RESUME

LE RENDEMENT AU CHAMP

D'UN SYSTEME D'IRRIGATION PAR ASPERSION

ACTIONNE PAR UNE EOLIENNE

Le rendement au champ, ainsi que la puissance utile d'un nouveau modèle d'éolienne rapide, fut évalué, celle-ci actionnant un système d'irrigation par aspersion.

La régularité d'application d'eau fut mesurée pour un système d'irrigation actionné d'une part par l'éolienne et d'autre part par un moteur diésel. Dans les limites de la gamme des pressions d'opération choisies pour ce système d'irrigation activé par l'éolienne, il fut conclu qu'aucune différence sensible n'existait entre la régularité d'aspersion du système fournie par la puissance de l'éolienne ou l'énergie du moteur diésel.

On a tracé des courbes de débits versus vitesses du vent pour le site expérimental du Greenland à la Barbade. Ceci permit d'estimer le potentiel de débit possible en se servant des données horaires de la vitesse du vent. Ces abaques furent utilisées afin de prédire le débit du système pendant des périodes aléatoires de sept (7) jours consécutifs et cela pendant la saison sèche.

En s'appuyant sur les résultats obtenus à la suite de la présente étude il fut conclu qu'avec une bonne régie des cultures il est possible d'employer une éolienne comme source énergétique afin d'actionner un système d'irrigation. Cependant, pour un régime des vents tel que celui existant au Greenland, l'éolienne ne pourrait compétitionner avec le moteur diésel comme source d'énergie alimentant le système d'irrigation.

Suggested short title:

PERFORMANCE OF A WINDMILL POWERED

SPRINKLER IRRIGATION SYSTEM

THE FIELD PERFORMANCE OF A WINDMILL POWERED SPRINKLER IRRIGATION SYSTEM

by

John Malcolm Ionson, B.Sc. (Agr.Eng.)

THESIS SUBMITTED FOR A MASTER OF SCIENCE DEGREE

Agricultural Engineering Department

of

Macdonald College (McGill University)

Quebec, Canada

August 1969

ABSTRACT

The field and power performances of a new design airscrew windmill were evaluated with a sprinkler irrigation system. The water application uniformity was measured for a sprinkler irrigation system powered by the windmill, and the same sprinkler irrigation system powered by a diesel engine. Within the operating pressure range of the windmill powered irrigation system, it was concluded that there was no significant difference between uniformity done with windmill power and uniformity done with Diesel power.

Discharge versus windspeed graphs were developed for the Greenland experimental site in Barbados. This enabled the prediction of discharge capacity using hour by hour average windspeed data. These graphs were used to estimate the discharge during random seven day periods within the dry season. On the basis of the results, it was concluded, that with good crop management, the windmill powered irrigation system was feasible. However, it could not compete with Diesel powered irrigation in the Greenland wind regime. Given a better wind regime, in a region where conventional power is not technically understood, the windmill could be competitive for all types of irrigation systems and other continuous pumping operations.

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LIST OF SYMBOLS

Distribution

Cu	Coefficient of distribution uniformity
U	" " " "
A	" " " "

Hydraulic

U.S.G.P.M.	United States Gallons per Minute
I.G.P.M.	Imperial " " "
psig.	Pounds per Square Inch Gauge
Water H.P.	Water Horsepower
cfs	Cubic Feet per Second

Statistical

t	Student's "t" test value from table
t'	Calculated "t" from data
α	Level of significance
ν	Degrees of Freedom
$\geq$	Greater than or equal to
SD	Standard Deviation from Data
μ	Population mean
σ	Population Standard Deviation
Ho	Null Hypothesis

Aerodynamic

Cp	Power Coefficient
RPM	Revolutions per Minute

THE FIELD PERFORMANCE OF A WINDMILL POWERED SPRINKLER IRRIGATION SYSTEM

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J. M. Ionson

Introduction

The quantitative balance of wind, solar radiation, precipitation, and soil fertility determine the maximum of natural vegetative production. The unbalance of the first three climatic factors limits man's ability to produce basic food crops. On the grand scale, man has no control of these environmental conditions. However, irrigation on limited areas can meet the precipitation or related soil water deficit.

In all West Indian islands there are seasonal periods where drought limits the food crop growth. The problems are variable from island to island due to different location, size, topography, and soil condition.

During these periods of soil moisture deficit, and indeed all of the year round, quantities of unharnessed wind power pass over these islands. The original production of sugar from the West Indies depended on these easterly Trade winds to supply windmill power to extract the juice from the sugar canes. To utilize this power source, a modern airscrew windmill was designed and fabricated by Brace Research Institute in Barbados, West Indies. This wind machine was designed to develop the power required to pump large quantities of water and can therefore be used to supply irrigation water to adjust the soil water deficit. In accomplishing this, the wind, once a drying agent, becomes a useful dispenser of fresh water to growing food crops.

The purpose of this project was to apply the modern air-screw windmill in actual conditions and evaluate its potential. This evaluation of a field prototype is necessary to achieve efficient use of its power and preceeds serious consideration for mass production of the windmill. A field crop irrigation experiment was included to estimate the need and benefit derived from irrigation. The purposes of this study were as follows:

1) The irrigation uniformity of distribution with windmill power was to be compared to that of conventional power. The uniformity problems associated with a variable rate of water application due to the variable power supply of the windmill were to be examined.

2) The capacity of the windmill system in relation to the wind regime was to be observed and hopefully a method of predicting flow capacity could be found.

3) The operational and management problems associated with the operation of the windmill were to be observed. An estimation of the long term continuous operation performance would be of value in determining maintainance, starting, and safety features for the windmill.

4) It was hoped that an estimation of the benefits due to irrigation could be obtained. This would be necessary to determine the economic value of irrigation, and that of the windmill applied to irrigation.

CHAPTER 1

Background Information

1.1 The System Defined

Future reference to the system within this thesis pertains to the following description.

The supply of irrigation water for the trials comes from an offset pond fed from a small perennial stream, called the Greenland River. The pond is termed "offset" in that it is not an integral part of the river bed. The pumping is done from a concrete lined well close to the pond. The pond water surface and the wellwater surface are equalized by an interconnecting pipe to the bottom of each reservoir.

The pump, a Wade Rain 10 stage vertical turbine pump (size 6JC3, characteristics of which are given in Graph A1), was submerged in the well. Power was transmitted to the pump by means of shaft and gear box. The details of transmission coupling and construction are given in a M.Sc. thesis by R. E. Chilcott, who along with Dr. G. T. Ward of Brace Research Institute designed and co-ordinated the fabrication of the windmill.

The Brace 10 horsepower windmill and a Lister Diesel, a compression ignition engine of equal output capability, were the prime movers. These power sources shown in Figure 1 or Dwg. B-3-041, and Fig. 3a respectively could be attached alternatively to the pump. The power could be transmitted at several gear ratios obtainable through an Austin rear axle differential, a Land Rover 4 speed 2 range gear box transmission, and a Randolf right angle gear box.

The system was completed by two water pipe outlets. Common to both these water outlets was an instrumentation circuit shown in Figure 3b and described schematically in the Appendix (Dwg. D-3-016 and Dwg. C-3-013).

The water flow diversion to the pond, a 4" aluminum tube, was outletted by a manifold consisting of galvanized pipe and reducers with four electric valves in parallel configuration, shown in Figure 2a. The valves were Rainbird(2" electric)and were outletted by a 2" to 3/4" galvanized reducer and a pre-drilled 3/4" galvanized end plug. The size of this drilled jet could simulate a lateral with an equivalent area of discharging irrigation sprinkler nozzles.

The flow diversion to the field was completed by a pressurized portable aluminum tube irrigation system using 5" mains and 3" laterals with appropriate valving and 3/4" galvanized risers. A typical irrigation lateral configuration is given in Figure 2b.

1.2 The Site

The windmill and pond site were chosen with several factors in mind. The site had to be representative of the potential needs and natural resources available. The project required the co-operative effort of Brace Research Institute and the Barbados Government. It was hoped that local interest could be stimulated this way and the people would have a familiarity with the objective and a desire to see it accomplished. The site eventually chosen for these reasons was on the Government owned Greenland Plantation in St. Andrew parish. The plantation was operated through the government agency, Agricultural Development Corporation, (A.D.C.). The 10 acres required for the trials were adjacent to the Greenland River. The site detail is shown in Figures 3c, 3d, and the topographic survey figure 4.

At commencement of the one year evaluation for this thesis, the site conditions were these:

1) The test field donated by the A.D.C. was in sugar cane and had to be cut before cultivation could proceed.

2) The irrigation field trial was separated from the pumping system by the gully of the Greenland River. A bridge was necessary for general transport and to support irrigation tubing.

3) Previous flooding of the Greenland River had destroyed the original inlet of the pipeline reaching the offset pond. Consequently, the water supply pond was empty. This necessitated the construction of a new pond inlet.

CHAPTER 2

Literature Review and Discussion of Experimental Procedures

2.1 The Moisture Balance and Irrigation Requirements

The original wind study of Seawell data done by R. E. Chilcott[1] had led to the conclusion that Barbados had a favourable wind regime. This was supported by data from several other windmill applications done by Brace in Barbados. In choosing a windmill site, wind information is of prime importance. Golding[2] emphasizes the criteria for a wind evaluation and includes practical considerations of windmill site location. Topographically, the chosen site was not ideal. Hill formations exist at 1.5 miles to the windward side of the site. It was assumed, however, that there would be no serious interference in wind power due to these hills and that the application of the windmill on this site would constitute a good test for the proposed windmill pumping system.

In applying the windmill to irrigation it was necessary to assess the amount of irrigation water required. There were evapotranspiration calculations available for the island and rainfall data was available from a measuring station close to the trial site. The moisture balances referred to, had been based on the potential evapotranspiration formula of Thornthwaite[3]. The Thornthwaite formula, used on a world wide basis, has been found to require modification. This has been verified by Garnier[4] in Nigeria and Rouse[5] in Barbados.

The Penman Formula for evapotranspiration is a more accurate basis for a moisture balance[6]. However, much meteorological data is required and this data was not available for the Greenland site.

W. R. Rouse[5] and G. W. Smith[7] have done a Thornthwaite evapotranspiration analysis for Barbados. Smith has completed the same analysis for major islands of the British and former British West Indies. Rouse questioned the direct use of the Thornthwaite analysis and proposed a modified Thornthwaite equation based on solar radiation data.

To assess these balances, a Thornthwaite analysis was done for the Greenland site. Greenland plantation management had kept rainfall records for the last twenty years, and this data was used. The measuring station was 1/2 mile from the windmill site so it was felt that the records would be valid for the experimental field. Temperature data was obtained from nearby Seawell International Airport.

These three balances indicated consistantly that a need for supplemental water existed during the "dry season" which is from late December to early June. The remainder of the year is termed the "wet season" but the balance done for the Greenland site indicated that supplemental irrigation could be used to advantage on several occasions during the wet season of each of the 10 years studied.

Other balancing techniques such as the Robertson-Holmes "modulated Budget"[8] make use of the computer and more rigorous analysis requiring data on crop stage and moisture holding ability of the soil. These laborious methods are good for large uniformly affected areas, however, soils and rainfall vary drastically over the small land mass of Barbados so that the Thornthwaite method was the best for practical purposes. In a semi bare soil condition such as with vegetable production, it was assumed that the Thornthwaite evapotranspiration calculation would be an overestimation. Graph A3 summarizes these evapotranspiration estimates.

2.2 Production Potentials for Irrigated Crops

The agricultural production of the West Indies has been developed by economic pressure and the availability of natural resources. Barbados is principally a sugar island and its diversification has been mainly into root crop production. These types of crops adapt well to the wet and dry season condition that occurs, and they supply the local food requirements suiting the local tastes. The fancy or luxury table vegetables are seasonal and usually in short supply. Consequently, this situation coupled with relatively high prices keeps the demand low for these types of vegetables.

Barbados, with a substantial tourist population, does have the added demand for luxury vegetable items. To meet this demand for quantity of quality vegetables, importing is done. The Barbados Marketing Board is attempting to rectify this situation. They attempt to organize local and export markets. Such an estimate of production was completed by the past chairman of the Board, Mr. C. Sides [9], unpublished Market Estimates Oct. 1/67-Oct. 5/68. The problems of quality grading, marketing, storage, and production must be answered for viability of a vegetable industry. These basic problems and answers must be co-ordinated to the point where production and market grow at the same rate. This project is vitally concerned with vegetables produced for the quality table market. This is because of the high relative return per acre necessary to offset the cost of the irrigation system.

2.3 The Benefits of Irrigation

It was concluded that little conclusive information was available for predicting yield increase due to irrigation. It was felt that a twofold increase might be anticipated with proper management and that certainly more efficient use could be made of the dry season. This would mean three crops per year instead of two in the case of many vegetables.

Pangola grass, a valuable forage pasture crop, is difficult to establish without ample rainfall or supplemental irrigation. This was confirmed by local plantation management.

2.4 Irrigation Systems

The foregoing suggested the needs and benefits of irrigation. It then became necessary to determine the best mode of irrigation. There exist three principal methods; surface, sub-surface, and sprinkler irrigation. All these methods are affected by soil type, which must have a good structure, and topography, which must be flat. Sprinkler irrigation was the most suitable for the site. However, the windmill power could be more efficiently used with the other methods, where a site would be favourable. This is because lower pump lifts are required for surface and sub-surface irrigation. Furthermore, the head required for sprinkler operation can be used to pump water from greater well depths. This gives the system more flexibility. The initial trial for the windmill was its application to a sprinkler irrigation system.

2.5 Irrigation Application Rate

Sprinkler irrigation has been used for artificial climate control. The addition of irrigation water in droplet form through the plant's surrounding atmosphere and eventually into its supporting soil, controls plant transpiration to reduce stomata and root stresses in periods of heat and drought. In considering the efficient use of water to these ends, we must control application rate.

Application rate is used to best advantage when designed for plant micro-climate control and soil structure conservation. The design of sprinkler irrigation systems used in large semi-arid vegetable production areas like California, U.S.A., includes long term pumping periods through low discharge sprinklers, and employs a solid set piping system. Heavy application rates allow shorter pumping periods, but the large droplets, which are characteristic of the greater nozzle discharge required, break down soil aggregates. This reduces infiltration rates for soil water, and plant root respiration. Furtnermore, the associated surface sealing that occurs due to heavy application rates, is a major problem in the irrigation of clay soils. In view of the fact that the irrigation was to be done with the windmill in conjunction with a portable irrigation system, these criteria were accepted:

1) It was desirable to irrigate at rates lower than the rate where surface"ponding" of water occurred. This would conserve the soil structure and decrease the loss of water through evaporation that occurs with ponding on the surface.

2) It was desirable to operate at low sprinkler pressures to get a high total volume pumped, obtaining the most efficient use of time and power available for pumping.

To realize both these criteria, compromises had to be made as heavy application rates gave more efficient irrigation tube, sprinkler head, and power utilization.

2.6 Irrigation Uniformity

The purpose of an irrigation system is to distribute water over a given area of soil surface. The measure of effectiveness in irrigation is the observation of uniformity of distribution of the water applied. Uniformity of distribution is defined as the variation of depth of water applied, with location on the soil surface. The test of the windmill irrigation system was then to observe the uniformity of distribution it produced, and compare it to a conventional power source distribution uniformity. This is in fact a comparison between sprinkler irrigation in the steady and the unsteady state of pressure and flow.

Uniformity is typically measured by sampling the irrigation water pattern produced from a sprinkler or system of sprinklers with a rectangular grid of catch cans. The individual cans receive a measurable amount of water during a uniformity test. These amounts are recorded and applied to one of several statistical expressions for uniformity.

Christiansen's formula (1941)[24] suggested $Cu = 100\ (1 - \frac{X}{MN})$. The coefficient of uniformity "Cu" varies between perfectly uniform coverage at 100 and non-uniform coverage at 0. "X" is the absolute deviation from the mean "M" depth of water. "N" is the number of catch cans with a measurable amount of water. Christiansen's formula is the most widely used in the irrigation industry but is not the best statistical measure of uniformity.

Wilcox and Swailes (1947)[25] introduced the coefficient of uniformity $U = 100\ (1 - \frac{SD}{M})$. "U" varies as Cu, and "SD" is the standard deviation of the mean "M" which is the mean depth of water caught in the catch cans. This is a more statistically justified formula.

These two formulae were supplemented by a more statistically statisfactory formula proposed by Benami and Hore (1964)[26]. This formula more clearly recognized the crop water need, giving weight to the figures over and under the mean depth of water applied. The formula was $A = 166\ \frac{Na}{Nb}\ (\frac{2Tb\ Db\ Mb}{2Ta\ Da\ Ma})$

Na is the number of values above the general mean.

Nb " " " " " below " " " .

Ma is the mean of the group of readings above the general mean.

Mb " " " " " " " " below " " " .

Ta is the sum of readings above Ma.

Tb " " " " " below Mb.

Da is the difference between the number of readings below and the number above Ma.

Db is the difference between the number of readings above and the number below Mb.

H. C. Corven[10] compared these three formulae and found, "The high degree of correlation among the three uniformity coefficients Cu, U, and A proves that there is little difference between them". Thus, the simplest formula, Christiansen's Cu was used. Uniformity trials could then be done, and comparisons of uniformity made on the basis of Cu of a sprinkler system powered by windmill and Cu of a sprinkler system powered by Diesel engine.

K. Nathan[11] (1966) did uniformity trials attempting to show the difference in uniformity coefficients calculated from a complete irrigation system and those coefficients calculated from a single sprinkler pattern superimposed upon itself to simulate the complete system. The conclusions were as follows: "The laboratory tests thus showed that statistically different results are about as likely to be caused by the use of different sprinkler specimens for individual sprinkler tests as by the use of a complete system test when compared to individual sprinkler tests"; and "Under field conditions, differences between the two methods of testing can be assumed to be even less pronounced than those in tests described here".

Using these conclusions, the field uniformity trials at Greenland were calculated using a single sprinkler head distribution pattern observed from a 10 feet by 10 feet rectangular catch can grid and geometrically superimposing it upon itself in order to cover a specific test region within the irrigated area. The average of four individual calculations made up the uniformity for a given sprinkler head, nozzle size, average pressure, and windspeed.

Distribution uniformity in any irrigation system is a cost consideration. It is necessary to assess the need for uniformity when installing irrigation equipment. G. Levine[12] reported that uniformity was of secondary importance in a humid area where there is a good chance of natural rainfall. Barbados meteorological data indicates a reasonable chance of rainfall, especially in the wet season (Graph A2).

Crop uniformity is of importance where a crop is being harvested by machine. Stage of crop maturity and size affect the picking apparatus. The harvesting done on the Greenland plantation was done by hand, in several pickings. This is typical of the situation where the windmill can be applied.

On a small land mass like Barbados, efficient land utilization is important but with the above considerations it must also be realized that the extra cost of the uniform irrigation system must be justified by the extra yield it provides. It was decided that Cu values between 70 and 100 would be acceptable for the uniformity of irrigation from the windmill system. Most vegetable irrigation systems work within this limit.

CHAPTER 3

Associated Construction

3.1 The Offset Pond

The pond had been constructed at the onset of the windmill fabrication. Its design capacity was two million Imperial gallons. This pond was supplied with water from the Greenland stream by means of a buried pitchfiber pipe that extended upstream to a point where the elevation of the streambed slightly exceeded the desired overflow elevation of the pond. A flood in 1966 had washed out the coral stone gabion dam that had diverted water into the inlet of the pipeline. This problem was compounded by the severe scouring that had lowered the streambed four feet and the unstable nature of the new streambed.

Calculations on a new dam indicated that the expense of footings, capable of withstanding further flood movement, was unrealistic. The most suitable method for filling the pond was by means of an external intake pipeline and streambed inlet filter. The filter outlet elevation was 0.59 feet above the pond overflow. This was necessary to account for friction loss in the 650 feet of pitchfiber pipe and the 1000 feet of 6 inch aluminum tube that conveyed the water to the pond. The construction was completed by the Soil Conservation Authority of the Barbados Ministry of Agriculture and Fisheries. Construction details are given in the Figures A1 and A2.

The foundation hole was dug with a large backhoe and the filter was constructed principally by hand labour. When it was observed that the installed filter was working, the aluminum tube pipeline was added. The used aluminum tube for the pipeline was provided by Soil Conservation Authority. New aluminum couplings for the pipeline were obtained through the efficient effort of Mr. John Kerr, Rain Bird Irrigation Equipment, Guelph, Ontario, Canada. Construction was spread over a period of one month. Delays had been caused by the difficulty in working with a mobile, semi-fluid stream bed, a 2.5 inch dry season rainfall, and the unavailability of couplings on the island. Upon completion of the filter it was hoped that future floods would pass over the filter structure leaving it and the pipeline undamaged. The pipeline was left exposed in the streambed, and weighted every 30 feet at the couplings with a 1/2 cubic yard of concrete. This mass of concrete was to counteract the buoyant effect of the pipeline should it contain air at the time of flooding and to resist external fluid drag. The filter intake performed flawlessly during the trials. The pond filled and overflowed. Drawdown that occurred on pumping was due to the low flow of the stream water source.

3.2 The Bridge

To convey irrigation water from the pumping system to the vegetable plots in Smith Field, a pipe and general transport bridge was required. Two sections of an obsolete crane were located and secured from the sugar factory at Haggats. A splice was engineered and the final placement of the bridge spanning the Greenland River gully was accomplished by suspending the bridge with steel cable between two opposing track tractors, one on each side of the Greenland gully. Design consideration was made for the rough handling encountered in the final placement of the bridge. The bridge is shown in Figure A3.

CHAPTER 4

Experimentation

4.1 The Soil

A soil test was performed on Smith and Bush fields which are shown on the plan Fig. 4. A composite test sample was taken from random areas and the sample was composed of surface sub-samples taken in a serpentine pattern, as described in Soil Chemical Analysis by Jackson[13]. The samples were analysed by the Macdonald College Soils Department.

The soils map of Barbados compiled by Vernon and Carroll[14], March 1965, described the soil of the Greenland site as "mapping unit 172". This soil was described as alluvial, of low clay content, and that this led to rapid drainage and a drought condition in the dry season. The soil was occasionally stony and of low natural fertility. From the sampling carried out it was observed that there was considerable clay content in some of the samples taken. This suggested an association with a nearby soil, "Mapping unit 141". This soil is of a decided clay content as a brick factory is established nearby. In general the soils of the region are neutral to basic.

The previous use of the soil was for continuously cropped sugar cane. Several years earlier, English potatoes had been grown in the area, but the results had been discouraging. The quality of the potatoes had been poor. This was probably due to excess of soil water and low soil aeration. There was some evidence that dredged material, from adjustments made to the stream bed of the Greenland River, had been spread on the west end of Smith Field. This accounted for the clay properties observed in some of the samples.

4.2 The Water

The source of water for the Greenland River (or really stream) was in the island's coral cap and ground water seepage from the 1700 acre watershed. There has been, on several occasions, considerable run off from heavy rainfalls. A storm, in 1966, was such an occasion and the dam that diverted stream water to the offset pond had been washed out. During the peak of the dry season, the stream source was gauged with a "V" notched weir and the flow was 63 U.S.G.P.M.

The water was tested by the Sugar Technology laboratory at Edgehill. The total salinity was indicated to be 600-700 parts per million. This salt concentration is medium to high in reference to Soil and Water Conservation Engineering (15) and depending on Sodium ion concentration, could be dangerous. Assuming the worst, the soil will need good management and will have to be well drained allowing leaching. Leaching may be accomplished in the wet season. Addition of organic matter will be helpful and chemical ammendments may be required.

4.3 The Climate

Climatic data was collected from a meteorological station erected on the windmill site. These standard meteorological instruments were used:

1) 48" evaporation pan
2) Maximum and minimum thermometers
3) Wet and dry bulb thermometers

4) Marquis plastic rain guage

5) Gunn Bellani solarimeter

6) Casella cup counter anemometer at 33 feet elevation in reference to the windmill foundation

The twice daily readings and maintenance of equipment were done by local school boys. Continuity and accuracy presented the major problem in analysing these results that appear in Table A2.

4.4 The Soil Moisture

Soil samples, for moisture content, were taken at weekly intervals from the vegetable plots. The samples were taken centered at depths of 3", 6", 12", 18", and 24", and the moisture analysis was done classically with an electric balance and drying oven. A bulk density determination was done on soil cores taken with one quart oil cans. The cans were inserted in the undisturbed soil at three locations within the 24 inch profile. The consistency of results allowed the use of a mean bulk density of 1.39. The soil moisture content was plotted in Graph A4.

4.5 Uniformity Trials

4.5.1 Measuring Cu

The uniformity trials were done on the vegetable plots and immediate area in Smith field. The orientation of the trial laterals was north-south, so that the sprinkler distributions were affected by a cross wind. Each uniformity trial included four sprinkler heads well spaced, for independence of irrigation water pattern, along the test lateral shown in Fig. 2C. Surrounding each sprinkler head was a 10 feet by 10 feet rectangular grid of one quart catch cans. The dimensions of these oil cans allowed a 200 millilitre volume to equal 1.0 inches of actual irrigation water application. The volume figures were used in the calculation of Cu and a final conversion was done to give irrigation in inches per hour.

These trials were run at random with reference to the average windspeed. Power source, sprinkler head, and nozzle size were the controllable variables. The many trials which were done gave enough duplication in average windspeed to allow a statistical comparison of uniformity of a given sprinkler head and nozzle size powered with the windmill and then with the Diesel engine. Initially, the three points of interest in these uniformity trials were: the irrigation system powered by the wind with and without a surge chamber in the hydraulic curcuit, and the system powered by the Diesel motor. A summary of the distribution findings is given in Table A1.

4.5.2 Calculating Cu

For the many distribution trials done, it was necessary to find an efficient method of calculating Cu for various sprinkler field spacings. The field data from a single sprinkler head was recorded on Form A1. To obtain Cu, this raw data was then put into a series of Cu calculation forms similar to Form A2. These forms accomplished geometric superposition of a single sprinkler pattern to simulate a total field irrigation system consisting of sprinklers identical to the one recorded. To obtain the best estimation of the total system, similar compilations were done for the other three similar, but not operationally identical, sprinkler heads which operated during a single uniformity trial. These values of Cu were then recorded on Form A3. Form A3 gave the average Cu for a specified sprinkler head and nozzle and also indicated the Cu at the different spacings used. These averages were used in statistical comparisons.

Sprinkler spacing along the lateral had to be fixed because of the aluminum tube lengths which were a standard 30 feet long. For the sprinklers used, 60 feet spacings of sprinklers along the lateral were found to give unacceptable distribution uniformity. Figure 5 indicates the spacing geometry used.

4.6 The Crops

The crop seed, fertilizer, labour, and management were supplied by A.D.C. The field layout is superimposed on the topographical survey in Figure 4. The original intention was a field trial involving forage grasses, and vegetables. The pangola grass established poorly due to the lack of supplemental irrigation at the time of planting. This was before the new pond intake could be constructed. The Elephant grass established without irrigation, but the field time available, limited the major thesis effort to the vegetable crops and the performance of the windmill irrigation system.

The cabbage and tomato plots were given the same fertilizer application of seven cwt. per acre of 12-12-17[2]. The carrots were not fertilized. The yield comparison was made between total yields on irrigated and non-irrigated replicates.

4.7 Windmill Performance

The vegetable crops were established and for the most part matured by windmill powered irrigation. Several times diesel power was used to supplement. This was due to the necessity of irrigation at crop transplanting time. When the wind was available the planting could be done with windmill powered irrigation. This suggests the need for co-ordination in the crop planting and operation of the windmill.

During the irrigation trials, information on windspeed and gallons pumped was kept. These figures were used to compare the predicted and actual capacity of the windmill pumping system. The data used for predicted capacity performance of the windmill was gathered during a long term continuous operation test. The first test lasted one week. During the continuous operation there was a man stationed at the windmill at all times. This procedure was necessary to collect the required data, and in the event of blade or drive train failure, to prevent destruction of the windmill.

A log book was kept for the period of operation and a set of readings was taken every half hour. These figures were recorded:

1) Wind miles run during the time interval

2) Integrated count of the pressure and time giving the average pressure

3) Average water discharge during the interval in (Imperial gallons per minute)

4) Pond elevation

5) Discharge or total nozzle area

6) Maintainance required

7) Gear ratio used

8) Windmill tower setting, or average direction of the wind

The windmill powered system during this time pumped water either to the field or, when not irrigating, back to the supply pond. The resulting power curves appear in the Graph 1. The reference water horsepower curve was determined by R. E. Chilcott[1]. The best single gear curve called Old H3 was used as the water horsepower available in determining the pumping capacity of the system. The estimations of water discharge versus average hourly windspeed (Graphs 2 to 7) are from this power available curve, and practical estimation of the possible irrigation system size. The Graphs 2 to 7 are for use with hourly windspeed data to estimate hourly discharge rate with the defined irrigation system. These totaled, give the 24 hr., weekly, or yearly potential discharge. Similar treatment could be given to pumping with a fixed discharge nozzle area, as for simple pumping from a deep well to a reservoir.

Forms A4 and A5 indicate the data compilation. Hourly wind-speed data was available for the Greenland site from June 1966 to June 1968. The ten hour period during the day conforms with present agricultural labour practice on the plantation.

CHAPTER 5

Results and Observations

5.1 The Uniformity Trials

5.1.1 Diesel Powered Distribution Trials

To test for the difference in pressure level and uniformity of sprinkler irrigation, it was necessary to assume that the variable of power source, sprinkler type, nozzle size, field position, lateral spacing, wind velocity and direction could be fixed. It was assumed that the characteristic of a given average windspeed over the uniformity trial time period (usually 1 1/2 hours) was the same. Diesel power was used for pumping and the uniformity trial was run with four sprinklers at one trial. The use of diesel power allowed different pressure levels in the steady state to be examined for their effect on field performance.

Statistical analysis of the difference in Cu due to pressure level was done in reference to Bowker and Lieberman[16] and Steel and Torrie[17]. In analysis, unequal subclass numbers occurred when there was less duplication at a given average windspeed. The results from this analysis appear in Table 1 and a worked example follows in Table 2.

5.1.2 Windpowered versus Diesel Distribution Trials

Since it had been shown, for the sprinklers used, that the average pressure level may affect the distribution of irrigation water, it was decided to separate pressure levels when comparing the two power sources. The windmill distribution data was selected on the basis of average pressure plus or minus 5 psig. This data was then separated into the two average pressure levels of interest, namely average 20 psig. and average 40 psig.

Average pressure for a specific distribution trial was obtained from average windspeed and discharge data taken at the time of the trial. This information applied to Graph 1 allows the estimation of average pressure knowing the water horsepower available at that average windspeed. Discharge and pressure, from a typical sprinkler nozzle, vary in a non-linear fashion. Strictly speaking, the effective mean pressure at the sprinklers may have been slightly higher than the value obtained by calculating from the mean discharge. This difference would not greatly affect the Cu determination.

The final comparison of uniformity was now to determine the differences in pumping with the wind and pumping with Diesel power. The effect on Cu of the surge chamber was also considered. However, the two extremes of the steady and unsteady state were compared first. In the event of extreme differences in the uniformity, the surge chamber in the hydraulic circuit could have an effect on smoothing out the unsteady state of flow and pressure.

The basic assumptions for the statistical assessment are that Diesel uniformity and windpower uniformity are two independent populations with unknown mean μ and unknown standard deviation σ . To establish the difference in uniformity between a Diesel irrigation system and a windpower irrigation system, it was necessary to compare on the basis of similar pressures and windspeeds plus the other fixed criteria of the pressure level comparison. The comparisons were made for Diesel distributions at 40 psig. and windpower distributions at 40 psig. $\pm$ 5 psig.

The same comparison was made at an average pressure 20 psig. Finally, the total spectrum of 20 and 40 psig. was compared. It had previously been decided that pressure levels above 40 psig. were not practical from the uniformity and power usage point of view. At the pressure level of 40 psig., the Diesel distributions were significantly better than wind-powered distributions. However, at 20 psig., the windpower distributions were significantly better than the Diesel distributions. The total comparison, 20 psig. and 40 psig., indicated no significant difference between irrigation distribution done with Diesel power and windpower. Graph A5 gives the frequency distribution of Cu for all distributions done. Tables 3 and 4 show a particular statistical treatment. Table 5 summarizes this statistical comparison.

5.2 The Crops

The field experiment lasted for a period of four months. The vegetable plots were prepared, planted, maintained, and harvested by the management of Greenland plantation, Mr. N. Taylor followed by Mr. G. Garvey. Table 6 summarizes these field operations.

The amounts of irrigation (Table 7) were applied to the vegetable plots on the basis of observation of porous bulb moisture meters. These instruments were found to function poorly in the heavy soil. As the moisture meters became inoperative, the irrigation requirement was estimated on the basis of time. This was 1.0" of water per week and 0.5" to 1.0" was applied per lateral setting. The vegetable yields for the treatments indicated appear in Table 8.

5.3 The Capacity and Performance of the Windmill

5.3.1 Selecting a Gear Ratio

In performing work with the windmill, it is desirable to have efficient wind to power conversion throughout the airscrew speed range. Cp for the airscrew is not consistent with R.P.M. so that in fact, it is advantageous to alter gear ratio with power available, or average windspeed. During irrigation of the vegetable trial plots, it was found that on marginal days, hourly average windspeed between 9 and 12 MPH, it was necessary to approach windmilling gear ratios in order to maintain a reasonable operation of sprinklers in the field. As the average windspeed increased above this range, it was possible to operate with a single gear. The curves of various possible single gear ratios appear in the Graph 1.

It was noted that the airscrew tended to stall aerodynamically on gear ratios greater than 22.3 to 1 or Old H1. This ratio means 22.3 revolutions of the pump impeller to one of the airscrew. At the other end of the gear ratio spectrum it was observed that airscrew windmilling (or excessive air screw R.P.M. to power absorbed by the pump) occurred at the ratio 13.8 or New H2. The ratios between these two limiting aerodynamic conditions are where the optimum single gear ratio is located. The choice of ratios obtainable from the existing gear boxes was New L3 of ratio 19.55 and Old H3 of ratio 16.65. From the data plotted in Graph 1, the best gear ratio appeared to be Old H3.

5.3.1 Discussion of Graph 1

The plots of the curves for water horsepower in Graph 1 are estimations drawn through a considerable scatter of points. The curves were assumed to be cubic function and are referenced to a curve obtained earlier by R. E. Chilcott[1]. The Chilcott curve for the optimum gear ratio was based on data that was obtained from short time periods of instantaneous strip chart records. The curves presented in this thesis are based on data taken at half hour intervals. This long time interval did not allow the record of power peaks so that most of the data obtained fell under the Chilcott curve.

The observed dispersion of points used in estimating the gear ratio curves on Graph 1 was due to several factors, one of these being the difference in average windspeed characteristic. To establish an average windspeed characteristic, acceleration rates and deceleration rates of the air mass must be observed. Windspeed characteristic is a measure of the velocity consistency of the wind.

Differences in the mass of fluid in the irrigation system cause differences in the response of the windmill airscrew to a gust or lull in the wind velocity. It is in fact a change in the inertia of the dynamic system (defined as airscrew, gears, shafting, and water). This feature was examined with the data available. Graph A6 indicated that no conclusive evidence of inertia change could be obtained from this data. Table A3 shows the type of calculation performed on some strip chart data taken. The main observation was that actual guage pressure observed was consistently greater than the calculated change in pressure necessary to accelerate the mass flow of water to the actual observed velocity. To make this calculation more precise the formulation would have to include a differential term to account for the nozzles discharging the fluid.

Upon examination of the pump characteristic, Graph A1, it is observed that the system is usually operating in an area of high variation in pump impeller efficiency. During windmill, unsteady state pumping, the system will operate up and down this efficiency relationship, causing a part of the inconsistancy observed in the plotting of data for Graph 1.

5.3.3 <u>Discharge Capacity of the Windmill Sprinkler Irrigation System</u>

To predict windmill irrigation system discharge capacity, it is necessary and sufficient to obtain hour by hour average wind records. Forms A4 and A5 indicate the use of hourly windspeed data applied to any one of the discharge Graphs 2 to 7.

Graphs 2 to 7 are based on two postulated irrigation systems and the water horsepower available from the windmill using the best single gear ratio Old H3. The postulated irrigation systems are for the Greenland site and account for head losses due to average field elevation and flow in irrigation tubes, valves, risers and nozzles. The sprinkler head and nozzles used for these postulated systems cover a spectrum of uses, namely irrigating young transplanted seedlings, mature vegetables or grasses.

The lateral sizes were altered from 10 to 12 to 16 sprinklers per lateral and treated as operating within a rectangular field of appropriate width. These lateral lengths were observed to offer the flexibility required in altering the discharge to match the wind power available. Lateral discharge is calculated from the number of sprinklers on the lateral and the discharge versus pressure characteristic of the nozzles specified for the sprinkler head. Sprinkler and nozzle data comes from Rainbird Sprinkler Quick Reference Catalog[18].

An hour by hour average windspeed fluctuation was observed in the Greenland data. In windmill irrigation, to account for this fluctuation,the number of laterals operating is constantly being altered by the direction of the windmill operator. The efficient use of windpower available depends on the judgement of the operator. During the trial period, the basic instrumentation used to measure the performance was the pressure guage. The operator can also observe the misting or non-misting of water from the sprinkler nozzles and he can estimate the average windspeed.

This reasoning was applied when transferring the hourly data to the discharge Graphs 2 to 7. The operator would start the day opening the maximum number of laterals that would give a reasonable working effect in the field. Proceeding from hour to hour the average windspeed data indicates the addition or subtraction of laterals from the system. A one hour time lag is allowed for operator reaction to the power increase or decrease. During this lag time the irrigation system is either wasting power with unnecessarily high pressures or is performing poorly due to low pressures. As the pressure becomes noticably high, the operator turns on another lateral, and the discharge increases at the expense of a pressure decrease. The inverse would happen with a noticable decrease in average sprinkler operating pressure. In transitional operation, between lateral opening and closing, the sprinklers operate on a fluctuating pressure and discharge determined by their characteristics of discharge to average pressure.[18]

Graph 8 indicates the accuracy of the predicted discharge obtained by Graph 3. The calculated curve of discharge, in Graph 8, over the 10 hours studied from 7:00 to 17:00, was made on the basis of a given average windspeed producing a given average discharge (from Graph 3) over the 10 hours. This curve was checked with actual working data. The agreement was very good. Actual data for a different irrigation system as in Graph 6 was compared likewise. This showed a higher total discharge for the higher average wind velocities under which this system had been used in the field. This agrees with the corresponding increase in discharge observed in the higher windspeeds of the estimated discharge curve in Graph 6.

5.3.4 Irrigation Scheduling

Scheduling wind powered irrigation is difficult. It depends on diurnal and seasonal windspeed velocity fluctuations; also labour availability. In Barbados the situation suited windpower irrigation, in that the diurnal fluctuation and time of labour availability coincided. The dry season, however, can have weekly periods of low average windspeed. This is unfavourable for optimum use of sprinkler irrigation.

The use of electrically controlled, continuous irrigation systems is made where conventional power is readily available. This type of irrigation can be scheduled to meet crop moisture deficits and thereby use available irrigation water most efficiently. The windmill irrigation system is obliged to operate when the wind power is available.

CHAPTER 6

Discussion of Results and Conclusions

6.1 The Uniformity Trials

The uniformity trials indicated the acceptability of the windmill irrigation system from a distribution point of view. All distributions were considered acceptable in that they compared to expected values based on manufacturers' specifications. This meant a Cu of 70 to 100. The trials indicated also that the damping chamber would have no significant effect on distribution. This amounts to an installation saving. However, a surge tank for reduced "waterhammer" effect is worthwhile on irrigation systems with long mainlines.

It was observed that the optimum average operating pressure, with windmill pumping, was in the range of 20 psig. The uniformity at an average pressure of 40 psig. was decidedly lower but these uniformities with suitable spacing of laterals were acceptable.

Satisfactory operation could not be achieved with very small discharge nozzles and low pressure levels. Poor sprinkler head rotation and nozzle blockage occurred when operating 20A sprinkler heads with nozzles smaller than 9/64" diameter and an average pressure of less than 20 psig.

6.2 The Vegetable Plots

The yield of the vegetable plots could have been increased. It was unfortunate that the plantation had just started its agricultural diversification from sugar cane into vegetable and milk production, so that equipment and experience in vegetable production were yet to be obtained. Enthusiasm for the diversification and the desire to make it a success were apparent in the handling of the experimental plots and other production plots being maintained. In reference to carrot yields of 5000 to 6000 lbs. per acre suggested by Mr. T. Carr[19] of the Ministry of Agriculture, Trinidad, the Greenland yields were above expectation. Yields being obtained in parts of the U.S.A. and Canada suggest that further improvements could be obtained. The cabbages were the only crop to suffer insect damage. This could not have been prevented due to the lack of spraying equipment at the time needed. At planting time for the cabbage and tomatoes, it became apparent that it was necessary to adapt planting to the availability of wind power. Ideally it would mean planting small acreages of up to 1/2 acre per day per transplanting. Crops from seed, like the carrot, do not require this as the seed can stay dormant while the wind is not available.

6.3 Discharge Capacity of the Windmill Sprinkler Irrigation System

Based on the 10 hour operational day, the day to day capacity of the windmill irrigation system indicated a fluctuation from 0 to 2.45 acre inches. This includes a 70% efficiency of irrigation water application, and is related to the Greenland wind regime. The average irrigation discharge expected for the data used was 1.07 acre inches with the probability of experiencing a zero day of 1 in 6. These figures are for dry season data at the Greenland site, and give a simple treatment to a complex topic of weather probability and agriculture. There is this "no wind" risk factor and varying discharge capacity factor that must be accepted. These are not problems in a conventionally powered system.

Capacity of a similar sized irrigation system conventionally powered is approximately twice that of the windmill system. It is calculated that in a good wind regime, meaning an operating hourly windspeed of 14 MPH plus, the power available is equivalent to a Diesel system. T. A. Lawand[20] suggested that the economic break even point for Brace Windmill power is in a regime of 13 MPH to 16 MPH, when compared to electrical and diesel shaft power respectively. The monthly averages for the Greenland site indicate that it is a region of marginal economic feasibility for windmill operation. Monthly averages may be deceptive in their implications. Reference to Golding[2] and the observed field performance exemplify the necessity of evaluating a wind regime on the basis of time duration of windspeed and diurnal variation. This analysis applied to the Greenland site makes the windmill more feasible.

The Greenland site appears to be marginal for windmill usage due to average windspeed and the availability of alternative power. However, with little improvement in the average windspeeds and a more isolated location or one with no conventional power, the windmill would be feasible.

6.3.1 Other Considerations for Windmill Power

The windmill pumping system could also have better application than that of pressurized sprinkler irrigation. These would include pumping for surface irrigation or subsurface irrigation. These applications are suited to intermittent pumping, and continuous operation on a 24 hour basis. Drainage and municipal pumping have much potential with the windmill system. The attractive features of the windmill are its low maintainance, long life and zero fuel cost.

Presently the capital expense of windmill installation is greater than for the conventional power sources. Production costs are not available yet, however, standard production cost estimation procedures were accounted for in the Lawand Report[20]. The life of the windmill is dependent on the life of the plastic blades. The prototype blades indicated no visual strain damage at the end of the trial period, two years after being installed in the field. Gearboxes and bearings functioned without problem.

In considering the future of the windmill, these suggestions are made. The idea of windmill power must be sold. It must be realized that modern windmills have a potential and that this ancient form of power is still competitive, and moreover, useful. Promotion is necessary, and the best way of accomplishing this is by demonstration. To best demonstrate the windmill, continuous operation is required. At the Greenland site, upon installation of an automatic brake, pumping could be done continuously using the field plots or the pond recycling circuit. Concentrated, high value crops could best demonstrate the economic production potential of the system.

At the present time, potential uses for this windmill do exist, but as modern advertising has proven, the demand or desire for a product has to be created or pointed out to give the maximum effect.

CHAPTER 7

Summary of Conclusions

1) Distribution uniformity from the irrigation system powered by the Brace windmill was equivalent to distribution uniformity from the same irrigation system powered by the Diesel engine. At pressures of average 40 psig., the diesel water distribution was better than the windpowered water distribution but at pressures of average 20 psig., the opposite was observed. The coefficient of uniformity of a windmill powered sprinkler system (unsteady state), operating within the pressure range 20 psig. to 40 psig., is acceptable and equivalent to that of the same system operating in the steady state of discharge and pressure.

2) Vegetable crop production associated with windmill irrigation must be maximized. Cash vegetable crops grown at maximum plant density and well managed as to insect and disease control, can produce the yields required to amortize the capital investment. The maximum area for production is determined by the capacity of windmill irrigation which is dependent on the wind regime.

3) The discharge capacity of the windmill pumping system is dependent on the pumping heads required, the wind power available, and the period of functional operation. For the Greenland site, the day to day capacity during the dry season, is variable to the point where it is difficult to schedule the most efficient use of irrigation water to meet the plant moisture requirement. Depending on the moisture retention characteristic of the soil, the soil moisture deficit can be met with windmill irrigation applied to the appropriate surface area.

4) In continuous pumping applications, water storage capacity will depend on the wind regime. This day to day capacity would have to be accounted for when designing pump drainage storage or storage for municipal consumption.

5) The response of the windmill irrigation system to wind velocity increase and decrease, depends on the inertia of the system. The inertia of pump, shafting, gears and airscrew are constant. However, the total mass of fluid in the line is variable with alterations in length of main-line and number of laterals. The greater the mass of fluid to be accelerated, the less will be the response of the airscrew to wind velocity increase. Alternatively, there is a built in energy storage effect upon deceleration of the fluid due to wind velocity decrease.

6) To introduce the windmill into commercial operation, the production costs must be established. With the cost known, an agressive demonstrational program of promotion can be carried out. This means the establishment of several test plots for both irrigation pumping and municipal pumping in areas of potential economic or practical application. It is desirable to have some units working in commercial farm situations to obtain further operational cost and performance information.

CHAPTER 8

Recommendations for Further Study

1) There is a definite need to verify the benefits derived from irrigation of vegetables and grasses in the potential areas of irrigation interest. There is not sufficient information available to make good economic analyses for either wind powered or engine powered sprinkler irrigation systems. This requires quantification, where possible, as to social and economic benefit. This is suggested in agreement with a report by A. Wilson of the British Overseas Development Commission[21].

2) In studying the total feasibility of the windmill, a pilot municipal scheme for pump power utilization could be of value. This could be done through private endeavour on the part of a needy community or with a foreign aid scheme.

3) A close examination of the world geographical and meteorological conditions would indicate areas of priority for windmill applications. This would be of benefit in determining potential production of the windmill and give an estimate of the windmill potential in bettering the living conditions of mankind.

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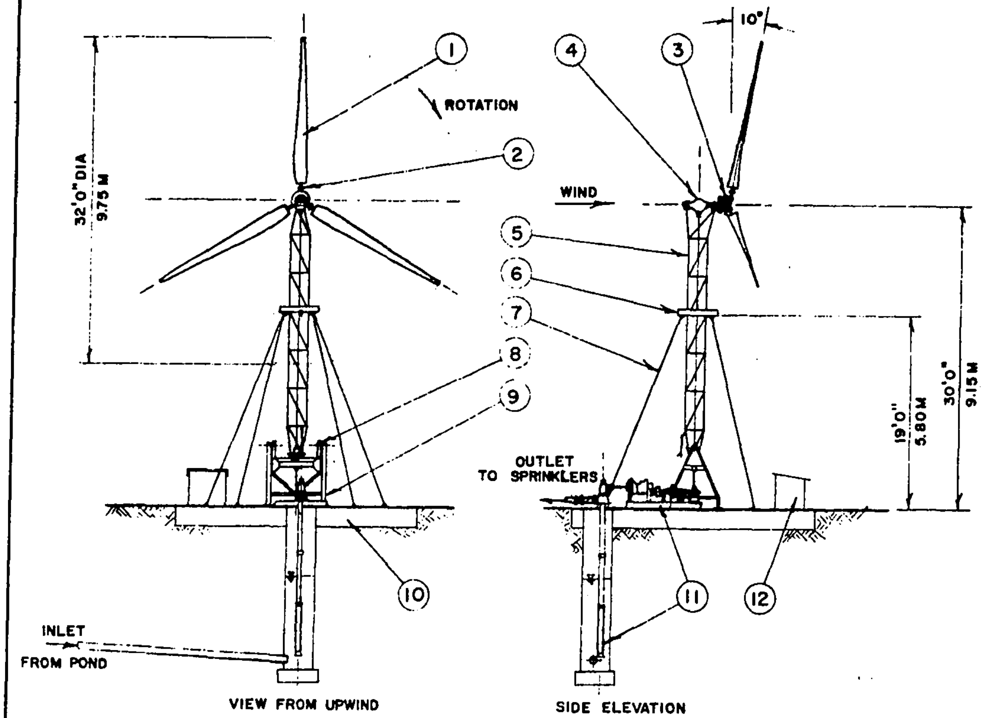


PROTOTYPE BRACE AIRSCREW WINDMILL PUMPING SYSTEM.

DRAWING NO.	ITEM NO.	DESCRIPTION
F-3-002	14	BLADE SHIPPING AND STORAGE CONTAINER
A-3-008	13	PARTS LIST FOR ONE SET OF BLADES
D-3-006	12	ERECTING GEAR
E-3-003	11	TRANSMISSION MACHINERY PAD AND PUMP
D-3-008	10	FOUNDATION
D-3-007	9	TOWER BASE
D-3-004	8	TOWER YOKE
C-3-012	7	GUYS
E-3-002/2	6	TOWER BEARING
E-3-004	5	TOWER
D-3-001	4	TRUCK REAR AXLE
D-3-005	3	AIRSCREW HUB
D-3-011	2	AIRSCREW BLADE ROOT
F-3-001	1	AIRSCREW BLADE

BRACE RESEARCH INSTITUTE
OF McGILL UNIVERSITY
MACDONALD COLLEGE, P.Q. CANADA

TITLE GENERAL ASSEMBLY
BRACE AIRSCREW WINDMILL

SCALE 1/100

DRAWN	R.H.WEYTS	JULY 1968
STRESSED		
CHECKED		
APPROVED	R.E.CHILCOTT	JULY 1968
ASSEMBLY		
DWG. No.	B-3-041	

Fig. 1. Prototype Brace airscrew windmill pumping system.

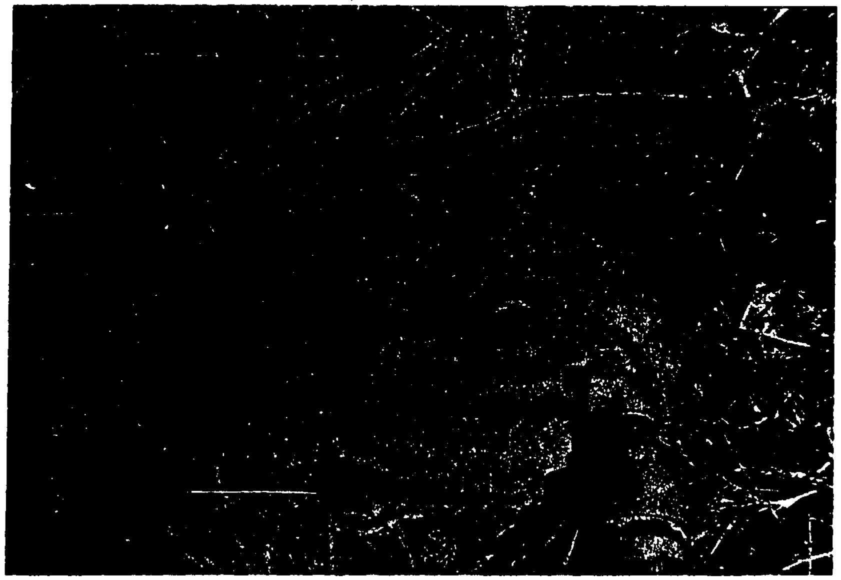


Figure 2a Electric Valve Manifold for Simulation of Field Lateral Discharge When Recycling Irrigation Water to Offset Pond

Figure 2b A Typical Irrigation Lateral Field Configuration

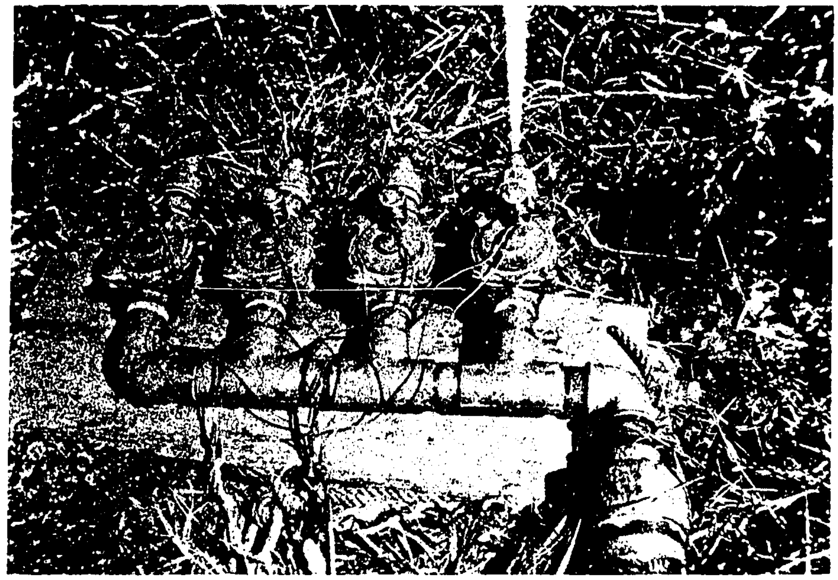


Figure 2a Electric Valve Manifold for Simulation of Field Lateral Discharge When Recycling Irrigation Water to Offset Pond

Figure 2b A Typical Irrigation Lateral Field Configuration

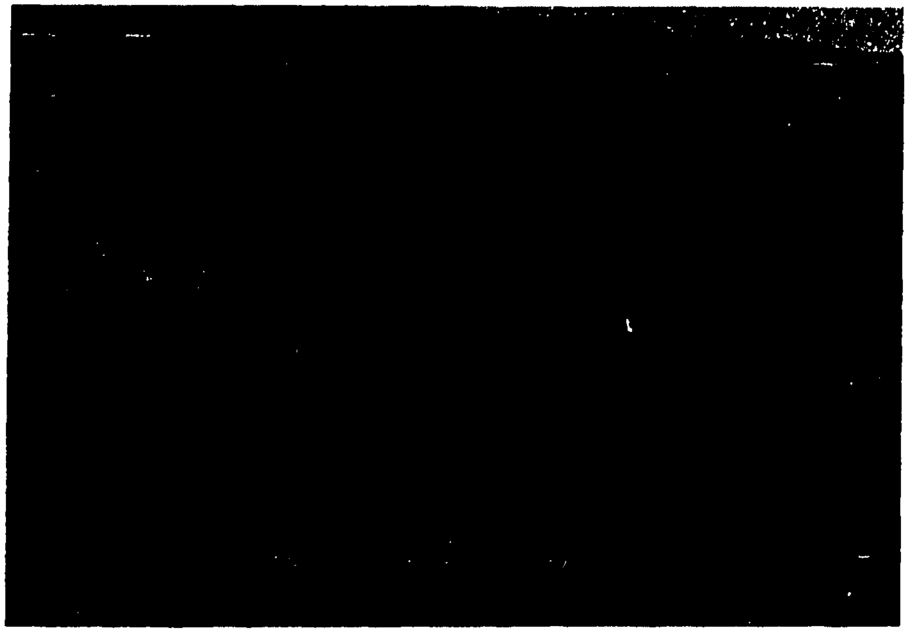


Figure 2c A Sprinkler Irrigation Uniformity of Distribution Field Trial Consisting of 4 Sprinklers Surrounded by a 10' x 10' Rectangular Grid of Catch Cans

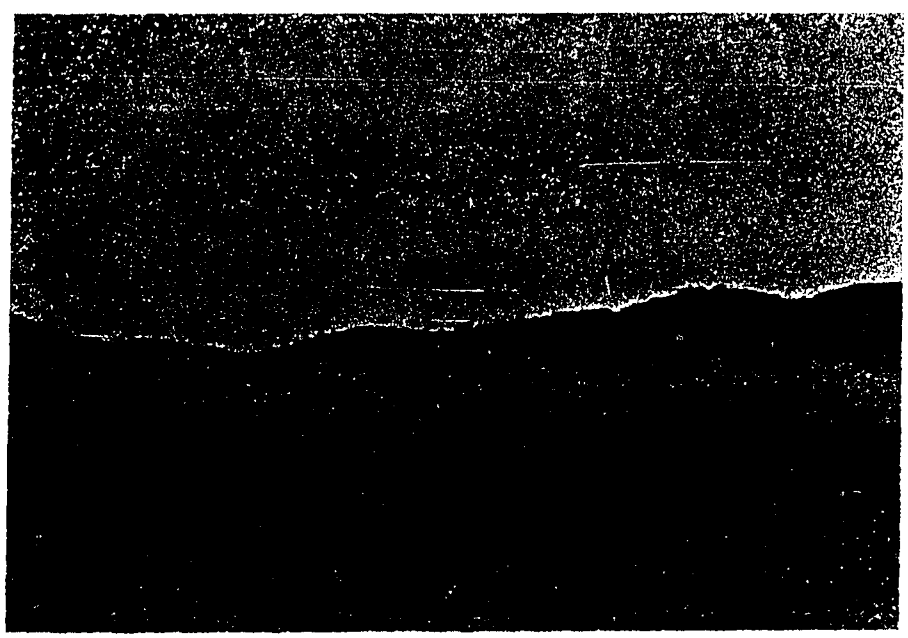


Figure 2d Windpowered Sprinkler Irrigation System Performance During a Period of Average Wind Velocity 18 MPH.

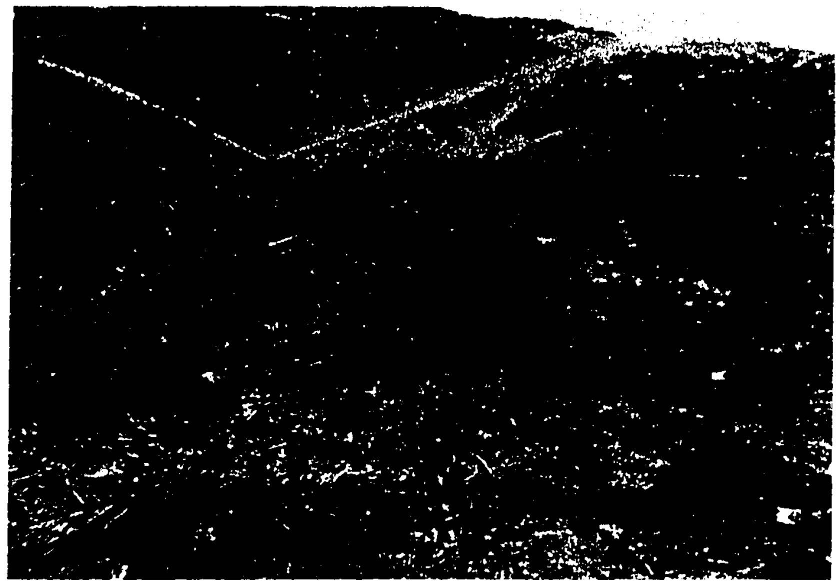
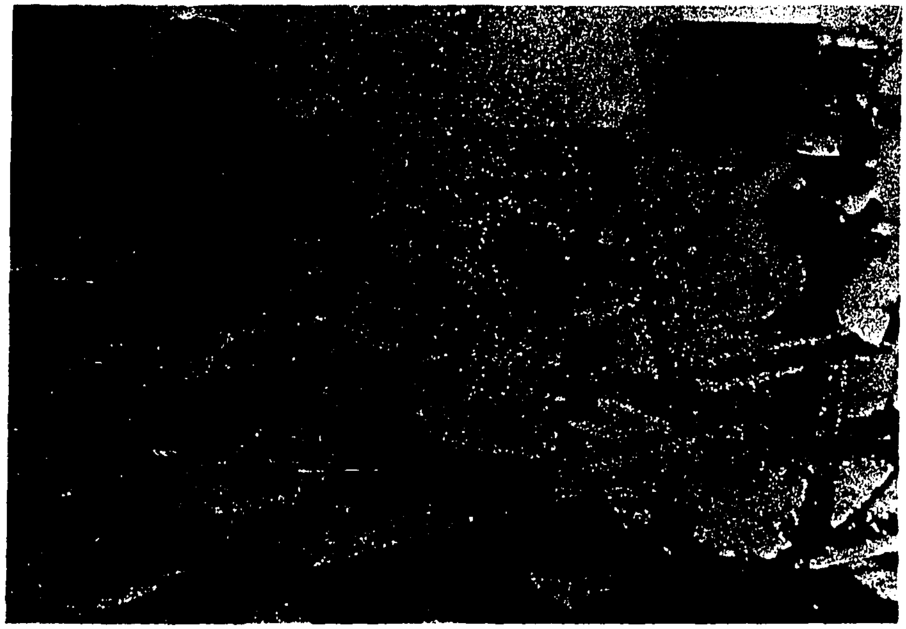


Figure 2c A Sprinkler Irrigation Uniformity of Distribution Field Trial Consisting of 4 Sprinklers Surrounded by a 10' x [illegible] Rectangular Grid of Catch Cans

Figure 2d Windpowered Sprinkler Irrigation System Performance During a Period of Average Wind Velocity 18 MPH.

Figure 3a Windmill Tower Base and Diesel Test Engine



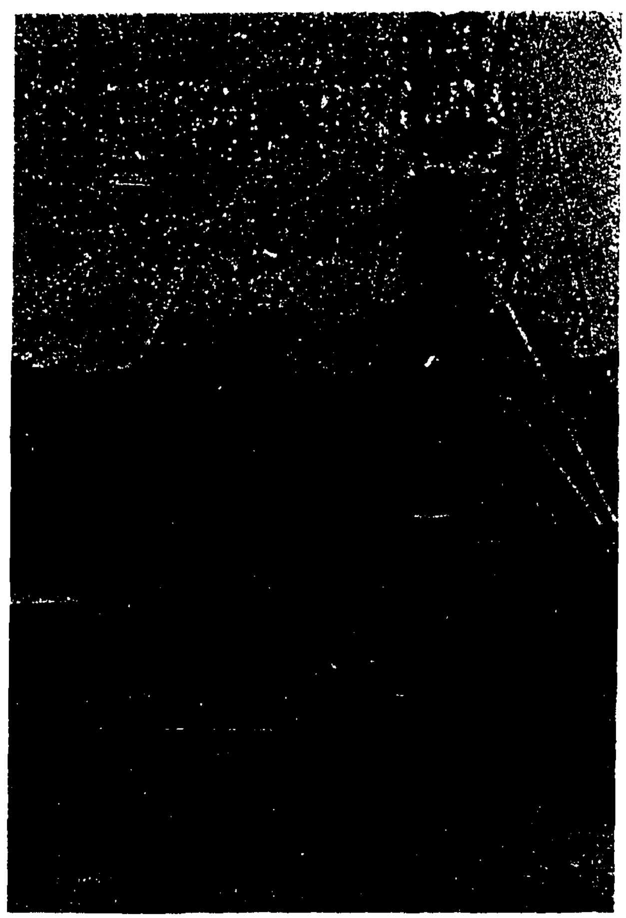
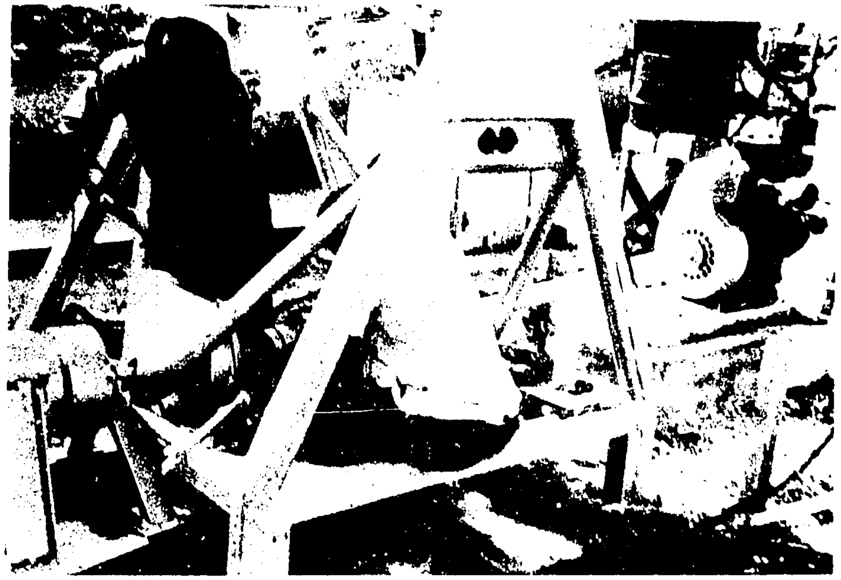


Figure 3b Hydraulic Measuring Circuit Featuring Surge Tank, Pressure Measuring, and Discharge Measuring Instrumentation

Figure 3a Windmill Tower Base and Diesel Test Engine



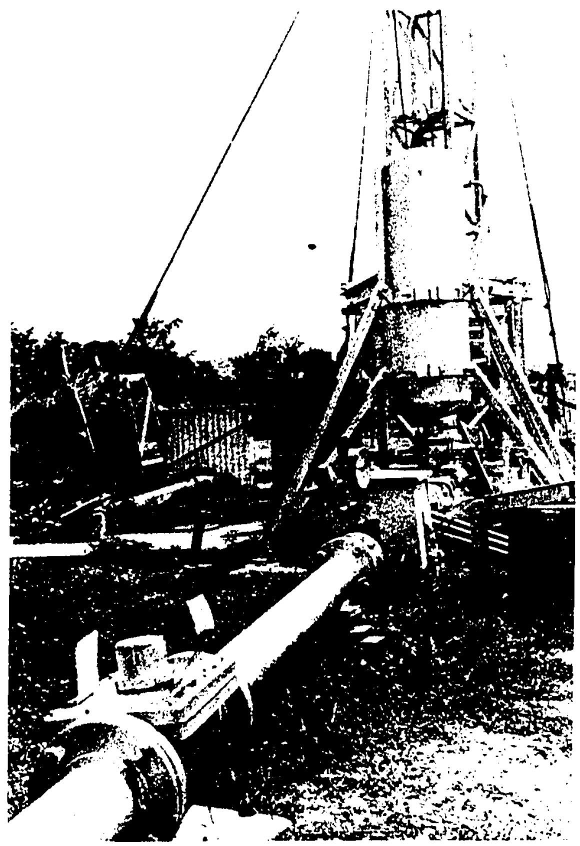


Figure 3b Hydraulic Measuring Circuit Featuring Surge Tank, Pressure Measuring, and Discharge Measuring Instrumentation

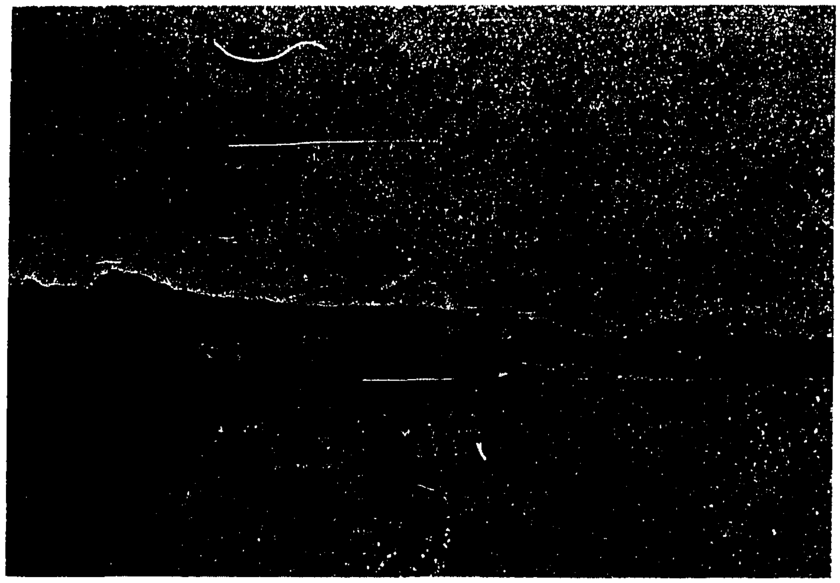


Figure 3c   Recycling of Pond Irrigation Water

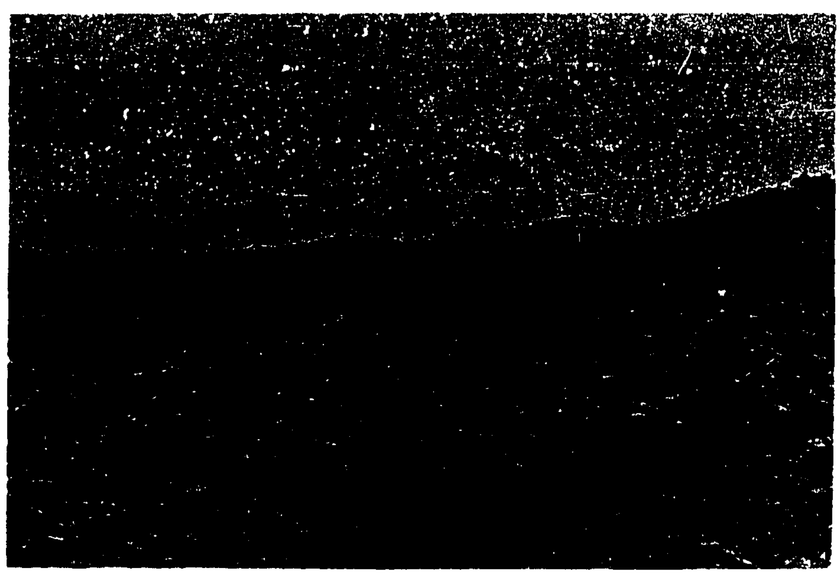


Figure 3d   The Vegetable Field Plots, Cabbage, Tomatoes and Carrots

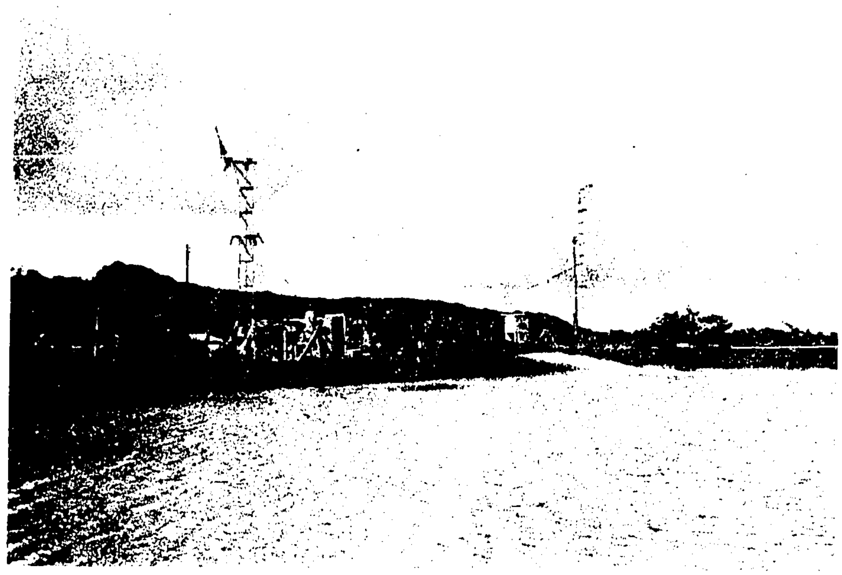
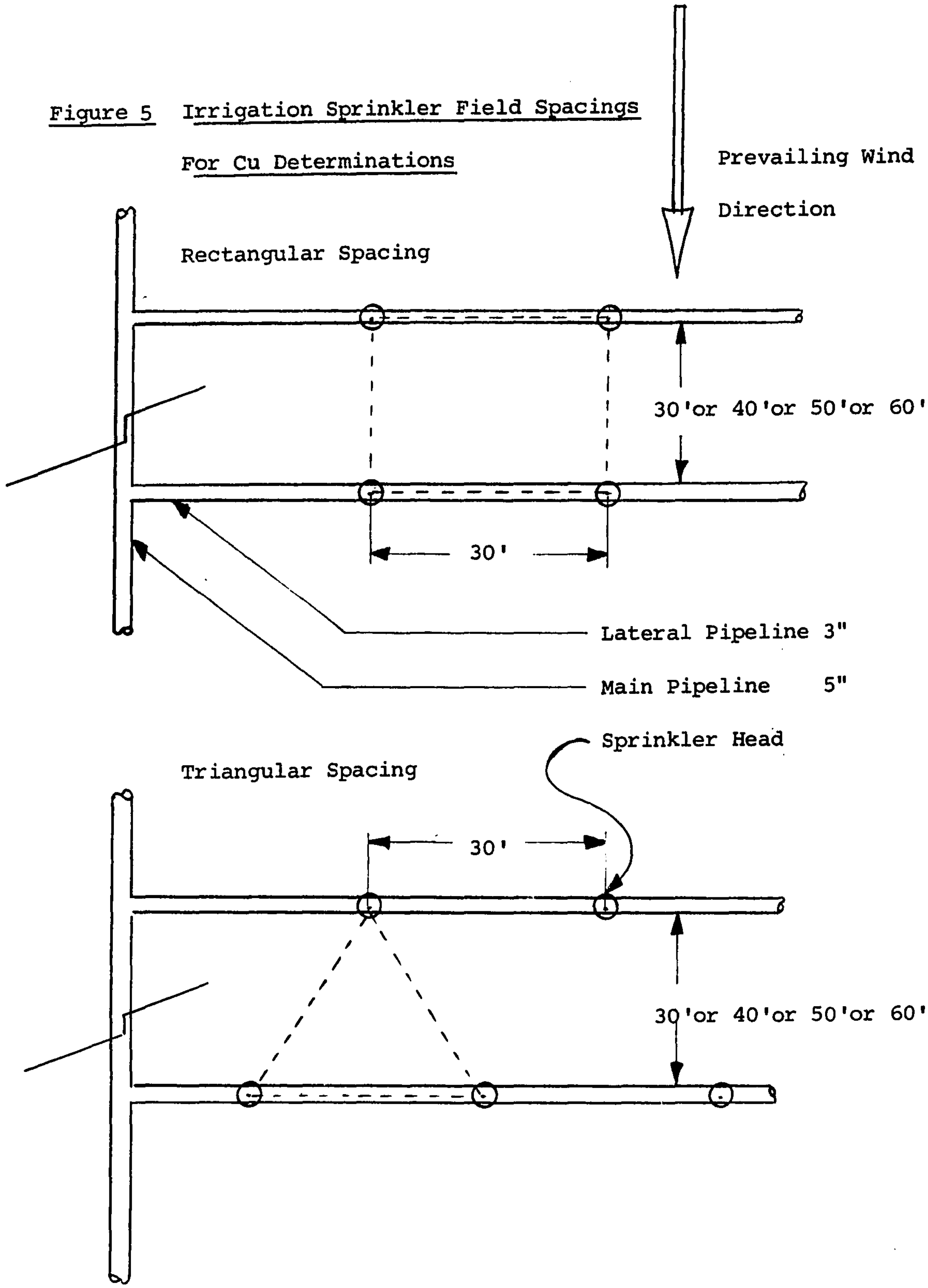
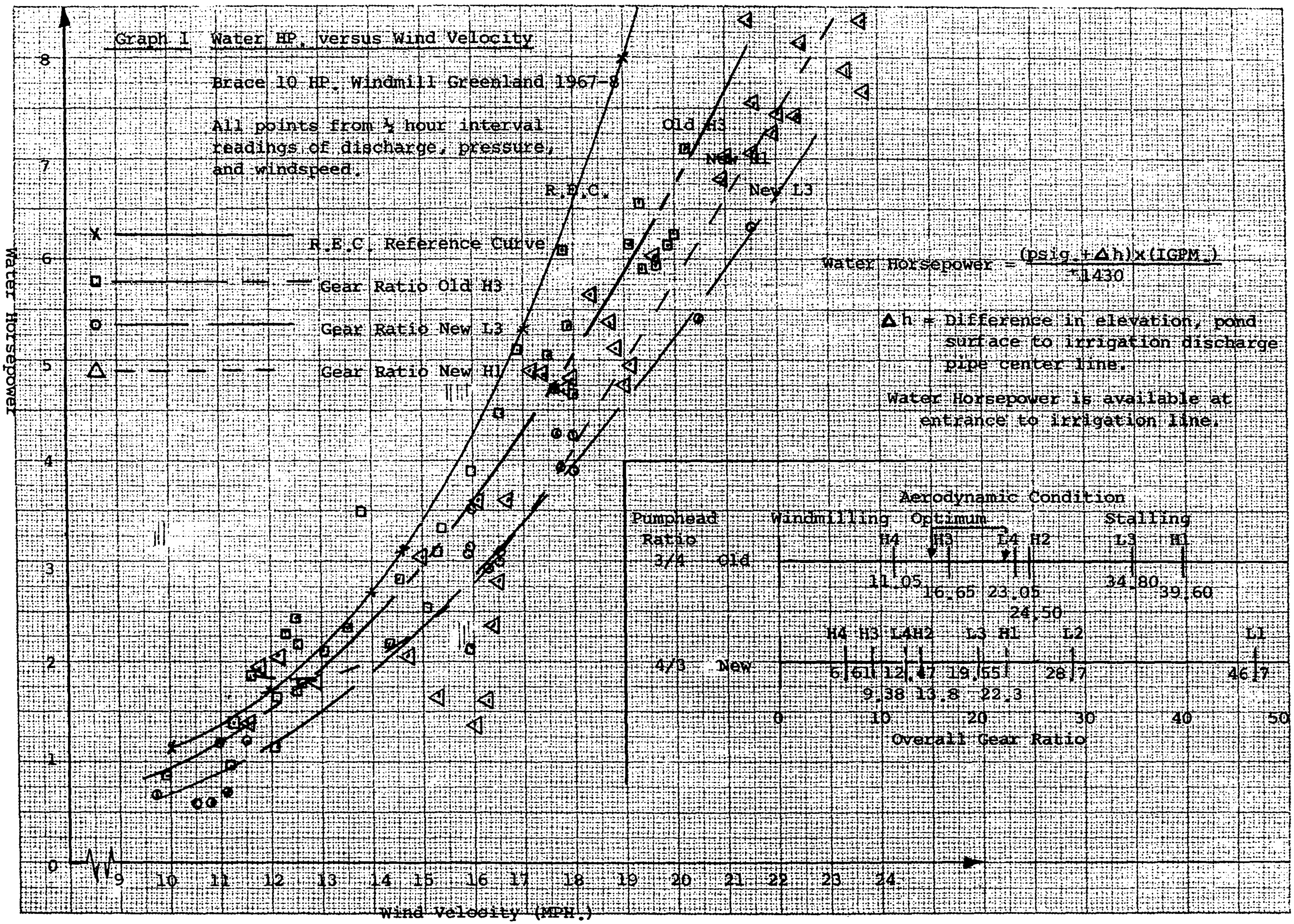


Figure 3c Recycling of Pond Irrigation Water

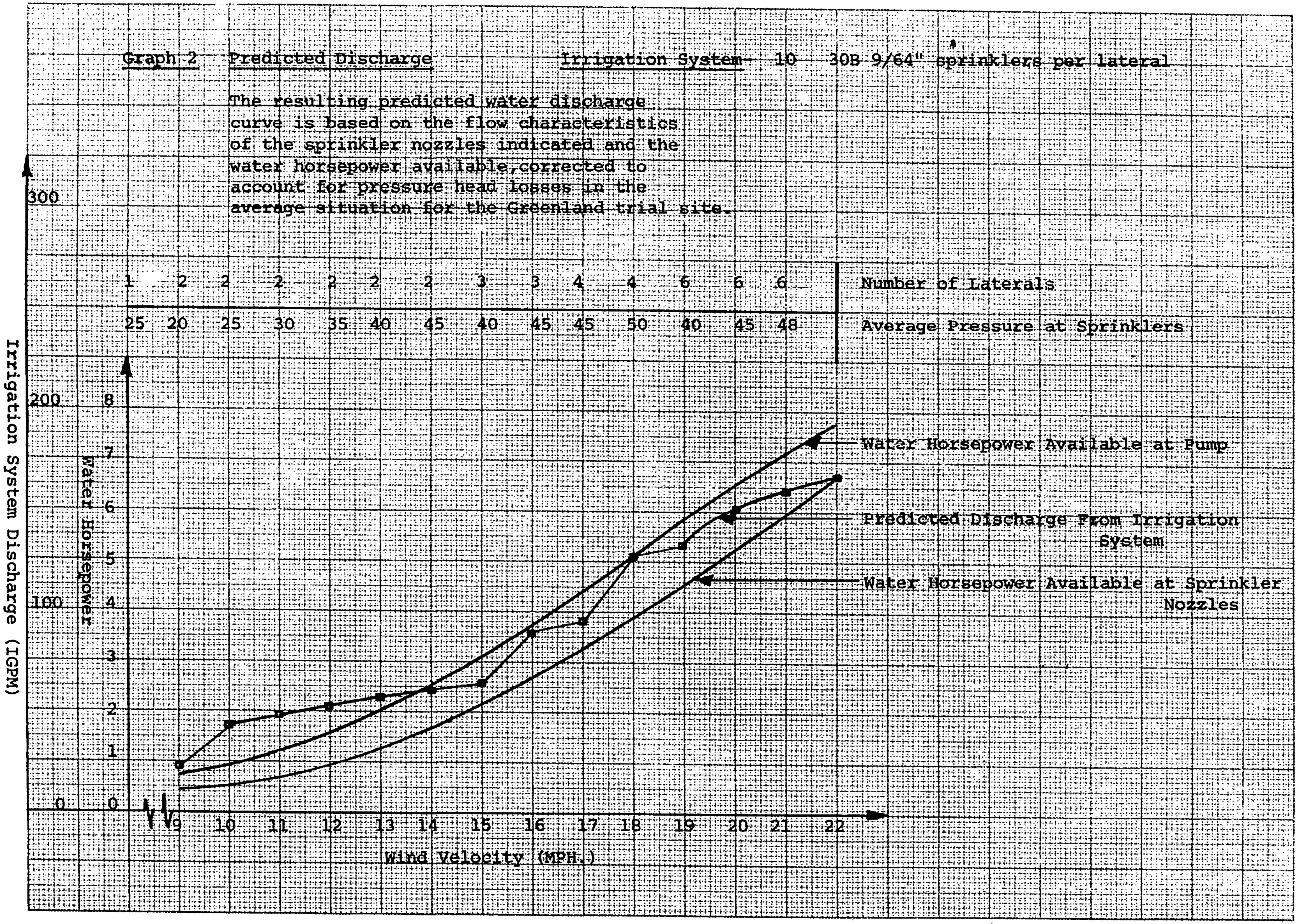
Figure 3d The Vegetable Field Plots, Cabbage, Tomatoes and Carrots

Figure 5 Irrigation Sprinkler Field Spacings For Cu Determinations



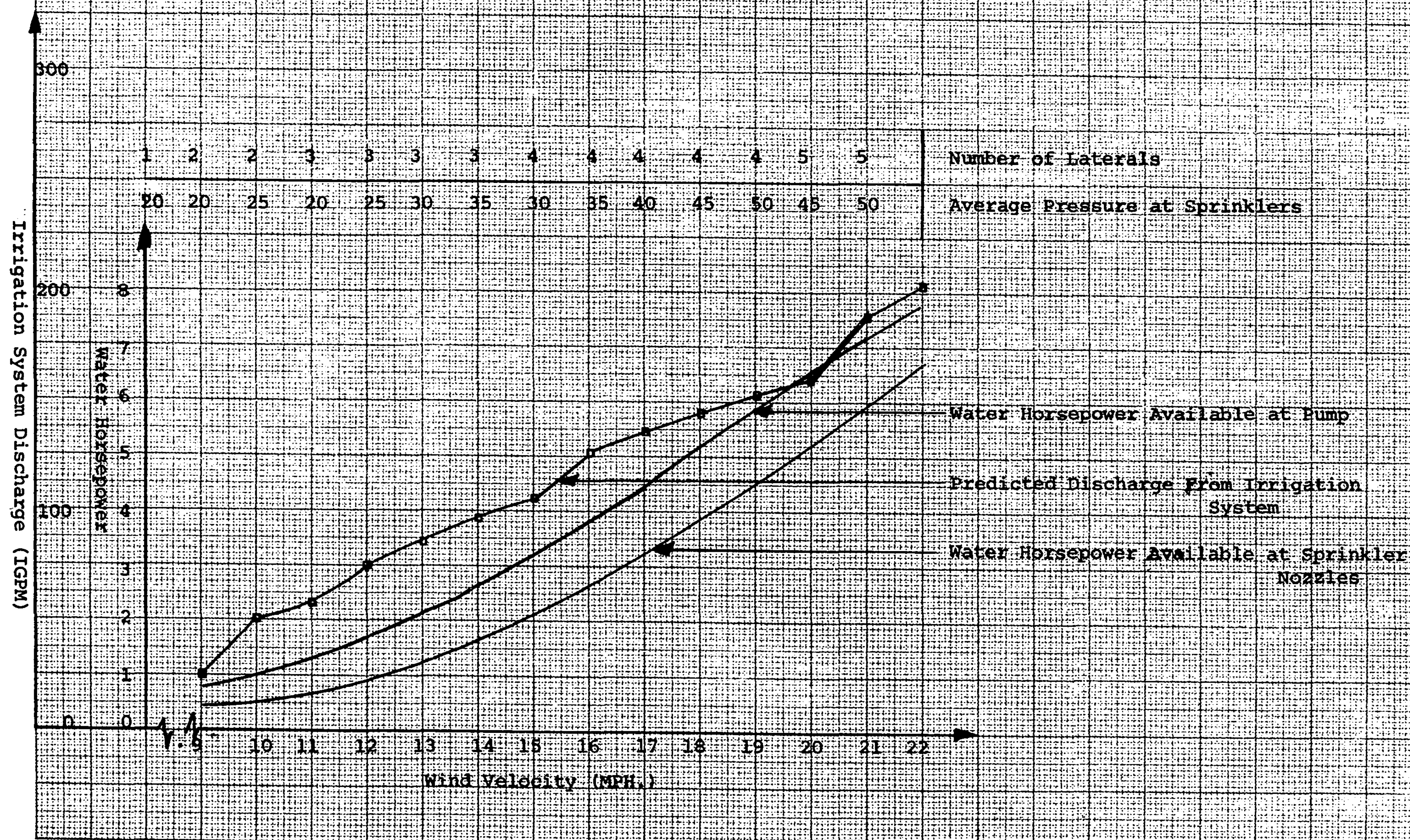


Graph I Water HP. versus Wind Velocity
Brace 10 HP. Windmill Greenland 1967-8
All points from ½ hour interval readings of discharge, pressure, and windspeed.
X R.E.C. Reference Curve
Gear Ratio Old H3
Gear Ratio New L3
Gear Ratio New H1
R.E.C.
Old H3
New H1
New L3
Water Horsepower = (psig. + Δh) x (IGPM.) / 1430
Δh = Difference in elevation, pond surface to irrigation discharge pipe center line.
Water Horsepower is available at entrance to irrigation line.
Aerodynamic Condition
Pumphead Ratio
Windmilling
Optimum
Stalling
3/4 Old
4/3 New
H4 H3 L4 H2 L3 H1
11.05 16.65 23.05 24.50 34.80 39.60
H4 H3 L4H2 L3 H1 L2 L1
6.61 12.47 19.55 28.7 46.7
9.38 13.8 22.3
0 10 20 30 40 50
Overall Gear Ratio
Water Horsepower
0 1 2 3 4 5 6 7 8
Wind Velocity (MPH.)
9 10 11 12 13 14 15 16 17 18 19 20 21 22 23 24


Graph 2 Predicted Discharge
Irrigation System 10 30B 9/64" sprinklers per lateral
The resulting predicted water discharge curve is based on the flow characteristics of the sprinkler nozzles indicated and the water horsepower available, corrected to account for pressure head losses in the average situation for the Greenland trial site.
Number of Laterals
1 2 2 2 2 2 2 3 3 4 4 6 6 6
Average Pressure at Sprinklers
25 20 25 30 35 40 45 40 45 45 50 40 45 48
Water Horsepower Available at Pump
Predicted Discharge From Irrigation System
Water Horsepower Available at Sprinkler Nozzles
Irrigation System Discharge (IGPM)
300
200
100
0
Water Horsepower
8
7
6
5
4
3
2
1
0
9 10 11 12 13 14 15 16 17 18 19 20 21 22
Wind Velocity (MPH.)

Graph 3 Predicted Discharge   Irrigation System- 12 30B 9/64" sprinklers per lateral

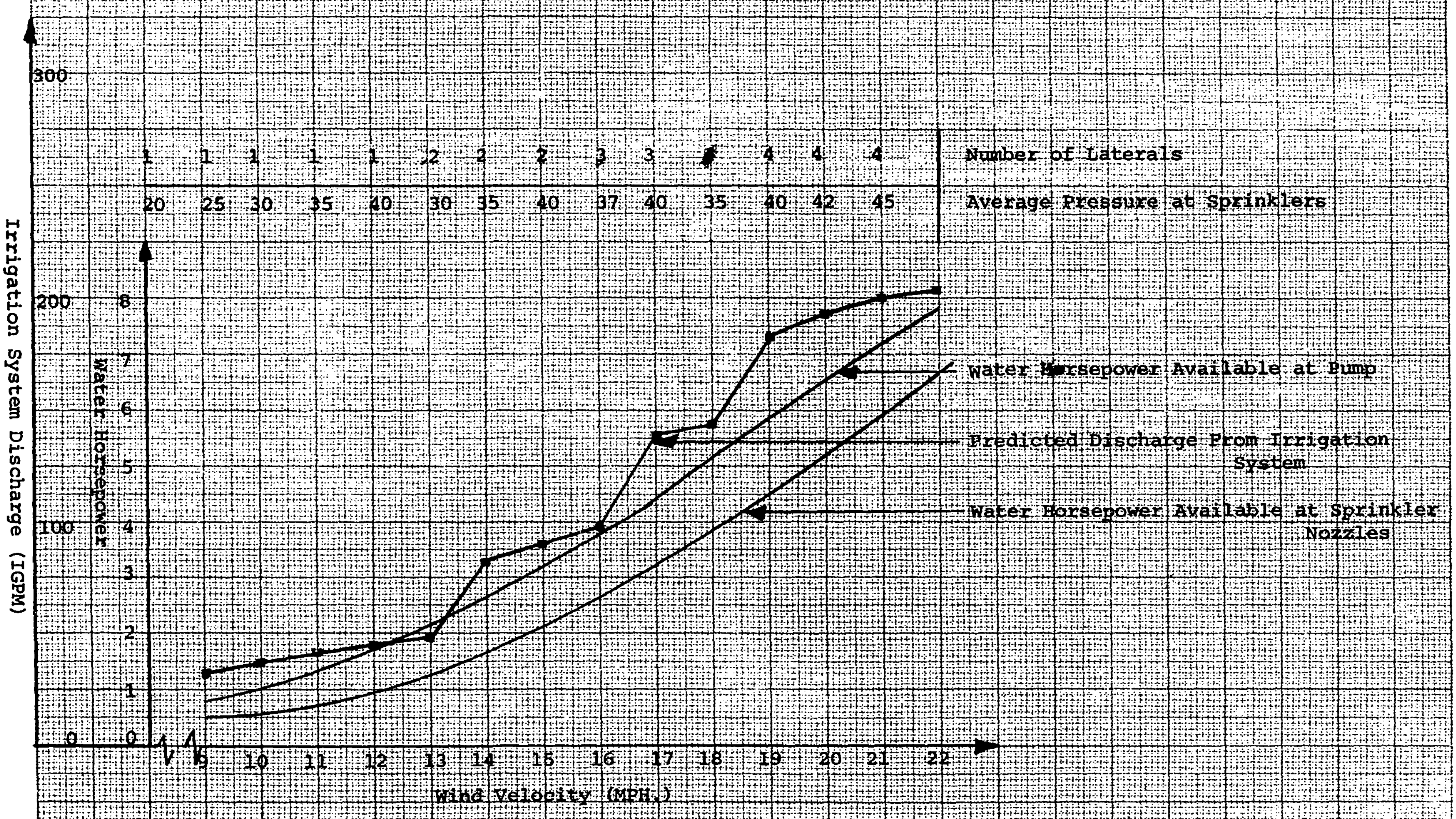
For basis of curves see Graph 2

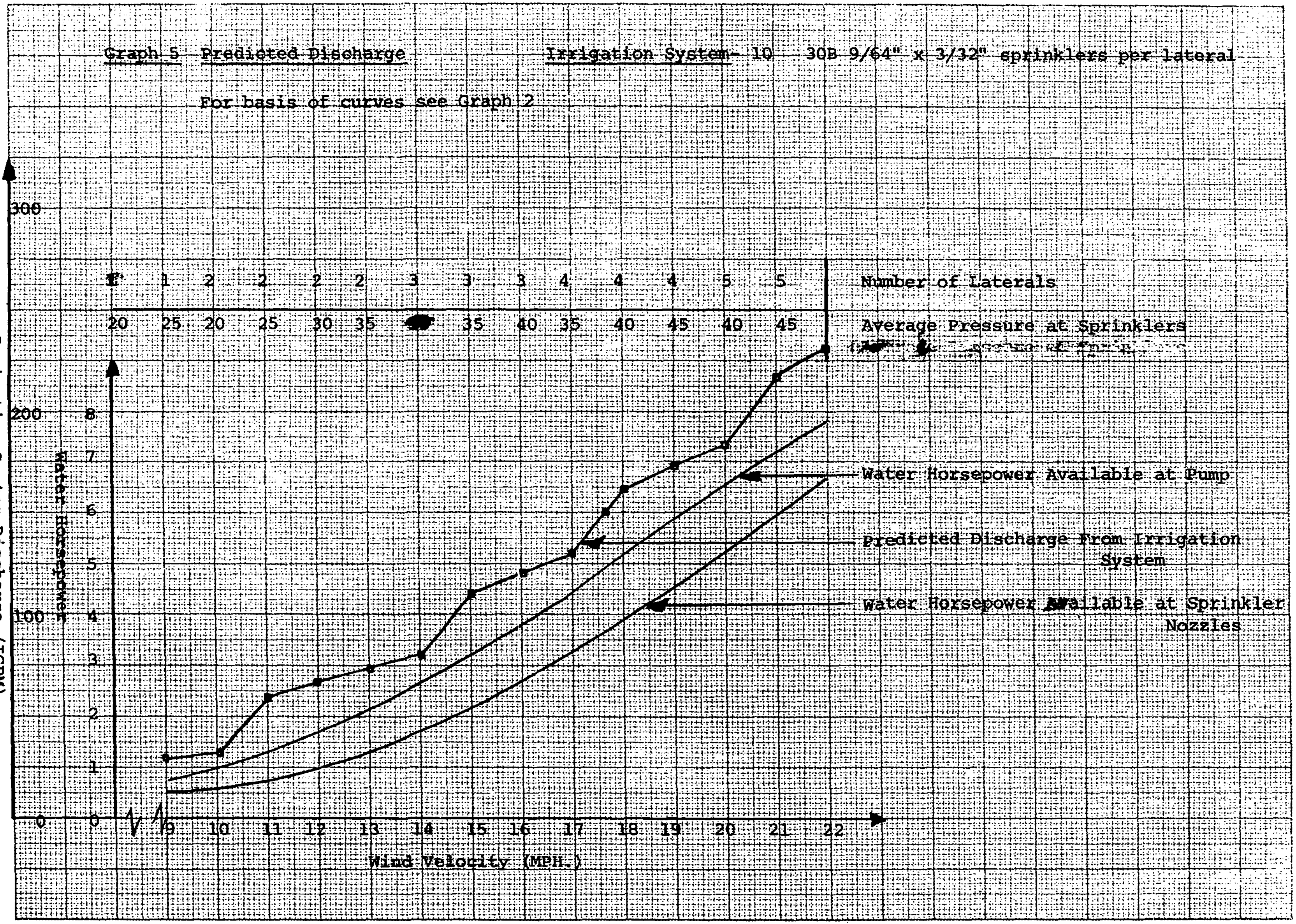


Graph 4 Predicted Discharge

Irrigation System- 16 30B 9/64" sprinklers per lateral

For basis of curves see Graph 2

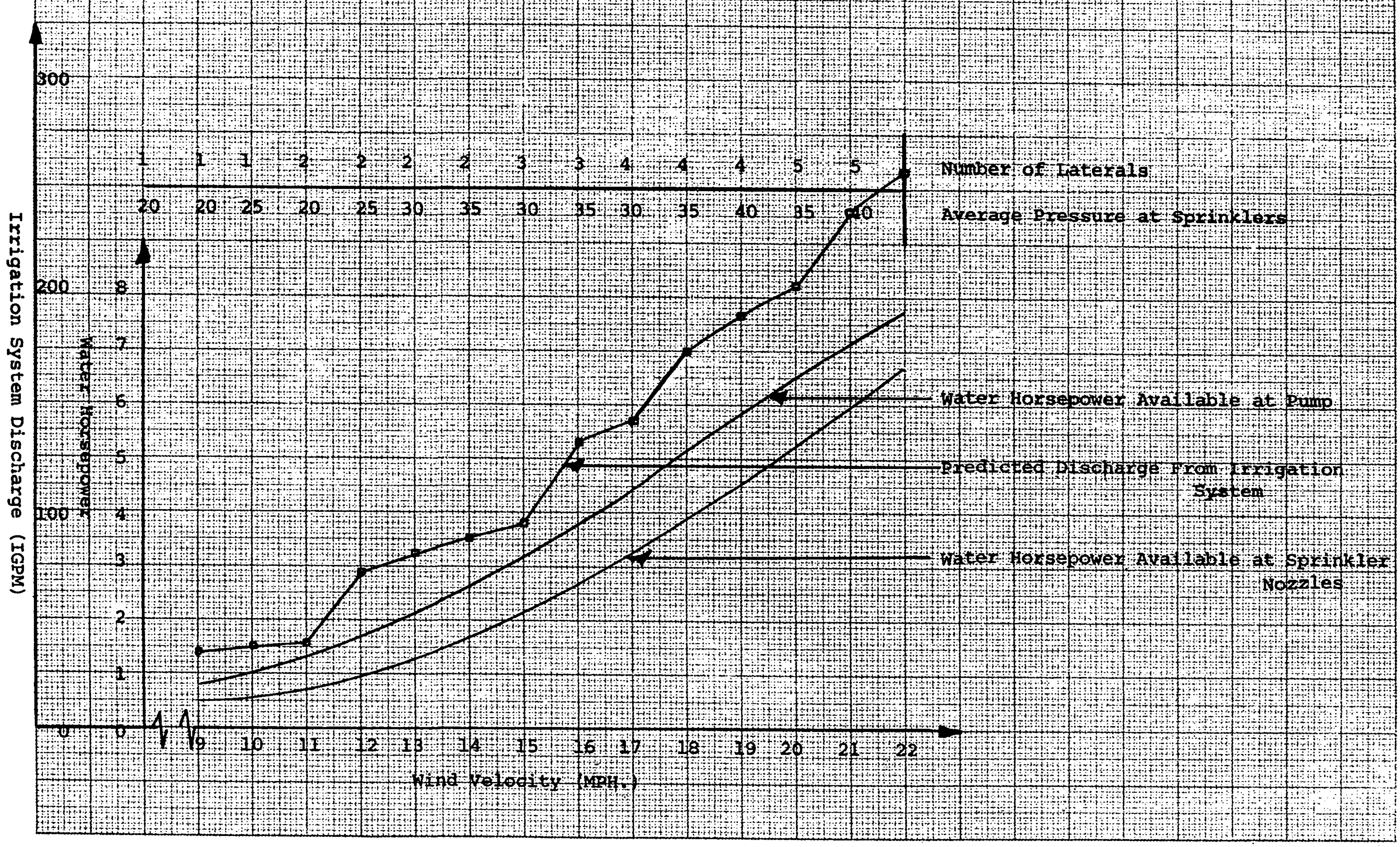


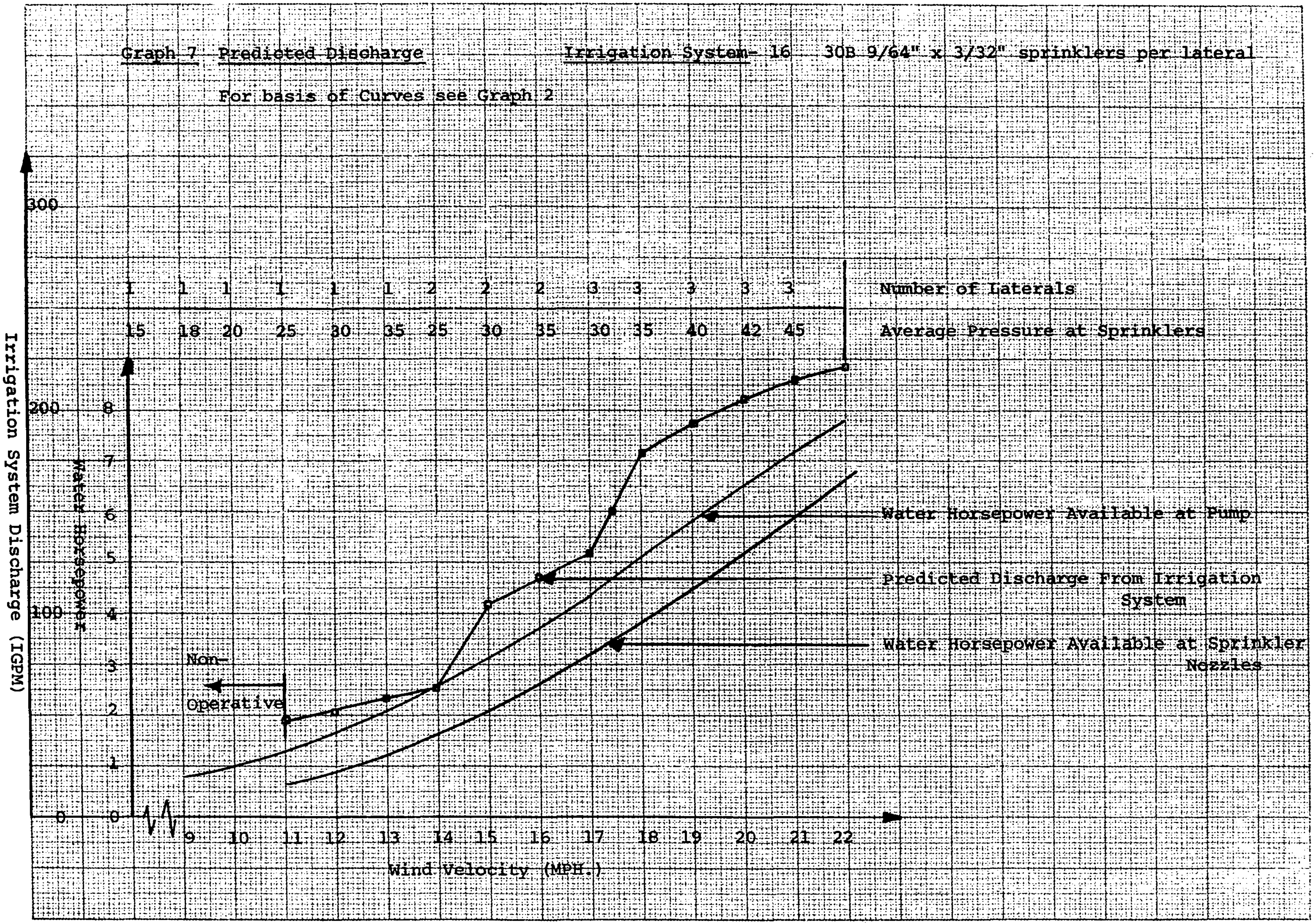


Graph 5 Predicted Discharge
Irrigation System- 10 30B 9/64" x 3/32" sprinklers per lateral
For basis of curves see Graph 2
Number of Laterals
Average Pressure at Sprinklers
Water Horsepower Available at Pump
Predicted Discharge From Irrigation System
Water Horsepower Available at Sprinkler Nozzles
Irrigation System Discharge (IGPM)
Water Horsepower
Wind Velocity (MPH.)

Graph 6 Predicted Discharge   Irrigation System- 12 30B 9/64" x 3/32" sprinklers per lateral

For basis of curves see Graph 2





Graph 7 Predicted Discharge
Irrigation System- 16 30B 9/64" x 3/32" sprinklers per lateral
For basis of Curves see Graph 2
Number of Laterals
1 1 1 1 1 1 2 2 2 3 3 3 3 3
Average Pressure at Sprinklers
15 18 20 25 30 35 25 30 35 30 35 40 42 45
Water Horsepower Available at Pump
Predicted Discharge From Irrigation System
Water Horsepower Available at Sprinkler Nozzles
Non-Operative
Irrigation System Discharge (IGPM)
0 100 200 300
Water Horsepower
0 1 2 3 4 5 6 7 8
Wind Velocity (MPH.)
9 10 11 12 13 14 15 16 17 18 19 20 21 22

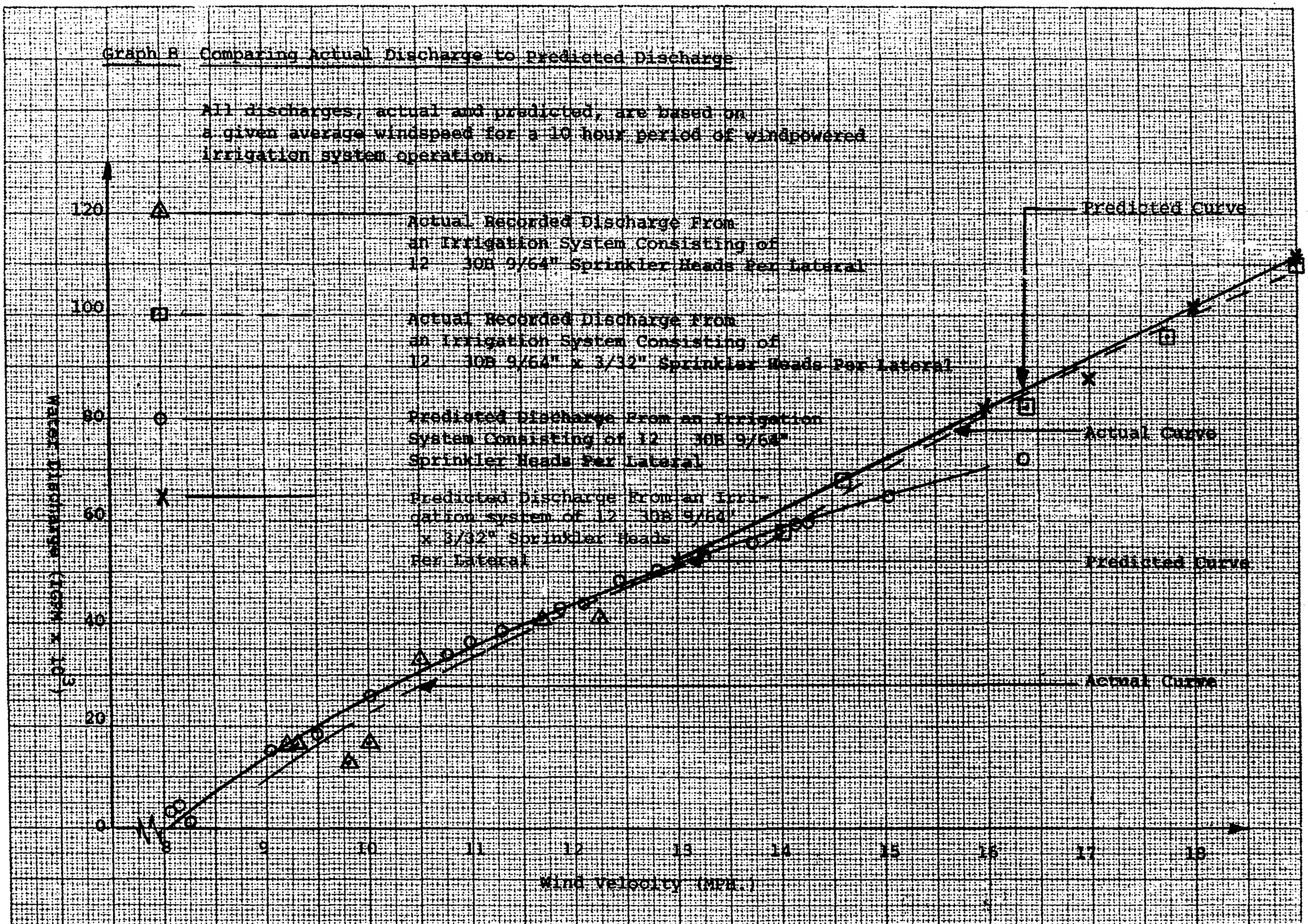

Graph 8 Comparing Actual Discharge to Predicted Discharge
All discharges, actual and predicted, are based on a given average windspeed for a 10 hour period of windpowered irrigation system operation.
Actual Recorded Discharge From an Irrigation System Consisting of 12 30B 9/64" Sprinkler Heads Per Lateral
Actual Recorded Discharge From an Irrigation System Consisting of 12 30B 9/64" x 3/32" Sprinkler Heads Per Lateral
Predicted Discharge From an Irrigation System Consisting of 12 30B 9/64" Sprinkler Heads Per Lateral
Predicted Discharge From an Irrigation system of 12 30B 9/64" x 3/32" Sprinkler Heads Per Lateral
Predicted Curve
Actual Curve
Predicted Curve
Actual Curve
Water Discharge (IGPM x 10^3)
0
20
40
60
80
100
120
8
9
10
11
12
13
14
15
16
17
18
Wind Velocity (MPH.)

Table 1 The Effect Of Pressure Level On Cu

Test criteria- 1. Diesel powered uniformity trials were done at pressure levels 20, 40, 60, and 80 psig.

2. Sprinkler spacing in the field was 30 feet by 30 feet (rectangular).

3. Statistical "t" test levels of significance were:

* between $t_{.05}$ and $t_{.01}$

** above $t_{.01}$

Sprinkler Type and Nozzle Size	Optimum Pressure Level		
	20 versus 40 (psig.)	40 versus 60 (psig.)	60 versus 80 (psig.)
30B 9/64"	N.S.D. t'= 1.67	N.S.D. t'= 1.24	N.S.D. t'= 1.00
30B 7/32"	40 psig. ** t'= 5.94	N.S.D. t'= 0.22	N.S.D. t'= 0.29
30B 3/16" X 9/64"	N.S.D. t'= 1.20	N.S.D. t'= 0.74	
20A 7/32"	40 psig. * t'= 3.62		

Note- N.S.D. means "no significant difference" between Cu at the two pressure levels compared.

Calculation For A Result In Table 1

Comparison criteria- 1. The sprinkler head used was 30B with a 9/64" nozzle.

2. The comparison was between Cu at 20 psig. and Cu at 40 psig. with steady state or Diesel powered pumping.

Statistical criteria- 1. Ho- There is no significant difference between Cu at 20 psig. steady state and 40 psig. steady state. Steady state refers to constant pump discharge and pressure.

2. Criteria for rejection of the Ho:

when $t' \geq t_{\alpha/2;\nu}$

Table 2 Statistical Calculation For The Comparison Of Cu At Different Pressure Levels

1. Pressure 20 psig				2. Pressure 40 psig.			
Distribution Number	Cu	$x - \bar{x}_1$	$(x - \bar{x}_1)^2$	Distribution Number	Cu	$x - \bar{x}_2$	$(x - \bar{x}_2)^2$
102	77.5	5.22	27.25	98	86.5	4.17	17.38
103	51.6	20.68	427.66	99	86.5	4.17	17.38
104	59.0	13.28	176.35	100	90.9	8.57	73.44
105	81.2	8.92	79.56	101	84.8	2.47	6.10
49	91.1	18.82	354.19	s-33	85.6	3.27	10.69
50	80.5	8.22	67.57	s-34	77.0	5.33	28.40
51	80.0	7.72	59.60	s-35	65.0	17.33	300.33
52	57.4	14.88	221.41	----			
Sum	578.3		1413.59		576.3		453.72
Mean $\bar{x}_1$	72.28			$\bar{x}_2$	82.33		
Variance $(s_1)^2$			201.9	$(s_2)^2$			75.6

$$t' = \frac{\bar{x}_1 - \bar{x}_2}{\sqrt{\frac{(s_1)^2}{\nu_1} + \frac{(s_2)^2}{\nu_2}}} = \frac{10.05}{\sqrt{\frac{201.9}{8} + \frac{75.6}{7}}} = 1.67$$

(From statistical "t" tables) $t_{.025;13} = 2.160$

$t' \not\geq t_{.025;13}$ On the basis of this calculation we accept Ho. There is no significant difference between $\bar{x}_1$ and $\bar{x}_2$ OR there is no significant difference between Cu at 40 psig. and Cu at 20 psig..

Table 3 Statistical Data For The Comparison of Effect of Irrigation Power Source On Uniformity Cu (At Average Pressure Level 40 psig.)

Distribution Number	Sprinkler Type Nozzle Size	Cu Windpower	Cu Diesel Power	Field Lateral Spacing (Feet)
244-47 vs.	20A 9/64"	74.7	77.5	30x30
276-79		65.1	72.1	30x40
		59.5	64.3	30x50
		62.0	72.1	30x40 tri.
260-63 vs.	20A 7/32"	77.6	83.2	30x30
264-67		70.4	73.3	30x50
		70.1	75.4	30x40 tri.
232-35 vs.	30B 9/64" x	83.9	88.2	30x30
236-39	3/32"	82.7	80.1	30x40
		80.2	82.5	30x50
		81.9	81.0	30x40 tri.
		76.4	80.6	30x60
224-27 vs.	30B 7/32"	89.5	91.1	30x30
204-211		81.5	81.2	30x60
196-99 vs.	30B 3/16" x			
118-21	9/64"	84.8	89.7	30x30
98 vs. 101	30B 9/64"	84.8	87.3	30x30
s11-s15 vs.	30B 9/64"	79.6	75.8	30x30
s33-s35				

* "tri." indicates triangular spacing

From Table 3, the difference in Cu is transferred to Table 4 for statistical calculation.

Calculation For A Result In Summary Table 5

Comparison Criteria: 1. All distributions were done with Diesel power or windpower.

2. The comparison was between Cu done with Diesel power and Cu done with windpower. The data was chosen on the basis of similar sprinkler head, sprinkler field spacing, and average wind velocity during the irrigation distribution trial.

Statistical Criteria: 1. Null hypothesis Ho- There is no significant difference in sprinkler irrigation Cu done with Diesel power pumping at 40 psig. and sprinkler irrigation Cu done with windpower at an average pressure of 40 $\pm$ 5 psig.

Table 3 Continued Statistical Data For The Comparison of Effect of Irrigation Power Source On Uniformity Cu (At Average Pressure Level 20 psig.)

Distribution Number	Sprinkler Type Nozzle Size	Cu Windpower	Cu Diesel Power	Field Lateral Spacing (Feet)
212-15 vs.	30B 7/32"	79.4	86.4	30x30
228-31		71.1	68.9	30x50
208-11 vs.	"	89.5	86.4	30x30
228-31				
268-71 vs.	20A 7/32"	76.7	72.0	30x30
256-59		64.3	68.5	30x50
		67.1	65.6	30x40 tri.
170-73 vs.		84.8	80.0	30x30
106, 111-13	30B 9/64"			
22-25 vs.	"	82.5	80.0	30x30
106-113				
17-20 vs.	"	77.6	64.7	30x30
102-05				
248-51 vs.	20A 9/64"	78.5	76.4	30x30
272-75		75.4	67.2	30x40
		75.3	61.6	30x50
		75.3	66.3	30x40 tri.
130-33 vs.	30B 9/64" x	88.3	83.4	30x30
134-37	3/32"			
130-33 vs.	30B 3/16" x	88.3	83.4	30x30
158-61	9/64"	79.0	78.5	30x50

Note: These Cu differences were given the same treatment as the data in Table 3 at 40 psig.. This indicated that there was a significant difference in the Cu windpower and the Cu Diesel power. Windpower Cu at pressure level 20 psig. was significantly better than Cu Diesel power.

2. This was a comparison of Cu differences and was considered a "two tailed t" test

3. Levels of significance are: 0.05 significant
   0.01 very significant

4. Criteria for rejection of Ho:

$$\text{When } t' \geq t_{\alpha/2,\nu}$$

Table 4 Statistical Calculation From Data In Table 3

Cu wind - Cu Diesel Difference d	$\lvert d - d' \rvert$	$(d - d')^2$
-2.8	0.18	00.03
-7.0	4.02	16.16
-4.8	1.82	03.31
-10.1	7.13	50.69
-5.6	2.62	06.86
-2.9	0.08	00.01
-5.3	2.32	05.38
-4.3	1.32	01.74
2.6	5.58	31.10
-2.3	0.68	00.46
0.9	3.88	15.05
-4.2	1.22	01.49
-1.6	1.38	01.90
0.3	3.01	09.06
-4.9	1.92	03.69
-2.5	0.48	00.32
3.8	6.78	45.97
Sum = -50.7		193.13

$$d' = \frac{-50.7}{17} = -2.98$$

$$(SD)^2 = \frac{\Sigma (d - d')^2}{17-1} = 12.07 \quad \text{Therefore} \quad SD = \sqrt{12.07} = 3.47$$

$$\text{(From "t" tables) } t_{\alpha/2,\nu} = t_{.025,16} = 2.120$$

$$t' = \frac{d'}{SD/\sqrt{K}} = \frac{-2.98\ (\sqrt{17})}{3.47} = -3.53$$

$$|t'| \geq t_{\alpha/2,\nu} = 2.131$$

Therefore, we reject Ho as the "t" test indicates that Cu done with Diesel power is"very significantly"greater than Cu done with windpower .

Table 5 Summary of The Statistical Comparison Between Cu Windpower and Cu Diesel Power (For All Sprinkler Heads and Nozzles)

Comparison	Diesel 20 psig. vs. Wind Avg. 20psig.	Diesel 40 psig. vs. Wind Avg. 40 psig.	Diesel 20 and 40 psig. vs. Wind 20 and 40 psig.
Better Cu Obtained With:	Wind	Diesel	No Significant Difference
Level of Significance	0.05 t' = 2.71	0.01 t' = 3.53	t' = 2.02

Table 6 Sequence of Vegetable Crop Production Operations 1967-68

Date	Operation	Remarks
Sept. 15 1967	Seedbed preparation **	The original stand of sugar cane was cut * for animal fodder and the soil disked. The area for grass was cultivated flat, the vegetable plots were ridged at 64" centers for drainage effect.
Feb. 6-7 1968	Planting *	Cabbage seedlings were planted. The first catch was poor so that a second planting followed on Feb. 14-15.
Feb 19	Fertilization *	Cabbage and Tomato plots were given 700 cwt./acre of 12-12-17[2].
Feb 20-21	Planting *	Carrot seed was planted.
Feb 26	Planting *	Tomato seedlings were planted
Mar 14 17 29-30	Spraying ***	The spraying was late, and the Cabbage plants became infested with aphid, some worm damage was also done.
April 4	Harvesting *	Cabbage was harvested and weighed
April 18- May 28	Harvesting *	Tomatoes were harvested and weighed in several pickings.
May 28	Harvesting *	Carrots were harvested and weighed

Mode of Operation: * by hand ** by track tractor *** by rubber tired tractor

Table 7 Summary of Irrigation Applied by Windmill Power (Dry Season 1968)

Month	Average Wind Velocity (MPH.)	Total Pumped Imperial Gals.	Acre-inches	Acres Applied to (acres)
Feb.	12.3	230878	10.2	3.14
Mar.	10.0	130468	5.8	1.80
April	9.7	176665	7.8	1.80
May	15.1	90000 estimated	4.0	1.80

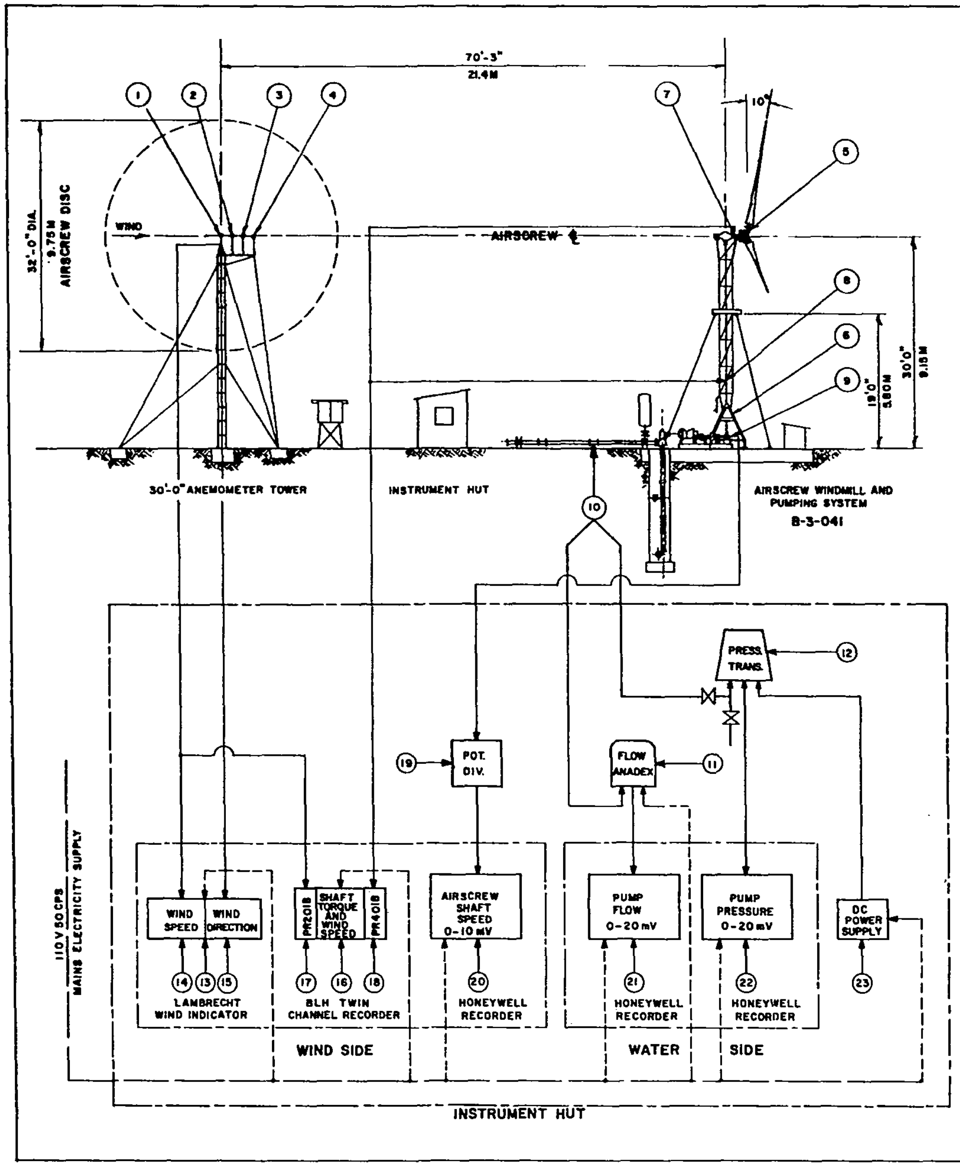
* Note- These amounts were applied to the vegetable plots. Greater amounts of water were pumped to other fields and recycled to the pond. Upon establishment of the crops during the month of Feb., the acreage for irrigation treatment became 1.80 . For establishment, all crops required irrigation.

Table 8 The Yields of Vegetable Produce (All grades, lbs./acre)

Crop	Yields		Difference Due To Irrigation	
	Irrigated	Non-irrigated	Lbs./acre	Factor of:
Carrots	7910	3560	4350	2.22
Cabbage	2840	2490	350	1.14
Tomatoes	5010	3480	1530	1.44

APPENDIX

Dwg. C-3-013 Test Instrumentation Diagram



NOTE FISCHER & PORTER EQUIPMENT ORDER No 66914

QTY	PART No	ITEM	DESCRIPTION	SIZE	FUNCTION
1	55GL1155	23	DC POWER SUPPLY F&P		4-20 MA DC
1	BRACE No2	22	HONEYWELL STRIP CHART RECORDER		PUMP PRESSURE 0-20MV
1	BRACE No1	21	HONEYWELL STRIPCHART RECORDER		PUMP FLOW 0-20MV
1	BRACE No5	20	HONEYWELL STRIPCHART RECORDER		AIRSCREW, RPM 0-10 MV
1	POTENTIAL DIVIDER	19	10 Ω PRECISION RESISTOR 0-1000 Ω BECKMAN HELIPOT		
1	PR401B	18	CARRIER OPERATED STRAIN GAUGE PREAMPLIFIER MODULE		SHAFT TORQUE RECORD
1	PR201B	17	MEDIUM GAIN DC PRE-AMPLIFIER MODULE		WINDSPEED RECORD
1	BSA-270BA	16	BLH TWO CHANNEL HIGH-SPEED STRIPCHART RECORDER		0.5-200 MM/SEC
1		15	WIND DIRECTION INDICATOR		
1		14	WIND SPEED INDICATOR		
1	1475	13	LAMBRECHT INDICATOR PANEL		
1	50EQ1071A	12	F&P PRESSURE TO CURRENT TRANSDUCER	½"	0-80 PSI CALIB.
1	PI-200PIKC	11	ANADEX FREQUENCY TO VOLTAGE TRANSDUCER		0-50 MV
1	10C1506A	10	FISCHER & PORTER TURBINE FLOWMETER	3"	40-500 USGPM
1	SA-757A-2	9	SERVOTEK TACHO GENERATOR		7 V/1000 RPM
1	SR-4-5000	8	BLH TYPE A-5 TORQUE PICKUP		5000 IN LB CAP. 5000 RPM MAX.
1	D-3-017	7	AIRSCREW SHAFT TORQUE METER		350 Ω
1	D-3-004	6	TOWER ALIGNMENT GAUGE	1°	
3	F-3-001	5	BLADE ANGLE GAUGE	½°	
1	W1208/1	4	CASELLA CUP COUNTER ANEMOMETER	KM	LONG TERM WIND RUN
1	1482	3	LAMBRECHT MECHANICAL WIND RECORDER	KM	HOURLY MAIN WIND-SPEED DIRECTION
2	1467G	2	LAMBRECHT WIND TRANSMITTER		WIND SPEED CHECK
1	1465G	1	LAMBRECHT COMBINED WIND TRANSMITTER		WIND SPEED AND DIRECTION INDICATION

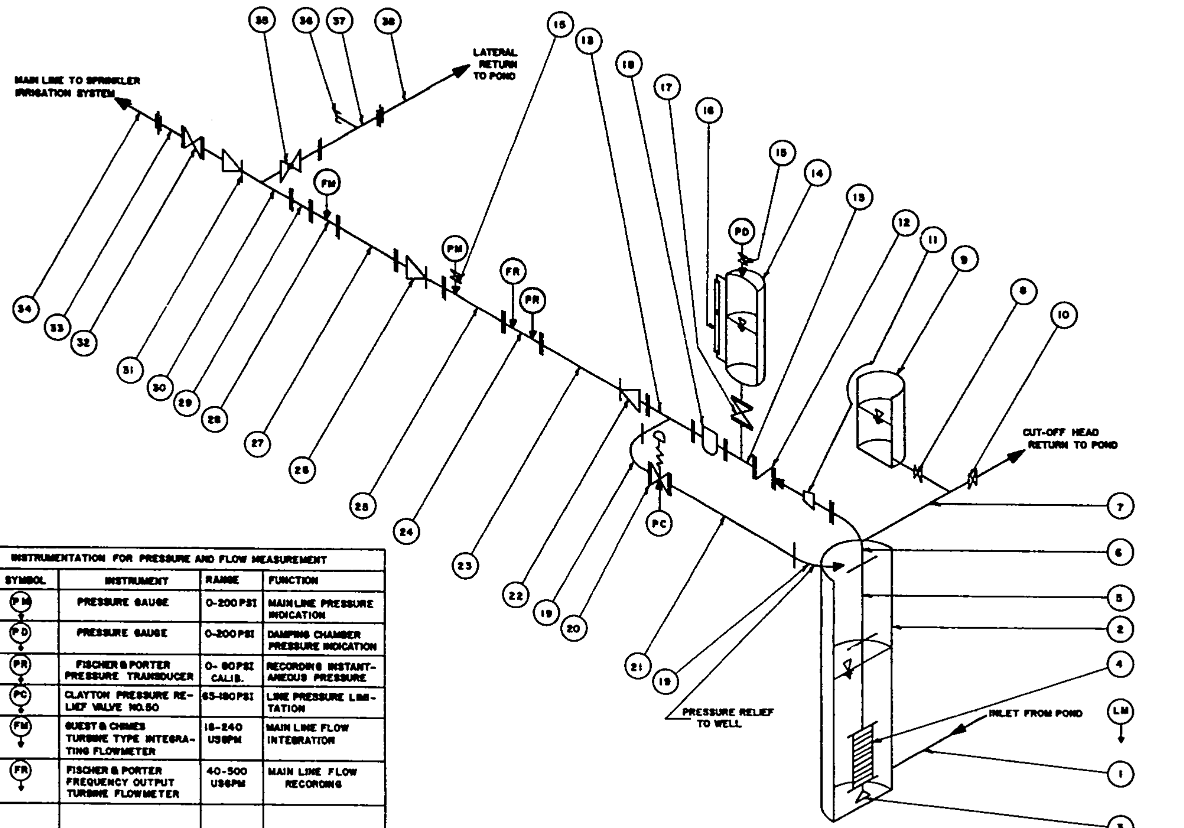
BRACE RESEARCH INSTITUTE
OF McGILL UNIVERSITY
MACDONALD COLLEGE, P.Q. CANADA

TITLE
TEST INSTRUMENTATION DIAGRAM
PROTOTYPE AIRSCREW WINDMILL

SCALE 1:50

DRAWN	R.WEYTS	JUNE 20 69
STRESSED		
CHECKED	R.E.C	JUNE 26 69
APPROVED	R.E.C	JUNE 26 69
ASSEMBLY		
DWG. No.	C-3-013	

Dwg. D-3-016 Instrumentation of Hydraulic Circuit



ITEM	INSTRUMENTATION FOR PRESSURE AND FLOW MEASUREMENT			
	SYMBOL	INSTRUMENT	RANGE	FUNCTION
	PM	PRESSURE GAUGE	0-200 PSI	MAIN LINE PRESSURE INDICATION
	PD	PRESSURE GAUGE	0-200 PSI	DAMPING CHAMBER PRESSURE INDICATION
	PR	FISCHER & PORTER PRESSURE TRANSDUCER	0- 80 PSI CALIB.	RECORDING INSTANTANEOUS PRESSURE
20	PC	CLAYTON PRESSURE RELIEF VALVE NO.50	65-180 PSI	LINE PRESSURE LIMITATION
28	FM	GUEST & CHIMES TURBINE TYPE INTEGRATING FLOWMETER	16-240 USGPM	MAIN LINE FLOW INTEGRATOR
24	FR	FISCHER & PORTER FREQUENCY OUTPUT TURBINE FLOWMETER	40-500 USGPM	MAIN LINE FLOW RECORDING

NOTES: ① 150 PSI PIPE FITTINGS
② FOR FURTHER INSTRUMENTATION DETAILS SEE DRAWING C-3-013

QTY	PART.	ITEM	DESCRIPTION	SIZE	MATERIAL
1	LM	39	POND LEVEL INDICATOR		
1		38	AL IRRIGATION PIPE RETURN TO POND	4"X20'-0"	
1		37	PUMP FLANGE TYPE AL IRRIGATION PIPE TEE	4"X4"X4"	
1		36	AL ENDCAP	4"	
1		35	GLOBE REGULATING VALVE	4"	
1		34	IRRIGATION PIPE TO SPRINKLER SYSTEM	6"X30'-0"	
1		33	PUMP FLANGE TYPE IRRIGATION PIPE LENGTH	6"	
1		32	GATE VALVE	6"	
1		31	REDUCER	6"X4"	
1		30	TEE	4"X4"X4"	
1		29	OUTLET PIPE FROM METER	4"X16"	
1	FM	28	GUEST & CHIMES C.I. TURBINE FLOW METER	4"	PLANET TYPE 58
1		27	INLET PIPE TO METER	4"X 6'-0"	
1		26	REDUCER	4"X 3"	
1		25	OUTLET PIPE FROM METER	3"X16"	
1	FR	24	FISCHER & PORTER TURBINE FLOWMETER	3"X500 USGPM	
1		23	INLET PIPE TO METER	3"X4'-0"	
1		22	REDUCER	4"X3"	
1		21	RETURN PIPE TO WELL	3"	
1	PC	20	PRESSURE RELIEF VALVE	3"	
2		19	ELBOW	3"	
1		18	A.O.SMITH STRAINER	4"	40 MESH
1		17	GATE DAMPING VALVE	3"	
1		16	SIGHT TUBE	3/4"	
2		15	GAUGE COCK	1/2"	
1		14	PRESSURE VESSEL	16"X5'-0"	
2		13	TEE	4"X4"X3"	
1		12	GUEST & CHIMES CHECK VALVE	4"	
1		11	BUSHING	5"X4"	
1		10	CUT-OFF HEAD RELIEF VALVE	1/2"	
1		9	PRE-LUBE RESERVOIR	2'X3'	
1		8	PRE-LUBE VALVE	1/2"	
1		7	PRE-LUBE PIPE	1/2"	
1		6	PUMP HEAD	5"	
1		5	PUMP COLUMN	5"X3/4"	
1		4	WADE RAIN 6JC3 PUMP	10 STAGE	
1		3	PUMP INLET	5"	
1		2	CONCRETE CULVERT SECTION WELL	3'X16'X3'-0" DIA	
1		1	PITCH FIBRE PIPE FROM POND	6"	

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HYDRAULIC CIRCUIT

PROTOTYPE AIRSCREW WINDMILL

REC

D-3-016

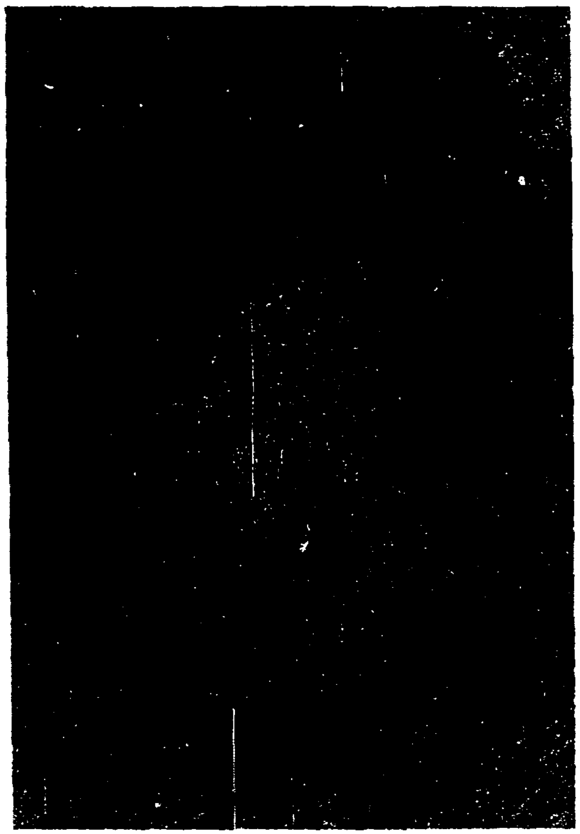
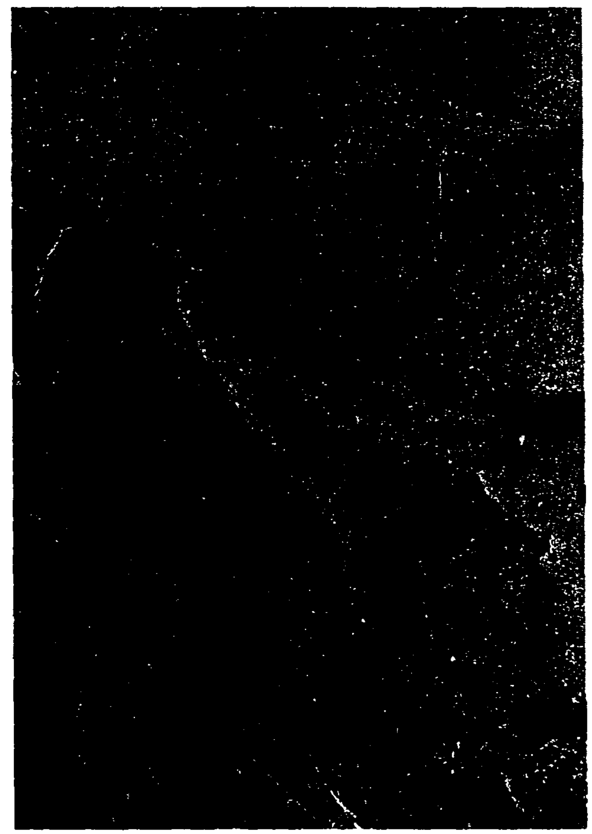


Figure A1 Gabion Filter Intake Completed



Discharging Pipeline From Filter Intake

Figure A1 Gabion Filter Intake Completed

Discharging Pipeline From Filter Intake

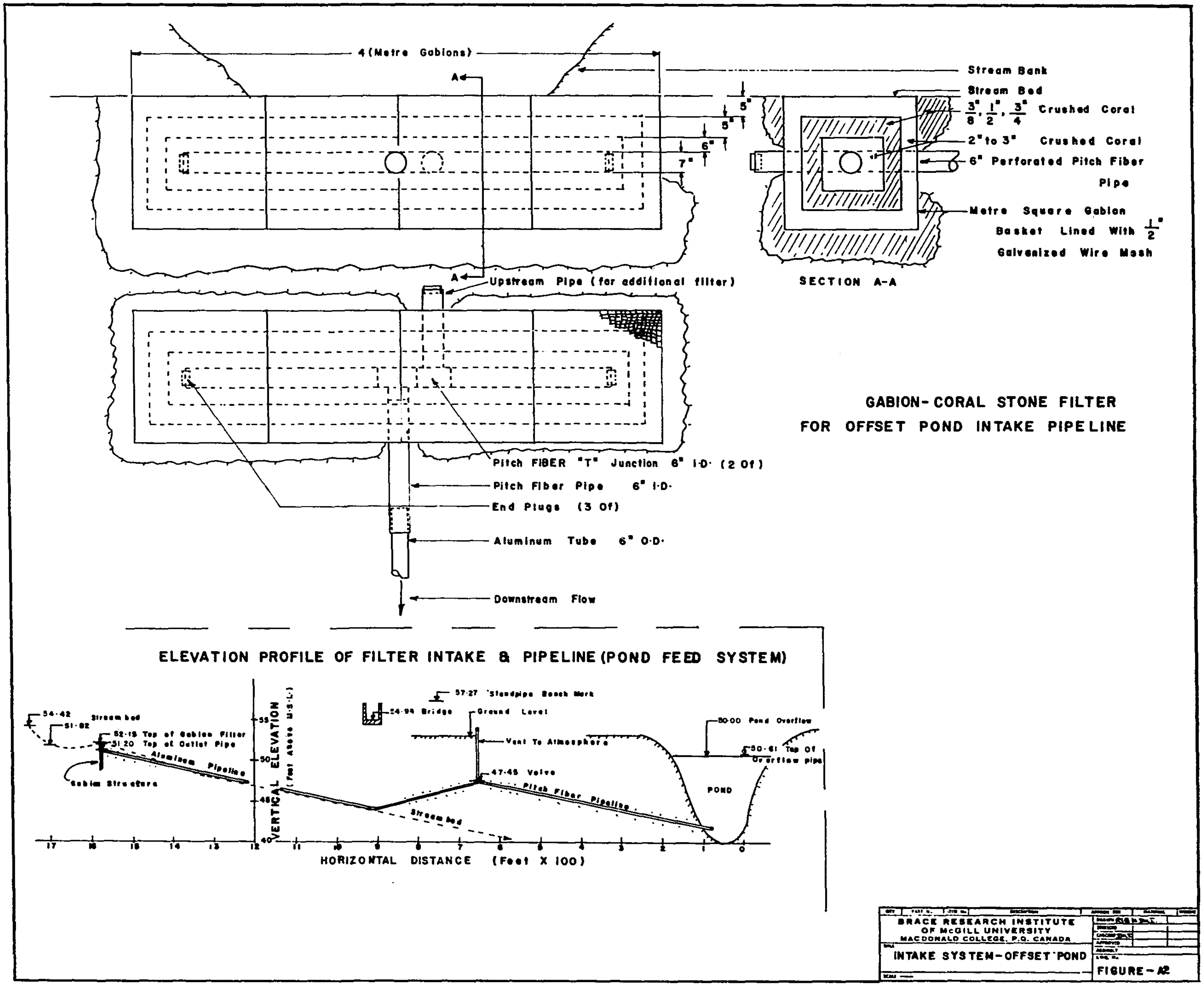


Figure A2 Intake System to Offset Pond

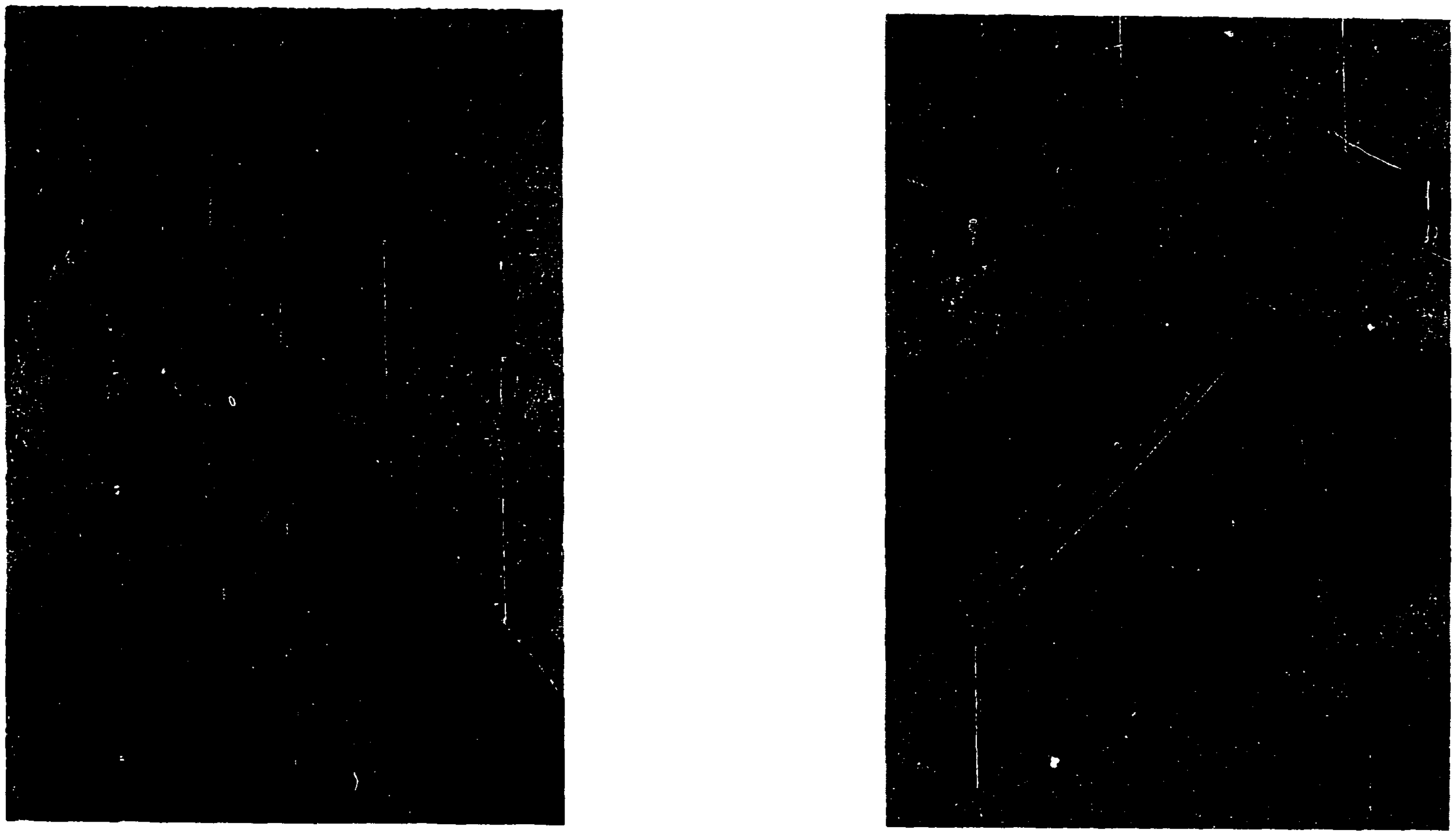
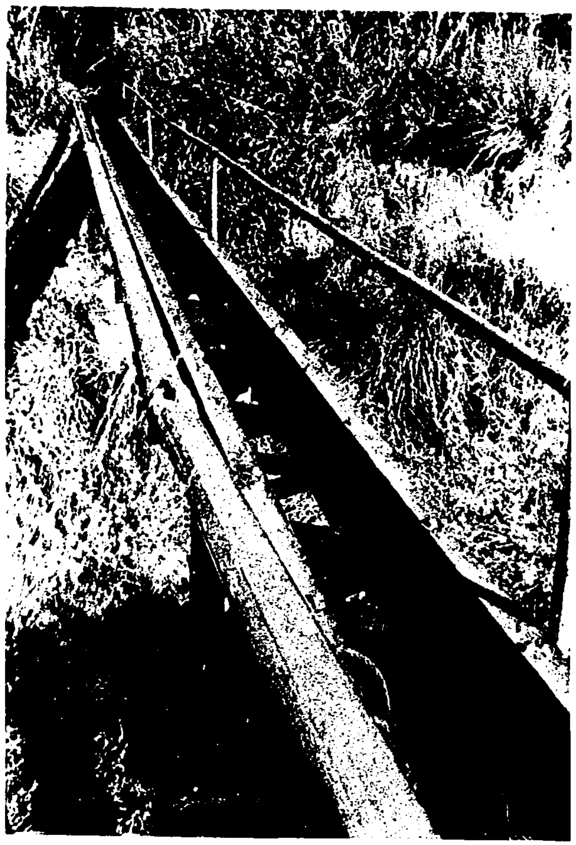


Figure A3 Scenes of the Pipe and General Transport Bridge



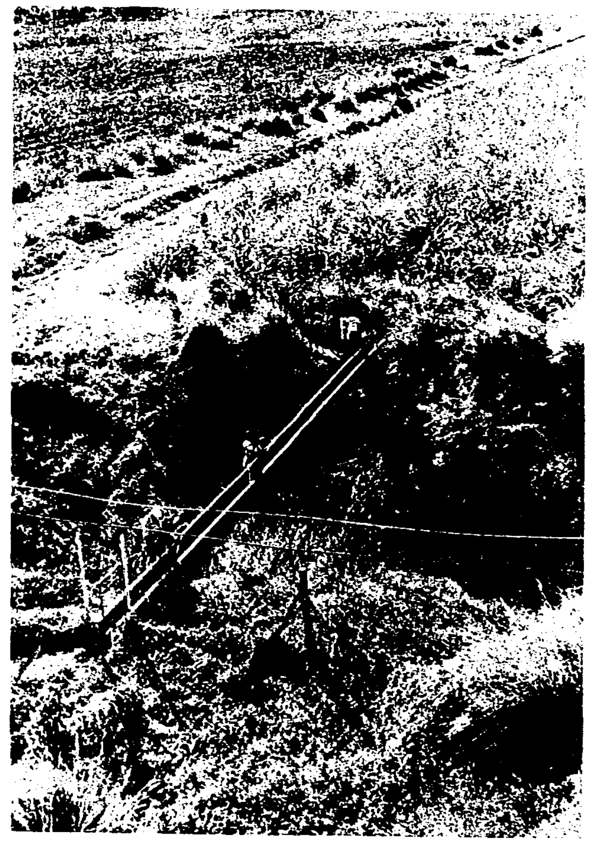


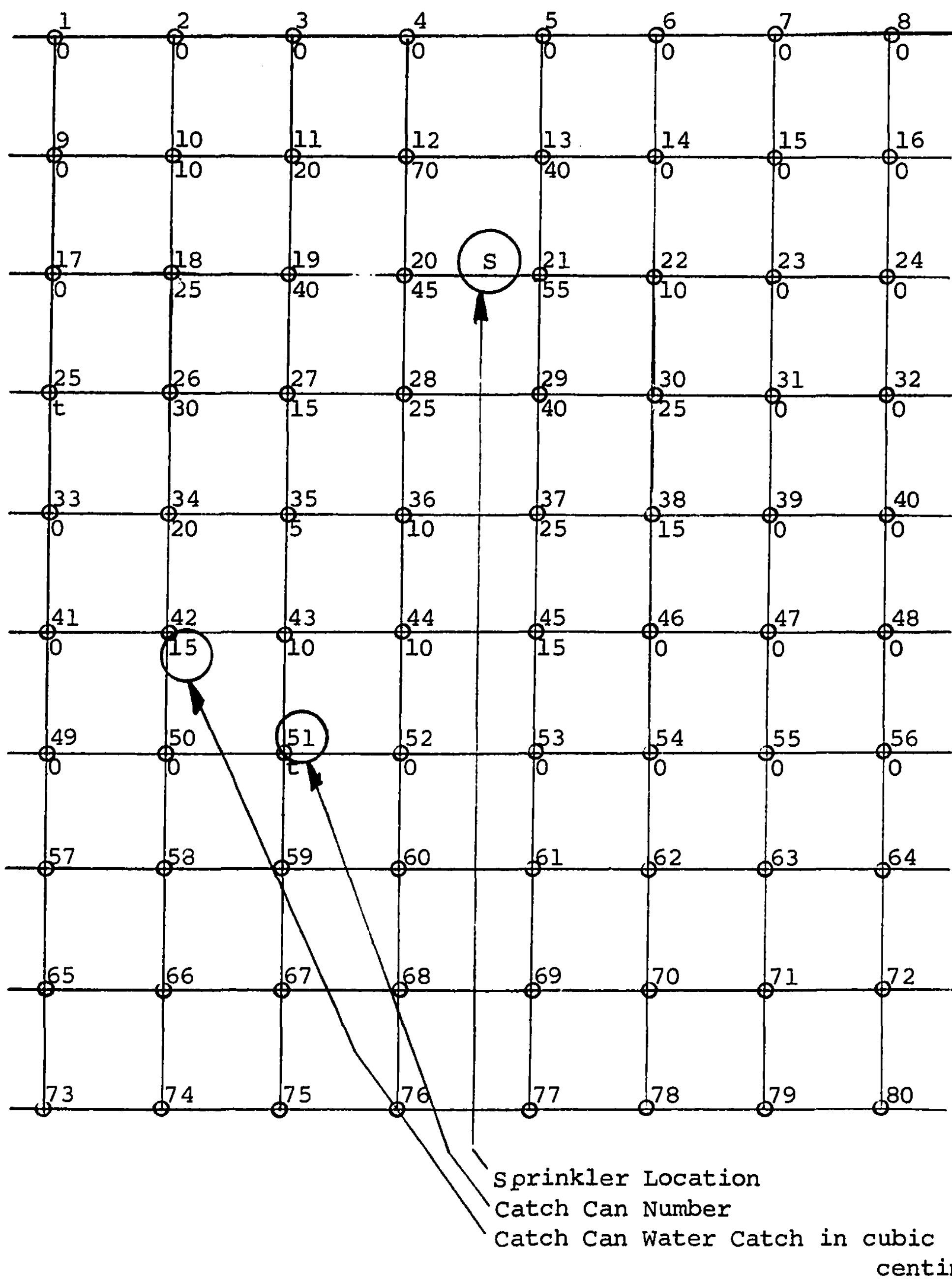
Figure A3 Scenes of the Pipe and General Transport Bridge

Form A1 — Sprinkler Distribution Raw Data Sheet

Distribution No. 245

Date- 13/6/68
Start Time- 12:43
Finish Time- 2:13
Sprinkler Type- 20A9/64"
Wind Direction- Tower Setting- 96°

Wind Miles Start - 275259 Kms.
Finish- 279370 Kms.
Discharge Start - 1414550 Imp. Gals.
Finish- 1429125 Imp. Gals.
Power Supply- Windmill



Note "t" indicates a trace of water found

Form A2

Cu Calculating Sheet For 30' x 30' Rectangular Spacing

Distribution No. 245

A 9		B10	10	C11	20	F17		G18	25	H19	40
12	70	13	40	14		20	45	21	55	22	10
15		16		35	5	23		24		43	10
33		34	20	38	15	41		42	15	46	
36	10	37	25	59		44	10	45	15	67	
39		40		62		47		48		70	
57		58				65		66			
60		61				68		69			
63		64				71		72			
Total A	80	B	95	C	40	D	55	E	110	F	60

K 1		L 2		(M) 3	
4		5		6	
7		8		27	(15)
25		26	30	30	25
28	25	29	40	51	
49		32		(54)	
52		50			
55		53			
31		56			
Total K	25	L	70	M	(40)

Field Location
Amount Caught ref. Form A1
Catch Can Number
Total for a Field Location
Number of Times Location is Duplicated in the Superposition

Ax(4)	=	320
Bx4	=	380
Cx2	=	80
Fx2	=	110
Gx2	=	220
Hx1	=	60
Kx2	=	50
Lx2	=	140
Mx1	=	40

Total= 1400

Mean - Total	A = 10	x4	=	40
" - "	B = 25	x4	=	100
" - "	C = 30	x2	=	60
" - "	F = 15	x2	=	30
" - "	G = 40	x1	=	40
" - "	H = 10	x1	=	10
" - "	K = 45	x2	=	90
" - "	L = 0	x2	=	0
" - "	M = 30	x1	=	30

Total*=440

Mean = $\frac{1400}{20}$ = 70 or (0.23) Inches/hour ← Time and Volume Conversion

$$Cu = 100 \left(1 - \frac{\text{Total*}}{\text{Total}} \right) = 100 \times \frac{440}{1400} = 68.6$$

Form A3

Cu Summary Sheet

Sprinkler Head and Nozzle- 20A 9/64"
Wind Velocity Average - 17.0 MPH.
" Direction Average - 095
Discharge Rate Average - 161.7 Igpm.

Distribution Number	Sprinkler Field Spacing															
	Rectangular								Triangular							
	30'x30'		30'x40'		30'x50'		30'x60'		30'x30'		30'x40'		30'x50'		30'x60'	
	Cu	iph.	Cu	iph.	Cu	iph.	Cu	iph.	Cu	iph.	Cu	iph.	Cu	iph.	Cu	iph.
244	75.1	.20	54.4	.14	57.4	.12			78.5	.21	55.5	.14				
245	68.6	.23	58.1	.18	53.1	.14			66.9	.22	60.2	.18				
246	78.9	.21	77.0	.17	65.0	.13			76.2	.20	66.4	.17				
247	76.4	.22	71.0	.18	62.4	.14			77.0	.22	65.9	.18				
Total	299.0	.86	260.5	.67	237.9	.53			298.6	.85	248.0	.67				
Mean	74.7	.21	65.1	.17	59.5	.13			74.8	.21	62.0	.17				

Sprinkler Head and Nozzle-
Wind Velocity Average -
" Direction Average -
Discharge Rate Average -

(Continued)

Irrigation Uniformity at These Field Spacings was Considered Unacceptable.

Form A4

Capacity Of Windmill Sprinkler Irrigation System

Location- Smith Field Greenland Pltn. Barbados

Period - Feb. 26 - March 4, 1967 INDICATING WINDSPEED (MPH.)

Date	26	27	28	1	2	3	4
Hourly Interval							
7-8	11.5	8.5	13.5	12.1	9.9	14.9	12.1
8-9	12.1	9.9	13.5	14.9	9.2	11.5	12.1
9-10	12.1	10.7	13.5	14.9	13.5	12.9	11.5
10-11	12.9	11.5	12.9	14.2	11.5	14.2	12.1
11-12	11.5	9.9	14.2	14.9	12.9	14.9	14.2
12-13	11.5	9.9	14.2	14.2	12.9	14.2	12.1
13-14	10.7	10.7	12.9	14.9	12.9	12.8	11.5
14-15	10.7	9.9	13.5	14.9	11.5	12.8	13.5
15-16	9.9	9.2	12.9	12.9	11.5	12.8	10.7
16-17	10.7	9.2	12.9	11.5	10.7	13.5	10.7
Total	113.6	99.4	134.0	139.4	116.5	134.5	120.5
Average	11.36	9.94	13.40	13.94	11.65	13.45	12.05

Form A5

Capacity of Windmill Sprinkler Irrigation System

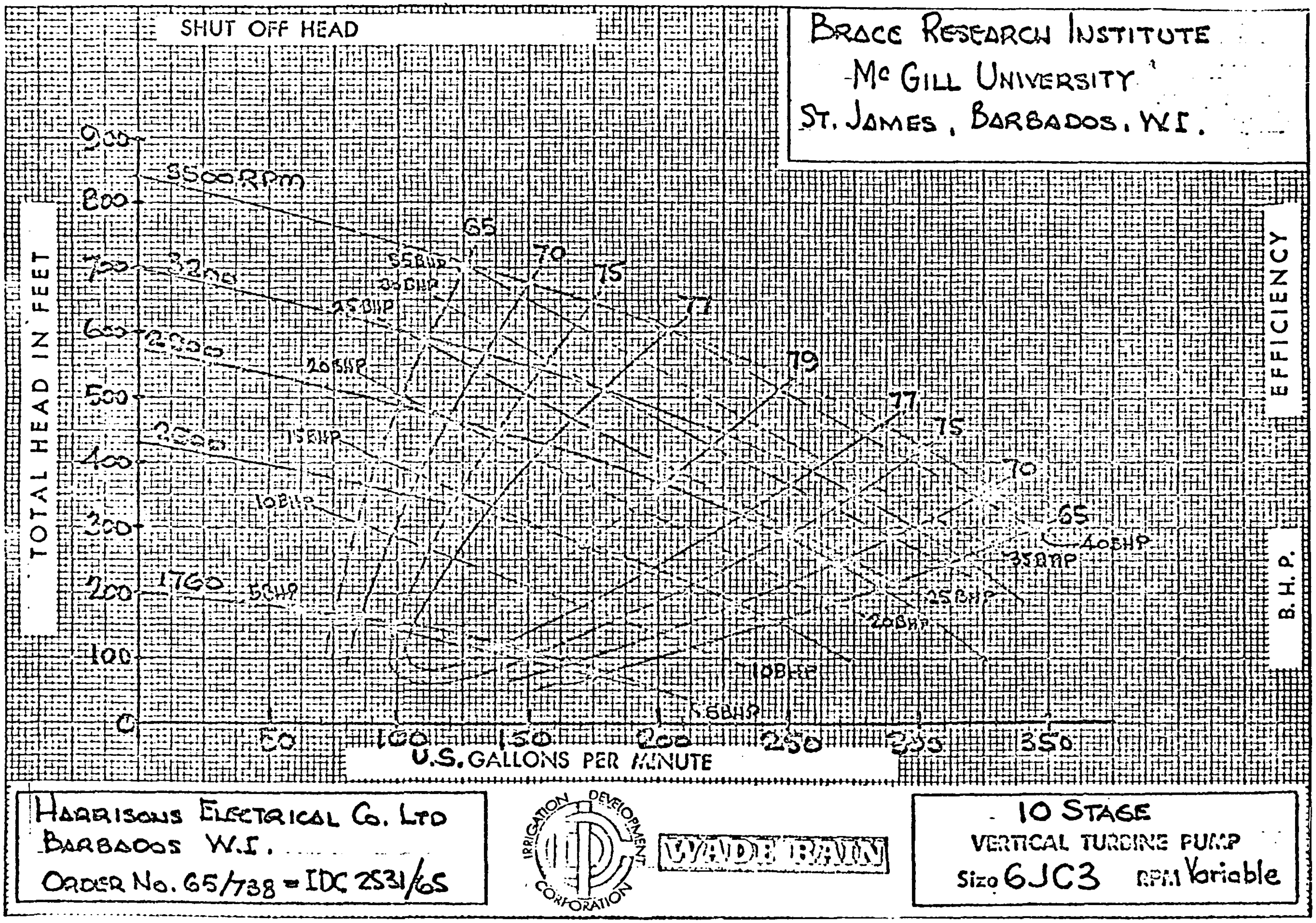
Location- Smith Field Greenland Pltn. Barbados

Period - Feb. 26 - March 4, 1967 INDICATING HOURLY DISCHARGE (IGPM.)

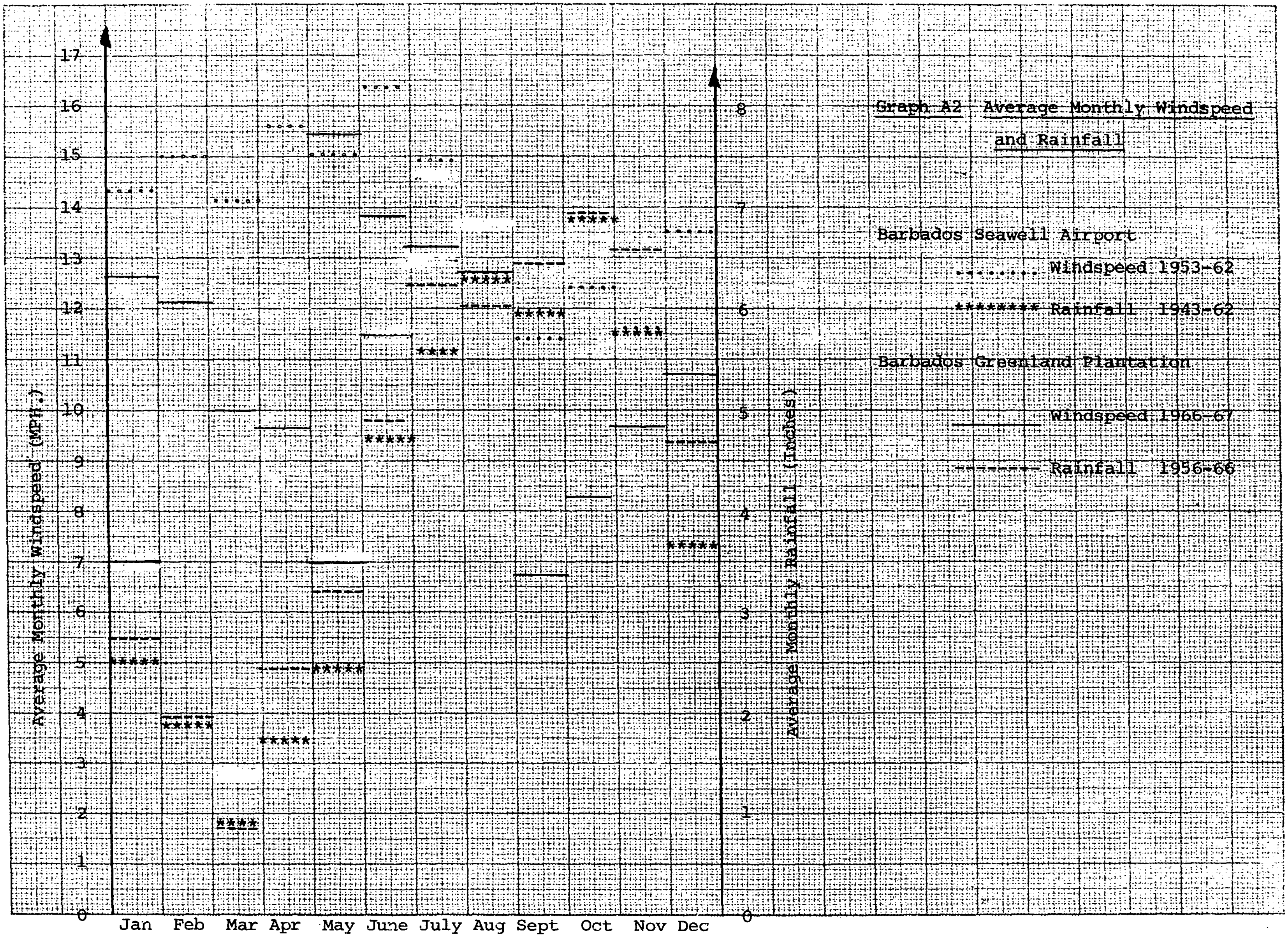
Date	26	27	28	1	2	3	4
Hourly Interval							
7-8	65	-	91	76	47	104	76
8-9	76	-	91	104	30	66	76
9-10	76	55	91	104	91	85	66
10-11	85	65	85	98	66	98	76
11-12	65	47	98	104	85	104	98
12-13	65	47	98	98	85	98	76
13-14	55	55	85	104	85	84	66
14-15	56	47	91	104	66	84	91
15-16	47	30	85	85	66	84	55
16-17	55	30	85	66	55	91	56
Total	645	376	900	943	676	898	736
Average	64.5	47.0	90.0	94.3	67.6	89.9	73.6
Total Gals. in 10 hrs.	38700	22560	54000	56550	40600	53900	44200
Acre-Inches at 100% effy.	1.71	0.99	2.38	2.50	1.79	2.38	1.95
Acre-Inches at 70% effy.	1.20	0.70	1.67	1.75	1.26	1.67	1.37

Total Acre-Inches Discharged in 7 Day Period 9.62 at 70% efficiency

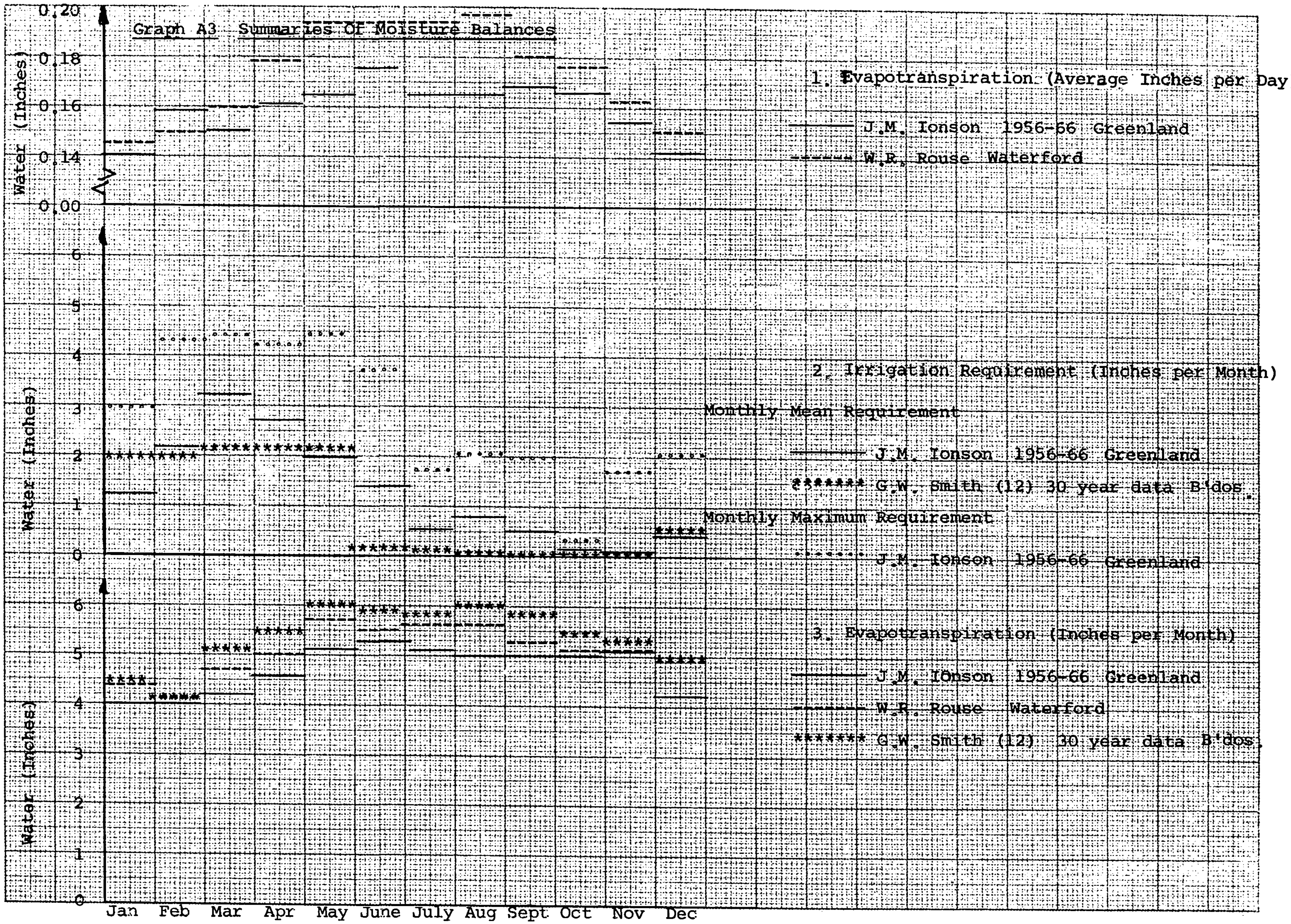
Note: The hourly discharges are obtained from Graph 3 Predicted Discharge for an irrigation system with 12 9/64" sprinklers per lateral. These hourly discharging rates are determined in conjunction with the windspeed data in Form A4 .


SHUT OFF HEAD
BRACE RESEARCH INSTITUTE
McGILL UNIVERSITY
ST. JAMES, BARBADOS, W.I.
TOTAL HEAD IN FEET
EFFICIENCY
B.H.P.
900
800
700
600
500
400
300
200
100
0
3500 RPM
3200
2900
2600
1760
55BHP
25BHP
20BHP
15BHP
10BHP
5BHP
40BHP
35BHP
65
70
75
77
79
50
100
150
200
250
300
350
U.S. GALLONS PER MINUTE
HARRISONS ELECTRICAL CO. LTD
BARBADOS W.I.
ORDER No. 65/738 = IDC 2531/65
IRRIGATION DEVELOPMENT CORPORATION
WADE RAIN
10 STAGE
VERTICAL TURBINE PUMP
Size 6JC3 RPM Variable

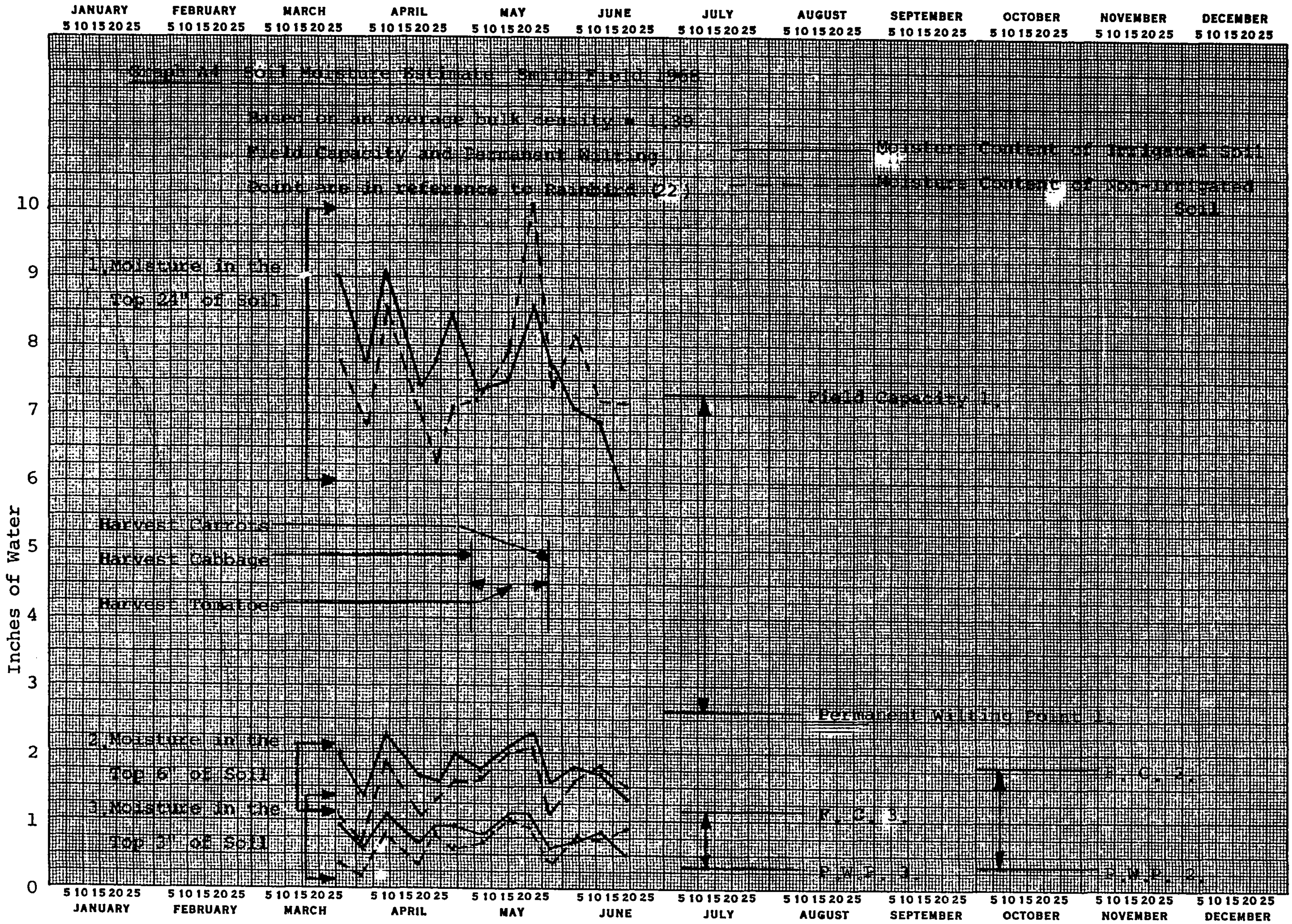
Graph A1

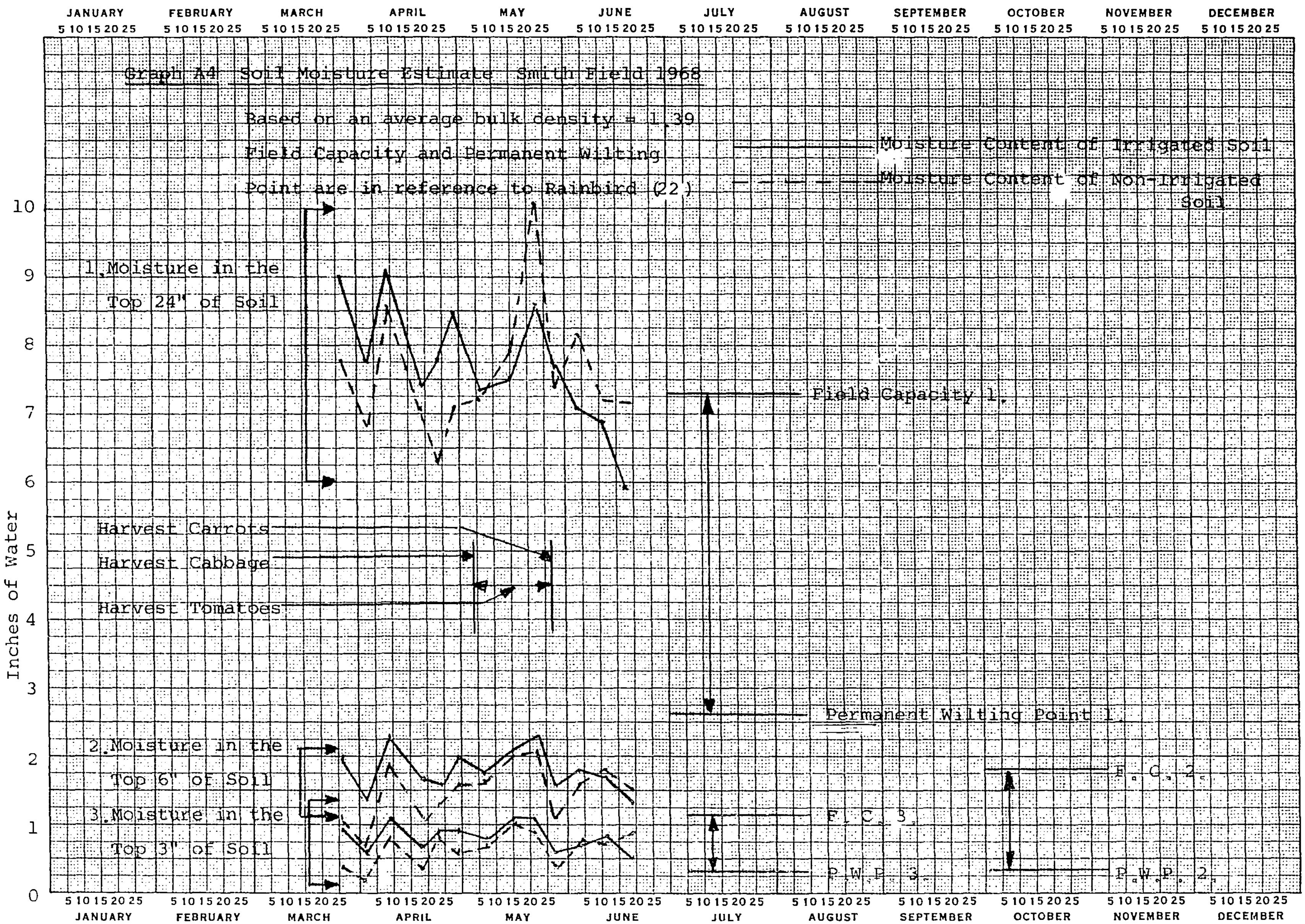


Graph A2 Average Monthly Windspeed and Rainfall
Barbados Seawell Airport
Windspeed 1953-62
Rainfall 1943-62
Barbados Greenland Plantation
Windspeed 1966-67
Rainfall 1956-66
Average Monthly Windspeed (MPH.)
Average Monthly Rainfall (Inches)
0
1
2
3
4
5
6
7
8
9
10
11
12
13
14
15
16
17
Jan
Feb
Mar
Apr
May
June
July
Aug
Sept
Oct
Nov
Dec



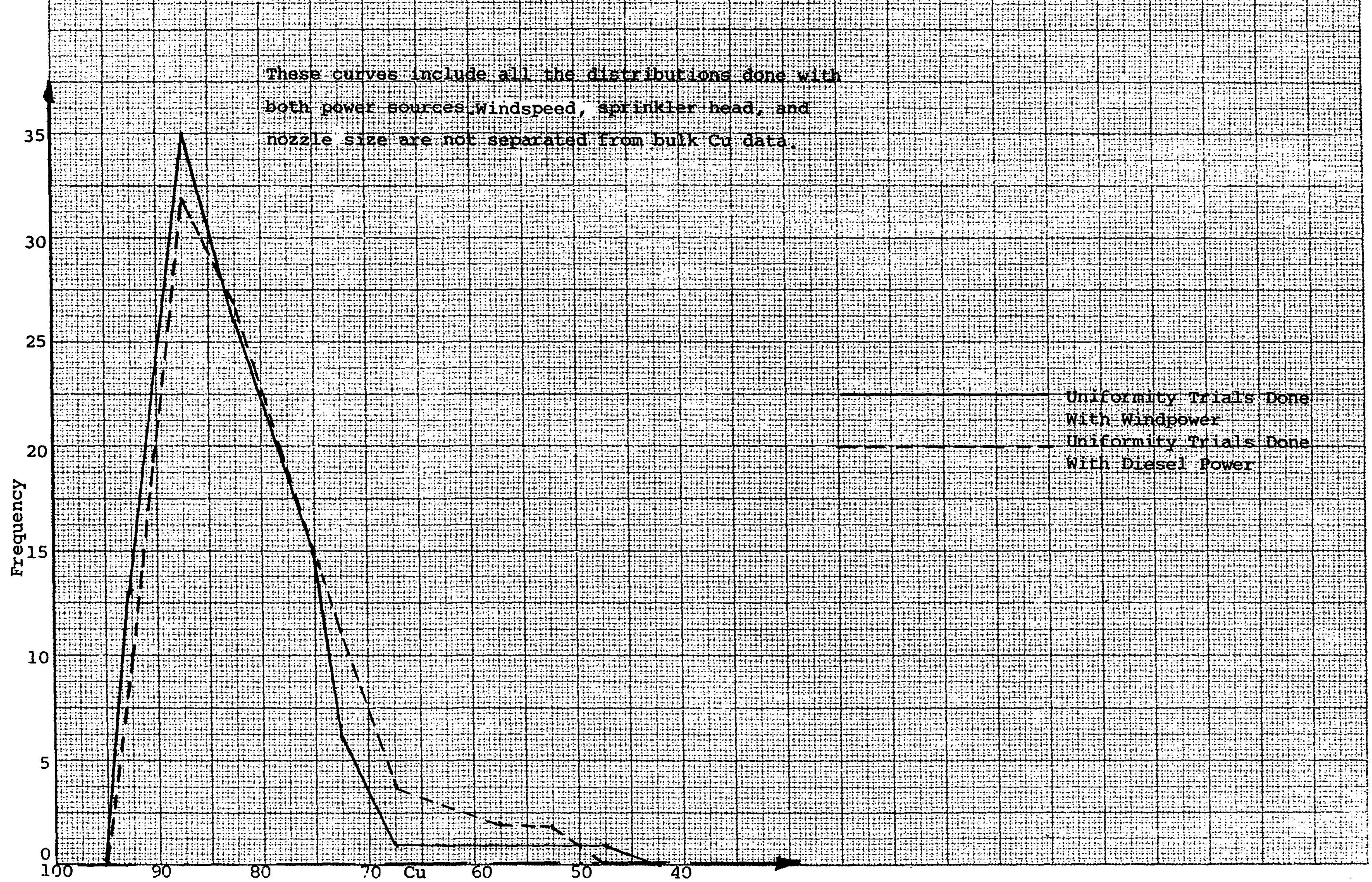
Graph A3 Summaries Of Moisture Balances
1. Evapotranspiration (Average Inches per Day)
J.M. Ionson 1956-66 Greenland
W.R. Rouse Waterford
2. Irrigation Requirement (Inches per Month)
Monthly Mean Requirement
J.M. Ionson 1956-66 Greenland
G.W. Smith (12) 30 year data B'dos.
Monthly Maximum Requirement
J.M. Ionson 1956-66 Greenland
3. Evapotranspiration (Inches per Month)
J.M. Ionson 1956-66 Greenland
W.R. Rouse Waterford
G.W. Smith (12) 30 year data B'dos.
Water (Inches)
0.20
0.18
0.16
0.14
0.00
6
5
4
3
2
1
0
Jan
Feb
Mar
Apr
May
June
July
Aug
Sept
Oct
Nov
Dec


Based on an average bulk density = 1.39
Field Capacity and Permanent Wilting
Point are in reference to Rainbird (22)
Moisture Content of Irrigated Soil
Moisture Content of Non-irrigated Soil
1. Moisture in the Top 24" of Soil
2. Moisture in the Top 6" of Soil
3. Moisture in the Top 3" of Soil
Harvest Carrots
Harvest Cabbage
Harvest Tomatoes
Field Capacity 1.
Permanent Wilting Point 1.
F. C. 2.
P. W. P. 2.
F. C. 3.
P. W. P. 3.
Inches of Water
0
1
2
3
4
5
6
7
8
9
10
JANUARY
FEBRUARY
MARCH
APRIL
MAY
JUNE
JULY
AUGUST
SEPTEMBER
OCTOBER
NOVEMBER
DECEMBER
5 10 15 20 25



Graph A4 Soil Moisture Estimate Smith Field 1968
Based on an average bulk density = 1.39
Field Capacity and Permanent Wilting
Point are in reference to Rainbird (22)
Moisture Content of Irrigated Soil
Moisture Content of Non-Irrigated Soil
1. Moisture in the Top 24" of Soil
2. Moisture in the Top 6" of Soil
3. Moisture in the Top 3" of Soil
Harvest Carrots
Harvest Cabbage
Harvest Tomatoes
Field Capacity 1.
Permanent Wilting Point 1.
F. C. 2.
F. C. 3.
P. W. P. 3.
P. W. P. 2.
Inches of Water
JANUARY
FEBRUARY
MARCH
APRIL
MAY
JUNE
JULY
AUGUST
SEPTEMBER
OCTOBER
NOVEMBER
DECEMBER
5 10 15 20 25
0
1
2
3
4
5
6
7
8
9
10

Graph A5 Frequency Curve from Uniformity Trials



Graph A6 Effect of Fluid Mass on Airscrew Response

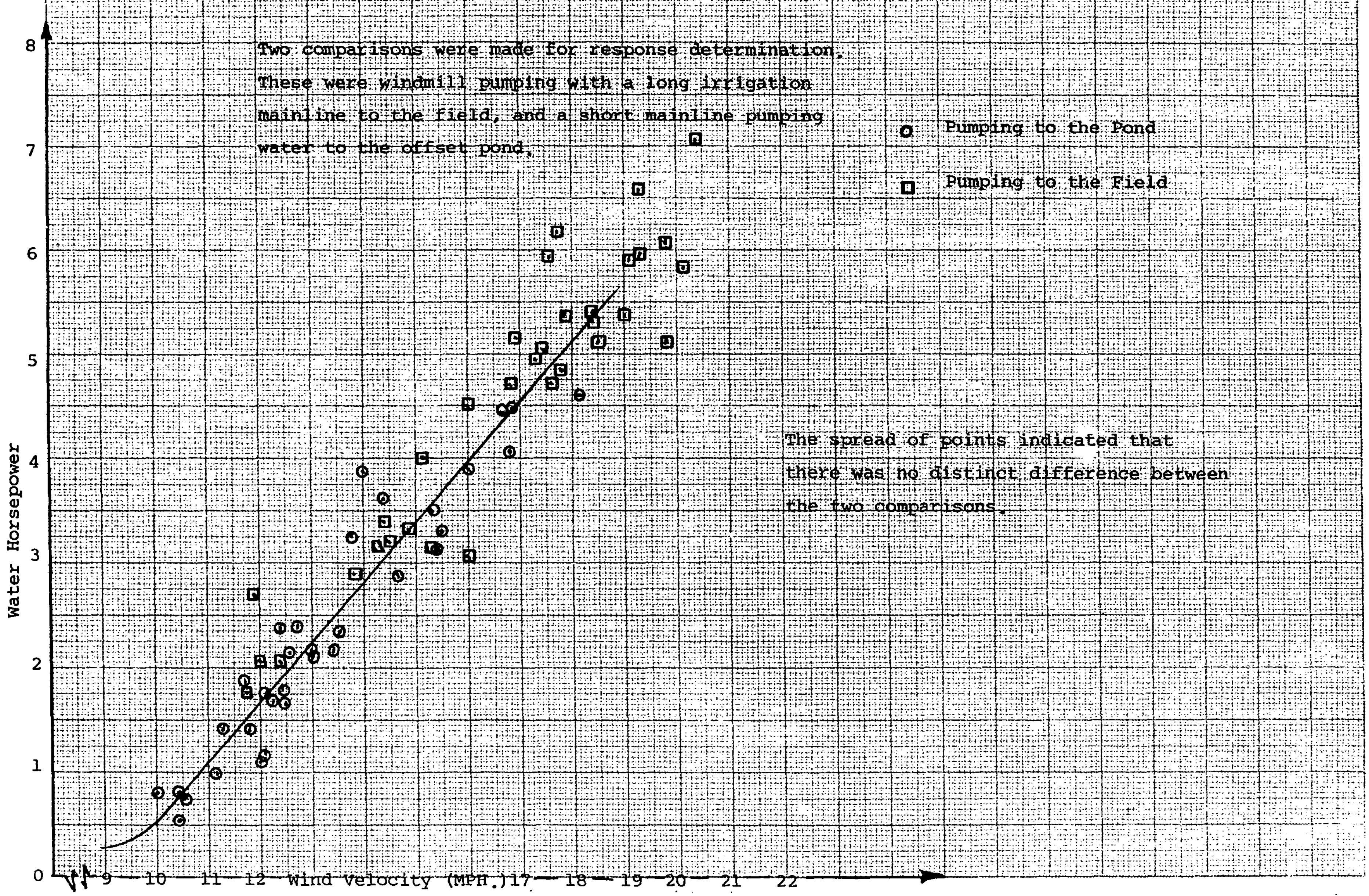


Table A1 Summary of Uniformity Trials

Sprinkler Head	Nozzle Size	Rectangular and Triangular Spacings			
		30x30	30x40	30x50	30x60
30B	9/64"	*	*		
	5/32"	*	*		
	7/32"	*	*	*	*
	9/64"x3/32'	*	*	*	*
	3/16"x9/64"	*	*	*	*
	5/32"x9/64"	*	*		
70E	1/4"x11/64"	*	*	*	
20A	3/32"				
	9/64"	*	*		
	7/32"	*	*	*	

Notes: 1. * indicates an acceptable Cu (70 - 100) on average.

2. All distributions were done with wind direction at right angles to the line of the irrigation lateral pipeline.

3. Windspeeds as high as 18 MPH. were observed in the acceptable Cu trial data.

4. Application rates calculated with Cu data indicate a reasonable agreement with the Rainbird Tables [22].

Table A2 Summary of Meteorological Data From Greenland Station

Date	Temperature Avg.Max (°F.)	Avg Min.	Relative Humidity (%)	Windspeed (MPH.)	Solar Radiation Avg./Day (langleys)	Avg. Evaporation (Inches)	Total Rain (Inches)
Dec 4-11	85	73	70	7.8	231	**	.05
11-18	85	75	70	10.6	254		.71
18-25	84	74	71	11.5	255		.87
25-Jan 1	84	73	66	12.9	266		.65
1-8	84	75	66	13.5	245		.10
8-15	84	75	68	12.6	261		.17
15-22	82	70	74	11.8	280		2.91
22-29	84*	72	66	7.5	279		.00
29-Feb 5	85*	75	60	9.0	271		.13
5-12	85*	75	66	11.5	270		.70
12-19	84*	73	70	11.9	305		.12
19-26	84*	72	74	10.4	278		1.31
26-Mar 4	86*	75	74	10.1	324		.78
4-11	83	76	70	10.2	334		.40
11-18	82	73	74	10.0	345		.94
18-25	84	74	75	8.7	318		.09
25-Apr 1	84	74	69	10.7	339		.22
1-8	85	75	77	11.4	328		.22
8-15	84	76	67	9.0	339		.86
15-22	85	74	82	6.1	326		.78
22-29	84	74	77	8.4	275		1.18
29-May 6	85	76	68	13.1	360		.22
6-13	86	75	78	10.9	351		1.46
13-20	85	77	76	11.4	271		2.77
20-27	85	78	78	15.2	323		1.32
27-June3	86	76	78	11.4	306		1.26
3-9	86	78	78	12.3	262		.78
9-16	85	77	77	13.0*	248		1.37

Notes: 1. ** Data unusable

2. * Data estimated

3. For daily data see also Meteorological Service Seawell International Airport, Barbados W.I. or McGill's Waterford station data through Department of Climatology.

Table A3 Strip Chart Data for Airscrew Pumping Performance

Discharging from 4 9/64" sprinklers in the field (700 Feet of mainline)
and 2 5/8" jets to offset pond (30 Feet of Mainline)

Time	Pressure on Guage	Discharge IGPM.	Windspeed MPH.	Airscrew Speed RPM.
1:00:00	39	117	22	80
:05	32	107.5	25	71
:10	30	110	24	70
:15	30.5	117.5	25	72
:20	29.5	107	29	70
:25	26.5	104	25	65.5
A → :30	25.5	119	22	70
→ :35	37	151	30	87
:40	42	131.5	27	84
:45	40	133	22	83
:50	45	145	22	87
:55	51	152.5	23	94
:60	46	134	23	87
1:01:00				

A Calculation for Inertia Effect

Interval A – Change in pressure 11.5 psi. (relative)

Change in discharge relatesto the change in average velocity of the water in the 5" aluminum pipe.

1:00:30 119 IGPM. = 0.3185 cfs. or velocity = 2.33 Feet/second

1:00:35 151 IGPM. = 0.4045 cfs. or velocity = 2.96 Feet/second

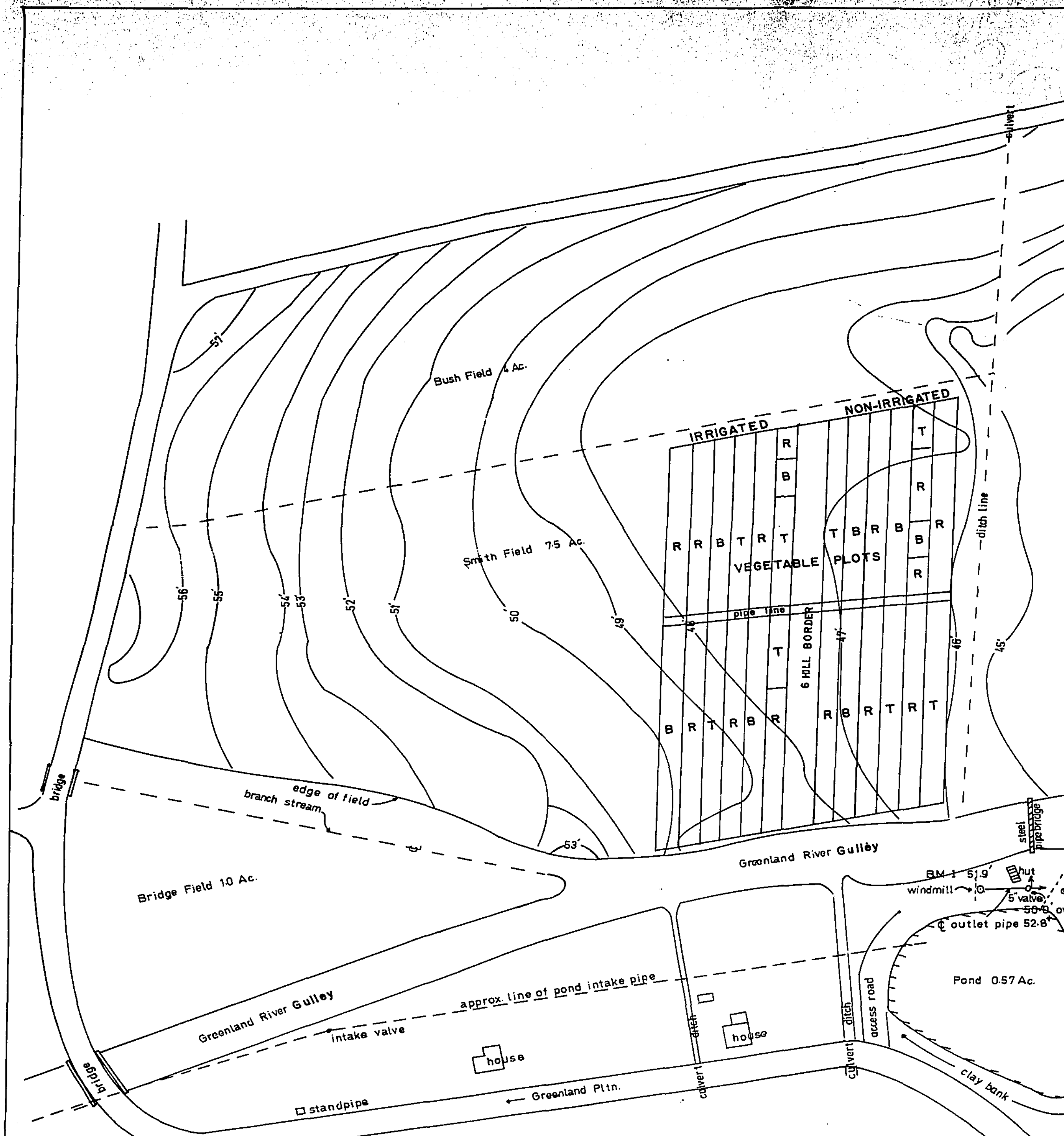
$$\text{Fluid Mass Acceleration} = \frac{2.96 - 2.33}{5} = 0.126 \text{ Ft./sec.}^2 = \text{F.M.A.}$$

From (23) Change in pressure to accelerate fluid mass $= \frac{\text{Length of pipe}}{32.2} \times \text{F.M.A.}$

$$= \frac{700}{32.2} \times 0.126$$

$$= 2.74 \text{ Feet or } 1.19 \text{ psi.}$$

The actual change in pressure was 11.5 psi. so that we see with this simplified theoretical consideration that there is a considerable inertia effect, and that it is dependent on the length of mainline, or mass of fluid in the irrigation system, and nozzle configuration.



NOTES:

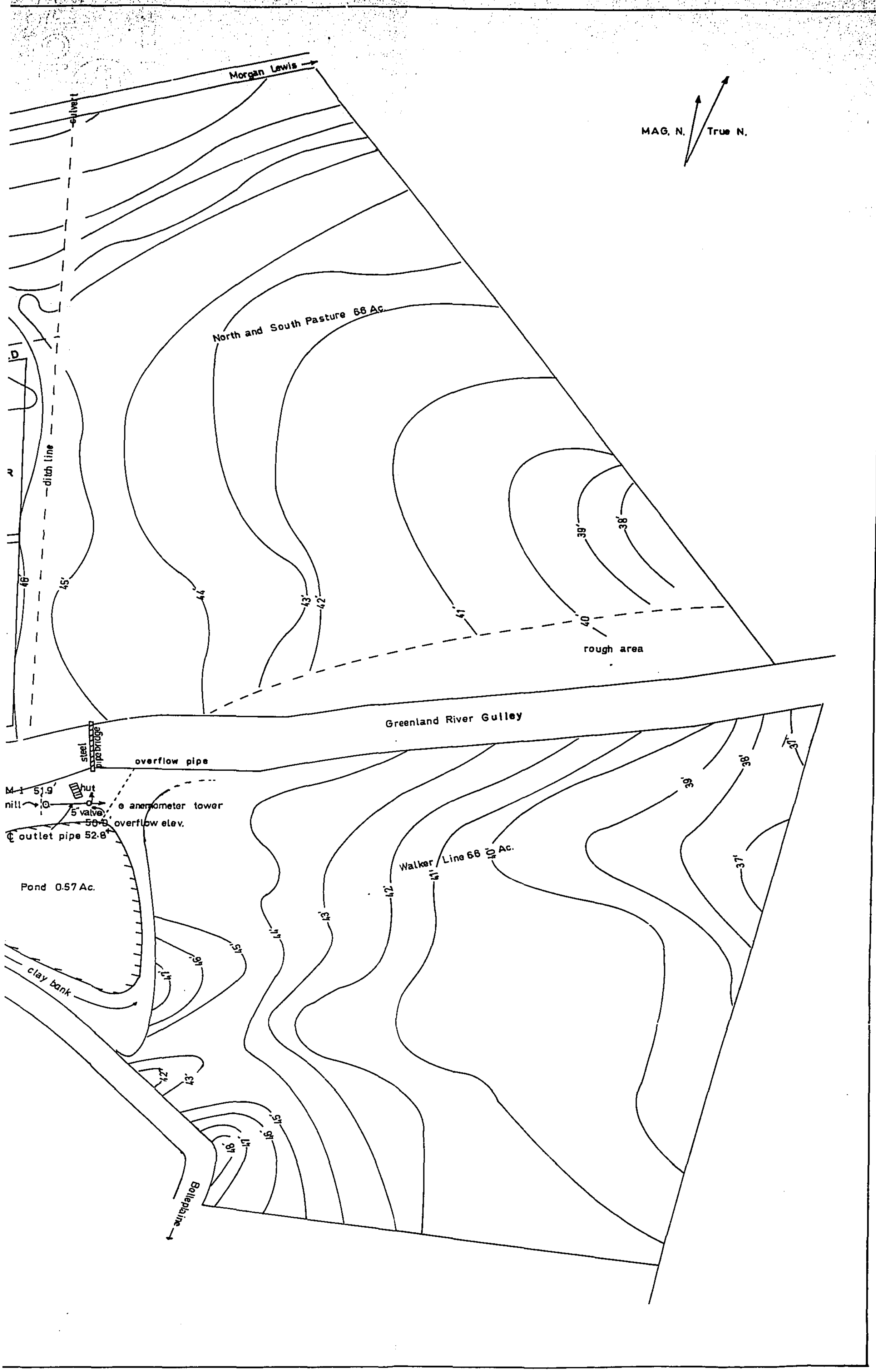
1. Contours based on survey to els.± 0.10'
2. Photographic Reproduction Alters Scale to 1.0" = 100.0' approx.

KEY:

To Vegetable Plots –
B · Cabbage
R · Carrots
T · Tomatoes

FIGURE 4

Description			
Drawn	Date 19/1/68	IRRIGATION PROJECT GREENLAND ST. ANDREW.	Drwg. No.
Mod	Date		Issue
Appvd	Date	BRACE EXPT. STA. ST. JAMES BARBADOS.	
Scale 1" = 50.0'	Superceded		


Morgan Lewis
culvert
MAG. N.
True N.
North and South Pasture 66 Ac.
ditch line
46'
45'
44
43'
42'
41
40
39'
38'
rough area
Greenland River Gulley
steel pipe bridge
overflow pipe
hut
anemometer tower
5' valve
50.0' overflow elev.
outlet pipe 52.8'
Pond 0.57 Ac.
Walker Line 66 Ac.
40'
41'
42'
43'
44'
45
46'
47'
48'
37'
clay bank
Belleplaine