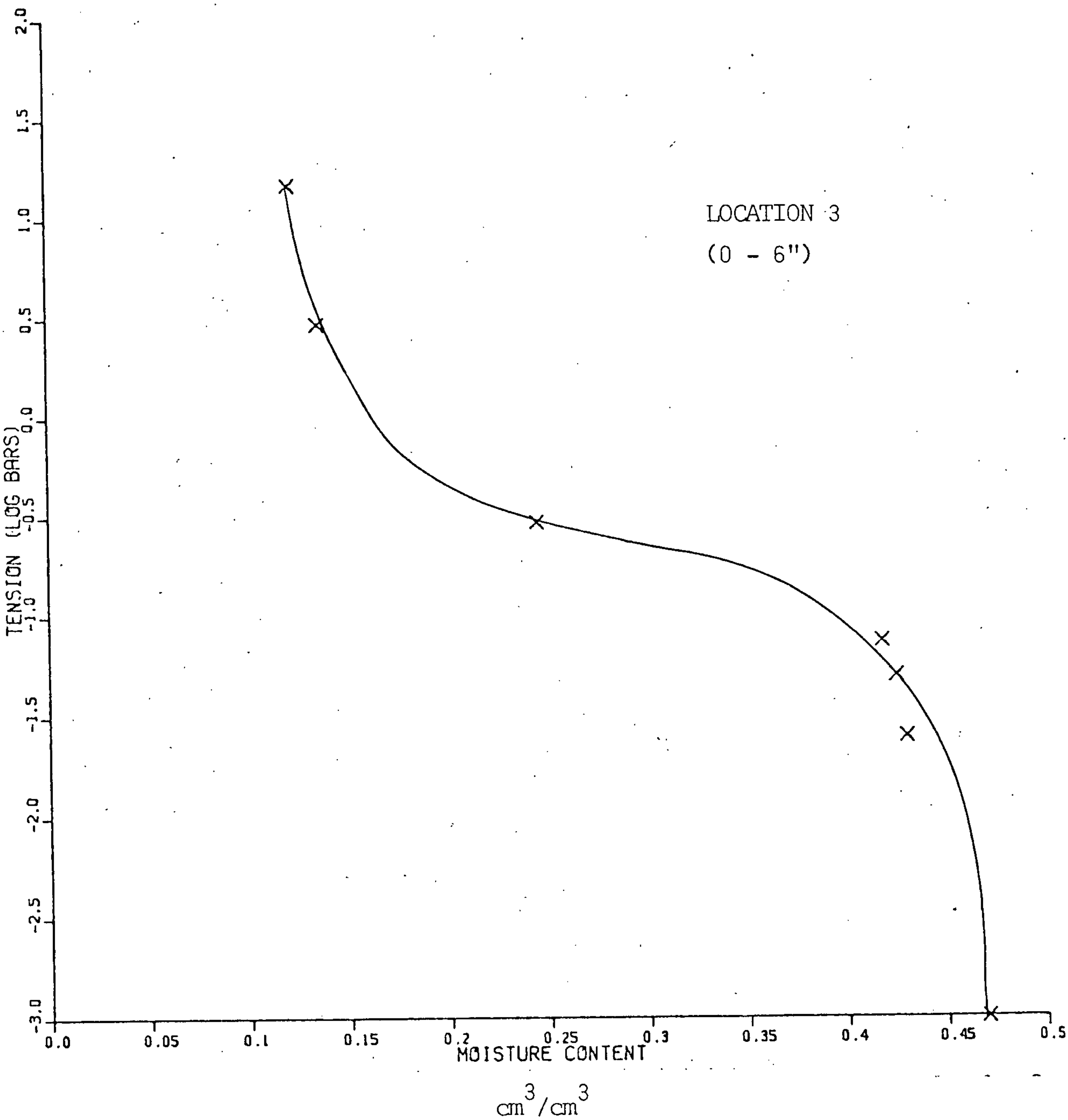
MOISTURE CONTENT
cm3/cm3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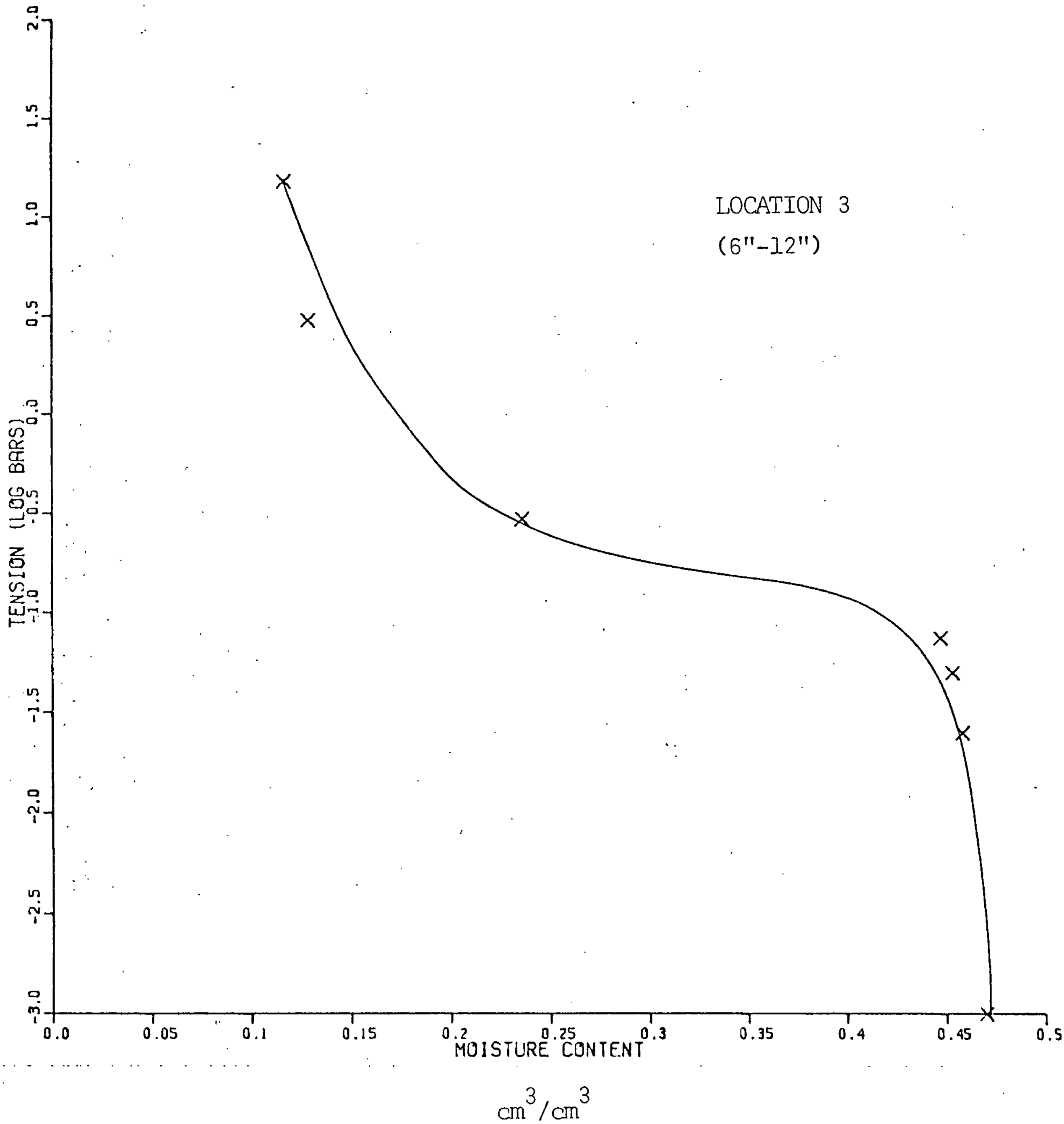
cm3/cm3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0.05
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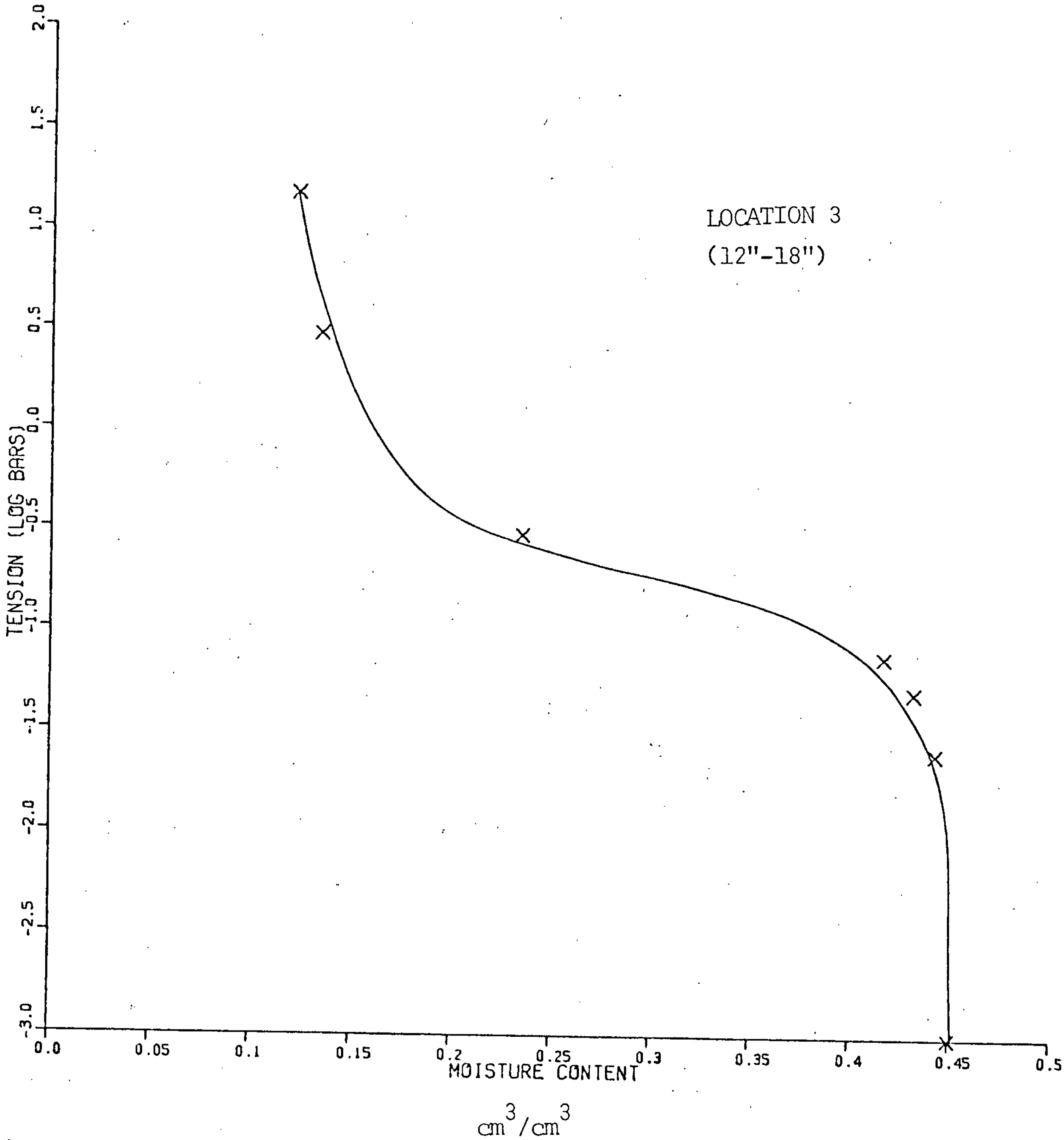
MOISTURE CONTENT
cm³/cm³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0.05
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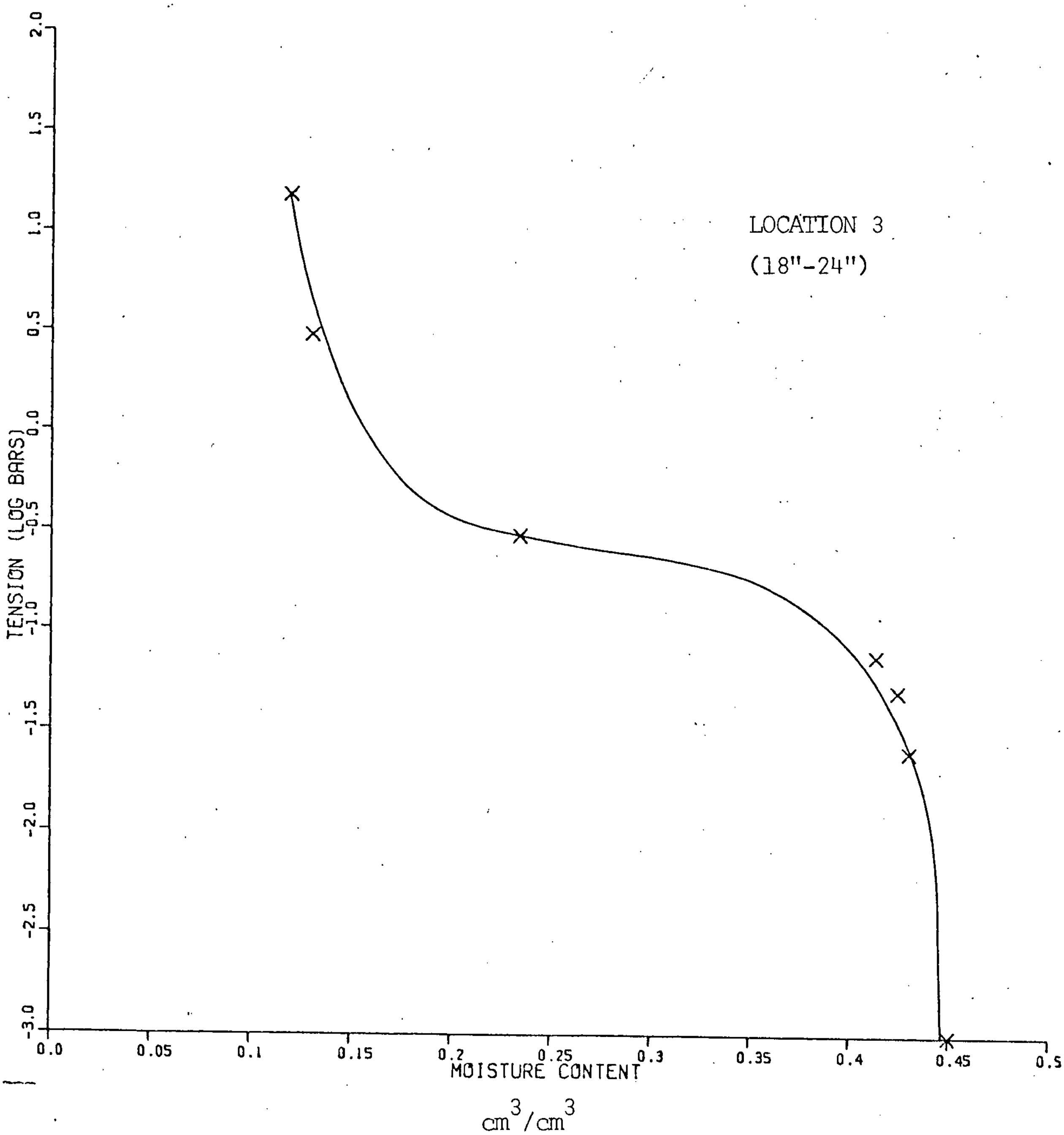
MOISTURE CONTENT
cm3/cm3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0.05
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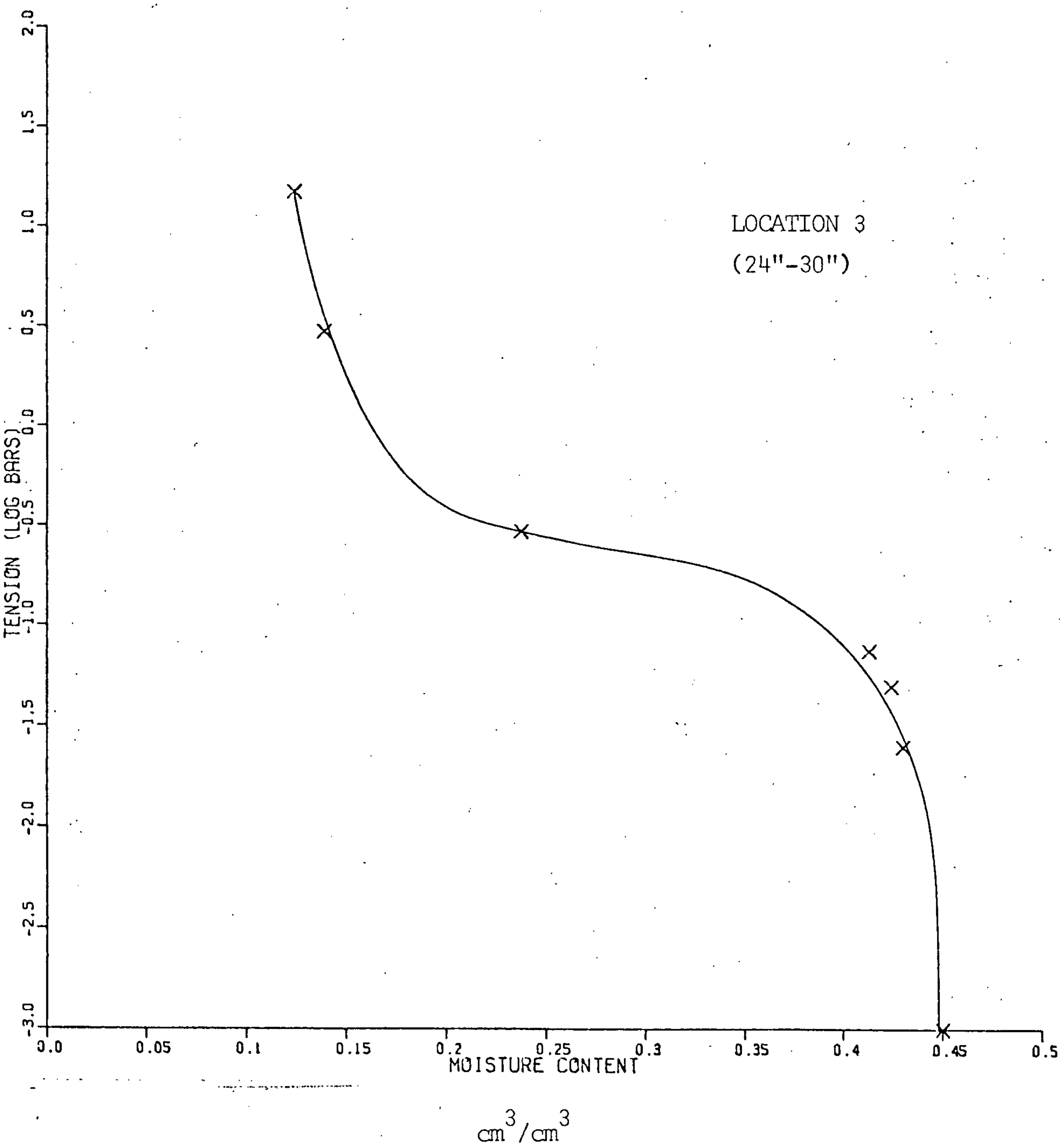
cm3/cm3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-3.0
0.0
0.05
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0.2
0.25
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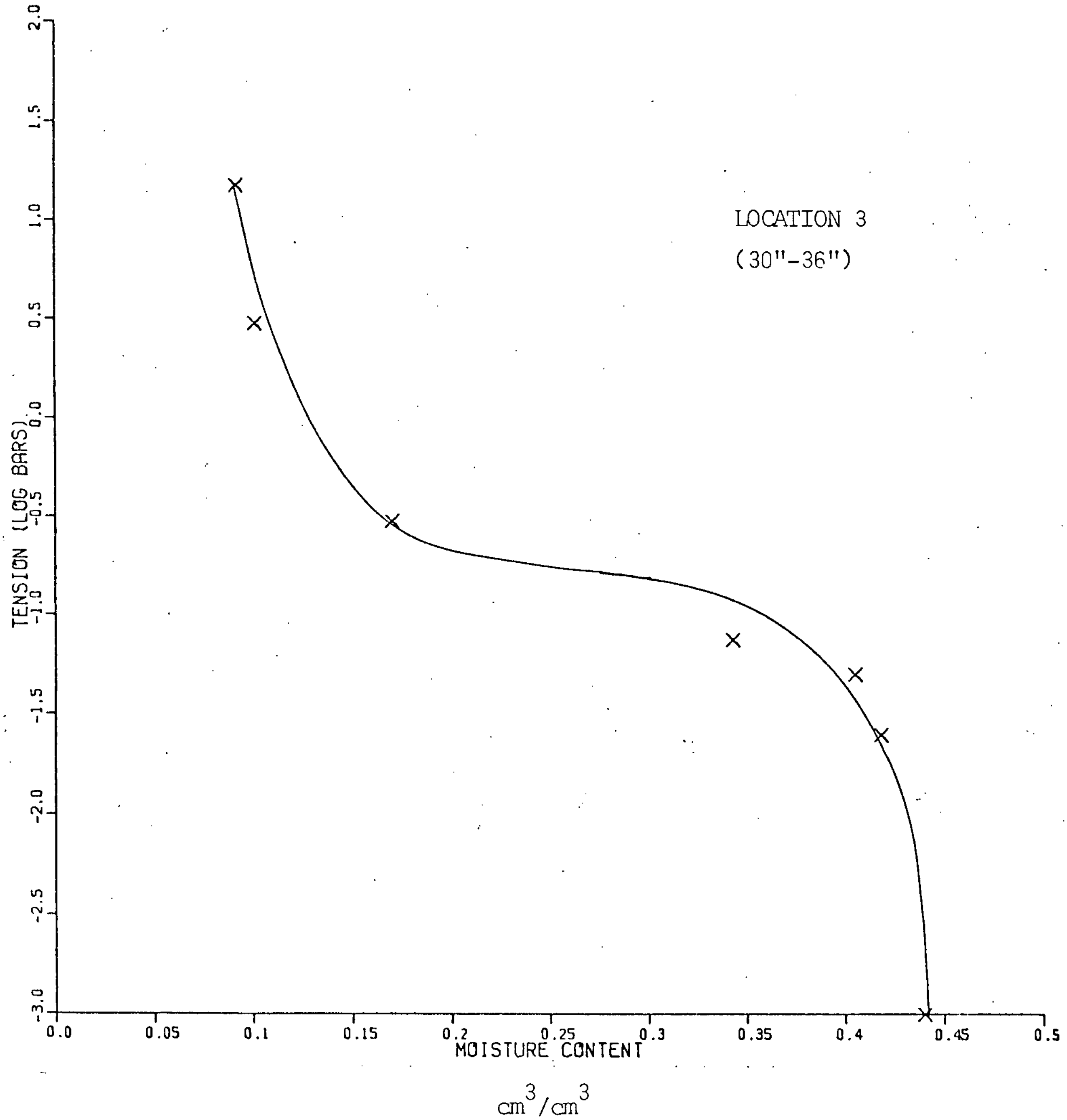
MOISTURE CONTENT
cm³/cm³



LOCATION 3
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2.0
1.5
1.0
0.5
0.0
-0.5
-1.0
-1.5
-2.0
-2.5
-3.0
0.0
0.05
0.1
0.15
0.2
0.25
0.3
0.35
0.4
0.45
0.5
MOISTURE CONTENT
cm3/cm3