HYDRAULICS OF TRICKLE IRRIGATION EMITTERLINES

by

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The information and conclusions in this report do not necessarily reflect the position of Utah State University, USAID, or the United States Government.

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ABSTRACT

Hydraulics of Trickle Irrigation Emitterlines

by

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A study was conducted to investigate the flushing flow characteristics of flushing emitters, the hydraulics of emitterlines under steady flow conditions, and the uniformity of distribution of emitters as influenced by emitter variations and other environmental factors.

The study was composed of three parts:

1. A theoretical analysis employing computer programs.
2. A laboratory analysis of emitterlines.
3. A field analysis of a trickle irrigation system under actual field environmental conditions.

Eight different types of emitters were studied, one non-flushing and seven flushing, and differences between emitters are discussed and recommendations are made concerning the selection of flushing emitters, design of emitterlines, and maintaining maximum efficiency in regards to uniformity of distribution.

(94 pages)

INTRODUCTION

There are basically three types of irrigation systems used today: surface (border or furrow), sprinkler, and trickle irrigation. Of the three, trickle irrigation is the most recent in development.

Trickle irrigation involves the use of drippers or emitters spaced along an emitterline. The emitters can be classified as one of two types: flushing or non-flushing.

Flushing emitters are designed to eliminate clogging by flushing out large particles which otherwise would clog the emitter. This requires an initial discharge greater than operating discharge for the flushing phase. As the head increases, a ball or piston-type valve seats and the emitters operate with a discharge proportional to the pressure head at that point. Flushing emitters are turbulent flow emitters, with the discharge being proportional to the square root of the pressure head, while non-flushing emitters are laminar flow type emitters, with the discharge being directly proportional to the pressure head.

With the increased interest in trickle irrigation, many farms and farming corporations are considering converting large acreage to trickle irrigation. When installing a trickle irrigation system, the decision must be made whether to install non-flushing or flushing emitters. Factors entering into this decision are labor costs, installation costs, water quality, and pumping and filtering costs.

In a non-flushing emitter, clogging will occur due to fine particles or algae, thus an efficient filter system is required. If particles

larger than the orifice are allowed to enter the system, obviously clogging will immediately occur. However, if the water is filtered with a screen having an opening much smaller than the orifice or discharge channel area of an emitter, clogging will gradually occur due to the laminar flow which produces a boundary layer causing particles smaller than the orifice opening to adhere to the wall of the emitter. These particles could perhaps be classified as silt or clay particle size.

Since a flushing emitter requires an initial dishcarge greater than the normal operating discharge, it has been assumed that an emitter-line functions in a similar manner, requiring an initial discharge greater than operating discharge in order to seat all the emitters on the line. It follows that this same concept could be applied on a larger scale to seating a system consisting of one or more laterals.

Due to lack of specific information, estimates have been made in order to determine the pump capacity necessary to "start" a trickle irrigation system. (The term "start" referring to the seating of the flushing emitters.) The necessary pump capacity to seat the system has been estimated to be 20 to 30% above the normal discharge capacity at operating head (Keller, 1972).

A properly engineered design of an irrigation system can save 20% on the total cost of the scheme (Driplex Manual, 1970). With respect to the hydraulics of design, no study has been published which provides specific information for maximum efficiency regarding head-discharge characteristics, which can be applied to trickle irrigation systems where flushing emitters are employed.

In analyzing the problems encountered in trickle irrigation design, the following questions can be presented:

1. If a flushing emitter is used, in view of the fact that a flushing emitter requires an initial discharge greater than operating discharge, what is the relationship between the additional discharge required to seat an emitter, the additional discharge required to seat an emitterline, and the additional discharge required to seat a system consisting of one or more laterals?

2. What factors must be determined to design emitterline length and determine the head loss in a line?

3. In operating with a non-flushing emitter, what is the length of time the system can be run before flushing of the system is required in order to maintain maximum uniformity of distribution?

REVIEW OF LITERATURE

Acceptance of Trickle Irrigation

Trickle irrigation is a relatively new type of irrigation, but is readily being accepted as a feasible and efficient type of irrigation.

Many studies have been conducted showing the advantages of trickle irrigation, by comparing the increase in yield produced by trickle irrigation to that produced by sprinkler or surface irrigation. Goldberg (1969) reported a significant difference in yields of crops of tomatoes, cucumbers, mush melons, and sweet corn grown in the Arava, in Israel, in sandy loam soil, with saline water. In the same study, Goldberg reported that with the use of trickle irrigation, comparable yields were produced using saline water and high quality water, therefore indicating the potential of trickle irrigation where irrigation water is saline.

Gustafson (1970) quoted reports of increased productivity in the Negev Desert, Israel, due to trickle irrigation. Gustafson stated that production increased as follows: melons - 70%, grapes - 30%, orchard yields - 20%-30%, and vegetable crops - 50%-100%.

Many of the studies of trickle irrigation have been related to showing the increase in productivity, or advantages where soil and/or water is saline. However, in regards to the hydraulic considerations of a trickle irrigation system, very little has been published. Most of the available literature in this regards is mainly in the form of pamphlets or manuals furnished by companies manufacturing emitters.

Studies Involving Hydraulics of Trickle Irrigation Systems

Regarding the type of material published, each manufacture usually publishes graphs showing the discharge versus head characteristics of a given emitter (Spears, 1970; Drip-Eze Tech Manual, 1972; Driplex Manual, 1970; Rinko Drip-Feed Irrigation System, 1971; Tricklon, 1971).

Some of the manufacturers have published manuals which supposedly would enable one to design a simple trickle irrigation system by providing equations which can be used to determine consumptive use, spacing number of emitters, and emitter discharge necessary. Friction loss charts or graphs are also provided to help design the system (Drip-Eze Tech Manual, 1972; Tricklon, 1971; Driplex Manual, 1970).

Non-flushing emitters

In tests involving non-flushing emitters, Wilke (1970) investigated hydraulic roughness of Micro-Por^{tm} pipe, which is a porous-walled sub-irrigation pipe. Also, Wilke and Wendt (1971) studied the performance of a twin-wall trickle irrigation system in regards to the uniformity of discharge versus hose inlet head and length of hose.

Flushing emitters

Davis and Nelson (1970) reported on 24 different types of emitters, both flushing and non-flushing. Two flushing emitters were studied: Spears and Uniflow. Davis and Nelson stated that these two emitters flushed at pressures below 15 psi, and that above 15 psi, the emitters would seat and emit at the designed emission rate.

Concerning the adequacy of the literature available, much is lacking regarding hydraulics of trickle irrigation systems, especially where flushing emitters are used.

PROCEDURE

Methods of Investigation

The flushing flow characteristics of emitters, the hydraulics of emitterlines under steady flow, and the uniformity of distribution of emitters were the three topics studied using:

1. A computer analysis.
2. A laboratory analysis employing emitterlines.
3. A field study of a large trickle irrigation system under actual field environmental conditions.

Computer analysis

Three computer programs were developed to analyze the roughness coefficient of an emitterline and the head-discharge relationship in emitterlines, while one program was developed for an analysis of variance.

The first three computer programs are related in basic theory, employing the same formulas. The following equations were used in relating head loss to the flow rate in a line:

$$V = Q/A \qquad [1]$$

$$Re = V \times D/\nu \qquad [2]$$

where

V = the water velocity, ft./sec.

Q = the flow rate, $ft.^3$/sec.

A = the cross sectional area of the hose, ft^2.

Re = the Reynolds Number, dimensionless

D = the inside diameter of the pipe, ft.

ν = the kinematic viscosity of the water, ft.^{2}/sec.

If the velocity is less than critical velocity, (Re<2,000), the Darcy-Weishbach head loss equation is used:

$$F = 64/Re \qquad [3]$$

$$HL = F \times L \times V^2/(D \times 2g) \qquad [4]$$

where

F = the friction factor, dimensionless

HL = the head loss, feet

L = the length of pipe, feet

g = the force of gravity, ft./sec.^{2}

If the velocity is greater than critical velocity, (Re>2,000), the Hazen-Williams head loss equation is used:

$$HL = (V/(1.318 \times C \times R^{.63}))^{1.85} \times L \qquad [5]$$

where

HL = head loss, feet

V = velocity, ft./sec.

L = length of pipe, feet

C = roughness coefficient, dimensionless

R = hydraulic radius, feet

The head is computed at each emitter and from a subroutine employing the individual emitter head-discharge characteristics, the discharge of each emitter on the line is computed.

The first program (See Appendix A) solves for the coefficient of roughness for the emitterline (See equation 5). Tests were made using 200, 250, and 400 foot emitterlines. The input data required for the program is the inlet head, flow rate, distal head, and the individual

emitter head-discharge characteristic data. From this data, the coefficient of roughness is found.

The second program (See Appendix B) utilizes a given inlet head, and solves for the inlet flow necessary to seat and operate the emitterline. The theoretical discharge of each emitter is also printed on the output statement.

The third program (See Appendix C) takes an inlet head, and a given flow rate, and solves for the discharge of each emitter in a given emitterline.

The fourth program (See Appendix D) statistically analyzes an emitterline, computing the average emitter discharge, the variance, the regression line slope, and the coefficient of variation.

Laboratory test

The laboratory test involved the use of eight types of emitters: Spears 3 gph (gallons per hour), Old Rebat 3 gph, New Rebat 3 gph, Old Uniflow 3 gph, New Uniflow 3 gph, Uniflow 2 gph, Spears 2 gph, and Drip-Eze 2 gph.

For the purpose of convenience, abbreviations will be used in referring to the various emitters, and are found in Table 1. The term "old" refers to the fact that the particular company updated the design of a particular emitter, and both "old" and "new" were tested.

The Dz2, NRbt3, and NUnf3 emitters were never used in the field, while the Sp2, Sp3, ORbt3, Unf2, and OUnf3 had all been used in the field for varying periods up to four months.

The emitters tested are shown in Figure 1.

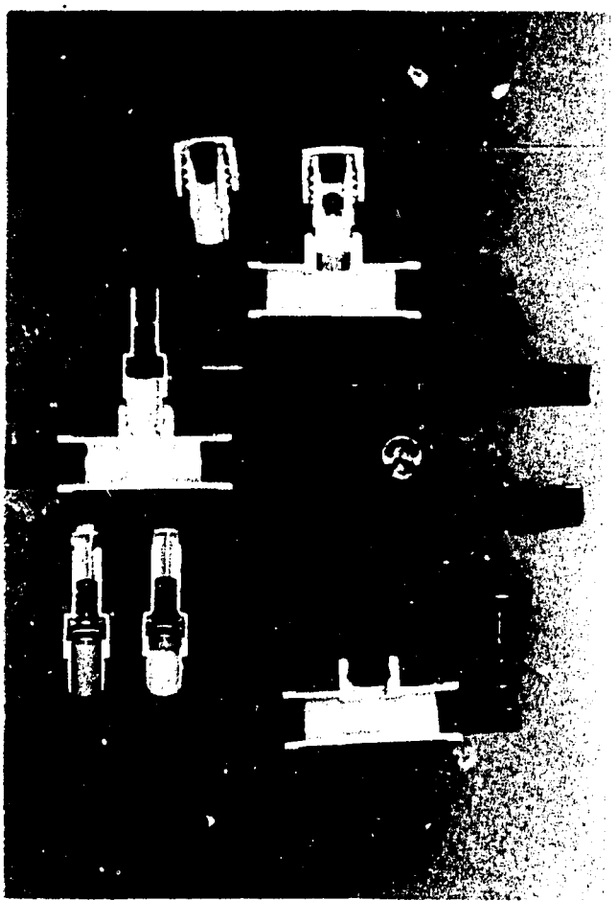
The Sp2 and Sp3 emitters are made of PVC (polyvinylchloride), with

a rubber orifice secured by a cap. The ball bearing is shown in flushing position in the Sp3, and seated in the Sp2.

Table 1. Emitter abbreviations

Emitter	Abbreviation	Design Discharge (gallons per hour)
Spears 2 gph	Sp2	2
Spears 3 gph	Sp3	3
Old Rebat 3 gph	ORbt3	3
New Rebat 3 gph	NRbt3	3
Uniflow 2 gph	Unf2	2
Old Uniflow 3 gph	OUnf3	3
New Uniflow 3 gph	NUnf3	3
Drip-Eze 2 gph	Dz2	2

The three Uniflow emitters are all made of PVC and operate the same, utilizing a piston. In Figure 1, all are shown in flushing position. As the pressure increases, the piston is pushed to the top of the chamber, in seating position.



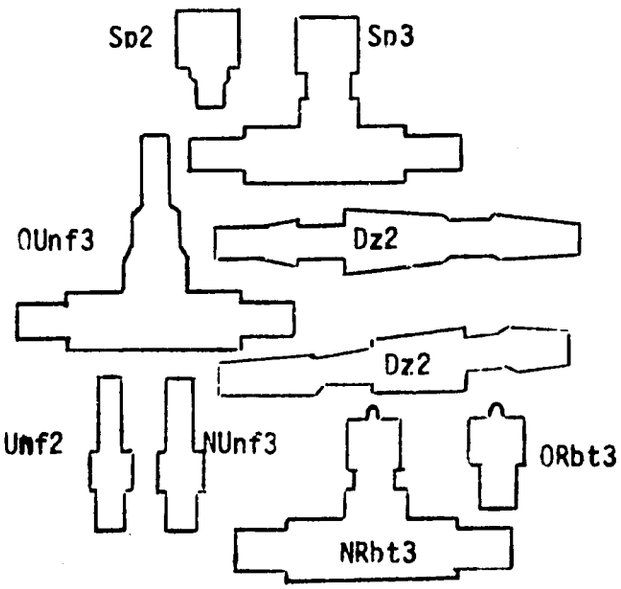


Figure 1. Emitters tested and code for identification purposes

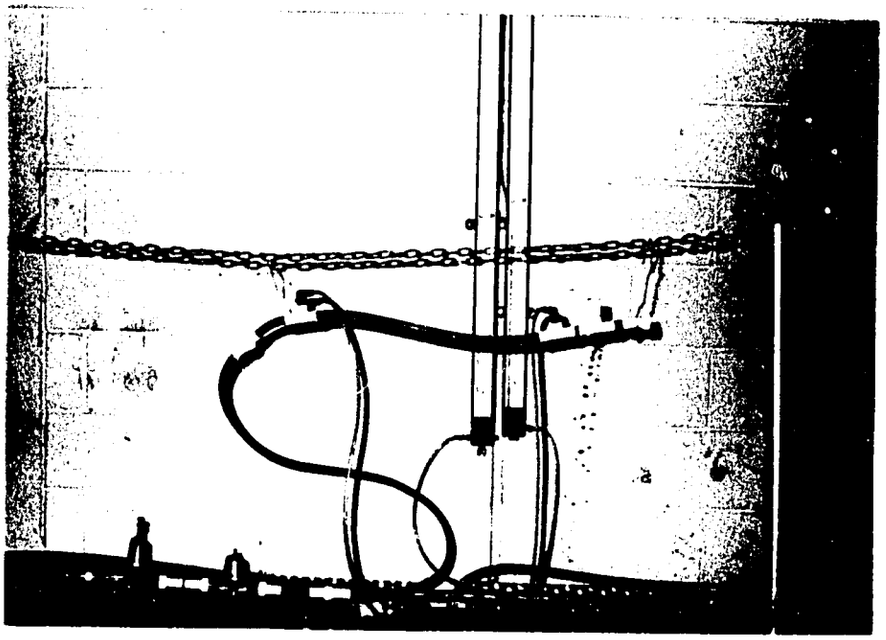


Figure 2. Equipment used in determining emitter head-discharge curve

The two Rebat emitters are also made of PVC and function the same as the Spears emitters with the exception of a steel washer with a hole in the center replacing the rubber orifice.

The Dz2 emitter is made from a polypropylene co-polymer. It consists of one section of spiral channels which fit inside the other section, which has smooth walls. When operating, the two sections are forced apart by the water pressure, and the spiral channels are formed as the smooth wall fits flush against the spiral ridges. The spiral channels are to reduce the head such that the flow will be laminar. The water enters the channel at the larger end of the emitter and exits at the tapered end. The emitter can be manually flushed by pushing the two sections together, causing the ridges to separate from the smooth wall, creating turbulent flow which flushes out any particles in the emitter.

Emitter installation. The Dz2 emitter is plugged into polyethylene hose, while all other emitters are screwed into a PVC tee, which is glued to PVC hose.

Emitterline assembly. The emitterlines were assembled in the Utah State Water Research Laboratory. 400 feet of polyethelene hose was used, employing 80 Dz2 emitters spaced 5 feet apart. The hose is glued into the tees, and the emitters are screwed into the tees. The Spears, Rebat, and Uniflow emitters all can be interchanged using the same tees.

Water supply. The system was connected to the domestic water supply at the Utah State Water Research Laboratory, using a pressure regulator to insure steady pressure.

Emitter head-discharge curve characteristics. In determining the head-discharge curve characteristics of a flushing emitter, an eight foot water manometer was used. A connecting section of hose was

assembled, using a special fitting screwed into a tee to connect the manometer hose. The manometer connection was placed adjacent to the tee containing the emitter being tested. (See Figure 2.)

The head was increased in increments of 2 inches, and the discharge recorded using a 500 milliliter flask and a stop watch. The head was increased until seating occurred, at which point the manometer fitting was replaced with a pressure gage in order to determine the rest of the curve, up to 40 psi.

This procedure was repeated using 10 different emitters of each type, selected randomly, and an average head-discharge curve was then determined for all seven flushing emitters.

Since the Dz2 emitter is a non-flushing emitter, the pressure gage was used for all head-discharge readings.

Emitterline head-discharge curve characteristics. The head-discharge curves for the emitterlines were determined by use of a pressure gage and flow meter connected at the emitterline inlet.

For flushing emitters the inlet head was gradually increased, and the flow rate was recorded for various heads until seating occurred. After the seating head had been established, the head was increased to obtain the rest of the curve up to "operating pressure." The operating pressure of the flushing type emitters, as recommended by the manufacturers, is usually 30 psi.

For the Dz2 emitter, flow rate readings were made at various heads to obtain the head-discharge curve. The recommended operating pressure for non- flushing emitters is 10 psi to 15 psi. The operating pressure used in testing the Dz2 emitter was 15 psi.

Head versus discharge curves were made for the Dz2 emitter with emitterline lengths of 200 and 400 feet, for the Sp2 with lengths of

200 and 250 feet, for the Sp3 with lengths of 200, 300, and 400 feet, and for the ORbt3, NRbt3, OUnf3, and Unf2 emitters with an emitterline length of 200 feet.

Uniformity of distribution. The uniformity of distribution is an indication of the deviation from the average discharge that will occur along an emitterline.

In order to determine the uniformity of distribution of the various emitters, discharge readings were made using a 500 milliliter flask and a stop watch. Starting with the second emitter on the line, every other emitter was sampled on the emitterline. A 200 foot emitterline was used in all tests, with 20 emitters being sampled along the line.

The results of the sampling were then compared with the theoretical uniformity of distribution provided by the computer program. (See Appendix D.)

Normal distribution. In order to determine that the emitters used in the test adhered to manufacturing tolerances which would produce a normal distribution, 30 emitters of each type were randomly selected from a population of 80 and the discharge of each emitter was recorded at the same pressure. The Dz2 emitter was tested at 15 psi, while the rest were all tested at 30 psi.

The mean, the mode, and the median values were then calculated using the following equations:

$$\bar{x} = \Sigma fX/N \qquad [6]$$

where

f = the frequency of each class

X = the mean value of each class

N = the total frequency

$$\text{Median} = L_1 + \left(\frac{N/2 - (\Sigma f)_1}{f_{med}}\right) \times C \qquad [7]$$

where

L_1 = the lower class boundary of the median class

$(\Sigma f)_1$ = the sum of frequencies of all classes lower than the median class

N = the total frequency

f_{med} = the frequency of the median class

C = the size of the median class interval

$$\text{Mode} = L_1 + \left(\frac{\Delta_1}{\Delta_1 + \Delta_2}\right) \times C \qquad [8]$$

where

L_1 = the lower class boundary of the modal class

Δ_1 = the excess of modal frequency over frequency of nest lower class

Δ_2 = the excess of modal frequency over frequency of next higher class

C = the size of the modal class interval

Field analysis

Location. The field analysis was conducted at The Superior Farming Company, on Ranches 14 and 16, located 20 miles north of Bakersfield, California.

Trickle irrigation field layout. A typical trickle irrigation field layout employed by The Superior Farming Company is shown in Figure 3.

Tests conducted. Tests were conducted on the Sp3 and Dz2 emitters, which are the two main emitters used by The Superior Farming Company. The inlet head on the emitterlines tested varied between 40 and 48 psi for the Sp3 emitters, and 17-22 psi for the Dz2 emitters.

The Sp3 emitters were tested for uniformity of distribution of discharge. The discharge of the emitters was determined using a 500 milliliter flask and a stop watch. Since the orifice of the Sp3 emitter is

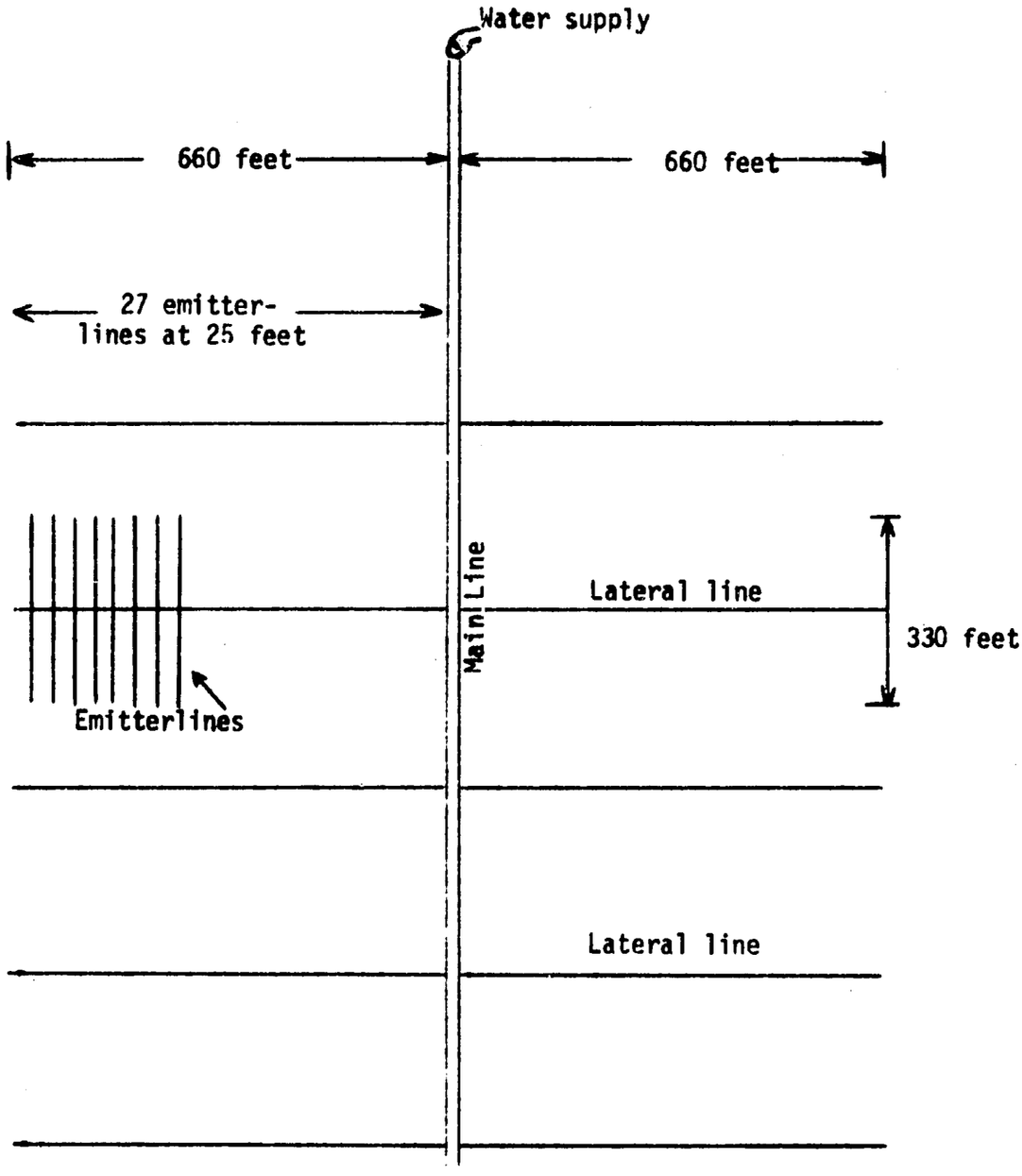


Figure 3. Trickle irrigation field layout

rubber, which can deform, aging effects were tested by measuring the discharge of each emitter on an emitterline, replacing the orifices in the emitters with new orifices, and measuring the discharge of each emitter with the new orifice.

The Dz2 emitters were tested for uniformity of distribution with the same method used for the Sp3 emitters. Since the Dz2 emitters are non-flushing, aging effects were tested by recording the discharge of each emitter on an emitterline, flushing each emitter by pushing the two sections together, and recording the discharge of each emitter after flushing.

RESULTS AND DISCUSSION

Flushing Flow

The head-discharge curves for the individual emitters are shown in Figures 4-11.

Figure 4 is a Dz2 emitter which is a non-flushing emitter, and the average discharge at 15 psi was found to be 2.0 gph, which is the design discharge.

Figure 5 is the Sp2 emitter which was found to have an average flushing discharge of 13 gph at .40 gph at .49 psi, and an average operating discharge of 3.06 gph at 30 psi.

Figure 7 is the ORbt3 emitter which was found to have an average flushing discharge of 18 gph at 3.75 psi, and an average operating discharge of 3.38 gph at 30 psi.

Figure 8 is the NRbt3 emitter which was found to have an average flushing discharge of 18 gph at .64 psi, and an average operating discharge of 3.18 gph at 30 psi.

Figure 9 is the Unf2 emitter which was found to have an average flushing discharge of 8 gph at 3.75 psi, and an average operating discharge of 1.92 gph at 30 psi.

Figure 10 is the OUnf3 emitter which was found to have an average flushing discharge of 7 gph at 3.75 psi, and an average operating discharge of 2.20 gph at 30 psi.

Figure 11 is the Nunf3 emitter which was found to have an average flushing discharge of 6.6 gph at 3.75 psi, and an average operating

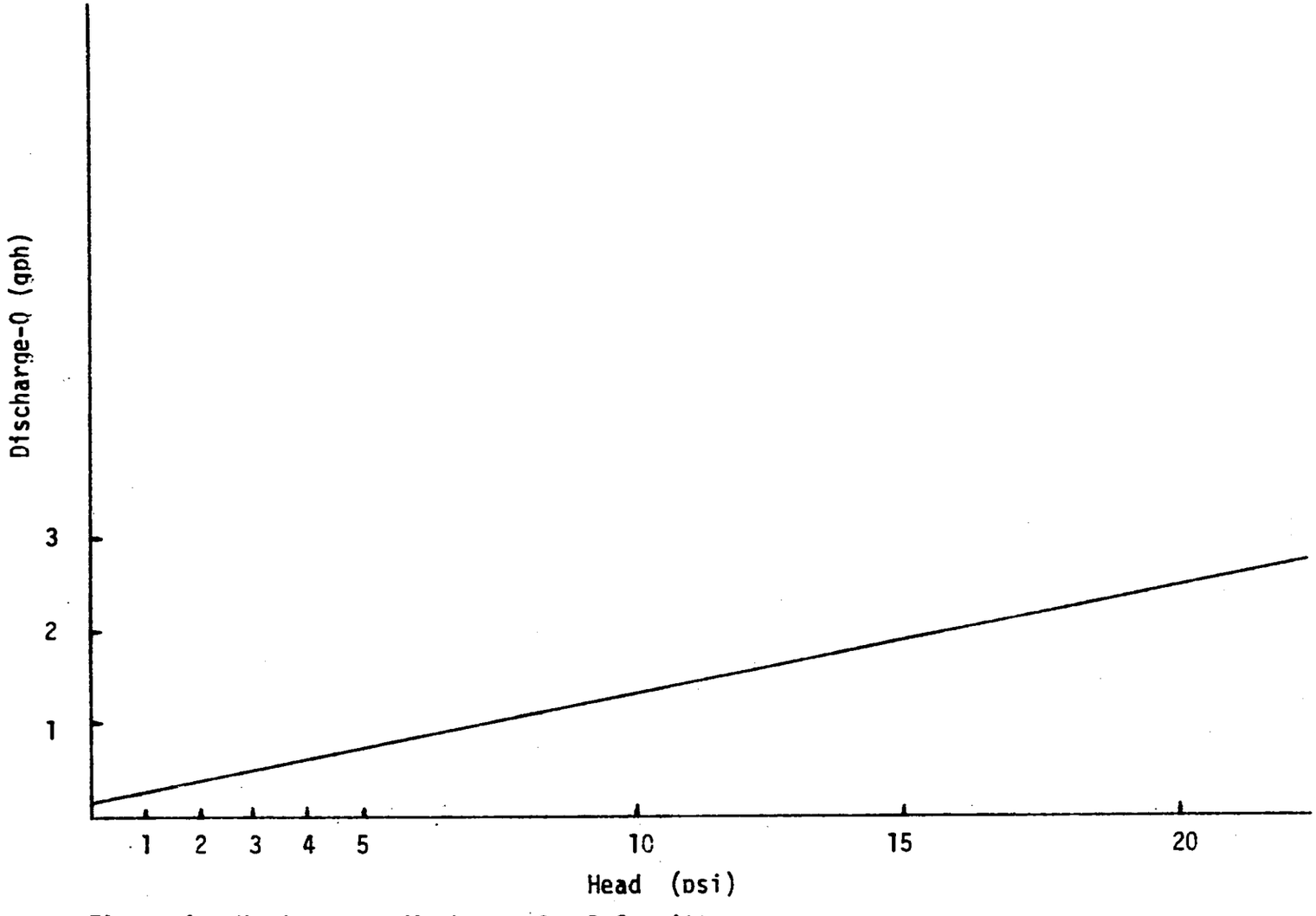


Figure 4. Head versus discharge for Dz2 emitter

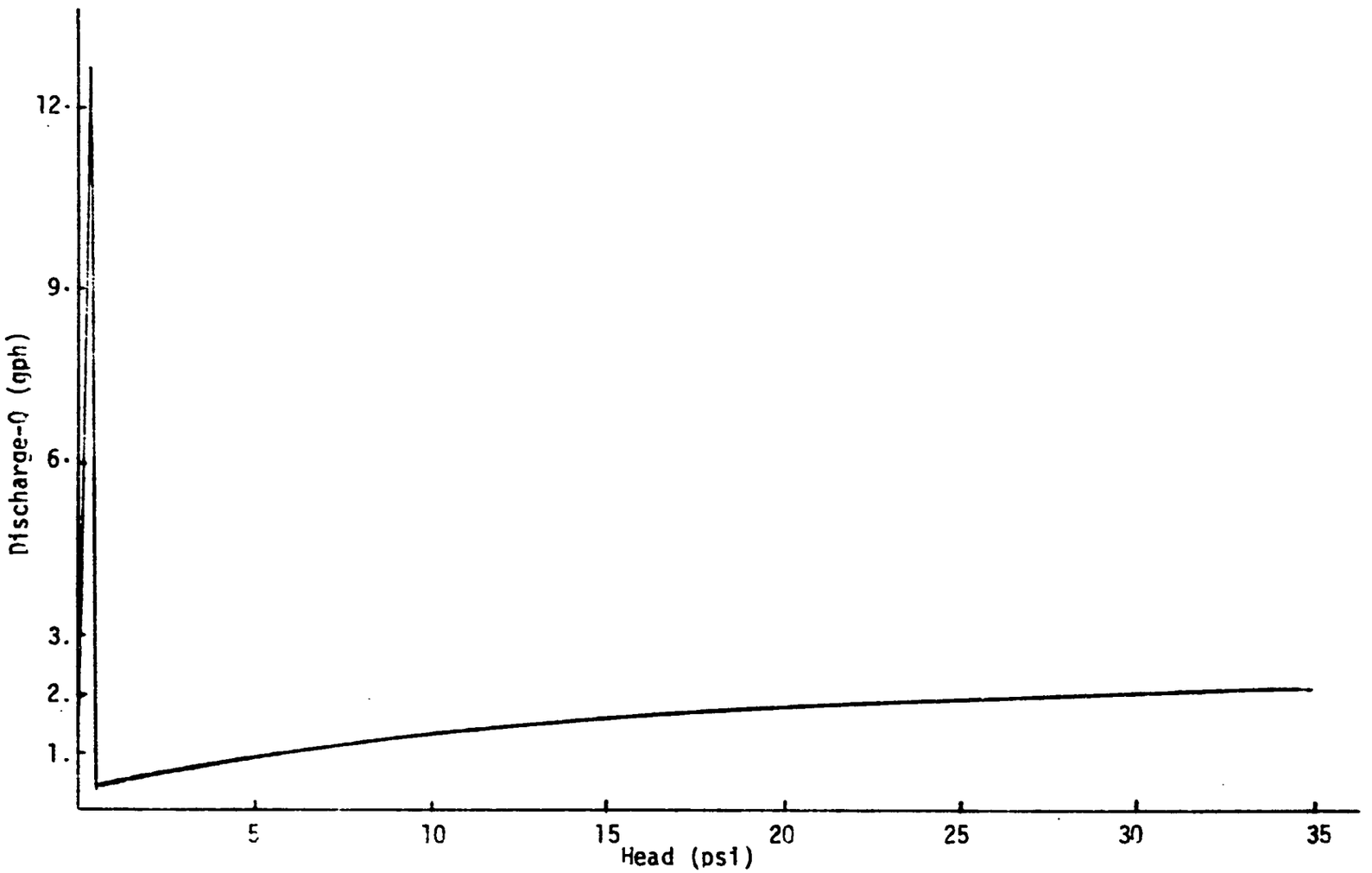


Figure 5. Head versus discharge for Sp2 emitter

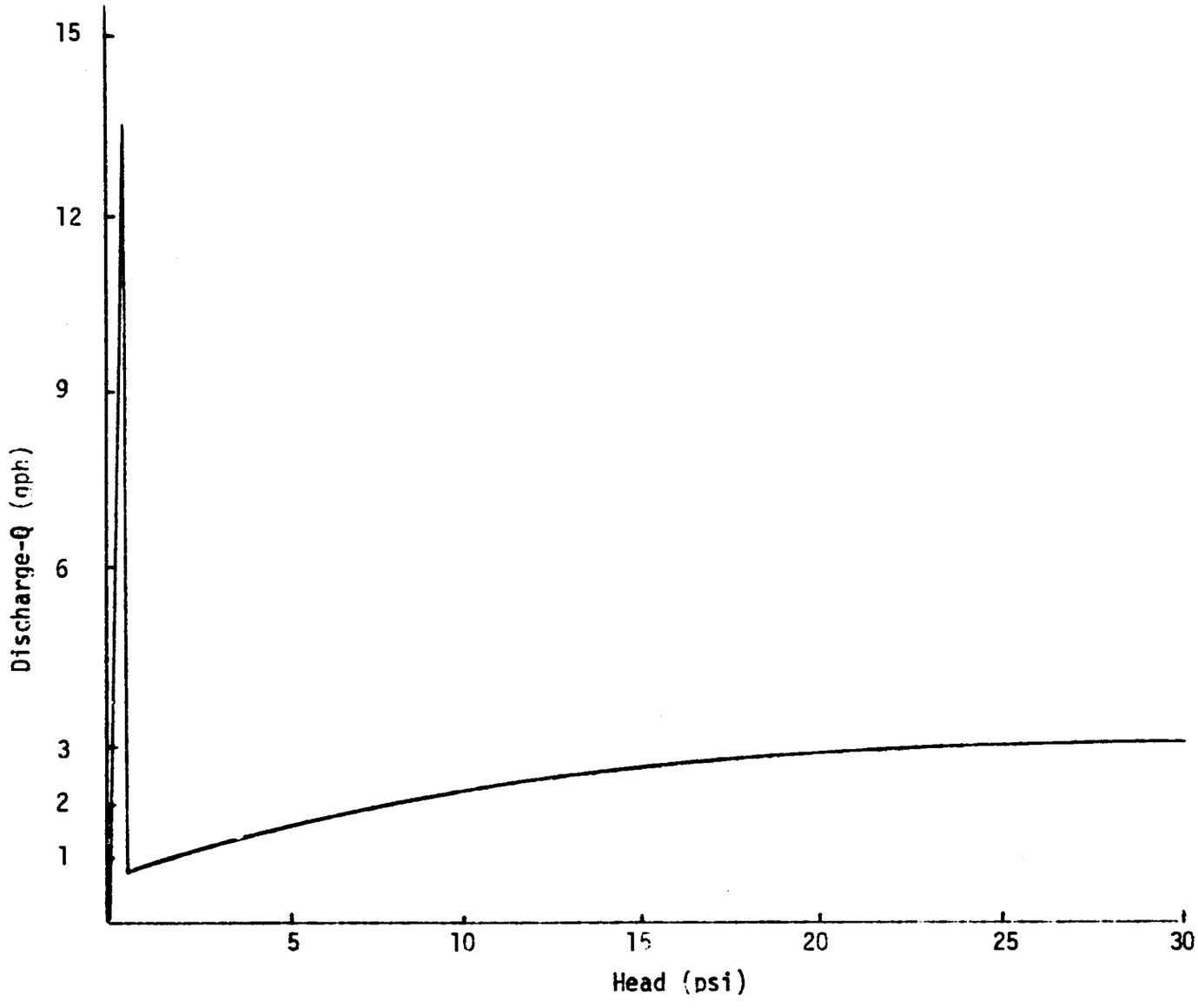


Figure 6. Head versus discharge for Sp3 emitter

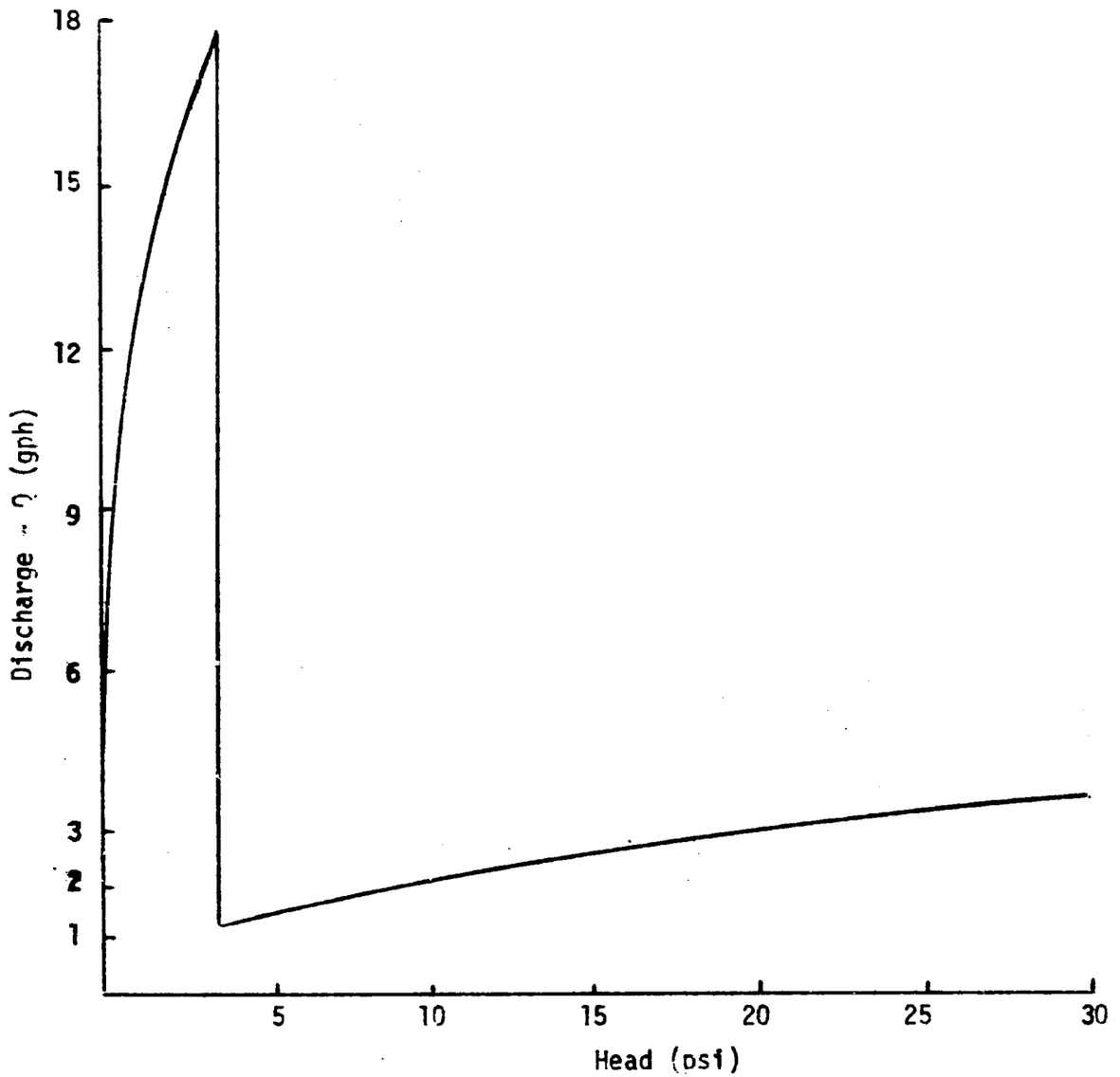


Figure 7. Head versus discharge for ORbt3 emitter

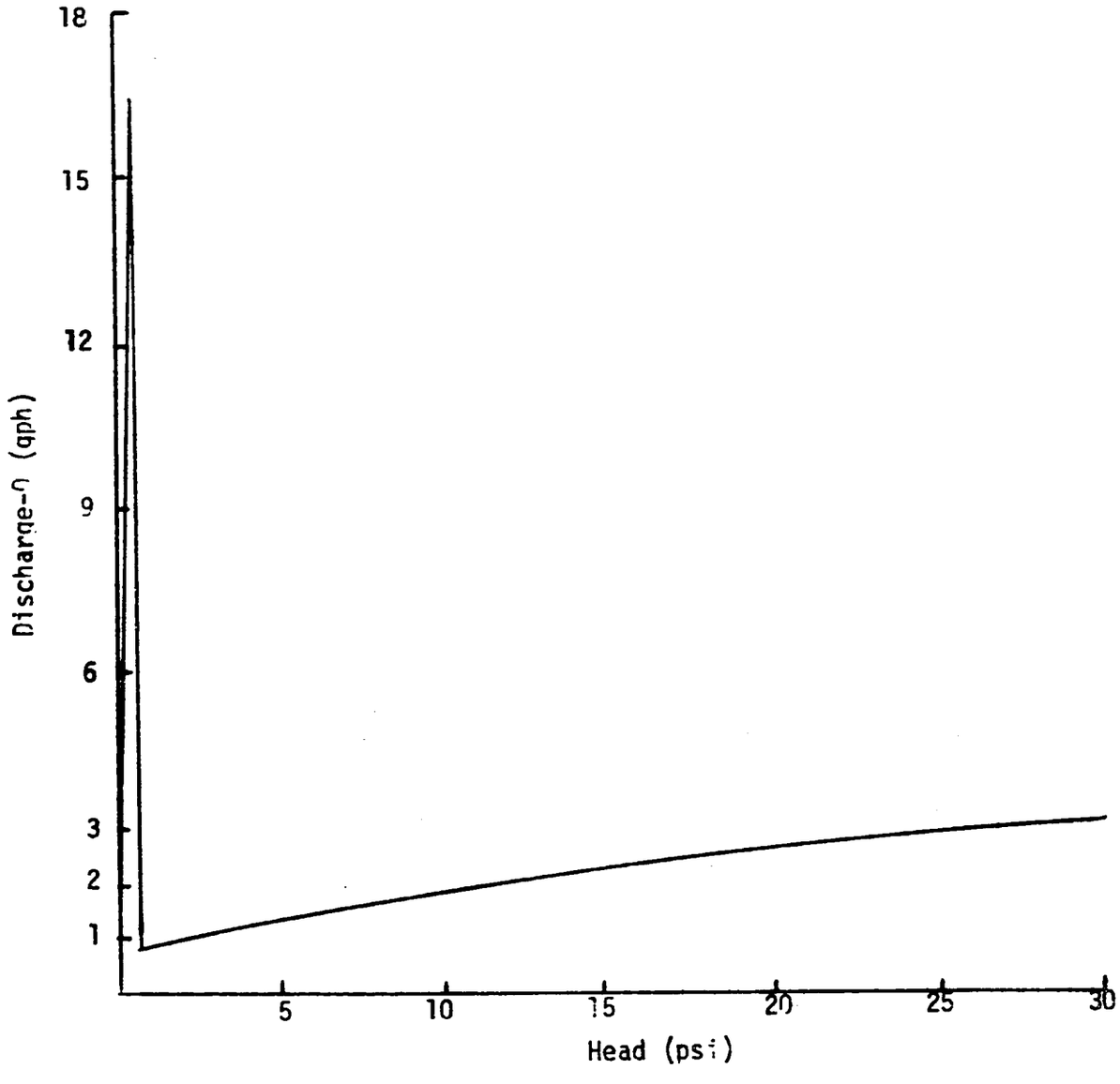


Figure 8. Head versus discharge for NRbt3 emitter

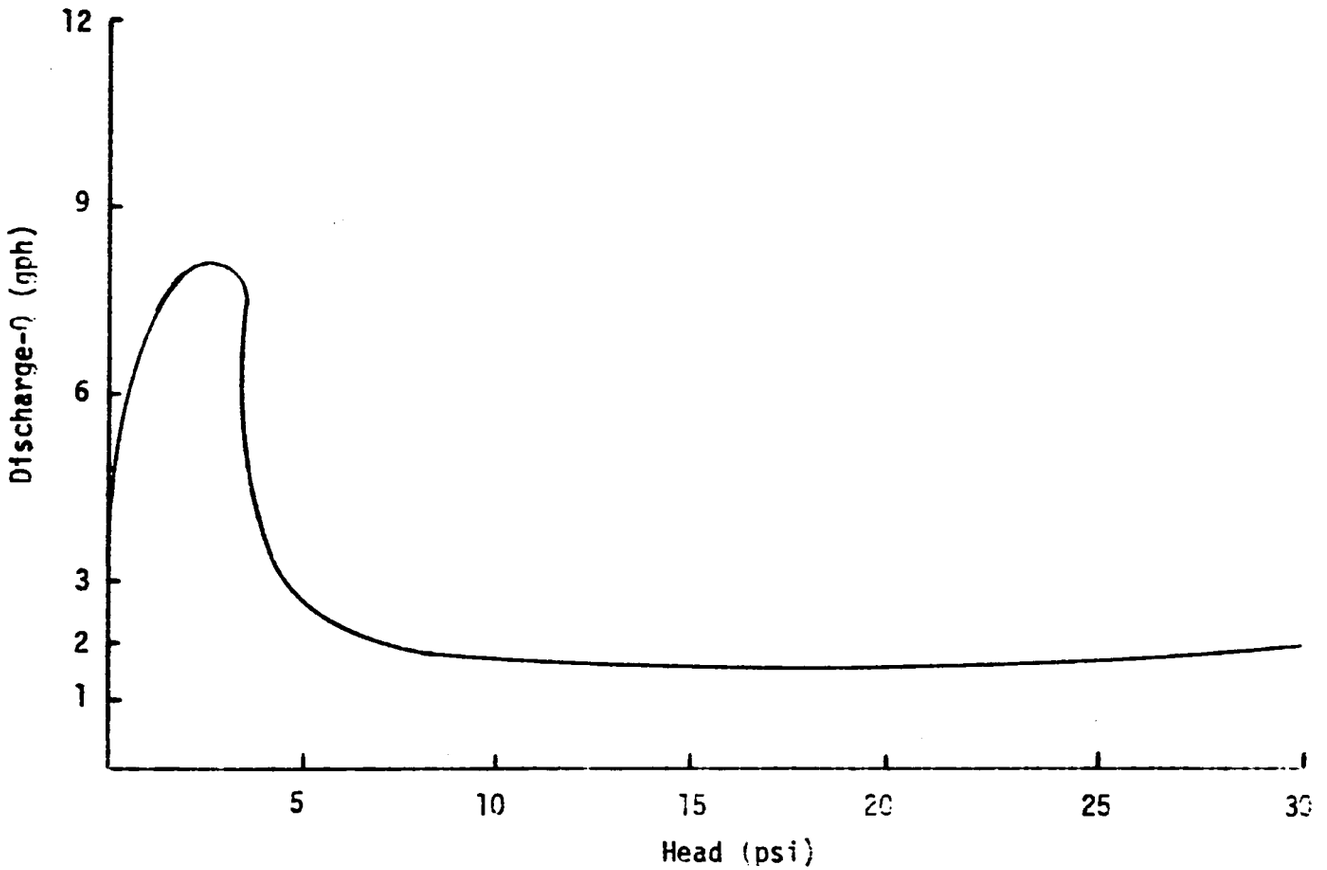


Figure 9. Head versus discharge for Unf2 emitter

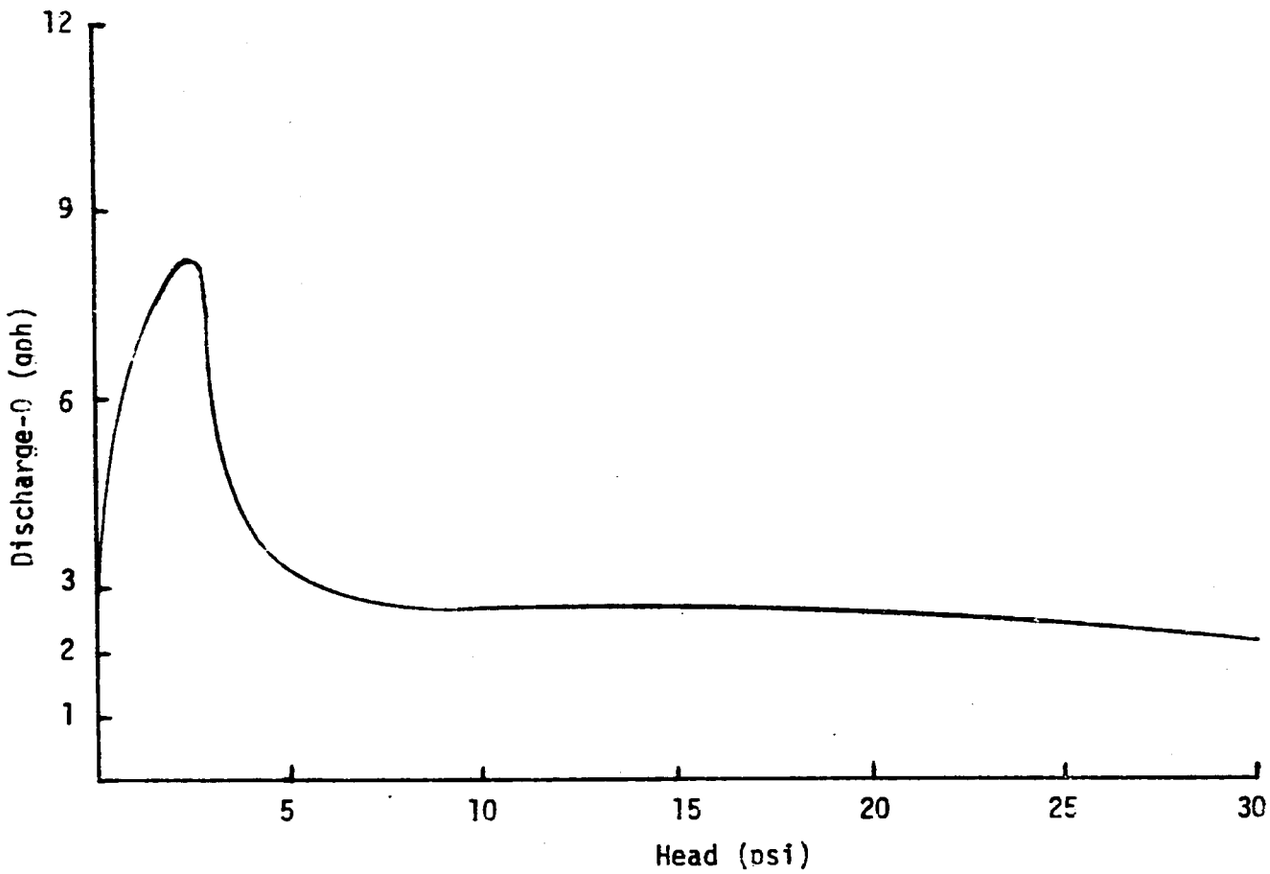


Figure 10. Head versus discharge for 9Unf3 emitter

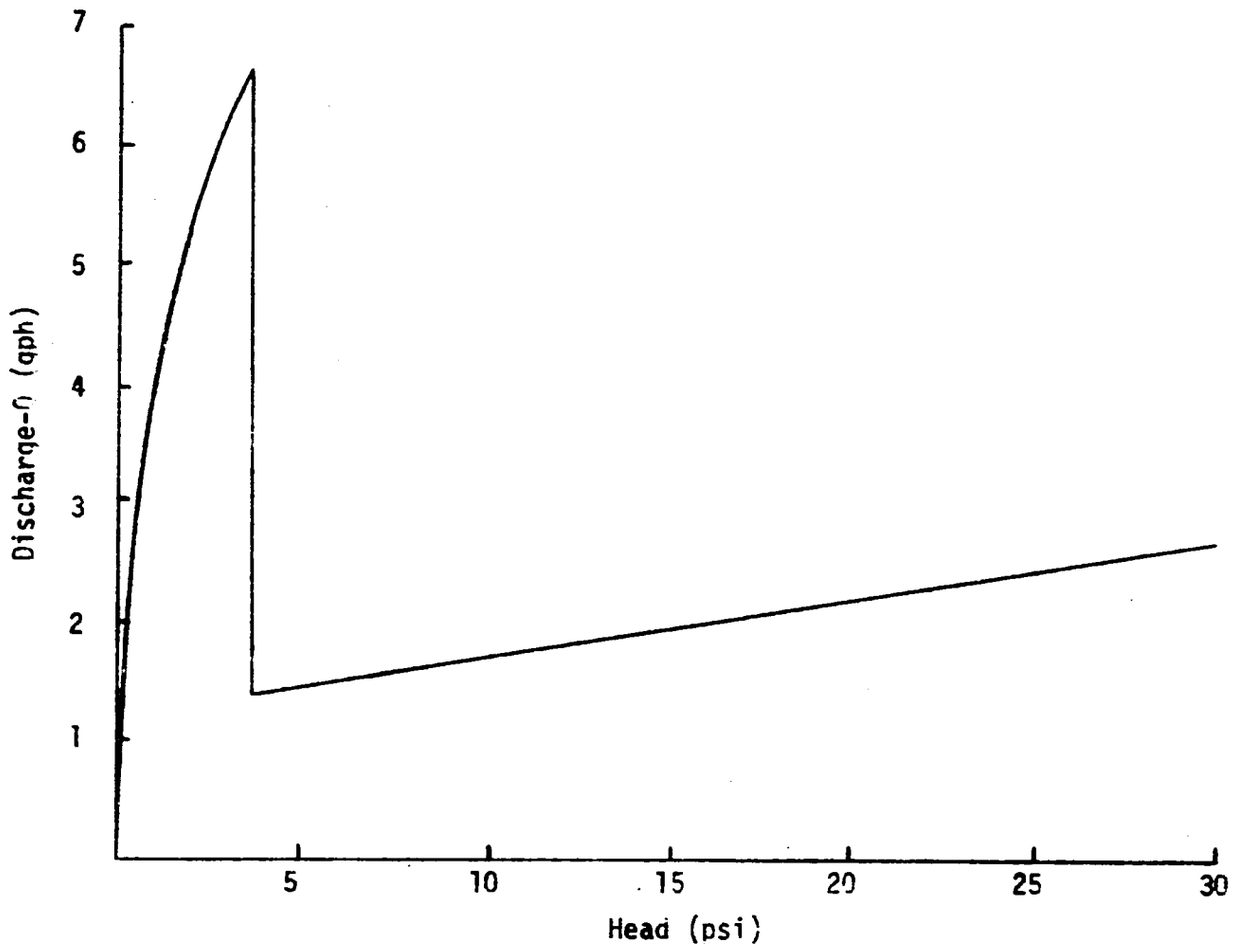


Figure 11. Head versus discharge for NUnf3 emitter

discharge of 2.70 gph at 30 psi.

Assuming that 30 psi is a normal operating head for a flushing emitter, it can be seen from the graphs, that the flushing flows vary between 4.5 and 6.5 times greater than the normal operating discharges. (14-18 gph as compared to 3 gph).

Figures 12, 13, and 14 are emitterline head-discharge curves, and show that the emitterline curves are somewhat similar in shape to the individual emitter curves, with each emitterline seating at a discharge greater than operating discharge.

In a typical emitterline, as the head increases, the emitters will begin to seat until about three-fourths of the emitters have seated. The remaining emitters will be flushing until that "critical" head and discharge is reached. "Critical" meaning that if the pump does not produce that head and discharge, the line will not completely seat. After reaching the "critical" head and discharge, the remaining emitters will simultaneously seat, and the inlet head will increase while the inlet flow rate decreases.

In analyzing the individual emitter and emitterline curves, it was determined that the head at which the individual emitter seats is the critical factor in determining the additional discharge necessary to seat an emitterline employing that particular emitter.

The Sp3 emitter proved to be the most efficient emitter, in that it required the least amount of additional discharge above operating discharge in order to seat an emitterline. The NRbt3 proved to be second best in this respect. The Sp3 emitter seats at an average head of .49 psi with a flushing discharge of 13.5 gph before seating. The NRbt3 seats at an average head of .62 psi, with a flushing discharge of 18 gph prior to

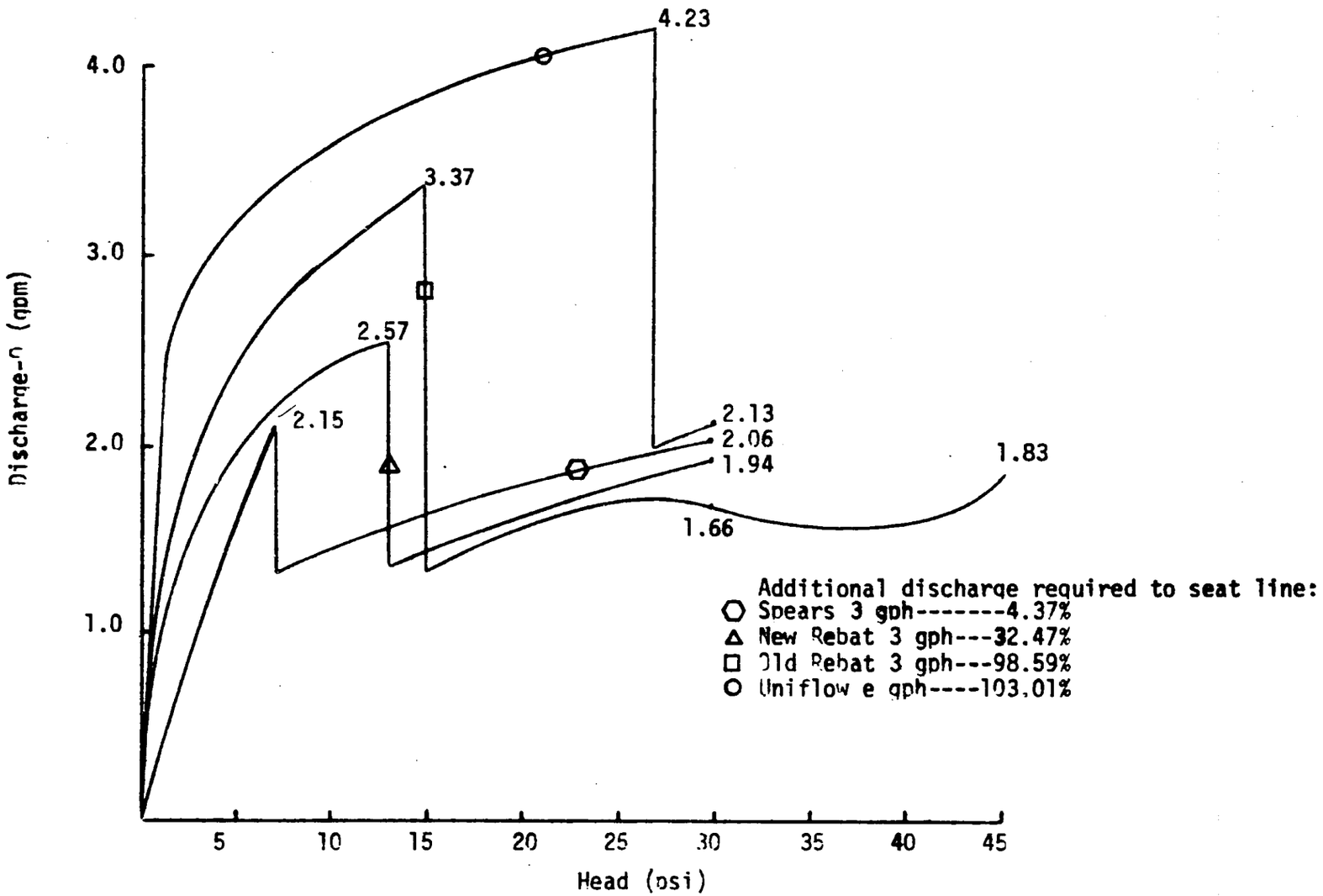


Figure 12. Head-discharge curves for 3 gph emitters on 200 foot emitterline

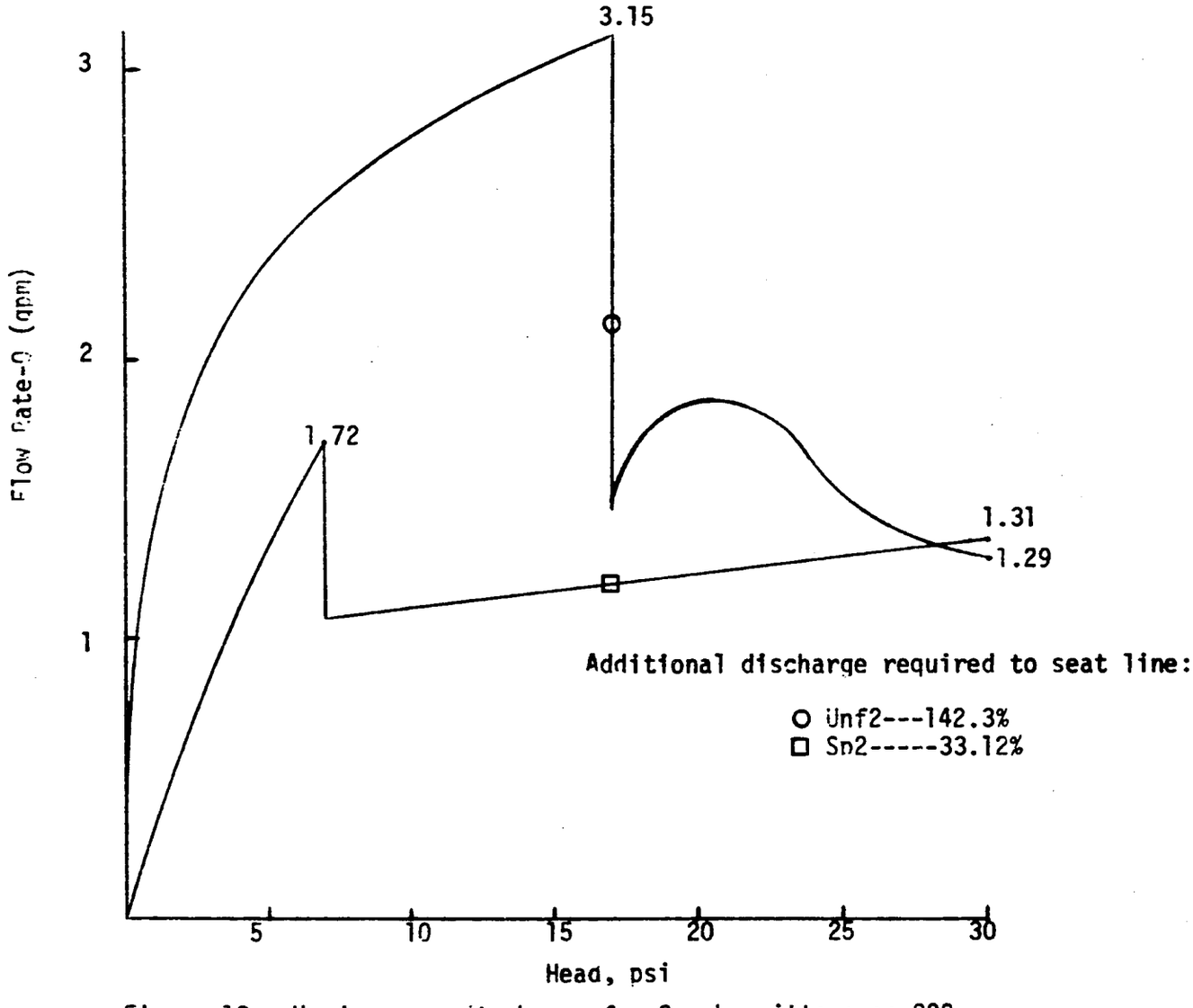


Figure 13. Head versus discharge for 2 gph emitters on 200 foot emitterlines

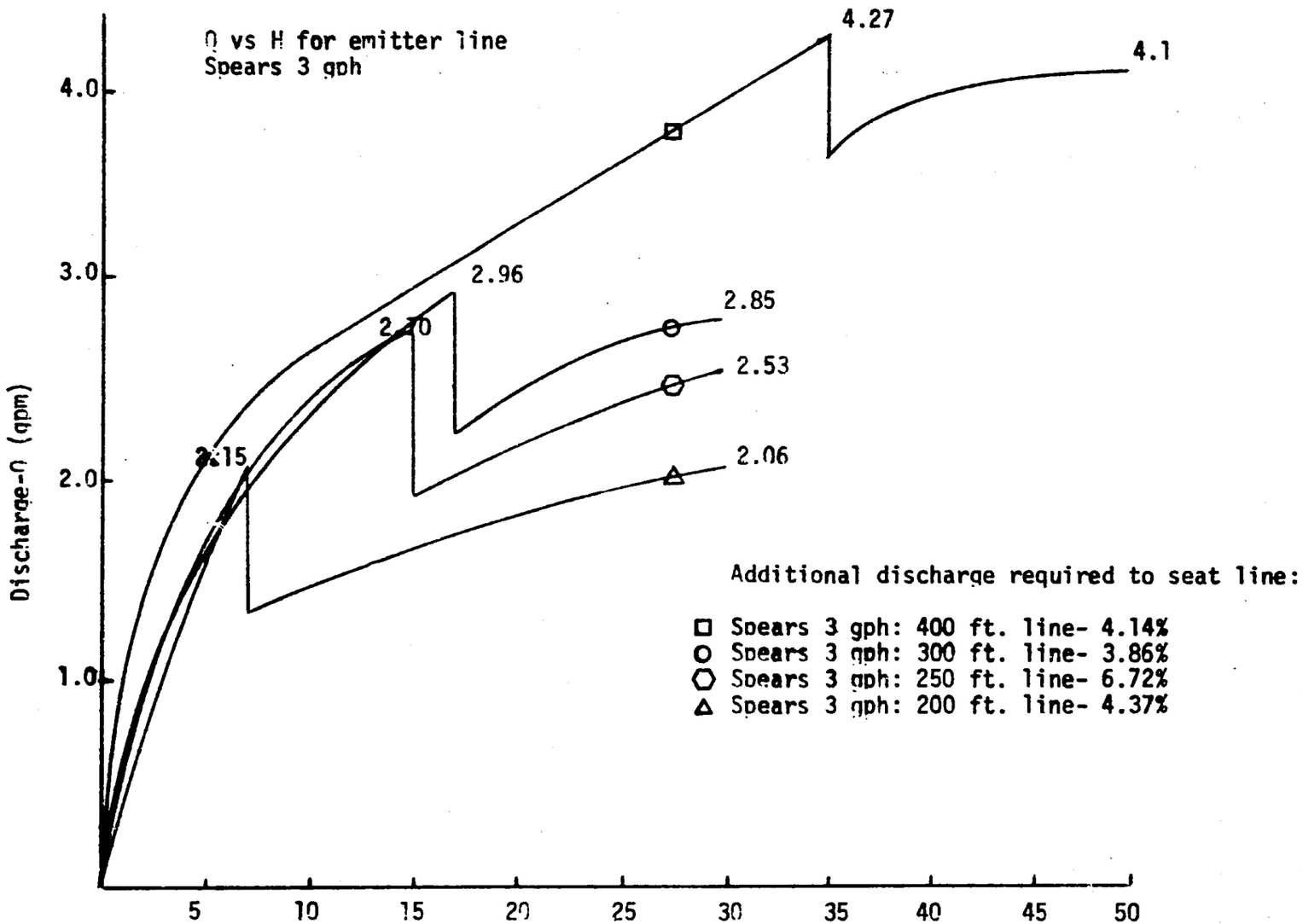


Figure 14. Head-discharge curves for Sp3 emitters on 200, 250, 300, and 400 foot emitterlines

seating. This is an increase of head of 26% over the Sp3 emitter. Figure 12 shows that this difference in seating head caused a 200 foot emitterline with NRbt3 emitters to require a 32.5% increase in discharge to seat the line, as compared to 4.4% increase with the Sp3 emitters.

The additional flow required to seat an emitterline is computed by the following equation:

$$\Delta Q = \frac{Qmax - Qop}{Qop} \times 100 \qquad [9]$$

where

ΔQ = the percent additional flow required, %

Qmax = the maximum flushing discharge, gph

Qop = the discharge at operating pressure, gph

The maximum flow in the line will always occur just before the line completely seats.

In all the tests conducted, the emitters were all spaced five feet apart, regardless of the emitterline length.

It might be argued that the increase in flushing discharge between the Sp3 and the NRbt3 emitters was also 26%, and this is the main factor causing the difference in the additional discharge necessary to seat an emitterline. However, in comparing the ORbt3 with the NRbt3, the flushing discharge prior to seating is the same for both emitters, while the seating head for the ORbt3 is 3.75 psi as opposed to .62 psi for the NRbt3. As shown in Figure 12, the additional discharge necessary to seat a 200 foot line with ORbt3 emitters is 98.6% over the operating discharge, as opposed to the 32.5% increase necessary for seating the 200 foot line of NRbt3 emitters. Since the flushing discharge prior to seating is the same for both emitters, it is concluded that the critical factor is the head at which the emitter seats.

Table 2 shows the seating head, maximum flushing discharge, and the additional flow required to seat a 200 foot emitterline for six different flushing emitters.

Rebat emitter

In comparing the two Rebat emitters, a great difference can be seen in the seating heads of the emitters and also in the additional flow required to seat the 200 foot emitterline.

The reason for this difference is the size of the hole in the center of the washers, shown in Figure 15. The ORbt3 has the smaller hole, thereby requiring a greater head to maintain the ball bearing in seated position against the washer, without fluctuation. The NRbt3 emitter was revised such that the hole is larger, thereby providing a larger area and requiring a smaller head to permanently seat the ball bearing.

Spears emitter

The Sp3 emitter proved to be the most effective in minimizing the additional flow necessary for seating an emitterline. Figure 14 shows that the percent increase in discharge to seat the emitterline was minimal not only on a 200 foot line, but also on a 250, 300, and 400 foot emitterline.

Uniflow emitter

The Uniflow emitters, Unf2 and OUnf3, proved to be erratic in behavior, and required a substantial increase in flow to seat an emitterline. The additional flow required ranged from 103% to 142% over the normal operating flow rate.

Figures 9 and 10 show the head-discharge curves for the Unf2 and OUnf3 emitters. As can be seen from the graphs, the emitters do not seat instantly, but gradually. Both emitters reach their maximum flushing

Table 2. The percent additional discharge above operating discharge required to seat a 200 foot emitterline

Emitter	Seating Head, psi	Flushing Discharge, gph	Additonal Flow Required,%
Sp3	.49	13.5	4.4
NRbt3	.64	18	32.5
ORbt3	3.75	18	98.6
OUnf3	3.75	7	103.
Sp2	.40	13	33.1
Unf2	3.75	8	142.3

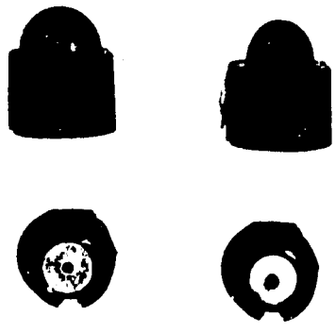


Figure 15. Two types of Rebat emitters showing revision in design by changing the size of the washer opening. NRbt3 shown on right.

flow and begin seating at 3.75 psi. After seating, the pressure was increased to 30 psi, at which head the OUnf3 should have an average discharge of 3 gph, while the Unf2 should have an average discharge of 2 gph. Neither emitter, however, reached the design discharge, with the Unf2 being 6% under, and the OUnf3 being 28.3% under the design discharge.

A new Uniflow emitter, NUnf3, was tested, but due to an insufficient quantity, tests could not be conducted with this emitter on an emitterline. However, the emitter was tested to obtain an emitter head-discharge curve, shown in Figure 11. This graph reveals that the seating head of the NUnf3 is also 3.75 psi, but the seating action is instantaneous, not gradual as with the other two Uniflow emitters. The NUnf3, at psi, reached an average discharge of 3 gph, which is the design discharge.

The Unf2 and OUnf3 emitters had both been used in the field, while the NUnf3 had not been used at all prior to testing. This fact, with the results observed in comparing these three Uniflow emitters show that perhaps with use, the walls of the piston chamber become dirty and do not allow the piston to slide freely, thus causing erratic behavior.

Hydraulics of Steady Flow

Roughness coefficient

In order to determine the head loss in an emitterline, the Hazen-Williams head loss equation was used. (See equation 5.) Employing the computer program listed in Appendix A, the roughness coefficient was computed for the various emitters using emitterlines of different lengths. The condensed results are listed in Table 3, while the results of all tests conducted are listed in Appendix F.

Table 3. Roughness coefficient, C, for the Hazen-Williams head loss equation:

$$HL = (V/1.3.8\ C\ R^{.63})^{1.85}L$$

Emitter	Roughness Coefficient C
Sp2	136.0
Sp3	136.0
Unf2	136.0
OUnf3	136.0
ORbt3	118.0
NRbt3	120.0
Dz2	98.0

The roughness coefficient determined is not actually the roughness coefficient for the hose, but for the complete system of hose, tees, and emitters. This suggests the reason for the C values of less than 150, which is the normal C value for PVC and polyethylene hose.

The roughness coefficient for the flushing emitters was found to be higher than that of the non-flushing Dz2 emitter. In the Hazen-Williams head loss equation, as the value of C increases, the head loss decreases. As shown in Figure 1, the PVC hose is glued into the tee holding the emitter, which actually increases the diameter of the system as the flow enters the tee. On the contrary, the Dz2 emitter is plugged into the polyethylene hose, thereby decreasing the diameter of the system as the flow enters the emitter. This is one apparent reason for the high C value for the flushing emitters and the low C value for the Dz2 emitter.

In view of the fact that the PVC hose is glued into the tees holding the flushing emitters, it is possible that if an excess amount of glue is used, some of the glue could drip inside the hose and cause an obstruction, thereby increasing the head loss.

Uniformity of Distribution in Field Analysis

There are several factors, in addition to variations in individual emitters, which can influence the uniformity of a trickle irrigation system, such as clogging due to sand and algae, aging of emitter parts, and variations in temperature. Insects may also damage emitter parts. According to Ben Olsen, orifice damage caused by ants was found in the Sp3 emitters on Superior Farms (Per. Com., 1972).

The two factors investigated in the field analysis were the clogging and aging effects. The studies were conducted on the Dz2 and Sp3

emitters. The Dz2 emitter is susceptible to clogging, while the Sp3 is susceptible to aging of parts.

The results of the tests are shown in Table 4. These tests were conducted after the emitters had been in operation approximately four months.

Clogging effects in Drip-Eze emitters

For a 167 foot emitterline consisting of 27 Dz2 emitters operating with an inlet pressure of 20 psi, the average emitter discharge was 1.87 gph with a coefficient of variation of 21.1%. After hand flushing the emitters, the average emitter discharge increased to 2.36 gph with a coefficient of variation of 8.5%. (See Table 4.)

These tests revealed that a significant amount of clogging had occurred. According to Ben Olsen of the Superior Farming Company, the water used to supply this trickle irrigation system is filtered with a nylon screen of 160-200 mesh (Per. Com., 1972). A 100 mesh screen has an opening of .00587 inches, while a 200 mesh screen has an opening of .00291 inches. The flow channel in the Dz2 emitter was measured and the opening varied between.036 and .038 inches. This shows that the smallest opening of the Dz2 emitter flow channel is at least six times larger than any particle that would have passed through the nylon mesh. This would tend to substantiate the argument that when the water is adequately filtered, the clogging of a laminar flow emitter is not due to larger particles completely blocking the flow, but small particles adhering to the emitter walls as a result of the laminar flow, with this gradual accumulation decreasing the channel area.

Aging effects in Spears emitters

Since Spears emitters have a rubber orifice, deformation of the

Table 4. Average discharge and coefficient of variation for emitters on a 167 foot emitterline under field conditions

Emitter	Operating Pressure and Condition	Average Discharge, gph	CV,%
Dz2	20 psi (not flushed)	1.87	21.1
Dz2	20 psi (flushed)	2.36	8.5
Sp3	30 psi (old orifices)	2.79	18.4
Sp3	30 psi (new orifices)	3.23	8.5
Sp3	40 psi (old orifices)	3.10	12.0
Sp3	45 psi (old orifices)	2.63	18.0

orifice could occur, causing a change in the discharge of the emitter. This was substantiated by the results shown in Table 4.

After operating four months, a 167 foot emitterline with 28 Sp3 emitters had an average emitter discharge of 2.79 gph with a coefficient of variation of 18.4%. After replacing the old orifices with new ones, the average emitter discharge increased to 3.23 gph with a coefficient of variation of 8.5%.

The emitterlines tested had been operating at pressures between 40 and 48 psi. In order to test an emitterline under field conditions at 30 psi, the inlet pressure had to be reduced. It is possible that the orifices had been deformed due to the high pressures, therefore it is not known how accurate the results are with the Sp3 emitter operating at 30 psi under field conditions.

The emitterlines utilizing Sp3 emitters with new orifices, operating with an inlet pressure of 30 psi had an average discharge 7.7% above the design discharge of 3.0 gph.

Emitterlines which had been operating at 40 and 45 psi were tested under field conditions without replacing the orifices, or reducing the inlet pressure. Table 5 shows that Sp3 emitters operating at 40 psi were emitting at an average discharge of 3.3% above design discharge, while the Sp3 emitters operating at 45 psi had an average discharge 9.0% below design discharge.

The results show that operating at high pressures will deform the orifices, thus decreasing the discharge.

The majority of the emitterlines tested had been operating at 40-48 psi, which is at least twice the pressure at which the Sp3 was

designed to emit 3 gph. According to Spears Manufacturing Company, the Sp3 emitter is rated 3 gph at 20 psi (Spears, 1972). This may partially account for the results found due to deformation of the orifice.

Uniformity of emitterlines

In conjunction with the tests used in this publication, Young (1972) conducted an analysis of variance between emitterlines along a lateral, and found no significant difference in emitterlines operating along the same lateral.

Young also conducted an analysis of variance between emitterlines on different laterals, and found a significant difference, which is the result of each lateral having a pressure regulator at the main line, which is set by the ranch foreman. Pressure differences could exist between laterals as a result of the manual control, and thereby cause a significant difference in the performance of an emitterline on one lateral when compared to an emitterline on a different lateral line.

Uniformity of Distribution in Laboratory Analysis

In determining the uniformity of distribution, a 200 foot emitterline was used to test all the types of emitters.

Twenty of the forty emitters on the line were sampled for each type of emitter. The flushing emitters were operating with an inlet head of 30 psi, while the non-flushing Dz2 emitter had an inlet head of 20 psi.

Analysis of variance results

The analysis of variance results are presented in Table 6. For each type of mitter, a theoretical analysis of variance was determined for comparison, by taking the inlet head and flow rate, and by use of the computer program listed in Appendix C, the theoretical discharge for each

Table 5. The difference between the average emitter discharge and the design discharge of emitters on a 167 foot emitterline

Emitter Description	Difference between average discharge and design discharge	
	in gph	% error
Dz2		
Field conditions Operating at 20 psi	-0.13	-6.5
Dz2		
Flushed in field Operating at 20 psi	+0.36	+18.0
Sp3		
Field condtions Operating at 30 psi	-0.21	-7.0
Sp3		
New orifices in field Operating at 30 psi	+0.23	+7.7
Sp3		
Field Conditions Operating at 40 psi	+0.10	+3.3
Sp3		
Field Conditions Operating at 45 psi	-0.27	-9.0

Table 6. Analysis of variance (ANOVA) for emitters on 200 foot emitter-line. The indicates the theoretical analysis of variance

Emitter type	S,%	Sigma gph^2	Average discharge, gph	Coefficient of variation, %
Sp3	-.99	.196	3.11	6.3
Sp3Th	-.0028	.0356	2.97	1.19
Sp2	+.198	.285	2.07	13.8
Sp2Th	-.10	.013	1.88	0.69
NRbt3	-1.19	.245	2.75	8.9
NRbt3Th	-.71	.0899	2.93	3.07
OUnf3	-.95	.402	2.04	19.7
OUnf3Th	+.49	.067	2.29	2.9
Unf2	-.92	1.02	2.14	47.35
Unf2Th	-.25	.0307	1.83	1.74
Dz2	-.32	.08	2.06	3.89
Dz2Th	-.32	.039	2.36	1.63

emitter on the emitterline was calculated. The theoretical discharge for the same 20 emitters sampled were inserted in the ANOVA computer program, listed in Appendix D, thus providing a theoretical analysis of variance.

In analyzing the actual results, the two most uniform emitters were the Dz2 (non-flushing), having an average emitter discharge of 1.06 gph with a coefficient of variation 3.89%, and the Sp3 (flushing), having an average emitter discharge of 3.11 gph with a coefficient of variation of 6.3%.

The theoretical analysis is actually an analysis of the variance due to the head loss along the emitterline, and does not consider any variation due to manufacturing tolerances of the different emitters.

In comparing the theoretical results with the actual results of the sampling, it can be seen that one cannot predict whether variations in the emitters will increase or decrease the average discharge of the emitterline. In the case of the Sp2, Sp3, and Unf2 emitters, the average discharge was increased between 4 and 14%.

The slope of the regression line, S, is an indication of the change in emitter discharge going from the inlet to the end of the emitterline. As seen in Table 6, the Sp2 variations caused S to be positive, indicating that the average emitter discharge increases going from the inlet to the end.

Due to the erratic nature of the individual emitter head-discharge curves for the OUnf3 emitter, the theoretical results indicated a positive regression slope, which is invalid and will not be considered as accurate.

Distribution results

In order to help analyze the effects of variations within emitters on an emitterline, distribution tests were conducted to determine whether or not the emitter distributions were normal.

The histograms for the emitters (See Appendix H) showed that all seven emitters can be considered normal, with the mean, median, and model all very close to each other, with the greatest deviation among the three values being 5% with the Sp2 emitter.

In the case of the OUnf3 and Unf2 emitters, the curves were normally distributed, but the average results were 41% and 14%, respectively, below the design discharge.

The results listed in Table 6 are the analysis of variance of an actual emitterline compared to an analysis of variance of a theoretical line consisting of identical emitters. Since the analysis of the theoretical line explains the variance due to the pressure drop along the line, the difference between the actual and the theoretical is the variance due to individual emitter differences.

The coefficient of variation of the distribution histograms is an indication of the variance in emitters due to manufacturing tolerances.

By comparison,a correlation was found between the coefficients of variation, CV, of the distribution results and the coefficients of variation caused by differences in emitters on a 200 foot emitterline.

The results (See Table 7) showed that if the CV from the distribution results was small, the CV due to emitter variations on a 200 foot line was also small, and as the CV from the distribution results increased, the CV due to emitter variations on a 200 foot line also increased.

Table 7. Comparison of coefficients of variation due to emitter differences, from normal distribution results and from uniformity of distribution results on a 200 foot emitterline.*

Emitter	Coefficient of variation from normal distribution results, (individual emitter differences), %	Coefficient of variation from uniformity of distribution results on 200 foot line, %
Dz2	7.5	2.26
Sp3	11.9	5.11
NRbt3	15.0	5.83
Sp2	13.29	42.30
Unf2	58.00	45.61

* The coefficient of variation from the uniformity of distribution results is the difference between the actual and theoretical results shown in Table 6.

CONCLUSIONS AND RECOMMENDATIONS

The objectives of this experiment were to examine the flushing flow characteristics of emitters, the hydraulic factors under steady flow conditions, and the uniformity of distribution of emitters along an emitterline.

Flushing Flow

In determining the head-discharge curve for the individual emitters, the flushing flow was 350-550% greater than the flow rate at operating pressure (30 psi).

With the emitters installed on an emitterline, the additional discharge required to seat the line varied between 4% and 142%, which is a substantial decrease from 350-550%. One of the factors in reducing the discharge required to seat an emitterline is the fact that as each emitter seats, the large volume of flushing discharge is suddenly forced through the hose, causing pressure surges along the emitterline. These pressure surges help to increase the head, thereby seating the next emitter on the line. This surge in pressure occurs each time an emitter seats.

A great amount of time was spent developing a computer program, based on non-transient analysis (See Appendix B), to analyze the effects of flushing emitters on an emitterline. This was done to determine a relationship between the additional discharge above operating discharge that is required to seat an individual emitter, and the additional flow required to seat an emitterline. Because of the transient flow effect

caused by the pressure surges, this analysis did not prove to be valid, and the relationship between the head and discharge required to seat an emitter, an emitterline, and a large system could not be determined.

In analyzing the laboratory results, no direct relationship could be determined between the seating head of an emitter and the additional discharge required to seat an emitterline.

The purpose in trying to establish some relationship was to be able to predict the behavior of an emitterline from the individual emitter head-discharge characteristics, and then project the results to a large system, but because of the pressure surges, this analysis must be conducted under transient flow conditions.

It was found, however, that in order to minimize the additional discharge necessary to seat a line, the seating head of an emitter should be 8-10 inches of water, or less.

Hydraulics of Emitterlines Under Steady Flow

The main factor considered under steady flow conditions was the roughness coefficient C, (See equation 5) for an emitterline.

The results of the tests showed, as might be expected, that for a system with emitters which are plugged into the line, the roughness coefficient will be low, as opposed to a system where the hose is inserted or glued into a tee.

If a trickle irrigation system is to be designed employing one-half inch hose, it is suggested that a C value of 95 for a plug-in type, and 125 for a system utilizing tees, could be used for determining the head loss in an emitterline.

Since the roughness coefficient is a function of the hose, tees, and

emitters, it must be assumed that these values are valid only for 5 foot spacings between emitters.

For design purposes, the roughness coefficient of an emitterline can be determined using the computer program listed in Appendix A. The program can also be adapted for varied lengths between emitters.

The input data required would be the inlet head, flow rate, head at the end of the emitterline, and the head-discharge characteristics of the emitter (See Figures 4-11). This would require a test emitterline with the same emitter spacing as in the field. Once the roughness coefficient is determined, emitterlines of any length can be designed, providing the spacing between emitters remains the same as the test emitterline.

Uniformity of Distribution

From the analysis of variance of the emitters in the field, it was concluded that the Sp3 and Dz2 emitters are equally efficient in regards to uniformity of distribution. This conclusion was based on the results showing that after flushing the Dz2 emitters, and replacing the orifices in the Sp3 emitters, the coefficient of variation was 8.5% for both types of emitters on a 167 foot emitterline.

In analyzing the resuls of the laboratory tests, it was concluded that the variance in emitter discharge along an emitterline is not affected as greatly by the pressure drop along the line, as by the variations in emitters due to manufacturing tolerances.

Practical Applications

Flushing emitters

In the case where a flushing emitter is desired, a simple test can be

conducted using a section of emitterline hose with a tee for the emitter and a manometer connnection, in order to determine the seating head. (See Figure 2.) As determined in the tests, a seating head of 8-10 inches of water, or less, is desirable in order to minimize the amount of additional discharge that would be required to seat the line. As seen from the test results of the Sp3 emitter, the additional discharge required above operating discharge can be minimized to 5%, which in turn would minimize puming costs.

If a flushing emitter is to be used, the additional flow required to seat the emitterline can be determined employing a flow meter and pressure regulator at the inlet point. By incrementally increasing the head until complete seating occurs, and recording the flow rate for each incremental change in head, the discharge required to seat the line can be determined. After determining the normal operating flow rate, Equation 9 can be used to calculate the percent additional discharge required to seat the line.

As mentioned in the introduction, estimates of the additional discharge necessary to seat an emitterline have been 20-30%. Many farming operations are using electric pumps, which must be selected according to the maximum design discharge and head required by the system. Since, with electric pumps, the pumping costs are fixed regarding the pump selected, if the additional discharge required above operating discharge was reduced from 20-30% to 5%, the pumping costs could be efficiently minimized.

Roughness coefficient

As discussed in the previous section, the roughness coefficient, C, for an emitterline can be determined using a test emitterline. Once C has been determined, emitterlines of any length can be designed, since

C is a function of the emitters, hose, and the tee connections.

If lines of the same length are to be used, a practical method would be to assemble several emitterlines of the length desired for field use, and by installing pressure gages at the inlet and end of the lines, the head loss can be determined. The average of several lines could be used as an insurance against variations in emitterlines.

Uniformity of distribution

Since the majority of the variance in emitter discharge along a line can be attributed to the manufacturing tolerances in emitters, a distribution test could be conducted on randomly selected emitters. This would give an indication as to whether the variance along an emitterline will be large or small.

If non-flushing emitters are to be used, an analysis of variance should be run on several lines to estab ish an average initial value for the variance in a line. As the system is run, clogging will occur, and tests should be conducted periodically to determine the variance in the line, which can be compared to the initial value. This will help determine when flushing of the system is required in order to maintain an efficient distribution.

Recommendations for Future Study

The results presented involved only eight different types of emitters, two of which were studied in the field.

In view of the fact that there are many varieties of emitters manufactured, an informative study could be conducted with other flushing emitters to determine the flushing flow characteristics, and how the emitters function on an emitterline, in order to find emitters which

require a minimal increase in discharge above operating discharge to seat a line. This increase in discharge could perhaps be minimized to under 5%.

The two types studied under field conditions proved to be very similar in regards to variations in emitters on the emitterline, after four months of operation. An informative study could be conducted to analyze these two emitters after a year or more of operation, to determine the clogging effects with the Dz2 emitter, and the effect of orifice deformation with the Sp3 emitter.

Since a steady state theoretical analysis failed to establish any relationship between the seating of emitters and the flow required to seat an emitterline, a transient flow analysis, which would consider the pressure surges in a system would perhaps help establish a relationship, with which one could predict how an emitterline would behave using a given emitter. This same concept could then be projected on a larger scale in predicting how a system would behave in seating all the emitterlines.

One other area to be considered would be the design of emitters. By determining the critical factors in the operation of flushing emitters, an emitter could be designed which would minimize the additional discharge required to seat an emitterline, while still providing the desired flushing characteristic.

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APPENDICES

Appendix A

Computer Program for Determining Roughness Coefficient

```
C     SOLUTION FOR HYDRAULIC COEFFICIENT
C     DESIGN HYDRAULICS FOR TRICKLE IRRIGATION SYSTEMS
C     ASSIGN T-CARD AS
C     ASSUMPTIONS ALL LENGTHS OF PIPE ARE INITIALLY EMPTY FOR ALL DIM
C     CD=DIMENSIONS
      DIMENSION Y(100),DARCL(50),TIME(50),QE(50),PRESSE(50),HL(50),QEMM(50)
      COMMON QF(50),HAE(50),HP
   70 FORMAT(5X,I5,4X,F10.0,5X,F10.0,5X,F7.2)
  100 FORMAT(1H0,2X,5F10.0,5X,F7.2)
      WRITE(6,101) N,D,DIDL,SL,DOL,HOL,C,HP,E
  101 FORMAT(1H0,I5,F5.2,5F10.0,5X,F7.2)
C     READ-DATA OF EMITTERS
C     NUMBER-TOTAL LENGTH OF PIPE (FEET)
C     DIDL=INITIAL DIAMETER OF EMITTERLINE PIPE (SQUARE FEET)
C     SLOLE=DISTANCE BETWEEN EMITTERS (FEET)
C     DOL=INITIAL Q (GALLONS PER MINUTE)
C     HOL=INITIAL HEAD (FEET OF WATER)
C     C= POWER-LOSS COEFFICIENT
C     HP= NUMBER OF DATA POINTS ON EMITTER HEAD-DISCHARGE CURVE
C     E=FINAL HEAD AT THE END OF THE EMITTER LINE
      READ(5,80) (HAEA(L), L=1,HP)
  800 FORMAT(10F5.0)
      READ(5,900) (QEA(L), L=1,HP)
  900 FORMAT(10F5.0)
      WRITE(6,109)
  109 FORMAT(1H0,'QEA(L)')
      WRITE(6,110) (QEA(L), L=1,HP)
  110 FORMAT(1H,20F6.2)
      WRITE(6,116)
  116 FORMAT(1H0,'HAE(L)')
      WRITE(6,115) (HAE(L), L=1,HP)
  115 FORMAT(1H,20F6.2)
C     QF(L) IS THE DISCHARGE CORRESPONDING WITH THE HEAD HAE(L) OF THE
C     DISCHARGE-HEAD CHARACTERISTICS OF THE EMITTERS
      R=DIDL/2.
      A=3.1416*DIDL*DIDL/4.
      DO 195 I=1,50
      E=0.
      EINC=0.
      TA=0.0
C     HOL=HEAD ENTERING EMITTERLINE (INITIAL H IN FEET OF WATER)
C     DOL=FLOW ENTERING EMITTERLINE (INITIAL Q IN GALLONS PER MINUTE GPM)
    6 QZ(I)=DOL
C     QZ(I)=THE FLOW IN THE EMITTERLINE AT THE ITH EMITTER (GPM)
      HOL=HOL
C     HOLD HYDRAULIC GRADELINE
      T(I)=SL*60.*60./DARCL(I)
      WRITE(6,500) HOL, DOL, C
  500 FORMAT(1H0,'HOL=',F9.3,17X,'DOL=',F9.4,3X,'C=',F6.3)
      DO 190 I=1,N
      V=.0027*QZ(I)/A
      VCR=.02/DIDL
      IF(V .LE. VCR) GO TO 13
      GO TO 15
   13 RN=DIDL*V*100000.
      F=64./RN
      HL(I)=(F*SL*V*V)/(DIDL*32.4)
      GO TO 16
   15 WRITE(6,1000) RN,F,V,DIDL,I,SL,DOL
C     HL(I)=HEAD LOSS AT THE ITH EMITTER IN FEET OF WATER
   16 HAE(I)=HOL-HL(I)
C     HAE(I)=THE HEAD AT THE ITH EMITTER IN FEET OF WATER
      PRESSE(I)=HOL-HL(I)/2.307
C     PRESSE(I)=PRESSURE PER SQUARE INCH
      HSL=HAE(I)
      AA=HAE(I)
      IF(AA .LT. .02) .0 TO 3
      CALL EMITTER(HAE(I),QEE(I))
      QF(I)=QEE(I)
      DARCL(I)=DARCL(I)-QEE(I)
C     QE(I)=THE DISCHARGE OF THE ITH EMITTER IN THE EMITTERLINE (GPM)
      T(I)=T(I)+(L*L*60.)/60./(DARCL(I))
C     T(I)=TIME FOR WATER TO REACH THE ITH EMITTER (SECONDS)
      IF(I .LE. N) GO TO 7
      TPO=DOL(I)*QE(I)
      IF(TT) 2,100,100
    2 E=0.
      GO TO 4
    7 DO=HAE(N)-E
      IF(ABS(DO) .LE. 2.0) GO TO 30
      IF(DO) 3,30,0
    3 IF(DO .GE. 1) GO TO 0
      E=0.
      TAA=TAA+1
      GO TO 0
    4 IF(DO .GE. 1) GO TO 5
      E=0.
      GO TO 105
    5 EINC=.5*EINC
      E=E+EINC
      GO TO 5
    6 EINC=.5*EINC
      E=E-EINC
      IF(EINC .LE. .01) GO TO 30
      GO TO 0
   30 WRITE(6,109)
  100 FORMAT(1H,'I',4X,'DARCL(I)',4X,'HAE(I)',4X,'PRESSE(I)',4X,'QE(I)',
     1X,'QF-QE(I)',7X,'HL(I)',4X,'T(I)')
      DO 40 I=1,N
      QF(I)=QF(I)/60.
   40 WRITE(6,70) I,DARCL(I),HAE(I),PRESSE(I),QE(I),QF(I),HL(I),T(I)
  200 FORMAT(1H,I5,F10.0,4X,F8.2,3X,F8.2,3X,F8.2,4X,F8.2,3X,F8.2,3X,F8.2)
      GO TO 22
  100 CONTINUE
  105 CONTINUE
   90 STOP
      END
      SUBROUTINE EMITTER(HAE,QE)
      COMMON QF(50),HAE(50),HP
      DO 8 L=1,HP
      IF (HAE(L) .LE. HAE .AND. HAE .GT. HAE(L+1)) GO TO 9
      GO TO 8
    9 IF (HAE(L+1)-HAE(L)) 5,5,6
    5 QE=QF(L+1)
      GO TO 0
    6 QE=QF(L)+(HAE-HAE(L))/(HAE(L+1)-HAE(L))*(QF(L+1)-QF(L))
      GO TO 0
    8 CONTINUE
    0 RETURN
      END
```

Appendix B

Computer Program for Theoretical Design Solution

```
C     DESIGN HYDRAULICS FOR TRICKLE IRRIGATION SYSTEMS
C     WRITTEN BY [illegible]
C     GRANT HANSEN
C     ASSUMPTION: ALL LENGTHS OF PIPE ARE INITIALLY EMPTY FOR ALL Q.N
C     COMMENTS:
      DIMENSION [illegible]
      COMMON [illegible]
   20 [illegible]
  100 [illegible]
C     NOMENCLATURE OF VARIABLES
C     DIAMETER OF PIPE (INCHES)
C     DIMENSIONAL DIMENSION OF TRIBUTARY PIPE (SQUARE FEET)
C     [illegible] EMITTERS (FEET)
C     [illegible] COEFFICIENT
C     [illegible] OF DATA POINTS ON EMITTER HEAD-DISCHARGE CURVE
      [illegible]
  000 [illegible]
      [illegible]
  000 [illegible]
      WRITE(6,100)
  100 FORMAT(3X,'HEAD(L)')
      WRITE(6,110) (H(L),L=1,NP)
  110 FORMAT(3X,20F6.1)
      WRITE(6,115)
  115 FORMAT(3X,'MAE(L)')
      WRITE(6,119) (MAE(L),L=1,NP)
  119 FORMAT(3X,20F6.2)
C     Q(L) IS THE DISCHARGE CORRESPONDING WITH THE HEAD HAE(L) OF THE
C     DISCHARGE-HEAD CHARACTERISTICS OF THE EMITTERS
      A=0.
      A0=3.14159*DIDL*DIDL/4.
      NINC=1
      DO 200 J=1,20
      HDL=HDL+.2*NINC
C     HDL=HEAD ENTERING EMITTERLINE (INITIAL H IN FEET OF WATER)
      DO 195 K=1,20
      IN2=0
      QINC=1
    2 QDL=QDL+1*QINC
C     QDL=FLOW ENTERING EMITTERLINE (INITIAL Q IN GALLONS PER MINUTE GPM)
    4 QADL(I)=QDL
C     QADL(I)=TOTAL FLOW IN THE EMITTERLINE AT THE ITH EMITTER (GPM)
      HGL=HDL
C     HGL= HYDRAULIC GRADELINE
      T(I)=SL/A*60.7GA/QADL(I)
      WRITE(4,505) HGL, QDL
  500 FORMAT(1X,'HGL=',F9.3,3X,'QDL=',F9.0)
      DO 199 I=1,N
      VM=.0072*QADL(I)/A
      HL(I)=(4/(1.318*C*R**.63))**2.85*SL
C     HL(I)=HEAD LOSS AT THE ITH EMITTER IN FEET OF WATER
      HAE(I)=HGL-HL(I)
C     HAE(I)=THE HEAD AT THE ITH EMITTER IN FEET OF WATER
      PRESS(I)=(HGL-HL(I))/2.307
C     PRESS=PSI (POUNDS PER SQUARE INCH)
      HGL=HAE(I)
      A=HAE(I)
      IF(A .LE. .02) GO TO 900
      CALL EMITTER(HAE(I),QE(I))
      QE(I)=QE(I)*60.
C     QE(I) IS THE EMITTER DISCHARGE IN GALLONS PER HOUR (GPH)
      QADL(I)=QADL(I)-QE(I)
C     QF(I)=F DISCHARGE OF THE ITH EMITTER IN THE EMITTERLINE (GPM)
      T(I)=T(I)+(L*A*60.7GA/(QADL(I)))
C     T=TIME TO WATER THE ITH EMITTER (SECONDS)
      IF(HGL .LT. 5.) MINC=1.
      [illegible]
      IF(HGL .GT. 15. .AND. HGL .LE. 50.) MINC=20.
      IF(HGL .GT. 50. .AND. HGL .LE. 125.) MINC=50.
      IF(HGL .GT. 125.) GO TO 20
    9 TTOT=TTOT+T(I)
      IF(TT) 3,3,5
    3 IF(I .EQ. N) GO TO 6
      IF(QADL(I) .GE. .00) QINC=0.
      IF(INZ .GT. 0.0) GO TO 10
      GO TO 9
    5 IF(I .EQ. N) GO TO 7
      GO TO 199
    6 QI=(QADL(I)-QE(I))
      WRITE(6,15) I,
   15 FORMAT(3X,'I=',F8.0)
      CC=QSS(I)/QE(I)
      IF(CC .LE. .03) GO TO 30
      QDL2=QDL
      QDL=QDL2+QSS(I)/2.
      QDL=QDL
      GO TO 4
   10 QDL2=QDL2-QS/2.
      QDL=QDL2
      GO TO 4
    7 T2=(QASL(I)-QL(I))
      IN2=IN2+1
      QDL2=QDL
      QS=QT/QE(I)
      QDL2=QDL2-QS/2.
      QDL=QDL2
      WRITE(6,111)
  111 FORMAT(1X,'I',3X,'T2',7X,'QDL2',3X,'QDL3',5X,'QINC',5X,'QS')
      WRITE(6,121) I,T2,QDL2,QDL3,QINC,QS
  121 FORMAT(3X,F7.0,3X,F7.0,3X,F7.0,3X,F7.0,3X,F5.0,3X,F8.0)
      IF(QS .LE. .03) GO TO 30
      GO TO 4
   30 WRITE(6,600)
  600 FORMAT(1X,'I',3X,'DISCL(I)',3X,'QE(I)',3X,'PRESS(I)',3X,'QE(I)',
     2X,'QE(I)',7X,'HL(I)',3X,'T(I)')
      DO 40 L=1,N
      QE(L)=QE(L)/60.
   40 WRITE(6,700) L,DISCL(L),QE(L),PRESS(L),QE(L),QE(L),HL(L),T(L)
  700 FORMAT(1X,3X,F9.0,3X,F9.0,3X,F9.0,3X,F9.0,3X,F9.0,3X,F9.0,3X,F9.0)
      GO TO 200
  190 CONTINUE
  195 CONTINUE
  200 CONTINUE
      GO TO 20
   99 STOP
      END
      SUBROUTINE EMITTER(H,QE)
      COMMON DIDL,DIDL,DIDL,NP
      DIMENSION
      IF (H(K) .GE. QE(K) .AND. H(K) .LT. H(K+1)) GO TO 3
      GO TO 8
    3 IF (H(K+1)*H(K)) 3,9,6
    9 QE=Q(K)
      GO TO 8
    6 QE=Q(K)+(H-H(K))/(H(K+1)-H(K))*(Q(K+1)-Q(K))
      QE(K)=QE(K)
      GO TO 8
    8 CONTINUE
    9 RETURN
      END
```

Appendix C

Computer Program for Emitterline Solution from Actual Data

```
C     THEORETICAL EMITTER DISCHARGE (FOR ANDYO)
C     DESIGN PROGRAM FOR TRICKLE IRRIGATION SYSTEMS
C     WRITTEN TWISS BE
C     GARY HANSEN
C     ASSUMPTIONS ALL LENGTHS OF PIPE ARE INITIALLY EMPTY FOR ALL D,H
C     CONDITIONS
      DIMENSION PE(10) ,DEL(15),T(15),DE(15),PRESS(15),HL(15),DEMD(15)
      CONTROL LT(15),HAE(15),AP
   2A READ(5,190,END=99) NODE,DIAM,AL,HOL,E,NP
  100 FORMAT(I5,F5.2,F5.2,I5,4,I5)
      WRITE(6,101) NODE,DIAM,AL,HOL,E,NP
  101 FORMAT(I5,I5,F5.2,F5.2,I5,4,I5)
C     NUMBERS OF EMITTERS
C     DIAMETER OF PIPE (INCHES)
C     DISTANCE BETWEEN EMITTERS (FEET)
C     ALTITUDE OF EMITTER (FEET)
C     EMITTER COEFFICIENT
C     NUMBER OF DATA POINTS ON EMITTER HEAD-DISCHARGE CURVE
      READ(5,200) (DEA(L), L=1,NP)
  200 FORMAT(10F5.0)
      READ(5,200) (HAE(L), L=1,NP)
  200 FORMAT(10F5.0)
      WRITE(6,100)
  100 FORMAT(1X,'DEA(L)')
      WRITE(6,110) (DEA(L), L=1,NP)
  110 FORMAT(1X,20F6.3)
      WRITE(6,114)
  114 FORMAT(1X,'HAE(L)')
      WRITE(6,115) (HAE(L), L=1,NP)
  115 FORMAT(1X,20F6.2)
C     DEA(L) IS THE DISCHARGE CORRESPONDING WITH THE HEAD HAE(L) OF THE
C     DISCHARGE HEAD CHARACTERISTICS OF THE EMITTER
      A=DIAM/2.
      A=3.141*A*A/144.
C     HOL=(E) ENTERING EMITTERLINE (INITIAL H IN FEET OF WATER)
C     QOL=(J) ENTERING EMITTERLINE (INITIAL Q IN GALLONS PER MINUTE GPM)
    0 QOL(1)=DIM
C     DIAL(I)=THE FLOW IN THE EMITTERLINE AT THE ITH EMITTER (GPM)
      HOL=HOL
C     HOL= HYDRAULIC GRADELINE
      T(1)=HL*HOL*60.7A6/QOL(1)
      WRITE(6,500) HOL, QOL
  500 FORMAT(1X,'HOL=',F9.3,3X,'QOL=',F9.4)
   39 WRITE(6,600)
  600 FORMAT(4X,'I',6X,'QOL(I)',6X,'HE(I)',6X,'PRESS(I)',3X,'DE(I)',
     2X,'EM(I)',7X,'HL(I)',6X,'T(I)')
      DO 190 I=1,N
      V=.0022*Q*QOL(I)/A
      VCR=.02/DIAM
      IF(V .LE. VCR) GO TO 13
      GO TO 14
   13 RN=DIAM*V*100000.
      HL(I)=(F*HL*V)/(DIAM*64.4)
      GO TO 16
   15 HL(I)=(V/(1.310*LOG(RN)))**1.85*HL
C     HL(I)=HEAD LOSS AT THE ITH EMITTER IN FEET OF WATER
   16 HE(I)=HOL-HL(I)
C     HE(I)=THE HEAD AT THE ITH EMITTER IN FEET OF WATER
      PRESS(I)=(HE-HL(I))/2.307
C     PRESS=PSI (POUND) PER SQUARE INCH
      HOL=HE(I)
      HE=HE(I)
      IF(HE .LE. .00) GO TO 90
      CALL EMITT(I,HE(I),DE(I))
      DE(I)=DE(I)*60.
C     DE(I) IS THE ITEM DISCHARGE IN GALLONS PER HOUR (GPH)
      DEL(I)=DE(I) *DEL(I)
C     DE(I)=THE DISCHARGE OF THE ITH EMITTER IN THE EMITTERLINE (GPM)
      T(I)=T(I)*DL*60.7A6/(DEL(I)*Q)
C     T(I)=TIME FOR ENTER TO REACH THE ITH EMITTER (SECONDS)
   9  TT=DEL(I)+DE(I)
      IF(TT) 20,20,250
  250 WRITE(6,700) I,DEL(I),HE(I),PRESS(I),DE(I),DE(I),HL(I),T(I)
  700 FORMAT(5X,I3,F9.0,F9.3,F9.3,F9.3,F9.0,F9.0,F9.3,F9.0)
  190 CONTINUE
      GO TO 20
   99 STOP
      END
      SUBROUTINE EMITT(I,HE,DE)
      COMMON DEA(15),HAE(15),NP
      NEW=0
      DO 8 L=1,NP
      IF (HAE(L) .LE. HE .AND. HE .LT. HAE(L+1)) GO TO 5
      GO TO 6
    3 IF (DEA(L+1)-DEA(L)) 5,5,8
    5 DE=DEA(L+1)
      GO TO 9
    6 DE=DEA(L)+(HE-HAE(L))/(HAE(L+1)-HAE(L))*
     2(DEA(L+1)-DEA(L))
      GO TO 9
    8 WRITE(6,7)
    9 RETURN
      END
```

Appendix D

Computer Program for ANOVA

```
C     ANOVA FOR UNIFORMITY OF DISTRIBUTION IN AN EMITTERLINE
      DIMENSION X(20), Y(20)
 20   READ(5,100,END=99) N
 100  FORMAT(I5)
      READ(5,101) (X(I), I=1,N)
 101  FORMAT(16F5.3)
 21   READ(5,101,END=99) (Y(I), I=1,N)
      WRITE(6,102) (X(I), I=1,N)
 102  FORMAT(1H0,19F6.2)
      WRITE(6,105) (Y(I), I=1,N)
 105  FORMAT(1X,19F6.2)
      SUMX=0.0
      SUMY=0.0
      SUMX2=0.0
      SUMY2=0.0
      SUMXY=0.0
      DO 8 I=1,N
      SUMX=SUMX+X(I)
      SUMY=SUMY+Y(I)
      SUMX2=SUMX2+X(I)*X(I)
      SUMY2=SUMY2+Y(I)*Y(I)
      SUMXY=SUMXY+X(I)*Y(I)
 8    CONTINUE
      WRITE(6,103) SUMX,SUMY,SUMX2,SUMXY
 103  FORMAT(4F10.5)
      B=(SUMY*SUMX2-SUMX*SUMXY)/(N*SUMX2-SUMX*SUMX)
      RH=(N*SUMXY-SUMX*SUMY)/(N*SUMX2-SUMX*SUMX)
      SIG=SQRT(N*SUMY2-SUMY*SUMY)/N
      YB=SUMY/N
      COVA=SIG/YB
      WRITE(6,104) B,RH,SIG,YB,COVA
 104  FORMAT(1H0,'B=',F10.5,3X,'RH=',F10.5,3X,'SIG=',F10.5,3X,'YB=',
     2F10.5,3X,'COVA=',F10.5)
      GO TO 21
 99   STOP
      END
```

Appendix E

Emitter Head-discharge Data

Table 8. Emitter-discharge data for Sp3 emitter

Head, psi	Emitter discharge, gph							
	Emitter number							
	1.	2.	3.	4.	5.	6.	7.	8.
.144	.11	6.60	6.42	6.42	6.66	7.08	6.00	5.7
.289	10.50	10.50	10.38	10.50	9.54	10.74	9.54	9.54
.361	12.42	12.18	11.70	11.76	10.98	12.42	10.80	10.98
.433	13.86	12.96	12.96	12.90	12.18	14.10	12.24	12.42
.505	-----	14.88	14.34	13.68	13.62	-----	12.90	13.20
2.5	1.10	1.15	11.16	1.19	1.14	1.20	1.08	1.07
5.	1.57	1.59	1.58	1.62	1.56	1.62	1.50	1.47
10.	2.15	2.26	2.13	2.26	2.16	2.33]	2.06	2.02
15.	2.54	2.64	2.46	2.64	2.52	2.76	2.34	2.38
20.	2.78	2.94	2.64	2.88	2.76	3.06	2.54	2.64
25.	3.00	3.12	2.82	3.00	3.00	3.13	2.76	2.76
30.	3.11	3.24	2.94	3.18	3.00	3.24	2.92	2.88

Table 9. Emitter discharge data for Sp2 emitter

Head, psi	Emitter discharge, gph							
	Emitter number							
	1.	2.	3.	4.	5.	6.	7.	8.
.072	6.72	5.4	5.21	6.24	6.18	4.5	2.7	5.34
.144	8.98	8.86	8.38	8.76	8.46	6.9	6.54	7.14
.217	10.08	9.78	9.6	10.98	9.3	8.64	8.7	9.54
.289	11.52	11.28	11.1	12.18	11.52	10.68	10.38	11.40
.361	13.38	12.84	12.36	-----	13.5	12.48	12.3	11.76
.433	-----	-----	14.52	-----	-----	-----	14.22	14.22
.867	.396	.348	.372	.336	.336	.462	.384	.306
1.30	.48	.432	.372	.336	.414	.558	.474	.372
2.5	.6	.498	.648	.522	.54	.636	.66	.468
5.	.876	.714	.9	.75	.75	.99	.91	.672
10.	1.28	1.02	1.19	1.09	1.46	1.49	1.32	1.0
15.	1.59	1.14	1.42	1.27	1.79	1.79	1.56	1.16
20.	1.84	1.2	1.59	1.45	2.07	2.00	1.80	1.28
25.	2.00	1.26	1.66	1.54	2.24	2.21	1.95	1.35
30.	2.13	1.33	1.72	1.61	2.16	2.33	2.07	1.36

Table 10. Emitter-discharge data for ORbt3 emitter

Head, psi	Emitter discharge, gph							
	Emitter number							
	1.	2.	3.	4.	5.	6.	7.	8.
2.5	18.12	15.24	14.76	15.72	16.2	17.16	14.76	13.86
3.13	20.52	16.68	15.69	1.35	16.2	-----	-----	18.6
3.75	-----	17.64	17.16	-----	-----	20.04	17.16	18.0
4.38	-----	18.60	-----	-----	-----	-----	-----	18.6
5.	1.22	1.27	19.08	1.56	-----	-----	19.08	19.1
10.	1.70	1.25	1.91	2.30	2.30	1.99	1.91	1.98
20.	2.47	2.39	2.71	3.26	3.29	2.78	2.78	2.81
30.	3.02	2.94	3.34	4.13	4.13	3.34	3.34	3.46

Table 11. Emitter-discharge data for NRbt3 emitter

Head, psi	Emitter discharge, gph							
	Emitter number							
	1.	2.	3.	4.	5.	6.	7.	8.
.072	1.49	2.86	-----	-----	-----	-----	-----	-----
.144	-----	-----	6.78	6.9	6.9	6.42	6.66	6.66
.21	7.5	8.86	8.1	9.18	9.3	8.52	9.06	8.58
.43	12.72	13.02	13.02	13.98	13.68	12.84	13.98	13.14
.58	14.76	15.0	15.24	-----	16.68	15.0	15.72	15.24
.72	-----	17.64	17.64	-----	-----	-----	-----	-----
1.25	.864	.828	.786	.798	.846	.804	.793	.714
5.	1.35	1.27	1.20	1.19	1.27	1.64	1.19	1.16
10.	1.91	1.83	1.75	1.59	1.83	1.83	1.67	1.51
15.	2.39	2.26	2.11	1.94	2.26	2.23	2.07	1.91
20.	2.78	2.62	2.54	2.25	2.94	2.99	2.71	2.71
30.	3.45	3.24	3.10	2.86	3.62	3.34	2.98	2.99

Table 12. Emitter-discharge data for Dz2 emitter

Head, psi	Emitter discharge, gph							
	Emitter, number							
	1.	2.	3.	4.	5.	6.	7.	8.
1.25	.24	.3	.34	.34	.50	.52	.48	.50
5.	.78	.84	.82	.81	.79	.79	.80	.83
10.	1.43	1.50	1.50	1.50	1.43	1.51	1.51	1.51
15.	1.98	1.92	2.06	2.06	2.05	2.06	2.06	2.06
20.	2.4	2.4	2.46	2.46	2.46	2.50	2.36	2.30
25.	2.82	2.7	2.86	2.86	2.86	2.89	2.86	2.46

Table 13. Emitter-discharge data for OUnf3 emitter

Head, psi	Emitter discharge, gph							
	Emitter							
	1.	2.	3.	4.	5.	6.	7.	8.
2.5	9.06	5.76	8.34	9.78	6.18	8.10	10.5	8.34
3.75	3.46	3.70	3.22	4.61	2.71	4.06	8.86	3.97
5.0	2.94	2.47	2.23	3.10	1.51	2.54	7.61	4.61
10	2.78	2.78	2.30	1.99	1.27	3.26	4.30	2.78
20	1.91	2.07	1.59	1.99	1.59	3.58	6.36	2.07
30	1.67	2.07	1.67	2.07	1.43	3.18	2.62	2.47

Table 14. Emitter-discharge data for NUnf3 emitter

Head, psi	Emitter discharge, gph							
	Emitter Number							
	1.	2.	3.	4.	5.	6.	7.	8.
2.5	8.62	5.72	6.42	3.98	7.89	8.18	4.77	5.61
3.75	8.82	7.86	4.77	5.41	8.41	8.63	5.16	6.33
3.75	2.04	1.27	-----	-----	1.11	1.79	2.11	1.35
5.	1.44	1.41	1.35	1.59	1.42	1.38	1.57	1.41
10.	1.68	1.51	1.35	1.91	1.65	1.57	1.79	1.55
20.	2.23	2.30	2.28	2.30	2.30	2.27	2.58	2.45
30.	3.02	3.02	2.94	3.02	3.11	2.94	3.02	2.92

Table 15. Emitter-discharge data for Unf2 emitter

Head, psi	Emmiter discharge, gph							
	Emitter number							
	1.	2.	3.	4.	5.	6.	7.	8.
1.25	8.62	8.14	8.38	7.14	8.86	8.86	8.62	8.86
2.5	8.82	9.3	9.3	6.61	9.54	6.42	8.76	8.82
3.75	3.10	3.53	10.5	3.34	2.7	3.10	8.86	4.41
5.0	1.99	2.06	4.10	1.59	1.19	1.91	5.24	2.06
10.	2.14	1.11	1.35	1.67	1.35	2.06	2.15	2.06
20.	1.59	1.51	1.75	1.91	1.43	1.67	1.27	1.35
30.	1.91	1.82	2.06	2.30	1.75	1.99	1.51	1.75

Appendix F

Roughness Coefficient Data

Table 16. Roughness coefficient data for laboratory tests with emitterlines

Emitter Type	C	Inlet Head,ft.	End Head,ft.	Theoretical End Head,ft.	Length, ft.	Q, gpm
NRbt3	117	69.21	57.85	56.52	200	1.94
NRbt3	120	69.21	59.29	58.73	200	1.92
NRbt3	120	57.68	42.68	42.82	250	2.07
Sp3	136	57.68	46.14	47.77	200	1.97
Sp3	136	92.28	35.76	37.14	400	4.20
Sp3	136	69.21	39.22	38.96	300	2.85
Sp3	136	69.21	56.52	57.25	200	2.18
Sp2	136	69.21	59.28	61.75	250	1.57
Sp2	136	69.21	63.66	62.98	200	1.25
Dz2	98	34.61	21.22	20.20	400	1.9
Dz2	98	69.21	27.91	25.91	400	2.37
Dz2	98	46.14	18.2	19.0	400	1.35
OUnf3	136	46.14	41.06	40.11	200	1.53
OUnf3	136	57.58	48.45	47.35	200	1.77
OUnf3	136	69.21	62.29	61.89	200	1.66
Unf2	136	46.14	42.68	41.51	200	1.9
Unf2	136	69.21	64.60	64.79	200	1.3
ORbt3	118	69.21	58.89	58.11	200	2.13
ORbt3	118	69.21	56.12	55.80	250	2.5

Appendix G

Emitter Distribution Data

Table 17. Emitter distribution data

Emitter number	Discharge, gph						
	Sp3	Sp2	Dz2	NRbt3	Unf2	Ounf3	NUnf3
1	3.29	1.73	2.07	2.94	1.92	1.43	2.39
2	2.88	1.83	2.03	3.23	2.15	1.11	2.46
3	3.26	1.35	2.07	3.23	2.23	2.06	3.18
4	3.19	1.91	2.07	3.18	1.83	1.67	2.78
5	2.86	2.46	1.99	3.10	1.35	1.12	2.63
6	3.18	1.78	2.02	3.26	1.99	1.35	2.94
7	3.34	1.59	2.15	2.78	1.99	1.35	2.94
8	3.10	2.15	1.96	3.16	1.35	1.03	2.79
9	2.94	2.93	2.07	2.54	1.51	.95	2.95
10	3.34	2.23	2.07	3.02	1.59	1.67	3.02
11	3.34	2.46	2.07	3.21	1.59	1.67	3.02
12	3.26	1.59	2.07	3.18	1.19	2.78	3.02
13	2.86	2.31	2.04	2.86	1.83	2.39	2.95
14	3.50	2.54	1.99	3.02	1.35	1.67	3.10
15	3.42	1.43	2.04	3.26	1.83	2.06	3.02
16	3.40	1.67	1.96	2.94	1.59	1.83	3.02
17	3.50	1.75	2.07	3.10	1.91	1.43	2.95
18	3.45	2.35	1.99	2.78	1.83	1.43	2.86
19	2.83	2.31	1.91	3.34	2.15	1.99	3.02
20	3.60	1.19	2.15	2.86	1.12	2.30	3.02
21	3.26	2.62	2.07	2.78	2.71	1.27	2.86
22	3.37	2.07	2.10	3.02	1.59	1.59	3.02
23	3.58	2.31	2.07	3.42	1.75	1.99	2.86
24	2.94	2.15	2.15	2.91	1.91	1.43	----
25	1.54	2.46	2.07	2.94	1.67	2.07	----
26	3.07	2.15	2.07	2.86	2.07	1.91	----
27	3.34	1.78	2.07	2.70	1.83	3.97	----
28	2.15	1.67	2.07	3.02	1.67	1.91	----
29	3.02	2.39	1.99	2.86	1.35	1.91	----
30	3.02	2.10	2.07	3.10	1.83		----

Appendix H

Emitter Distribution Histograms

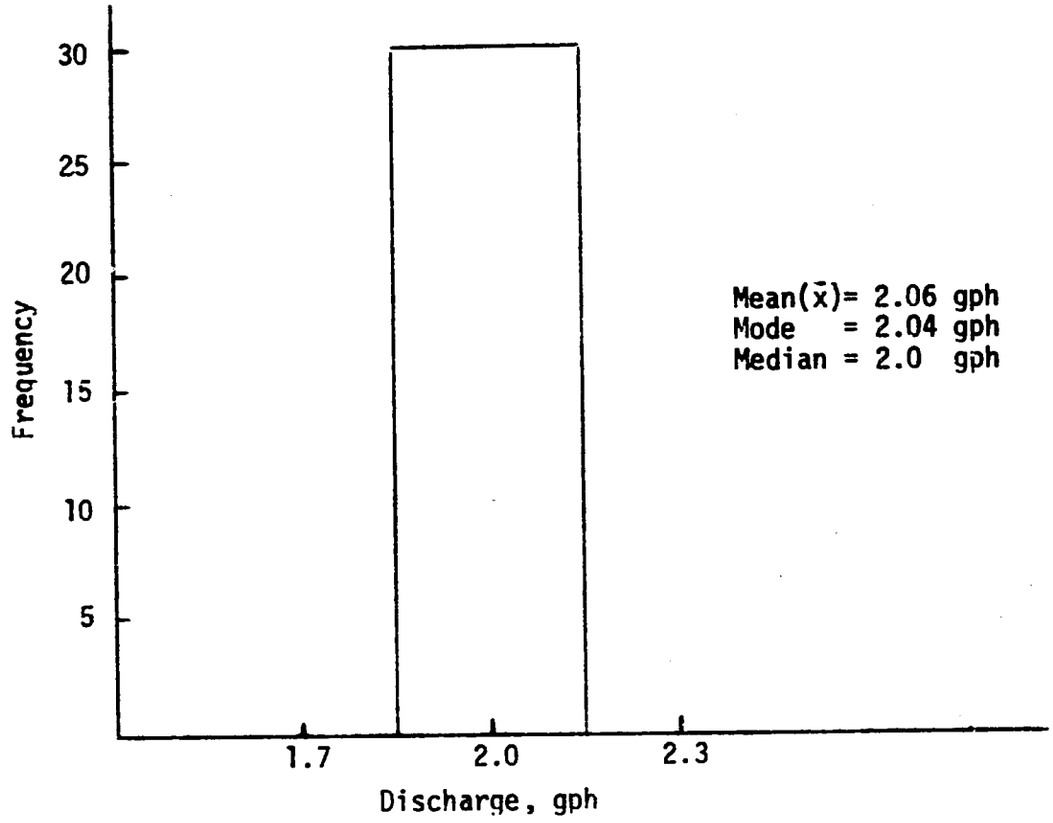

Figure 16. Distribution historgram for Dz2 emitter

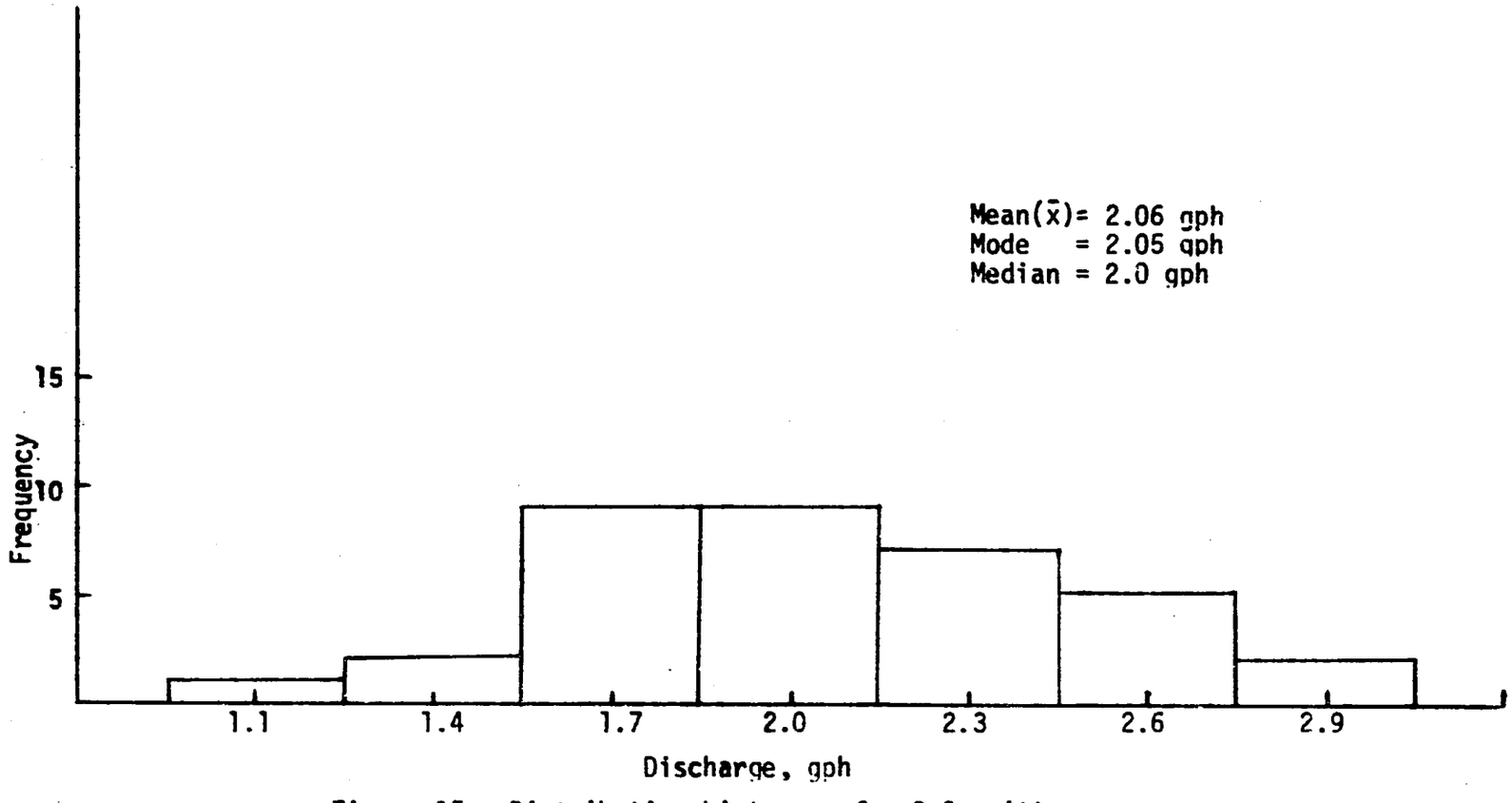

Figure 17. Distribution histogram for Sp2 emitter

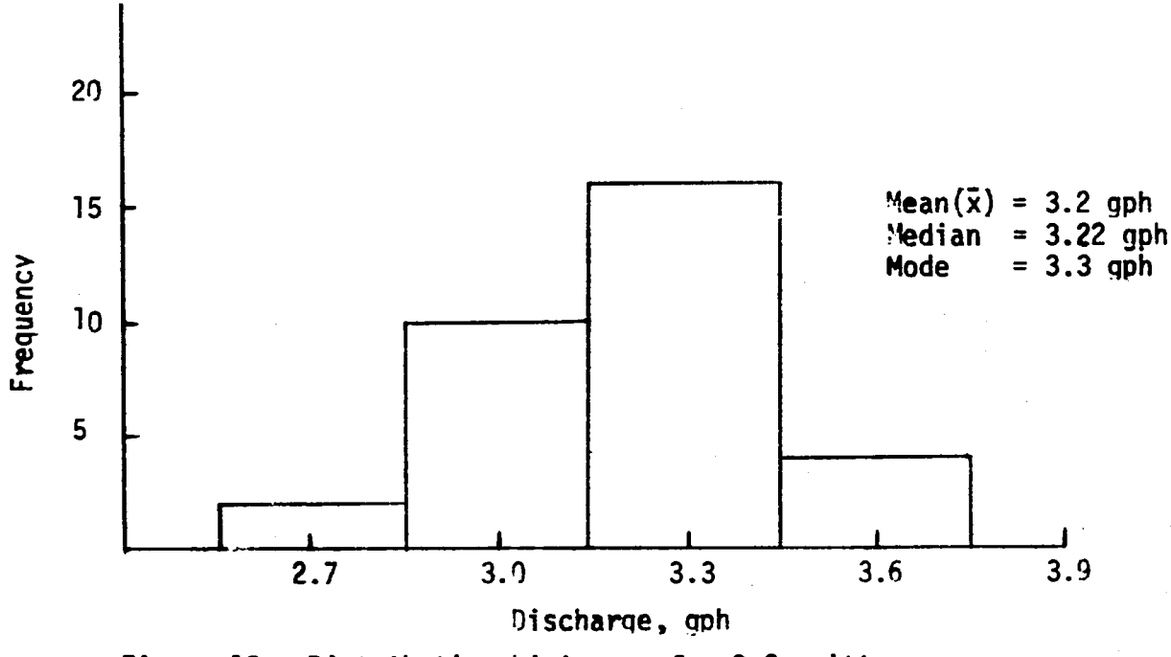

Figure 18. Distribution histogram for Sp3 emitter

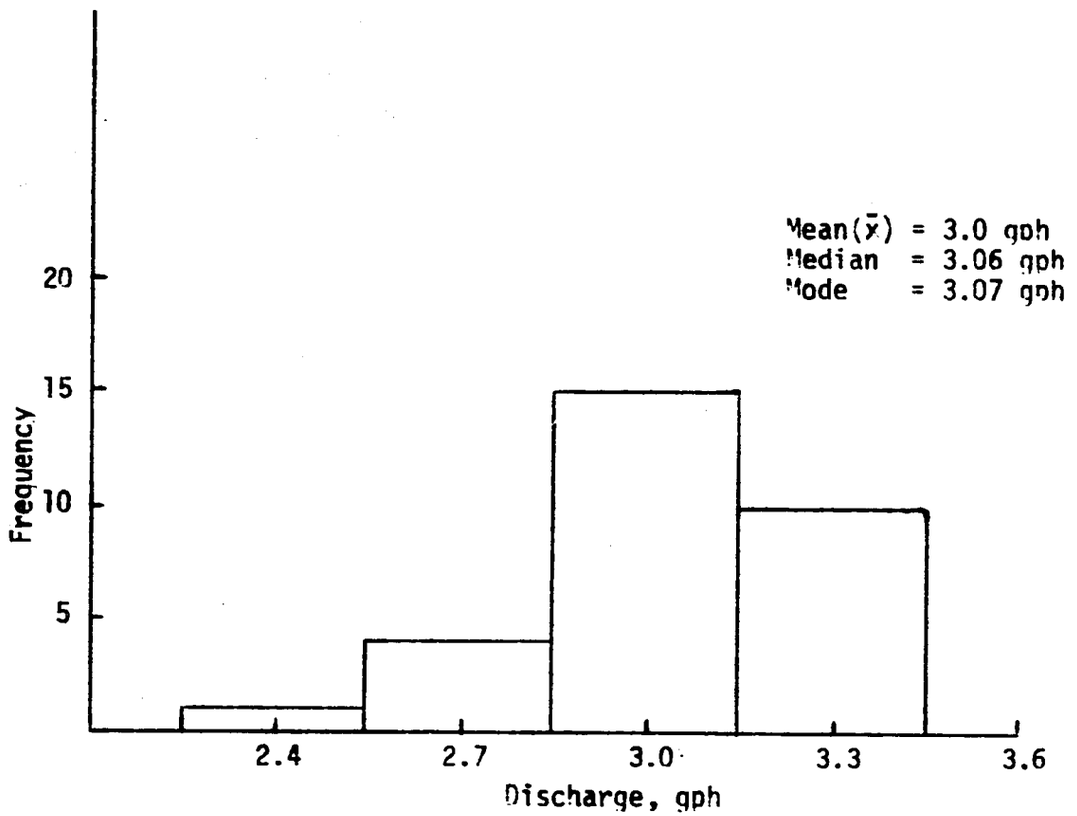

Figure 19. Distribution histogram for NRbt3 emitter

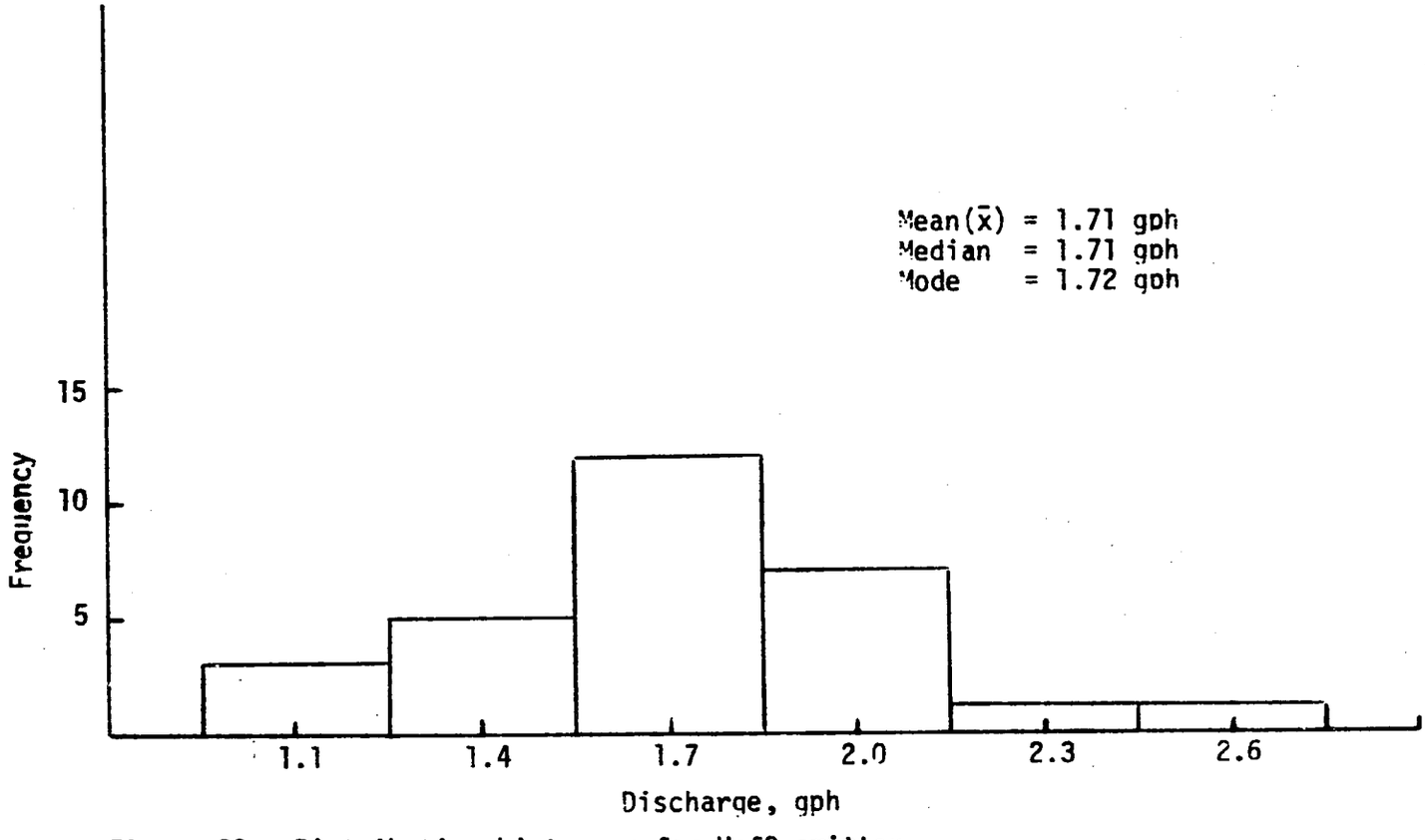

Figure 20. Distribution histogram for Unf2 emitter

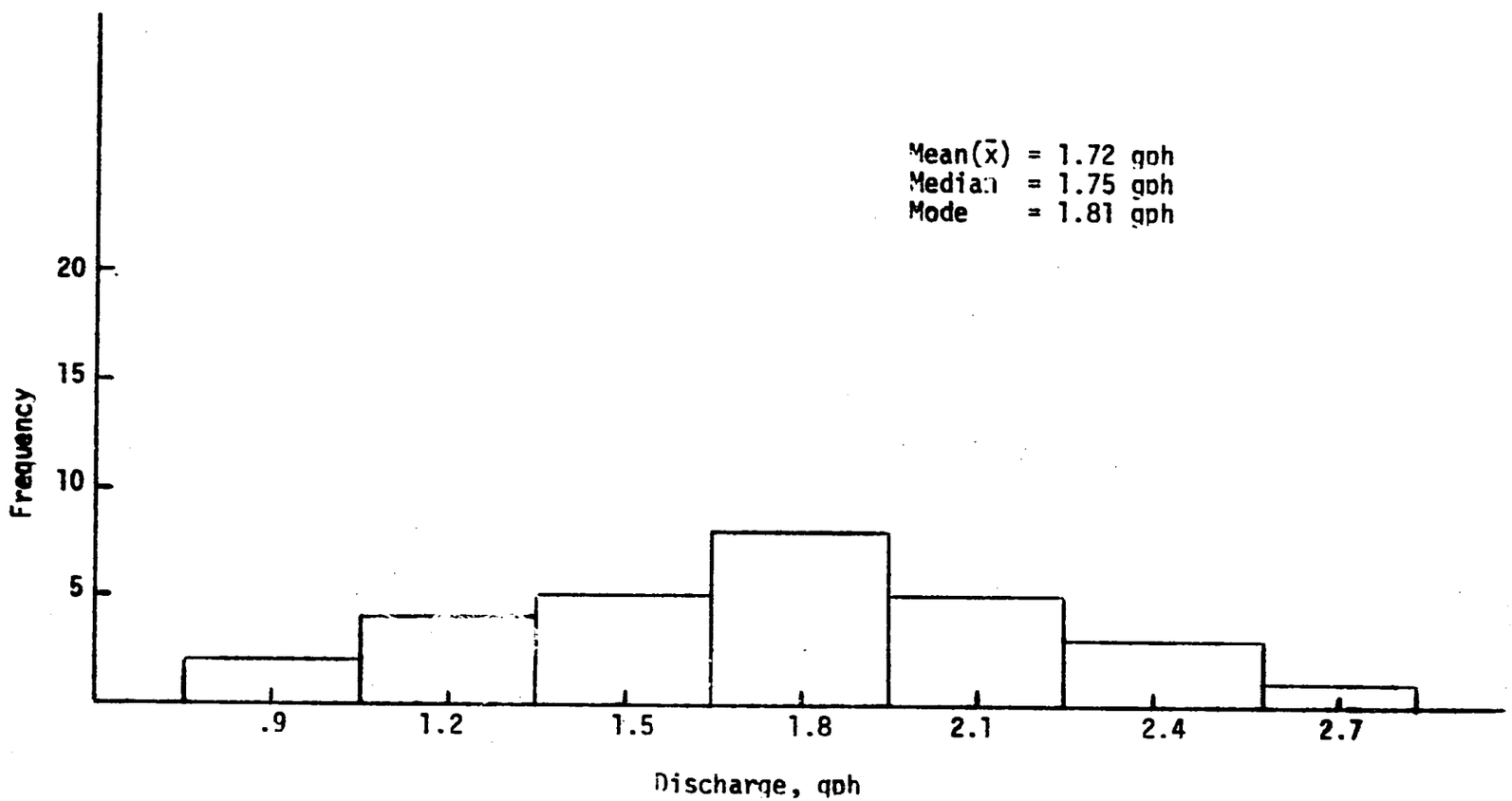

Figure 21. Distribution histogram for QUnf3 emitter

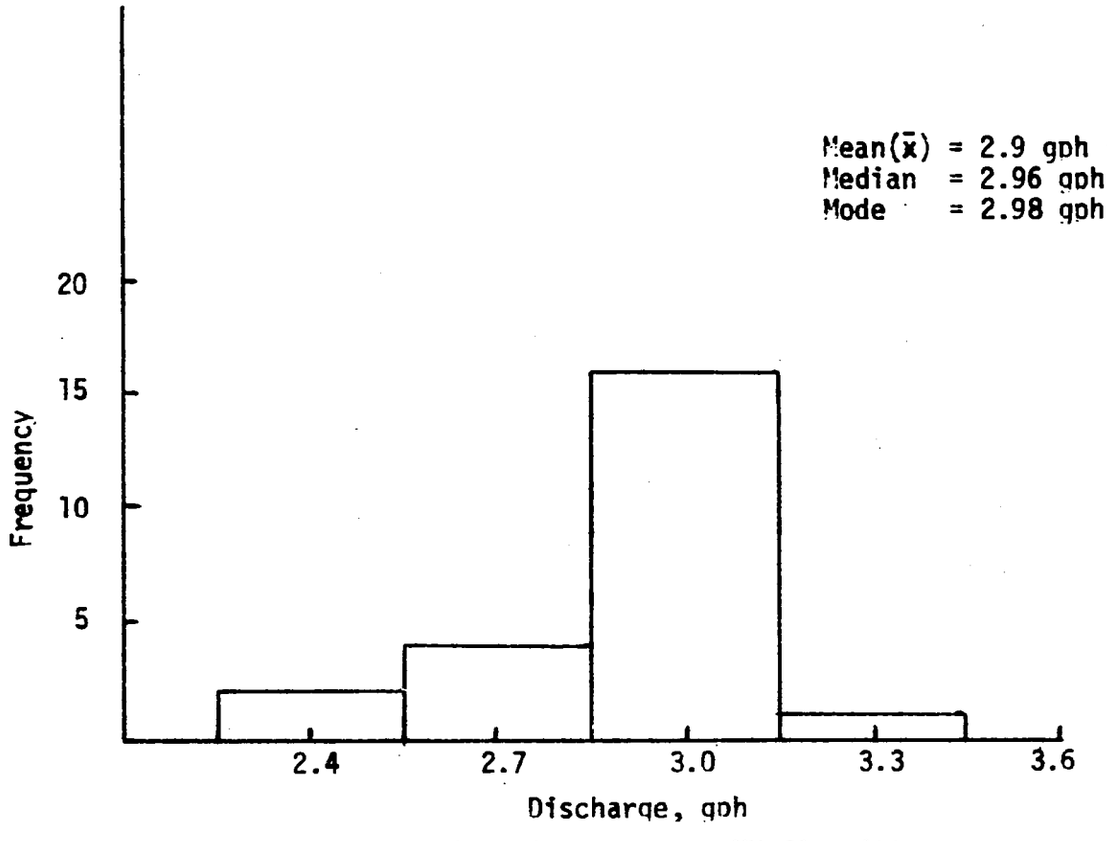

Figure 22. Distribution histogram for NUnf3 emitter

Appendix I

Emitter Discharge Data for ANOVA

Table 18. Emitter discharge data from 200 foot emitterline

Emitter Number	Discharge of emitters sampled, gph					
	OUnf3	Unf2	Sp3	Sp2	Rbt3	Dz2
2	2.39	1.51	3.26	2.07	2.81	2.26
4	2.31	2.23	3.40	2.19	3.02	2.15
6	2.31	2.15	3.13	1.46	2.75	2.07
8	2.23	1.75	3.42	2.07	2.62	2.05
10	1.59	2.62	3.02	2.23	3.13	2.07
12	1.75	1.83	3.34	1.99	2.94	2.0
14	2.94	1.99	3.29	2.39	2.86	2.15
16	1.83	1.83	3.02	2.26	2.94	2.07
18	1.67	2.58	3.18	2.23	2.94	2.07
20	2.15	1.99	3.02	2.07	2.62	1.91
22	1.67	4.65	3.26	1.59	2.91	2.07
24	1.83	1.59	2.89	2.39	2.78	1.99
26	2.78	1.91	3.26	2.31	2.62	2.07
28	1.75	5.25	2.86	1.67	2.86	1.99
30	2.07	1.99	2.78	1.83	2.62	2.15
32	1.99	1.67	3.18	2.15	2.94	2.07
34	2.00	1.62	2.94	1.59	2.70	2.07
36	1.83	1.51	3.26	2.07	1.99	1.91
38	2.46	1.19	2.97	2.39	2.62	2.07
40	1.27	1.02	2.78	2.39	2.39	1.99

VITA

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