IMPACT OF DIFFERENT PATTERNS OF EMITTER CLOGGING ON HYDRAULIC CHARACTERISTICS OF MICROIRRIGATION LATERALS LAID ON FLAT AND SLOPED TERRAINS.

By

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ABSTRACT

A field experiment was conducted to evaluate the effects of different numbers and locations of clogged emitters on the hydraulics of a microirrigation system installed on flat and sloped terrains. The results obtained were compared with the theoretical results calculated using a computer program. The emitter flow variation, head loss, pressure variation, coefficient of uniformity, field emission uniformity, distribution uniformity, statistical uniformity of the emitter discharge, emitter statistical uniformity due to hydraulics, application efficiency, emitter discharge coefficient of variation, hydraulic design coefficient of variation, emitter discharge coefficient of variation due to hydraulics, and emitter performance coefficient of variation were evaluated. Five different slopes (0%, 3% and 7% up- and down-slopes) were used to examine eight different patterns (stage 1 to 8) of emitter clogging along the laterals.

On the basis of the results obtained from this study, when 10% or more of total number of emitters are partially clogged, the uniformities (*CU, EU', DU,* and U_s) are poor and unacceptable if the criteria suggested by ASAE EP458, and ASAE EP405.1 (1997) is applied. In case of *flat terrain*, the number and locations of clogged emitters were the major factors affecting the H_f, H_{var}, q_{var}, V_{qs}, V_{hs}, V_{qh}, and V_{pf}. The location of clogged emitters was not a significant factor affecting *CU, EU', DU,* and U_s, but the number and degree of clogged emitters were the major factors effecting the uniformities in a microirrigation system. In case of *slope terrain*, the *location* of clogged emitters and the *slope* of lateral had significant impact on the H_{var}, q_{var}, V_{qh} and V_{hs}, but the latter had a higher impact than the former. It was found that the number and location of clogged emitters were the major factors affecting H_f, V_{qs}, V_{pf}, *CU, EU', DU,* and U_s, but the former is more significant than the latter. No observed significant impact of *lateral slopes* on these parameters. In case of *down-slopes* in a *no-clogged situation*, the uniformities were higher (about 1-4%) than that in up-slope conditions. However, under the *clogged situation* there was no observed significant difference between the uniformities obtained from up- and down-slopes. In all different slopes studied, stages 4 and 5 (when 30% of total number of emitters are clogged and located at the first one-third section of lateral or randomly located along the lateral) were the worst situations of emitter clogging.

A computer simulation program based on the solution of fundamental hydraulics relationship was constructed to simulate the effect of different patterns of clogged emitters on the hydraulics of a microirrigation system. The model predicts lateral flow rates with respect to the variation of individual emitter discharge due to pressure change within the lateral. Patterns similar to those of emitter clogging in the field experiment were used in the computer program. In all slopes and stages studied, the computed results did not deviate more than ±5% from the field observations.

Based on field and synthetic data, the effects of different patterns of clogged emitters on reduction of crop yields (cotton yield in this study) were simulated and the farmer's loss was estimated. It was found that the reduction of crop yields was directly related to the number and degree of clogged emitters in different slopes.

The effect of variation of air and water temperatures on hydraulic characteristics of emitters were examined. Results show that there were no significant differences in emitter flow rate along the lateral under various temperatures at the experimental site. The impact of lateral flushing on emitter flow rate was also investigated. It was found that although flushing the lateral improves the emitter flow rate, it can also create or increase the emitter clogging problem by introducing small suspended particles from the lateral flow into the emitter.

The effects of injecting (using the venturi injector) water with different degrees of salinity on the emitter's hydraulic characteristics were studied. Two different cases were evaluated: (1) to maintain a constant value of electrical conductivity (*EC*) at the emitter's outlet and (2) a constant *EC* value of the injecting saline water was maintained and the *EC* variation at the emitter outlet. It was found that the turbulent flow at the venturi throat allows sufficient mixing of the liquid injection with the motive flow. Therefore, the mixed water of almost constant *EC* along the lateral was obtained over time. Results show that when the venturi was installed and the liquid was injected, the values of hydraulic parameters varied from those values obtained from a "no liquid injection" condition. The variation in hydraulics parameters is unavoidable unless the pressure at the venturi's outlet is adjusted to the same value as in the "no liquid injection" situation.

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GLOSSARY

Symbols	***Description***
a	A fraction of the area receiving a full irrigation, %
A	Irrigation area, ha
C_H	Pipe roughness coefficient
C	Proportion of emitter completely plugged
C%	percentage number of clogged emitter along the lateral
C_d	degree of emitter clogging
C′	Concentration of elemental nitrogen (N), kg/l
$\mathrm{C_q}$	Emitter coefficient
CU	Christiansen Coefficient of Uniformity, %
$\mathrm{CU_R}$	Reduction in coefficient of uniformity, %
CV	Coefficient of variation
d	Flow cross section diameter, cm (in)
D	Inside diameter of pipe, mm (in)
$\mathrm{d_m}$	Flow cross section diameter of a multi-exit orifice emitter, cm (in)
DU	Distribution uniformity, %
$\mathrm{DU_R}$	Reduction in distribution uniformity, %
Ea	Application efficiency, %
EC	Electrical conductivity, dS/m (mmhos/cm)
$\mathrm{EC_i}$	Electrical conductivity of irrigation water, dS/m (mmhos/cm)
$\mathrm{EC_L}$	Electrical conductivity of injection liquid, dS/m (mmhos/cm)
$\mathrm{EC_m}$	Electrical conductivity of mixed water, dS/m (mmhos/cm)
ET	Evapotranspiration or crop water-consumption-use rate, mm/day (in/day)
$\mathrm{ET_o}$	Reference evapotranspiration, mm/day (in/day)
$\mathrm{ET_{ave}}$	Mean evapotranspiration, mm/day (in/day)
$\mathrm{ET_d}$	Average evapotranspiration in the deficit area, mm/day (in/day)
$\mathrm{ET_m}$	Evapotranspiration of the crop under non-moisture stress condition, mm/day (in/day)

EU	Design emission uniformity, %
EU'	Field emission uniformity, %
EU'_R	Reduction in field emission uniformity, %
f	Dimensionless friction factor
F_{20}	Friction coefficient for water at 20°C
F_r	Quantity of nutrient to be applied, kg/ha (lb/acre)
F_T	Friction coefficient for a given water temperature
$F_{(n°)}$	corrective function to account for the discharge through the outlets on the pipe (Adjustment correction factor)
g	Acceleration due to gravity, m/s^2 (ft/s^2)
G	Ratio of the required irrigation depth (I) to satisfy ET_m to the mean of irrigation depth
H	Pressure head in the lateral pipe, m or kPa (ft or psi)
h	Working pressure head at the emitter, m or kPa (ft or psi)
H_{ave}	Average pressure along the lateral, m or kPa (ft or psi)
h_f	Head loss due to friction, m (ft)
H_F	Total head loss along the lateral, m (ft)
h_{fi}	Head loss at each section along the lateral, m (ft)
H_i	Pressure at the inlet of lateral, m or kPa (ft or psi)
H_{min}	Minimum pressure along the lateral, m or kPa (ft or psi)
H_o	Total energy (pressure head) at the inlet, m or kPa (ft or psi)
h_{var}	Pressure variation, %
I	Irrigation depth, mm
i	Ratio of a given length or l/L
I_d	Average depth of irrigation in the deficit area, mm
K_H	Conversion factor depending on selection units
k_c	Crop coefficient
K	The constant of the proportionality that characterizes each emitter (emitter discharge coefficient)
$K\%$	Percentage reduction of emitter coefficient

k_i	Fraction of K
K_y	Yield response factor
L	Length of lateral, m (ft)
l	Length position along the lateral, m (ft)
l_c	Length of the flow path in emitter, cm (in)
m	Flow exponent in the friction loss equation
m	Number of emitter exits
n	Exponent of the inside diameter
N	Number of outlets on the lateral
n	Number of emitter in the sample
n_o	integer variable expressing the number of outlets on a given pipe
Ns	Number of section along the lateral
OP	Percentage of opening of the emitter cross section area, %
p_1	pressure at point 1 along a pipe, m or kPa (ft or psi)
p_2	pressure at point 2 along a pipe, m or kPa (ft or psi)
q	Emitter discharge rate, *l/h* (gph)
Q	Total pipe flow, *l/h* (gpm)
q%	percentage of reduction in emitter flow rate, %
q_a	Average emitter discharge of all the emitters under consideration, *l/h* (gpm)
q_{ave}	Average emitter flow rate, *l/h* (gpm)
q_c	Rate of injection of liquid fertilizer solution, *l/h* (gpm)
q_i	Discharge of an emitter, *l/h* (gpm)
Q_i	Lateral flow at i^{th} section, *l/h* (gpm)
Q_L	Flow at the inlet of lateral, *l/h* (gpm)
q_m	discharge of a multi-exit orifice, *l/h* (gpm)
q_m	Minimum emitter discharge computed with the minimum pressure, *l/h* (gpm)
q_{max}	Maximum emitter flow rate, *l/h* (gpm)
q_{min}	Minimum emitter flow rate, *l/h* (gpm)
q_n	Average of the lowest quarter of the emission flow rate, *l/h* (gpm)
q_{var}	Emitter flow variation, %

R'_i	Ratio of $\Delta H'_i$ and $\Delta H'$
R_i	Friction drop ratio
Se	emitter spacing, m (ft)
S_h	Standard deviation of the hydraulic pressure
S_q	Standard deviation of the emitter discharge rate in the sample
T	Water temperature, °C
T_a	Irrigation application time (set time), h
TC%	Total percentage of emitter clogging, %
t_r	Ratio between set time and fertilizer time
U_s	Statistical uniformity coefficient, %
U_{sh}	Emitter statistical uniformity due to hydraulics, %
V	Average velocity of the flow, m/s (ft/s)
v_m	Manufacturer's coefficient of variation
V_{hs}	Coefficient of variation due to hydraulics
V_{pf}	Emitter performance coefficient of variation
V_{qh}	Emitter discharge coefficient of variation due to hydraulics
V_{qp}	Emitter discharge coefficient of variation including emitter plugging
V_{qs}	Emitter flow coefficient of variation
V_T	Total emitter coefficient of variation
x	Emitter discharge exponent
Y_{ave}	Average yield from the field, kg (lb)
Y_{max}	Maximum yield under non-moisture stress conditions, kg (lb)
Y_R	Reduction in cotton yield, kg (lb)
$\bar{I}$	Mean irrigation depth, mm (in)
$\bar{q}$	The mean emitter flow, *l/h* (gpm)
S_h^2	Variance of the hydraulic pressures
$\Delta\bar{q}$	Mean deviation of the emitter flow from the mean value, *l/h* (gpm)
μ	Dynamic viscosity, kg/ms
ρ	Fluid density, kg/m^3 (lb/ft^3)

ν	Kinematics viscosity, m^2/s (ft^2/s)
ν_T	Kinematics viscosity of water at $T^{\circ}C$, m^2/s (ft^2/s)
ν_{20}	Kinematics viscosity of water temperature at $20^{\circ}C$, m^2/s (ft^2/s)
"F"	Adjustment correction factor
ΔH	Total friction drop at the end of lateral line, m (ft)
$\Delta H'$	Total energy gain or loss, m (ft)
$\Delta H'_i$	Energy gain or loss at i^{th} location, m (ft)
ΔH_i	Total friction drop at a given length ratio, m (ft)
ΔL	length between points 1 and 2 along the pipe, m (ft)
Δp	pressure drop, m or kPa (ft or psi)

To my wife Sara

and our beloved Sally and Reza

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Chapter 1

1. INTRODUCTION

1.1 Background:

Water is one of the limiting natural resources affecting agricultural crop production. As the world's population increases, more efficient use of irrigation water is required to safeguard food supplies. The aim of irrigation is to provide adequate moisture to crops for the purpose of crop production, complementing natural rainfall. Irrigation systems can be broadly classified as being either gravity flow or pressurised. Gravity flow system are characterised by water flow in channels (furrow, border, contour, overland flow, etc.) across the field. Pressurised systems deliver water under pressure through pipes and release it from small orifices, tubes (spaghetti tube) or sprinkler nozzles. In many parts of the world, natural precipitation is not sufficient to provide adequate soil moisture for optimum crop growth. Inadequate rainfall limits plant growth and crop yields. Water conservation is very important due to high water prices and small allocated quotas in arid and semi-arid areas such as Africa, Saudi Arabia, Iran, etc.. Economical crop production in these areas is not possible without irrigation. Surface irrigation continues to be the predominant system in many countries due to historical knowledge and the low cost of implementation. The high cost associated with the pressurisation of irrigation water and operating energy use is also an important parameter in the design of pressure irrigation systems. Use of low volumes of water and low operating pressure can be achieved with a microirrigation system. However, to irrigate fields and orchards with fruit trees, there is evidence to support the claim that a microirrigation system is often a more efficient and advanced system than other irrigation methods (Dexroix and Malaval, 1985; Hanson *et al.*, 1997). Microirrigation has resulted in considerable increases in water-use efficiency (yield per unit of water applied) over furrow and sprinkler irrigation (Hiller and Howell, 1973; Hanson *et al.*, 1997). To obtain identical yields, microirrigation requires 50% less water than furrow irrigation (Singh *et al.*, 1978). Microirrigation systems are presently being used successfully on a variety of row and tree crops. This type of system is not only applicable in the arid areas but is also useful in humid areas where supplemental water is needed during dry periods. A microirrigation system is one of the most suitable systems with high application efficiency for tree fruits, vegetables, berries, and vines in British Columbia, Canada (Chieng, 1993). Microirrigation systems are used for various crops and fruits, and are practical for areas with hilly topography, poor soil and water shortages.

The term “microirrigation” is broadly used to refer to several methods of pressurised irrigation, such as subsurface trickle, surface trickle, drip, pulse, spray, bubbler, and micro-sprinkler. Microirrigation is considered a low pressure irrigation method. It is usually operated at a pressure of less than 103 kPa (15 psi). Microirrigation is described as the slow but frequent application of small quantities of water, which is accomplished by using small-diameter polyethylene or PVC pipe with devices called "emitters" or "applicators" at selected spacing intervals to deliver water on, above, or beneath the soil near the base of the plants (Howell and Hiller, 1974; Nakayama and Bucks, 1986; ASAE S526.1, 1997). The emitter is responsible for direct water discharge to the field. After leaving the emission device, water is distributed by its normal movement through the soil profile; therefore the area which can be wetted from each emitter along the lateral is limited by the horizontal water flow. Ideally, all emitters in a microirrigation system should deliver equal flow rate at irrigation events (Wu and Gitlin, 1973). The purpose of microirrigation is to apply water uniformly through the soil (Wu and Giltin, 1973; Wu, 1975). The application rate for pressurised systems is typically designed to be less than the ponded infiltration rate. In the case of uniformly spaced emitters, this would require that each emitter have the same rate of discharges even though pressure differences are unavoidable (Solomon and Keller, 1978). The uniformity of microirrigation system can be determined based on emitter flow variation along a lateral or sub-main (Bralts and Kenser, 1983; Wu, 1993). The application efficiency of the microirrigation system and the uniformity of emitter flow depends on the emitter flow variation along the lateral lines. Fertilizer or chemical may be applied directly into the microirrigation system by an injector. Ideally, all the emitters along the lateral should deliver the same amount of the liquid injection near the base of the crop. Non-uniformity of the chemical application caused by emitter flow variation along the lateral have a major impact on crop yield. The term “coefficient of variation” can be used to assess the uniformity of water and fertilizer application through the microirrigation sub-main unit (Hahn and Bralts, 1983). A microirrigation system consists of a control head (water supply, pump, pressure regulator, filter, flow meter, injector, etc.), a network of plastic pipes (usually polyethylene pipe such as main, sub-main, lateral) followed by the emitters. Figure 1.1 shows an example of the microirrigation system components.

The pressure variation along the lateral line changes the emitter flow rate and hence water application uniformity. The pressure variation along a lateral is greatly affected by the combination of line slope and friction loss. In reality, unit to unit emitter discharge is variable. The emitter flow variation is affected by not only hydraulic design but also emitter manufacturer's variation, grouping of emitters, emitter characteristics, number and degree of clogged emitters through the lateral, friction loss along the line, topographic variation (slope), and temperature (Wu and Gitlin, 1981; Bralts *et al.*, 1981; Keller and Bliesner, 1990; Wu, 1993). In considering uniformity of water application in microirrigation systems, Keller and Karmeli (1974) used basic hydraulics and manufacturer's variation to develop the emission uniformity concept. Wu and Gitlin (1974, 1975), Howell and Hiller (1974a, b), Mayer and Bucks (1972) developed lateral line design procedures based on the hydraulic energy gradient.

Of all the factors affecting the uniformity of microirrigation systems the hydraulic design with an emitter flow variation of 10%-20% produces the least effect on the coefficient of variation(CV) or uniformity coefficient (CU). Wu (1997) showed the hydraulic design to be one of the minor factors in the evaluation of overall uniformity of a microirrigation system. In some instances, the microirrigation system was installed with little concern for basic engineering hydraulic principles and resulted in non-uniform emitter discharge throughout the irrigation plots. Over or under irrigation can result from non-uniformity (Bralts *et al.*, 1981b).

Among the factors affecting the uniformity of microirrigation system, the emitter clogging is one of the most significant, since it is associated with the operation and maintenance of microirrigation system. Wu (1997) reported that the clogging is the most significant factor,

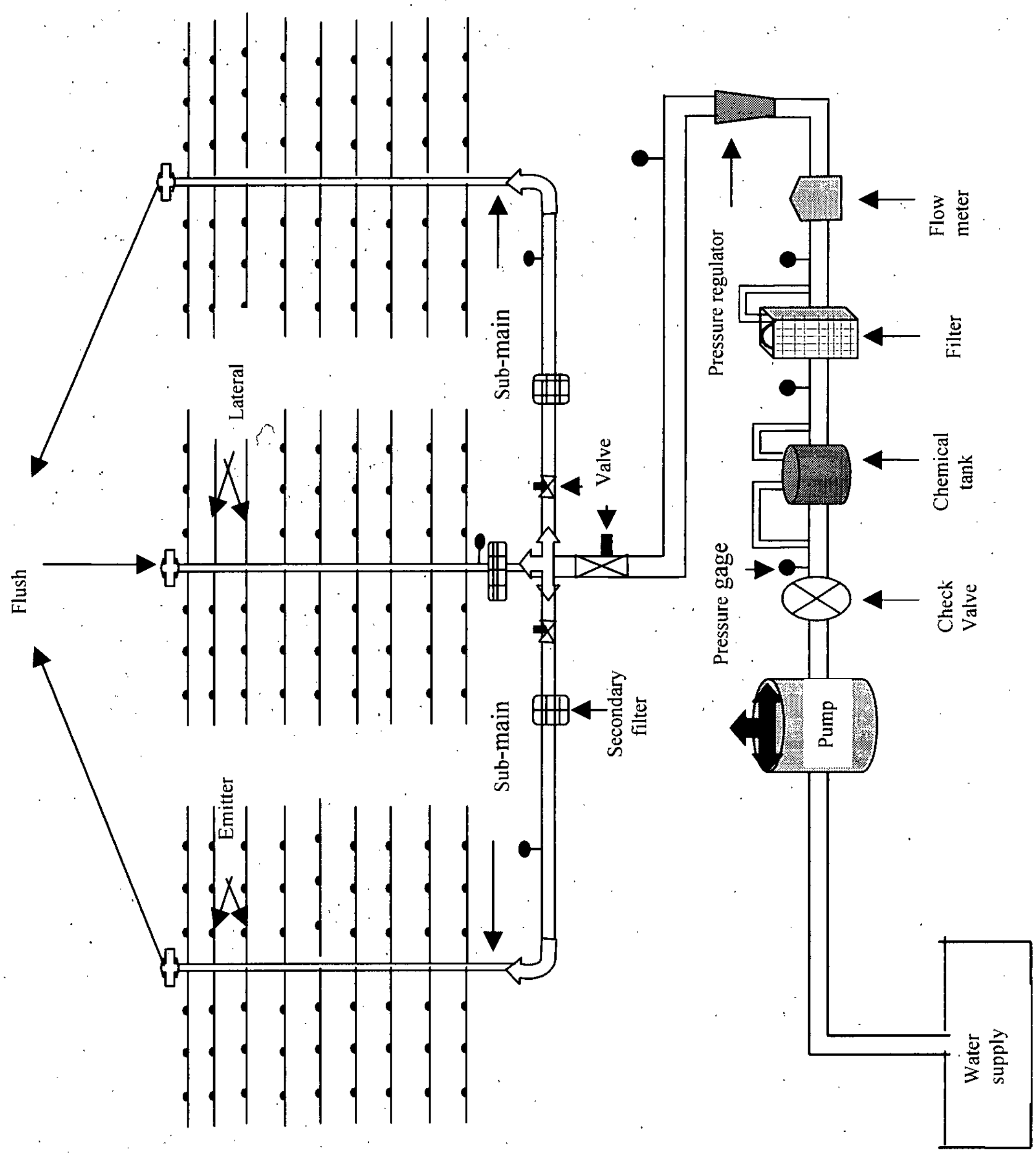


Figure 1.1 Basic components in a microirrigation system.

emitter spacing (grouping of emitters) is the second most significant, and that the hydraulic variation ($q_{var(H)}$) in a clogging situation is a less significant factor affecting the uniformity. It is known that emitter clogging is directly proportional to the irrigation water quality. However, knowing the exact factors that cause the emitter clogging is difficult because the various elements in the water can interact with each other and result in more clogging problems. Irrigation water should be carefully examined to assess any potential clogging problems. The stream of irrigation water carries organic particles such as algae and weed seeds as well as inorganic particles like sand, silt and clay. In some cases, particles may not adequately removed from the irrigation water by filtration treatment before it enters the pipe network. If lateral lines are not flushed regularly to remove the particles which pass through the filter, they may settle out of the water in the lateral. Bucks *et al.* (1979) classified the factors in irrigation water which cause emitter clogging in three groups: physical (suspended solid), chemical (interactions of the fertilizer with the dissolved chemicals in irrigation water can be precipitated), and biological (bacteria and algae). Common causes of the emitter clogging are salt precipitation, microbial slime, insect lodging, and sediment bridging in the emitter passageway (Gilbert and Ford, 1986). Emitter clogging results in changes in the uniformity of emitter flow and lateral hydraulics (Keller and Karmeli, 1974; Bralts *et al*, 1982). Proper fertilisation and chemical treatment of irrigation water usually can reduce emitter clogging.

The problem of major concern in emitter clogging is the change in discharge rates caused by partial to complete clogging of the emitters and how this affects water application through the field (Nakayama and Bucks, 1981). Several studies have related emitter clogging to hydraulics of the microirrigation system (Nakayama and Bucks 1981; Bralts *et al.*, 1987; Solomon, 1985; and Hills *et al.*, 1989). The effect of clogged emitters on the hydraulics of microirrigation is a challenging problem that has caused many operators to abandon their installations. Clogged emitters will not provide the plants with the proper amount of water and fertilizer. This affects the growth of plants and yield. One or two partially clogged emitters may not make changing the whole line economical. However, as the number of clogged emitters increases, the need to replace the line becomes more acute. Prediction of the number, degree, and location of clogged emitters along the lateral is almost impossible in practice. To date, there exists no guideline for the microirrigation users to determine when the clogged emitters or the lateral line should be replaced.

Although many researchers have studied microirrigation uniformity, most of the assessments have been limited in scope and restricted either to a typical lateral (Wu and Gitlin, 1974 and Howell and Hiller, 1974) or to only a few of the factors known to affect microirrigation uniformity (Nakayama and Bucks, 1981). Bralts *et al* (1982) examined the emitter clogging and microirrigation lateral hydraulics. However, uniform or non-uniform clogging patterns along the lateral and their effect on hydraulics parameters were not considered. While many studies on the hydraulics of microirrigation laterals (Solomon, 1985) were made, little work has been done on the effects of emitter clogging. There exists no literature considering the effect of all the factors such as hydraulic design, manufacturer's variation, emitter clogging, emitter spacing, and temperature on emitter flow and uniformity in a microirrigation system.

1.2 Statement of the problem:

In 1991, the International Commission on irrigation and Drainage (ICID) indicated that only 1,768,987 ha of 250 million ha of the total global irrigated area are irrigated by microirrigation systems. The majority of microirrigation was in the United States, where the area has expanded from 185,300 ha in 1981 to 606,000 ha in 1991. The area under microirrigation systems in Canada has expanded from 4,700 ha in 1981 to 6,149 ha in 1991 (Bucks, 1993). Total percent of areas under microirrigation are 3% in the United States, 48.7% in Israel, 7.8% in Australia and 0.65% in Canada. IRNCID (1993) indicated that 1.2% of irrigated land in Iran is under pressurised systems (micro and sprinkler irrigation). About half of the irrigated areas in the world (half of the 250 million ha) are in the arid and semi-arid regions. As the cost of water increases, there is heavier reliance on low-volume microirrigation systems. Land characteristics such as topography (slope) and soil texture (e.g. coarse) of the field orients farmers towards the use of microirrigation system. Microirrigation has been particularly successful in region with sandy soil and saline irrigation water (Goldberg and Shmueli, 1970; Goldberg *et al.*, 1971). Also, there have been significant increases in the use of microirrigation in many countries such as Egypt, Mexico, Italy, India, Iran, Japan, France and Thailand (Bucks, 1993). The effects of clogged emitters on hydraulics of microirrigation systems are widespread problem that has caused many early users to abandon their installation.

The problem with clogged emitters is that the plants that are to receive water and fertilizer do not receive the proper amounts. For example, if an emitter is 50 percent clogged, the plant at that location may only receive half the necessary water and the rest of emitters will receive too much water. Less water means less plant growth and crop production. If more water is delivered at one time than the soil in the plant root zone will hold, then that water will be lost to deep percolation. In the case of a completely clogged emitter, the plant will only have the water that was originally in the root zone available for growth. If fertilizer and other pesticides are delivered in the water, their distribution depends on the ability of the system to deliver the water uniformly.

It is practically impossible to make emitters clog predictably. Salt and fertilizers that are completely soluble can not clog emitters. Emitters are only clogged by particulate matter such as silt, sand, clay, clumps of bacterial matter that grow in the water, or precipitates caused by interaction between the fertilizer and salts in the water. To avoid soil particle clogging, a screen or filter which is four to five times smaller than the opening in the emitter should be used in the microirrigation system. Emitters clog mostly because of bacterial bodies and by-products or dirty water. Growers/farmers who use microirrigation are often criticised for just about any choice of technology they use. Their decisions almost always stem from the bottom line of financial stability. They really need to know when the clogging is impairing their crops so badly that they should replace the lateral line. One clogged emitter would not make changing the whole line economical, but a number of clogged or partially clogged emitters would make changing the whole lateral worthwhile.

The problem with the hydraulics of microirrigation is that when the emitter is clogged, the pressure and flow rate will vary throughout the lateral line. If the pressure in the lateral line is unbalanced, the crop production will vary along a lateral just due to the normal hydraulic pressure variation. The study of hydraulics of microirrigation with different numbers and patterns of emitter clogging along the lateral enables the microirrigation system users to predict how much clogging is acceptable and when a lateral will need to be replaced.

When the emitter discharge rates and uniformity of the emitters along a lateral is determined, it is possible to predict what the effect on crop growth will be or how much production will be lost due to clogged or partially clogged emitters. It is also possible to estimate how much money in terms of water and fertilizer is wasted due to emitter clogging and variation of emitter flow rate along the lateral.

In some developing countries in the arid region, there exists no experience of using microirrigation systems. Therefore, the study of effects of clogged emitters on the hydraulics of microirrigation will help the system users to estimate the degree of over- and under-irrigation based on hydraulics.

1.3 Research objectives:

The aim of this research was to determine the effect of different patterns of emitter clogging on the hydraulics of microirrigation laterals. The effects of saline water injection on emitter flow variation and the hydraulics of lateral were also examined. The research objectives of this study were:

1- to quantify the flow uniformity and flow patterns along a lateral with different degrees and patterns of emitter clogging.

2- to simulate the pressure variations along a lateral with different number of clogged emitters and different clogging patterns and lateral slopes. Field experimental data will be collected to verify the simulated results.

3- to assess the location of the most severely clogged emitters along the lateral which have the highest impact on the coefficient of uniformity.

4- to examine the effect of injecting different degrees of saline water (by using the venturi injector) on the emitter's hydraulic characteristics.

5- to investigate the change, over time, in injected fertilizer or chemical concentration along a lateral consisting of no-clogged and partially clogged emitters when the venturi injector is used.

6- to evaluate the hydraulics of a microirrigation lateral with a venturi injector installed.

7- to predict the economic effects of emitter clogging on crop production.

8- to construct a mathematical computer spreadsheet program to predict the effects of emitter clogging on the hydraulics of microirrigation systems and crop yield.

Chapter 2

2. LITERATURE REVIEW

2.1 Hydraulics of Microirrigation and Flow Variation:

Microirrigation is a type of pressurised pipe network with a generally low operating pressure and application rate. The actual emitter discharge rate for typical field layouts varies considerably and is very sensitive to pressure variation, partial or complete emitter clogging, water quality variation, temperature variation, design emitter characteristics, emitter manufacture variation, friction head loss throughout the pipe distribution network, and topographic variation (slope). Therefore it is recommended that the system be monitored with time sequencing (Keller and Karmeli, 1974). The hydraulics of microirrigation has been fairly well established and documented by many researchers (Karmeli *et al.*, 1985; Bralts *et al.*, 1987). The flow condition in microirrigation lines (lateral or submain) is considered steady and spatially varied with decreasing discharge in the line. Among the factors affecting the microirrigation uniformity, the hydraulic design can be controlled by the engineers who design the system for a certain specified design criterion (Feng and Wu, 1990).

Wu and Gitlin (1975) and Myers and Bucks (1972) derived the hydraulic energy gradient line for determining the emitter flow variations and uniformity along a lateral line. Howell and Hiller (1974) used the hydraulic energy gradient principle and developed lateral line design equations based upon specific uniformity criteria. Wu and Gitlin (1983) indicated that the microirrigation application efficiency can be estimated from the emitter flow variation caused by hydraulics alone or by the hydraulics and manufacturer's variation combined. The emitter flow variation or any non-uniformity of emitter flow results in an extra amount of irrigation to meet the crop water requirements. Wu (1975) and Wu and Irudayaraj (1989) developed a computer simulation program to determine all emitter flows within a submain unit with respect to energy gradient curve and changes of energy due to slope conditions. The shape of energy gradient line will not be a straight line but a exponential curve. They also developed a simulation model which randomly selects the emitter flow samples for field evaluation purposes. The computer simulation model can also be used for determining the emitter flow through the lateral line caused by emitter manufacturer's variation or hydraulic design. Howell and Hiller (1974) presented a design equation for determining the length of microirrigation lateral to meet specific uniformity criteria. They also presented dimensionless graphs for trickle irrigation lateral design. Wu and Gitlin (1973) and Wu et. al. (1975) presented a dimensionless energy gradient line for drip irrigation lines. The dimmensionless energy gradient line can be used to determine energy drop along the line if total energy drop (head loss) at the end of the line is determined.When the pressure gradient line is estimated, then the uniform outflow can be achieved by using different sizes of emitter, different lengths of the lateral line or a combination of the length and diameter (size) of emitter, and different emitter spacing. Keller and Bliesner (1990) and Wu *et al.* (1986) reported that in a well designed microirrigation system, the emitter discharge variation along the lateral lines should not exceed 10%. For most normal emitters to achieve this range of discharge variation, the pressure variation along the laterals and manifold should not be more than 20%. The manufacturer's variation of emitter flow for microirrigation emitters is in a range of 2-20% (Solomon, 1979). The hydraulic variation in a microirrigation system will be less significant when an emitter with 10% or more manufacturer's variation is selected (Wu, 1997). If, for constant flow for each emitter, the pressure distribution is determined along a lateral line, the uniform irrigation can be achieved by using different sizes of emitters, different emitter spacing, and different lengths (Mayers and Bucks, 1972; Kenworthy, 1972; Wu *et al.*, 1973). In a microirrigation system, the way that the water is distributed is one of the most important design aspects. One of the major design criteria is the minimization of emitter flow variation along a lateral or submain. The emitters are responsible for direct water delivery to the crop, and they play an important role in achieving high emission uniformity (Kimura, 1987). The discharge variation can be controlled by pressure variation along the line. Gillespier (1979) developed procedures to identify pressure profiles by land-slope and total friction drop at the end of the line. Howell and Hiller (1974) and Wu and Giltin (1973 and 1979) suggested that when the kinetic energy is considered to be negligible in microirrigation line, the pressure variation will be simply a linear combination of the friction drop and energy gain or loss due to the slope. Wu *et al.* (1977) developed design charts based on hydraulic energy considerations and computer simulation. The chart allows a maximum of 20% variation in pressure in the submain. Microirrigation should be designed to minimize pressure variation so that the flow into all lateral lines and emitters will be nearly equal. Howell and Hiler (1974) developed a computer program to determine the lateral pressure loss and emitter flow ratio, emitter spacing and lateral slope. Wu and Gitlin (1979) developed various dimensionless design charts for lateral lines laid on non-uniform slopes. They suggested that if a relatively long lateral is laid on a non-uniform down-slope, a simple down-slope design can be used with variable pipe sizes. In case of a lateral with several sections, each section having a uniform slope, the pipe size for each section can be determined simply by the mean discharge and the slope. A method for designing microirrigation laterals on non-uniform slopes was developed using the finite element method (Kang *et al.*, 1996). They reported that the diameter and length of a single lateral affects the uniformity of water application on sloped fields. The uniformity of water application is considerably decreased or increased if a small increment or reduction in lateral diameter or length of lateral occurs. They reported that it can not be said *a priori* that a shorter lateral or larger diameter will improve, or a longer lateral or smaller diameter reduce, uniformity of water application. They did not consider the effect of emitter clogging on uniformity in their hydraulic analysis. A personal computer is needed for this hydraulic analysis method; however, dimensionless design charts suggested by Wu and Gitlin (1979) are more practical for design of microirrigation laterals on non-uniform slopes. The energy gradient line approach, polyplot, and uniplot developed by Wu and Gitline (1979) and Wu (1985) are widely used to design microirrigation laterals on non-uniform slopes. A set of equations and graphs has been developed by Howell and Hiler (1974) to determine the length of a lateral with respect to desirable discharge uniformity and emitter spacing. Solomon and Keller (1978) derived an expression for the pressure head in a microirrigation lateral and through the pipe network. They provided the flow rate histograms which show the combined effects on emitter discharge variation, head losses and variation in emitter manufacture. They claimed that the emission uniformity can be improved about 2% by doubling the number of emitters. They reported that there is no practical analytical means for dealing with all factors affecting emitter discharge rate during system design. Nakayama *et al.* (1979) developed a method to show the water application uniformity by microirrigation emitters based on the emitter's coefficient of variation. They compared the emitter flow uniformity by estimating the average flow rates for a specified subgroup of the entire emitter population. Myers and Bucks (1972) reported that the emitter flow variation can be reduced by water filtration, improved manufacturing processes, and management technique to avoid salt precipitation, but the major problem from the standpoint of the system design is the friction-induced pressure changes in the lateral pipe. Unless the system is designed to compensate for the pressure changes, emitter discharge will vary along the lateral line.

2.2 Hydraulic performance of the microirrigation system

2.2.1 Emitter flow equation:

The emitter is responsible for emitting the water into the soil at the plant root zone. Kimura (1987) and Keller (1980) reported that most emission devices (drippers, bubblers, sprayers) commercially available regulate flow by dissipating energy through friction resistance. Microirrigation emitters vary in their design from the simple orifice type, long-path emitter to pressure-compensating devices. The emitter flow at any section along a lateral of a microirrigation system is controlled by the pressure in that section. Theoretically, the emitter outflow is a function of the square root of the pressure (Karmeli, 1977; Wu *et al.*, 1979). The emitter's discharge characteristics are usually characterised by the relationship between discharge, pressure and an emitter discharge exponent. The equation for emitter flow that has been used by many researchers (Wu, and Gitlin, 1974; Karmeli, 1977; Howell and Hiler, 1974; Keller and Karmeli, 1974) can be expressed as:

$$q = Kh^x \tag{2.1}$$

where:

q = emitter discharge rate *l/h* (*gph*)

h = working pressure head at the emitter in m (*psi*)

K= the constant of proportionality that characterizes each emitter. The magnitude of K is a size or capacity parameter for an emitter since its value is equal to the emitter flow rate when h equals unity (Howell and Hiller, 1974; Braud and Soom, 1981).

x = the emitter discharge exponent that is characterized by the flow regime. It is the measure of how sensitive the emitter discharge is to pressure.

Solomon (1976) Karmeli (1977) and Wu (1974) suggested that K and x can be determined by measuring the slope of a log plot of pressure versus discharge. To determine the x, q at two different operating pressures should be known. If q_1 and q_2 are emitter discharges at two operating pressures of h_1 and h_2, then the x can be analytically determined as:

$$x = \frac{\log\left(\frac{q_1}{q_2}\right)}{\log\left(\frac{h_1}{h_2}\right)} \qquad 2.2$$

The value of x depends on the type of flow regime. Karmeli (1977), Howell and Hiller (1972,1974), and Wu and Gitlin (1974) reported the following:

$x = 0.5$ in fully turbulent flow (non-compensating orifice and nozzle emitters are always fully turbulent)

$x = 1.0$ in laminar flow

$0.5 < x < 1$ for unstable flow regime

$x = 0.0$ for fully pressure-compensating

The lower the value of x, the less the discharge is affected by the pressure variation. Values of x in pressure-compensating emitters are normally near zero. With the value of x known, equation 2.1 can be used to determine K. Another common way to determine the x and K values is to perform a linear regression on the logarithms of the emitter flows and operating pressures. Equation 2.1 can be presented in logarithmic formula as: $log(q) = x\ log(h) + log(K)$; this formula is the linear form of $y = na + b$, where $y = log(q)$, $n = x$, $a = log(h)$, and $b = log(K)$.

The values of *n* and *b* can be reached from a linear regression of *log(h)* versus *log(q)*. Since $b = \log(K)$, and $k=10^b$, the equation 2.1 can be expressed as:

$$q = 10^{b} h^{n} \qquad 2.3$$

where *n* or *x* is determined from the linear regression and is a measure of the flow variation due to changes in pressure.

The flow in a microirrigation lateral can be considered to be hydraulically steady, and spatially varied with lateral flow. In the other words, the total flow through the lateral changes, usually decreasing with respect to the length of lateral. Figure 2.1 shows the flow and pressure distribution along a lateral with equally spaced emitters along the line.

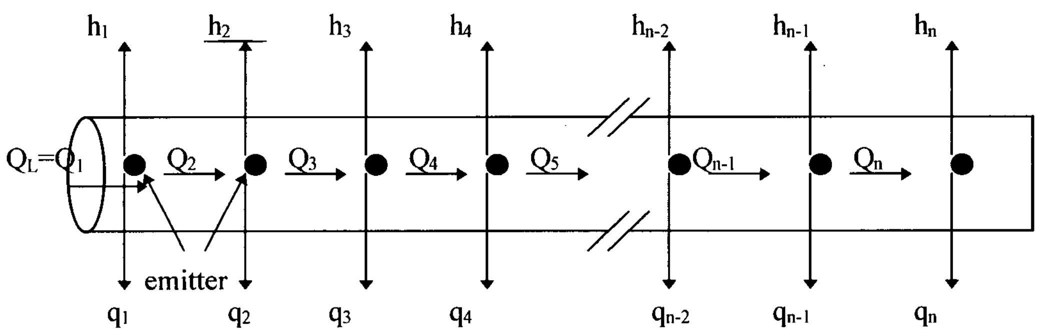


Figure 2.1 Emitter discharge and pressure along the microirrigation lateral

The emitter discharges are presented by q_i ($i = 1,2,3,4,...n-2, n-1, n$). Figure 2.1 shows that the inlet lateral flow (Q_L) is the summation of all emitters' discharge along the line. Q_L can be estimated as follows:

$$Q_L = \sum_{i=1}^{n} q_i = \sum_{i=1}^{n} K h_i^x \qquad 2.4$$

where, Q_L is the inlet lateral flow, q_i is the emitter discharge and h_i is the pressure at i^{th} section .

There are different types of emitters used in a microirrigation system. The flow characteristics of emitters can be characterized by the relation between flow rate, pressure, and emitter discharge exponent, which is related to the flow regime. Karmeli (1977) defined several equations for determining flow rate in different type of emitters as follows:

2.2.2 Turbulent flow in orifice emitters:

In this case water flows through an opening of small diameter, the flow regime is fully turbulent and most of the head loss takes place. The emitter discharge can be determined as:

$$q = A.C_q\sqrt{2gH} \qquad 2.5$$

where:

$A =$ the flow cross section area

$C_q =$ the emitter coefficient that accounts for areal and discharge effects and depends on the nozzle characteristics

$g =$ acceleration due to gravity

$H =$ pressure head in the lateral pipe at the emitter under consideration.

As equation 2.5 shows in the turbulent flow discharge, q is the proportional to the square root of pressure.

2.2.3 Long-path emitters flow:

In this case head loss will occur in the long-flow path and is directly proportional to the length of the flow path in the emitter. The flow can be estimated as follows:

$$l_c = \frac{H.g.d^5\pi}{8.f.q^2} \qquad 2.6$$

where:

l_c = length of the flow path in the emitter

g and H have the same definition as in equation 2.5

f = friction coefficient which is linearly dependent on the inverse of Reynolds number ($f=64/R_e$, and $R_e = \rho VD/\mu = Vd/\nu$, since $V = 4q/\pi d^2$, then $R_e = 4q/\nu\pi d$)

ρ = fluid density (kg/m^3), μ is the dynamic viscosity (kg/ms)

ν = kinematic viscosity (the ratio of viscosity to density) of the water which is equal to 1.0×10^{-6} m^2/s at 20°C

d = flow cross section diameter

V = average velocity of the flow in the emitter

q = emitter discharge.

For the long-path laminar emitters' flow, the equation 2.6 can be modified as:

$$l_c = \frac{H.g^2.d^4.\pi}{128.q.\nu} \qquad 2.7$$

Equation 2.7 shows that the discharge is directly proportional to H under the laminar flow condition.

2.2.4 Flow in multi-exit orifice emitters:

There are two types of multi-exit emitter: a single orifice type supplies several outlet tubes, and the other type is twin-bore tubing. Most pressure head loss occurs in the inner orifice, and a small amount of head loss occurs in outlet tubes. Assuming a circular cross section, the discharge from the single-exit and multi-exit orifice emitter can be determined as follows:

$$d_m = \frac{d\sqrt{q_m}}{\sqrt{q}} = d\sqrt{m} \quad 2.8$$

where:

d_m = flow cross section diameter of a multi-exit orifice emitter

m = number of emitter exits

d = diameter of a single exit orifice emitter having the same discharge as one of the exits of the multi-exit emitter

q = discharge of a single-exit orifice emitter

q_m = discharge of a multi-exit orifice emitter.

2.3 Flow Regime:

The flow in the pipe can be characterized as a laminar, transition and turbulent flow depending on the magnitude of the external force, and density and the velocity of the flowing fluid (Papanastasiou, 1994). For a given flow rate, it turns out that the pressure drop, Δp, (assume $\Delta p = p_2 - p_1$, where p_1 and p_2 are the pressures at points 1 and 2 along a pipe) is directly proportional to ΔL length between points 1 and 2 along the pipe. By varying the flow rate and the pressure gradient ($\Delta p/\Delta L$) along the pipe line, three distinct flow regimes (laminar, transition, and turbulent) can be characterized. Sir Osborne Reynolds (1883 and 1901) correlated these flow regimes by means of a unique dimensionless number that incorporates the average fluid velocity (V), its density (ρ) and viscosity (η), and the diameter (D) of the pipe. Reynolds number can be determined by the equation as given in section 2.2.3 (equation 2.6).

Karmeli (1977) defined four flow regimes based on Reynolds number (R_e) as described in Table 2.1.

Table 2.1 Flow regimes based on Reynolds number.

Flow regimes	***Reynolds number***
Laminar flow	$0 < R_e < 2000$
Unstable flow	$2000 < R_e < 4000$
Partially turbulent flow	$4000 < R_e < 10{,}000$
Fully turbulent flow	$10000 < R_e$

2.4 Head loss:

Microirrigation laterals are mostly made of smooth materials (such pvc or polyethylene). Flow in lateral is generally assumed to be turbulent. Sometimes fully turbulent flow exists at the upstream end of the lateral and becomes laminar at the downstream reach where the velocity decreases to zero. If the microirrigation lateral is considered to be hydraulically smooth, any of several empirical equations can be used to calculate head loss due to friction (Bralts and Edwards, 1987). Usually, the designers are searching for simpler calculation methods that do not compromise accuracy. In a microirrigation system, either the Darcy-Weisbach or Hazen-Williams equation is generally used to compute the head loss of microirrigation pipes (Wu and Yue,1993; Bagarello *et al.*,1997). The Darcy-Weisbach equation is one of the more complex methods for calculating the head loss that are universally accepted (Watter and Keller, 1978; Pitts *et al.*,1986; Hill *et al.*, 1989; Hathoot et el. 1993; Reynolds *et al.*, 1995; Bagarello *et al.*, 1997). The Darcy-Weisbach equation is considered to be theoretical because of its derivation. This equation includes the friction factor, *f*, which is a function of Reynolds number and the pipe roughness as follows (Bralts and Edward, 1987; Von Bermuth, 1990):

$$h_f = f\left(\frac{LV^2}{D2g}\right) \qquad 2.9$$

where:

h_f = head loss due to friction (m)

f = dimensionless friction factor

L = length of pipe (m)

V = average velocity of water in the pipe (m/s)

D = diameter of the pipe (m)

g = acceleration of gravity (9.807 m/s^2).

It is the calculation of the friction factor f that complicates the Darcy-Weisbach equation, because the friction factor cannot be conveniently expressed mathematically. There are theoretical methods for estimating the f: in these cases the solution is reached either by iteration or by reference to the Moody diagram. To estimate the f, empirical approaches are commonly used. Blasius (1913) proposed a simple equation for estimating f for very smooth pipes as: $f = a.R_e^{\,b}$, where f is the friction factor, R_e is the Reynolds number and "a" and "b" are the empirically determined coefficients. However, the equation is valid for virtually any pipe size as long as the Reynolds number is limited to 10^5. In laminar flow or unstable (critical zones) flow when the Reynolds number is less than 4000, the Blusius equation will overestimate the friction factor by as much as a factor of five. If flow is assumed to be laminar, f can be estimated by: $f = 64/R_e$. Practicing engineers do not like to use the Darcy-Weisbach equation and prefer simpler empirical equations which do not require calculation of the Reynolds number and reference to a table of viscosity values. Failure to correct for viscosity differences can cause significant error in results.

In a microirrigation system, a widely used empirical equation for calculating the pipe friction loss is the Hazen-Williams formula (Howell and Hiller, 1974; Keller and karmeli, 1974; Wu and Gitlin, 1975 and 1977; Gillespie *et al.*, 1979; Braud and Soom, 1981; Jepson, 1982; Bralts and Edward, 1987; Feng and Wu, 1990; Keller and Bliesner, 1990; Tajrishy and Hills, 1992; Wu and Yue, 1993) as expressed below:

$$h_f = K_H . L\left(\frac{Q}{C_H}\right)^{1.852} (D)^{-4.87} \qquad 2.10$$

where:

h_f = head loss due to pipe friction (m)

K_H = conversion factor depending on selected units (1.212×10^{10} in this case)

L = length of pipe (m)

D = inside diameter of the pipe (mm)

Q = total pipe flow (l/s)

C_H = pipe roughness coefficient.

The popularity of this equation is due to the simple calculation resulting from a single roughness coefficient factor for any pipe size or velocity. Equation 2.10 holds for a description of flow in any kind of pipe depending on the material as expressed by C_H. However, the difficulty is that if accuracy is very important, a single Hazen-Williams factor (C_H) cannot be used for all range of flows or diameter (Haughes and Jepson, 1978). The value of the friction coefficient C_H has a strong influence on the friction loss calculation. Many friction loss charts for smooth plastic pipe have been developed with a C_H value of 150. Previous work (Keller and Karmeli, 1974) shows that for plastic pipe, $C_H = 150$ is normally used. However, Hansen (1973) found that the laterals with emitters spaced at 1.52 m (5 ft) intervals had equivalent C_H values between 98 and 136. Utah State Division of Health allows only C_H =120 (Haughes and Jepson, 1978). Braud and Soom (1981) showed that the Blasius and Hazen-Williams equations are in good agreement at C_H = 130. Hughes and Jepson (1978) reported that the C_H factor of 150 recommended by most pvc pipe manufacturers is too high. They manipulated the Hazen-Williams equation into the form of the Darcy-Weisbach equation and then identified "f" as a function of C_H. They measured coefficients averaging 133 which is closed to that predicted by superimposing Hazen-William's coefficients on the Moody diagram. They also reported that by the Moody diagram analysis, flow through PVC pipe at Reynolds numbers ranging from 10^3 to 10^4 requires C_H of 130 to 140. In general practice, the C_H value is assumed to be 140 for smooth polyethylene pipe (Sneed, 1973; Tajrishi and Hills, 1992). Howell and Barinas (1980) measured emitter friction loss in laterals and established a relationship between obstruction area and its friction effect. In the Hazen-Williams equation, the ability to adjust the friction factor C_H for emitter presence is an advantage.

For a given pipe size and length, the total friction loss in a pipe consisting of a number of equally spaced outlets is less than in that of a constant flow and a single outlet (Scaloppi, 1988; Tajrishi and Hills, 1992). The concept of adjustment correction factor "*F*" has been developed by Christiansen (1942) to correct the friction loss calculated from the general formula that assumes that all of the water is carried to the end of the line. In this procedure, Christiansen assumed that all outlets along the lateral had equal spacing and discharges and that the total flow entering the pipe left through the line. Christiansen (1942) proposed a simple and fairly accurate solution for head loss in laterals with multiple outlets as:

$$h_f = FK_H L\left(\frac{Q}{C_H}\right)^m (D)^{-(2m+n)} \qquad 2.11$$

where:

m = velocity exponent (m = 1 for laminar flow, and m = 1.852 for fully turbulent flow in the Hazen-Williams formula)

n = exponent of the inside diameter

F = adjustment correction factor.

Equations 2.9, 2.10 or 2.11 are used to determine the flow friction loss in a lateral or manifold in a microirrigation system. The head loss in a microirrigation lateral with flow rates along its length is not linear but parabolic, with a steep slope at the beginning of the lateral and almost flattening toward the distal end. Keller and Karmeli (1974) reported that in a single lateral line for a wide range of emitter exponent and pressure losses, the average pressure head occurs at L=0.39 (L = length of lateral). They also reported that approximately 77% of total lateral head loss occurs between L = 0.0 and L = 0.39, while 23% of head loss occurs between L = 0.39 and L = 1.

The losses through the lateral fittings and emitter connections are not included in those equations. Where there are only a few pipe fittings, the pressure loss across these fittings is termed a minor loss. If there are a large number of fittings present in a microirrigation system, the minor losses can be an important consideration. In the present reseach, the friction loss due to a few pipe fittings is not considered.

2.5 Adjusted *F* factor:

An adjusted *F* factor to compute pressure head loss in a multiple outlet pipe with equally spaced outlets has been derived by several researchers. The *F* factor introduced by Christiansen was derived by assuming that the first outlet is located one outlet spacing away from the lateral or manifold inlet (Jensen, 1980). The following approximation of adjusted "*F*" factor was presented by Christiansen (1942):

$$F = \frac{1}{m+1} + \frac{1}{2N} + \frac{\sqrt{m-1}}{6N^2} \qquad 2.12$$

where N is the number of outlets on the lateral, and m is the velocity exponent (in Hazen-Williams formula m = 1.852). For N>10 the last term of the equation 2.12 can be omitted. Jensen and Fratini (1957) modified the equation 2.12 to account for the first outlet being located one-half an outlet spacing from the supply line as follows:

$$F = \frac{1}{2N-1} + \frac{2}{(2N-1)N^m}\left[(N-1)^m + (N-2)^m + \ldots + 1^m\right] \qquad 2.13$$

Utilizing the coefficient values from Jensen and Fratini (1957) in a nonlinear least squares correlation procedure yields the explicit function as follows (Gohering, 1976; Oron and Walker, 1981):

$$F_{(n_\circ)} = 0.63837 n_\circ^{-1.8916} + 0.35929 \qquad 2.14$$

where n_o is an integer variable expressing the number of outlets on a given pipe.

2.6 Variation of emitter flow rate:

The uniformity of emitter flow depends on the emitter flow variation, which is mainly affected by several factors as explained in previous sections.The main parameters affecting emitters flow variation are discussed below.

2.6.1 Dimensionless energy gradient line:

In a microirrigation system the pressure variations in the lateral affect emitter flow rate. The pressure variation along the lateral can be determined by using the energy gradient line. Wu and Gitlin (1975) developed a procedure to determine the dimensionless energy gradient line. They assumed that all the emitters along the lateral line discharge the same flow. This approximation, which results in the energy gradient line in a curve of exponential type (not straight line), can be used to calculate the head loss directly at any point along the lateral. When a constant emitter flow rate along the lateral is assumed, the shape of the energy gradient line can be expressed dimensionlessly as the energy drop ratio (R_i) as follows:

$$R_i = \frac{\Delta H_i}{\Delta H} = 1 - (1 - i)^{m+1} \qquad 2.15$$

Where R_i defines the shape of the energy gradient line and is expressed as a friction drop ratio, ΔH is the total friction drop at the end of lateral line (i.e., computed from equation 2.11), ΔH_i is the total friction drop at a given length ratio(i), i is a ratio of a given length from the inlet l to the total length of lateral L $(i=l/L)$, m a power coefficient of total discharge in the friction drop equation (when Hazen-Williams formula is used, m is 1.852), then the equation 2.15 can be expressed as:

$$R_i = 1 - (1 - i)^{2.852} \qquad 2.16$$

The total pressure variation along a lateral in a microirrigation system can be expressed as a linear combination of the original pressure and the variation due to the energy slope and line(terrain) slope (Wu and Yue, 1993). Using the dimensionless energy gradient line concept and uniform slopes the pressure at any *i* location along the lateral line can be determined as follows (Wu and Gitlin, 1974; Wu *et al.*, 1979; Bralts *et al.*, 1987):

$$h_i = H_\circ - \Delta H_i + \Delta H'_i \qquad 2.17$$

or

$$h_i = H_\circ - R_i \Delta H \pm R'_i \, \Delta H' \qquad 2.18$$

where h_i is the pressure at any *i* location along the lateral, H_o is the total energy (pressure head) at the inlet and is specified as the operating pressure, ΔH is the total head loss due to friction at the end of lateral, $\Delta H'$ is the total energy gain or energy loss ("+" for down-slope and "-" for up-slope), R'_i is defined as the ratio of $\Delta H'_i$ and $\Delta H'$ $(R'_i = \Delta H'_i / \Delta H')$, where $\Delta H'_i$ is the energy gain or loss (for down-slope or up-slope situations) at the *i* location along the lateral. For uniform slopes, R'_i is the same as the length ratio, *i*. With respect to the general equation of emitter flow and considering energy gradient line formula, the emitter flow rate along the lateral at any *i* location (q_i) is directly related to the pressure variation at the same *i* location along the lateral as follows:

$$q_i = K\left(H_\circ - R_i \Delta H \pm R'_i \, \Delta H'\right)^x \qquad 2.19$$

On uniform slopes, the term of $R'_i \Delta H'$ can be changed to $i\Delta H'$ (Wu *et al.*, 1986). Theoretically, flow rates of the pressure-compensating emitters should be independent of operating pressure (Madramootoo, 1988) and pressure variation along the lateral. Therefore, pressure-compensating emitters have an advantage, especially on sloped terrain.

2.6.2 Emitter manufacturer's variation:

Manufacturing of an emission device must be precise because the emitter flow path is usually small, less than 2mm in diameter. Due to inconsistencies in the material used for manufacturing the emitter and the inability to hold constant pressure and temperature, it is difficult to manufacture two emitter flow passages that are exactly alike (Solomon, 1979; Özekici and Sneed, 1995). Small deviations in the critical dimensions of the emission devices would result in relatively large deviations in the emitter flow rates, although the absolute magnitude of the variation might be very small. In order to have a consistent flow rate, emitters must maintain the same physical characteristics over their lifetime. In manufacturing the pressure-compensating emitters, elastomeric material is used to achieve flushing action and pressure compensation, and these parts are very difficult to manufacture with consistent dimensions. It is generally assumed that the variations resulting from the manufacturing process are normally distributed about their mean value. The concept of manufacturer's variation of emitters was first developed by Keller and Karmeli (1974) and then researched by Solomon (1979). A number of researchers defined a parameter called the manufacturer's coefficient of variation, *CV*, as a statistical parameter used to identify the quality of a sample of new emitters (Solomon, 1979; Bralts *et al.*, 1981; Wu, 1983; ASAE EP405.1, 1997). This parameter is used to evaluate the variation in discharge in a sample of new emitters when operated at a constant temperature and near the design operating pressure of the emitter. The value of *CV* can be calculated by measuring the discharge from a sample of new emitters at a fixed inlet pressure; however, it is usually available from the manufacture. The emitter manufacturer's coefficient of variation can be determined as follows (Keller, 1980; Wu, 1983; ASAE EP405.1, 1997):

$$CV = \frac{S_q}{q_{ave}} \qquad 2.20$$

where:

CV = manufacturer's coefficient of variation

q_{ave} = average discharge of emitters in the sample (*l/h*)

S_q = standard deviation of the emitter discharge rate in the sample.

q_{ave} and S_q can be determined as follows:

$$q_{ave} = \frac{1}{n}\sum_{i=1}^{n} q_i \qquad 2.21$$

$$S_q = \left[\frac{\sum_{i=1}^{n}(q_i - q_{ave})^2}{n-1}\right]^{\frac{1}{2}} \qquad 2.22$$

where:

q_i = discharge of an emitter

n = number of emitters in the sample.

CV is one of the significant factors affecting the overall uniformity of the microirrigation system. Wu (1997) found that *CV* is one of the statistical terms which can be used to show the microirrigation system uniformity. Reasonable ranges of *CV* for evaluating the system uniformity vary from 0.05 or less to 0.15 or more. Numerous guidelines have been suggested for *CV*, but those recommended by ASAE EP405.1 (1997) shown in Table 2.2 are used for this research.

Table 2.2 Classification of manufacturer coefficient of variation recommended by ASAE, EP405.1 (1997)

Classification	***Manufacturer's coefficient of variation***
< 0.05	excellent
0.05 to 0.07	average
0.07 to 0.11	marginal
0.11 to 0.15	poor
> 0.15	unacceptable

2.6.3 Temperature Variation:

Microirrigation lines and emitters on the ground surface are subject to temperature changes which affect the hydraulics of microirrigation lines. The effect of temperature variation on emitter discharge variation occurs over a period of time with day-night, day-to-day, and seasonal weather changes, and through the lateral due to solar heating of black pvc or polyethylene pipe. As the water discharges through the lateral line, viscosity decreases and rate of heating increases. If the end-to-end of lateral line temperature variation due to solar heating is minimal, the seasonal temperature variation (i.e., spring and summer) can cause discharge variation from -20 to +10 percent (Parchomchuk, 1976). Karmeli (1977) showed that the Reynolds number, R_e, is sensitive to water temperature variation due to change in water viscosity. The kinematic viscosity (ν) of water changes with respect to the temperature. The kinematic viscosity of water for any temperature T with respect to the viscosity of water at 20°C as a base can be shown as follows (Assaf, K and S.A. Asaf, 1974):

$$\nu_T = \nu_{20} \left(0.98\right)^{T-20} \qquad 2.23$$

where ν_{20} and ν_T are the kinematic viscosity of water at 20°C and T°C water temperatures.

Keller and Bliesner (1990) found that the discharge from most long-path emitters depends on the water viscosity, which changes with temperature. They indicated for a long-path emitter the increase in discharge due to decreased water viscosity is roughly 1% for each 2°C increase in water temperature. For a tortuous-path emitter, the increase of discharge is roughly 1% for each 4°C increase in water temperature. Solomon (1985) reported that the flow rate from some emitters is sensitive to water temperature and the influence of water temperature on emitter flow rate is linear. Therefore the variation in water temperature through the subunit must be considered. Parchomchuk (1976) measured the effect of temperature variation on emitter flow rate for various types of emitter and found the effects of temperature to be less than theoretically predicted, but still significant. There is general agreement that the emitter flow rates should not vary more than ± 10% for uniform water application (Bucks and Myers, 1974; Wu and Gitlin, 1974; Keller and Karmeli, 1974). Water viscosity changes that are due to changing water temperature cause emitter flow variation greater than the maximum ±10% limit if the flow through the emitter is laminar (Parchomchuk, 1976). On the other hand, turbulent flow emitters are not affected by viscosity changes. Discharge variation at the temperature range +5°C – +60°C was reported 23 – 53% (Parchomchuk, 1975), while Keller and Karmeli (1974) expressed a list of theoretical discharge variation based on viscosity changes in the temperature range +5°C – +60°C as 2.8% per °C.

The effect of water temperature on discharge variation can be decreased by creating turbulent flow or can be neglected when turbulent flow emitters are used. The microtube and spiral passage type of emitters are affected more by water temperature variation than orifice and vortex type emitters (Peng *et al.*, 1986; Wu and Phene, 1984; WU, 1988; Parchumchuk, 1976). In a turbulent flow regime the effect of viscosity changes on emitter flow rate is insignificant [since $\nu = 4q/(R_e \pi d)$ when R_e has a high value, changes of ν in turbulent flow can be ignored]. Peng *et al.* (1986) derived several theoretical equations which showed that temperature differences ranging from ±20°C – ±50°C along the line causes only a 1% – 2% difference in relative friction loss at the middle section of the line. They reported that in a practical situation a temperature difference ranging from 10°C – 20°C will create only a 5%–6% difference in total friction at the end of the line. Zur and Tal (1981) measured the long-path emitter discharge along a lateral line exposed to solar radiation. They reported that with increasing distance from lateral inlet, the emitter discharge became less dependent on pressure distribution and more sensitive to the temperature distribution along the lateral and the discharge sensitivity to temperature. They found a linear relationship between the emitter discharge and temperate distribution along the lateral. They also reported that the sensitivity of emitter flow to temperature depends on the type of emitter (the labyrinth-type, for instance), the effect of temperature variation along the lateral on emitter discharge variation can be neglected. The following equations show the effects of temperature variation on the hydraulic of microirrigation lateral lines (Peng *et al.*, 1986):

$$F_T = a\left(\frac{VD}{v_{20}(0.98)^{T-20}}\right)^b \qquad 2.24$$

where:

F_T = friction coefficient for a given water temperature

a and b = constant and dependent on the Reynolds number (the range of "a" is 0.0699–0.545 and "b" is between -0.133 and -0.315)

V = mean velocity (m/s)

D = inside diameter of pipe (m)

v_{20} = kinematics viscosity (m^2/s) of water temperature at 20°C which is 1.0×10^{-6} m^2/s

T = water temperature in °C.

The friction coefficient for water at 20°C (F_{20}) can be determined as follows:

$$F_{20} = a\left(VD/v_{20}\right)^b \qquad 2.25$$

It is suggested that shading or burying lateral lines will reduce the end-to-end lateral line temperature variation. Operating the system during the night will also completely eliminate the effect of solar heating.

2.7 Clogging in the microirrigation system

2.7.1 Emitter clogging:

Emitter clogging is a major problem in the microirrigation system unless correct preventive measures are taken. Field evaluation of emitter clogging is a very difficult task. Partial clogging is just as bad as complete clogging, because both reduce application uniformity and alter the hydraulics of the entire system (Wu and Lau, 1991; Nakayama and Bucks, 1991). Partial clogging of emitters can be defined as the partial constriction of flow due to a decrease in emitter cross section area. A completely clogged emitter is a special case of clogged emitter where the emitter cross sectional area is zero (Bralts *et al.*, 1981). Award (1982) indicated that in polyethylene pipe line, as temperature is increased, the rate of chemical clogging will also be increased. The reason for this phenomena is that of some chemical action and reaction under temperature variation of water causes carbonate sedimentation (from soluble bicarbonate) in the lateral or emitter. Different factors cause emitter clogging in a microirrigation system. Clogging will affect the hydraulics of the microirrigation system and adversely affect the rate of water application. Following the cause of emitter clogging and its impact on the hydraulics of a microirrigation system are discussed.

2.7.2 Causes of emitter clogging:

Knowing the exact factor that causes emitter clogging is difficult, because the various elements in the water can interact with each other and result in more clogging problems. The cause of emitter clogging varies from location to location. According to a lot of different research aimed at solving the clogging problems in microirrigation system, emitter clogging is still the major problem in some arid and semi arid areas. The International Commission of Irrigation and Drainage have reported that the clogging results from physical, chemical, and biological factors. Bucks *et al.* (1979) classified the factors in irrigation water which cause emitter clogging into three groups: physical (suspended solids,), chemical (dissolves chemical in water which can be precipitated), and biological (bacteria and algae). Reservoir water contains a variety of phytoplankton and zooplankton which are developed during storage according to the specific conditions prevailing in the reservoir. Nakayama and Bucks (1991) and Bucks *et al.* (1979) have derived a water quality classification scheme relative to its potential for a microirrigation system as shown in Table 2.3.

Table 2.3 Classification of water quality relative to its potential for emitter clogging

Clogging factors	Hazard Rating		
	Minor	Moderate	Severe
PHYSICAL *(mg/l)*			
Suspended solids	<50	50-100	>100
CHEMICAL *(mg/l)*			
pH	<7.0	7.0-8.00	>8.00
Dissolved solids	<500	500-2000	>2000
Manganese	<0.1	0.1-1.50	>1.50
Total iron	<0.2	0.2-1.50	>1.50
Hydrogen sulphide	<0.2	0.2- 2.0	>2.00
BIOLOGICAL *(No./ml)*			
Bacterial number	<10000	10000-50000	>50000

Table 2.3 can be used as a guide for identifying potential clogging hazards as well as for selecting and designing water treatment systems.

Emitter clogging is also related to emitter design and to the level of filtration treatment. Boman (1995) studied the effects of orifice size on emitter clogging rate. He reported that the clogging rates ranged from 1.6–34.4%, depending on the mechanisms used to disperse the water. Emitter designs which used enclosed caps to disperse water had the highest clogging rates. He also found that an inverse relationship was evident between the number of emitters clogged and orifice area. Ravina *et al.* (1997) studied the control of clogging in microirrigation when the system utilised treated wastewater effluent stored in a surface reservoir. They reported that there are differences between and among emitters of various manufacturers, as to their sensitivity to clogging. They also found when the water is pumped from a depth where the dissolved sulphide concentration is high and the water is slightly oxygenated, the growth of sulphur bacteria is stimulated and a clogging biomass is formed. The most common causes of microirrigation emitter clogging are physical particles, chemical reactions in the water and biological growths such as bacteria and algae causing scale build-up (Pitts *et al.*, 1990). Emitter clogging is usually caused by a combination of more than one of these factors. Gilbert *et al.* (1979) have reported in an experiment with Colorado River water on citrus trees that five of the eight emitter systems required sand and screen (200 mesh) filtration plus chemically conditioned water to prevent emitter clogging from physical suspensions. They explained that dominant cause of emitter clogging and flow reduction was physical particles, whereas biological and chemical factors were of secondary importance. Emitter clogging is affected more by physical factors if surface water (river or channel water) is the main source for irrigation. Emitter clogging may be caused by relatively large amounts of physical particles, which usually accumulate at the inlet of the emitter, or by instantaneous sedimentation of small particles through the emitter waterway. If ground water is used in a microirrigation system, the emitter clogging is usually caused by chemical components such as calcium, magnesium, and carbonate or sulphate (Gorgly, 1986). Salt or chemicals can precipitate in the emitters even after filtration if proper precautions are not taken. Waters relatively high in multivalent cation, pH and temperature are conducive to chemical precipitation. Hills *et al.* (1989) studied the chemical clogging effects of high calcium content water on drip irrigation uniformity. They evaluated the water qualities with electrical conductivity of 0.59, 1.12, and 2.02 ds/m by injecting the calcium, magnesium and bicarbonate ions into the water source. They found a reduction in submain flow rate over time. Emitter flow reduction was most dramatic for the water with high salt content and least for the water with the lowest salt content.

Generally, emitter clogging begins with the emitter located at the far end of the lateral (Zeier and Hills, 1987; Ravina *et al.*, 1992). Any carelessness in operating may cause a big problem in microirrigation systems. Nakayama *et al.* (1991) have reported that either the large quantities of microscopic to sand-size plastic material which originate from the sawing of the pipes during the installation, or oil and grease particles which are leaked from the booster pump or other parts of microirrigation system cause emitter clogging. Biological activities are another factor that causes emitter clogging. The biological factors of emitter clogging are filaments, slimes, and microbial depositions such as iron, sulphur, and manganese (Bucks *et al.*, 1979). Different types of organic components (slimy material) are classified in four groups: compounds of iron, manganese compounds, sulphur compounds, and unspecific compounds (Ford, 1976). The timing of water sampling is important, especially when there are large fluctuations in water quality during the irrigation season. The quality of water may be good or poor at different times of the year (Bucks *et al.*, 1979). The effects of fertilizer or other chemicals on the irrigation water may create clogging problems but can be tested by the operator by treating the water with the additive (Gilbert and Ford, 1986). Bucks *et al.* (1979) and Nakayama and Bucks (1991) suggested that chemical and physical analyses of the irrigation water should be made before a new microirrigation system is installed. If different water qualities are to be mixed, this mixture may require further evaluation as chemical and physical interactions may occur that can drastically change the quality of the resultant water.

2.7.3 Emitter clogging and hydraulics:

Emitter clogging will adversely affect the rate of water application and uniformity of water distribution, and will increase operating costs (Bucks and Nakayama, 1978). Bralts *et al.* (1982) found that due to emitter clogging, the total flow of lateral line will be decreased and thereby reduce the total friction in the lateral line. Reduction in friction along the lateral line results in a slightly higher pressure, or more flow from non-clogged emitter through the lateral. Regarding these hydraulic changes, a 20% rate of emitter clogging will not necessary correspond to a 20 percent reduction in lateral flow, but flow reduction should be less than 20 percent. The term "coefficient of variation" can be used to relate the effects of emitter clogging on the statistical uniformity and emitter clogging (Bralts *et al.*, 1981). A statistical term called "emitter discharge coefficient of variation including emitter plugging" has been used by ASAE EP458 (1997) to calculate the effect of emitter plugging on the coefficient of variation.

Several methods have been used for describing the uniformity of water application in microirrigation, but as yet, none of these methods has isolated the effect of clogging (Nakayama and Bucks, 1981). Bralts *et al.* (1982) developed a theoretical equation to evaluate the effects of emitter clogging on drip irrigation for both single and dual chamber lateral line hydraulics, based on the assumption that the clogging is uniformly distributed along the lateral. For example, they reported that the percentage of total flow under 10% clogging situation can be calculated as: $P_{0.1} = q_{0.9}/q_0 = [0.9\ nC\ (0.874\ h_0)^{0.5}]/[nC\ (0.85\ h_0)^{0.5}] = 0.913$, where $P_{0.9}$ is the percentage of total flow for 10% clogging. Their results indicated that 10% clogging will result in 91.3% total flow or only an 8.7% reduction of total flow. They made similar calculations for all other percentages of clogging and they showed the results of the calculations by several curves. They indicated that the relationship between clogging and flow rate was very close to a direct proportion for a single chamber lateral, whereas for dual chamber lateral lines, it was dependent on the design ratio of inner to outer orifices. The dual chamber is usually designed to have a ratio equal to 4 or 5 to 1. They claimed that when the inner and outer orifice are of equal size, the percentage of total flow is affected more by inner orifice clogging than by outer orifice. With different sizes of inner and outer orifices, the larger size of the outer orifice results in less change in total flow due to clogging. Emitter manufacturers attempt to meet the ideal characteristics such as accuracy, cost and feasibility to manufacture the emitter, but the characteristics are, to a certain degree, contradictory. A lower emitter flow rate requires smaller flow passages which clog easily. The benefits of pulse irrigation have been reported by Jackson and Kay (1987). They suggested that if pulse irrigation is used, emitter size can be increased, thus reducing clogging without diverse effects on soil water wetting patterns. On the other hand, a major factor limiting high-pulse discharge is surface water ponding. When the flow rate exceeds the local soil infiltration rate, ponding will spread rapidly and result in run-off losses and soil erosion. Hills and Ebaby (1990) studied the characteristics of six different types of self-cleaning emitters under clear water, but with organic or inorganic impurity conditions. They found that all emitters were relatively successful at self-cleaning when the water's impurities were inorganic. However, organic impurities resulted in gradual clogging through microbial growth (bacterial slimes) within the emitters.

Nakayama and Bucks (1981) developed a simulation model to evaluate the uniformity and the average water discharge rate of a microirrigation system with different degrees of emitter clogging. They introduced various combinations of clogging into the model, randomly selected the clogged emitter, and did not take into account partial clogging. They also reported that the simulation model did not consider the practical hydraulic implications of clogging. In a general way, the emitter clogging can lead to over-irrigation since the remaining, normally functioning emitters would be subjected to an increase in line pressure. Wu (1993) reported that the clogging can be decreased by reducing the emitter spacing when the spatial uniformity is under consideration. Bralts *et al.* (1982) predicted emitter clogging rates based on the lateral flow rate change. These predictions were based on the assumption that the clogging is uniformly distributed along the lateral line. Wu *et al.* (1991), confirmed that clogging is not based on a random process in which it may be distributed uniformly along the lateral line. Rather, more clogging is concentrated in the downstream quarters.

2.7.4 Prevention and reducing clogging:

The prevention of clogging in drip systems begins with the proper design. Recommendations and guidelines for preventive maintenance, including water filtration, pipeline flushing, chemical treatment, and field inspection, have been presented by Bucks *et al.* (1979). In addition, proper procedures for the flushing and field inspection of a microirrigation system are essential. Gilbert *et al.* (1980) have reported that chemically conditioning the water with continuous acid provided further benefit to control emitter clogging. An experiment in Florida indicated that chlorinating successfully controls iron slime when iron concentrations were less than 3.5 *mg/l* and the pH below 6.5 (Nakayama and Bucks, 1986). It is important to keep debris from entering pipes and emitters before, during and after installation. Nakayama (1986) suggested that the municipal water which has been treated to remove suspended particles and bacteria is the ideal water for use in a microirrigation system. However, municipal water may be too expensive or not readily available for irrigation puprposes. An alternative source of water suitable for farm operation is water treated onsite to an acceptable level for the proper performance of microirrigation system. It is very rare that irrigation water does not need some sort of filteration treatment. If the filter is utilized in a microirrigation system, the high quality of water may be maintained to prevent emitter clogging. However, complete removal of the suspended materials from the irrigation water for use in a microirrigation system is impractical (Nakayama, 1986; Zeier and Hills, 1987). Particles present in the irrigation water range in size from the submicrometer virus to the larger sand-size. The size of filter varies and depends on the water source and quality of water (Bruce, 1985). However, if the filters are the first line of defence in preventing clogging, they should be monitored and cleaned regularly.

The microirrigation researchers and equipment manufacturers have chosen two approaches in order to reduce the emitter clogging. Emitter device developing is the first approach, which may require less or minimum maintenance (Wilson, 1972; Solomon, 1976,1979). The second approach is to focus attention on improving the quality of water before it reaches the emitters (McElhoe and Hilton 1974; Bucks *et al.*, 1976).

Many inventors and manufactures sold different types of emitter such as non-clogging or self-cleaning emitters which were supposed to solve the problem of emitter clogging but unfortunately did not adequately do so (Nakayama *et al.*, 1991). The most important maintenance for microirrigation systems is preventative: there should be a regular routine of flushing all microirrigation lines whether they need it or not. The more frequent the flushing of the microirrigation system lines, the longer the system will provide trouble-free service. Most clogging factors can be found in open reservoirs and storage of waste-water effluent for use in microirrigation systems (Bucks *et al.*, 1979; Gilbert *et al.*, 1981; Nakayama and Bucks, 1991). Since the emitter clogging is caused by chemical, physical, and biological contaminants, filtration systems should also be flushed regularly to prevent orifice clogging and an excessive pressure loss through the filters.

Jackson and Kay (1987) described the result of their laboratory study which showed the effects of pulsing flows on the reduction of clogging. They reported that an alternative approach to the clogging problem is to increase the emitters' waterway size. However, this may increase the emitter discharge, change the pattern of wetting in the soil, and cause surface water ponding, run-off and soil erosion. There is evidence to suggest, however, that an established soil wetting pattern can be maintained at the higher discharge rate if the flow is pulsed. Therefore, it is possible to increase the emitter size in order to reduce the clogging tendency. Emitter discharge variability may be periodically tested to identify the emitter clogging. The degree of emitter clogging can be used as an indirect measure for assessing the effectiveness of a microirrigation filtration system, and it can also be used as a measure of the effectiveness of preventative practices such as chemical water treatment. ASAE EP458 (1997) reported that in order to preventing emitter clogging, specific and detailed studies of the water quality and application of fertilizers or other chemicals should also precede the design. Neglecting to analyse the water and provide adequate treatments could result in the failure of the microirrigation system to function properly.

2.8 Water treatment and chlorination:

Water quality is critical to microirrigation. Proper water treatment is the main approach to controling emitter clogging, and the type of treatment is based on the quality of irrigation water (Nakayama and Bucks, 1991). Presently, the major source for microirrigation is the water diverted from other traditional irrigation usage, such as waste water from cities and industries. In general, water with low amounts of suspended inorganic and organic particulate materials, dissolved chemical constituents (i.e. calcium carbonate, iron and manganese), and microbes that cause slime development, appears to create the least problems (Nakayama *et al.*, 1987). Bruce (1985) reported that organic matter such as algae is not easily removed from the screen filter mesh because screen filters are used in systems where low amounts of organic matter are present in the water. For surface water supplies, total suspended solids may vary from 1 *mg/l* to 75 *mg/l* or more (Nakayama *et al.*, 1978). Ayers (1975, 1977) suggested the four general problem areas of salinity, toxicity, permeability, and miscellaneous to evaluate the quality of water. Quality is difficult to evaluate except in terms related to specific use.

Municipal water that is chlorinated for controlling disease-causing bacteria has the least problems, but treatment of agricultural water to this quality can be impractical and uneconomical (Bucks *et al.*, 1979). Irrigation water with a high concentration of sulphide can cause iron precipitation. The dissolved sulphide anion can also react with active chlorine when the water is chlorinated, and in this case, the effectiveness of chlorination is reduced. Consequently, the chlorination requirement of irrigation water including sulphide is higher than that of the typical non-sulphide irrigation water. When the soluble iron in irrigation water is high (>0.4 *mg/l*), the chlorination can cause large amounts of iron to precipitate. In this case, the chlorine injection should be made at a sufficient distance upstream from the filtration system to allow sufficient time for mixing and chemical reaction to take place before the iron flocculent reaches the filter to removal (Nakayama and Bucks, 1991). Gamble (1985) reported that adding hypochlorite into the wells with high soluble iron content can control the iron clogging in a microirrigation system. Bucks *et al.* (1979) suggested that when the pH of irrigation water is above 7.5 and water hardness (calcium or magnesium) is also high, the calcium or magnesium carbonate can be precipitated in the filter, tubing, or emitter. Adding acid to irrigation water will lower the pH and reduce chemical precipitation. They reported that the clogged emitters can be reclaimed by treating the system for about 24 hours with high chlorine and acid (100 *mg/l* of *Cl* at a pH of 2). They found that by this treatment, the partially clogged emitter flow rates can be increased from 50% to approximately 90%–95% of design, and continuous 1 *mg/l* chlorine at a pH of 7 helped to maintain the system operation for several years. Gilbert *et al.* (1981) reported that in an experiment with Colorado River water on citrus trees under a microirrigation system, the emitter performance was best in a treatment with continuous acid. They claimed that the most efficient treatment for prevention of emitter clogging is continuous acid for pH control of carbonate formation and precipitation coupled with sand and screen filtration. Table 2.3 shows the water quality classification scheme relative to its potential for microirrigation system. Bucks *et al.* (1979) and Nakayama and Bucks (1991) suggested that chemical and physical analyses of the irrigation water should be made before a new microirrigation system is installed. They found that when different water qualities are mixed, this mixture may require further evaluation as chemical and physical interactions may occur that can drastically change the quality of the resultant water. In general, in a microirrigation system it is possible to use a lower quality of water which is generally considered unacceptable in a conventional irrigation method (Seifert *et al.*, 1975). Bernstein and Francois (1973), in a study of comparison of different irrigation methods, used saline water with a salt concentration of 450 *mg/l* and 2450 *mg/l* (high salinity water) in a trickle irrigation system. Similar work has been done by Singh *et al.* (1978) in which saline water at 3000 *μmhos/cm* (≈1920 *mg/l*) and 10000 *μmhos/cm* (≈6400 *mg/l*) was used for drip irrigation.

2.9 Chemigation and fertigation:

Chemigation involves injecting a water soluble fertilizer, herbicide, insecticide, fungicide, or nematicide into the microirrigation system. Fertigation is the process of dissolving soluble fertilizer into the irrigation water and applying the solution to the microirrigation system. In arid and semi-arid regions, fertigation is necessary to supply sufficient fertilizer, especially nitrogen for fields irrigated with a microirrigation system (Keller and Bliesner, 1990). The criteria for fertilizer application in microirrigation have been developed by Rolston *et al.* (1986). They consider the solubility of the fertilizer and the interactions of the fertilizer with the dissolved components in the irrigation water. Many different liquid, liquid suspension, and dry fertilizer materials are applied to the irrigation water through the microirrigation system. There is a wide variety of soluble dry fertilizers containing N, P, and K for dissolution in the irrigation water through the system. There are some chemical problems related to the injection of various fertilizers into the irrigation water. For instance, ammonia injection causes a rise in pH and potential precipitation of both soluble calcium and magnesium which may result in coating the inside of the lateral pipe and, consequently, emitter clogging (Keller and Bliesner, 1990).

Several kinds of ammonium phosphates are commonly used for both nitrogen and phosphorus in fertilizer (Pair *et al.*, 1983). Ammonium sulphate (21-0-0), ammonium nitrate (34-0-0), ammonium phosphate sulphate (16-20-0), monoammonium phosphate (11-48-0), and diammonium phosphate (16-46-0) are widely used fertilizers (Van Der Gulik, 1987; Keller and Karmeli, 1975; Keller and Bliesner, 1990). The water quality must be considered before deciding to inject phosphorus fertilizer into the system. Phosphorus will be precipitated as dicalcium phosphorus in the pipe line and emitter flow passage if the irrigation water contains an appreciable amount of calcium. Emitter clogging can be overcome by injecting the phosphoric acid with an injection of either sulphuric or hydrochloric acid. The rate of injection of liquid fertilizer into the irrigation water in the microirrigation system can be computed as follows (Keller and Bliesner, 1990):

$$q_c = \frac{F_r . A}{C' . t_r . T_a} \qquad 2.26$$

where:

q_c = rate of injection of liquid fertilizer solution into the system in *l/h*

F_r = quantity of nutrient to be applied (fertilizer application rate) per each irrigation cycle in *kg/ha*

T_a = set time or irrigation application time in *h*

A = irrigated area in *ha*

t_r = ratio between set time and fertilizing time

C' = concentration of actual nutrients in the liquid fertilizer *kg/l*.

2.10 Microirrigation uniformity concepts:

Uniformity is a key factor in the evaluation of irrigation. It is nearly impossible for any irrigation system to supply the same amount of water to all plants within a field. A variety of terms have been developed to describe the irrigation uniformity. The uniformity of a microirrigation system is a quantitative measurement of the distribution of emitter discharge along a lateral line. Considerable work has been done regarding the uniformity in a microirrigation system. Karmeli and Keller (1974) described the emission uniformity based on the average low rate of the lowest quarter of all the emitter discharge. Solomon (1985) developed a simulation model for the study of trickle irrigation uniformity. Nakayama and Bucks (1981) developed a simulation model to evaluate the uniformity and the average water discharge rate of a trickle system with different degrees of clogging. Bralts *et al.* (1981) recommended that when emitter clogging is considered in a microirrigation system, the statistical uniformity coefficient is useful to determine the design of the emitter flow uniformity along the lateral lines.

In any irrigation system, the degree of uniformity is a consequence of the irrigation system itself and the soil variability. In a microirrigation system the variation is primarily due to uneven applications (Warrik, 1983). The factors that influence the uniformity of application from microirrigation systems include emitter factors and hydraulic system factors (Solomon, 1985). In microirrigation systems where applied water passes almost directly from the emitters into the soil, the uniformity of application depends entirely on the uniformity of the emitter flow throughout the system (On-Farm ICID, 1978). The emitter flow of a microirrigation system can be considered to have a normal distribution when it has a high uniformity (Wu and Gitlin, 1983; Bralts and Kesner, 1983; Solomon, 1985; Wu, 1988). Several uniformity definitions have been proposed and used to describe the uniformity of the system. A microirrigation system is designed based on the system uniformity and spatial uniformity. System uniformity shows the uniformity of emitter discharges with respect to the water pressure in the system, whereas spatial uniformity shows the amount of water application in the field. In general practice, emitter coefficient of variation *(CV)* is used to show the system uniformity and Christiansen coefficient of uniformity *(CU)* can be used to show the spatial uniformity (Wu, 1997). The *CU* has been most extensively used not only in microirrigation but also in the evaluation of sprinkler irrigation. Nakayama *et al.* (1979) reported the uniformity based on modification of Christiansen's definition used for sprinkler irrigation.

Microirrigation does not apply water to the entire field surface. Reducing the wetting surface area minimizes soil evaporation. Soil surface run-off and drainage losses can be reduced under this condition. It is often assumed that all water applied from one or from a group of emitters is available to the corresponding plant (Bos and Nugteren, 1990). Microirrigation is typically designed with an application rate less than the infiltration rate, which can prevent run-off. Amir and Dag (1992) observed different uniformities of wetting pattern, width and depth of application rates by different types of emitters. Their experience indicated that a high application rate of water increases the uniformity of the wetting pattern and its width, and decreases the depth. On the other hand a high application rate, when it exceeds the soil water intake rate, will cause water ponding on the soil surface and, consequently, water run-off. Distribution uniformity and application efficiencies are also the two important terms which are considered in microirrigation system design (Wu and Gitlin, 1983; Bucks and Mayers, 1973; Nakayama and Bucks, 1986; Anoyji and Wu, 1994). The definition of distribution uniformity is based on how uniformly irrigation water can be distributed on irrigated land, whereas how well irrigation water is applied by microirrigation to the field can be determined by application efficiency. In microirrigation, the moisture distribution depends on the emitter spacing, water application rate, soil permeability, soil surface, evaporation rate, and crop distribution (Obbink, 1977). In many cases, crop yield may be directly related to the uniformity with which water is applied. Solomon (1985) describes the possible relationships between yields and different uniformity measures. In general, yield response to over-irrigation and under-irrigation is not linear (Clemmens, 1987). Linear relationship between cumulative evapotranspiration and yield have been reported (Sammis, 1981; Wu, 1988). Slight amounts of over- or under-irrigation have no significant impact on yields; however, large deficit or over-applications of water have a significant effect on crop yields. Application uniformity depends on the uniformity of emitter flow, which is a function of emitter characteristics including manufacturer's variation, temperature effect, emitter clogging, and the hydraulic design of the microirrigation system. Sammis and Wu (1985) studied the effect of the design and management parameters on cotton yield by applying different daily drip irrigation amounts, different application uniformity, and different sensitivity to moisture stress.

In a microirrigation system the uniformity of dissolved fertilizer or chemicals when injected through the system is also important. The coefficient of variation can be used to assess the uniformity of water and fertilizer application through a microirrigation system. Hahn and Bralts (1983) studied the significance of differences in uniformity of water application and uniformity of fertilizer application in a trickle irrigation system. They also determined the relationship of injector type to the uniformity of fertilizer application in the trickle system.

Any non-uniformity in emitter flow will require an extra application of water to compensate for the non-uniform distribution. Different methods have been used to describe the water application uniformity in the microirrigation system. Non-uniformity reduces application efficiency and may increase the deep percolation in areas which are over-irrigated. Solomon and Keller (1978) reported that the emitter flow variations can significantly decrease the uniformity. Nakayama and Bucks (1981) have also found significant decreases in uniformity when only 1-5% of the emitters were completely clogged, even with 2–8 emitters per plant. Wu (1993) indicated that the emitter spacing is also a significant factor affecting spatial uniformity: a drop of 30%-40% uniformity coefficient was reported for an emitter spacing varying from 0.2–0.9 of the diameter of the wetting pattern.

Wu (1997) suggested four commonly used parameters for evaluating microirrigation system uniformity, which are: Christiansen coefficient of variation *(CU)*, emitter coefficient of variation *CV*, statistical uniformity coefficient *(UCS)*, and emitter flow variation (q_{var}).

2.11 microirrigation system evaluation:

Microirrigation design needs to be checked after installation and evaluated at least once a year (Bucks *et al.*, 1982). The purposes of evaluating any irrigation system have been stated by Merriam *et al.* (1980) as:

1- to obtain information that will assist the engineers in designing the other system

2- to determine how effectively the irrigation system can be operated and if it can be improved

3- to determine the system efficiency as it is being used

4- to obtain information to enable comparison of various methods, systems, and operating procedures as a basis for economic decisions.

The methods for evaluating the microirrigation system, the emitter flow uniformity, application efficiency, emitter flow variation caused by hydraulics, coefficient of variations, statistical uniformity coefficient, and hydraulic variations are discussed below.

2.11.1 Emitter flow uniformity and application efficiency:

In a microirrigation system, the emitter flow uniformity depends on the variation of emitter flow rate along the lateral lines. The emitter flow variation is mainly affected by the manufacturing variation, hydraulic design, temperature and emitter clogging. If the effect of temperature on emitter discharge variation can be assumed to be negligible, the emitter flow variation will be caused by clogging, manufacturing and hydraulic variation. The Christiansen coefficient of uniformity can be used to estimate the spatial uniformity in a microirrigation system (Yitaew and Warrik, 1980,1986; Nakayama and Bucks, 1979; Wu and Gitlin, 1974,1983; Keller and Bliesner,1990; WU, 1997):

$$CU = 100\left[1 - \frac{\sum_{i=1}^{n}|q_i - q_{ave}|}{nq_{ave}}\right] = 100\left(1 - \frac{\Delta\bar{q}}{\bar{q}}\right) \qquad 2.27$$

where:

CU = Christiansen Coefficient of Uniformity

$|q_i - q_{ave}|$ = absolute deviation of emitter flow from the mean

n = number of emitters

q_{ave} or $\bar{q}$ = the mean emitter flow

$\Delta\bar{q}$ = mean deviation of the emitter flow from the mean value.

According to equation 2.27 the uniformity of emitter flow rate will have an impact on the coefficient of uniformity (*CU*). In a microirrigation system, *CU* greater than 80–90% are considered; however, Wu (1974) has recommended $CU \geq 98\%$ in a microirrigation system.

Keller and Karmeli (1974, 1975) were the first to define an empirical design emission uniformity as a ratio of the minimum emitter discharge to the average discharge expressed as a percentage. They expressed the equations to determine the emission uniformity from design data or field test data. The design emission uniformity (*EU*) is the manufacturers discharge ratio, which is the average discharge of the low 1/4 to the average discharge of a test sample of the emitters operated at a reference pressure head. The average of the lowest 1/4 was selected as a practical value for the minimum discharge, as recommended by the Soil Conservation Service (1964) for the field evaluation of an irrigation system. Kimura (1987) reported that the term of low quarter is a consistent approach, since a single plugged emitter in a field would otherwise give an *EU'* of 0%. *EU* can be determined as (Keller and Karmeli, 1975):

$$EU = 100\left(1 - \frac{1.27v}{\sqrt{e}}\right)\frac{q_m}{q_a} \qquad 2.28$$

where:

v = manufacturer's coefficient of variation

e = 1.0 or the number of emitter per plant

q_m = minimum emitter discharge computed with the minimum pressure using equation 2.1 in (*l/h*)

q_a = average emitter discharge of all the emitters under consideration (*l/h*).

There are several reasons for the importance of the estimation of field uniformity in a microirrigation system. From the engineer's standpoint, field uniformity is important in confirming whether a design was satisfactory; from the purchase's perspective in confirming product performance; and from the irrigator's point of view, in considering irrigation application efficiency and schedules (Bralts *et al.*, 1987). The field test emission uniformity (*EU'*) is expressed as a percentage of the average emitter flow rates from the lowest 1/4 of the field data to the average emitter flow rates of all the data. *EU'* evaluates the emission uniformity from all the emission points within the microirrigation system and is determined as follows (Keller and Karmeli,1974,1975; Hill and Keller,1980; Keller and Bliesner, 1990):

$$EU' = 100\left(\frac{q_n}{q_a}\right) \qquad 2.29$$

where

EU' = field emission uniformity

q_n = average of the lowest quarter of the emission flow rate from the field data (*l/h*)

q_a = average of all the emitters flow rate (*l/h*)

Keller and Karmeli (1974) suggested that the desirable emission uniformity should be 94% or more and should never be less than 90%. Bralts *et al.* (1987) found that the primary disadvantage of the field emission uniformity is its non-statistical basis, which makes a further breakdown of the components of emitter flow variation impossible.

Distribution uniformity (*DU*) is the another term of uniformity which can be used in a microirrigation system. *DU* is a useful indicator of distribution problems (Clemmens and Solomon, 1997). A low *DU* indicates that excessive deep percolation losses will occur if adequate irrigation is supplied to all areas (On-Farm ICID, 1978; Burt *et al.*, 1997). For lower quarter distribution uniformity, *DU* can be determined as (Keller and karmeli, 1974; Warrick, 1983; Hathoot *et al.*, 1993):

$$DU = \frac{4\left[\sum_{i=\frac{3}{4}}^{n} q_i\right]}{n\overline{q}} \qquad 2.30$$

Keller and Bliesner (1990) presented an empirical equation which shows the relationship between *CU* and *DU* as:

$$DU = 100 - 1.59(100 - CU) \qquad 2.31$$

where:

DU = distribution uniformity

q_i = emitter discharge

$\overline{q}$ = mean emitter dischage

n = number of emitter.

Hill and Keller (1980) reported that since the *EU'* definition given by equation 2.29 is identical to the definition of distribution uniformity *DU*, it can be related to the coefficient of uniformity *CU* by:

$$EU' = DU = 1.6CU - 60 \qquad 2.32$$

Application efficiency in a microirrigation system is related to pressure variation. Van Der Gulik (1987) and Keller and Bliesner (1990) reported an empirical equation for the efficiency of application as:

$$Ea = 100\left(\frac{q_{\min}}{q_{ave}}\right) = 100\left(\frac{H_{\min}}{H_{ave}}\right)^{x} \qquad 2.33$$

where:

q_{min} = minimum emitter flow rate (*l/h*) computed from minimum pressure in the system

q_{ave} = average emitter flow rate (*l/h*) for the average pressure

H_{min} = minimum pressure (m)

H_{ave} = average pressure (m)

x = emitter flow exponent.

2.11.2 Emitter flow variation caused by hydraulics:

The emitter flow variation along a lateral line caused by hydraulics can be determined by emitter flow profiles. In uniform slope situations, the emitter profile is a smooth curve. However, all emitter flow along the lateral can be determined by equation 2.19, and the emitter flow variation can then be expressed by (Gillespi *et al.*, 1979; Bucks *et al.*, 1982; Wu and Yue, 1993; Wu, 1997):

$$q_{\text{var}} = \frac{q_{\max} - q_{\min}}{q_{\max}} \qquad 2.34$$

where

q_{var} = emitter flow variation

q_{max} and q_{min} are the maximum and minimum emitter discharge along the lateral respectively.

Wu and Gitlin (1974,1975) recommended the general criteria for q_{var} values which are: 10% or less, desirable; 10 to 20%, acceptable; and greater than 20%, not acceptable. A major limitation of this procedure is that the q_{var} does not include the factors of emitter flow variation due to manufacturing or clogging which could be significant in the microirrigation lateral uniformity. Assuming the same expression, the pressure variation along the lateral can be determined as:

$$h_{var} = \frac{h_{max} - h_{min}}{h_{max}} \qquad 2.35$$

in which h_{var} is the pressure variation along the lateral, h_{max} and h_{min} are the maximum and minimum pressure along the lateral respectively. With respect to equations 2.1, 2.34, and 2.35 the relationship between q_{var} and h_{var} can be expressed as:

$$q_{var} = 1 - (1 - h_{var})^x \qquad 2.36$$

The relationship between h_{var} and q_{var} is dependent upon the type of emitter (Keller and Karmeli, 1974; Karmeli and Kellrer, 1975). Both q_{var} and h_{var} are used for hydraulic design only (WU and Yue, 1993; Wu, 1997).

2.11.3 Coefficient of variations:

In addition to the emitter manufacturer's coefficient of variation (equation 2.20) which is used to describe the variation in emitter flow rate for a sample of new emitters, there are several statistical terms of coefficient of variation reported by researchers that can be used for evaluating a microirrigation system, as discussed below.

2.11.3.1 Emitter flow coefficient of variation and statistical uniformity coefficient:

The emitter flow coefficient of variation V_{qs} is described as the standard deviation of emitter discharge S_q, divided by the mean emitter discharge $\bar{q}$ (ASAE, 1990; Bralts *et al.*, 1987,1993). The emitter coefficient of variation can then be used to calculate the statistical uniformity U_s. Bralts *et al.* (1981 a,b) recommended the use of the statistical uniformity coefficient U_s for a microirrigation lateral line. Sammis and Wu (1985) reported that the application uniformity in a microirrigation system depends on hydraulic flow variation from the irrigation system. The hydraulic flow variation results from two major components: hydraulic pressure variation (the hydraulic components include the effect on flow of complete or partial emitter clogging) and emitter manufacturer's variation. Application uniformity of a microirrigation system can be *quantified* by the statistical uniformity coefficient, U_s. Therefore, by using the statistical uniformity coefficient, most of the various factors such as lateral line friction, elevation differences, emitter manufacturer's variation, and emitter clogging are included in the final uniformity estimation. Emitter flow coefficient of variation V_{qs} and its relationship with U_s can be expressed as follows:

$$V_{qs} = \left(\frac{S_q}{\bar{q}}\right) \qquad 2.37$$

$$U_s = 100\left(1 - V_{qs}\right) = 100\left(1 - \frac{S_q}{\bar{q}}\right) \qquad 2.38$$

$\bar{q}$ = mean emitter dischage

U_s = statistical uniformity coefficient.

One of the advantages of determining the statistical uniformity is to get information which assists in recognizing problem areas such as emitter performance and hydraulic variation. A graphical technique for field determination of statistical uniformity based on the time needed to fill a container (100 or 200 *ml*) rather than on the emitter flow rate was also presented by

Bralts (1986). The general criteria suggested by Bralts (1986) for an acceptable U_s in a microirrigation system are given in Table 2.4

Table 2.4 General criteria for an acceptable statistical uniformity (after Bralts, 1986)

U_s	Rating
90% or greater	excellent
80% - 90%	very good
70% - 80%	fair
60% - 70%	poor
< 60%	unacceptable

An acceptable U_s due to hydraulics depends on all of the various factors which affect uniformity. It is also suggested that in a microirrigation system, the value of U_s due to hydraulics of 90% or better is recommended. Any system having a U_s less than 90% requires a design change or replacement of existing emitters with the pressure-compensating type. Where the value of U_s is less than 85% due to emitter performance, cleaning, replacing of clogged emitters, or placing an additional emitter per plant will improve the statistical uniformity. A statistical uniformity of 80% is the minimum acceptable value when fertilizer injection is used.

2.11.3.2 Hydraulic variation:

Previous work shows that many researchers have used the term "hydraulic variation" to describe the variation in hydraulic pressures found along a microirrigation lateral line or submain. The statistical term "coefficient of variation due to hydraulics", V_{hs}, is used to quantify the variation in emitter pressures along a lateral line. However, from the engineering point of view, the variation of pressure due to hydraulics can be determined with the energy gradient line using equations 2.17, and 2.18 (Wu and Gitlin, 1983; Bralts *et al.*, 1987). The coefficient of variation due to hydraulics, V_{hs}, can be determined as follows (WU and Gitlin, 1983; Bralts *et al.*, 1987; ASAE EP458, 1997):

$$V_{hs} = \frac{S_h}{H_{ave}} = \sqrt{\frac{S_h^2}{H_{ave}^2}} \qquad 2.39$$

where:

V_{hs} = coefficient of variation due to hydraulics

S_h = standard deviation of the hydraulic pressures

S_h^2 = variance of the hydraulic pressures

H_{ave} = mean hydraulic pressure.

If the emitter clogging and manufacturer's coefficient of variation are held constant, acocording to equation 2.39, the emitter flow variation due to hydraulics can be related to the hydraulic coefficient of variation as:

$$V_{qh} = x.V_{hs} \qquad 2.40$$

where:

V_{qh} = emitter flow coefficient of variation due to hydraulics

x = emitter discharge exponent

V_{hs} = coefficient of variation due to hydraulics.

Using the value of V_{qh}, the emitter statistical uniformity due to hydraulics U_{sh}, can be determined as (ASAE EP458, 1997):

$$U_{sh} = 100(1 - V_{qh}) \qquad 2.41$$

The hydraulic and manufacturer's variations are the two most important factors affecting the uniformity of emitter flow along the lateral when the emitters are initially installed in a microirrigation system. However, other factors such as emitter wear and partial clogging will affect the performance of the emitters in the field over time. Emitter performance coefficient of variation (V_{pf}) is a statistical term and is a measure of emitter discharge variability due to emitter manufacturer's variation, hydraulic variation, water temperature, emitter wear, and emitter clogging. Emitter performance coefficient of variation, V_{pf}, can be determined as (ASAE EP458, 1997; Bralts *et al.*, 1987; Bralts and Edwards, 1986):

$$V_{pf} = \left(V_{qs}^2 - V_{qh}^2\right)^{1/2} \qquad 2.42$$

where:

V_{pf} = emitter performance coefficient of variation

V_{qs} = emitter discharge coefficient of variation

V_{qh} = emitter discharge coefficient of variation due to hydraulics.

The criteria for emitter performance coefficient of variation recommended by ASAE EP458 (1997) are shown in Table 2.5. It is also recommended if the V_{pf} value is excessively high (greater than 0.2), emitter cleaning or replacement will improve the emitter performance coefficient of variation.

Table 2.5 The criteria for the emitter performance coefficient of variation recommended by ASAE EP458 (1997)

V_{pf}	Rating
< 0.05	excellent
0.05 - 0.1	very good
0.1 - 0.15	fair
0.15 - 0.2	poor
> 0.2	unacceptable

Another statistical term called emitter discharge coefficient of variation including emitter plugging *(V_{qp})* was also reported by ASAE EP458 (1997). V_{qp} can be determined as:

$$V_{qp} = \left[\frac{1}{1-C}\left(V_{qs}^2 + 1\right) - 1 \right]^{1/2} \qquad 2.43$$

where:

V_{qp} = emitter discharge coefficient of variation including emitter plugging

C = proportion (decimal) of emitter completely plugged

$1\text{-}C$ = proportional (decimal) of emitters openly flowing.

The impact of different degree of partially clogged emitters along the lateral on V_{qp} is not considered in this equation.

2.12 Emitter flow variation and crop response:

A microirrigation system is often operated to satisfy the evapotranspiration (*ET*) requirement of the crop. In any irrigation operation, the application uniformity, depth of application, and crop sensitivity to moisture stress are among the factors affecting the average yield over the irrigated field. The average depth of application water in a microirrigation system is normally determined from the evapotranspiration requirements (ET_m) of the crop under non-moisture stress conditions. In those parts of the field which are under moisture stress condition, the evapotranspiration decreases, resulting in an average evapotranspiration over the field (*ET*) of less than ET_m (Sammis and WU, 1985). ET_m can be determined from reference evapotranspiration (ET_o) and an empirically derived crop coefficient (k_c). Reference evapotranspiration can be estimated from daily meteorological data using Penman equation or any other methods given in Jensen *et al.* (1990). The relationship between ET_m and ET_o can be determined as :

$$ET_m = k_c \times ET_o \qquad 2.44$$

Sammis and Wu (1985) reported that in cases where part of the field is fully irrigated, the ET can be determined as $ET = ET_m = k_c \times ET_o$. When a portion of the field is under deficit irrigation, then $ET_d \geq I_d$, where I_d is the average depth of irrigation in the deficit area, and ET_d is the average evapotranspiration in the deficit area. They also found the relationships between mean evapotranspiration, ET_{ave}, non-moisture stress evapotranspiration, ET_m, and the fraction of area under fully and deficit irrigation as follows:

$$ET_{ave} = ET_m a + ET_d(1-a) \qquad 2.45$$

$$\left(1-\frac{ET_{ave}}{ET_m}\right) = \left(1-\frac{ET_d}{ET_m}\right)(1-a) \qquad 2.46$$

where:

a = a fraction of the area receiving a full irrigation

$1-a$ = fraction of the area under deficit irrigation

$1-(ET_{ave}/ET_m)$ = mean relative deficit evapotranspiration in the total area.

All of these parameters are the functions of application uniformity and the mean depth of application. In a microirrigation system, the application uniformity depends on hydraulic flow variation from the irrigation system. The total emitter coefficient of variation (V_T) resulting from manufacturer's variation (CV) and the hydraulic design (V_{hs}) can be determined as (Bralts *et al.*, 1981):

$$V_T = \sqrt{V_{hs} + CV} \qquad 2.47$$

Sammis and Wu (1985) reported that for given values of V_T, a dimensionless plot of $Et_m/\bar{I}$ can be made. They found that when the mean irrigation depth ($\bar{I}$) is equal to the daily ET_m, 50% of the field is under deficit irrigation. As the $\bar{I}$ is increased relative to the ET_m, or when

$ET_m / \bar{I} \leq 1$, a smaller percentage of the area is deficit irrigated and ET_{ave} / ET_m approaches 1 ($\approx Et_{ave} = ET_m$). The mean relative deficit evapotranspiration over the total area ($1 - ET_{ave}/ET_m$) can be determined as (Wu and Gitlin, 1983; Sammis and Wu, 1985, Wu, 1995):

$$\left(1 - \frac{ET_{ave}}{ET_m}\right) = \frac{C}{G} \qquad 2.48$$

where:

C is the total deficit

G = ratio of the required irrigation depth I to satisfy ET_m to the mean of irrigation depth $\bar{I}$.

Walker (1979) presented an analysis of G for different V_T and percentage of the area under deficit irrigation (P_D) as:

$$\frac{C}{G} = \frac{0.0032 V_T P_D^{1.233}}{G} \qquad 2.49$$

Walker's analysis did not equate the C/G to $1-(ET_{ave}/ET_m)$ because G was assumed to be equal to $I / \bar{I}$. Based on a table for a normal distribution presented by Hart and Reynolds, (1965) the mean relative deficit evaporation over the total area $[1-(ET_{ave}/ET_m)]$ can be computed for different $\bar{I} / ET_m$. The results are adapted and presented in Table 2.6 for different V_T. Table 2.6 shows, for instance, that when the irrigation amount is applied at the ET_m rate ($\bar{I} / ET_m = 1$), an increase of V_T by 10% causes a decrease in relative evapotranspiration of 4%. It was also reported when the V_T is small ($V_T < 10\%$) the relative deficit evapotranspiration is less than 4% for an irrigation amount equal to or greater than ET_m rate ($\bar{I} / ET_m > 1$).

Table 2.6 Total emitter coefficient of variation (V_T) and deficit evapotranspiration 1-(ET_{ave}/ET_m) when $\bar{I}/ET_m$ is 1 and 50% of area is fully irrigated (adopted from Sammis and Wu, 1985).

V_T (%)	$\bar{I}/ET_m$	Percent fully irrigated (%)	$1-(ET_{ave}/ET_m)$ (%)
0	1	50	0
10	1	50	4
20	1	50	8
30	1	50	12
40	1	50	16
50	1	50	20

Sammis and Wu (1985) developed an equation to determine the reduction in yield caused by reduction in relative evapotranspiration as follows:

$$\left(1-\frac{Y_{ave}}{Y_{\max}}\right) = K_y\left(1-\frac{\sum_{i=1}^{n} ET_{ave_i}}{\sum_{i=1}^{n} ET_{m_i}}\right) \qquad 2.50$$

or:

$$Y_{ave} = Y_{\max}\left[1-K_y+\left(K_y\frac{\sum_{i=1}^{n} ET_{ave_i}}{\sum_{i=1}^{n} ET_{m_i}}\right)\right] \qquad 2.51$$

where:

Y_{ave} = average yield from the field

Y_{max} = maximum yield under non-moisture stress conditions

K_y = yield response factor (K_y = 0.85 for cotton, consequently a 4% reduction in relative deficit evapotranspiration is equivalent to a 3.4% reduction in cotton yield)

n = number of days in the growing season.

When $\Sigma ET > \Sigma ET_{m(i)}$, then $Y_{ave}=Y_{max}$, otherwise equation 2.51 can be used to estimate the average of the yield.

Chapter 3

3. SIMULATION COMPUTER MODEL

3.1 Microirrigation simulation computer model:

Many computer simulation models for designing, management and evaluation of microirrigation system were developed by researchers. For example, Howell and Hiler (1972) developed a computer solution method for determining lateral lengths for selected uniformities subject to emitter spacing and downstream pressure. Wu (1975) used the dynamic programming optimization to determine the optimal energy gradient lines to design the main line of drip irrigation. Bralts et al. (1993); Bralts and Segerlind (1985); Kang and Nishiyama (1996); and Kang et al. (1996) developed a finite element computer model to analyze the hydraulics of microirrigation laterals and submains. A simple computerized design method was used by Feng and Wu (1990) for a lateral and submain unit design. Most of the researchers adapted distinct computational approaches to deal with pipeline hydraulics. Feng (1989) used equations derived from the concept of energy gradient line to compute head loss. Anoyji and Wu (1987) used a statistical approach for drip lateral design. Gonzal and Hills (1986) developed a computer program using a step-by-step procedure based on the Darcy-Weisbach equation for the design of trickle irrigation laterals on non-uniform slopes. In most of the developed computer programs mentioned above, the average emitter flow rates along the lateral are assumed to be constant. Therefore, the discharge at the lateral inlet is simply determined by multiplying the number of emitters along the lateral by its constant average flow rate. In practice, the emitters along the lateral will never have equal or constant flow rate, due to manufacturer's variation, hydraulic variation, emitter clogging, and other factors affecting their discharges. The hydraulic spreadsheet simulation program described herein employs Hazen-Williams equation for computation of head loss at any section along a single lateral. The amount of flow at the inlet of the lateral is determined by summing up the flow rate of all the emitters along the lateral.

3.2 Computer model description:

A computer simulation program was constructed to determine the effects of number, location, and degree of clogged emitters on hydraulics in microirrigation laterals. This program was developed in Microsoft Excel (ver. 5 for Windows 95). This computer model was constructed to assist in the evaluation of microirrigation system uniformity and spatial uniformity by simulating emitter flows. A range of different patterns was used, including emitter clogging along the lateral, hydraulic variations, topography variations (slope), and manufacturer's variation. Each emitter flow for all emitters along a lateral was measured directly in the field, and the synthetic data were used to predict the hydraulics of microirrigation lateral and system uniformity. When using the synthetic data, manufacturer's variation (*CV*) was applied randomly to the emitters along the lateral. The reason for applying *CV* randomly to the emitters is to reproduces closely as possible the conditions of the field experiment. In reality, the emitter discharge from all the new emitters differs because of manufacturer's variation. In a sample of new emitters, some emitters may have the exact flow rate reported by the manufacturer, but the discharge from the rest may be higher or lower than the nominal flow rate. In practice, it is impossible to control the emitter's manufacturing variation and their locations along the lateral. Therefore, in the simulation model, the value of manufacturing variation is randomly applied to the emitters along the lateral.

The emitter clogging was made by random selection along the lateral based on clogging patterns similar to those in the field experiment. Clogging was considered as "complete clogging," in which the emitter flow for the clogged emitter is zero. For the present research, partial clogging was considered as that in which the emitter flow was less than the initial emitter flow (3.78 *l/h*) reported by manufacturer. The simulations for emitter clogging, manufacturer's variation, and topographic variations were conducted to determine the worst situations of emitter clogging along the lateral. This analysis was based on emitter flow variations, system uniformity, spatial uniformity and the values of most of the hydraulics parameters in a microirrigation lateral. The program allows its user to simulate the effect of emitter clogging on the hydraulics of a single lateral consisting of 10, 20, 30, 40, 50, and 60 sections. The length of the lateral depends upon the emitter spacing and total number of sections along the lateral. Emitter spacing and total number of sections along the lateral are chosen by the user. Thus, the length of lateral can be determined as:

$$L = N_S \times S_e \qquad 3.1$$

where:

L = length of lateral (m)
N_S = number of sections along the lateral
S_e = emitter spacing (m).

For instance the length of the lateral is selected as 90 m when desired sections and the emitter spacing along the lateral are assumed to be 60 and 1.5m respectively. The main objective of this program is to predict the effect of different numbers, locations and degrees of clogged emitters on the hydraulics of a microirrigation lateral. Figure 3.1 shows the schematic flowchart with the main steps used in the computerized hydraulics computation. This model requires only simple input data regarding basic information for microirrigation hydraulics consideration. The input data include emitter flow rate along the lateral (field data or synthetic data) in *l/h*, emitter discharge coefficient *K*, emitter exponent *x*, lateral inlet pressure *P(psi)*, lateral diameter (m), lateral slope *(%)*, emitter spacing S_e (m), friction coefficient C_H, and manufacturer's coefficient of variation *CV*. In an evaluation of a microirrigation system, the accuracy of the hydraulics computation is the basis of a successful estimation of real field conditions. Total flow at the inlet of lateral (Q_L) is determined using equation 2.4 (previous chapter) by summing up the flow rate of all the emitters (obtained from field or synthetic data) along the lateral.

The head loss at each section h_{fi} along the lateral is estimated based on the input values of emitter flow rates along the lateral and using the Hazen-Williams equation (equation 2.10,

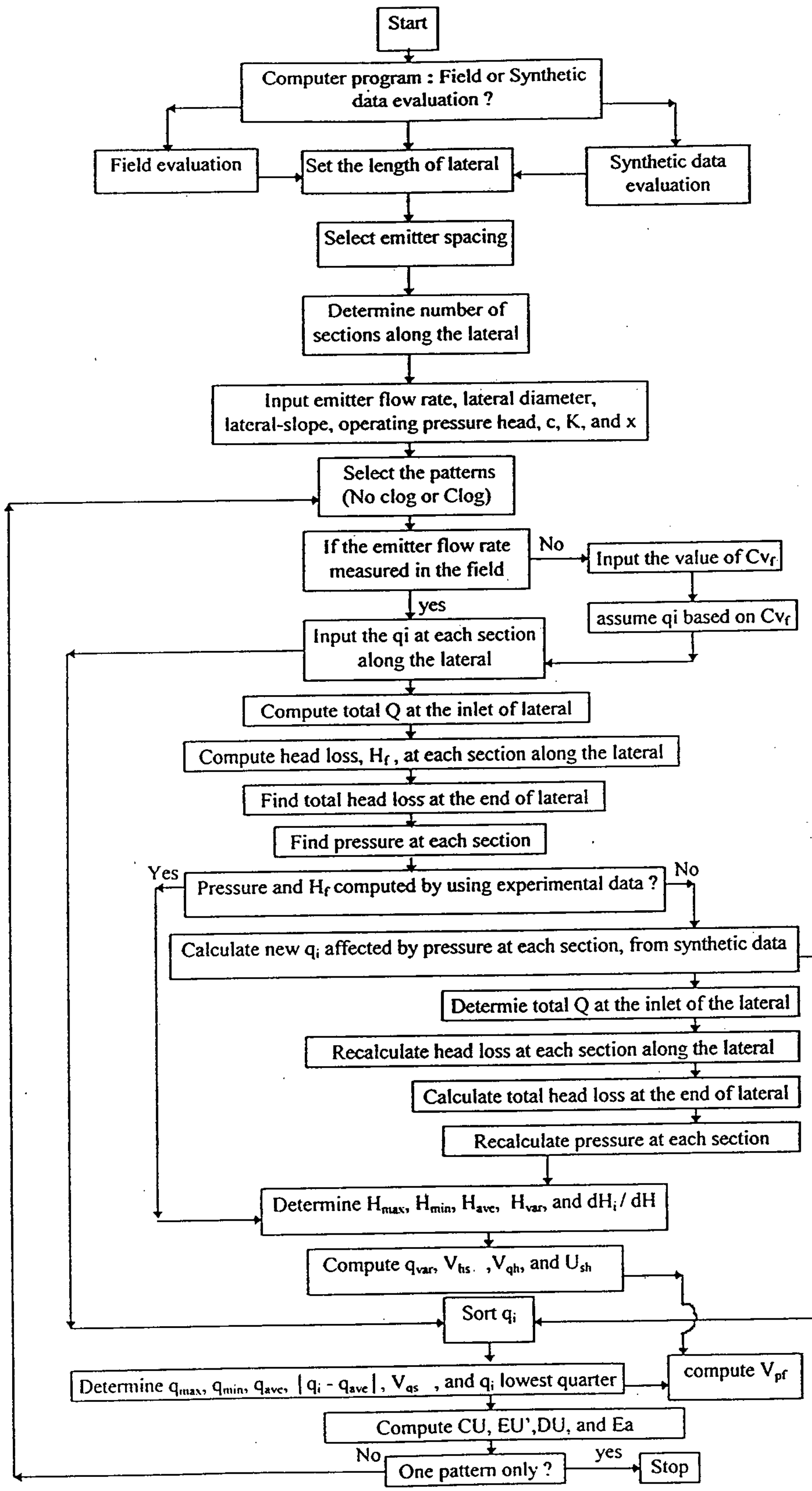


Figure 3.1 flowchart of the computer simulation model

previous chapter). To calculate the head loss at each section (h_{fi}), total lateral flow at the corresponding section (Q_i) is required. The following equation is employed in the model to determine the lateral flow at each section along the lateral:

$$Q_i = Q_L - \sum_{i=1}^{n}(q_{i-1}) \qquad 3.2$$

where:

Q_i = lateral flow at i^{th} section (l/h)

Q_L = flow at the inlet of lateral (l/h)

q_{i-1}= emitter flow rate at section i-1.

Based on Q_i determined in equation 3.2, the head loss at each section (h_{fi}), is then determined by equation 2.10. The process is repeated for each downstream section with one emitter per section. The total head loss along the lateral (H_F) is determined by:

$$H_F = \sum_{i=1}^{n} h_{f_i} \qquad 3.3$$

where h_{fi} is the head loss at each section along the lateral. The pressure (h_i) at each section along the lateral is calculated when the H_F was determined. The impact of lateral slope (up- or down-slopes) on h_i is also considered. The new values of emitter flow rate (q_i) affected by pressure variation at each section is then calculated. Therefore, in the case of simulation with the synthetic data, if a constant value for an initial emitter flow rate (i.e. 3.78 l/h) is chosen for all emitters along the lateral, the model will change the values to the more realistic values of emitter flow rate in the field. This is the result of considering the effect of pressure variation along the lateral and the impact of pressure gain or loss due to lateral slope on emitter flow rate. The following equations are used in the model to determine the h_i and q_i at each section along the lateral:

$$h_i = H_o - \left[1-\left(1-\frac{l}{L}\right)^{2.852}\right] \times H_F \pm l/L\left(L \times slope\right) \qquad 3.4$$

$$q_i = K\left[H_o - \left(1-\left(1-l/L\right)^{2.852}\right) \times H_F \pm \frac{l}{L}\left(L \times slope\right)\right]^x \qquad 3.5$$

where:

H_o = pressure at the inlet of lateral in *m*

l = length of pipe along lateral from the lateral inlet in *m*

L = total length of lateral in *m*

K = emitter constant

x = emitter exponent.

Since the inlet lateral flow is a function of emitter flow rate along the lateral, the effect of pressure variation on emitter flow rate is accounted for in the simulation program. In other words, once H_F is calculated by the initial input of emitter flow rate, this value is used to determine the pressure at each section along the lateral. Then the emitter flow rate (q_i) at each section is computed by equation 3.5. Next, the total new head loss is computed with respect to the new emitter flow rate computed from equation 3.5. Therefore, an iterative procedure is employed to determine the emitter flow caused by pressure variations at each section along the lateral.

The pressure losses due to friction are very small in microirrigation circuits in flat terrain [less than 2-3 psi (1.4-2.1m) per 2-3 hundred feet (60-100m) of lateral length], whereas a 2-3 m rise in elevation along the lateral could double the pressure loss. Since the emitters operate at low pressure [usually 10-15 psi (7-10.5m)], pressure loss or gain by elevation can cause significant variations in the emitter discharge along the lateral. The simulation allows users to evaluate the hydraulics of microirrigation laterals laid on flat or any type of uniform slopes (down-slope or up-slope) terrain. Eight different patterns (or stages) of emitter clogging along the lateral were simulated as follows:

Stage 1 - *no-clogged emitter* through the lateral.

Stage 2 - 30% of *total number of emitters* with different degrees of clogging are located at the last section (one-third from the downstream end) of the lateral.

Stage 3 - same as stage 2, except the *location of the clogged emitters* is in the *middle one-third* section of the lateral.

Stage 4 - same as stage 2, except the *location of the clogged emitters* is in the *first one-third* section of the lateral.

Stage 5 - same as stage 2, except the *clogged emitters* are *randomly located* along the line.

Stages 6, 7 and 8 - 20%, 10% and 5% of the total number of emitters are *partially clogged* and *randomly located* along the lateral.

In order to calculate the hydraulic parameters under different patterns of clogging, equations number 2.20-2.22, 2.27, 2.29, 2.31, 2.33, 2.35-2.41, and 2.51 were employed in the simulation program. In addition, the relationships between these parameters are also plotted on the worksheet for each stage and can be easily compared to each other.

The hydraulic model also accounts for the total emitter coefficient of variation (V_T) and deficit evapotranspiration [1- (ET_{ave}/ET_m)] detailed in chapter 2, to determine the impact of different patterns of emitter clogging on crop yield (cotton yield, see 2.51) for different areas. The reason for choosing the cotton yield was based on the availability of several parameters required for the crop yield analysis from previous studies reported by Sammis and Wu (1985). Therefore, the computer model incorporates the data adopted from Sammis and Wu (1985) by means of an interpolation procedure to determine V_T when clogging occurs in different patterns along the lateral. The interpolation procedure is used to determine the exact value of deficit evapotranspiration on the *Y* axis (in this study, *Y* values deficit evapotranspiration) corresponding to the value of V_T on *X* axis (in this study, *X* values emitter coefficient of variation) by the following equation and figure 3.2:

$BC/AC = BE/DE$ or: $(y_2-y_1)/(x_2-x_1) = (y_2-Y)/(x_2-X)$ or:

$$Y = y_2 - \frac{(y_2 - y_1)(x_2 - X)}{(x_2 - x_1)} \qquad 3.6$$

where:

$y_2 - y_1 = BC$

$x_2 - x_1 = AC$

$y_2 - Y = BE$

$x_2 - X = DE$

y_1 and y_2 = values corresponding to the deficit evapotranspiration [$1-(ET_{ave}/ET_m)$]

x_1 and x_2 = values related to the total coefficient of variation (V_T) as indicated in Figure 3.2

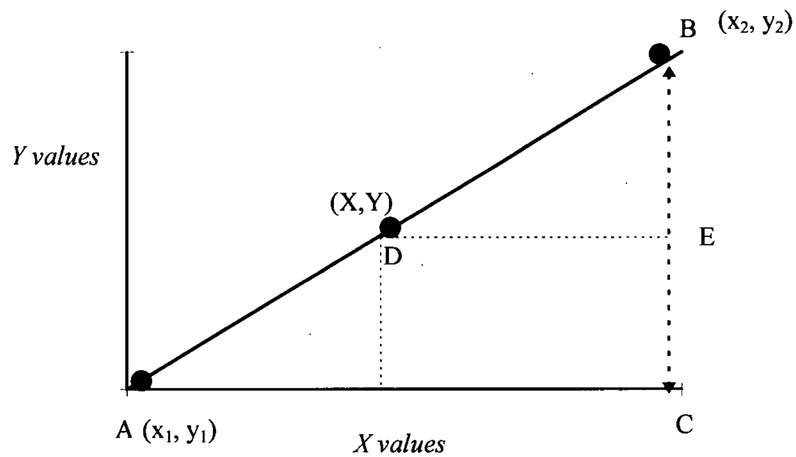


Figure 3.2 interpolation by coordinate method

3.3 Effect of different patterns of clogging on hydraulics of different lengths of lateral:

Six different lengths of laterals of 10, 20, 30, 40, 50, and 60m, all 15 mm in diameter were selected to simulate the effect of eight different patterns of emitter clogging on hydraulic characteristics of microirrigation laterals laid on flat terrain. The values of emitter hydraulic characteristics, lateral inlet pressure, emitter spacing, nominal emitter flow rate and emitter manufacturer's variation were selected to be similar to those values used in the experimental set-up which will be explained in the following chapter. The eight different patterns of emitter clogging described in previous section were used for each length of lateral. The manufacturer's variation (*CV*) of 0.0193 was applied randomly to the emitters along the lateral. The value of 0.0193 was determined from a sample test of emitters which is detailed in chapter 5.

Clogging was considered to be "complete clogging," in which the emitter flow for the clogged emitter is zero. Partial clogging considers the condition in which the emitter flow rate was less than the minimum emitter discharge after the manufacturer's variation was applied to the emitters along the lateral. The computer simulation was used to assess if there are significant differences in the hydraulic characteristics of different lengths of lateral affected by clogging. Then, based on the results obtained from the simulation program, the appropriate length of lateral for the experimental set-up was selected. Head loss, emitter flow variation, coefficient of uniformity, application efficiency, distribution uniformity, statistical uniformity, emitter coefficient of variation, hydraulic design coefficient of variation, emitter discharge coefficient of variation due to hydraulics, and emitter performance coefficient of variation were evaluated. Results presented in Tables A.3.1 to A.3.16 in appendix A show that the hydraulic characteristics of different lengths of laterals have similar trend under eight different patterns of emitter clogging. Figures 3.3 to 3.12 show the relationship between all aforementioned hydraulic parameters and the different lengths of lateral under eight different stages of emitter clogging. Based on these theoretical analyses, the 20m lateral was considered to be the appropriate length for the field experiment.

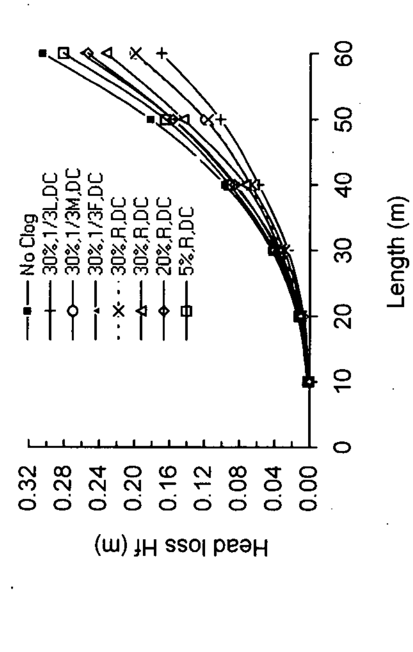


Figure 3.3- Effect of number, location, and degree of clogged emitters on head loss.

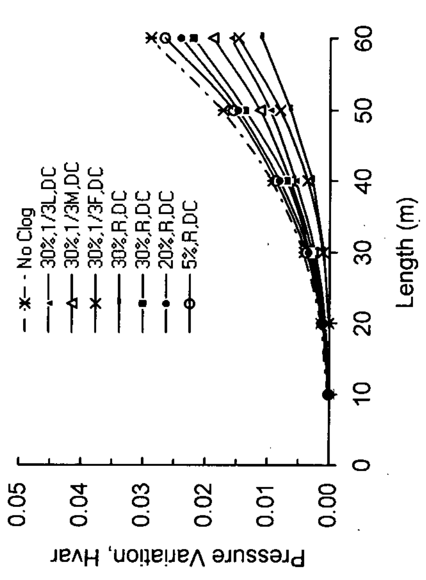


Figure 3.4- Effect of number, location, and degree of clogged emitters on pressure variation.

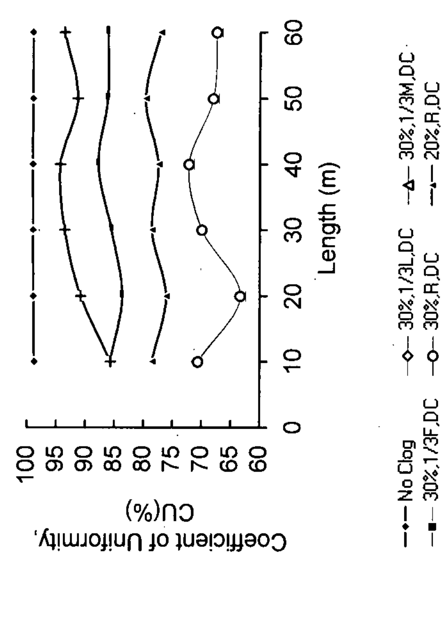


Figure 3.5- Effect of number, location, and degree of clogged emitters on coefficient of uniformity.

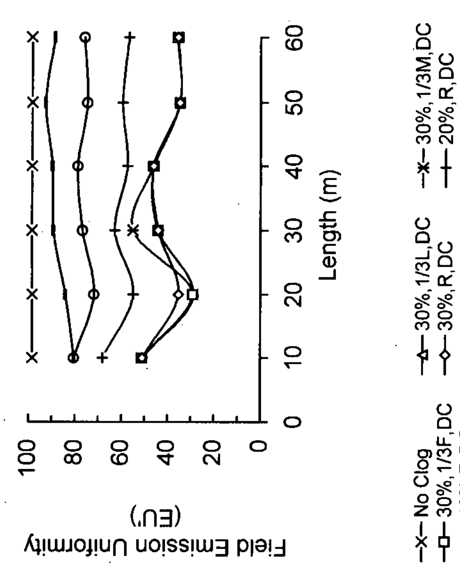


Figure 3.6- Effect of number, location, and degree of clogged emitters on field emission uniformity.

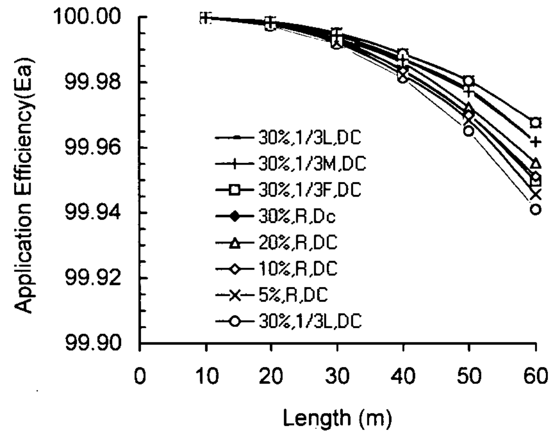


Figure 3.7- Effect of number, location, and degree of clogged emitters on application efficiency.

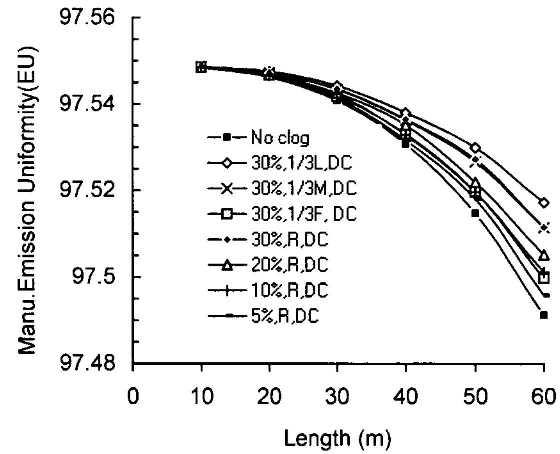


Figure 3.8- Effect of number, location, and degree of clogged emitters on Manu. Emission uniformity .

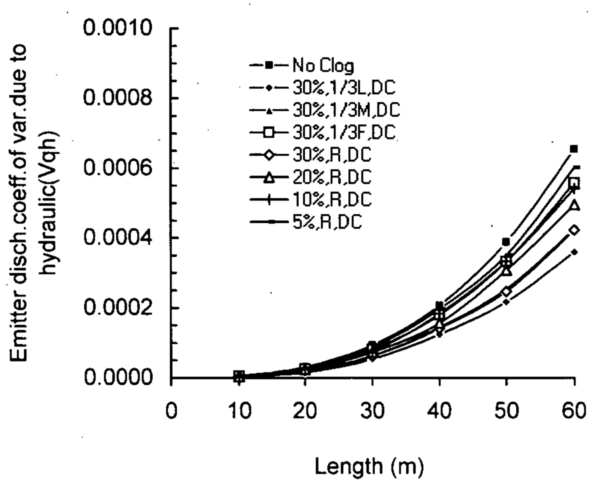


Figure 3.9- Effect of number, location, and degree of clogged emitterson emitter discharge coefficient of variation due to hydraulics .

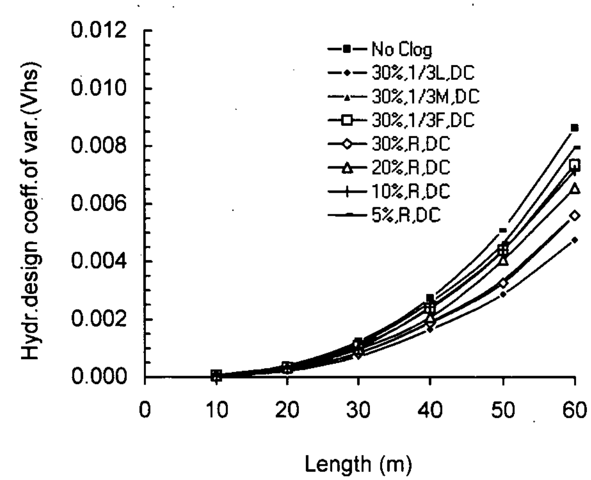


Figure 3.10- Effect of number, location, and degree of clogged emitters on hydraulioc design coefficient of variation .

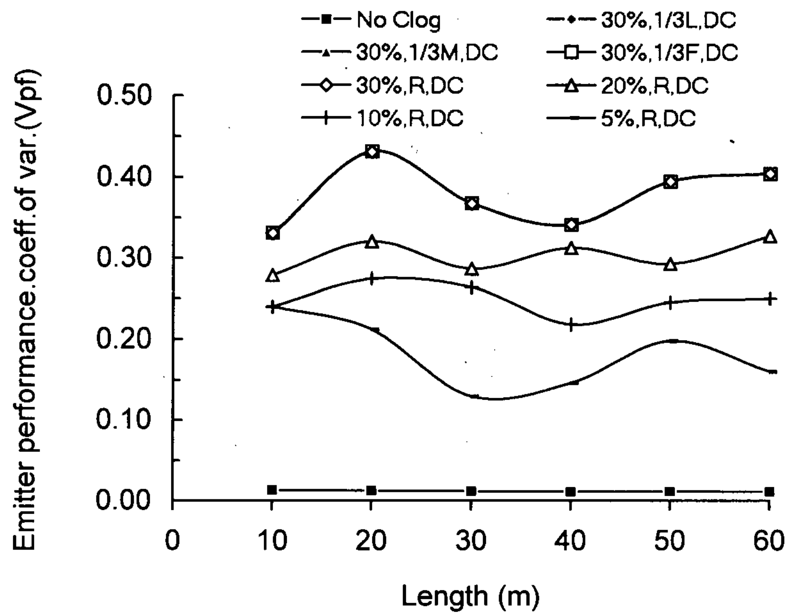


Figure 3.11- Effect of number, location, and degree of clogged emitterson emitter performance coefficient of variation.

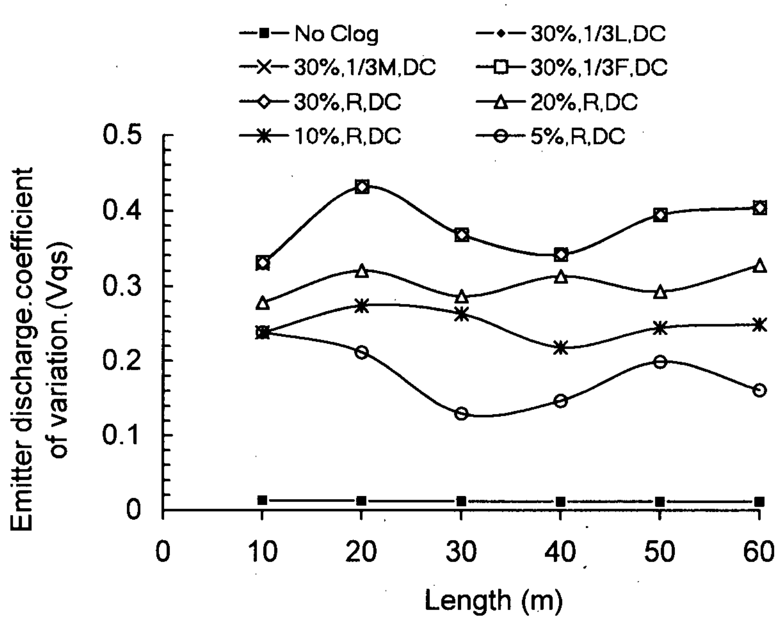


Figure 3.12- Effect of number, location, and degree of Clogged emitters on emitter discharge coefficient of variation .

Chapter 4

4. MATERIALS AND METHODS

4.1 Description:

In May of 1995, a microirrigation system was constructed at the Plant Science Research Field (near S.W. Marine Drive) of the University of British Columbia. The average slope of the field experiment was 3.25% in the north-south and less than 1% in the west-east direction. A 20m rectangular wood frame, 60 cm in height, 1m in width, was made to support two suspended lateral lines horizontally above the ground surface. Figure 4.1 shows the experimental layout (flat terrain). Two 20m polyethylene laterals (A and B) of 15 mm inside diameter were used. The laterals were spaced 1m apart and connected to the wood frame at 60 cm above the ground. Each lateral was divided into 20 sections. Pressure-compensating emitters (DPJO4-A, Hardi Turbo SC™ Plus) with a nominal emitter flow rate of 3.78 *l/h*, manufacture coefficient of variation (*CV*) of 0.0193 and emitter flow exponent (*x*) of 0.075 were used (Figure 4.2). Calculation of values of *CV* and *x* is detailed in chapter 5. The pressure at the inlet of lateral was kept at a recommended pressure of 105 kPa (15 psi) using a pressure regulator. The emitters were inserted on-line in the polyethylene lateral. Emitters were spaced 1 m apart along the laterals. A 20 mm polyethylene hose as a main line carried the clean water (drinking water) into the system. A polyethylene manifold 15 mm in diameter was used to carry the water from the main line to the laterals. The average pressure of the city water supply was 420 kPa (60 psi). A pressure regulator and a pressure gauge were installed at the manifold inlet. Two valves were also installed in the manifold after pressure regulator and close to each lateral inlet. Four pressure gauges were also installed for monitoring and measuring the pressure, one pressure gauge at the inlet and the other at the end of each lateral. In addition, one portable pressure gauge was connected to a 3 cm piece of metal pipe (3mm outside diameter) and used to measure the pressure at each emitter location along the lateral. The ends of the laterals were closed by a plug. Eight different patterns (as described in chapter 3) of emitter clogging were used. The partially and completely clogged emitters were artificially made by introducing some fine sand (as will be discussed later) into the emitter through the emitter barb. In May 1996, another rectangular wood frame, 1 m in height was constructed and placed on the top of the

Figure 4.1 The field experimental lay out (flat terrain)

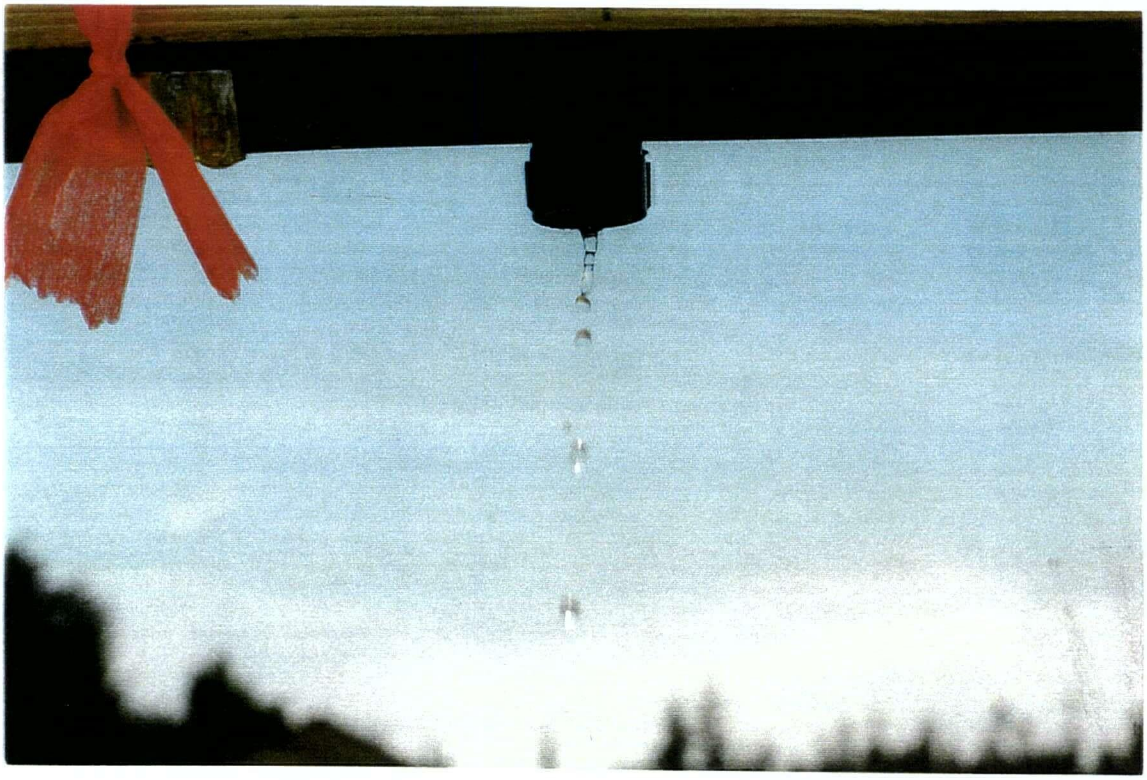


Figure 4.2 Pressure compensating emitter, Hardi Turbo SC^{TM} Plus

previous set-up. Therefore, the experimental set-up consisted of two frames (Figure 4.3), one at the bottom and the other at the top. Two 20m polyethylene laterals 15 mm in diameter were connected under the 20m piece of straight bar and were laid along the top frame. The system consisted of four laterals, two laterals laid on flat terrain at the bottom frame and the others laid on the sloped terrain at the top frame. Four different slopes (3% up-slope, 3% down-slope, 7% up-slope, and 7% down-slope) were tested. The slope of lateral could be changed by moving the 20m (wood) bar upward or downward to achieve the desired slope. The pressure regulator, pressure gauges and the manifold were disconnected from the previous set-up and connected to the new laterals laid on the slope terrain. The former laterals (laid on the flat terrain at the bottom frame) were connected to the manifold by a 1m piece of polyethylene pipe 15mm in diameter. Patterns of emitter clogging similar to those in flat terrain were used for sloped terrain. Then the effect of number, degree and the location of clogged emitters along the lateral laid on sloped terrain on hydraulics of microirrigation system were determined. The laterals on flat terrain were also operated whenever the laterals on slope terrain were running.

In May 1997, the emitters along the laterals (A and B) located in the bottom frame were examined. The cap of each individual emitter was removed in order to inspect the inside of the emitter to see if natural clogging occurred. The number, degree, and the type of clog particles were determined. Then the effect of naturally clogged emitters on coefficient of uniformity (*CU*) was measured and a least-square regression equation was determined (as detailed in chapter 5). In May 1997, the laterals laid on slope terrain were disconnected from the top wood frame and the new laterals were installed. Two 20m, 15mm diameter polyethylene laterals were installed on the top frame with zero slope. A venturi injector (model Mazzei 484, 3/4", the smallest commercial size available in the market) with 68 *l/h* (18 gph) injection capacity was chosen for injecting the saline water into the lateral. A barrel of 180 liters capacity was used as an injection tank. The city water was carried into the injection tank by a piece of polyethylene pipe connected to the main line. The venturi injector was installed right after the pressure regulator and gauge in the manifold (Figure 4.4). The impact of the venturi injector and the injection of the saline and the city water on the variation of emitter flow rate along the laterals (consisting of naturally clogged and no-clogged emitters) and their effect on

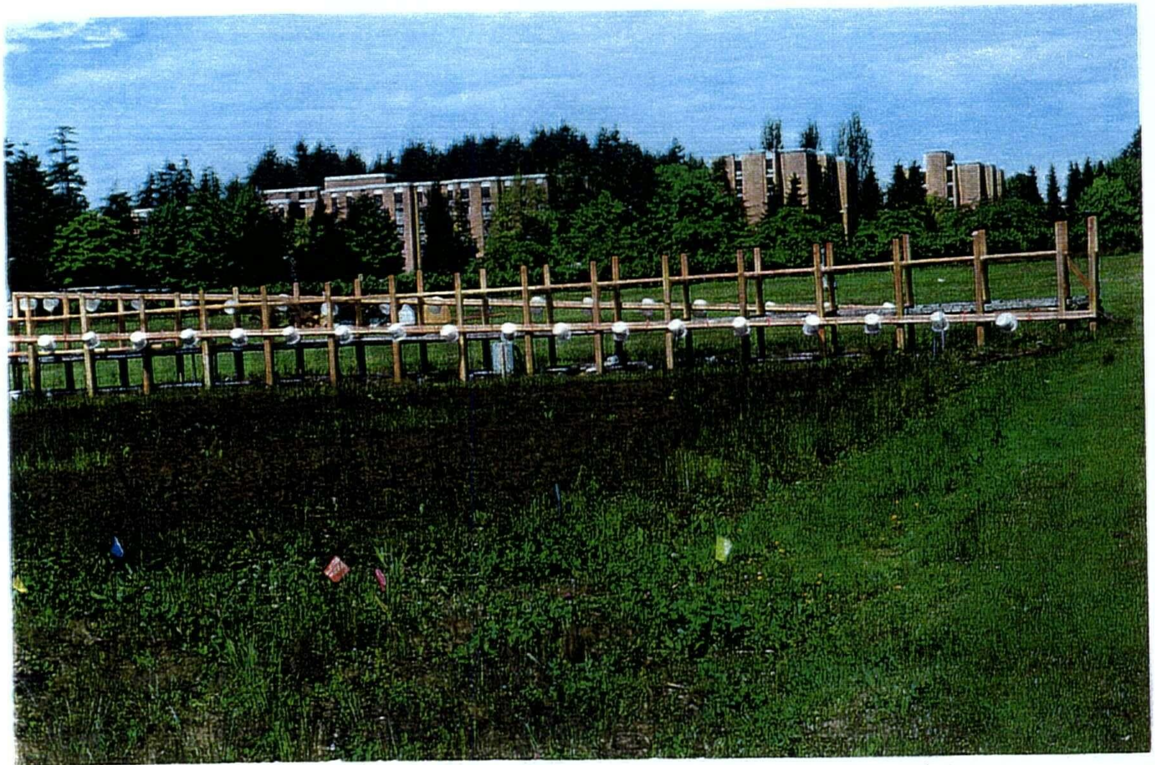


Figure 4.3 The field experimental lay out (slope terrain)

Figure 4.4 Venturi injector model Mazzei 484 and injection barrel

hydraulic characteristics of microirrigation laterals were determined. The length of lateral was increased to 40m, and a similar test as on the 20m lateral was done on the 40m.

The effects of the venturi injector and saline water injection on hydraulic characteristics of laterals consisting of new emitters were investigated. Table salt was used to prepare the saline water with different levels of electrical conductivity (*EC*). Three different tests were conducted to examine the impact of injecting different degrees of saline water (using the venturi injector) on the emitter's hydraulic characteristics:

(1)- In the first test, 20m and 40m laterals consisting of new emitters, the venturi injector, and the city water (*EC* = 0.022 *mmhos/cm*) were used. The effect of the venturi injector and the injection of city water on emitter flow rate and the system uniformity was examined.

(2)- The second test was done in order to maintain a constant value of electrical conductivity (*EC*) at the emitter's outlet. *EC* values of 1.5 and 3.0 *mmhos/cm* were maintained.

(3)- The third test was similar to the second, but a constant *EC* value of the injected saline water was maintained and the *EC* variation at the emitter outlets was investigated.

The system was run under different phases of venturi injector operation. Different phases were applied in three runs at each test. Each run was repeated once and the average measurements were taken. The flow of each individual emitter at each section along the lateral was collected in each run for 30 minutes. Then emitter flow rates along the lateral were determined. The impact of emitter flow variation on the hydraulic characteristics of the microirrigation were investigated.

The impact of air and water temperatures on emitter flow rates along the lateral (consisting of naturally clogged emitters) and their effects on the hydraulic characteristics of the lateral were also examined.

4.2 Field Measurements:

The microirrigation system was operated and field data were collected in three distinct steps:

1. The first step was done on flat terrain from May to September 1995.
2. The second step was done on sloped terrain from May to September 1996.
3. The third step was done on flat terrain under the venturi injector and injection of saline water from May to October 1997.

4.2.1 Step 1 of Field Experiment:

Experimental system was constructed during May to July of 1995 and the first step of the research experiment started in August, 1995. Figure 4.5 shows the field experiment in step 1. The first step of the experiment was done on a flat terrain to determine the effect of number, location, and degree of clogged emitters on the hydraulics of the microirrigation system.

Two 15 mm inside diameter polyethylene laterals (A and B) of 20m length were used. The laterals were spaced 1m apart and laid under the top side of wood frame 60 cm above the ground surface. The laterals were connected flush with the wood frame, with zero slope (flat). Each lateral was divided in 20 sections. The pressure compensating emitter model DPJO4-A, Hardi Turbo-SC™ Plus, was used for this experiment (Figure 4.2). The emitters were inserted on-line in the polyethylene laterals. Each lateral consisted of 20 emitters, one emitter per section along the lateral.

Before operating the system in the field, the emitter flow rates were measured and compared with the manufacturer data. 50% of the emitters from a total of 40 emitters were randomly selected in order to test the emitter manufacturer's coefficient of variation (variation in emitter flow rate). A piece of 1 meter polyethylene pipe was used and a 15 psi pressure regulator and a pressure gauge were installed at the inlet of this pipe. The end of the pipe was plugged. Then,

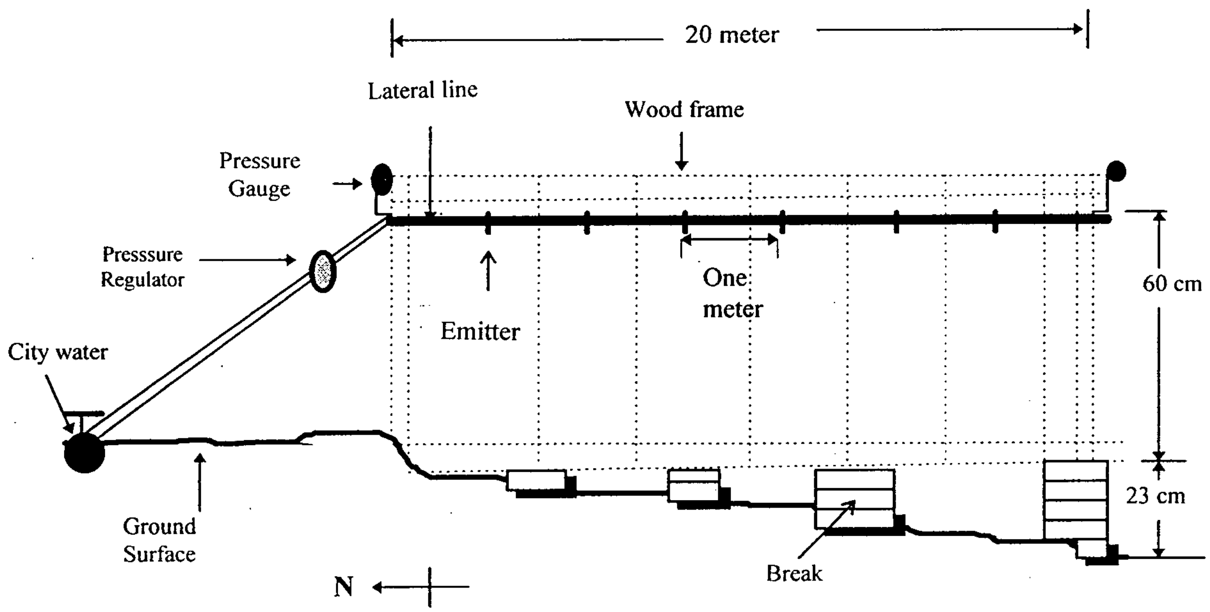


Figure 4.5 The field experiment layout in step-1 (not to scale)

emitter number 1 was inserted on-line 50 cm from the inlet of this pipe. The system was run for 2 hours, then the emitter flow was collected in a container for three different duration times (3 minutes, 15 minutes, and 1 hour). This test was done for all 20 emitters six times at the same duration intervals. In spite of installing a pressure regulator to fix the pressure inlet at 15 psi, the pressure gauge showed a pressure variation of 15 to 15.5 psi during the tests. The standard deviation of the emitter flow rate and the average emitter flow rate were computed, and the emitter manufacturer's coefficient of variation CV were then determined.

In order to determine the emitter's hydraulic characteristics, the emitter flow rate and pressure data given by the Hardi Turf Irrigation Products Catalogue (1995) were used. The flow rate versus pressure curve can be fitted into an emitter flow formula. Based on these data, the values of x and K (in equation 2.1) were found by the least-square regression analysis of the natural logarithm of flow rate against the natural logarithm of pressure (detail given in Chapter 5). The x and K values of 0.0757 and 3.147 were obtained respectively. The emitter flow equation for this type of pressure-compensating emitter was established as follows:

$$q = 3.147h^{0.0757} \qquad 4.1$$

where q is the emitter flow rate in *l/h* and h is the pressure in (m).

The first emitter was spaced 1m from the lateral inlet. The laterals were connected to a 15mm inside diameter polyethylene manifold. Water was carried to the manifold from a 16mm inside diameter hose connected to the city's water main. Four pressure gauges were installed and used to measure the pressures at the inlet and end of each lateral. The pressure at the inlet of the lateral was kept at the recommended of 105 kPa (15 psi) by using a pressure regulator. Due to pressure variation in the city's water main, the inlet pressure varied between 15 psi and 16.8 psi. Different patterns of emitter clogging along the lateral in 8 different stages were examined as follows:

Stage 1: desired situation with *no-clogged emitter* along the lateral A. The system was operated under this condition and the emitter flow rates along the lateral were measured. In order to ensure that the pressure and temperature had reached equilibrium, the system was running for 1.5 to 2 hours before data collection. Then, the emitter flow rate from each individual emitter was directly measured by using a stopwatch, bucket, and a graduated cylinder. The volume of water from each individual emitter was collected for 30 minutes and emitter flow rate was determined. The average pressure at the inlet and at the end of lateral were also recorded. This test was repeated four times (four runs) and the average emitter flow rate was determined. The system under the conditions of stage 1 was continuously operated for one and half months, 3 hours per day, in order to investigate if any emitter clogging occurred along the lateral.

Stages 2 to 8 were done on lateral B. In these stages, several partially or fully clogged emitters (artificially clogged emitters) were inserted at different locations along the lateral B. Fully or partially clogged emitters were manufactured by introducing very small amounts of fine sand ($100mesh < D < 40mesh$ and $40mesh < D < 14mesh$, where D is the diameter of a sieve through which sand was screened) into the emitter from the emitter inlet. Uniform clogging could not be achieved because of the characteristics of elastomeric disk placed on the top of the spiral path of the emitter. For the present experiments *different numbers* and *degrees* of emitter clogging were made and used in stages 2 to 8 as follows:

Stage 2: 30% of the *total number of emitters* were *partially clogged* and located at the last section (one-third from the downstream end) of the lateral. This stage was assigned as 30%, 1/3L, DC (30%, Last 1/3 of lateral, Different degree of Clogging).

Stages 3 and 4 : same as stage 2 except the partially clogged emitters were located in the middle and first one-third sections of the lateral respectively. These stages were assigned as 30%-1/3M-DC and 30%-1/3F-DC.

Stage 5 : same as stage 2 except the *clogged emitters* were *randomly located* along the lateral.

Stages 6, 7 and 8 : at these stages 20%, 10% and 5% respectively of the total number of emitters were partially clogged and *randomly* located along the lateral. Each emitter along the lateral was known by a number assigned to its location. The number of partially clogged emitters and their locations are shown in table 4.1.

Table 4.1 Number and location of clogged emitters at different stages along the lateral.

Stage #	Clogged emitters #	Location
Stage- 1	No clogging	------------
Stage- 2	15,16,17,18,19,20	1/3 from downstream end
Stage- 3	7,8,9,10,11,12	1/3 middle of lateral
Stage- 4	1,2,3,4,5,6	1/3 first of lateral
Stage- 5	1,3,5,9,11,16	randomly
Stage- 6	3,6,8,12	randomly
Stage- 7	4,13	randomly
Stage- 8	16	randomly

Similar patterns of emitter clogging as in step 1 were simulated with the synthetic data by the computer spreadsheet program (explained in chapter 3). Figure 4.6 shows different patterns (stages 1 to 8) of emitter clogging along the lateral.

4.2.2 Step 2 of the field experiment:

Step 2 was done at the same location as step 1. The effects of emitter clogging on the hydraulics of microirrigation laterals laid on a uniform *sloped terrain* were investigated. To achieve the different slopes for step 2, a wood frame of 20m length and 1m in height was constructed. This frame was placed on the top of the frame constructed for step 1. Therefore, the total height of the frame was 1.6m in step 2. Four different uniform slopes of 3% and 7% (up- and down-slope) were chosen. Two 20m polyethylene laterals were connected to the two 20m straight bars. Two tests were done in step 2, tests A and B as described below:

Test A- This part of the experiments consisted of two lateral lines laid on 3% and 7% uniform up-slopes. Lateral A was laid on a 7% up-slope in one side of the frame. Lateral B was also placed on a 3% up-slope on the other side of the frame. Figures 4.7 and 4.8 show the laterals A and B laid on 7% and 3% up-slopes respectively. The difference in elevation between the fronts and ends of lateral A and lateral B were 1.4 and 0.6m respectively. The impact of partially clogged emitters on the hydraulics of laterals laid on 3% and 7% up-slopes

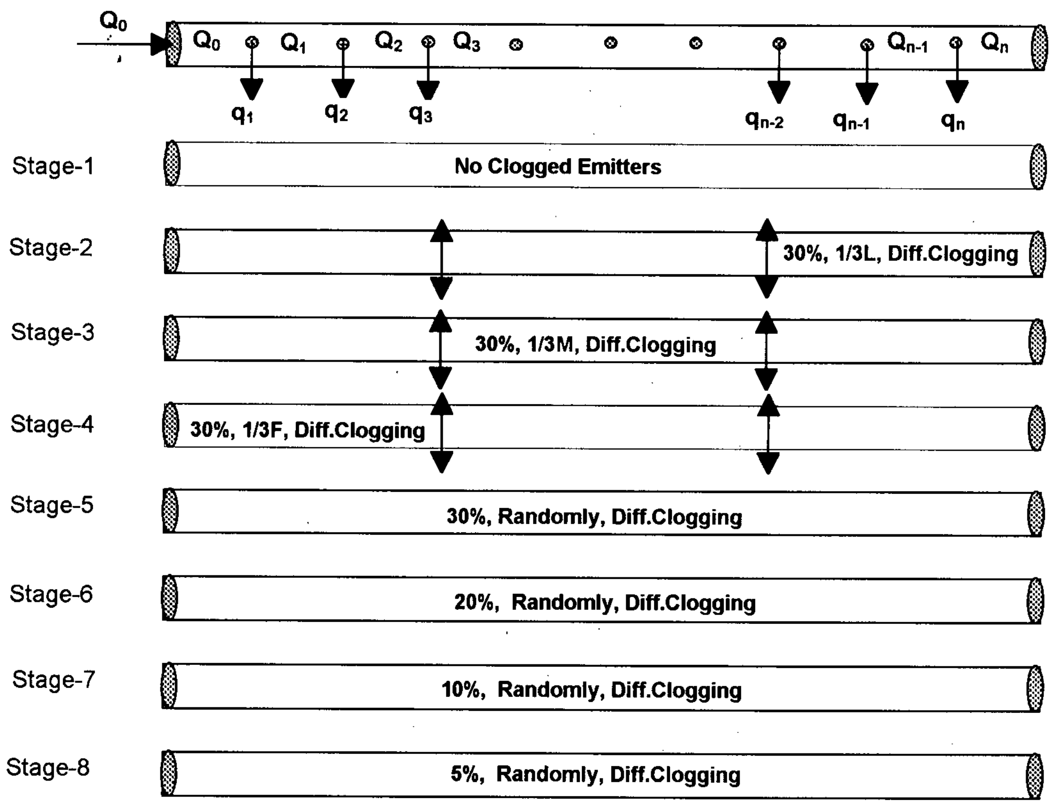


Figure 4.6 Different patterns of emitter clogging along the lateral

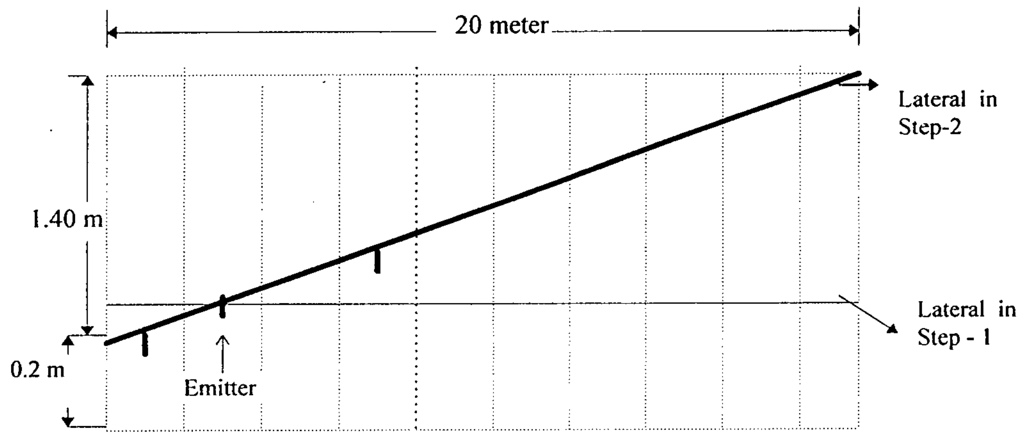


Figure 4.7 Lateral A laid on 7% up-slope (not to scale)

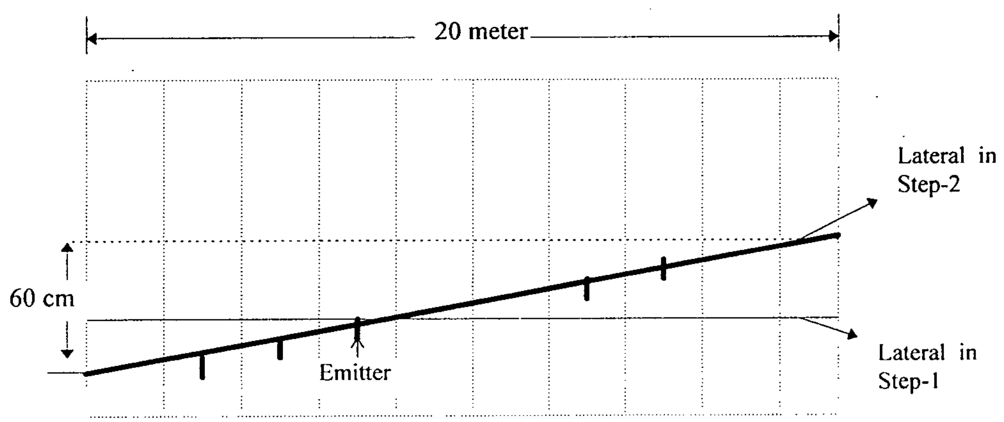


Figure 4.8 Lateral B laid on 3% Up-slope (not to scale)

were investigated.

Test A consisted of eight different stages similar to those reported in step 1. Similar patterns of emitter clogging as in test A were simulated with synthetic data by the computer program.

Test B- This experiment also consisted of two 20m laterals laid on 3% and 7% uniform down-slope. Lateral A was installed on a 7% down-slope on one side and lateral B on a 3% down-slope on the other side of the frame. The difference in elevation between the front and the end of lateral was same as in test A. Figures 4.9 and 4.10 show the laterals laid on 3% and 7% down-slopes. Similar patterns of emitter clogging as explained in step 1 were done in eight different stages.

The volume of emitter flow was measured along the laterals A and B at each stage four times, for 30 minutes duration each. The average individual emitter flow rate along the lateral was then determined. The impact on the hydraulics of the microirrigation system of clogged emitters along the laterals laid on sloped terrain was then determined.

4.2.3 - Step 3 of the field experiment:

The last part of the field experiment was done from May to September of 1997. The effects of naturally clogged emitters, no-clogged emitters, the venturi injector, and injection of saline water on the hydraulics of microirrigation laterals laid on flat terrain were investigated. The following tests were done in this step:

1- Inspection of the system to determine the number, degree, and the formation of naturally clogged emitters along the 20m laterals (laterals A and B) laid on flat terrain and installed in June 1995.

2- Determination of the hydraulic parameters of 20m and 40m laterals consisting of naturally clogged emitters laid on flat terrain. The results obtained from the naturally clogged emitters were compared with the results obtained from the artificial clogging and the synthetic data in

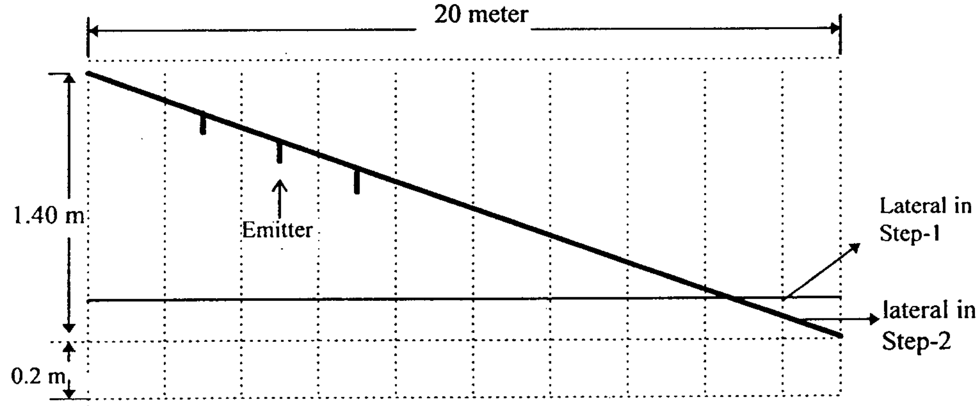


Figure 4.9 Lateral A laid on 7% down-slope in step-2 (not to scale)

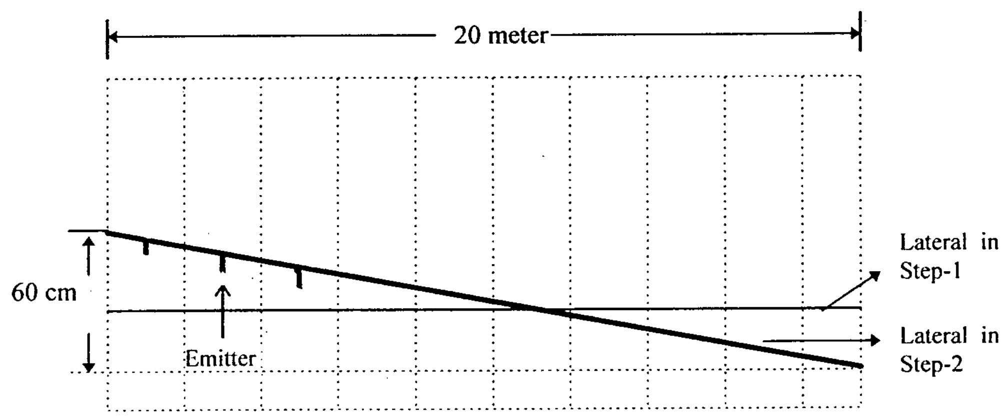


Figure 4.10 Lateral B laid on 3% down-slope in step-2 (not to scale)

1995.

3- Comparison of the emitters flow rate along the laterals (laid on flat terrain) before and after flushing the laterals under naturally clogged conditions.

4- Investigation of the impact of air and water temperature on the flow rate of naturally clogged emitters (on flat terrain).

5- Test of the venturi injector (Mazzei Venturi Injector model 484) with city water in order to determine the pressure differences between the inlet and outlet of venturi needed to creates a vacuum at the throat of the venturi injector. This vacuum is the suction for injecting the liquid fertilizer or chemical (saline water in this research) into the microirrigation system.

6- Investigation of the impact of the installation of the venturi in the microirrigation system on the hydraulic parameters of laterals laid on flat terrain.

7- Installation of the new 20m and 40m polyethylene laterals with the new pressure-compensating emitters (same type of emitters as in previous steps) laid on flat terrain. The venturi injector was also installed in order to determine the impact of saline water injection on the hydraulics of microirrigation laterals under the no-clogged condition.

8- Injection of different degrees of saline water as a nutrient liquid by the venturi injector through the 20m and 40m laterals. The flow rate and electrical conductivity (*EC*) of each emitter flow were measured in order to determine how uniformly the nutrient (saline water) was distributed along the lateral.

4.2.3.1 Inspection of the clogged emitters:

The microirrigation system consisting of four 20m laterals (A and B on flat and sloped terrain) were installed in the field from June 1995 to summer 1997. The system was run three hours a day, four days a week from August to September 1995 and from May to September 1996. The system did not operate from October 1996 to May 1997. Since laterals A and B were operated several times from 1995 to 1996, some emitter clogging was expected to occur along the laterals. In May 1997, each emitter along laterals A and B was carefully opened to reveal the formation and degree of clogging. Different types of particles were found in several emitters along laterals A and B. The number, degree, and the nature of the clogging formations were investigated. In order to determine the number of clogged emitters, the system was operated for 30 minutes in May 1997. Then the emitter flow rates along laterals A and B were measured. It was assumed that every emitter along laterals A and B with a flow rate less than the minimum emitter flow rate measured in June 1995 was partially clogged. Then, the number of partially clogged emitters along the laterals was determined. The caps of partially clogged emitters randomly located along the laterals were removed and the insides of the emitters were inspected. The caps were then closed and the system was run for 30 minutes [Keller and Bliesner (1990) suggested that a minimum velocity of 0.3 m/s is necessary to adequately flush fine particles from the lateral if the lateral hoses of the system are flushed for about one hour. The velocity of water was about 5.7m/s in this study]. It was confirmed that the clogged particles were still there; they were not removed from the emitter. The clogging was mostly from slime, insect feathers, and in some cases, very small particles of fine sand. The system with the naturally clogged emitters was run, and the volume of water delivered by each emitter along the lateral was measured for 30 minutes. This run was repeated three times and the average of each individual emitter flow rate along the 20m laterals was determined. In order to extend the length of lateral to 40m, the laterals A and B were joined and extended by a 1m piece of polyethylene pipe. Similar runs were done on 40m lateral and the average of emitter flow rate along the lateral was determined. The variations of emitter flow rate along the lateral were then plotted.

The degree of clogging (C_d%) of the *naturally clogged* emitters was estimated using the equation of linear relationship between the degree of clogging and the reduction of emitter flow rate obtained from the field experiment data in 1995 (detail given in chapter 5). The degree of clogging of the *artificially clogged* emitters in step 1 were also estimated by the same equation. Then, the *total degree of clogging* (*TC%)* along the laterals was measured by adding all the degrees (C_d%) of clogged emitters along the lateral. The average degree of clogging was calculated as: Ave.$C_d\% = TC\%/n$ where, n is the number of emitters along the lateral.

A linear relationship between C_d% and coefficient of uniformity (*CU*) was found in such a way that the values of *CU* under *naturally* and *artificially* clogged emitters were measured.

Then the values of CU versus average $C_d\%$ obtained from the *naturally* and *artificially* clogged emitters was plotted and a least-square regression was determined. In addition, a similar calculation to the one mentioned above was done to determine CU and $C_d\%$ using synthetic data. Different numbers of clogged emitters (0%,10%, 20%.... to 100% of the total number of emitters) and different percentages of clogging were simulated along the 20m lateral. CU and C_d were then measured and plotted, and a least-square regression was determined. A general relationship between CU and $C_d\%$ was found by combining all values of CU and $C_d\%$ obtained from *natural*, *artificial*, and *synthetic* data.

The hydraulic parameters (H_f, CU, EU', H_{var}, q_{var}, V_{qs}, V_{hs}, V_{pf}, and V_{qh}) of microirrigation laterals obtained from the no-clogged, naturally clogged, artificially clogged, and synthetically clogged conditions were compared to each other.

4.2.3.2 Lateral flushing:

The effect of lateral flushing on the naturally clogged emitter's flow rate was also examined. In order to flush the lateral, the pressure gauge and the hose plug from the end of lateral was removed and the system was run for 30 minutes. Then the end of lateral was plugged and the system was run for one hour. The volume of water delivered from each emitter along the lateral was measured in 30 minutes and the emitter's flow rates were determined. This test was done for both 20m and 40m lateral lengths and each run was repeated twice. The variations of emitter flow rate along the lateral before and after flushing were determined and compared to each other.

4.2.3.3 Air and water temperature :

It is suspected that temperature may have an impact on the emitter flow rate and hydraulics of laterals in microirrigation systems. The impact of air and irrigation water temperature at the experiment site on emitter flow rate was examined. Different water and air temperatures could be achieved under different weather conditions such as cloudy, sunny, immediately after sunset, and immediately after sunrise in July, 1997 on different days. The microirrigation system consisting of naturally clogged emitters was run under various air and water temperatures (high and low temperatures) on different days. The volume of water delivered from each emitter along the lateral was measured and the emitter flow rate was determined. In all cases, the pressure at the inlet and end of the lateral was checked and recorded. The variations of emitter flow rate under different temperatures versus sections along the lateral were measured, plotted and compared to each other.

4.2.3.4 Venturi Injector:

The maximum amount of lateral inflow was determined based on the total number of emitters along the lateral and their nominal emitter flow rate. Different values of pressures [i.e. 70 kPa to 420 kPa (10 psi to 60 psi)] in upstream and downstream were chosen in order to determine the size of venturi injector for the experiment. The diameter of the venturi throat (d) was calculated based on the maximum required flow, the diameter of the lateral, and the pressure at the upstream and downstream. Then, the minimum and maximum values of venturi throat diameter were found. The venturi injector (model Mazzei 484 ,3/4", the smallest commercial size available on the market) with 68 *l/h* (18 gph) injection capacity was selected for the experiment. The venturi injector was tested before installation under different pressures in up- and downstream. Figures 4.11a,b,c show the test of the venturi injector's lay out. A pressure regulator and two pressure gauges were used to test the venturi injector under different inlet and outlet pressures. The city's water was used in the test. This test was done in order to determine the amount of pressure difference required between the inlet and outlet of the venturi injector at the experiment site. The amount of liquid flow (injected liquid through the throat) under different motive flows (venturi inlet flow) and inlet and outlet pressure was compared to the values reported by the manufacturer. The minimum amount of motive flow was about 600 l/h (≈3 gpm) when the pressures at the venturi inlet and outlet were 168 and 105 kPa (24 and 15 psi) respectively. This amount of inflow and pressure difference between the venturi inlet and outlet create a vacuum at the venturi throat to inject the liquid. The effects of injecting water of different degrees of the salinity (by using the venturi injector) on the emitter's hydraulic characteristics were examined (detail is given in chapter 5). In addition, the hydraulic parameters (i.e. CU, EU', q_{var}, V_{qs}) when the venturi

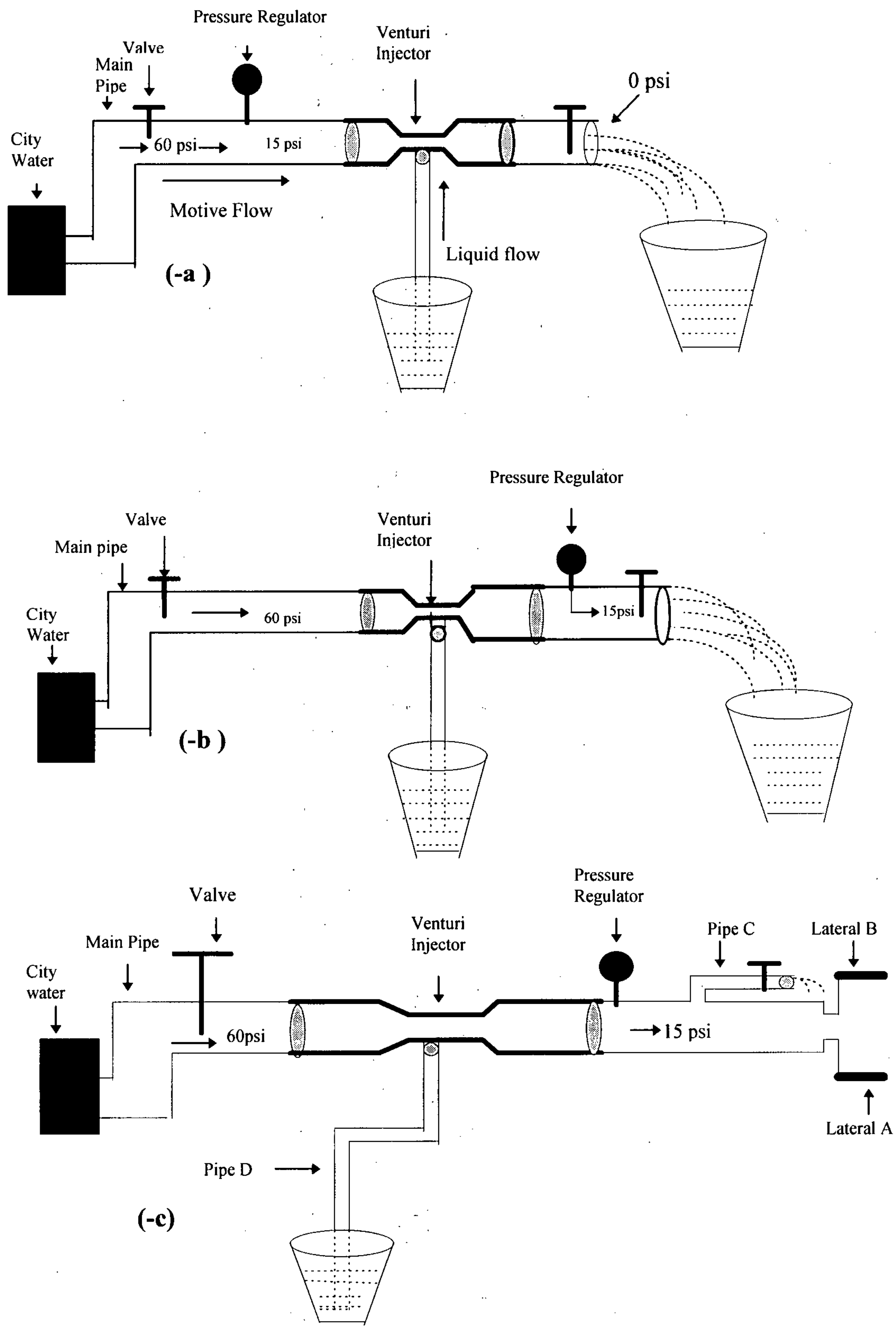


Figure 4.11 Test of venturi injector lay out

injector was installed were measured and a comparison was made to the parameters that existed without the injector. The venturi injector was installed in the system and used in different tests as follows:

4.2.3.4.1. *City water* injection in *naturally clogged* condition:

Two 20m laterals (A and B) consisting of naturally clogged emitters were used for this experiment. The venturi injector was connected to the manifold right after the pressure regulator and before the lateral inlet. Two pressure gauges were also installed, one right after the venturi outlet close to the inlet of lateral A, and the second at the end of lateral A. The end of lateral was connected to a pressure gauge, a valve and a piece (5 m) of polyethylene pipe. Therefore, the amount of motive flow (venturi inlet flow) could be adjusted by gradually opening or closing the valve at the end of the lateral. Increasing the lateral flow (at a fixed length and number of emitters) can be simulated with longer lengths of lateral. This test was done on 20m lateral A and city water was used as an injection liquid. A 180 liter barrel was used as an injection tank. The system was run in three different phases. In the first run, the throat of the venturi injector was shut off and the city water was delivered to the system from the main line. The pressure regulator was adjusted to 175 kPa (25 psi) and the inlet lateral pressure was also adjusted to 105 kPa (15 psi) by controlling the amount of motive flow by adjusting a valve at the end of lateral A. Therefore, the pressure difference between the inlet and outlet of the venturi was adjusted to 10 psi (25 psi at the venturi inlet and 15 psi at the venturi outlet). In order to ensure that the pressure and temperature had attained equilibrium the system was running for one hour before data collection. Then, the emitter flow rate from each individual emitter was directly measured by using a stopwatch, bucket, and graduated cylinder. The volume of water from each individual emitter was collected twice for 30 minutes each time. Then the average emitter flow rate was obtained. The amount of flow rate from the pipe connected at the end of lateral was also measured. In the second run the suction pipe of venturi was opened and put into the injection barrel (180 liter). The venturi outlet pressure (lateral inlet pressure) was dropped to 84-87 kPa (12-12.5 psi) immediately. Under this condition, the water was delivered to the system from the main pipe and the injection barrel. In order to ensure that the pressure and temperature had attained equilibrium, the system was running for 30 minutes before data collection. Then the volume of water delivered from each emitter was measured for 30 minutes. The volume of liquid suction from the barrel and the flow rate at the end of the lateral (the flow from the additional piece of polyethylene pipe) were also measured at the end of 30 minutes. In the third run, the pressure at the inlet of lateral was adjusted to 105 kPa (15 psi) by adjusting pressure regulator and increasing the pressure at the venturi inlet to 34 psi. Then, as in the second run, the volume of water delivered by each emitter and the volume of liquid injection from the barrel were measured for 30 minutes. The flow rate at the end of the lateral from the connected pipe was also measured. The length of lateral was extended to 40m by joining the two 20m laterals. The same test as with the 20m lateral was done with the 40m. In all cases, the pressure at the beginning and the end of lateral was checked by a pressure gauge and recorded. In the case of the 40m lateral, the pressure at the middle was also checked. The hydraulic parameters were determined in the three runs and evaluated. The variation of emitter flow rates obtained from the three different runs versus sections along the laterals were then plotted.

4.2.3.4.2 *City water* injection in *no-clogged* condition:

Two 20m *new* polyethylene laterals (laterals A and B) with 1m emitter spacing (similar to the description in step 1) were installed on flat terrain. Two tests were carried out. The first test was done without the venturi injector and the second test was done when the venturi injector was installed in the manifold before lateral inlet. Lateral A was used for the first test. Two pressure gauges were connected, one at the lateral inlet and the other at the end of lateral. In order to ensure that the pressure and temperature had attained equilibrium, the system was run for 1 hour before data collection. Then, the emitter flow rate from each individual emitter was directly measured. The average emitter flow rate was obtained from four measurements (replications). The pressure inlet of each individual emitter along the lateral was also measured by a pressure gauge. The length of lateral was extended to 40m with one emitter spacing. Similar measurements as for the 20m lateral were done for the 40m lateral. The hydraulic parameters were measured and then plotted for both 20m and 40m laterals.

In the second test, the venturi injector was installed in the manifold right after the pressure regulator. A barrel of 180 liter capacity was used for storing the liquid (city water in this case). The system was run under three different pressures at the venturi and the lateral inlet (25 and 15 psi, 25 and 12 psi , and 34 and 15 psi pressures at the venturi and lateral inlet respectively). The volume of water from all emitters along the lateral was collected for 30 minutes. The average emitter flow rate was obtained from two measurements (replications). Three different runs were done similar to those described in the previous section.

4.2.3.4.3 *Saline water* injection in *no-clogged* condition:

Similar tests as reported in the previous sections were done with an injection of saline water. Saline water represented the nutrient (fertilizer) injected into the microirrigation system. The electrical conductivity (*EC*) of water was measured as a degree of salinity. The *EC* of city water for this experiment was 0.022 mmhos/cm. To make the saline water, different types of salt could be used to increase the salinity of the water. Table salt (Windsor salt, iodized) was chosen for this experiment as it is cheap and easy to get. The saline water with different *EC* was artificially made by adding the amount of salt to the known volume of city water. Two different cases for injection of saline water through the microirrigation system were considered as:

(1)- Ideal case

(2)- Conventional case

In the *ideal case*, the aim was to maintain a constant value of electrical conductivity (*EC*) at the emitter's outlet. *EC* values of 1.5 and 3 *mmhos/cm* were maintained. Therefore, it was assumed that saline water with a constant and known value of *EC* is expected to be delivered from all emitters along the lateral. This case can be simulated in a field condition when a fixed concentration of chemical liquid (fertilizer and pesticide) is required to be delivered from the emitters in a microirrigation system. To provide saline water as an injection liquid in an ideal case, the amount of salt per liter of city water was determined based on the percentages of liquid flow and motive flow. In this case, high saline water with an *EC* of 13 to 15 mmhos/cm and 27.5 mmhos/cm was used as an injection liquid, and the city water with an *EC* equal to 0.022 mmhos/cm was used as the motive flow (detail is given in Chapter 5). A conductivity meter model CDM3 Radiometer/Copenhagen was used to measure the electrical conductivity of high saline water.

In the *conventional case*, a constant *EC* value for the injecting saline water was maintained, and the *EC* variation at the emitter outlets was investigated. In this case it was assumed that two different kinds of irrigation water with different *EC*'s are going to be applied in a microirrigation system. Therefore, the conventional case was set-up in order to investigate how venturi injector and pressure variations (venturi and lateral inlet pressures) affect the *EC* of the injected liquid along the lateral (or *EC* of the mixed water delivered by the emitters). In this case two different saline water with *EC* of 1.5 and 3 mmhos/cm were used as the liquid injection and the city water as the motive flow.The conventional case can also be simulated with the real conditions in the field when two different sources of irrigation water (such as sea water of high salinity and well or river water of low salinity) are available to irrigate the crops.

In both cases, the saline water was stored in a barrel so that it could be injected through the microirrigation system. In both cases, the *EC* of mixed water was dependent upon the portion of liquid flow and its *EC* (EC_L) and the portion of motive flow and its *EC* (EC_i). Three runs similar to those indicated in the previous section were considered in each case. In both cases, each run was repeated and the average emitter flow rate along the laterals was determined. The electrical conductivity of mixed water delivered from each individual emitter along the 20m and 40m laterals was also measured. A portable conductivity pDS meter model EP11/pH, M6/pH was used to measure the *EC* of mixed water along the lateral. In all runs, the pressure at the venturi inlet, lateral inlet and end of lateral were checked and recorded. The variations in emitter flow rate along the laterals obtained from the three runs were measured and then plotted. In addition, the impact of the venturi injector being installed, venturi inlet pressure in three different runs, and the different injection liquids on total emitter flow rates and the hydraulic parameters of laterals were measured and then plotted. In both cases, the air and water temperatures at the experiment site were also recorded.

4.3 Impact of emitter clogging on crop yield and farmer benefit:

The effects of different patterns of clogged emitters on the hydraulics of laterals and their impact on reduction in cotton yield (the reason for selecting cotton was discussed in chapter 3) and farmer's loss per unit area were simulated. The computer simulation model determines the value of the total emitter's coefficient of variation (V_T) by means of interpolating the data (using table 2.6) as explained in chapter 3. This is to account for relative deficit evapotranspiration ($1- ET_{ave}/ET_m$) when clogging occurs. The cotton yield under the no-clogged condition and reduction in yield under different numbers of partially clogged emitters were determined by using equation 2.51. The average of cotton yield harvested per acre and the average marketing price were adopted from the data in the Agricultural Statistics United States, Department of Agriculture (1994). Relationship between the yield reduction and farmer's loss versus different areas were plotted. Relationship between the yield reduction and number of clogged emitters were also plotted and a least-square regression was determined for each area.

Chapter 5

5. Results and Discussion

5.1 Introduction:

The following sections describe and compare the field experimental measured and predicted values of hydraulics parameters of microirrigation laterals affected by different patterns of emitter clogging along the lateral. First, the hydraulic characteristics of the pressure-compensating emitter model DPJO4-A, Hardi Turbo SC™ Plus, and the emitter manufacturer's coefficient of variation (*CV*) are determined. Then the test of emitter clogging simulated in the experimental set-up by modifying the Hardi Turbo SC™ emitter in different ways is presented. Next, a relationship between the percentage or degree of clogging, reduction in emitter flow rate and *K* (emitter coefficient that accounts for areal and discharge effects) is presented. Then, the results obtained from the field experiments are discussed and compared with the theoretical results obtained from computer model with synthetic data. The theoretical results consist of two parts. The first part includes the impact of different patterns of emitter clogging along the *different lengths* of laterals (10-60 m) on the hydraulics of microirrigation. In the second part, the effect of similar patterns and degrees of emitter clogging as in the field experiment on the hydraulics of a 20m lateral is presented.

5.2 Hydraulic characteristics of emitter:

The pressure-compensating emitters are characterized by a very low value of emitter discharge exponent *x*. The values of *K* (emitter coefficient that accounts for areal and discharge effect) and *x* (emitter exponent) in emitter flow equation (equation 2.1) were estimated to determine the discharge rate for the Hardi Turbo SC™ Plus emitter. A least-square regression analysis based on the logarithm of pressure and discharge of the emitter yielded: $x = 0.0757$ and $K = 3.147$ (Figure 5.1). Table 5.1 shows the emitter flow rates operated under different pressures from which the regression analysis was determined. The emitter discharge coefficient *K* accounts for conversion factors to balance both sides of equation 2.1. The slope of the regression line in Figure 5.1 is the emitter discharge exponent *x*, which is the measure of the change in emitter flow rate with variations in operating

Table 5. 1 Average discharge values of Hardi Turbo SC™ Plus, model DPJO4-A emitters, at different pressures (adopted from Hardi manufacturer's manual).

Emitter #	Pressure(P) (psi)	Pressure(P) (M)	Flow (q) (L/h)	Log(P) (M)	Log(q) (L/h)
1	5	3.52	3.14	0.55	0.50
2	7	4.93	3.60	0.69	0.56
3	10	7.04	3.94	0.85	0.60
4	15	10.56	3.86	1.02	0.59
5	20	14.08	3.94	1.15	0.60
6	25	17.60	4.01	1.25	0.60
7	30	21.12	4.05	1.32	0.61
8	35	24.64	4.05	1.39	0.61
9	40	28.16	4.01	1.45	0.60
10	45	31.68	3.97	1.50	0.60
11	50	35.20	3.90	1.55	0.59

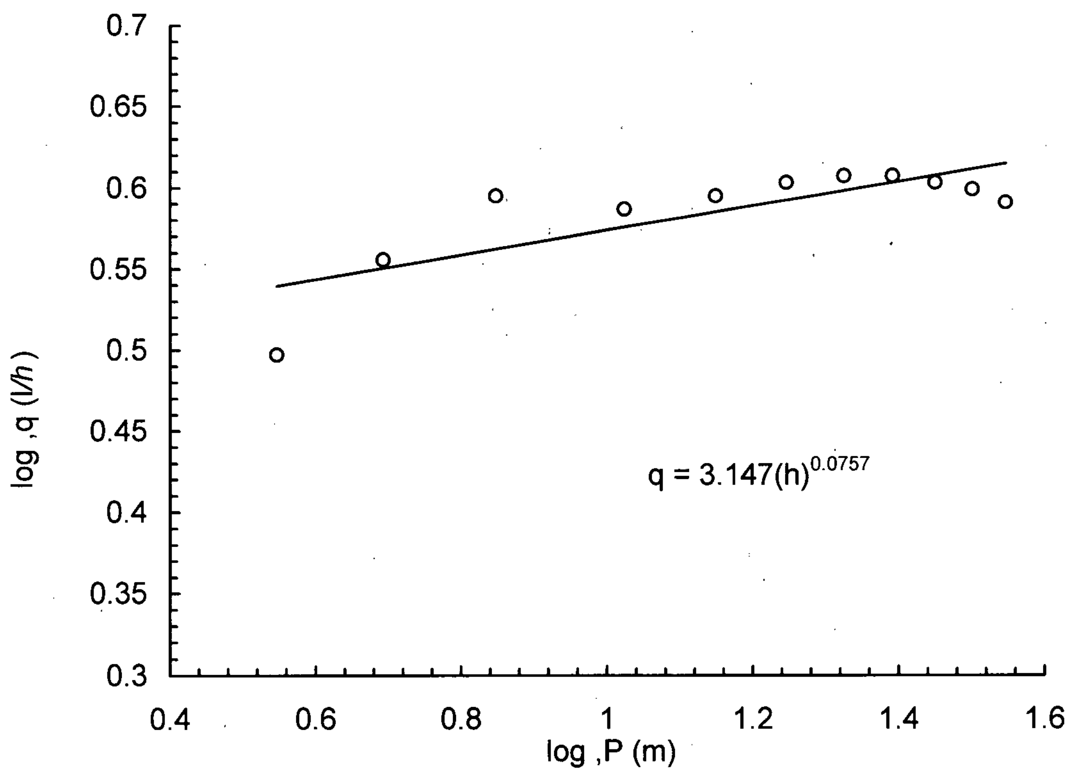


Figure 5.1 Logarithm of the average emitter discharge and pressure to determine K and x for the pressure compensating emitter model DPJO4-A, Hardi Turbo SCTM Plus.

pressure. Based on equation 2.1 and Figure 5.1, the emitter flow equation for this type of pressure-compensating emitter is found to be:

$$q = 3.147h^{0.0757} \qquad 5.1$$

According to Karmeli (1977); Kimura (1978); Keller and Karmeli (1975) and Von Bernuth and Solomon (1986), the values of x normally fall between 0.0 and 1.0. The larger the value of x, the more sensitive the emission device flow rate is to a change in pressure. In fully turbulent flow $x = 0.5$ and in a laminar flow, $x = 1$. For non-compensating orifice and nozzel emitters, x would be 0.5, and for fully compensating emitters $x = 0$. When x is equal to 1.0, a change in pressure will be matched by a proportional (equal percentage) change in flow rate (laminar flow). A value of $x = 0$ means no flow variation with pressure. Values of x greater than 1.0 or less than 0.0 are possible when the elastomeric parts are used in the flow passages. The value of the discharge exponent x (0.0757) obtained from the least-square regression analysis indicates the fully turbulent flow regime for this type (Hardi Turbo SC™) of pressure-compensating emitter. However, it is expected that the emitter flow rates of pressure-compensating emitters should be independent of operating pressure, but our field experiments (to be discussed later) indicate that the discharge from the pressure-compensating emitters may not be constant if a variation in operating pressure occurs.

5.3 Manufacturer's coefficient of variation (*CV*):

The emitters' flow paths are very small and the performance of an emission device is strongly influenced by the quality and consistency with which the devices are manufactured. The manufacturer's coefficient of variation (*CV*) is a function of the emitter type and the quality control exercised during the manufacturing process. A sample of 20 emitters from total of 40 emitters were randomly chosen to determine the emitter manufacturer's coefficient of variation for the first step of this research. Table 5.2 shows the average emitter flow rate and pressure for this sample. The coefficient of variation was computed by dividing the standard deviation of discharges by the average of emitter flow rate at specific pressure level (equation 2.20). In spite of installing the pressure regulator, it was still difficult to achieve the

Table 5.2 Average emitter flow rate and pressure for sample test.

Emitters	Average Pressure (psi)	Average Pressure (kPa)	Average Flow Rates(l /h)
1	15.0	105.0	3.94
2	15.2	106.4	3.79
3	15.0	105.0	3.90
4	15.5	108.5	3.90
5	15.1	105.7	3.75
6	15.2	106.4	3.87
7	15.0	105.0	3.90
8	15.3	107.1	3.75
9	15.2	106.4	3.90
10	15.0	105.0	3.78
11	15.1	105.7	3.95
12	15.3	107.1	3.79
13	15.2	106.4	3.90
14	15.3	107.1	3.78
15	15.0	105.0	3.85
16	15.1	105.7	3.90
17	15.5	108.5	3.78
18	15.4	107.8	3.70
19	15.0	105.0	3.75
20	15.2	106.4	3.85
Standard deviation = 0.074	**Average emitter flow rate =3.83**	**CV = 0.0193**	

constant pressure for this experiment due to the fluctuation of pressure in the city water pipe line. Therefore, the pressure could only be adjusted to 15-15.5 psi by a pressure regulator under the experiment conditions. The calculated value of 0.019 (Table 5.2) for this type of emitter is classified as excellent by the ASAE EP405.1 (1997). Therefore, the computed *CV* indicates an acceptable quality control during the manufacturing process.

5.4 Influence of energy gain or loss on pressure-compensating emitter:

Theoretically, discharge from the pressure-compensating emitters should be independent of operating pressure or energy gain or loss due to slope when the pressures fall within the manufacturer's recommendation. Emitter manufacturers have claimed that the pressure-compensating emitters offer an advantage, especially on sloped terrain. In order to get a reliable measurment of pressure compensation by the Hardi Turbo SC™ emitter, 5 emitters (# 1, 6, 10, 15, and 20) under no-clogged conditions were randomly selected along the lateral line laid on flat terrain (experimental set-up described in previous chapter). The system was operated under the 15 psi (average) inlet pressure. Discharge of the relevant emitters were measured two times and average values were determined. Next, this lateral was changed to 3% and then 7% up-slopes conisting of the same number and locations of emitters along the lateral as on flat terrain. Similar measurements were carried out. Table 5.3 shows the average values of pressure and discharge of emitters along the lateral on flat terrain, up-slope at 3% and 7% and down-slope at 3% and 7%. A comparison of discharge variations on flat, up- and down-slopes with manufacturer emitter discharge is shown in Figure 5.2. Table 5.3 and Figure 5.2 indicate that none of the 5 emitters tested under different slopes were even close to the manufacturer's claim. The average deviations in emitter flow (when compared to the manufacturer data) were ± 5.9%, ±3.47% and ±4.51% in flat terrain, and 3% and 7% up-slope respectively. Results show that the emitter flow rates in the case of down-slope terrains were less than the manufacturer's emitter discharge. The average emitter flow variation in 3% and 7% down-slopes were 6.64% and 5.12% respectively. Based on these results, it is concluded that the pressure-compensating emitter may not produce a constant and uniform emitter flow rate along the lateral under pressure variations (i.e. energy gain or loss) caused by sloped terrain.

Table 5.3 Emitter discharge and pressure on flat, and sloped terrain affected by energy gain or loss

Emitter	Flat Terrain		-3% (up-slope)		-7% (up-slope)		3% (down-slope)		7% (down-slope)	
#	P (psi)	q (l/h)	P (psi)	q (l/h)	P (psi)	q (l/h)	P (psi)	q (l/h)	P (psi)	q (l/h)
1	13.97	3.73	14.95	3.67	14.90	3.64	15.05	3.52	15.10	3.81
6	13.80	3.97	14.70	3.74	14.40	4.11	15.30	3.60	15.60	3.57
10	13.67	3.53	14.50	3.94	14.00	3.70	15.50	3.49	16.00	3.62
15	13.50	3.85	14.25	3.93	13.50	4.02	15.75	3.62	16.50	3.61
20	13.33	3.67	14.00	3.84	13.00	4.04	16.00	3.77	17.00	3.76

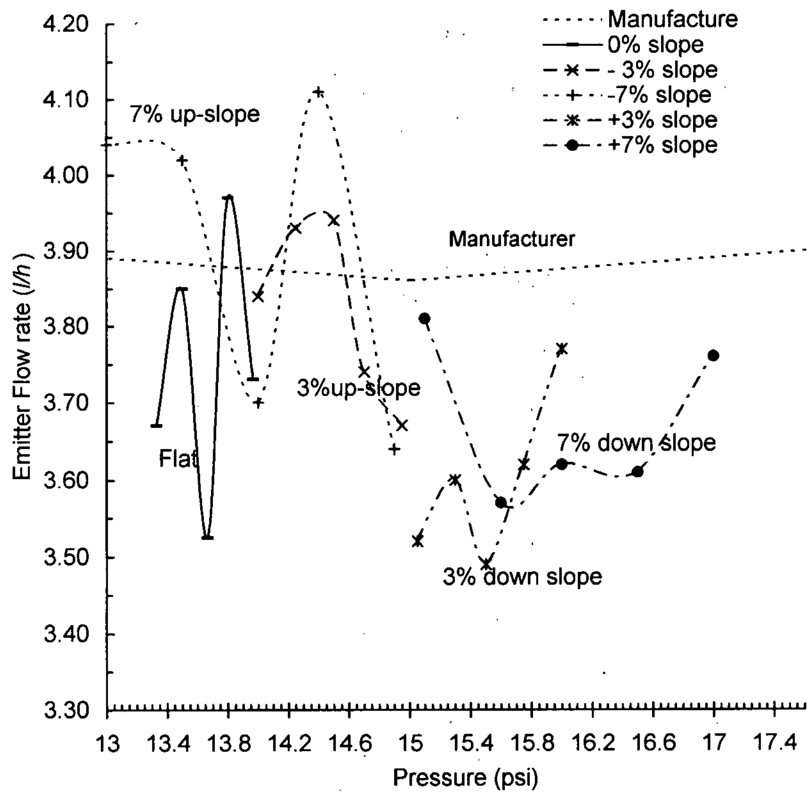


Figure 5.2 Comparison of emitter discharge on flat and sloped terrain with manufacturer's emitter flow rate

5.5 Simulation of emitter clogging:

Partially or completely clogged emitters were artificially made for this research to be placed at different locations along the lateral. Partial clogging may be simulated by installing smaller emitters, and a plug would simulate complete clogging. Many researchers have used a smaller size of emitter to obtain the uniform emitter clogging of their prediction. The problem with this type of simulation is that the hydraulic path-way of the smaller size of emitters may not have the same hydraulic characteristics as the larger size emitters. The other problem with using smaller sized emitters for partial clogging is that it creates uniform partial clogging along the lateral. In practice, this uniform clogging rarely occurrs. A perfectly uniform partially-clogged emitter in a microirrigation system rarely happens in the field due to different types of particles and chemical reactions which cause the clogging. In a microirrigation system, non-uniform clogging often occurs due to the settling of different particles or salt precipitation caused by the interaction of chemical elements with liquid fertilizer or pesticide applied through the system. Therefore, to achieve a more realistic clogging situation, the emitter clogging was simulated by modifying the Hardi Turbo SC^{TM} (nominal emitter flow rate 3.78 *l/h*) in different ways as follows:

A- Removing the emitter cap and randomly plugging several holes of the pressure regulator in the emitter with epoxy glue.

B- Gluing the perimeter of the elastomeric disk of the emitter with epoxy.

C- Inserting 4-10g coarse sand (40mesh<D<14mesh) on the top of elastomeric disk.

D- Introducing 4-15g fine sand (100mesh<D<40mesh) from the inlet barb into the emitter.

Table 5.4 shows different types of emitter clogging by epoxy or by introducing sand into the emitter. The volume of water delivered from each clogged emitter under 15 psi pressure was collected 2-4 times and the average emitter discharge was determined as shown in Table 5.4. Data shows that different types and degrees of clogging resulted in different out-comes from the emitters. It was found that introducing the same amount of particles but at different locations of particles inside the emitter caused different impacts on emitter flow rate. The emitter flow rate was lower than the nominal flow rate in most cases. However, in some cases, the emitter flow rate was higher when the same amount and size of sand was inserted into the emitter *under* the elastomeric disk. Adding very small particles (fine texture) of sand into the emitter *on the top* of the elastomeric disk could decrease the emitter discharge. The variation of emitter flow rate was dependent upon the location of particles that settled inside the emitter inlet. Table 5.4 shows that the same amount of fine sand decreased the emitter flow rate from 3.78 *l*/h to 2.63 *l*/h for test #19 (introducing sand *on the top* of the elastomeric disk) or increased the emitter flow rate from 3.78 to 5.59 *l*/h for test #22 (introducing sand *under* the elastomeric disk). When coarse and medium textured sand was put into emitters #17 and #18, the emitter flow rate decreased from 3.78 to 3.35 and 1.69 *l*/h respectively. Results show that there was an almost 90% chance of lowering the emitter discharge by inserting sand or epoxy into the emitter *on the top* of elastomeric disk. There was an uncontrolled variable of emitter clogging for this type of pressure-compensating emitter. The variation of flow rate of clogged emitter was dependent upon the amount of clog particles and the nature of the clogging inside the emitter. An emitter having a discharge less than the nominal emitter flow rate (<3.78 *l/h*) was assumed as the partial clogged emitter in this research. Several partially clogged emitters were artificially made by introducing sand into emitter and measuring the emitter discharge. It was practically impossible to achieve a pre-determined degree of emitter clogging. Therefore, different degrees of emitter clogging were made and used in different stages as explained in the previous chapter.

Table 5.4 Effect of different types and amount of particles on pressure-compensating emitter (Hardi Turbo SC™ model DPJO4-A) flow rate.

Test No.	Type of clogging	Time	Volume of water (cc)	q (*l/hr*)
1	7 holes from 15 pressure regulator holes were clogged by epoxy glue.(50% clog)	13' 26'8" 13' 37"	250 cc 250 cc 250 cc	1.115 1.1 1.108 AVE.=1.11
2	3 holes from 15 pressure regulator holes at the middle were clogged by epoxy glue (20% clogging)	5' 57" 5' 58" 5' 58"	250 250 250	2.52 2.51 2.51 AVE.= 2.51
3	Same test as test No. 2 but the clogged location was different. Three clogged holes (by epoxy glue) were selected at the middle part of the 15 pressure regulator holes.	16' 12'	250 250	0.94 1.25 AVE.=1.09
4	50% of the single outlet hole was clogged by epoxy glue.	3' 05' 3' 06" 3"03"	250 254 250	4.86 4.58 4.91 AVE.= 4.78
5	1 hole (the last hole) from 15 pressure regulator holes was clogged by epoxy glue.	12' 50" 13' 14"	250 250	1.168 1.13 AVE.=1.15
6	Same test as test No. 5, but the last hole include outlet were partially clogged.	17' 26" 35' 02"	100 200	0.34 AVE.=0.34
7	4 holes from the end part of 15 pressure regulator holes were clogged by epoxy glue.	180'	0.00	0 AVE.=0.0
8	3 holes (include inlet) from 15 pressure regulator holes were clogged by epoxy glue.	16' 14" 15' 30"	250 250	0.92 0.97 AVE.=0.95
9	All holes except inlet and outlet holes were clogged by epoxy glue.	23' 28" 42'	130 250	0.33 0.36 AVE.=0.35

Continue (Table 5.4)

10	Perimeter of the elastomeric disk was completely clogged by epoxy glue(except the inlet hole)	4' 40" 4' 44" 4' 45" 3' 45"	250 250 250 250	3.21 3.17 3.16 3.88 AVE.=3.18
11	3 holes at the last part (include out-let) from 15 pressure regulator holes were clogged by epoxy glue.	10' 8.5" 10' 8.5"	250 250	1.47 1.47 AVE.=1.47
12	Sand was put into the central hole (a few particles of sand into the outlet) *under* the elastomeric disk.	3' 38.5" 3' 38"	250 250	4.11 4.12 AVE.=4.11
13	Same test as No. 12 but more sand was put into the central hole (*under* elastomeric disk).	2' 13" 2' 13"	250 250	6.7 6.7 AVE.= 6.7
14	The mixed texture of sand was put around the top of elastomeric disk.	4' 13.5" 5' 6"	250 308	3.55 3.62 AVE.=3.58
15	Sand *under* the elastomeric disk into the pressure regulator holes.	2' 30" 5' 04"	250 500	6 5.92 AVE.=5.96
16	Same test as test No. 15 but the amount of sand was different .	1' 4.5" 0' 56" 1' 0" 1' 2" 1' 45"	250 250 250 250 250	13.95 16.07 15.0 14.51 13.95 AVE.=14.68
17	Coarse texture sand was introduced into the emitter from the inlet barb (not removing the cap).	4' 25" 4' 31.5" 4' 29"	250 250 250	3.39 3.31 3.34 AVE.=3.35
18	Medium texture sand was introduced into the emitter from the inlet barb(not removing the cap).	8' 34" 3' 32" 3' 33" 3' 38"	250 100 100 100	1.75 1.69 1.69 1.65 AVE.=1.69
19	Fine texture was introduced into the emitter from the inlet barb (not removing the cap)	5' 38" 5' 44" 5' 43.5"	250 250 250	2.66 2.62 2.62 AVE.=2.63

Continue (Table 5.4)

20	A small amount of sand was put on the top of elastomeric disk from the inlet (not removing the cap)	5' 54" 5' 16" 2' 50"	250 250 115	2.54 2.84 2.43 AVE.=2.52
21	Removed the cap, then a grains of medium textured sand was put on the top of elastomeric disk (test 21,22, 23, and 24 were done with three emitters installed to a piece of polyethylene pipe, 10 cm apart from each other)	7' 53" 8' 05" 3' 18"	250 250 100	1.9 1.85 1.82 AVE.=1.86
22	Removed the cap, fine texture of sand was put *under* the elastomeric disk	1' 08" 2' 35" 2' 38"	100 250 250	5.29 5.8 5.7 AVE.=5.59
23	Removed the cap, mixed texture of sand was put on the elastomeric disk	12' 9' 9" 9' 22"	318 250 250	1.59 1.63 1.6 AVE.=1.61
24	Removed the elastomeric disk from emitter, no sand or particles inside the emitter. This emitter was inserted to the one meter polyethylene pipe close to in emitters that had been clogged. The pressure was decreased from 15 psi to 12.5 psi.	0' 12" 0' 12" 0' 12.5"	250 250 250	75 75 75 AVE.=75
25	0.22 gram coarse sand (40 mesh < D < 14 mesh) was put on the top of elastomeric disk by removing cap.	4' 29.5" 4' 31" 4' 30"	250 250 250	3.34 3.34 3.33 AVE = 3.33
26	0.22 gram coarse sand was put on the top of elastomeric disk as same as test No. 27, but the system was operated for 8 hours, then the emitter flow rate was measured.	6' 26" 6' 31.5" 6' 34" 10' 15" 10' 29"	250 250 250 250 250	2.33 2.3 2.28 1.46 1.43 AVE.=1.96
27	0.22 gram coarse sand on the top of elastomeric disk (removed cap) same as test No. 27 and 28	5 hr.	0.0	0.0 AVE.=0.0
28	0.15 gram fine sand (100 mesh < D < 40 mesh) was put on the elastomeric disk from the inlet barb.	67' 5' 25.5" 5' 26"	3319 250 250	2.97 2.76 2.76 AVE.=2.86
29	0.15 gram fine sand (100 mesh < D < 40 mesh) was put *under* the elastomeric disk by removing the cap.	56' 30" 3' 46" 3' 40" 3' 48"	3915 250 250 250	4.15 3.98 4.09 3.94 AVE.=4.04

5.6 Relationship between dimensionless values of *K*%, C_d%, and *q*%:

Based on emitter flow rate and pressure at each section along the lateral (flat terrain) obtained from the field and synthetic data, the reduction of parameters *K* and *q* (expressed as *K%* and *q%*), and the degree of emitter clogging (C_d%) for different patterns of emitter clogging were determined. Table 5.5 shows the values of emitter flow rate, pressure, *K%, q%,* and C_d% along a 20m lateral obtained from the field experiment. The relationship between *K%, q%,* and C_d% was plotted (Figure 5.3) and a least-square regression was performed. The *K%, q%,* and C_d% were determined as follows:

There are two flow paths when water is flowing in the lateral of a microirrigation system. One is the path toward the downstream end inside the lateral, and the other is within the emitter. Theoretically, when the pressure-compensating emitters are used in a microirrigation system, the emitter flow rate is independent of operating pressure, if it falls within the pressure range recommended by the manufacturer. In the general equation of emitter discharge (equation 2.1), *K* is a constant of proportionality that characterizes each emitter and accounts for areal and discharge coefficients. According to the Hardi Manufacturer, the *average* emitter discharge from the Hardi Turbo SC™ is 3.78 *l/h* under the operating pressure range of 35 to 350 kPa (5 to 50 psi). Therefore, it can be assumed that the *x* value in Equation 5.1 for pressure variation along the lateral (within manufacturer's pressure range) is constant. The value was determined to be 0.0757. Equation 5.1 can be used to determine the *K* value as:

$$K = \frac{q}{h^{0.0757}} \qquad 5.2$$

In this study, the *K* value of 3.147 was found for a no-clogged condition. Equation 5.2 shows that both *q* and *h* have an impact on *K*. Any reduction of *q* can lower the value of *K*. A lower value of *K* means a smaller cross-section area of emitter passageway in the emitter. Assuming that C_d% is the degree of clogging, then under a no-clogged condition, C_d% is zero, and the emitter flow rate should be 3.78 *l/h* (within manufacturer's pressure range) for the type of emitter used in this study. In equations 2.1 and 5.1, when *x* is constant, the parameters that

Table 5.5 Values of K%, q%, and C_d% of 20 emitters along the lateral laid on flat terrain when 30% of the emitters are partially clogged and located at the one-third from the downstream end (Field data)

q_i	h_i	k_i	$K\%$	$q\%$	$C_d\%$
3.64	10.56	3.045	3.24	3.70	3.24
3.43	10.56	2.870	8.82	9.26	8.82
3.50	10.56	2.928	6.96	7.41	6.96
3.60	10.56	3.012	4.30	4.76	4.30
3.69	10.56	3.087	1.90	2.38	1.90
3.65	10.56	3.054	2.97	3.44	2.97
3.71	10.55	3.104	1.37	1.85	1.37
3.48	10.55	2.911	7.49	7.94	7.49
3.68	10.55	3.079	2.17	2.65	2.17
3.76	10.55	3.146	0.04	0.53	0.04
3.52	10.55	2.945	6.42	6.88	6.42
3.71	10.55	3.104	1.37	1.85	1.37
3.40	10.55	2.845	9.61	10.05	9.61
3.63	10.55	3.037	3.50	3.97	3.50
2.49	10.55	2.083	33.80	34.13	33.80
2.63	10.55	2.200	30.08	30.42	30.08
0.30	10.55	0.251	92.02	92.06	92.02
1.49	10.55	1.247	60.39	60.58	60.39
1.23	10.55	1.029	67.30	67.46	67.30
0.00	10.55	0.000	100.00	100.00	100.00

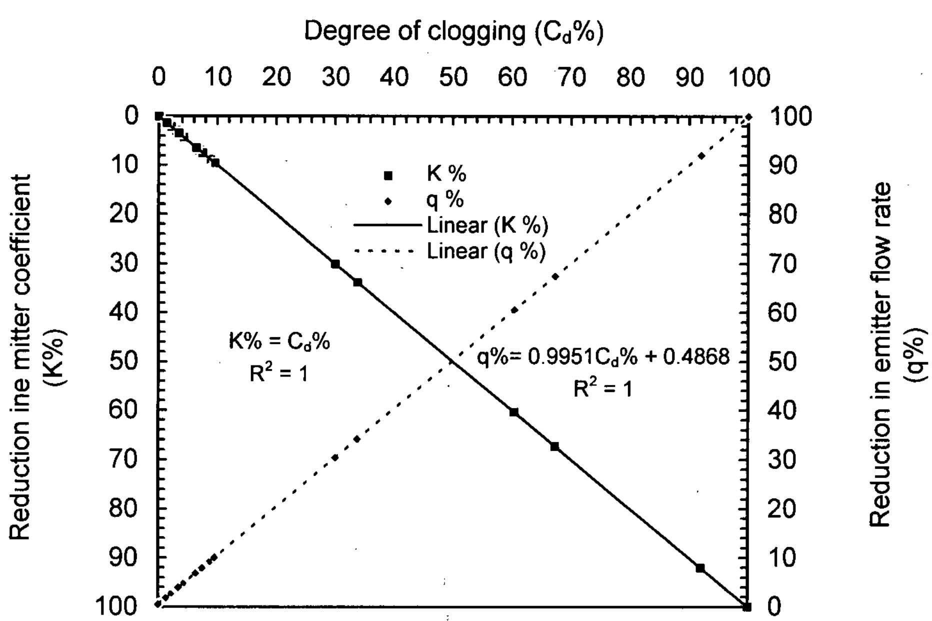


Figure 5.3 Relationship between K%, q%, and C_d% for 20 emitters along the lateral laid on flat terrain when 30% of total emitters are partially clogged and located at the last section (one-third from downstream end) of lateral.

will affect the emitter discharge q are K and h. Assume q_i is an emitter flow rate from a "partially clogged" emitter located at ith section along the lateral (hence its value is less than the nominal flow rate q) and h_i is the pressure at the corresponding section (i.e. ith section). Under this condition, the emitter coefficient k_i can be determined as follows:

$$k_i = \frac{q_i}{h_i^x} \qquad 5.3$$

where k_i is a fraction of K. The percentage reduction of emitter coefficient can then be determined as:

$$K\% = \left(\frac{K - k_i}{K}\right)100 \qquad 5.4$$

where the K value was found 3.147 (as explained in section 5.1). In a no-clogged situation the percentage of clogging is zero (or degree of clogging, $C_d\%=0$), and the emitter is fully opened (100% open), K has its maximum value (3.147). Based on equation 5.4, when there is no reduction in emitter coefficient (i.e. $k_i = K$) $K\%$ is 0.0, and $C_d\%$ would be zero (no-clogged condition). Under a partially clogged condition, when the value of emitter coefficient decreases to k_i, the fraction of the passageway in the emitter that is clogged is $C_d\% = K\%$ and the fraction that is still operating (functioning) can be calculated by:

$$Op = (1 - K\%)100 \qquad 5.5$$

Where Op is the percentage or degree of opening (%). The dimensionless reduction of emitter flow rate from the nominal emitter flow rate can be determined as follows:

$$q\% = \left(\frac{q - q_i}{q}\right)100 \qquad 5.6$$

where $q\%$ is the dimensionless value of reduction in emitter flow rate.

In order to obtain a relationship between *K%*, *q%*, and $C_d\%$, the flow rates from 20 emitters along the 20m lateral (one emitter per section) laid on flat terrain were measured (see Chapter 4 for details). The pressure at each section along the lateral was determined by equation 2.18. The pressure at the inlet, middle; and end of the lateral was also measured with pressure gauges and was 15psi, 15psi, and 14.9psi respectively. These values were then compared with the computed values shown in Table 5.5. The values of *K%*, *q%*, and $C_d\%$ were computed by equations 5.4, 5.5, and 5.6 (Table 5.5) and were then plotted (Figure 5.3). The least-square regression analysis for the stage with 30% partially clogged emitters located at the last section (one-third from the downstream end) of the lateral was performed and the linear regression between *q%*, *K%*, and $C_d\%$ was found as follows:

$$q\% = 0.4868 + 0.9951 C_d\% \quad 5.7$$

and

$$K\% = C_d\% \quad 5.8$$

By assuming the conditions of the same field experiment, synthetic data were used in the simulation program for the case of 10, 20, 30, 40, 50, and 60m lengths of laterals. The manufacturer's coefficient of variation of 0.0193 (Table 5.2) was also applied to those emitters that were not clogged. Computed values for *K%*, *q%*, and $C_d\%$ for the same condition as described above are given in Table A.5.1 (Appendix A). The least-square regression equation for each length of lateral was determined as shown in Table 5.6. Results show that the relationship between *K%* and degree of clogging ($C_d\%$) is independent of the length of lateral. However, the relationship between reduction of emitter flow rate (*q%*) and degree of clogging ($C_d\%$) is dependent on the length of lateral. Table 5.6 shows that the intercept and slope values varied in all 6 linear equations for different lengths of lateral. However, these variations which are due to the insignificant differences in pressure variation along the laterals laid on the flat terrain, are not considered to be significant. Table 5.6 shows that the percentage of reduction in emitter flow rate is directly related to the degree of clogging. It is found that the rate of reduction in emitter discharge is slightly higher than the rate of degree of emitter clogging. For example, 30% of emitter clogging resulted in 30.19% and 30.22% reductions of emitter flow rate for the emitters located on 20m and 60m lateral lengths respectively.

Table 5.6 Relationship between reduction in emitter flow rate (*q%*) dimensionless reduction of emitter coefficient (*K%*), and degree of clogging (C_d*%*) for different length of laterals (synthetic data).

Length of lateral (m)	Regression equations	
10	$q\% = 0.2732 + 0.9987C_d$	$K\% = C_d\%$
20	$q\% = 0.2488 + 0.9983\ C_d$	$K\% = C_d\%$
30	$q\% = 0.2473 + 0.9987\ C_d$	$K\% = C_d\%$
40	$q\% = 0.2671 + 0.9987\ C_d$	$K\% = C_d\%$
50	$q\% = 0.2720 + 0.9980\ C_d$	$K\% = C_d\%$
60	$q\% = 0.2720 + 0.9980\ C_d$	$K\% = C_d\%$

5.7 Comparison of adjusted "F" factor:

Computed value of adjusted "F" factor used in head loss equation suggested by Christiansen (1942), Jensen and Fratini (1957), Walker (1976) and Gohering (1976) when 1-200 outlets (emitters) were located along the lateral are given in Table A.5.2 (Appendix A). The value of "F" was computed based on assumptions that the first outlet was located 1 outlet spacing away from the lateral (equation 2.12) or the first outlet was located 1/2 an outlet spacing from the supply line (equations 2.13 and 2.14). Figure 5.4 shows a similar trend in the relationship between the values of "F" obtained from these equations and the number of outlets. Results show that when the number of outlets were less than 20, the "F" values obtained from Jensen, Walker, and Gohering did not deviate more than 4% from "F" values computed by the Christiansen equation. As the number of outlets increased along the lateral, "F" values obtained from all three equations closely approach to each other. Therefore, to determine "F", where either the first outlet is located one outlet or a half outlet spacing from the lateral inlet, one of the aforementioned equations can be used and applied to the Christiansen head

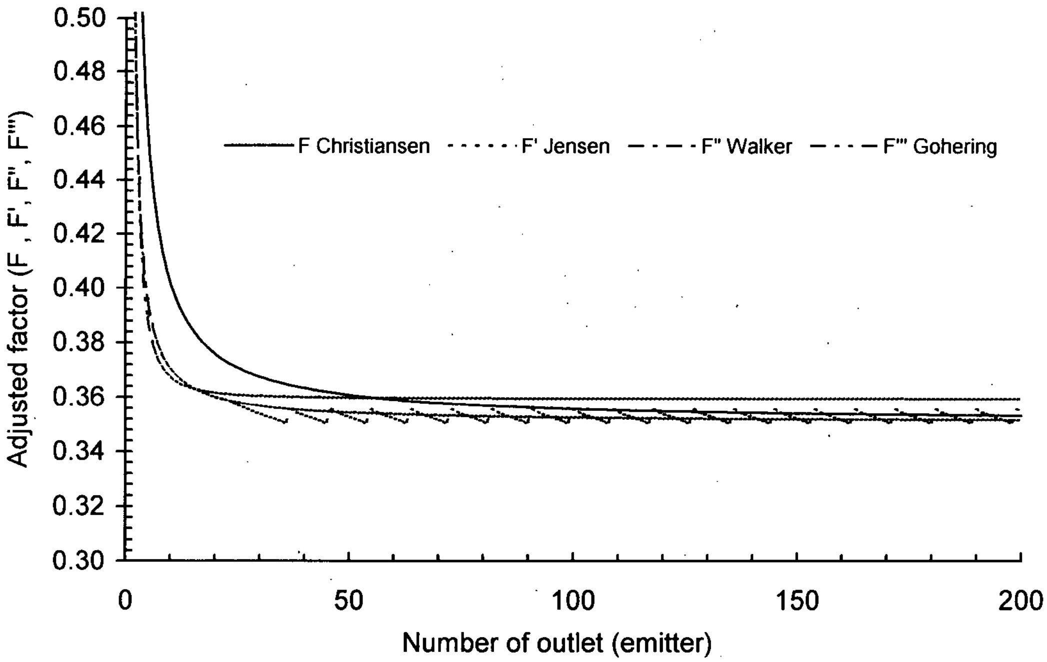


Figure 5.4 Comparison of adjusted "F" factor (F,F',F'',F''') for multi-outlet pipe

loss equation. In this study, as the first emitter was located one spacing away from the lateral inlet, the Christiansen equation was used to calculate "F". Table A.5.2 shows the value of "F" is equal to one when there is one outlet along the lateral. Therefore, in determining the head loss (h_f) at each section consisting of one emitter per section along a lateral, both the Hazen William equation (equation 2.10) and the Christiansen equation (equation 2.11) will yield the same result.

5.8 Field experiments

5.8.1 Step 1, hydraulic characteristics of lateral laid on flat terrain:

Step 1 of the field experiment was conducted to evaluate the effects of different patterns of emitter clogging (different number, degree, and location of clogged emitters) on the hydraulic characteristics of a microirrigation lateral laid on a flat terrain (Figure 4.1). The results obtained were compared to those simulated with the computer program. Head loss (H_f), pressure variation (H_{var}), emitter flow variation (q_{var}), emitter discharge coefficient of variation (V_{qs}), emitter discharge coefficient of variation due to hydraulics (V_{qh}), hydraulic design coefficient of variation (V_{hs}), and emitter performance coefficient of variation (V_{pf}) were evaluated. To estimate the uniformity through the microirrigation system, the impact of different patterns of clogging on coefficient of uniformity (CU), field emission uniformity (EU') , distribution uniformity (DU), application efficiency (Ea), statistical uniformity of emitter discharge (U_s), and emitter statistical uniformity due to hydraulic (U_{sh}) were also evaluated. In addition, by using the field and synthetic data, the impact of clogging on reduction of cotton yield was simulated and the farmer's money loss caused by emitter clogging along the lateral in a microirrigation system were estimated for different areas. Equations number 5.1, 2.4, 2.10, 2.15, 2.18, 2.19, 2.27, 2.29, 2.31, 2.33, 2.35, 2.36, 2.37, 2.38, 2.39, 2.40, 2.41, 2.42, and 2.51 were used to calculate the above parameters.

Two 20m, 15mm inside diameter polyethylene laterals (laterals A and B) were used for this step of the field experiments. Twenty pressure-compensating emitters with a nominal emitter flow rate of 3.78 l/h were inserted on-line along each lateral. The first emitter was located

1m away from the lateral inlet. A 105 kPa (15 psi) pressure regulator was installed at the inlet of the laterals to keep the pressure at the manufacturer's recommended level. The emitter flow variation along the laterals was measured under eight different patterns of clogging (stages 1 to 8) as explained in Chapter 4. The term "desired situation" (stage 1) was used to express an operating condition in the microirrigation system shown in Figure 4.1, with no emitter clogging and with the application of city water into the system. Lateral A was used in the first stage (no-clogged condition) and lateral B was used in the rest of the seven stages consisting of several partially clogged emitters. Different percentages and degrees of emitter clogging were applied in a lateral line of the microirrigation system. The number of partially clogged emitters is expressed as the percentage of the total number of emitters along the lateral. The experimental set-up had 20 and 40 emitters per lateral. Therefore, a 30% partial clogging pattern means that 6 and 12 emitters respectively had been simulated to reduce their flow to lower than the nominal emitter flow rate. The individual emitter flow rates along the laterals were measured four times in each stage. The average emitter flow rates obtained from the field experiment are shown in Table 5.7 for all the eight stages. Although the constant and equal discharges from the no-clogged emitters were expected, as Table 5.7 shows, the emitter flow rates along the laterals were not the same at each section—even in stage 1 with the desired situation. The reasons for the variations in emitter flow rates in all of stages are the emitter manufacturer's variation and pressure variations along the lateral. Figure 5.5 shows how the manufacturer and pressure variations along the lateral have an impact on the discharge of emitters. The microirrigation system was operating within the pressure (15 psi) recommended by the manufacturer, but the emitter discharge along the lateral varied between 3.4 and 3.97 *l/h*. Non-overlapping curves in Figure 5.5 also indicate the variation of discharge from no- clogged emitters along the lateral in different stages. For example, the first 6 emitters in stages 2 and 3 (no-clogged emitters) which should have delivered the same flow rate show different values of discharge, as shown in Table 5.7. It is found that any clogged emitters along the lateral have significant impact on the flow rate of the rest of the no-clogged emitters along the line. However, it is practically impossible to predict the exact nature of clogging and its actual impact on the rest of the emitters in the system.

Table 5.7 Average emitter flow rate (*l/h*) along the laterals laid on flat terrain under different stages with clogged and no-clogged emitters*

Emitter #	Stage- 1 *q (l/h)*	Stage- 2 *q (l/h)*	Stage- 3 *q (l/h)*	Stage- 4 *q (l/h)*	Stage- 5 *q (l/h)*	Stage- 6 *q (l/h)*	Stage- 7 *q (l/h)*	Stage- 8 *q (l/h)*
1	3.73	3.64	3.83	1.71	1.99	3.78	3.61	3.65
2	3.55	3.43	3.48	2.58	3.46	3.47	3.38	3.43
3	3.74	3.50	3.89	2.11	1.72	1.92	3.46	3.56
4	3.78	3.60	3.70	2.47	3.76	3.78	2.14	3.75
5	3.62	3.69	3.48	0.55	0.26	3.58	3.46	3.52
6	3.97	3.65	3.72	0.86	3.73	1.03	3.51	3.60
7	3.91	3.71	1.74	3.66	3.66	3.69	3.59	3.65
8	3.69	3.48	0.05	3.46	3.92	3.19	3.77	3.89
9	3.42	3.68	1.67	3.68	1.32	3.64	3.54	3.60
10	3.52	3.76	2.49	3.77	3.49	3.52	3.39	3.46
11	3.74	3.52	2.22	3.50	1.17	3.72	3.58	3.62
12	3.55	3.71	2.17	3.74	3.42	0.92	3.37	3.43
13	3.50	3.40	3.42	3.40	3.37	3.40	0.33	3.60
14	3.83	3.63	3.65	3.63	3.61	3.66	3.51	3.56
15	3.85	2.49	3.56	3.80	3.59	3.63	3.45	3.48
16	3.54	2.63	3.46	3.42	2.24	3.54	3.44	1.85
17	3.48	0.30	3.54	3.55	3.53	3.52	3.44	3.42
18	3.40	1.49	3.62	3.64	3.57	3.57	3.50	3.54
19	3.73	1.23	3.64	3.62	3.64	3.61	3.54	3.59
20	3.67	0.00	3.72	3.80	3.66	3.70	3.56	3.63
lateral inl	73.22	58.54	61.05	60.95	59.11	64.87	65.57	69.83

* Stage- 1: no-clogged emitters
* Stage- 2 to 8: partially or fully clogged emitters

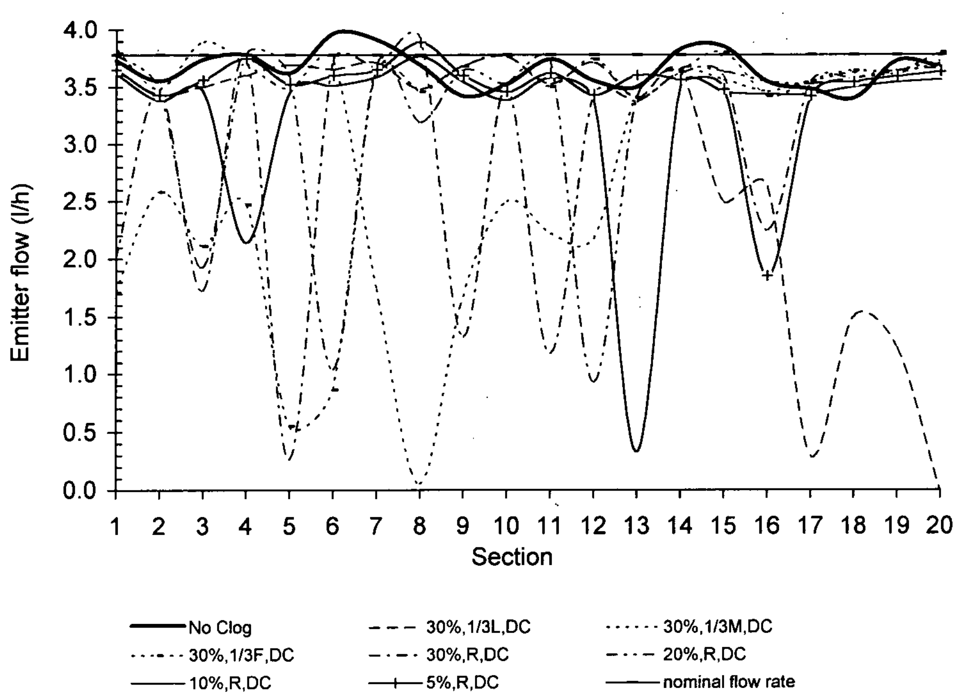


Figure 5.5 Variations of emitter discharge along the lateral due to emitter clogging, manufacturer and pressure variations.

5.8.1.1 Total head loss (H_f):

Total head loss along the lateral was directly related to the amount of flow at the lateral inlet. Table 5.8 shows the values of head loss (H_f) and the lateral inlet discharge. The highest head loss was found under no-clogged conditions (stage 1). The minimum head loss was obtained in stage 2, when 30% of emitters are partially clogged and located at the last one-third section of the lateral. Figure 5.6 shows the variations in head loss and the flow at the lateral inlet under different patterns of emitter clogging. As number of clogged emitters along the lateral increased, the amount of flow at the lateral inlet and, consequently, the total head loss will decrease. Tables 5.8 and 5.9 show the values of head loss increased from 0.0073m in stage 2 (30% clogging) to 0.0119m in stage 8 (5% clogging) and 0.0132m in stage 1 (no-clogged). Similar results as in the field experiment were obtained from computer simulation of the synthetic data (Table 5.10). Figure 5.7 shows the total head loss and pressure variations under different stages consisting of different percentages of clogged emitters. The variations in H_f in stages 2 to 8 were due to the different locations and degrees of clogged emitters. As shown in Table 5.8 and Figures 5.6 and 5.7, as the clogged emitters occurred closer to the lateral inlet, the total H_f approached that of the no-clogged condition. It was found that if the clogged emitters were located at the first one-third section of the lateral, they had no significant impact on the emitter flow rate from the rest of the emitters along the lateral. Figures 5.6 and 5.7 also show that stages 2 to 5 with 30% of emitter clogging at different locations, the same manufacturer's variation, and almost the same lateral inlet discharge have different impacts on head loss. The pressure was almost constant at each section along the lateral laid on flat terrain in each stage. Figure 5.8 show that there are no significant differences between pressure in each section under different stages. Table A.5.3 and A.5.4 (Appendix A) show the values of head loss and pressure per section, and energy drop ratio and total pressure drop per section obtained from the experimental set-up. Results show that the location and the degree of clogged emitters were the major factors affecting H_f along the lateral on flat terrain. This is because the different locations of clogged emitters cause different pressure variations along the lateral, which have different effects on head loss (Figure 5.7). As shown in Table 5.8, there were no significant differences in H_f obtained from stages 4, 6, and 8 with 30%, 20% and 5% clogged emitters. Results show that the number of partially clogged emitters had less effect on H_f than location and degree of

Table 5.8 Flow rates at lateral inlet and head loss under different patterns of clogging

Stage #	Inlet lateral Q_L (l/h)	Head loss H_f(m)
1	73.22	0.0132
2	58.54	0.0073
3	61.05	0.0095
4	60.95	0.0113
5	59.11	0.0098
6	64.87	0.0110
7	65.57	0.0108
8	69.83	0.0119

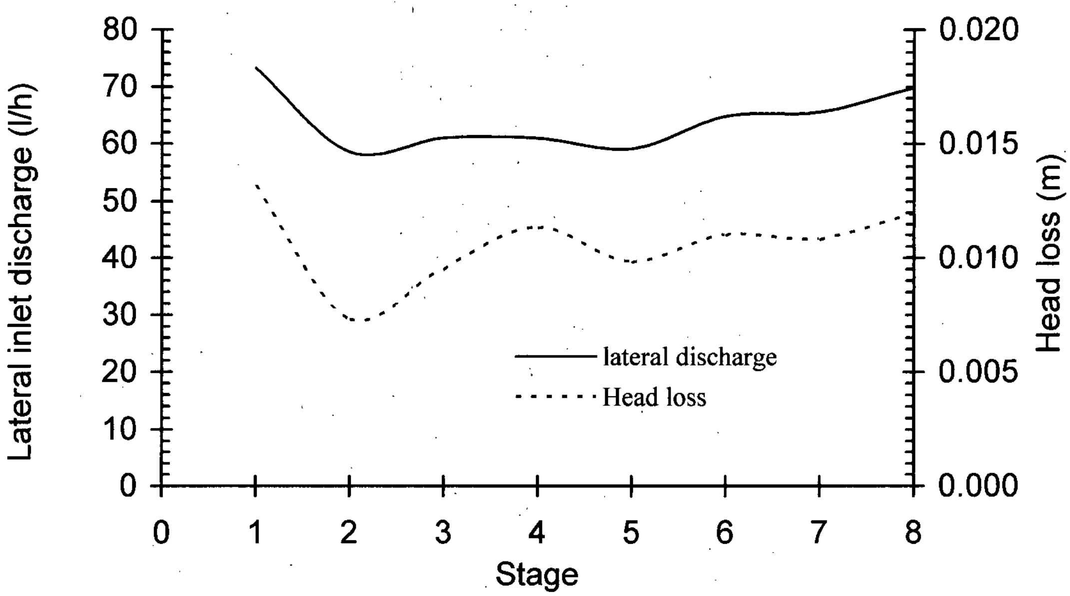


Figure 5.6 Relationship between discharge at lateral inlet and total head loss under different patterns of clogged emitters.

Table 5.9 Values of hydraulic parameters under 8 different patterns of clogged emitters along the lateral (field results)

Stage No.	Total Hf (m)	Hvar (%)	qvar (%)	CU (%)	Ea (%)	EU' (%)	DU (%)	Us (%)	U_{Sh} (%)	Vqs	Vhs	Vqh	Vpf
1	0.0132	0.1250	0.0095	96.261	99.99743	94.619	94.05	95.66	99.9971	0.0434	0.00038	2.9E-05	0.0434
2	0.0073	0.0692	0.0052	67.810	99.99858	37.649	48.82	60.16	99.9984	0.3984	0.00021	1.6E-05	0.3984
3	0.0095	0.0899	0.0068	73.874	99.99815	51.433	58.46	67.87	99.9979	0.3213	0.00027	2.1E-05	0.3213
4	0.0113	0.1072	0.0081	73.733	99.99779	50.533	58.23	67.97	99.9975	0.3203	0.00033	2.5E-05	0.3203
5	0.0098	0.0927	0.0070	69.437	99.99809	43.715	51.40	64.35	99.9979	0.3565	0.00028	2.1E-05	0.3565
6	0.0110	0.1040	0.0079	81.767	99.99786	64.498	71.01	73.83	99.9976	0.2617	0.00032	2.4E-05	0.2617
7	0.0108	0.1022	0.0077	87.534	99.9979	76.925	80.18	77.30	99.9976	0.2270	0.00031	2.4E-05	0.2270
8	0.0119	0.1129	0.0085	94.618	99.99768	89.303	91.44	88.77	99.9974	0.1123	0.00034	2.6E-05	0.1123

Table 5.10 Values of hydraulic parameters under 8 different patterns of clogged emitters along the lateral (computed results).

Stage No.	Total Hf (m)	Hvar (%)	qvar (%)	CU (%)	Ea (%)	EU' (%)	DU (%)	Us (%)	U_{Sh} (%)	Vqs	Vhs	Vqh	Vpf
1	0.01393	0.1319	0.0100	98.94	99.99728	98.47	98.314	98.74	99.9969	0.0126	0.00040	3.1E-05	0.0126
2	0.00770	0.0729	0.0055	66.61	99.9985	35.96	46.917	59.40	99.9983	0.4060	0.00022	1.7E-05	0.4060
3	0.01008	0.0954	0.0072	72.66	99.99804	49.53	56.525	67.02	99.9978	0.3298	0.00029	2.2E-05	0.3298
4	0.01203	0.1139	0.0086	72.44	99.99766	48.54	56.186	67.04	99.9974	0.3296	0.00035	2.6E-05	0.3296
5	0.01047	0.0992	0.0075	68.14	99.99796	41.73	49.348	63.35	99.9977	0.3665	0.00030	2.3E-05	0.3665
6	0.01175	0.1112	0.0084	80.86	99.99771	63.74	69.57	73.14	99.9974	0.2686	0.00034	2.6E-05	0.2686
7	0.01220	0.1156	0.0088	86.96	99.99762	96.66	79.274	76.74	99.9973	0.2326	0.00035	2.7E-05	0.2326
8	0.01226	0.1161	0.0088	90.79	99.99761	84.28	85.353	78.83	99.9973	0.2117	0.00035	2.7E-05	0.2117

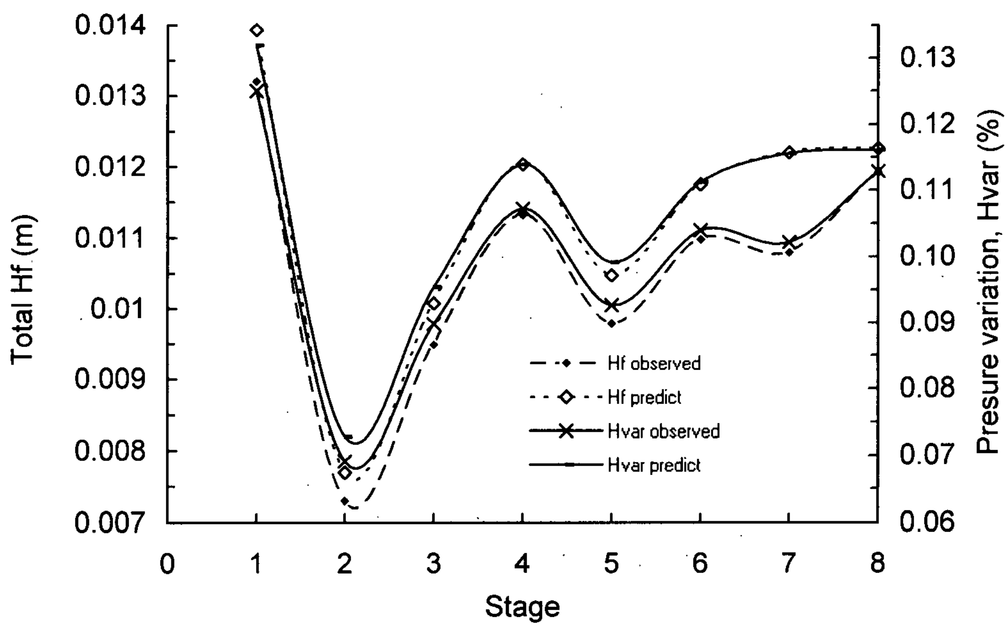


Figure 5.7 Head loss and pressure variation under different stages

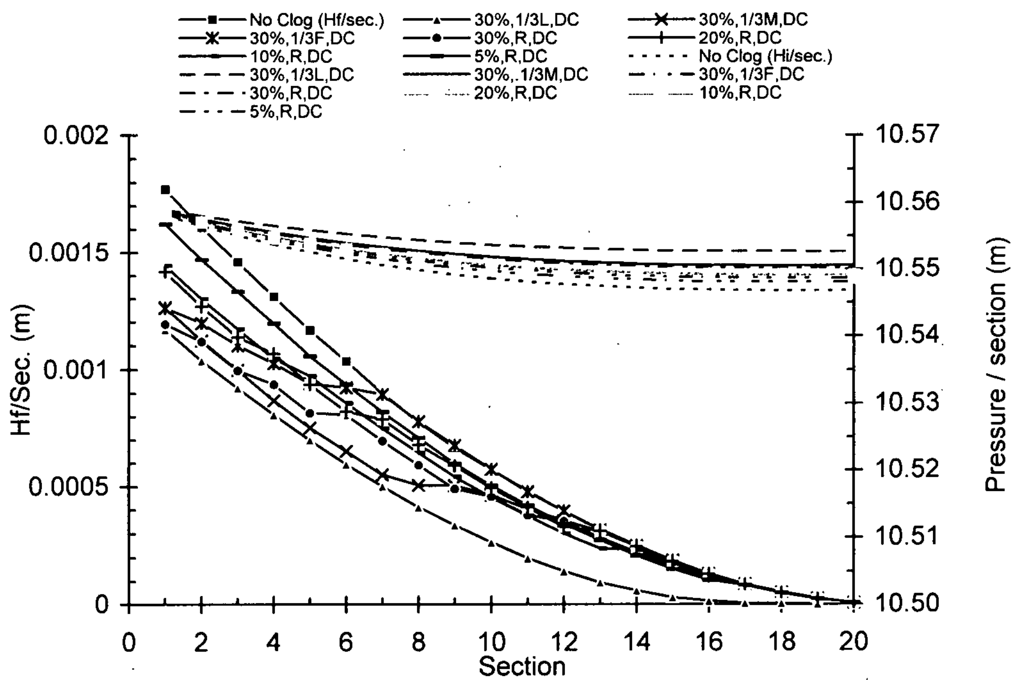


Figure 5.8 Head loss and pressure per section along a lateral laid on flat terrain.

clogged emitters. Similar results as in the field experiment were found for H_f from the computer simulation program. Figure 5.7 compares the observed (field) results and predicted results (from simulation) of H_f whitin different patterns of clogging. Figure 5.9 shows the relationship between the cumulative H_f and head loss per section along the lateral. The total H_f at each section was rapidly increased at the first 0.4L of lateral and was almost constant at the last 0.6L of lateral. These results closely agreed with those reported by Keller and Karmeli (1974). Figure 5.9 also shows that the increment of total head loss at each section decreased from inlet to the end of lateral and is almost zero at the last section of lateral. This is due to the reduction of flow in the lateral along the line toward the downstream end.

5.8.1.2 Pressure variation (H_{var}):

The pressure variation H_{var} shows the variation between maximum and minimum pressures along a lateral. The largest pressure variation (0.12%) was found in stage 1, and the lowest (0.069%) occurred in stage 2. Figure 5.7 shows that pressure variations follow a similar trend to head loss whitin different patterns of clogging. In the case of 30% clogging in stages 2, 3, 4, and 5, the higher pressure variation was obtained when clogging occured near the lateral inlet (stage 4) and the minimum H_{var} was observed when the clogging occurred at the lateral downstream end (stage 2). Therefore, the location of clogged emitters had an impact on pressure variation along the lateral. The average pressure variation in stages 2, 3, 4, and 5 was 0.089%, where, the values of H_{var} were 0.10%, 0.10%, and 0.12% in stages 6, 7, and 8 respectively. Results show that as the number and degree of clogged emitters along the lateral decreased, the pressure variation increased. Figure 5.10 shows that the energy drop ratio in all 8 different stages studied have a similar trend.

5.8.1.3 Emitter flow variation (q_{var}):

The variation of emitter flow rate was evaluated in each stage by using equation 2.36. Under a no-clogged condition the emitter discharges along the lateral were not equal to each other. Most of the emitters along the lateral had higher or lower discharges than the nominal emitter flow rate in stage 1. Figure 5.5 shows that the maximum and minimum emitter discharge in the no-clogged condition (3.97 and 3.4 l/h) were obtained from emitters number 6 and 18 respectively.

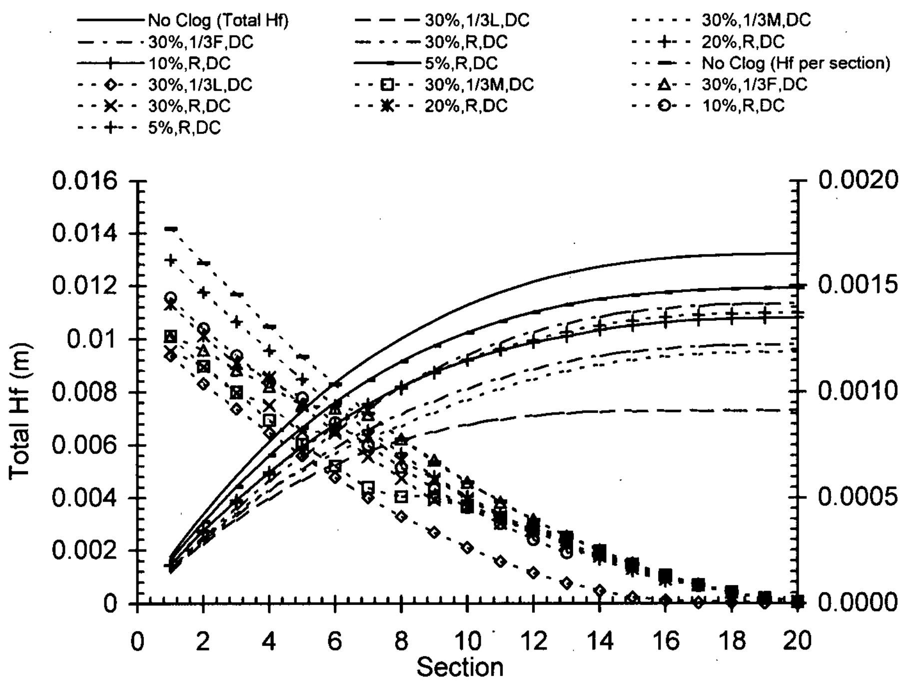


Figure 5.9 Total head loss and H_f per section under different patterns of emitter clogging (flat terrain).

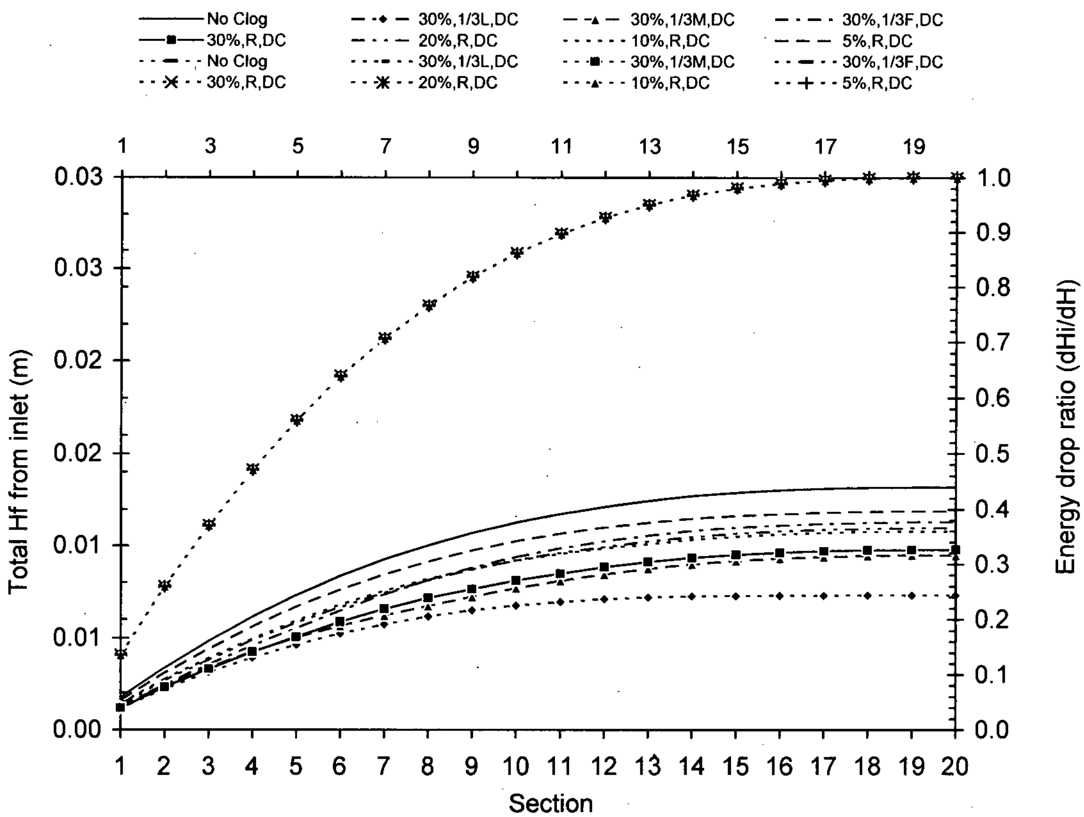


Figure 5.10 Relationship between total head loss and energy drop ratio under different sections along lateral.

The major reason for these variations is the emitter manufacturer coefficient of variation (*CV*). Wu and Gitlin (1974) reported that a microirrigation system can be designed hydraulically to maintain emitter flow uniformity within 10% or 20% emitter flow variations. The emitter flow variation (q_{var}) caused by hydraulics was found to be 0.0101 (or about 1%) in stage 1, which is in the acceptable ranges according to Wu and Gitlin (1974) and Bralts et al. (1987) (The value of q_{var} less than 10% for a well-designed system and greater than 20% is not acceptable).

The relationship between the observed and predicted q_{var} and pressure variations along the lateral are shown in Figure 5.11. It was found that the q_{var} was indirectly related to the number of clogged emitters. On the other hand, as the number of clogged emitters along the lateral increased, the value of q_{var} decreased. The reason is that the reduction in lateral flow due to clogged emitters reduces the pressure variation and resulted lower q_{var}. The q_{var} is changed whenever the pressure changes along the lateral. Therefore, q_{var} is used in a microirrigation system for hydraulic design evaluation.

Figure 5.12 shows the relationship between q_{var} and H_{var} resulting from the field and synthetic data in different stages. A linear relationship was found as: $H_{var} = 13.198\ q_{var} + 0.00005$ with $R^2 = 0.99999$ for a lateral laid on flat terrain under different patterns of emitter clogging. At least two factors can result in this high correlation: one is the use of pressure-compensating emitter, and the second is that there was no significant pressure variation along the lateral laid on flat terrain. This close relationship verified that q_{var} is one useful parameter which can be used for evaluating the hydraulic design of a microirrigation system.

Figure 5.11 shows that q_{var} varied in stages 2 to 5. These stages consisted of 30% clogged emitters along the lateral at different locations. It was found that the location of clogged emitters has an impact on q_{var}. For example, Tables 5.8 and 5.9 show that the total lateral flow in stages 3 (61.05 *l/h*) was higher than in stage 4 (60.95 *l/h*) but the values of H_{var} and q_{var} in stage 3 were less than stage 4. The q_{var} according to these stages were 0.0061 and 0.0081. This means higher lateral flow in stage 3 resulted in a lower value of H_{var} and q_{var}. The major factor in this reduction was the location of clogged emitters.

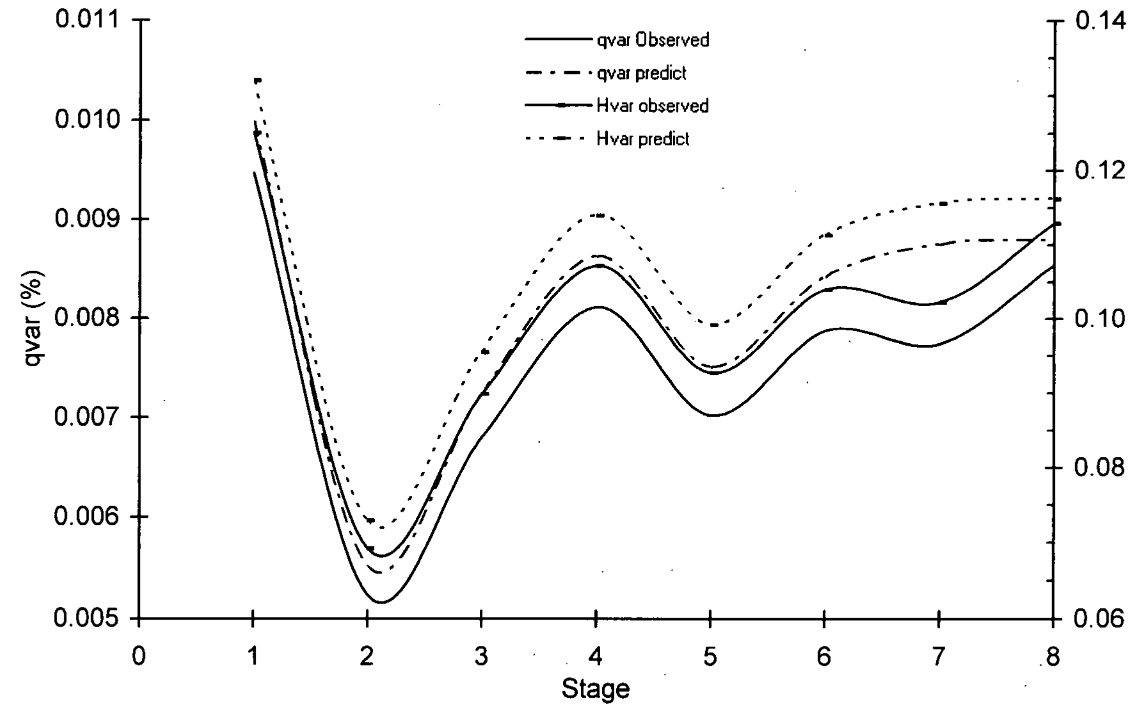


Figure 5.11 Emitter flow and pressure variations along the lateral under different patterns of clogging.

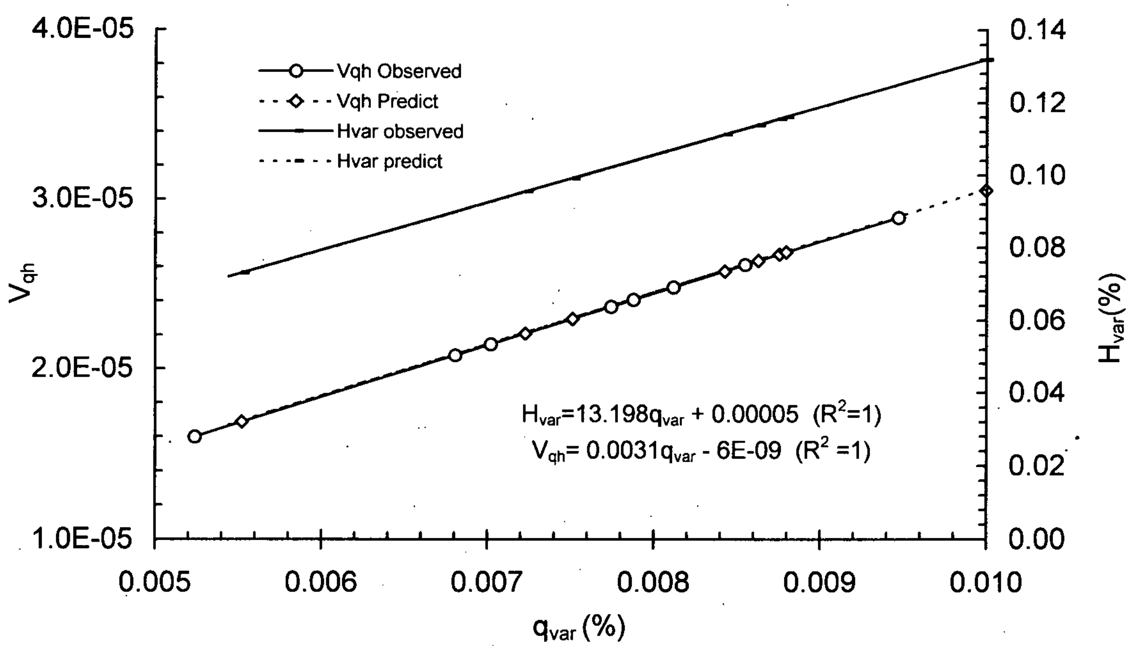


Figure 5.12 Relationship between V_{qh}, and H_{var} versus emitter flow variation(q_{var}) in flat terrain.

5.8.1.4 Emitter discharge coefficient of variation (V_{qs}):

The emitter discharge coefficient of variation (V_{qs}) is the statistical term used to describe the variation in emitter flow rate in a microirrigation system for a given set of operating conditions.Tables 5.9 and 5.10 show the values of V_{qs} obtained from the field and synthetic data respectively. The maximum and minimum V_{qs} were found in stages 2 and 1 respectively. The emitter discharge coefficients of variation were 0.04 and 0.01 in stage 1 resulting from the field and computer simulation respectively. This means that there is no significant difference in emitter flow rate under this stage. The values of V_{qs} increased as the number of clogged emitters along the lateral increased. Figure 5.13 shows the relationship between coefficients of variation versus different patterns of emitter clogging. Emitter discharge coefficient of variation, V_{qs} is directly related to the degree and number of clogged emitters. Therefore, the more clogged emitters along the lateral, the higher the values of V_{qs}. Results show that the values of V_{qs} were 0.4, 0.32, 0.32, and 0.35 in stages 2, 3, 4, and 5 consisting of 30% emitter clogging, whereas its values were 0.04, and 0.1 in stages 1 and 8 with no-clogged and 5% clog conditions respectively. It is evident that the fewer the clogged emitters (higher lateral flow), the smaller the coefficient of variation of emitter flow in a microirrigation system. Results also show that the location of clogged emitters along the lateral has a different impact on the emitter discharge coefficient of variation (Figure 5.13 and Table 5.9). For example, 30% clogging in stage 2 resulted in 0.398 of V_{qs} and 58.54 *l/h* in lateral flow (Table 5.8), whereas they were 0.356 and 59.11 *l/h* in stage 5 respectively. It is found that in spite of an existing lateral flow in stage 2 lower than in 5, the V_{qs} was higher in stage 2.

5.8.1.5 Emitter discharge coefficient of variation due to hydraulic (V_{qh}):

The maximum (2.9×10^{-5}) emitter discharge coefficient of variation due to hydraulic (V_{qh}) was found in stages 1 and the minimum (1.6×10^{-5}) in stages 2 in both experimental and simulation results. The values of V_{qh} were 2.1×10^{-5}, 2.5×10^{-5}, and 2.1×10^{-5}, in stages 3, 4, and 5. Results indicated that although location of clogged emitters have an impact on V_{qh}, the number of clogged emitters is a major factor affecting V_{qh}.The higher the number of clogged emitters along the lateral, the lower the values of V_{qh}. The smallest value of V_{qh} was found in stage 2, consisting of 30% clogged emitters with the highest value of emitter discharge coefficient of variation (V_{qs}). This is because the 30% clogged emitters in the last one-third section of lateral reduced the lateral flow and decreased the pressure along the lateral.

Figure 5.13 shows the inverse relationship between V_{qs} and emitter discharge coefficient of variation due to hydraulic, V_{qh}. It also shows that the V_{qh} is slightly changed under all eight stages. This is due to the very small variations of pressure along the lateral laid on flat terrain.

5.8.1.6 Hydraulic design coefficient of variation (V_{hs}):

The V_{hs} is a statistical term used to describe the variation in hydraulic pressure in a lateral or throughout the microirrigation system. It is found that there were no significant differences in hydraulic design coefficient of variation at different stages under the flat terrain condition. However, as the number of clogged emitters along the lateral decreased, the value of V_{hs} increased. Figure 5.13 shows that V_{hs} has a trend similar to the emitter discharge variations due to hydraulic (V_{qh}). The maximum value of V_{hs} (3.8×10^{-4}) was obtained in stage 1 and the minimum value (2.2×10^{-4}) occurred in stage 2. Table 5.9 shows that the values of V_{hs} varied within the stages 2, 3, 4, and 5 when the 30% clogged emitters were located at different parts along the lateral. The differences of V_{hs} in stage 1 and 2 with 0% and 30% clogging was 1.7×10^{-4}. The values of V_{hs} also differed up to1.2 $\times 10^{-4}$ in stages 2 to 5 consisting of 30% clogged emitters. Higher values of hydraulic variations were found in stages 6 to 8 than in stages 2 to 5. The reason was the lower number of clogged emitters in stages 6 to 8 resulted the higher discharge and pressure variation along the lateral. Results show that the number, degree and location of clogged emitters along the lateral affect V_{hs}, but the former have a higher impact than the latter.

5.8.1.7 Emitter performance coefficient of variation (V_{pf}):

The values of emitter performance coefficient of variation obtained from field and synthetic data are presented in Tables 5.9 and 5.10. The values of V_{pf} versus different stages were plotted as shown in Figure 5.13. In stage 1, the value of V_{pf} was 0.04 and it was considered to be acceptable according to the ASAE criteria (ASAE EP458, 1997). In stages 2 to 5 where 30% of total number of emitters were partially clogged, V_{pf} was greater than 20%. The

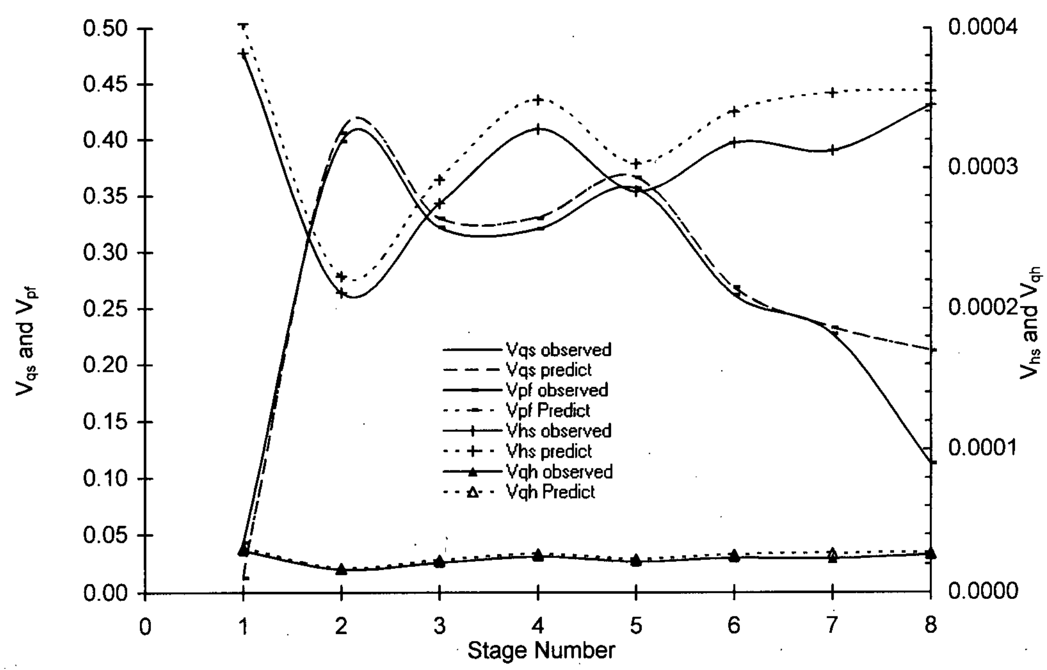


Figure 5.13 Coefficients of variation of V_{qs}, V_{hs}, V_{qh}, and V_{pf} *in* different stages studied.

highest value (0.40) of V_{pf} was found in stage 2. Different values of V_{pf} were found under stages 2 to 5 (0.40, 0.32, 0.32, and 0.36 respectively). According to the ASAE EP458 (1997) a value of V_{pf} greater than 20% is unacceptable. In stage 8, when 5% of total number of emitters were partially clogged, the V_{pf} decreased to 0.11 which is fair for the microirrigation system. Figure 5.13 shows that V_{pf} has a similar trend to V_{qs} at different stages. Results show that very small variations of V_{qh} along the lateral have no significant impact on V_{pf}. It is found that the number of clogged emitters has a higher impact on emitter performance coefficient of variation than the location of clogged emitters does.

5.8.1.8 Coefficient of Uniformity (*CU*):

In general practice, the coefficient of uniformity (*CU*) is used for the evaluation of spatial uniformity in a microirrigation system. Under field conditions, the *CU* indicates the uniformity of water application to the soil resulting from the emitter water distribution and soil moisture overlapped by emitter spacing along the lateral. The *CU* was used to evaluate the application uniformity under the 8 different stages studied. As expected, *CU* was high (> 95%) under the no-clogged condition (Tables 5.9 and 5.10). The minimum *CU* were found in stages 2 and 5 (67.8% and 69.44%) when 30% clogged emitters were located at the last one-third section or randomly located along the lateral. The values of *CU* were 73.87% and 73.73% in stages 3 and 4 respectively. In stages 6, 7, and 8 as the number of clogged emitters decreased, the values of *CU* increased as compared to stages 2 to 5. Figure 5.14 shows that the *CU* increased from 81.7% to 94.6% in stages 6 to 8. Results show that the number of clogged emitters along the lateral was the major factor affecting *CU*. Although the minimum value of *CU* was found in stage 2, there were no significant differences between the values of *CU* in stages 2 to 5. This means that different locations of clogged emitters along a lateral laid on flat terrain have no impact on *CU*. A *CU* of 95% or higher is expected for a well-designed microirrigation system. However, Wu (1974) has recommended a *CU* of 98% or higher. Results show that the coefficient of uniformity was low in stages 2 to 7 (*CU* were between 67% to 87%). The value of *CU* in stages 1 and 8 were 96.26% and 94.62% which indicates excellent and good uniformity throughout the microirrigation system. It is concluded that the number and degree of clogged emitters are the most important factors affecting *CU*. It is also found that the

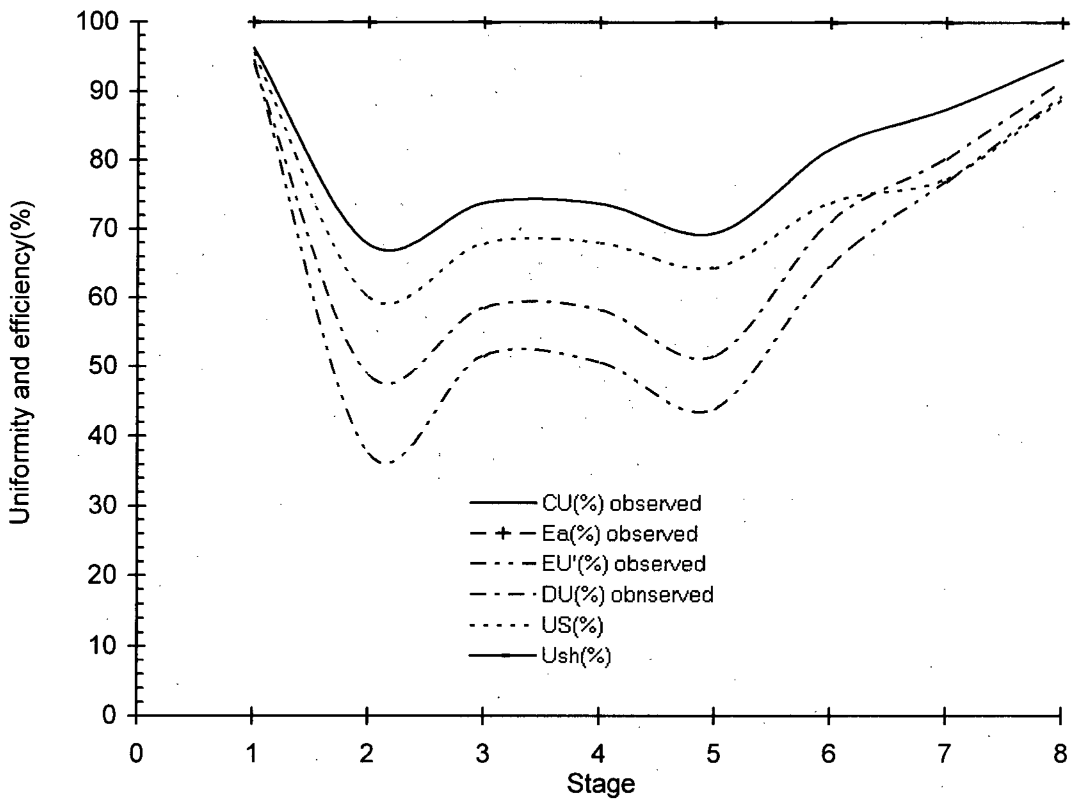


Figure 5.14 Variations of CU, Ea, DU, Us, and Ush under eight different stages.

impact of the location of clogged emitter on *CU* was not significant for the lateral laid on flat terrain.

5.8.1.9 Statistical uniformity (U_s):

Statistical uniformity is used to estimate the uniformity of emitter flow rates throughout the system in similar way as for *CU*. The results show that both U_s and *CU* have similar trends under all eight stages on a flat terrain (Figure 5.14). The maximum value of U_s (>95%) was obtained under the no-clogged condition, and its value decreased as the number of clogged emitters along the lateral increased. Lowest U_s occurred in stage 2 and 5 (60.1% and 64.3%). As with *CU*, the location of clogged emitters had no significant impact on U_s. According to ASAE criteria (ASAE EP458, 1997) and Bralts and Edward (1986), the statistical uniformity of the emitter discharge was poor (60%-70%) in stages 2 to 5 and fair (70%-80%) in stages 6 and 7 (Table 5.9 and 5.10). The values of U_s in stages 1 and 8 are 95.66% and 88.77%, which indicates excellent and good uniformity. Since the values of U_s were low in the case of 30% clogging at different locations along the lateral, the clogged emitters should be replaced. If 10%-20% of emitters are partially clogged, the cleaning of clogged emitters will improve the statistical uniformity. Results show that the number, location, and degree of clogged emitters along the lateral all have an impact on U_s, and U_s is more sensitive to the number and degree of partially clogged emitters than to the location of clogged emitters. In all 8 patterns of clogging, the values of U_s were about 9% lower than the values of coefficient of uniformity. The *CU* and U_s obtained from experimental and theoretical analysis are summarised in Table 5.11. The *CU* versus U_s were plotted (Figure 5.15) and a least-square analysis on the *CU* and U_s yielded the following linear regression equation:

$$CU = 14.017 + 0.896Us \qquad 5.9$$

The statistical uniformity due to hydraulics (U_{sh}) was also analysed for different patterns of emitter clogging and presented in Tables 5.9 and 5.10. The small differences in the values of U_{sh} obtained from experimental and theoretical analyses illustrated that the U_{sh} was not affected by pressure variation along a lateral on a flat terrain. Figure 5.14 shows the values of U_{sh} at

Table 5.11 Coefficient of uniformity and statistical uniformity obtained from experimental and theoretical results for 20 m lateral laid on flat terrain.

Stages	Us(%)	CU(%)
1	98.737	98.939
1	95.661	96.261
8	88.765	94.618
8	78.834	90.788
7	77.297	87.534
7	76.742	86.965
6	73.826	81.767
6	73.142	80.862
4	67.966	73.733
3	67.869	73.874
4	67.037	72.444
3	67.025	72.657
5	64.349	69.437
5	63.348	68.143
2	60.156	67.810
2	59.400	66.615

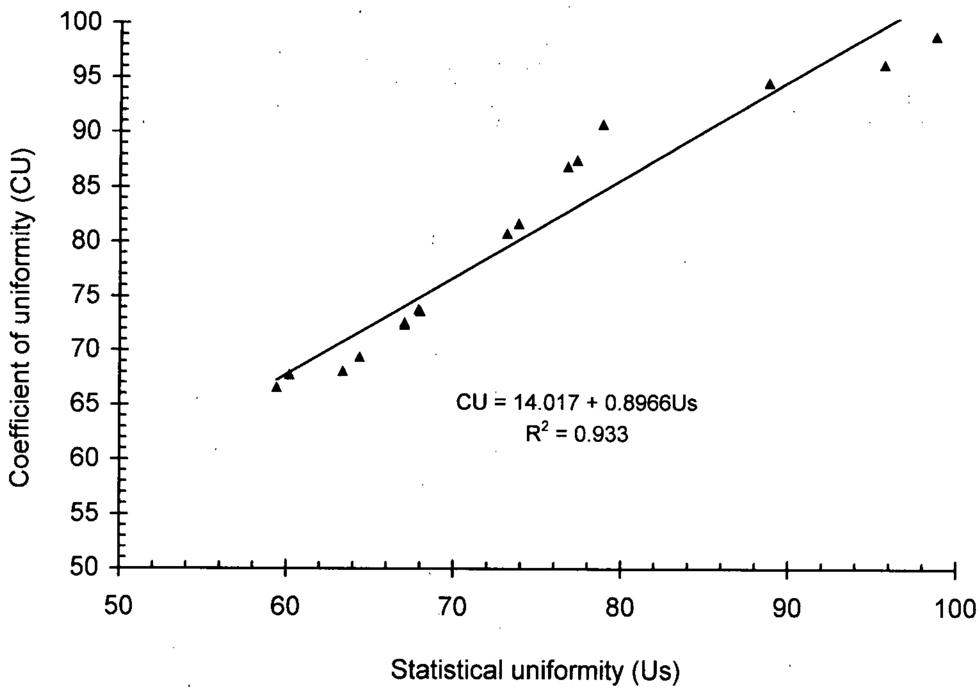


Figure 5.15 Relationship between CU and Us under different patterns of clogging for a lateral laid on flat terrain (experimental and theoretical results).

different stages. The flat line of this graph indicates that the U_{sh} was almost constant and equal to 99.99% in all stages. It is indicated that the reason for low values of U_s in stages 2 to 7 (mentioned above) was the combined impact of emitter clogging and emitter manufacturer's variations.

5.8.1.10 Distribution uniformity (*DU*) and application efficiency (*Ea*):

The highest value of distribution uniformity was 94% under the no-clogged condition (Stage 1). It was decreased to 48%, 58%, 58%, and 51% in stages 2 to 5 respectively (Tables 5.9 and 5.10). The reason for the low value of *DU* in stage 2 is the higher degree of emitter clogging (see Table 5.8). Results indicated that there were no significant differences between values of *DU* when 30% of emitters were clogged and located at different parts along the lateral. Figure 5.14 shows that as the number of clogged emitters decreased, the *DU* increased. It was found that *DU* increased from 71% to 91% when the number of clogged emitters along the lateral decreased from 20% to 5% in stages 6 to 8 respectively. Results indicated that the number and degree of clogged emitters are the major factors affecting *DU*. The location of clogged emitter has little impact on distribution uniformity in a microirrigation system.

The application efficiency (*Ea*) indicates how well the irrigation water is applied to the field. In other words, it reflects how efficiently a microirrigation system delivers water from its source to the field (or to soil near the crop root zone). The values of *Ea* in both experimental and theoretical results were greater than 99.9% for the eight different stages studied (Figure 5.14). Since the minimum and the average pressure along the lateral are considered in the application efficiency equation, the small pressure variations along the lateral line on a flat terrain have no significant impact on either emitter discharge or, consequently, on *Ea* under different patterns of clogging. Results obtained from the field and synthetic data presented in Table 5.9 and 5.10 show that there is a high correlation between *Ea* and U_{sh}. Figure 5.16 shows the relationship between the *Ea* and U_{sh} for a lateral laid on flat terrain. A least-square regression line was fitted through the data point in Figure 5.16 and a linear equation was determined as follows:

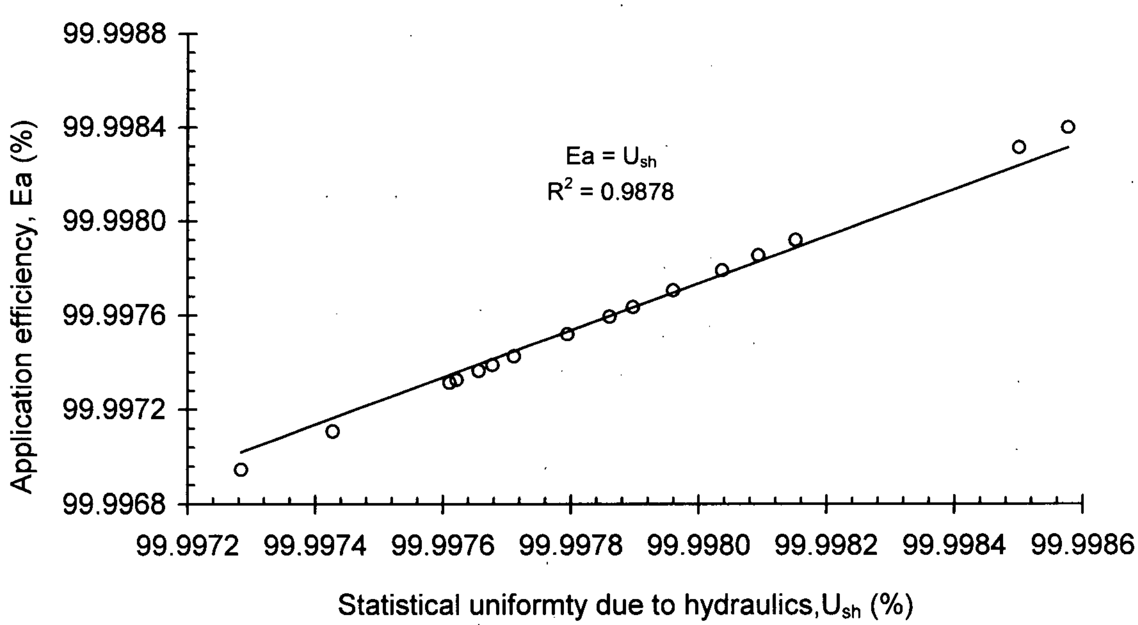


Figure 5.16 Relationship between Ea and U_{sh} on a flat terrain.

$Ea = U_{sh}$ $(R^2 = 0.9878)$ 5.10

It should be noted that a high value of *Ea* does not necessarily mean a good distribution of water by the microirrigation system.

5.8.1.11 Field emission uniformity (*EU'*):

The maximum value of field emission uniformity obtained from the field experiment was 94.62% in stage 1 under the no-clogged condition (Tables 5.9 and 5.10). In stages 2 and 5, *EU'* decreased to 37% and 43% respectively (Figure 5.14) and its values in stages 3 and 4 were 51.4% and 50.5% respectively. Figure 5.14 also shows that as the number of clogged emitters along the lateral decreases, the emission uniformity will increase. Figure 5.14 shows that the values of *EU'* in stages 2 to 5 consisting of 30% clogged emitters varied from one stage to the other. There are two factors which affect the emission uniformity in stages 2 to 5. One is the degree of emitter clogging and the other is the pressure variation. Both factors affect emitter discharge and hence the emission uniformity. However, it was found that the degree of clogging has a higher impact on *EU'* than the pressure variation along the lateral. When the total number of clogged emitters along the lateral decreased from 20% to 5% in stages 6 to 8, *EU'* increased from 64% to 89% respectively. Results indicated that the number, degree, and location of clogged emitters effected field emission uniformity. The number and degree of clogged emitters were the major factors, but the impact of the location of clogged emitters was not significant.

5.8.1.12 Crop yield reduction due to emitter clogging:

Uniform application of water in agriculture has a major impact on crop production and net farm income. This part of study presents a *rough estimation* and the theoretical analyses of cotton yield based on the emitter coefficient of variations values obtained from different patterns of clogged emitters along the lateral in the experimental set-up. Cotton was selected as a sample crop because of the availability of several parameters required for the crop yield analysis from previous studies which were done by Sammis and Wu (1985). The effects of different patterns of emitter clogging on cotton yield and the loss caused to farmers were studied for different areas. The cotton yield reduction in percent was calculated using Equation

2.51. This equation was applied both to results obtained from the field and synthetic data, and the results are given in Tables A.5.5 and A.6.6 (Appendix A). Results show that the minimum reduction of yield (1.475%) occurred in stage 1 (no-clogged) and the maximum reduction (10.64%) obtained in stage 5 consisting of 30% clogged emitters randomly located along the lateral. The reason for the reduction in yield in stage 1 was the emitter manufacturer's coefficient of variation. Results indicated that as the number and degree of clogged emitters increased, the reduction of cotton yield increased. There were no significant differences in yield reduction caused by different locations of clogged emitters along the lateral. Therefore, the number and degree of clogged emitters were the major factors affecting the cotton yield.

According to the data reported by Agricultural Statistics US. Dept. of Agric. (1994), the average cotton yield of 0.7076 ton/hectare was determined from data in 1984 to 1993 (Table 5.12). The average value for cotton was also determined and estimated to be equal to US $1.3/kg (Table 5.12). Five different sized areas of 1 ha, 10 ha, 100 ha, 1000 ha, and 10,000 ha were selected in order to illustrate the reduction in cotton yield and money loss under different patterns of clogged emitters. Table 5.13 shows the reduction in cotton yield under different areas for stages 5, 6, 7, and 8 when the 30%, 20%, 10%, and 5% clogged emitters were randomly located along the lateral. The reason for selecting stages 5 to 8 was that these patterns can be encountered under real contitions. In the field conditions, there exists more chance of random clogging along the lateral. It is clearly shown that the larger the number of clogged emitters along the lateral, the higher the reduction in cotton yield. By assuming the constant conditions at different areas, the cotton yield and money loss caused by clogging are directly related to the size of planted area. Results show when there are just 5% clogged emitters along the lateral, the reduction of cotton yield is 0.027 ton/ha , whereas the reduction in cotton yield with 30% clogging is 0.085 ton/ha. If the cotton is planted in an area of 10,000 ha, the yield reductions increased to 270.29 ton and 857.7 ton under 5% and 30% clogging respectively (Table 5.13). Figure 5.17 shows the relationship between cotton yield reduction and the different number of clogged emitters randomly located along the lateral. It is shown that the reduction of cotton yield with 10% clogging is 0.054 (almost double the reduction with 5% clogging) and with 20% clogging is 0.062 ton/ha. The reason for the jumps in yield reduction under 10% clogging (Figure 5.17) is

Table 5.12 Yield production and value of cotton, United States, 1984-93 (Adopted from Agric.Statis. US.Dept. of Agric., 199

Year	Yield *lb/Acre	Yield Kg/ha	Marketing US Cent/lb	Marketing US $ /Kg
1984	600	672.50	58.9	1.30
1985	630	706.12	56.3	1.24
1986	552	618.70	52.4	1.16
1987	706	791.31	64.3	1.42
1988	619	693.79	56.6	1.25
1989	614	688.19	66.2	1.46
1990	634	710.61	67.1	1.48
1991	652	730.78	56.8	1.25
1992	700	784.58	54.9	1.21
1993	606	679.22	58.0	1.28
AVE	631.3	707.58	59.15	1.3040
*1 Acre=0.4047hectare	1 Pound=0.4536 kg			

Table 5.13 Reduction in cotton yield (ton/Area)under different number of clogged emitters randomly located along the lateral.

# of clogged emitters(%)	Area(ha) 1	Area(ha) 10	Area(ha) 100	Area(ha) 1000	Area(ha) 10000
5	0.027	0.270	2.703	27.029	270.29
10	0.055	0.546	5.462	54.620	546.20
20	0.063	0.630	6.297	62.970	629.70
30	0.086	0.858	8.577	85.770	857.70

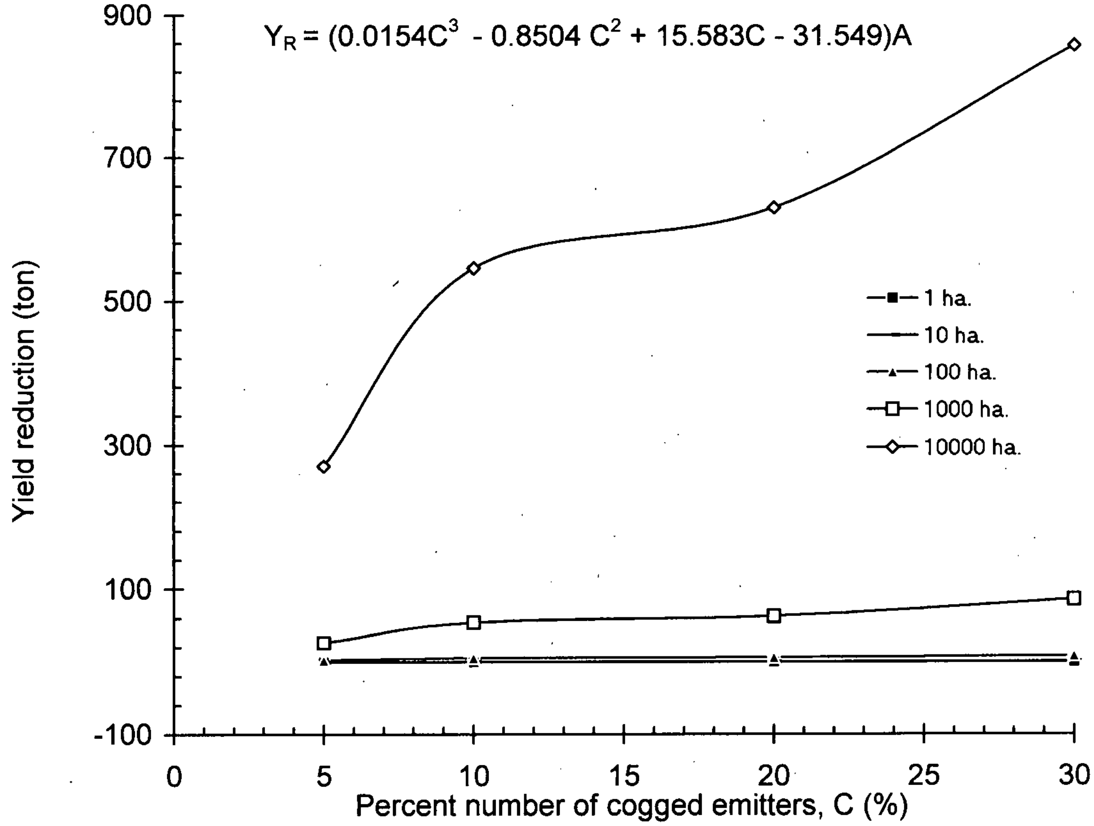


Figure 5.17 cotton yield reduction at different areas when different number of clogged emitters are randomly located along the lateral.

the higher degree of emitter clogging. A regression equation was performed in order to determine the yield reduction caused by emitter clogging. Based on experimental data, the reduction of cotton yield (Y_R) and percentage number of clogged emitters (C) randomly located along the lateral at any planted area (A) can be expressed by the regression equation as follows:

$$Y_R = \left(0.0154C^3 - 0.8504C^2 + 15.583C - 31.549\right)A \qquad 5.11$$

where Y_R is in *Kg*, *C* in percent, and *A* in hectares. The higher correlation ($R^2 = 0.93$) between Y_R and C in polynomial rather than linear type of regression justifies the use of equation 5.11.

Tables 5.14 and A.5.7 (Appendix A) summarise the reduction in cotton yield and farmer's money loss under eight different stages in different areas. Results show the minimum value of yield reduction in stage 1 (no-clogged) due to emitter manufacturer's coefficient of variation. The values of yield reduction in stage 1 were 0.01 and 104.38 tons in 1 ha and 10000 ha respectively. The amounts of money lost were $13.6 and $1361.7 in this stage for these areas. Table 5.14 also shows that the maximum money lost ($1,250,001.2) was obtained in stage 2 which consisted of 30% clogged emitters in a 10,000 ha planted area. Figure 5.18 shows the relationship between yield reduction and money lost in eight different stages of clogging resulting from the field. Figure 5.18 also shows that the effect of emitter clogging on yield reduction and money lost is more significant as the crop area becomes larger. There are no significant differences between the results obtained using the field and synthetic data.

5.8.2 Step 2, hydraulic characteristics of lateral laid on sloped terrain:

In step 2 a similar field experiment as in step 1 was conducted to evaluate the effects of different patterns of clogged emitters along the lateral on hydraulics characteristics of laterals laid on *sloped terrain.* The impact of clogging on all hydraulic parameters described in previous sections was examined. Four 20m polyethylene laterals with 15 mm inside diameters were used. The laterals were laid on 3% and 7% uniform up-slopes and 3% and 7% down-slopes with equally spaced emitters (S_e=1 meter). The sand was introduced into the emitter artificially. Eight different patterns (stages) of clogging as used in step 1 were tested at each slope. A total of 2560 ($8_{\text{stages}} \times 4_{\text{slopes}} \times 4_{\text{replicates (runs)}} \times 20_{\text{flow rates/run}}$) emitter flow rates were

Table 5.14 Cotton yield reduction and money ($) lost in different areas under different patterns of clogging.

Area (ha)	Yield reduc. Stage 1 (ton)	Yield reduc. Stage 2 (ton)	Yield reduc. Stage 3 (ton)	Yield reduc. Stage 4 (ton)	Yield reduc. Stage 5 (ton)	Yield reduc. Stage 6 (ton)	Yield reduc. Stage 7 (ton)	Yield reduc. Stage 8 (ton)
1	0.010	0.096	0.077	0.077	0.086	0.063	0.055	0.027
10	0.104	0.959	0.773	0.771	0.858	0.630	0.546	0.270
100	1.044	9.586	7.730	7.707	8.577	6.297	5.462	2.703
1000	10.438	95.859	77.303	77.068	85.770	62.970	54.620	27.029
10000	104.38	958.59	773.03	770.68	857.70	629.70	546.20	270.29
Area (ha)	**$Lost per area Stage 1**	**$Lost per area Stage 2**	**$Lost per area Stage 3**	**$Lost per area Stage 4**	**$Lost per area Stage 5**	**$Lost per area Stage 6**	**$Lost per area Stage 7**	**$Lost per area Stage 8**
1	13.6	125.0	100.8	100.5	111.8	82.1	71.2	35.2
10	136.1	1250.0	1008.0	1005.0	1118.4	821.1	712.2	352.5
100	1361.2	12500.0	10080.3	10049.7	11184.5	8211.2	7122.4	3524.6
1000	13611.7	125000	100803	100497	111845	82112.4	71224	35246
10000	136117	1250001	1008026	1004966	1118446	821124	712238	352464

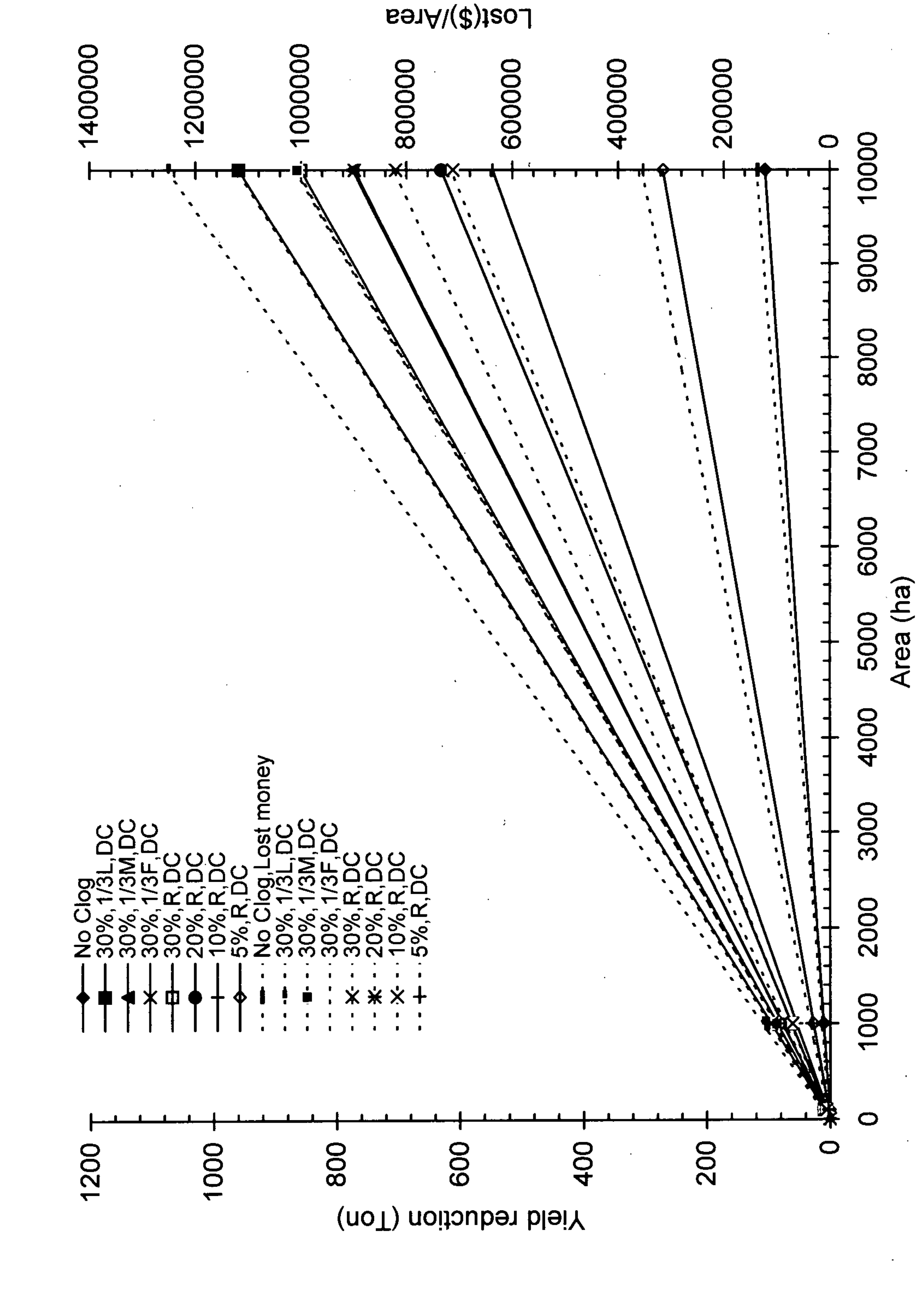


Figure 5.18 Cotton yield reduction and money lost in different areas under different patterns of emitter clogging along a lateral laid on flat terrain.

measured. Sample test data of emitter flow rate measurements at 7% down-slope are shown in Table A.5.8 (Appendix A.). The average emitter flow rate (*l/h*) and the lateral inlet flow (*l/h*) for different stages in 7% down-slope are also shown in Table A.5.9 (Appendix A). Similar calculations as explained in step 1 were done in order to determine the dimensionless values of emitter discharge, emitter discharge coefficient, and the percentage of clogging. Then the relationship between these values were plotted and the linear regression equations were determined for all different slopes (Table A.5.10 and Figure A.5.1). For example, a linear equation for stage 2 with a 7% down-slope was found and shown in Figure A.5.1. The impact of different patterns of clogging on hydraulics of lateral laid on four different slopes was examined. A comparable analysis of hydraulic parameters in a microirrigation lateral under different slopes reveals similar behaviour as in the flat terrain (step 1) as follows.

5.8.2.1 Total head loss (H_f):

In all four slopes tested, the highest head loss was found in the desired condition (stage 1). The minimum head loss obtained in stage 2 when 30% of total number of emitters were partially clogged and located at the last one-third section of the lateral. The results obtained from stages 2 to 4 show that when the location of clogged emitters was closer to the inlet of lateral, the total H_f approached that of the no-clogged condition. This is similar to those results obtained in step 1 on flat terrain. The results obtained in stages 2 to 5 show that when the same number of partially clogged emitters was located at different locations along the lateral, the value of H_f varied from one stage to the other. Figure 5.19 shows the relationship between head loss obtained from the field and synthetic data versus different patterns of clogging in different slopes terrain. The minimum H_f occurred at stage 2 for all different slopes. Head loss is a function of the lateral flow rate; i.e., as lateral flow increases H_f also increases. Results obtained from stages 5 to 8 show that head loss increased as the number of partially clogged emitters along the lateral decreased. The results show that the head loss in eight different stages in down-slope conditions were 7% to 15 % less than those in up-slope conditions. It is also found that the total amount of head loss at the end of lateral is slightly increased as the degree of slopes (down-slope or up-slope) increased. Tables 5.15 to 5.22 show the values of head loss in different slopes and stages. Total head loss from the lateral inlet and the pressure

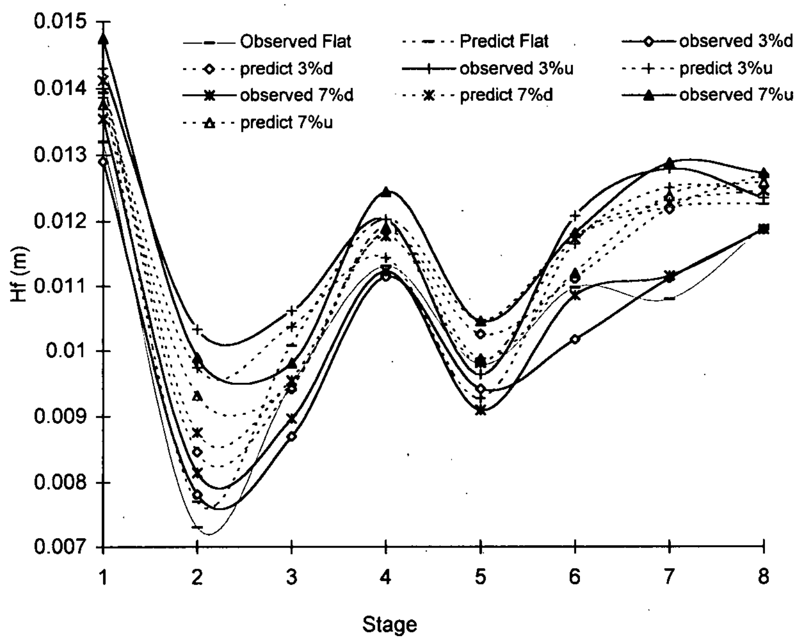


Figure 5.19 Total head loss in different stages under different slopes

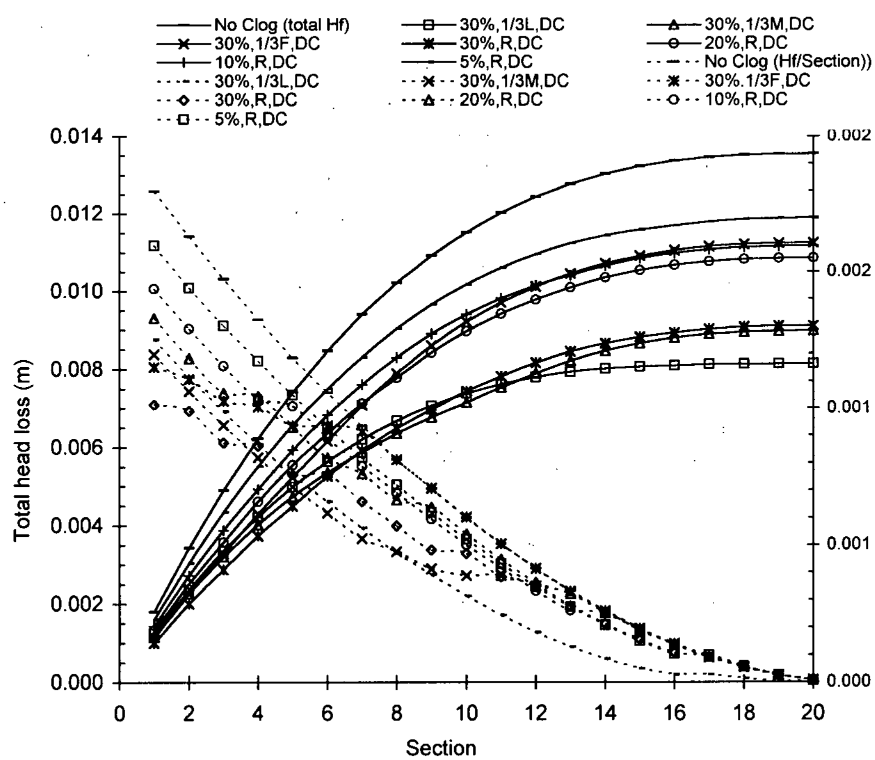


Figure 5.20 Total head loss and Hf per section along the lateral (7% down-slope)

Table 5.15 Values of hydraulic parameters under eight different patterns of clogged emitters along the lateral.
Field results:(3% down-slope)

Stage NO.	Total Hf (m)	Hvar (%)	qvar (%)	CU (%)	Ea (%)	EU' (%)	DU (%)	Us (%)	USh (%)	Vqs	Vhs	Vqh	Vpf
1	0.013	5.267	0.409	97.630	99.795	96.926	96.232	97.164	99.876	0.028	0.01641	0.00124	0.02833
2	0.008	5.310	0.412	72.931	99.792	48.875	56.960	66.877	99.875	0.331	0.01653	0.00125	0.33123
3	0.009	5.303	0.412	67.571	99.793	40.998	48.438	61.582	99.875	0.384	0.01651	0.00125	0.38417
4	0.011	5.282	0.410	62.453	99.794	30.052	40.299	56.059	99.875	0.439	0.01645	0.00125	0.43941
5	0.009	5.296	0.411	63.442	99.793	33.822	41.873	58.220	99.875	0.418	0.01649	0.00125	0.41780
6	0.010	5.290	0.411	73.582	99.793	48.091	57.996	66.040	99.875	0.340	0.01648	0.00125	0.33960
7	0.011	5.282	0.410	82.371	99.794	67.183	71.970	70.286	99.875	0.297	0.01645	0.00125	0.29714
8	0.012	5.276	0.409	92.125	99.794	84.310	87.479	82.470	99.876	0.175	0.01643	0.00124	0.17529

Table 5.16 Values of hydraulic parameters under eight different patterns of clogged emitters along the lateral.
Theoretical results from synthetic data (3% down-slope)

Stage NO.	Total Hf (m)	Hvar (%)	qvar (%)	CU (%)	Ea (%)	EU' (%)	DU (%)	Us (%)	USh (%)	Vqs	Vhs	Vqh	Vpf
1	0.014	5.256	0.408	98.947	99.795	98.519	98.326	98.751	99.876	0.012	0.01638	0.00124	0.01242
2	0.008	5.305	0.412	71.375	99.792	46.581	54.486	65.740	99.875	0.343	0.01652	0.00125	0.34260
3	0.009	5.296	0.411	66.664	99.793	39.661	46.996	60.991	99.875	0.390	0.01649	0.00125	0.39009
4	0.012	5.276	0.409	62.096	99.794	29.621	39.733	56.082	99.876	0.439	0.01643	0.00124	0.43918
5	0.010	5.289	0.411	62.508	99.793	32.510	40.387	57.478	99.875	0.425	0.01647	0.00125	0.42521
6	0.011	5.282	0.410	73.084	99.794	49.134	57.204	65.790	99.875	0.342	0.01645	0.00125	0.34210
7	0.012	5.273	0.409	83.821	99.794	72.046	74.276	72.809	99.876	0.272	0.01643	0.00124	0.27191
8	0.013	5.269	0.409	92.415	99.795	86.864	87.940	82.560	99.876	0.174	0.01641	0.00124	0.17440

Table 5.17 Values of hydraulic parameters under eight different patterns of clogged emitters along the lateral.

Field results:(3% up-slope)

Stage NO.	Total Hf (m)	Hvar (%)	qvar (%)	CU (%)	Ea (%)	EU' (%)	DU (%)	Us (%)	USh (%)	Vqs	Vhs	Vqh	Vpf
1	0.014	5.817	0.453	96.863	99.772	95.198	95.0127	96.345	99.863	0.037	0.01812	0.00137	0.03653
2	0.010	5.780	0.450	76.760	99.773	54.669	63.0483	66.898	99.864	0.331	0.01800	0.00136	0.33102
3	0.011	5.782	0.450	78.057	99.773	56.890	65.1104	66.698	99.864	0.333	0.01801	0.00136	0.33302
4	0.012	5.796	0.451	64.735	99.773	30.543	43.9284	55.747	99.863	0.443	0.01805	0.00137	0.44253
5	0.010	5.773	0.449	58.605	99.773	20.000	34.1827	51.441	99.864	0.486	0.01798	0.00136	0.48559
6	0.012	5.796	0.451	81.053	99.773	63.040	69.8737	74.102	99.863	0.259	0.01805	0.00137	0.25897
7	0.013	5.803	0.452	87.709	99.773	76.241	80.4566	79.024	99.863	0.210	0.01807	0.00137	0.20976
8	0.012	5.799	0.451	91.877	99.773	84.034	87.0840	81.838	99.863	0.182	0.01806	0.00137	0.18161

Table 5.18 Values of hydraulic parameters under eight different patterns of clogged emitters along the lateral.

Theoretical results from synthetic data (3% up-slope)

Stage NO.	Total Hf (m)	Hvar (%)	qvar (%)	CU (%)	Ea (%)	EU' (%)	DU (%)	Us (%)	USh (%)	Vqs	Vhs	Vqh	Vpf
1	0.014	5.813	0.452	98.937	99.773	98.508	98.310	98.739	99.863	0.013	0.01810	0.00137	0.01254
2	0.010	5.774	0.449	76.890	99.773	55.901	63.255	67.003	99.864	0.330	0.01799	0.00136	0.32996
3	0.010	5.780	0.450	77.979	99.773	56.761	64.987	66.800	99.864	0.332	0.01800	0.00136	0.33200
4	0.011	5.790	0.451	64.981	99.773	30.705	44.320	55.899	99.863	0.441	0.01803	0.00137	0.44101
5	0.009	5.770	0.449	58.569	99.774	19.733	34.124	51.417	99.864	0.486	0.01797	0.00136	0.48583
6	0.012	5.792	0.451	81.113	99.773	64.196	69.969	74.295	99.863	0.257	0.01804	0.00137	0.25705
7	0.013	5.800	0.451	87.687	99.773	78.498	80.423	79.305	99.863	0.207	0.01806	0.00137	0.20695
8	0.012	5.799	0.451	92.114	99.773	102.725	87.462	81.871	99.863	0.181	0.01806	0.00137	0.18129

Table 5.19 Values of hydraulic parameters under eight different patterns of clogged emitters along the lateral.

Field results:(7% down-slope)

Stage NO.	Total Hf (m)	Hvar (%)	qvar (%)	CU (%)	Ea (%)	EU' (%)	DU (%)	Us (%)	USh (%)	Vqs	Vhs	Vqh	Vpf
1	0.014	11.606	0.929	97.882	99.522	96.438	96.632	97.514	99.717	0.025	0.03734	0.00283	0.02470
2	0.008	11.646	0.933	74.899	99.519	50.816	60.089	64.627	99.716	0.354	0.03746	0.00284	0.35371
3	0.009	11.639	0.932	69.155	99.520	40.425	50.956	63.030	99.717	0.370	0.03744	0.00283	0.36969
4	0.011	11.623	0.931	63.363	99.521	31.151	41.747	56.873	99.717	0.431	0.03739	0.00283	0.43126
5	0.009	11.638	0.932	55.686	99.520	21.259	29.540	50.303	99.717	0.497	0.03744	0.00283	0.49697
6	0.011	11.625	0.931	76.842	99.521	54.290	63.179	69.025	99.717	0.310	0.03740	0.00283	0.30974
7	0.011	11.623	0.931	84.334	99.521	69.010	75.091	73.545	99.717	0.265	0.03739	0.00283	0.26454
8	0.012	11.618	0.931	90.012	99.521	80.023	84.118	78.743	99.717	0.213	0.03738	0.00283	0.21255

Table 5.20 Values of hydraulic parameters under eight different patterns of clogged emitters along the lateral.

Theoretical results from synthetic data: (7% down-slope)

Stage NO.	Total Hf (m)	Hvar (%)	qvar (%)	CU (%)	Ea (%)	EU' (%)	DU (%)	Us (%)	USh (%)	Vqs	Vhs	Vqh	Vpf
1	0.014	11.601	0.929	98.961	99.522	98.570	98.348	98.771	99.717	0.012	0.03733	0.00283	0.01196
2	0.009	11.641	0.933	73.579	99.520	48.942	57.990	64.115	99.717	0.359	0.03745	0.00283	0.35883
3	0.010	11.635	0.932	68.154	99.520	39.046	49.365	62.333	99.717	0.377	0.03743	0.00283	0.37666
4	0.012	11.619	0.931	62.911	99.521	30.589	41.029	56.909	99.717	0.431	0.03738	0.00283	0.43090
5	0.010	11.633	0.932	55.030	99.520	21.305	28.497	50.081	99.717	0.499	0.03742	0.00283	0.49918
6	0.012	11.619	0.931	76.146	99.521	54.906	62.072	68.695	99.717	0.313	0.03738	0.00283	0.31304
7	0.012	11.615	0.930	84.197	99.521	72.709	74.873	73.600	99.717	0.264	0.03737	0.00283	0.26398
8	0.012	11.614	0.930	91.001	99.521	84.669	85.691	79.323	99.717	0.207	0.03736	0.00283	0.20675

Table 5.21 Values of hydraulic parameters under eight different patterns of clogged emitters along the lateral.

Field results:(7% up-slope)

Stage NO.	Total Hf (m)	Hvar (%)	qvar (%)	CU (%)	Ea (%)	EU' (%)	DU (%)	Us (%)	USh (%)	Vqs	Vhs	Vqh	Vpf
1	0.015	13.397	1.083	96.375	99.440	94.032	94.236	95.594	99.671	0.044	0.04346	0.00329	0.04394
2	0.010	13.351	1.079	77.329	99.441	54.658	63.953	70.400	99.672	0.296	0.04330	0.00328	0.29598
3	0.010	13.350	1.079	69.347	99.441	39.754	51.262	61.961	99.672	0.380	0.04330	0.00328	0.38038
4	0.012	13.375	1.081	67.002	99.441	35.093	47.534	58.885	99.672	0.411	0.04338	0.00328	0.41114
5	0.010	13.357	1.079	66.537	99.441	37.398	46.793	59.755	99.672	0.402	0.04332	0.00328	0.40244
6	0.012	13.370	1.081	77.700	99.441	56.532	64.543	70.836	99.672	0.292	0.04336	0.00328	0.29162
7	0.013	13.380	1.081	88.069	99.441	76.332	81.030	80.169	99.671	0.198	0.04340	0.00329	0.19828
8	0.013	13.378	1.081	92.434	99.441	84.869	87.971	85.048	99.672	0.150	0.04339	0.00328	0.14949

Table 5.22 Values of hydraulic parameters under eight different patterns of clogged emitters along the lateral.

Theoretical results from synthetic data: (7% up-slope)

Stage NO.	Total Hf (m)	Hvar (%)	qvar (%)	CU (%)	Ea (%)	EU' (%)	DU (%)	Us (%)	USh (%)	Vqs	Vhs	Vqh	Vpf
1	0.0138	13.3879	1.0821	98.9283	99.4404	98.5539	98.296	98.718	99.6713	0.0128	0.04343	0.00329	0.01239
2	0.0093	13.3458	1.0785	77.2754	99.4416	54.5508	63.8679	70.436	99.6723	0.2956	0.04328	0.00328	0.29562
3	0.0095	13.3472	1.0786	69.1687	99.4416	39.4035	50.9782	62.092	99.6723	0.3791	0.04329	0.00328	0.37906
4	0.0119	13.3703	1.0806	67.1408	99.4409	35.1486	47.7539	59.070	99.6717	0.4093	0.04337	0.00328	0.40928
5	0.0099	13.3511	1.0790	66.6452	99.4415	37.4464	46.9658	59.899	99.6722	0.4010	0.04330	0.00328	0.40100
6	0.0112	13.3637	1.0800	77.5888	99.4411	57.5151	64.3661	71.177	99.6719	0.2882	0.04334	0.00328	0.28821
7	0.0124	13.3748	1.0810	88.7011	99.4408	80.14	82.0348	80.965	99.6716	0.1904	0.04338	0.00328	0.19032
8	0.0126	13.3768	1.0812	93.6902	99.4407	88.8658	89.9674	85.473	99.6716	0.1453	0.04339	0.00328	0.14523

drop at each section for all slopes were determined. Tables A.5.11 and A.5.12 (Appendix A) show the head loss and pressure drop at each section along the lateral laid on a 7% down-slope. Figure 5.19 shows that in stage 1, the values of H_f were 0.0129m and 0.0136m at 3% and 7% down-slope respectively, while H_f was 0.0143m and 0.0147m at 3% and 7% up-slopes respectively. It is found that H_f in stage 1 at down-slopes was 7% to 9% less than H_f in up-slope conditions. Similar trends were found for the rest of seven stages. Figure 5.20 shows that the variation of head loss per section was close to zero as the sections were closer to the end of lateral in each stage at a 7% down-slope. It is also shown that the head loss is almost zero at the last section of lateral in eight different stages. This was due to the very small flow at the last section. Figure 5.20 shows that the total head loss is rapidly increased at the first 40% length of the lateral and is almost constant at the last 60% of lateral length. Similar trends were observed for the other slopes. Results indicated that the total values of H_f in stage 4 at different slopes was almost same as total H_f in stages 7 and 8 (10% and 5% clogged emitters). On the other hand, total H_f in stages 2, 3, and 5 (30% clogging) at 7% down-slope were 19% to 28% and in up-slope 16% to 21% less than that in stage 4 (30% clogging). The lateral inlet flow presented in Table A.5.9 shows that the maximum Q_L (lateral inlet flow) was at stage 1 and resulted in maximum head loss. The Q_L in stages 2, 3, 4, and 5 (consisting of 30% clogging at different locations) were 60.65, 59.27, 58.05, and 54.16 *l/h* respectively. Theoretically, the minimum head loss should have occurred at stage 5, which had the least lateral inlet flow. Results indicated that the minimum head loss was obtained in stage 2 with Q_L greater than stages 3, 4, and 5. It is clearly concluded that although having a different number and degree of clogged emitters has an significant impact on head loss, the location of clogged emitters is also one of the major factors affecting H_f. Similar results were found from theoretical data produced by the computer simulation program.

5.8.2.2 Pressure variation (H_{var}):

Results showed that the highest pressure variations occurred in stage 1 at 3% and 7% up-slopes. However, in the case of 3% and 7% down-slopes, the maximum H_{var} values were found in stage 2. Figure 5.21 shows the relationship between H_{var} versus different stages and slopes. The minimum H_{var} were found in stage 1 at 3% and 7% down-slopes respectively, whereas the

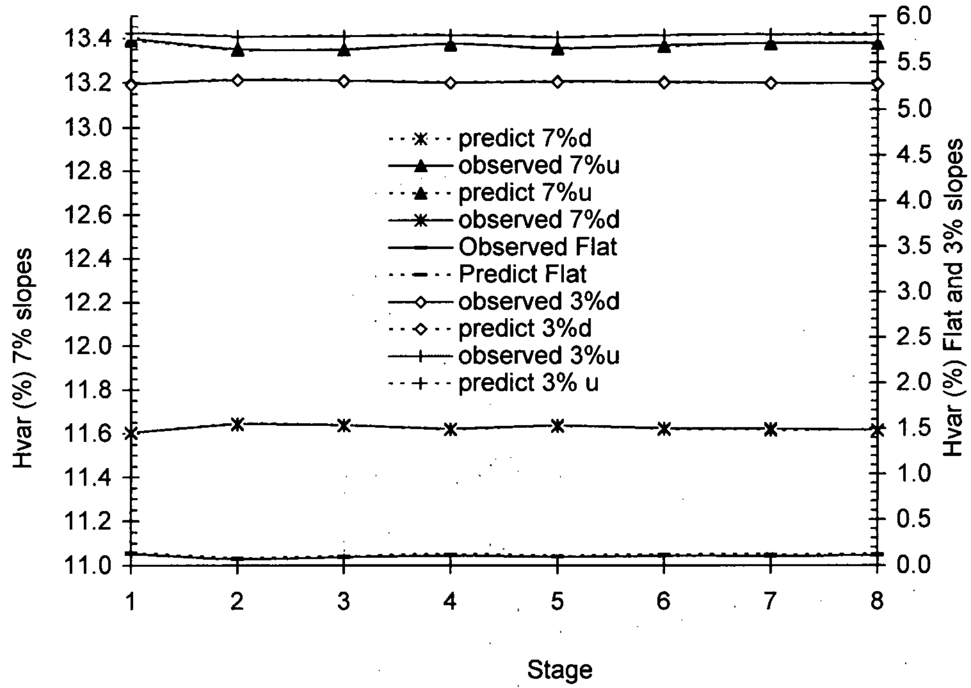


Figure 5.21 Pressure variation in different stages under different slopes

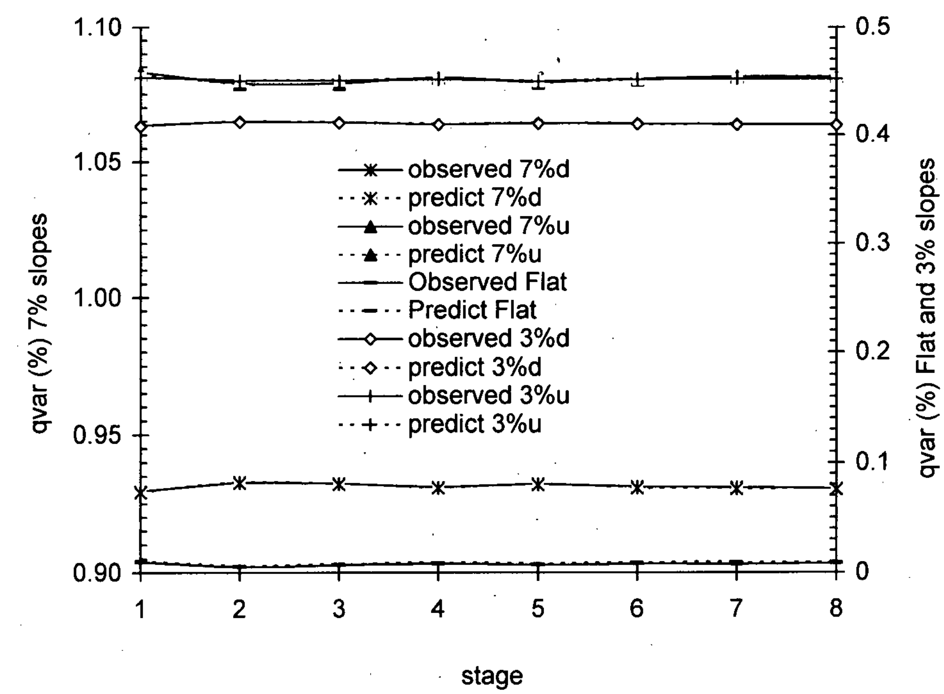


Figure 5.22 Emitter discharge variation in different stages under different slopes

minimum H_{var} values were found in stage 3 and 5 at 7% and 3% up-slopes respectively (Figure 5.21). The maximum and minimum values of H_{var} were found in different slopes as follows:

-Minimum H_{var} :	5.26% in 3% down-slope (stage 1)
	11.6% in 7% down-slope (stage 1)
	5.77% in 3% up-slope (stage 5)
	13.35% in 7% up-slope (stage 3)
-Maximum H_{var} :	5.51% in 3% up-slope (stage 1)
	13.39% in 7% up-slope (stage 1)
	5.31% in 3% down-slope (stage 2)
	11.64% in 7% down-slope (stage 2)

According to the location and percentage of clogged emitters, the maximum and minimum pressure variations were inversely related to each other on up-slope and down-slope conditions. In other words when the H_{var} was at a minimum on down-slope it was at a maximum on up-slope terrain. It was also found that H_{var} on 7% up- or down-slopes were almost double the values of H_{var} on 3% up or down-slope in eight different stages. This indicates that H_{var} was directly related to the degree of lateral slope. Tables 5.15 to 5.22 show that as the number of clogged emitters along the lateral decreased in stages 2 to 8, the pressure variation also decreased in the down-slope conditions, but it increased in up-slope terrain. However, these variations were not significant. Tables 5.15 and 5.21 show that the value of H_{var} in stage 4 was greater than in stage 6 on 3% and 7% down-slopes. In addition the H_{var} was varied in stages 2 to 5 (30% clogged) at all different slopes. The location of clogged emitters also has an impact on H_{var} along the lateral. Similar trends were found in the results obtained from synthetic data on down-slopes. Tables 5.15 to 5.22 show that although the variations of H_{var} in different stages were not significant, the values of H_{var} in all stages on up-slopes were about 13% higher than those values obtained from down-slopes. It was found that the slope of the lateral was a major factor affecting pressure variation in a microirrigation system, but number, degree, and location of clogged emitters have little impact on pressure variation along the lateral.

5.8.2.3 Emitter flow variation (q_{var}):

The flow rate from the emitters along the lateral varied from the nominal emitter flow rate. It was found that emitter flow variation varied from one slope to the other, but the variations of q_{var} were not significant at eight different stages (Figure 5.22). The highest and lowest emitter flow variations occurred in stages 1 and 5 in 3% up-slopes and in stages 1 and 3 in 7% up-slope conditions (Tables 5.17 and 5.19). In the case of down-slope conditions, the minimum and maximum q_{var} were found in stages 1 and 2 as shown in Figure 5.22. Results indicated that the location of clogged emitters has a higher impact than the numbers of clogged emitters on q_{var}. It was found that the emitter flow variation in all stages in up-slopes situations is greater than that in the down-slopes conditions.

5.8.2.4 Coefficient of uniformity (*CU*):

The highest *CU* was found in stage 1 at different slopes. The values of *CU* were 97.6%, 97.8%, 96.8% and 96.3% at 3% and 7% down-slopes and 3% and 7% up-slopes respectively (Tables 5.15 to 5.22). The values of *CU* in down-slopes were 0.8% to 1.5% greater than that those values in the up-slope conditions. Results show that the values of *CU* were between 55% to 78% in stages 2, 3, 4, and 5. The *CU* was lower as the degree of clogged emitters was higher (see Tables 5.15 to 5.22). Figure 5.23 shows that the lowest *CU* occurred in stage 5 at all different slopes except on the 3% down-slope where the minimum *CU* was found in stage 4. It was also found that the *CU* decreased as the clogged emitters were located closer to the first one-third section of the lateral. The number and degree of clogged emitters along the lateral were the major factors affecting *CU*. The slope and location of clogging have little impact on *CU*.

5.8.2.5 Application efficiency (*Ea*):

Results indicated that the application efficiency was greater than 99% in all stages and slopes. Figure 5.24 shows that although application efficiency was almost constant under the eight different stages, the small variations of *Ea* were found in different slopes. One reason for the constant values of *Ea* in all different stages is the small pressure variations along the lateral

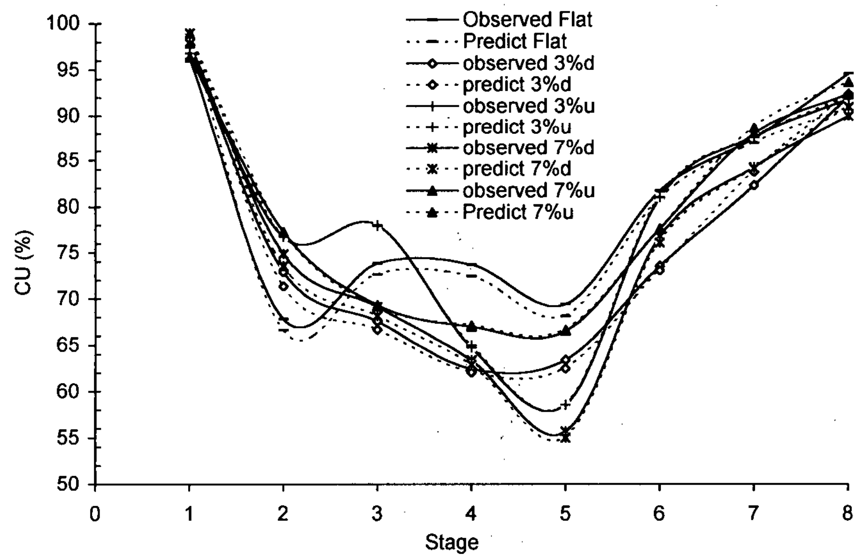


Figure 5.23 Coefficient of uniformity in different stages under different slopes

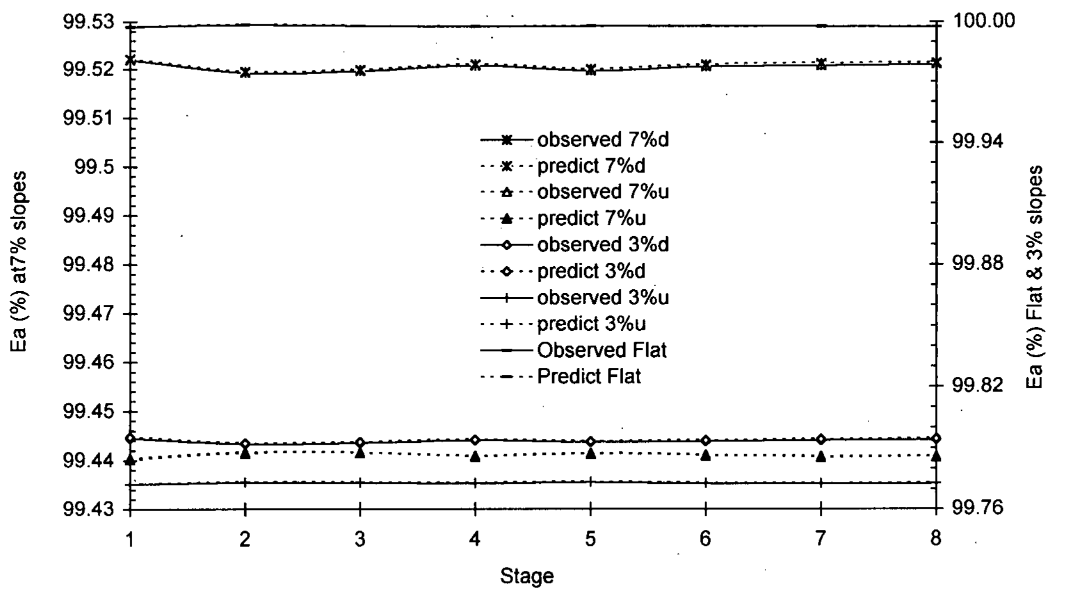


Figure 5.24 Application efficiency in different stages under different slopes

at each slope. The values of *Ea* were 99.79% and 99.52%, in the 3% and 7% down-slopes and 99.77% and 99.44% in the 3% and 7% up-slopes respectively in all different stages (Tables 5.15 to 5.22). It was found that the highest *Ea* occurred in the 3% down-slope and the lowest in the 7% up-slope in all different stages. Results also show that the *Ea* obtained from down-slopes was 1% greater than for up-slopes. The small differences between the values of *Ea* in up-slopes and down-slopes is not important for irrigation purposes. Therefore, the impact of slopes on application efficiency in a microirrigation lateral laid on sloped terrain is insignificant.

5.8.2.6 Field emission uniformity (*EU'*):

Similar trends as for *CU* were observed for *EU'*. The highest value of *EU'* was found in stage 1 at all slopes studied. Results show that *EU'* were 96.93% and 96.44% in stage 1 on 3% and 7% down-slopes and 95.2% and 94.03% in stage 1 on 3% and 7% up-slopes respectively. The values of *EU'* in stage 1 at down-slopes were greater than those obtained from the up-slope conditions up to a value of 2.5% (Tables 5.15 to 5.22). The lowest values of *EU'* were found as follows:

Up-slope: 7% -- 35.09% (stage 4) and 3% --20.0% (stage 5)

Down-slope: 7% -- 21.26% (stage 5) and 3% -- 30.05% (stage 4)

According to the criteria suggested by ASAE EP458 (1997) these values are within an unacceptable range (< 50%). It was found that the degree and number of clogged emitters (expressed in percentage of the total number of emitters along the line) are the important factors affecting *EU'*. Figure 5.25 shows that as the location of clogged emitters was closer to the first one-third section of the lateral, the *EU'* becomes lower. Results indicated that stage 5 in all four slopes represented the worst situation of emitter clogging affecting *EU'*.

5.8.2.7 Distribution uniformity (*DU*):

Similar trends as for *EU'* were obtained for distribution uniformity. The highest values of distribution uniformity were found in stage 1 in different slopes and the lowest values were obtained mostly in stages 4 or 5 (30% clogging). Results show that *DU* was 96.23% and 96.63% in stage 1 on 3% and 7% down-slopes and 95.01% and 94.24% in stage 1 on 3% and

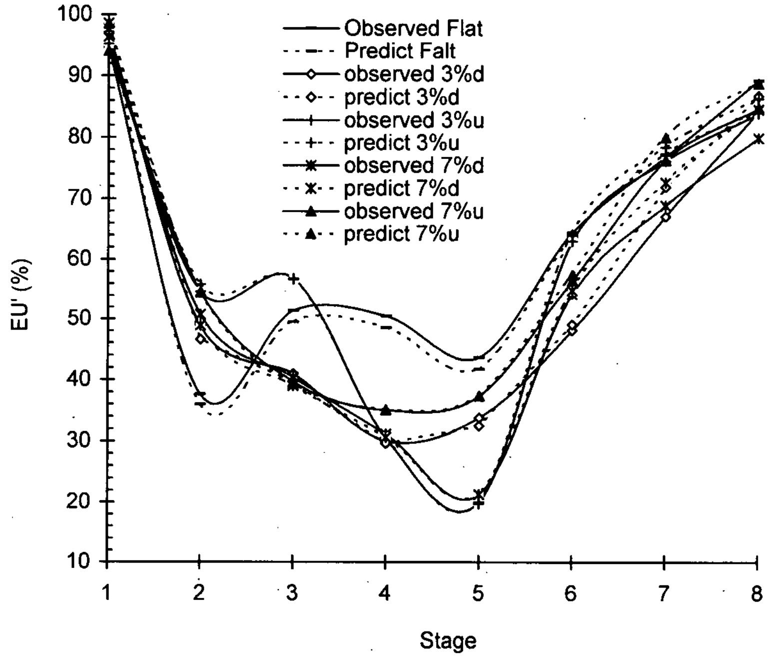


Figure 5.25 Field emission uniformity in different stages under different slopes.

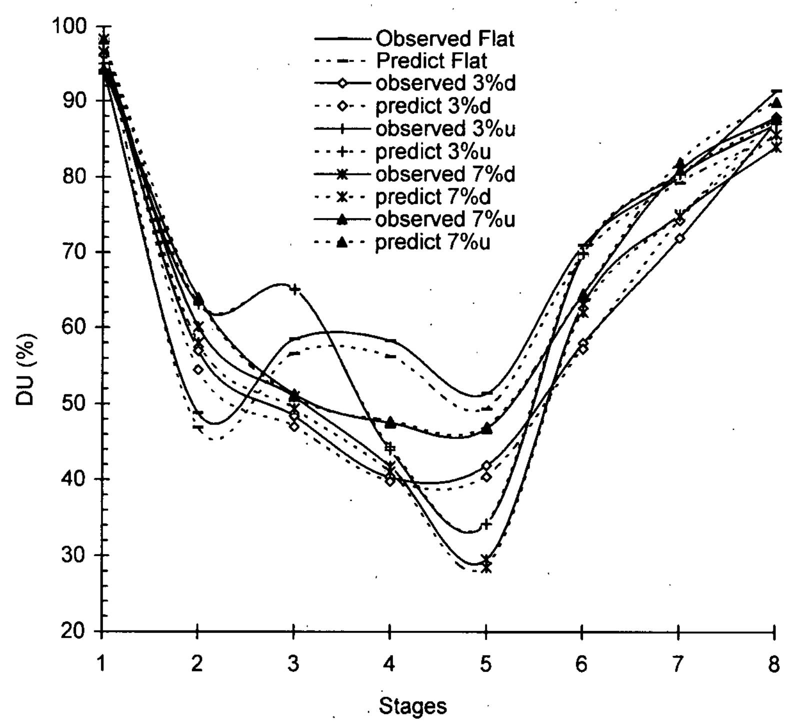


Figure 5.26 Distribution uniformity in different stages under different slopes.

7% up-slopes. It is found that *DU* in down-slope condition was about 1% to 2.5% greater than that in the up-slope. The minimum and maximum *DU* in different slopes were found as:

Minimum *DU* :	40.3% in 3% down-slope (stage 4)
	29.54% in 7% down-slope (stage 5)
	34.18% in 3% up-slope (stage 5)
	46.79% in 7% up-slope (stage 5)
Maximum *DU* :	96.23% in 3% down-slope (stage 1)
	96.63% in 7% down-slope (stage 1)
	95.01% in 3% up-slope (stage 1)
	94.24% in 7% up-slope (stage 1)

It is shown that the degree of slope has no significant effect on distribution uniformity. Figure 5.26 shows that the lowest values of *DU* occurred in stage 5 on 3% and 7% up-slopes, and 7% down-slope, and in stage 4 on 3% down-slope. Results also indicated that in the case of different locations of clogged emitters along the lateral, when the partially clogged emitters were located closer to the first one- third section of the lateral, the *DU* decreased in all different slopes. Stages 4 and 5 showed the worst stages of clogging patterns affecting *DU.* The number and degree of clogged emitters were the important factors affecting distribution uniformity. Results show that as the number of clogged emitters along the lateral decreased, the distribution uniformity increased. As presented in Tables 5.15 to 5.22, the values of *DU* were 58%, 63.18%, 69.87%, and 64.54% in stage 6 on 3% and 7% down-slopes and 3% and 7% up-slopes respectively, and were 87.48%, 84.12%, 84.03%, and 87.97% in stage 8 on 3% and 7% down-slopes and 3% and 7% up-slopes respectively. When the number of clogged emitters along the lateral decreased from 20% to 5%, *DU* increased up to 16% to 33%. It was also found that if the total number of clogged emitters increased from 5% to 30%, *DU* will decreased up to 64% at a 7% down-slope (Table 5.19). Results also show that when 30% of the total number of emitters are partially clogged and located at different locations along the lateral, *DU* varied up to 103% within stages 2 to 5 in a 7% down-slope. It is concluded that the slope of lateral has little impact on *DU*, but the degree, number, and the location of clogged emitters along the lateral have a significant effect on distribution uniformity. The former has a higher impact on *DU* than the latter.

5.8.2.8 Statistical Uniformity (*Us*):

The maximum and minimum values of *Us* were obtained in stage 1 and stages 4 or 5 respectively in all different slopes. Tables 5.15 to 5.22 show that the highest values of *Us* occurred in stage 1 at all different slopes. The minimum values were found in stage 4 at a 3% down-slope and 7% up-slope and in stage 5 at a 3% up-slope and 7% down-slope as follows:

Minimum U_s :	56.06% in 3% down-slope (stage 4)
	50.30% in 7% down-slope (stage 5)
	51.44% in 3% up-slope (stage 5)
	58.88% in 7% up-slope (stage 4)
Maximum U_s :	97.16% in 3% down-slope (stage 1)
	97.51% in 7% down-slope (stage 1)
	96.34% in 3% up-slope (stage 1)
	95.59 % in 7% up-slope (stage 1)

Figure 5.27 shows that the statistical uniformity was decreased as the partially clogged emitters were located closer to the first one-third section of lateral. Results show that *Us* increases as the number of clogged emitters along the lateral decreases in all different slopes. The variations of *Us* in each stage at different slopes were not significant. According to the criteria for an acceptable statistical uniformity of the emitter discharge suggested by ASAE EP458 (1997) and Bralts and Edwards (1986), the values of *Us* were poor or unacceptable (60% to 80%) in stages 2 to 6 in all slopes (*Us* were less than 80%). It was found that although the location of clogged emitters and slope of lateral have an impact on *Us*, the number and degree of clogged emitters are the major factors affecting statistical uniformity in a microirrigation system.

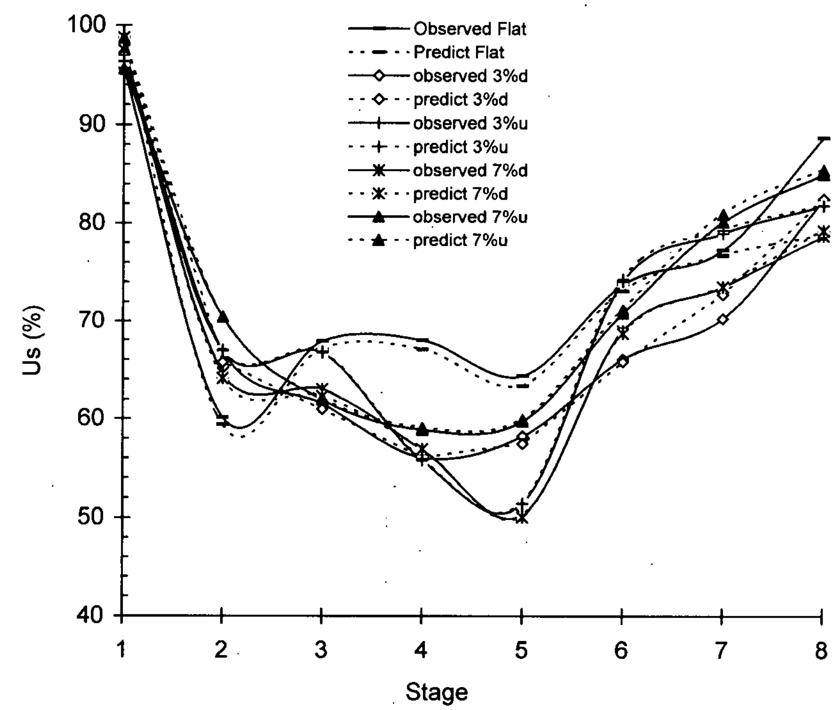


Figure 5.27 Statistical uniformity of emitter discharge in different stages under different slopes.

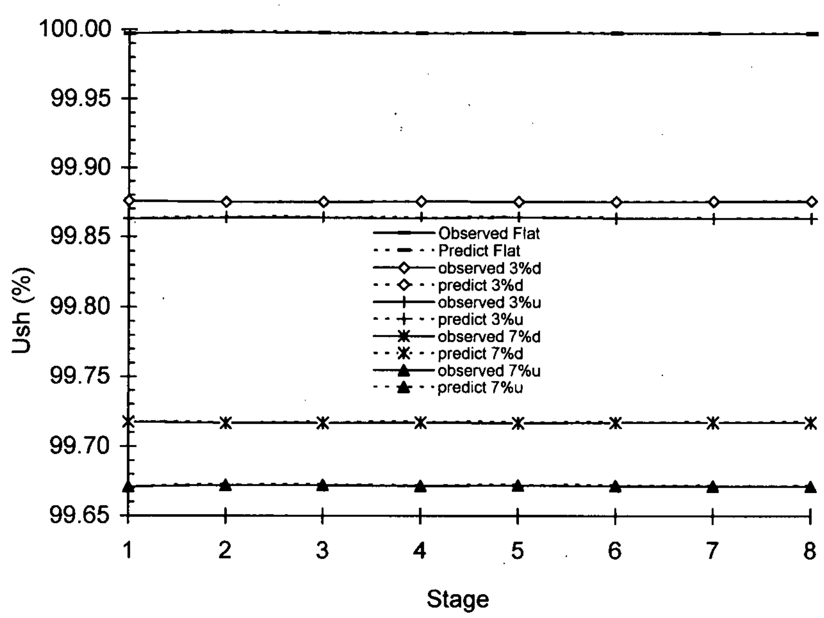


Figure 5.28 Emitter statistical uniformity due to hydraulics in different stages under different slopes.

The values of U_s versus *CU* values under different patterns of clogged emitters at different slopes were plotted (Figures A.5.2 to A.5.5 in Appendix A.). The least-square regression line was fitted through the data points at each slope and the regression equations were found as follows:

1- **For 3% and 7% up-slopes** as:

$$CU = 17.576 + 0.8661Us \quad 5.12$$

$$CU = 15.2 + 0.8806Us \quad 5.13$$

2-**For 3% and 7% down-slopes** as:

$$CU = 11.809 + 0.924Us \quad 5.14$$

$$CU = 11.566 + 0.936Us \quad 5.15$$

Equations 5.12 to 5.15 show that the differences in *CU* estimated from the regression equation for different slopes are not significant. For example, the U_s of 92% yields the *CU* of 96% to 97% at different slopes.

5.8.2.9 Emitter statistical uniformity due to hydraulics (U_{sh}):

The emitter statistical uniformity due to hydraulics was almost constant in the eight different stages at different slopes (Tables 5.15 to 5.22). Figure 5.28 shows that the variations in U_{sh} in different stages were less than 1% on all different slopes. These small variations come from the very small variations in emitter discharge coefficient of variation due to hydraulics, V_{qh} in all different stages. It was found that as the degree of slope increased, the U_{sh} decreased. Figure 5.28 shows that highest U_{sh} occurred on flat terrain, a lower value at 3% slopes and the lowest at 7% slopes. However, higher values of U_{sh} were found in down-slopes rather than in up-slopes.

5.8.2.10 Emitter discharge coefficient of variation due to hydraulic (V_{qh}):

The emitter coefficient of variation due to hydraulics, V_{qh}, were almost constant in all eight different stages at each slope but the values of V_{qh} vary from one slope to the other. The variations of V_{qh} at different slopes were similar to those of U_{sh} under different slopes but the trend was inverse. In other words, the V_{qh} in down-slopes was lower than in up-slopes. Also, V_{qh} decreased as the degree of slopes decreased. The highest value of V_{qh} was obtained in 7% slopes, the lower in 3% slopes, and the lowest was found on flat terrain. Figure 5.29 shows that the values of V_{qh} in eight different stages were almost constant, but it indicates that V_{qh} in up-slopes are 10% to 16% greater than those values occurring in down-slope terrain.This was due to the higher pressure variations in up-slopes than in down-slopes conditions. The values of V_{qh} were equal to 0.137% and 0.329% at 3% and 7% up-slopes and 0.124% and 0.283% at 3% and 7% down-slopes respectively (Tables 5.15 to 5.22). It was found that different locations, numbers, and degrees of clogged emitters had no major impact on V_{qh}, however, the former had a higher impact on V_{qh} than the latter. The slope of the lateral was the most important factor affecting V_{qh}.

5.8.2.11 Emitter discharge coefficient of variations (V_{qs}):

Figure 5.30 shows that the variation of V_{qs} in stages 5 to 8 was higher than that in stages 1 to 4 from down-slope to up-slope conditions. The minimum V_{qs} occurred in stage 1 and the maximum was found in stages 4 and 5 (Tables 5.15 to 5.22) as given below.

- Minimum V_{qs} :
  - V_{qs} = 3.6% in 3% up-slope (stage 1)
  - V_{qs} = 4.4% in 7% up-slope (stage 1)
  - V_{qs} = 2.8% in 3% down-slope (stage 1)
  - V_{qs} = 2.4% in 7% down-slope (stage 1)
- Maximum V_{qs} :
  - V_{qs} = 48.5% in 3% up-slope (stage 5)
  - V_{qs} = 41.0% in 7% up-slope (stage 4)
  - V_{qs} = 43.9% in 3% down-slope (stage 4)
  - V_{qs} = 49.6% in 7% down-slope (stage 5)

It was found that when 30% of the total number of emitters were clogged and located at the first one-third section of the lateral (or randomly located along the lateral), this represented the worst conditions for V_{qs}. It was also found that the degree, numbers, and locations of partially

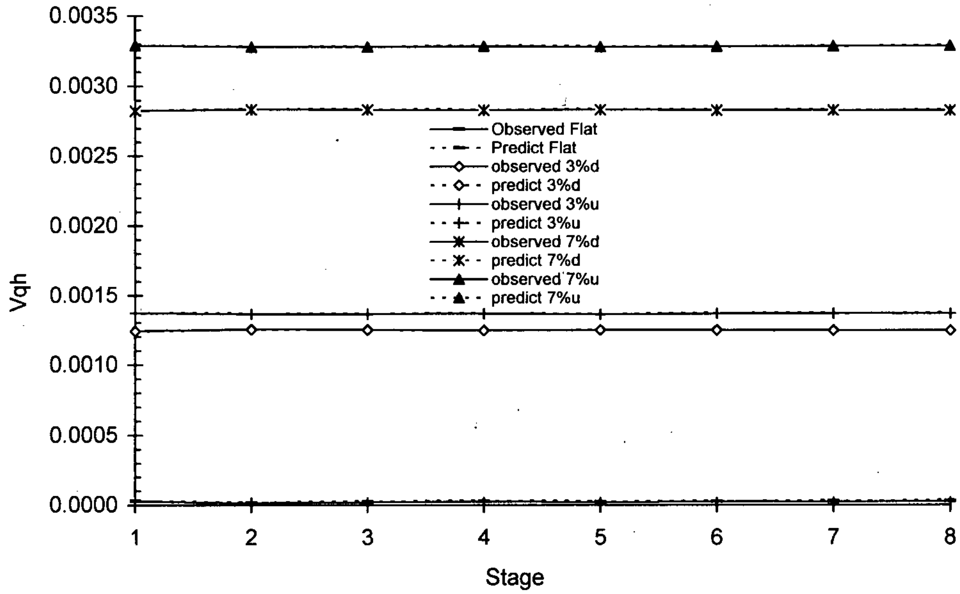


Figure 5.29 Emitter discharge coefficient of variation due to hydraulics in different stages under different slopes.

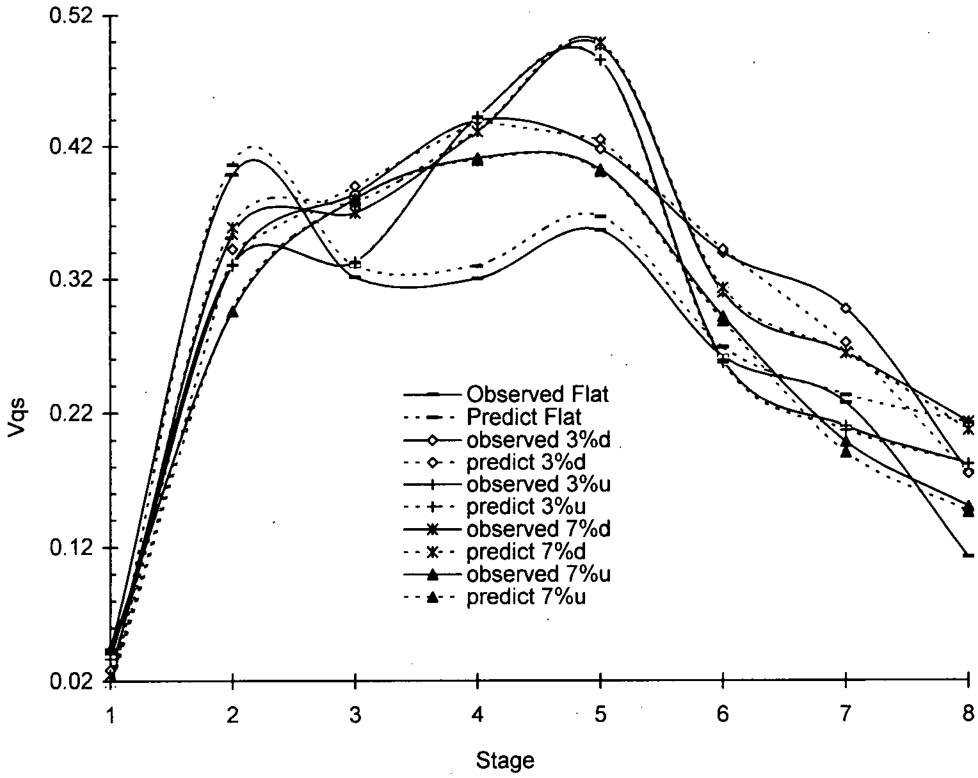


Figure 5.30 Emitter discharge coefficient of variation in different stages under different slopes.

clogged emitters along the lateral have a larger impact on V_{qs} than the slope of lateral line. However, the V_{qs} at most of the stages in up-slopes were higher than in down-slopes.

5.8.2.12 The hydraulic design coefficient of variation (V_{hs}):

Similar trends as for V_{qh} in different stages and slopes were found for V_{hs}. Figure 5.31 shows that V_{hs} were almost constant in different stages at different slopes. The values of V_{hs} in 3% and 7% up-slopes were 8.7% and 13.8% greater than those values obtained from 3% and 7% down-slopes respectively (Tables 5.15 to 5.22). Less than a 1% difference in the V_{hs} was found among the stages tested. Results indicate that the location of clogged emitters has a more significant impact on V_{hs} than the number and degree of clogged emitters. However, the slope of lateral was the major factor affecting V_{hs}.

5.8.2.13 Emitter performance coefficient of variation: (V_{pf}):

Similar trends as for V_{qs} were found for V_{pf} at different slopes. The lowest variations of V_{pf} were 4%, 4%, 2%, and 3% in stage 1 at 3% and 7% up-slopes and down-slopes respectively (Tables 5.15 to 5.22). The highest V_{pf} values were 49% and 50% in stage 5 at 3% and 7% down-slope conditions. In case of an up-slope terrain, the maximum V_{pf} was 44% at 3% up-slope and 41% at 7% up-slope in stage 4. Figure 5.32 shows that in stages 2, 3, and 4 the V_{pf} increased on all different slopes when the clogged emitters were located closer to the first one-third section of the lateral. The values of V_{pf} in stages 2, 3, 6, 7, and 8 were less than those values in stages 4, and 5 on all different slopes. It was found that stages 4 and 5 were the worst stages (highest V_{pf}) affecting V_{pf} on sloped terrain. The number and location of clogged emitters were found to be the major factors affecting V_{pf} on all different slopes.

Table A.5.13 (Appendix A) presents a sample of the results of the hydraulic parameters obtained from stage 2 at a 7% down-slope. Similar results to those shown in Table A.5.13 were found for all stages at different slopes. The summary of the impact of number and location of clogged emitters and slope of lateral on hydraulic parameters in a microirrigation system are shown in Figure 5.33.

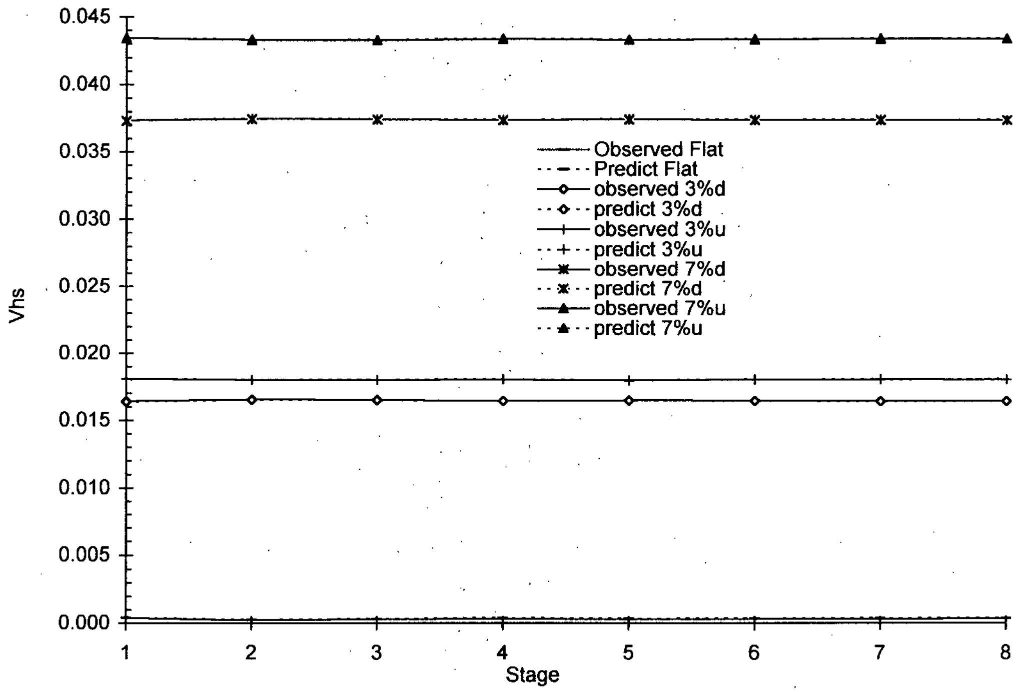


Figure 5.31 Hydraulic design coefficient of variation in different stages under different slopes.

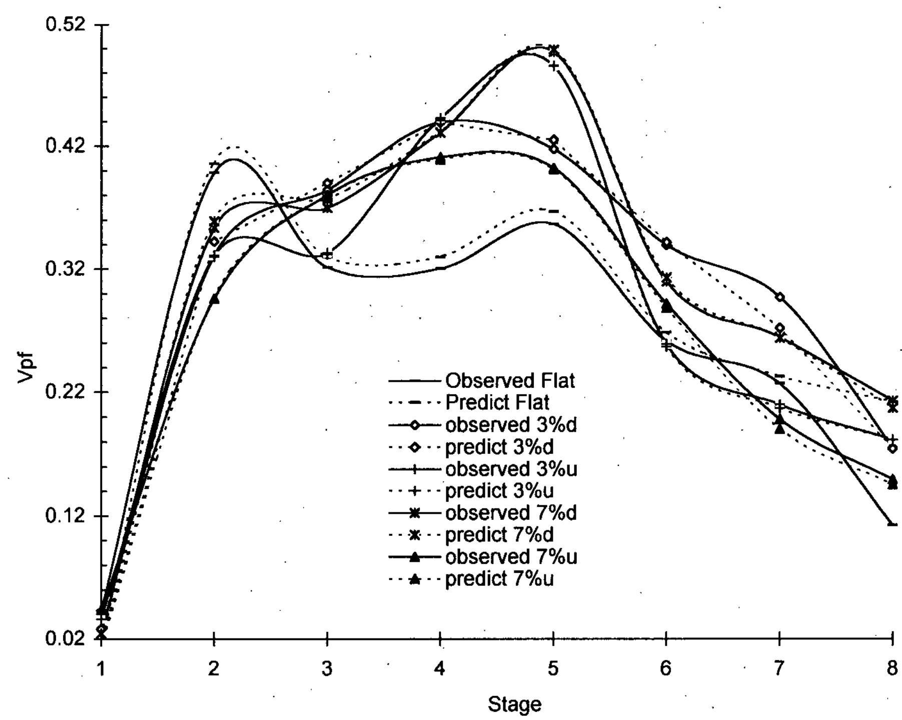


Figure 5.32 Emitter performance coefficint of variation in different stages under different slopes.

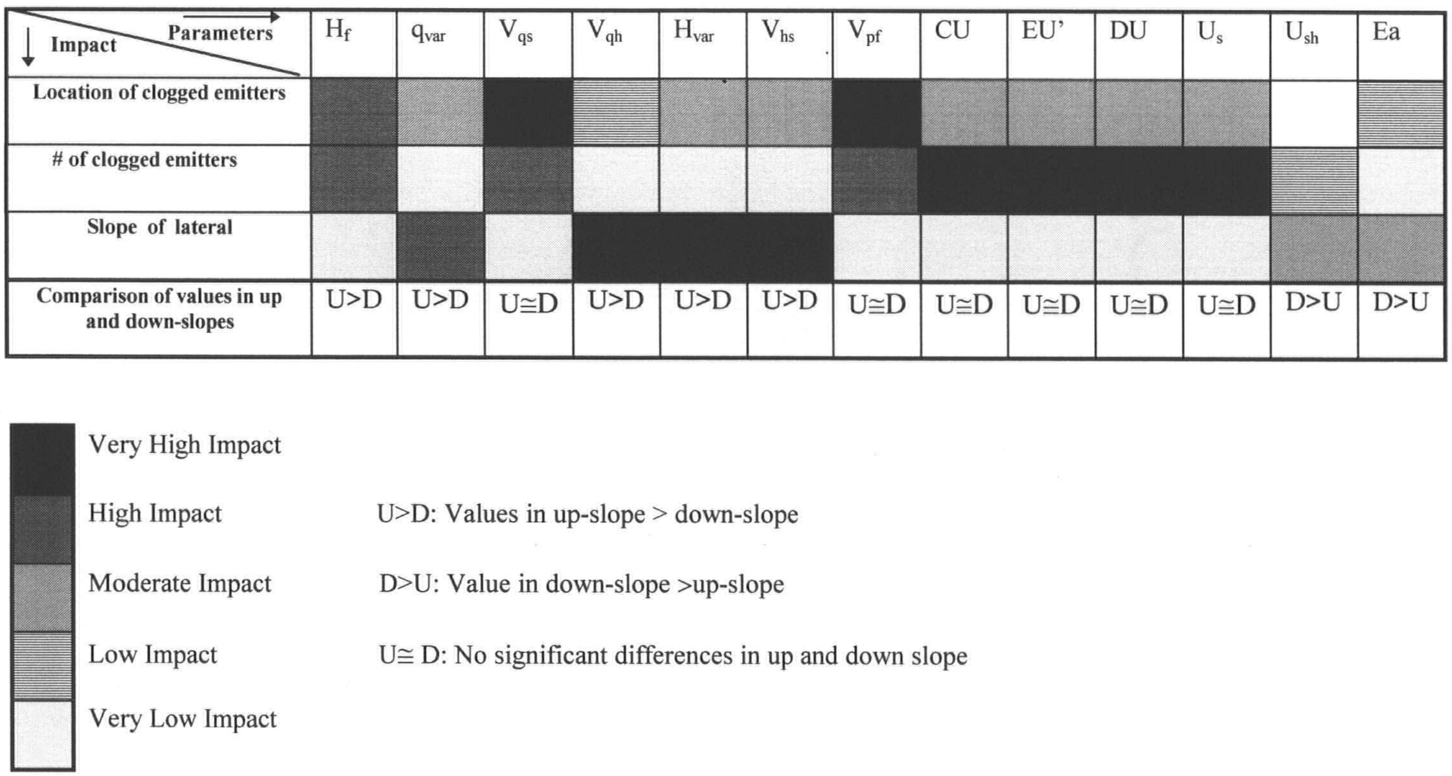


Figure 5.33 Impact of number and location of clogged emitters and slope of lateral on hydraulics of a microirrigation system

5.8.2.14 Crop yield reduction due to emitter clogging at different slopes:

Similar analysis of cotton yield and farmer's loss (money lost) in different areas and with different patterns of emitter clogging as described in step 1 were done in step 2. Tables A.5.14 to A.5.21 (Appendix A) show the results of reduction in cotton yield under different patterns of partially clogged emitters compared with a no-clogged situation at 3% and 7% down and up-slopes. For example, results show that 5% and 30% clogged emitters can reduce cotton yield up to 5.8% and 15.4% respectively, compared with the no-clogged situation in 3% and 7% down- and up-slopes. Results indicated that as the number of clogged emitters increases, the cotton yield decreases. In addition, it was shown that different locations of clogged emitters along the lateral have an impact on cotton yield. The closer the clogged emitters to the first one-third section of lateral, the greater the rate of reduction in cotton yield. The minimum yield reduction (1.1% to 2.1% in 3% and 7% slopes) was obtained in stage 1 (desired situation) at all different slopes. The maximum yield reduction (13.5% to 16.9%) was estimated in stage 4 and 5 consisting of 30% clogged emitters for all different slopes. Similar trends were obtained from synthetic data in different slopes.

The cotton yield reduction and money lost in different areas under different patterns of clogging are presented in Tables 5.23 to 5.30. For example, Table 5.24 shows that the cotton yield can be reduced from 10 kg/ha (0.01ton/ha) in a no-clogged condition up to 42.4 kg/ha (0.0424 ton per hectare) when 5% of the total numbers of emitters along the lateral are partially clogged in a 3% down-slope. It is also shown that the yield can be decreased by up to 100 kg/ha (0.1 ton per hectare) if 30% of emitters are clogged and randomly located along the lateral laid on a 3% down-slope. The reason for the yield reduction was the variation in emitter flow caused by manufacturing, hydraulics, and emitter clogging along the lateral. The relationship between cotton yield reduction and money lost in different slopes and areas versus different number of clogged emitters was plotted and is shown in Figures A.5.6 to A.5.13 (Appendix A). The linear relationship between the reduction in cotton yield (Y_R) and percentage of clogged emitters (C) found at different slopes is expressed by regression equations as follows:

Table 5.23 Cotton yield reduction and money ($) lost in different areas under different patterns of clogging at 3% down-slope.

Area (ha)	Yield reduc. Stage 1 (ton)	Yield reduc. Stage 2 (ton)	Yield reduc. Stage 3 (ton)	Yield reduc. Stage 4 (ton)	Yield reduc. Stage 5 (ton)	Yield reduc. Stage 6 (ton)	Yield reduc. Stage 7 (ton)	Yield reduc. Stage 8 (ton)
1	0.008	0.080	0.093	0.106	0.101	0.082	0.072	0.042
10	0.079	0.798	0.925	1.058	1.006	0.818	0.716	0.424
100	0.788	7.979	9.251	10.579	10.059	8.180	7.160	4.236
1000	7.877	79.788	92.511	105.789	100.595	81.798	71.596	42.358
10000	78.768	797.879	925.114	1057.889	1005.945	817.977	715.96	423.58
Area (ha)	**$Lost per area Stage 1**	**$Lost per area Stage 2**	**$Lost per area Stage 3**	**$Lost per area Stage 4**	**$Lost per area Stage 5**	**$Lost per area Stage 6**	**$Lost per area Stage 7**	**$Lost per area Stage 8**
1	10.3	104.0	120.6	137.9	131.2	106.7	93.4	55.2
10	102.7	1040.4	1206.3	1379.5	1311.8	1066.6	933.6	552.3
100	1027.1	10404.3	12063.5	13794.9	13118	10666	9336	5523
1000	10271.4	104043	120635	137949	131175	106664	93361	55235
10000	102714	1040434	1206349	1379487	1311753	1066642	933608	552349

Table 5.24 Reduction in cotton yield (ton/Area)under different number of clogged emitters randomly located along the lateral (3% down-slope).

# of clogged emitters(%)	Area(ha) 1	Area(ha) 10	Area(ha) 100	Area(ha) 1000	Area(ha) 10000
5	0.0424	0.4236	4.2358	42.3580	423.58
10	0.0716	0.7160	7.1596	71.5957	715.96
20	0.0818	0.8180	8.1798	81.7977	817.98
30	0.1006	1.0059	10.0595	100.595	1005.95

Table 5.25 Cotton yield reduction and money ($) lost in different areas under different patterns of clogging at 3% up-slope.

Area (ha)	Yield reduc. Stage 1 (ton)	Yield reduc. Stage 2 (ton)	Yield reduc. Stage 3 (ton)	Yield reduc. Stage 4 (ton)	Yield reduc. Stage 5 (ton)	Yield reduc. Stage 6 (ton)	Yield reduc. Stage 7 (ton)	Yield reduc. Stage 8 (ton)
1	0.010	0.080	0.080	0.107	0.117	0.062	0.051	0.044
10	0.098	0.798	0.802	1.066	1.169	0.625	0.507	0.439
100	0.981	7.976	8.024	10.655	11.691	6.246	5.065	4.391
1000	9.809	79.755	80.236	106.555	116.906	62.456	50.652	43.909
10000	98.091	797.551	802.356	1065.55	1169.056	624.562	506.52	439.09
Area (ha)	**$Lost per area Stage 1**	**$Lost per area Stage 2**	**$Lost per area Stage 3**	**$Lost per area Stage 4**	**$Lost per area Stage 5**	**$Lost per area Stage 6**	**$Lost per area Stage 7**	**$Lost per area Stage 8**
1	12.8	104.0	104.6	138.9	152.4	81.4	66.0	57.3
10	127.9	1040.0	1046.3	1389.5	1524.4	814.4	660.5	572.6
100	1279.1	10400.1	10462.7	13894.7	15244	8144	6605	5726
1000	12791.0	104001	104627	138947	152445	81443	66050	57257
10000	127910	1040007	1046272	1389474	1524450	814429	660497	572568

Table 5.26 Reduction in cotton yield (ton/Area)under different number of clogged emitters randomly located along the lateral (3% up-slope).

# of clogged emitters(%)	Area(ha) 1	Area(ha) 10	Area(ha) 100	Area(ha) 1000	Area(ha) 10000
5	0.0439	0.4391	4.3909	43.9086	439.09
10	0.0507	0.5065	5.0652	50.6516	506.52
20	0.0625	0.6246	6.2456	62.4562	624.56
30	0.1169	1.1691	11.6906	116.906	1169.06

Table 5.27 Cotton yield reduction and money ($) lost in different areas under different patterns of clogging at 7% down-slope.

Area (ha)	Yield reduc. Stage 1 (ton)	Yield reduc. Stage 2 (ton)	Yield reduc. Stage 3 (ton)	Yield reduc. Stage 4 (ton)	Yield reduc. Stage 5 (ton)	Yield reduc. Stage 6 (ton)	Yield reduc. Stage 7 (ton)	Yield reduc. Stage 8 (ton)
1	0.011	0.086	0.089	0.104	0.120	0.075	0.064	0.052
10	0.108	0.856	0.894	1.041	1.199	0.751	0.643	0.519
100	1.077	8.557	8.940	10.414	11.990	7.506	6.428	5.192
1000	10.771	85.574	89.396	104.144	119.901	75.059	64.276	51.920
10000	107.708	855.739	893.956	1041.44	1199.01	750.592	642.76	519.20
Area (ha)	**$Lost per area Stage 1**	**$Lost per area Stage 2**	**$Lost per area Stage 3**	**$Lost per area Stage 4**	**$Lost per area Stage 5**	**$Lost per area Stage 6**	**$Lost per area Stage 7**	**$Lost per area Stage 8**
1	14.0	111.6	116.6	135.8	156.4	97.9	83.8	67.7
10	140.5	1115.9	1165.7	1358.0	1563.5	978.8	838.2	677.0
100	1404.5	11158.8	11657.2	13580.4	15635	9788	8382	6770
1000	14045.1	111588	116572	135804	156351	97877	83816	67704
10000	140451	1115883	1165718	1358042	1563509	978773	838163	677041

Table 5.28 Reduction in cotton yield (ton/Area)under different number of clogged emitters randomly located along the lateral (7% down-slope).

# of clogged emitters(%)	Area(ha) 1	Area(ha) 10	Area(ha) 100	Area(ha) 1000	Area(ha) 10000
5	0.0519	0.5192	5.1920	51.9203	519.20
10	0.0643	0.6428	6.4276	64.2763	642.76
20	0.0751	0.7506	7.5059	75.0592	750.59
30	0.1199	1.1990	11.9901	119.901	1199.01

Table 5.29 Cotton yield reduction and money ($) lost in different areas under different patterns of clogging at 7% up-slope.

Area (ha)	Yield reduc. Stage 1 (ton)	Yield reduc. Stage 2 (ton)	Yield reduc. Stage 3 (ton)	Yield reduc. Stage 4 (ton)	Yield reduc. Stage 5 (ton)	Yield reduc. Stage 6 (ton)	Yield reduc. Stage 7 (ton)	Yield reduc. Stage 8 (ton)
1	0.015	0.072	0.092	0.099	0.097	0.071	0.049	0.037
10	0.149	0.720	0.921	0.995	0.974	0.709	0.488	0.374
100	1.487	7.197	9.210	9.946	9.738	7.093	4.883	3.745
1000	14.867	71.967	92.104	99.463	97.379	70.930	48.832	37.449
10000	148.674	719.667	921.036	994.633	973.793	709.305	488.32	374.49
Area (ha)	**$Lost per area Stage 1**	**$Lost per area Stage 2**	**$Lost per area Stage 3**	**$Lost per area Stage 4**	**$Lost per area Stage 5**	**$Lost per area Stage 6**	**$Lost per area Stage 7**	**$Lost per area Stage 8**
1	19.4	93.8	120.1	129.7	127.0	92.5	63.7	48.8
10	193.9	938.4	1201.0	1297.0	1269.8	924.9	636.8	488.3
100	1938.7	9384.5	12010.3	12970.0	12698	9249	6368	4883
1000	19387.0	93845	120103	129700	126983	92493	63678	48834
10000	193870	938446	1201031	1297002	1269826	924933	636775	488336

Table 5.30 Reduction in cotton yield (ton/Area)under different number of clogged emitters randomly located along the lateral (7% up-slope).

# of clogged emitters(%)	Area(ha) 1	Area(ha) 10	Area(ha) 100	Area(ha) 1000	Area(ha) 10000
5	0.0374	0.3745	3.7449	37.4490	374.49
10	0.0488	0.4883	4.8832	48.8325	488.32
20	0.0709	0.7093	7.0930	70.9305	709.30
30	0.0974	0.9738	9.7379	97.3793	973.79

- 3% down-slope :

$$Y_R = \left(0.0146C^3 - 0.8325C^2 + 15.782C - 17.563\right)A \qquad 5.16$$

- 3% up-slope :

$$Y_R = (0.009C^3 - 0.3254C^2 + 4.6588C + 27.628)A \qquad 5.17$$

- 7% down-slope :

$$Y_R = \left(0.0105C^3 - 0.4813C^2 + 7.5483C + 24.395\right)A \qquad 5.18$$

- 7% up-slope :

$$Y_R = \left(0.001C^3 - 0.0412C^2 + 2.7106C + 24.794\right)A \qquad 5.19$$

where Y_R is the yield reduction in Kg and A is the area in ha. For example, 25% of clogged emitters along a lateral will reduce the cotton yield by about 81.6 and 84.8 kg/ha at 3% up and down-slopes and 82.4 and 76.5 kg/ha at 7% up- and down-slopes (equations 5.16 to 5.19). Money lost per area due to emitter clogging can be interpreted as well as reduction in cotton yield in different slopes under different patterns of clogging. Based on the experimetal results and different factors affecting the hydraulic characteristics of lateral in different stages and slopes, it is found that stages 4 and 5 represented the worst conditions in all different slopes affecting cotton yield. Based on the field and synthetic data, the number and location of clogged emitters were the major factors affecting the cotton yield and money lost. The slopes of lateral have little impact on cotton yield under the conditions studied.

5.8.2.15 Relationship between random clogging and hydraulic parameters:

In this section, the effects of different percentages of *randomly clogged emitters* at five different slopes on hydraulic parameters are discussed. The number of partially clogged emitters is expressed as the percentage of the total number of emitters (PN) along the lateral. Tables 5.31 and 5.32 show the values of H_f, H_{var}, and q_{var}, in flat, 3%, and 7% up- and down-slopes under five different patterns of PN (0%, 5%, 10%, 20%, and 30%) *randomly* located along the lateral. Results show that as the pressure variation increases, the emitter flow variation also increases. They also show that the pressure and emitter flow variations

Table 5.31 Reduction or increment of head loss, pressure, and emitter flow variations due to emitter clogging at different slopes (field data).

Field Results															
	0% Slope (Flat Terrain)			3% Down-slope			3% Up-slope			7% Down-slope			7% Up-slope		
Percent # of clogging	Hf (Meter)	Hvar (%)	qvar (%)	Hf (Meter)	Hvar (%)	qvar (%)	Hf (Meter)	Hvar (%)	qvar (%)	Hf (Meter)	Hvar (%)	qvar (%)	Hf (Meter)	Hvar (%)	qvar (%)
0	0.0132	0.1250	0.0095	0.0129	5.2668	0.4087	0.0143	5.8172	0.4527	0.0136	11.6055	0.9295	0.0147	13.397	1.0830
5	0.0119	0.1129	0.0085	0.0119	5.2755	0.4094	0.0123	5.7987	0.4512	0.0119	11.6179	0.9305	0.0127	13.378	1.0813
10	0.0108	0.1022	0.0077	0.0111	5.2819	0.4099	0.0128	5.8030	0.4515	0.0112	11.6232	0.9310	0.0129	13.380	1.0814
20	0.0110	0.1040	0.0079	0.0102	5.2900	0.4106	0.0121	5.7962	0.4510	0.0109	11.6255	0.9312	0.0118	13.370	1.0806
30	0.0098	0.0927	0.0070	0.0094	5.2964	0.4111	0.0096	5.7731	0.4491	0.0091	11.6384	0.9323	0.0105	13.357	1.0794
Reduction(-) or increment(+) due to clogging on 0% Slope (Flat Terrain)				Reduction(-) or increment(+) du clogging on 3% Down-slope			Reduction(-) or increment(+) due to clogging on 3% Up-slope			Reduction(-) or increment(+) due to clogging on 7% Down-slope			Reduction(-) or increment(+) due to clogging on 7% Up-slope		
Percent # of clogging	Hf_{Ri} (%)	$Hvar_{Ri}$ (%)	$qvar_{Ri}$ (%)	Hf_{Ri} (%)	$Hvar_{Ri}$ (%)	$qvar_{Ri}$ (%)	Hf_{Ri} (%)	$Hvar_{Ri}$ (%)	$qvar_{Ri}$ (%)	Hf_{Ri} (%)	$Hvar_{Ri}$ (%)	$qvar_{Ri}$ (%)	Hf_{Ri} (%)	$Hvar_{Ri}$ (%)	$qvar_{Ri}$ (%)
5	-9.723	-9.723	-9.728	-7.939	0.165	0.169	-13.669	-0.318	-0.327	-12.325	0.106	0.113	-13.728	-0.143	-0.153
10	-18.224	-18.224	-18.233	-13.792	0.287	0.294	-10.545	-0.245	-0.252	-17.626	0.152	0.161	-12.635	-0.132	-0.141
20	-16.807	-16.807	-16.815	-21.116	0.440	0.451	-15.533	-0.362	-0.372	-19.885	0.172	0.182	-19.809	-0.207	-0.221
30	-25.845	-25.845	-25.857	-26.982	0.562	0.576	-32.565	-0.758	-0.779	-32.835	0.284	0.300	-29.068	-0.303	-0.324

Table 5.32 Reduction or increment of head loss, pressure, and emitter flow variations due to emitter clogging at different slopes (synthetic data).

Synthetic Results															
	0% Slope (Flat Terrain)			3% Down-slope			3% Up-slope			7% Down-slope			7% Up-slope		
Percent # of clogging	Hf (Meter)	Hvar (%)	qvar (%)	Hf (Meter)	Hvar (%)	qvar (%)	Hf (Meter)	Hvar (%)	qvar (%)	Hf (Meter)	Hvar (%)	qvar (%)	Hf (Meter)	Hvar (%)	qvar (%)
0	0.0139	0.1319	0.0100	0.0141	5.2565	0.4079	0.0139	5.8131	0.4523	0.0141	11.6013	0.9291	0.0138	13.388	1.0821
5	0.0123	0.1161	0.0088	0.0127	5.2686	0.4089	0.0124	5.7994	0.4512	0.0125	11.6136	0.9302	0.0126	13.377	1.0812
10	0.0122	0.1156	0.0088	0.0122	5.2729	0.4092	0.0125	5.8002	0.4513	0.0123	11.6149	0.9303	0.0124	13.375	1.0810
20	0.0117	0.1112	0.0084	0.0111	5.2820	0.4100	0.0117	5.7922	0.4507	0.0117	11.6190	0.9306	0.0112	13.364	1.0800
30	0.0105	0.0992	0.0075	0.0103	5.2893	0.4105	0.0093	5.7697	0.4489	0.0098	11.6331	0.9318	0.0099	13.351	1.0790
Reduction(-) or increment(+) due to clogging on 0% Slope (Flat Terrain)				Reduction(-) or increment(+) du clogging on 3% Down-slope			Reduction(-) or increment(+) due clogging on 3% Up-slope			Reduction(-) or increment(+) due clogging on 7% Down-slope			Reduction(-) or increment(+) due to clogging on 7% Up-slope		
Percent # of clogging	Hf_{Ri} (%)	$Hvar_{Ri}$ (%)	$qvar_{Ri}$ (%)	Hf_{Ri} (%)	$Hvar_{Ri}$ (%)	$qvar_{Ri}$ (%)	Hf_{Ri} (%)	$Hvar_{Ri}$ (%)	$qvar_{Ri}$ (%)	Hf_{Ri} (%)	$Hvar_{Ri}$ (%)	$qvar_{Ri}$ (%)	Hf_{Ri} (%)	$Hvar_{Ri}$ (%)	$qvar_{Ri}$ (%)
5	-12.002	-12.002	-12.009	-10.068	0.230	0.236	-10.427	-0.235	-0.242	-11.759	0.106	0.112	-8.503	-0.083	-0.088
10	-12.415	-12.415	-12.422	-13.715	0.313	0.321	-9.786	-0.221	-0.227	-13.038	0.117	0.124	-9.987	-0.097	-0.104
20	-15.705	-15.705	-15.713	-21.281	0.486	0.498	-15.867	-0.358	-0.368	-16.906	0.152	0.161	-18.56	-0.181	-0.193
30	-24.847	-24.847	-24.858	-27.321	0.624	0.640	-33.062	-0.747	-0.767	-30.474	0.274	0.291	-28.21	-0.275	-0.294

increased with the increase in the degree of slopes. In the down-slope case, the H_{var} and q_{var} increased as PN increased. A reverse trend was found in up-slope conditions. The variation of H_f in different slopes was mainly influenced by the number of clogged emitters. Although the values of H_f in up-slopes were greater than in down-slopes, the differences in H_f under each pattern of PN in up-slopes and down-slopes were not significant.

The aim of this part of study was to find out how *emitter clogging* effects H_f, H_{var}, and q_{var} at different slopes. It was also to find the relationships between the reduction in *CU*, *EU'*, and *DU* and the different numbers of random clogged emitters along the lateral. To assess and evaluate this impact, based on values obtained for H_f, H_{var}, and q_{var}, under *no-clogged* (0% clogging) and *clogged* situations at different slopes, the percentage of differences of these values were determined. When the values of H_f, H_{var}, and q_{var} under *no-clogged* condition were calculated, any reduction or increment of these values in clogged situations are related to emitter clogging when other factors such as manufacturer's variation, slopes and water temperature are similar to no-clogged situation. Tables 5.31 and 5.32 summarize the field and synthetic data of reduction (*negative values*) and increment (*positive values*) of H_f, H_{var}, and q_{var} at different slopes. These results show the variation of H_f, H_{var}, and q_{var} in different PN when compared to those in the no-clogged situation. Figure 5.34 shows the relationship between the head loss, pressure variations and different patterns of PN. Figure 5.34 shows the maximum H_f occurs under a no-clogged situation. The H_f decreased as the number of clogged emitters increased along the lateral. Figure 5.35 shows the reduction of head loss (H_{fR}), reduction or increment of pressure variation ($H_{var(Ri)}$), and the reduction or increment of emitter flow variation ($q_{var(Ri)}$) under different PN. Figure 5.35 shows that the H_f decreased from -8% in stage 8 (5% clogging) to -36% when the number of randomly clogged emitters was 30% (stage 5). Figure 5.35 also shows two different trends for $H_{var(Ri)}$ and $q_{var(Ri)}$ in up-slope and down-slope conditions. In the down-slope case, the values of H_{var} and q_{var} under randomly clogged conditions were greater than in the no-clogged situation. Both $H_{var(Ri)}$ and $q_{var(Ri)}$ in down-slope conditions increased as the PN increased. However the values decreased as the PN increased in up-slope cases. The values of H_{var} and q_{var} in up-slopes were greater than those values obtained from the down-slopes.

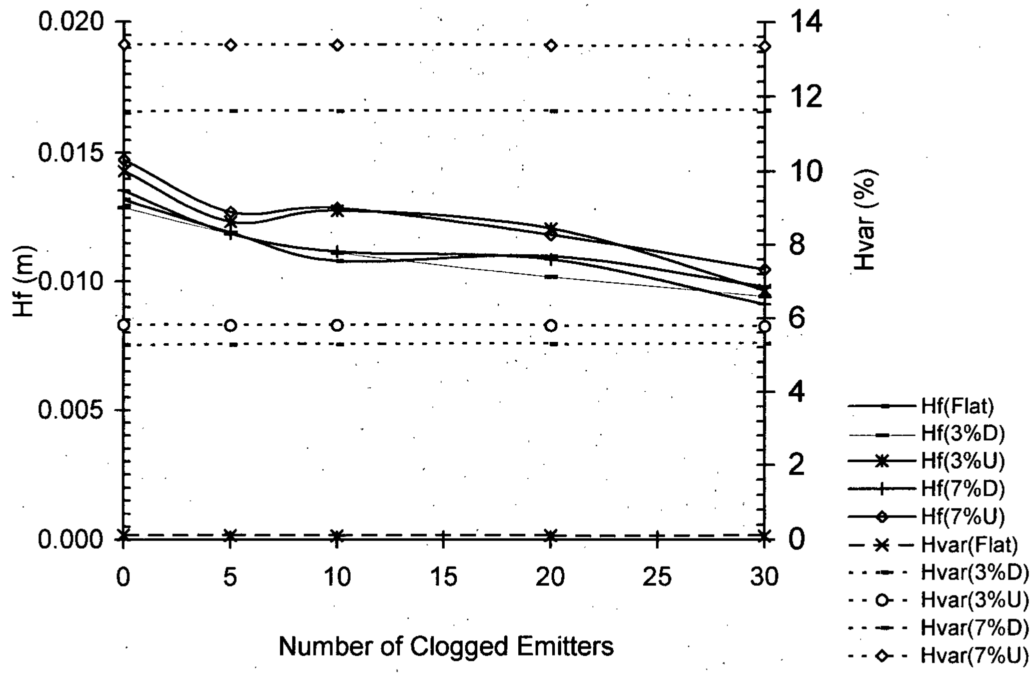


Figure 5.34 Relationship between head loss and pressure variation versus different number of clogged emitters randomly located along the lateral (field data)

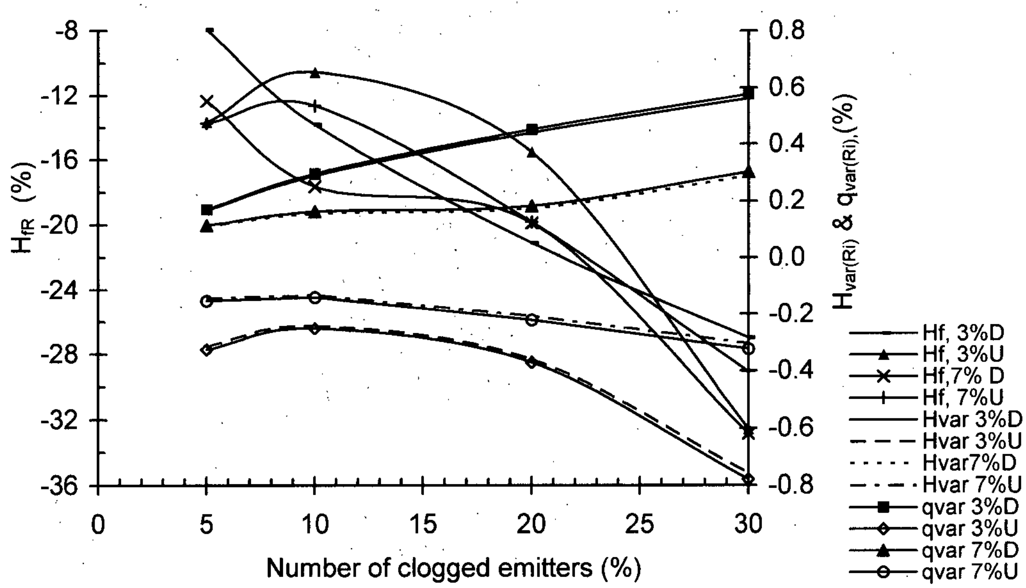


Figure 5.35 Relationship between the reductions in head loss, pressure and emitter flow variation versus different number of clogged emitters randomly located along the lateral (field data).

Theoretically, the value of 100% for *CU, DU,* and *EU'* can be expected under the ideal condition. However, this ideal condition never occurs. Tables 5.33 and 5.34 show the *reduction* in coefficient of uniformity (CU_R), *reduction* in field emission uniformity (EU'_R), and *reduction* in distribution uniformity (DU_R) due to the randomly clogged emitters. The reduction is defined in such a way that all values of *CU, EU'* and *DU* in randomly clogged conditions were compared to those values in no-clogged situations. Assuming that the values of *CU* under no-clogged and clogged conditions are X and X' respectively, the reduction of *CU* (CU_R) is determined as: $CU_R = [(X-X')/X]100$. For example, the values of *CU* under no-clogged and 5% clogged conditions were 96.26% and 94.61% (Table 5.9) respectively on flat terrain. Based on above definition, the CU_R under 5% clogging is determined equal to 1.71%. A similar calculation as defined for CU_R was used for DU_R and EU'_R. Tables 5.33 and 5.34 show that in the no-clogged condition the reduction of *CU, EU'* and *DU* due to the clogging were zero at different slopes. All of these uniformities decreased as soon as the number of clogged emitters occurred along the lateral. Results also show that the uniformity in down-slopes was greater than in the up-slopes, but the rate of reduction of the uniformities due to clogging were higher in down-slopes than that in the up-slopes (Table 5.33). For example the values of CU_R were 4.09% and 30.96% under 5% and 30% clogging situations in a 7% up-slope, and were 8.04% and 43.11% in a 7% down-slope. One of the reasons for this was the reduction in H_{var} and q_{var} in up-slopes and increment in H_{var} and q_{var} in down-slopes with respect to the increment in PN. The relationship between CU_R, EU'_R, and DU_R obtained from field and synthetic data and the different random numbers of clogged emitters were plotted and least-regression equations were determined (Figures 5.36 to 5.41). Results indicated that when the number of partially clogged emitters is expressed as the percentage of the total number of emitters along the lateral, the following three findings are reached: (1) The coefficient of uniformity decreased by about 0.9 to 1.3 times the *C%* (percentage number of clogged emitters), (2) the reduction of the field emission uniformity varied by 1.7 to 2.4 times the *C%,* and (3) the reduction of distribution uniformity is about 1.5 to 2.1 times the *C%.*

Table 5.33 Reduction in CU, EU', and DU due to random number of clogged emitters along a lateral (Field data).

Field Data					
Reduction in coefficient of uniformity (CU_R in %)					
# of clogging	0% Flat	3% D-slope	3% U-slope	7% D-slope	7% U-slope
0	0.00	0.00	0.00	0.00	0.00
5	1.71	5.64	5.15	8.04	4.09
10	9.07	15.63	9.45	13.84	8.62
20	15.06	24.63	16.32	21.49	19.38
30	27.87	35.02	39.50	43.11	30.96
Reduction in field emission uniformity (EU'_R in %)					
0	0.00	0.00	0.00	0.00	0.00
5	5.62	13.02	11.73	17.02	9.74
10	18.70	30.69	19.91	28.44	18.82
20	31.83	50.38	33.78	43.70	39.88
30	53.80	65.11	78.99	77.96	60.23
Reduction in distribution uniformity (DU_R in %)					
0	0.00	0.00	0.00	0.00	0.00
5	2.78	9.10	8.34	12.95	6.65
10	14.75	25.21	15.32	22.29	14.01
20	24.50	39.73	26.46	34.62	31.51
30	45.35	56.49	64.02	69.43	50.34

Table 5.34 Reduction in CU, EU', and DU due to random number of clogged emitters along a lateral (Synthetic data).

Synthetic data same as field data					
Reduction in coefficient of uniformity (CU_R in %)					
# of clogging	0% Flat	3% D-slope	3% U-slope	7% D-slope	7% U-slope
0	0.00	0.00	0.00	0.00	0.00
5	8.24	6.60	6.90	8.04	5.29
10	12.10	15.29	11.37	14.92	10.34
20	18.27	26.14	18.02	23.05	21.57
30	31.13	36.83	40.80	44.39	32.63
Reduction in field emission uniformity (EU'_R in %)					
0	0.00	0.00	0.00	0.00	0.00
5	14.42	11.83	12.32	14.10	9.83
10	21.50	26.87	20.31	26.24	18.68
20	35.27	50.13	34.83	44.30	41.64
30	57.62	67.00	79.97	78.39	62.00
Reduction in distribution uniformity (DU_R in %)					
0%	0.00	0.00	0.00	0.00	0.00
5	13.18	10.56	11.03	12.87	8.47
10	19.37	24.46	18.19	23.87	16.54
20	29.24	41.82	28.83	36.89	34.52
30	49.81	58.93	65.29	71.02	52.22

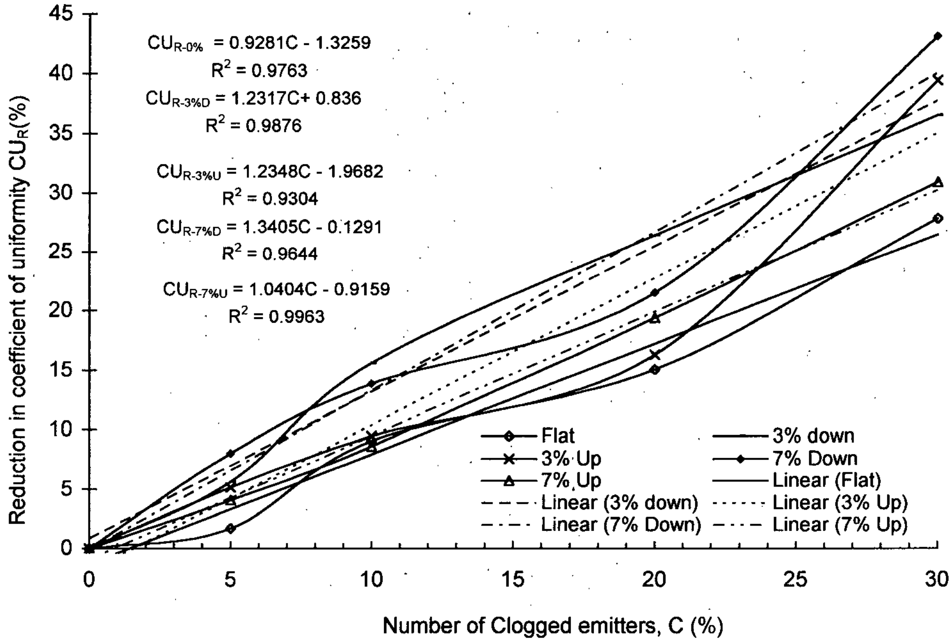


Figure 5.36 Relationship between number of clogged emitters (%) and reduction in coefficient of uniformity (Field Data)

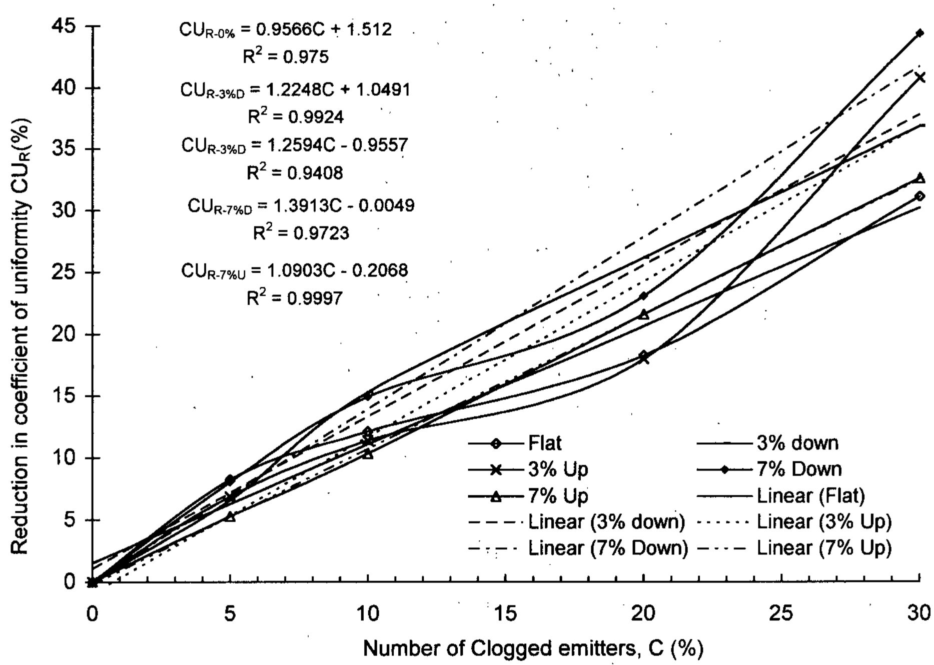


Figure 5.37 Relationship between number of clogged emitters (%) and reduction in coefficient of uniformity (Synthetic Data)

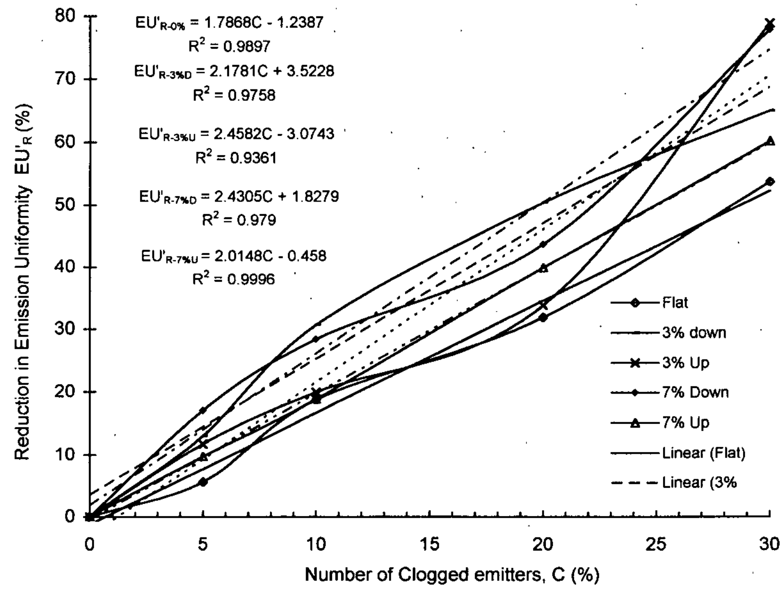


Figure 5.38 Relationship between number of clogged emitters (%) and reduction in Emission Uniformity (Field Data)

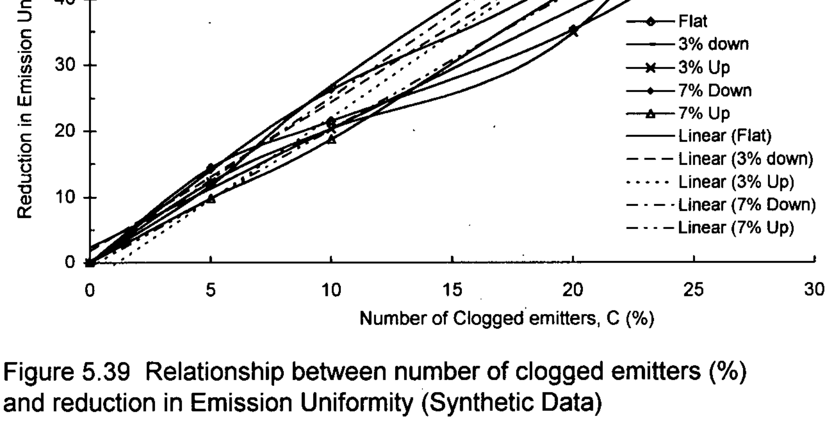


Figure 5.39 Relationship between number of clogged emitters (%) and reduction in Emission Uniformity (Synthetic Data)

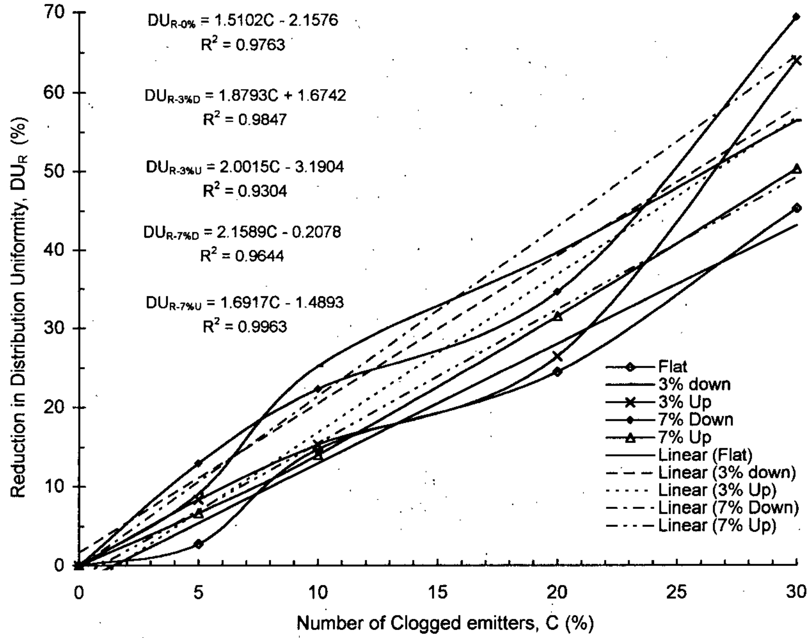


Figure 5.40 Relationship between number of clogged emitters (%) and reduction in distribution uniformity (field data).

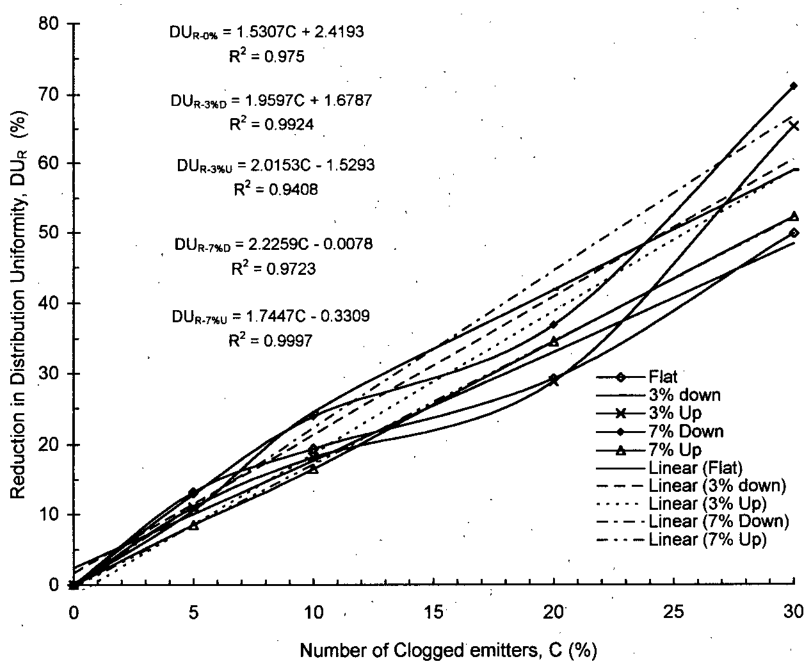


Figure 5.41 Relationship between number of clogged emitters (%) and reduction in distribution uniformity (synthetic data).

5.8.3 Step 3 hydraulic characteristics of lateral under naturally clogged emitters, venturi injector, and injection of saline water:

In step 3 the field experiment was carried out to evaluate the effects of naturally clogged emitters (discussed in Chapter 4), the use of the venturi injector, and the injection of saline water (representing a nutrient liquid) on the hydraulics of microirrigation laterals (20m and 40m) laid on flat terrain.The following sections present the findings:

5.8.3.1 Natural clogging and its relationship to *CU:*

The minimum and maximum emitter flow rates were found to be 3.4 *l/h* and 4.98 *l/h* under no-clogged condition on flat terrain. Based on a nominal emitter flow rate of 3.78 *l/h* reported by the manufacturer, the variations of -10% to +30% were observed in emitter discharge in a no-clogged situation. Tables A.5.22 to A.5.25 (Appendix A) show the average of emitter flow rates obtained from the measurements of four replications along the 20m and 40m laterals consisting of naturally clogged emitters. As shown in Figures 5.42 and 5.43, it was found that emitter numbers 2, 10, 13, and 17 along the 20 m lateral and numbers 1, 10, 13, 21, 24, and 28 along the 40m lateral were partially clogged. Results indicated that the naturally clogged emitters were randomly located along the lateral. These emitters were inspected and revealed some slime, insect feathers and some fine sand inside the emitters. Because of the irregular shape and structure of the waterpassage way of the pressure-compensating emitter, it was not possible to measure the cross section area of the emitter and relate the portion of clogged area to the degree of clogging. Therfore, equation 5.7 was used to estimate the percentage degree of emitter clogging. Table 5.35 shows the discharge and degree of clogging (C_d%) under naturally clogged emitters along the lateral. Similar computations as for step 1 were done for stages 5 and 6 (similar patterns as in natural clogging) with *artificially* clogged emitters in the 20m lateral. The degrees of clogging for artificially clogged emitters are shown in Table 5.35. The cumulative percentage of clogging or the total percentage of clogging (*TC%*) for 20m and 40m laterals was determined by adding the degrees of clogged emitters along the lateral. The values of *TC%* obtained from natural clogging were 50.95% and 154.18% for 20m and 40m laterals respectively. Then, the average degree of clogging along the lateral was determined as: average $C_d = TC\%/n$,where *n*

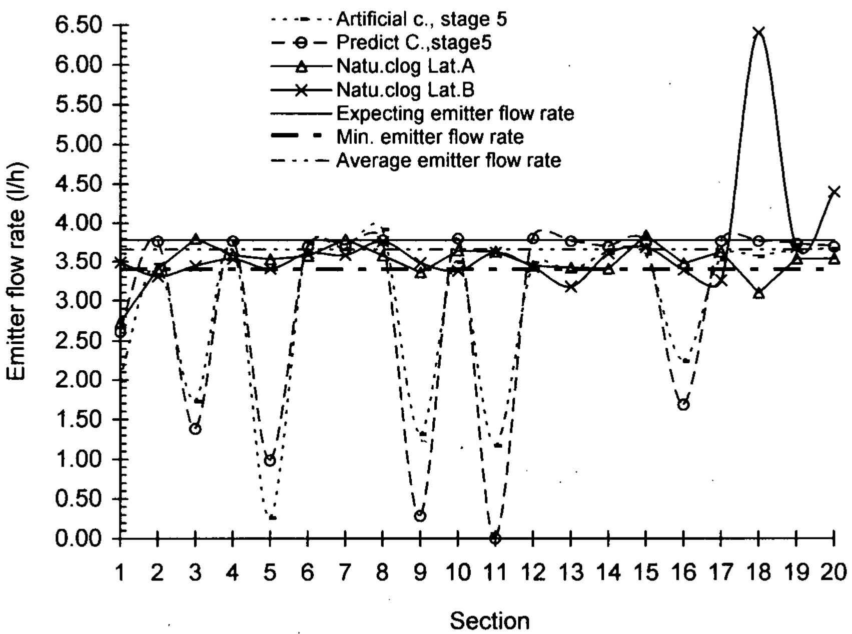


Figure 5.42 Emitter flow rate along a 20m lateral laid on flat terrain under naturally, artificially, and synthetically emitter clogged conditions.

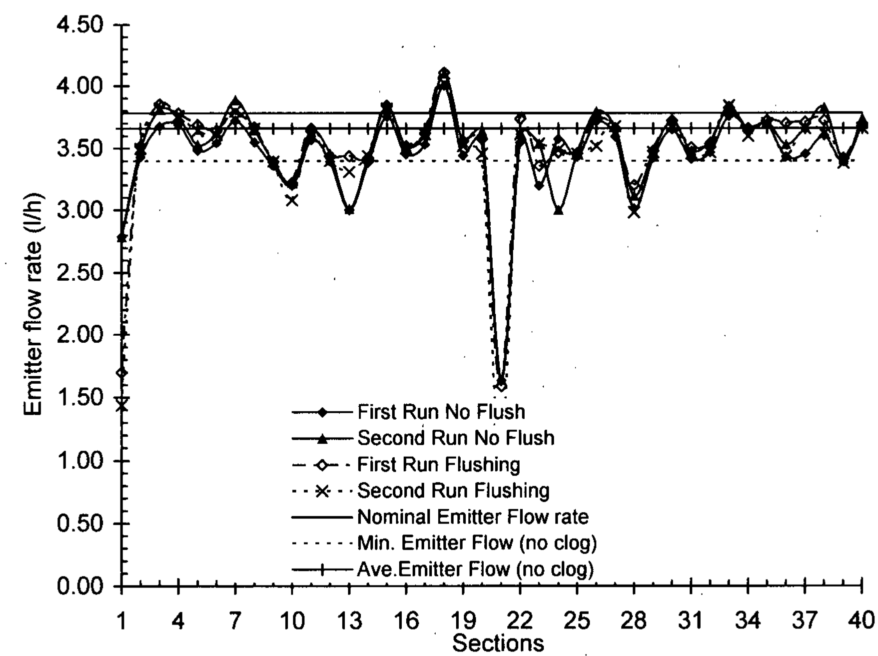


Figure 5.43 Emitter flow rate along a 40m lateral laid on flat terrain under naturally emitter clogged condition (before and after flushing).

Table 5.35 Degree of clogging (C_d%) and coefficient of uniformity obtained from naturally and artificially clogged emitters along a 20 and 40 meter laterals (flat terrain)

Naturally clogged emitters randomly located along the 40m lateral 'with different degree of clogging (laid on flat terrain)					**Artificially clogged emitters, (30%,R,DC) in 20 m lateral B laid on flat terrain (from step-1)**				
Number of Clogged Emitter	Emitter #	Emitter Flow rate *(l/h)*	Degree of Clogging C_d%	Cumulative Percent of Clogging (TC%)	Number of Clogged Emitter	Emitter #	Emitter Flow rate *(l/h)*	Degree of Clogging C_d%	Cumulative Percent of Clogging (TC%)
1	**1**	2.79	25.83	**25.83**	1	**1**	1.99	47.10	**47.10**
2	**10**	3.22	14.40	**40.23**	2	**3**	1.72	54.28	**101.37**
3	**13**	3.01	19.98	**60.21**	3	**5**	0.26	93.09	**194.47**
4	**21**	1.64	56.40	**116.61**	4	**9**	1.32	64.91	**259.38**
5	**24**	3.00	20.25	**136.86**	5	**11**	1.17	68.90	**328.28**
6	**28**	3.11	17.32	**154.18**	6	**16**	2.24	40.45	**368.73**
CU = 93.2%			**Ave.C_d%=3.85**		**CU = 69.44%**			**Ave.C_d%=18.43**	
Naturally clogged emitters randomly located along the lateral B (20m) with different degree of clogging (laid on flat terrain)					**Artificially clogged emitters, (20%,R,DC) in 20 m lateral B laid on flat terrain(from step-1)**				
Number of Clogged Emitter	Emitter #	Emitter Flow rate *(l/h)*	Degree of Clogging C_d%	Cumulative Percent of Clogging (TC%)	Number of Clogged Emitter	Emitter #	Emitter Flow rate *(l/h)*	Degree of Clogging C_d%	Cumulative Percent of Clogging (TC%)
1	**2**	3.31	12.01	**12.01**	1	**3**	1.92	48.96	**48.96**
2	**10**	3.38	10.14	**22.15**	2	**6**	1.03	72.62	**121.58**
3	**13**	3.18	15.46	**37.61**	3	**8**	3.19	15.20	**136.78**
4	**17**	3.26	13.34	**50.95**	4	**12**	0.92	75.54	**212.32**
CU = 90.43%			**Ave.C_d%=2.54**		**CU = 81.77%**			**Ave.C_d%=10.61**	
Natural CU= 93.2% (in 40 m) Artificial CU = 69.44% (in 20 m)					Natural CU = 90.43% (in 20 m) Artificial CU = 81.77% (in 20 m)				
Total Degree (%) of Naturally Clogging = 154.18% (in 40 m) Total Degree (%) of Artificially Cloging = 368.73% (in 20 m)					Total degree (%) of Naturally Clogging = 50.95% (in 20m) Total Degree (%) of Artificially Cloging = 212.32% (in 20m)				

is the total number of emitters along the lateral. The coefficient of uniformity, *CU*, was also determined for the 20m and 40m laterals under naturally and artificially clogged emitters. Table 5.35 presents the values of *CU*, *TC%*, and the average degree of clogging obtained from natural and artificial clogged emitters. The relationships between *CU* and average C_d% were plotted (Figure 5.44-a) and a regression equation was found as follows:

$$CU = -1.4333C_d + 96.383 \qquad 5.20$$

A similar analysis was made on synthetic data using the computer simulation program. In the simulation, it was assumed that 10%, 20%, 30%, 40%, ...and 100% of the number of emitters along the lateral were partially clogged. Table A.5.26 (Appendix A) shows the values of *CU* and C_d% under different numbers and degrees of clogged emitters obtained from synthetic data. The relationships between *CU* and the average C_d% were then plotted (Figure 5.44-b) and a regression equation was found:

$$CU = -0.9135C_d + 87.509 \qquad 5.21$$

The values of *CU* and the average C_d% obtained from natural, artificial, and synthetic data of clogged emitters were then combined (Table A.5.27) and plotted (Figure 5.44-c). A regression equation from the combination of data was obtained as follows:

$$CU = -1.0453C_d + 96.26 \qquad 5.22$$

The results of equation 5.22 are considered the most accurate, since a combination of data were used. *CU* can be estimated by using equation 5.22 if the average degree of clogging along the laterals is known. The equation accounts for any type of emitter clogging (uniform or non-uniform) along the lateral when evaluating *CU*. Equation 5.22 shows that the value of *CU* can be as high as 96.26% if there are no-clogged emitters along the lateral (C_d =0). Equation 5.22 indicates that any degree of emitter clogging along the lateral will reduce the

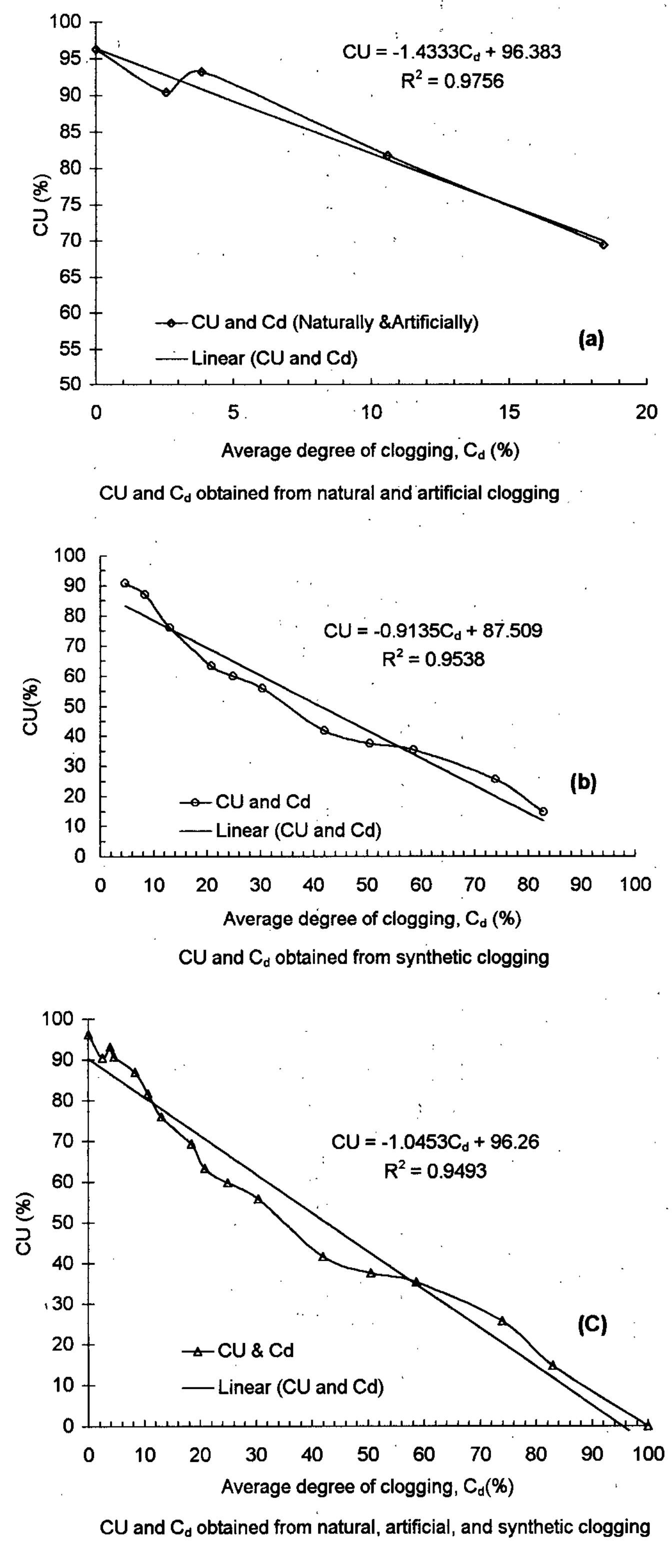


Figure 5.44 Relationship between coefficient of uniformity (CU) and average degree of emitter clogging (C_d) along the lateral

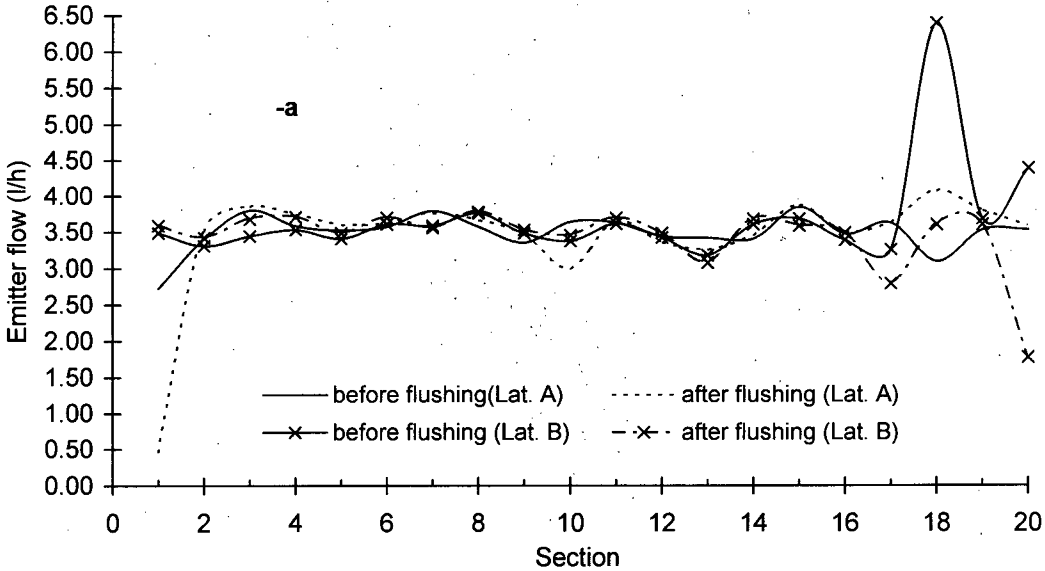
CU of the system. The maximum value of C_d in equation 5.22 can be 92% which results almost 0% coefficient of uniformity.

5.8.3.2 Impact of lateral flushing on emitter flow rate:

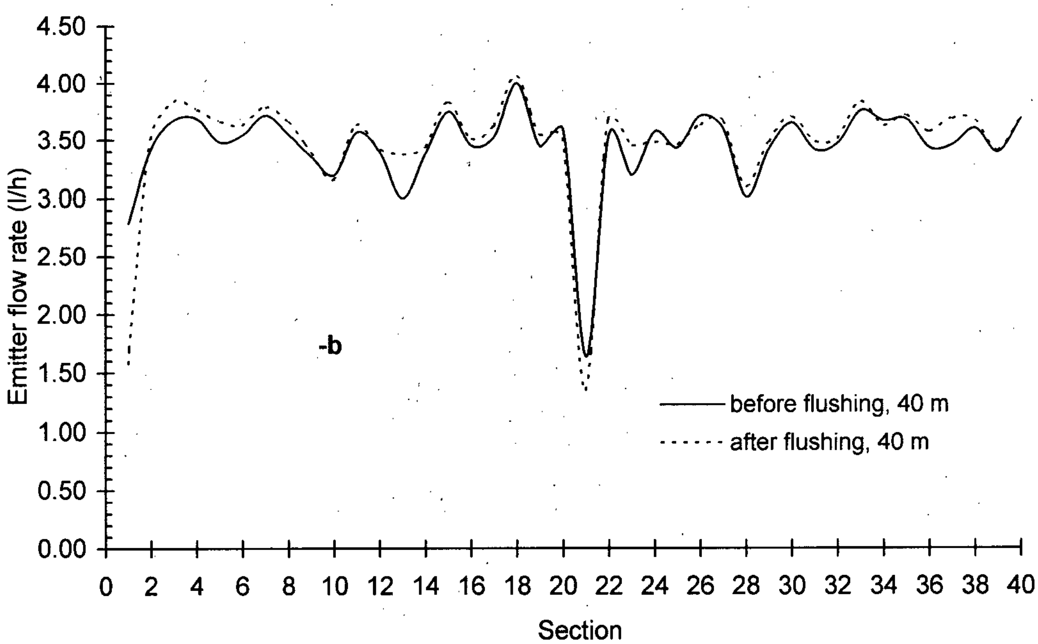
The effects of lateral flushing on emitter flow rates along the 20m and 40m laterals with naturally clogged emitters were evaluated. The emitter flow rates were measured in four replications and the average of emitter discharges was determined. Tables A.5.28 to A.5.30 (Appendix A) show the emitter discharge at four runs and the average emitter flow rate after 30 minutes of lateral flushing. The plots of emitter discharges obtained before and after flushing the laterals (Tables A.5.22 to A.5.25), and the emitter number along the lateral are shown in Figure 5.45 a and b. Results show that 30 minutes of lateral flushing increased the flow rate for most of the emitters along the lateral. A few emitters such as emitters number 1 and 10 in lateral A, numbers 17 and 20 in lateral B, and numbers 1 and 21 in the 40m lateral had reduced discharges after flushing. Figures 5.45 a and b show that the flow from emitter number 1 decreased from 2.73 *l/h* to 0.45 *l/h,* number 18 from 6.41 *l/h* to 3.61 *l/h*, number 20 from 4.4 *l/h* to 1.78 *l/h* in the 20m lateral and emitter number 1 decreased from 2.79 *l/h* to 1.57 *l/h* in the 40m lateral. Other studies (see chapter 2) suggested that flushing of the lateral improved the emitter discharge. This study shows that both increase and decrease in emitter flow rates occurred after flushing. It should be noted that flushing the lateral improves the flow rate of *most* of the emitters along the lateral.

5.8.3.3 Effect of temperature on emitter flow rate

The effects of air and water temperatures on the emitter flow rates along the lateral with naturally clogged emitters were investigated. The microirrigation system was operated at different temperatures and at different times. Different conditions including sunny and cloudy conditions, after sunset, and immediately after sunrise were chosen. Tables A.5.31 and A.5.32 show the average emitter discharges along the lateral A and B under the conditions. The maximum and minimum air temperatures were 21.8°C and 15.5°C during the study. The maximum and minimum water temperatures were 20.2°C and 14.7°C respectively. Water temperature varied along the lateral and increased as the water reached the downstream end



Emitter flow rates before and after flushing (20m lateral)

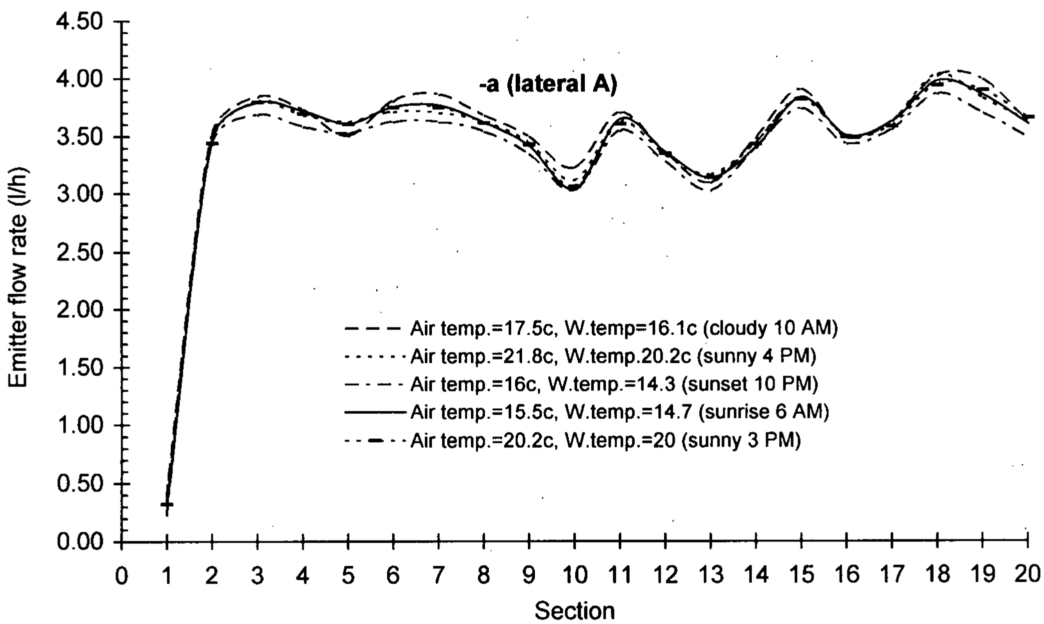


Emitter flow rates before and after flushing (40m lateral)

Figure 5.45 Effect of lateral flushing on emitter flow rate of lateral. Tables A.5.31 and A.5.32 (Appendix A) show the water temperature at the first, middle, and last sections of lateral. The maximum variation of water temperature along the lateral was 2.5°C (19°C and 21.5°C at the first and last section of lateral) and was obtained on a sunny day (Table A.5.31). Figures 5.46-a and b show the relationship between emitter flow rate and emitter number along the laterals. Results indicated that the variation in temperature at the experiment site has no significant impact on emitter flow rate. Figure 5.46 shows that the emitter discharges vary slightly in different conditions. The slight variation of emitter flow rate may be caused by the small variation in the elastomeric disk displacement of the emitter after shutting off the system. Results show that the variation in emitter flow rate at different temperatures during the day (continuously operating the system) was negligible. This is because of less change in the elastomeric disk displacement of the emitter during continuous running. This study found that the variations of air and water temperature had no significant impact on the emitter flow rate.

5.8.3.4 Comparison of hydraulic parameters under natural, artificial, and synthetic data of clogged emitters (flat terrain):

Table A.5.33 shows the values of hydraulic parameters obtained from natural, artificial (stage 5), and synthetic data (stage 5) of clogged emitters for the 20m lateral laid on flat terrain. The comparisons of coefficient of variations V_{qs}, V_{hs}, V_{qh} are shown in Figure 5.47-a, H_f in Figure 5.47-b, *CU* and *EU'* in Figure 5.47-c, and q_{var} and H_{var} in Figure 5.47-d. The values varied from one case to another, but similar trends in hydraulic variation were found among the natural, artificial and synthetic clogging. Table A.5.34 shows that although the degree of emitter clogging under naturally clogged conditions was less than the degree of emitter clogging in artificial and synthetic data, the H_{var} were higher than q_{var}, *CU* greater than *EU'*, and V_{qs} greater than V_{qh} under all conditions. The laterals flow rates were 73.66 *l/h* in laterals B under natural clogging and 59.09 *l/h* and 59.39 *l/h* under artificial and synthetic clogging. The value of *CU* was 90.43% under natural clogging, whereas it was 69.44% and 63.36% under artificial and synthetic clogging. The value of *EU'* was 89.66% under natural clogging, and 43.72% and 35.4% under artificial and synthetic clogging. The major reason for the differences in the value



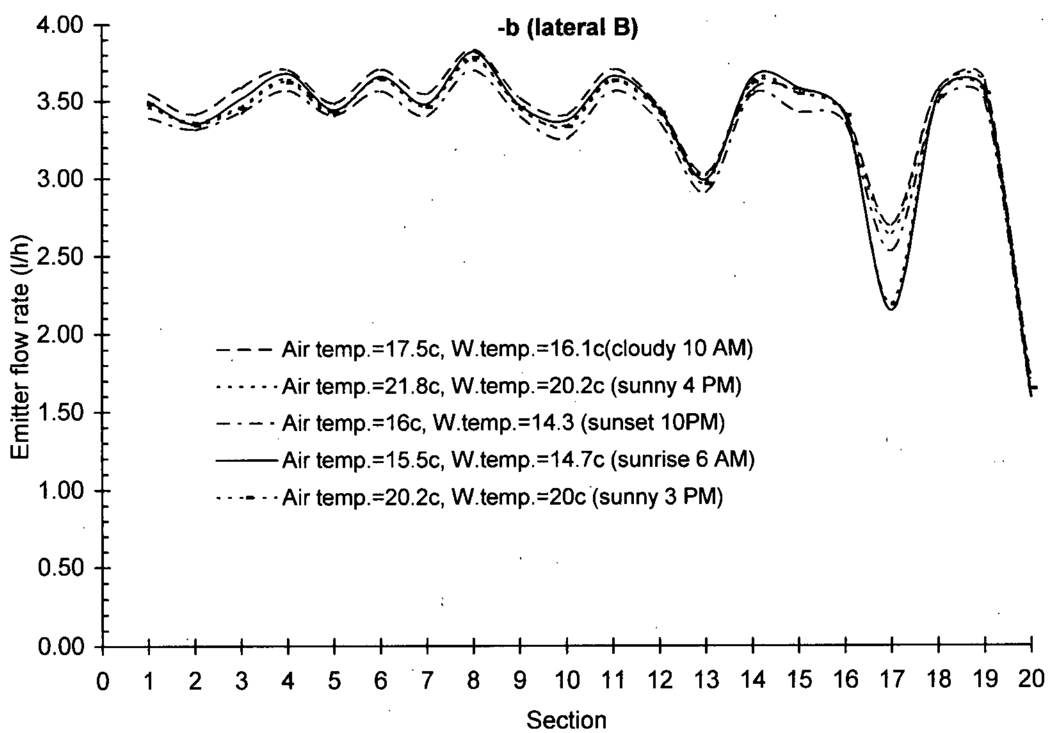


Figure 5.46 Effect of air and water temperature on emitter flow rate along the laterals A&B laid on flat terrain.

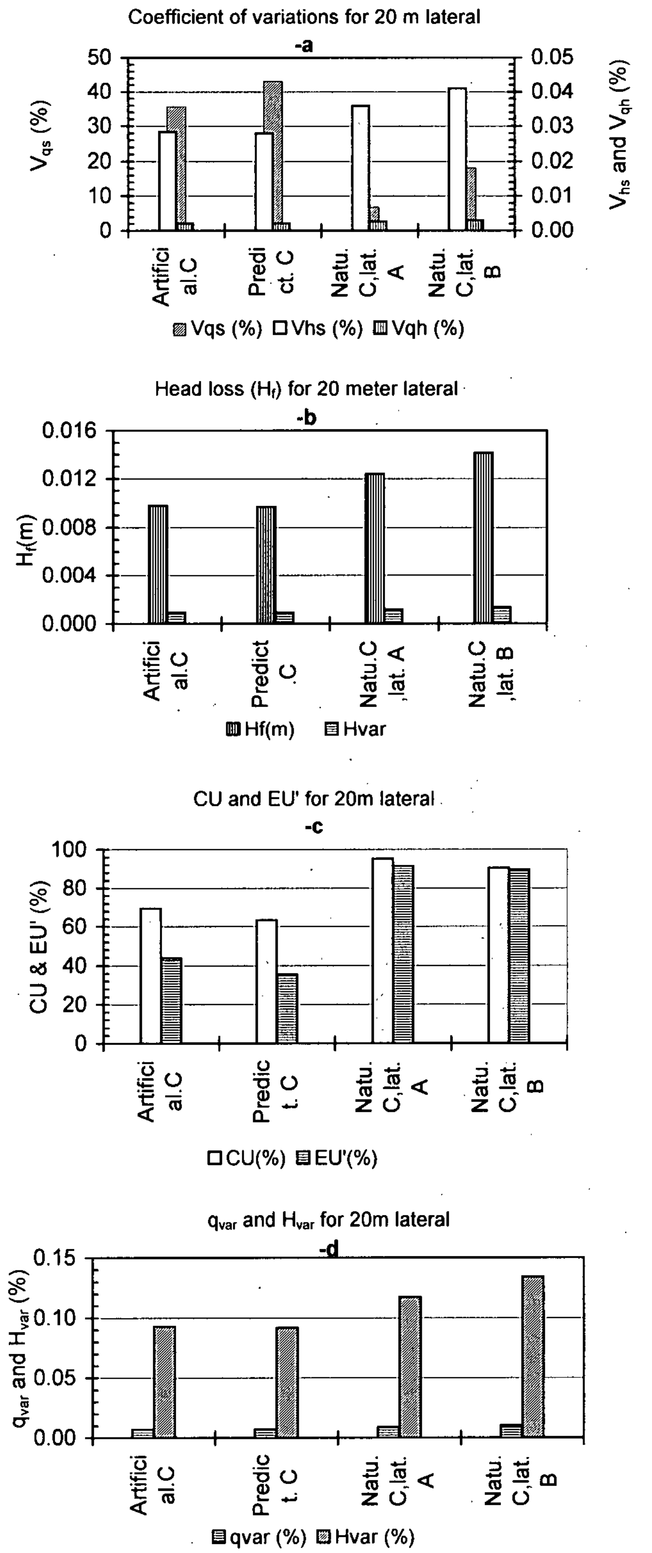


Figure 5.47 Comparison of hydraulic parameters in the microirrigation under artificially, synthetically, and naturally clogged conditions(flat terrain)

of the specific hydraulic parameter under different conditions was the difference in degree of clogged emitters, which was the uncontrollable factor.

5.8.3.5 Selection of venturi injector:

Based on the nominal emitter discharge, the maximum lateral inflow of 2.52 *l/min* was estimated for the field experiment. Different values of inlet and throat pressures for a venturi (explained in Chapter 4) were used to determine the optimum venturi *throat diameter* (d) for the experiment. Table A.5.35 (Appendix A) shows several estimated values of *throat* diameter based on the inlet and throat pressures for a 15 mm venturi inlet diameter. The minimum and maximum venturi throat diameters were found to be 0.141cm and 0.258 cm when the venturi inlet flow (motive flow) was 2.52 *l/min.* Table A.5.36 shows the values of minimum inlet flow (motive flow) for different pressures at the venturi inlet and throat. It was found that as the difference in inlet and throat pressures increased, more inlet flow (motive flow) was required to provide a vacuum (suction) condition for the venturi. Table A.5.36 also shows that the same amount of motive flow is required if the pressure differences under different inlet and throat pressures are equal. For example, when the inlet and throat pressure are 60 psi and 25 psi (35 psi difference in pressure) respectively, the required motive flow is 2.202 *l/min.* The same amount of motive flow is needed if the inlet and throat pressure are 50 psi and 15 psi (35 psi difference in pressure). Based on these results (Table A.5.36), the minimum venturi *throat diameter* of 0.141cm was chosen for this study. The smallest commercially available (for the irrigation industry) venturi injector was the Mazzei 484, 3/4″ with an injection capacity of up to 1.13 *l/min* (18 gph).

5.8.3.5.1 Calibration of Mazzei 484 venturi injector:

In order to calibrate the venturi injector and determine the required pressure difference between the inlet and outlet of the venturi, three different tests as shown in Figure 4.11 (Chapter 4) were conducted at the field experiment. City water supply was used as the injection liquid for all three tests. In the first test (Figure 4.11-a), the motive flow was adjusted to 1.26 *l/min* (equal to the amount of lateral flow consisting of 20 emitters of nominal flow of 3.78 *l/h*) under the 15 psi and 0 psi inlet and outlet pressures respectively. No liquid suction was observed at the

Table 5.36 Test of Mazzei 484 venturi injector under different pressure and motive flow (venturi inlet flow).

Test #	Pressure at venturi inlet (psi)	Pressure at venturi outlet (psi)	Motive flow (*l/min*)	Liquid suction (*l/min*)	venturi out flow (*l/min*)
1	15	0	1.26	0.00	1.26
2	60	15	1.26	0.00	1.26
	60	15	2.52	0.00	2.52
	60	15	4.53	0.46	4.98
	60	15	14.4	1.36	15.52
3	60	15	1.26	0.00	1.26
	60	15	2.52	0.00	2.52
	60	10	15.75	1.30	17.05
	30	15	11.2	0.92	12.12

throat of the venturi. Table 5.36 shows the rate of liquid injection in *l/min* applied in different tests. The second test (Figure 4.11-b) was done under 60 psi and 15 psi inlet and outlet pressures. The motive flows were adjusted to 1.26 *l/min*, 2.52 *l/min*, and 4.53 *l/min* which were the required flows in 1, 2, and 4, 20m laterals consisting of 20 emitters. There was also no liquid suction observed under 1.26 *l/min* and 2.52 *l/min* of motive flow, but the rate of liquid suction was 0.46 *l/min* when the amount of motive flow was increased to 4.53 *l/min*. Finally, the third test was done in such a way that the venturi injector was connected to the microirrigation laterals (as shown in Figure 4.11-c) and inlet and outlet pressures were adjusted to 60 psi and 15 psi. Table 5.36 shows that no liquid suction was observed when the venturi was connected to the laterals having 1.26 and 2.52 *l/min* flow rate. When the motive flow increased to 15.75 *l/min,* the pressure fell to 10 psi. The rate of liquid suction was measured as 1.3 *l/min* under this operation. Then, the inlet and outlet adjusted to 30 and 15 psi (15 psi was the required lateral inlet pressure) and the rate of liquid flow was measured. Results indicated that the minimum required motive flow for the Mazzei injector 484 when it was connected to the microirrigation system at the experimental site was about 11.2 *l/min* under 15 psi lateral inlet pressure. This amount of motive flow for this study allows the venturi injector to inject the liquid (saline water, or liquid chemical) into the microirrigation system. The following tests were carried out to investigate the effects of liquid injection on hydraulics in microirrigation laterals.

5.8.3.6 Hydraulics in lateral with venturi injector installed:

This test was done in order to find out whether the venturi injector has an impact on the emitter flow rate along the lateral and, if so, what its effect is on the uniformity. City water with an electrical conductivity (EC) of 0.022 (ds/m) was used. The test of hydraulics in laterals with a venturi injector installed was conducted on 20m and 40m laterals with naturally and no-clogged emitters. Tables A.5.37 and A.5.38 summarise the results obtained from three different runs of the microirrigation system on flat terrain. Table A.5.37 shows that in the first run (no liquid suction), the inlet lateral flow rate was adjusted to 745.9 *l/h* (12.4 *l/min*) and the pressures at the inlet and outlet of venturi were 25 psi and 15 psi respectively. The average pressure at the end of lateral was 12 psi. The reason for dropping the pressure to 12 psi was due to higher head loss resulted from increasing the lateral water flow in this test. Hydraulic parameters of *CU, EU', Ea,* q_{var}, and V_{qs} were 86.6%, 73.1%, 99.9%, 8.9×10^{-5}, and 0.242% respectively.

In the second run (injected liquid, pressure at the venturi outlet was not adjusted) the pressure at the venturi outlet dropped to 12 psi. Results in Table A.5.37 show that 96.4% of 792.98 *l/h* (13.2 *l/min*) of lateral inflow came from the main line of water supply and 3.56% from the liqiud injection tank (barrel). The values of *CU, EU', Ea,* q_{var}, and V_{qs} were 86.19%, 72.53%, 99.9%, 1.1×10^{-4}, and 0.243%.

In the third run, the pressure at the venturi outlet was increased to 15 psi (similar to the first run) by decreasing the lateral flow at the end of lateral. The *CU, EU', Ea,* q_{var}, and V_{qs} were 86.6%, 73.2%, 8.9×10^{-5}, and 0.242%. Results indicated that the values of hydraulic parameters obtained from the first and third runs were very similar. However, there were variations in the second run.

Similar tests were done on 40m laterals. For the third run, it was found that increasing the pressure at the venturi outlet by decreasing the lateral flow was not a practical concern. Therefore, on the third run of 40m lateral, the pressure at the venturi outlet was increased from 12 psi to 15 psi by increasing the venturi inlet pressure from 25 psi to 34 psi. Table A.5.38 shows the results of hydraulic parameters for 40m lateral.

Similar trends were found for 40m and 20m laterals in all three tests. Figures 5.48 a and b show the variation of emitter flow along the 20m and 40m laterals. It is shown that the emitter flow rates along the lateral in the first and third runs were similar, but varied in the second run. Table A.5.38 also shows the total emitter flow along the 40m laterals in three runs. In the second and third runs about 6.4% of the total lateral flow was provided from the liquid suction and 93.4% from the main line of water supply. Total emitter flow rates were 137.2 *l/h*, 130.3 *l/h*, and 135.3 *l/h* at the first, second, and third run respectively. The emitter discharge coefficients of variation (V_{qs}) were 19.05%, 20.7%, and 19.6% in the first, second and third run respectively.

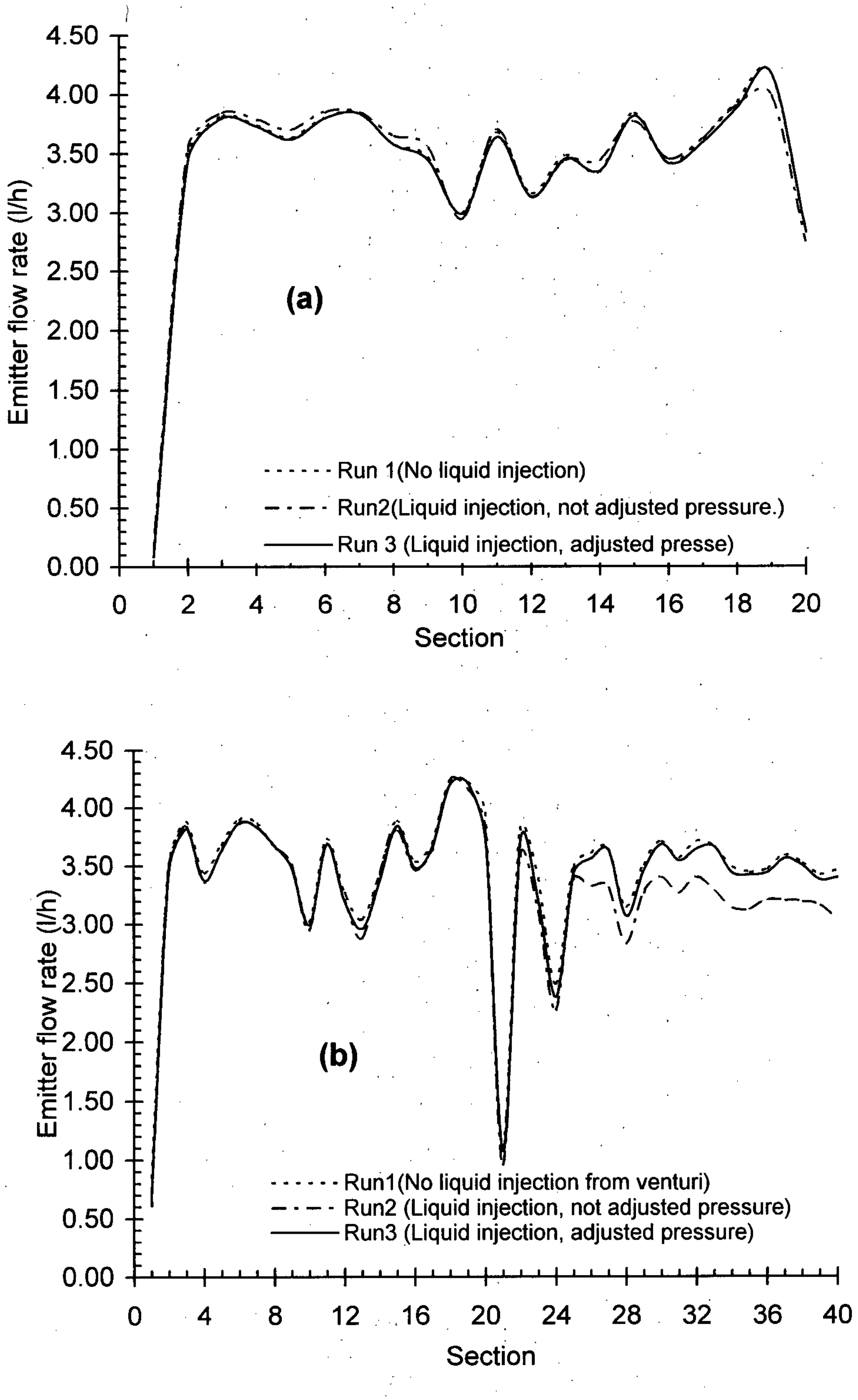


Figure 5.48 Variations of emitter flow rate along a 20m (a) and 40m (b) laterals with and without liquid injection using city water and naturally clogged emitters.

Similar tests were done on the system with the no-clogged emitters along the lateral. First, the average emitter flow rate was measured when there was no venturi injector installed in the system. Then, three runs with venturi injector similar to those in the naturally clogged condition were applied to the system. Tables A.5.39 and A.5.40 show the average emitter flow rates along the 20m and 40m laterals under *no-clogged* condition with and without venturi. The pressure variations measured at each section along the 40m laterals are also shown in Table A.5.40. The average inlet lateral pressure was 15 psi (14.5 to 15.5 psi). The pressure along the lateral varied from 15.5 psi (maximum pressure) at the first section to 14.8 psi (minimum pressure) at the last section. An increase of inlet lateral flow was needed (in the case of the 20m and 40m lengths of laterals) in order to create suction at the venturi throat. Increasing the lateral flow resulted in higher head loss and lower pressure at the end of laterals. Tables A.5.39 and A.5.40 show that in the first run the pressure at the venturi inlet and outlet were 25 psi and 15.5 psi respectively. In the case of 40m lateral the pressure varied from 15.5 psi at the first section to 9.6 psi at the last section along the lateral. Figures 5.49 a and b show the emitter flow and pressure variations along the 20m and 40m laterals. Figure 5.49 shows that the pressures at each section along the lateral in second run were almost 2 psi less than those pressures in the first and third runs. It was also found that not only emitter flow rate but also the pressures along the lateral were almost overlapped in the first run, third run, and when operating the system without the venturi. The differences between the emitter flow rate in the second run and other runs were higher from mid-way up to the end of the laterals. The average differences in emitter discharge between the second run and the others were 0.06 *l/h* at the first half and 0.4 *l/h* at the second half part of the lateral. Tables A.5.40 shows that the total emitter flow was 156.4, 146.3, and 155.7 *l/h*, and the V_{qs} were 7.4×10^{-4}, 7.8×10^{-4}, and 7.4×10^{-4} in the first, second and third runs respectively. The hydraulic parameters in the first and third runs were found to be similar but differed from that the second run.

5.8.3.7 Hydraulics of lateral with saline water injection:

Two different cases (ideal and conventional cases) were tested for injection of the saline water as a nutrient injection into the microirrigation system. This experiment was done in order to investigate how uniformly the nutrient injection is distributed along the lateral. In the ideal case,

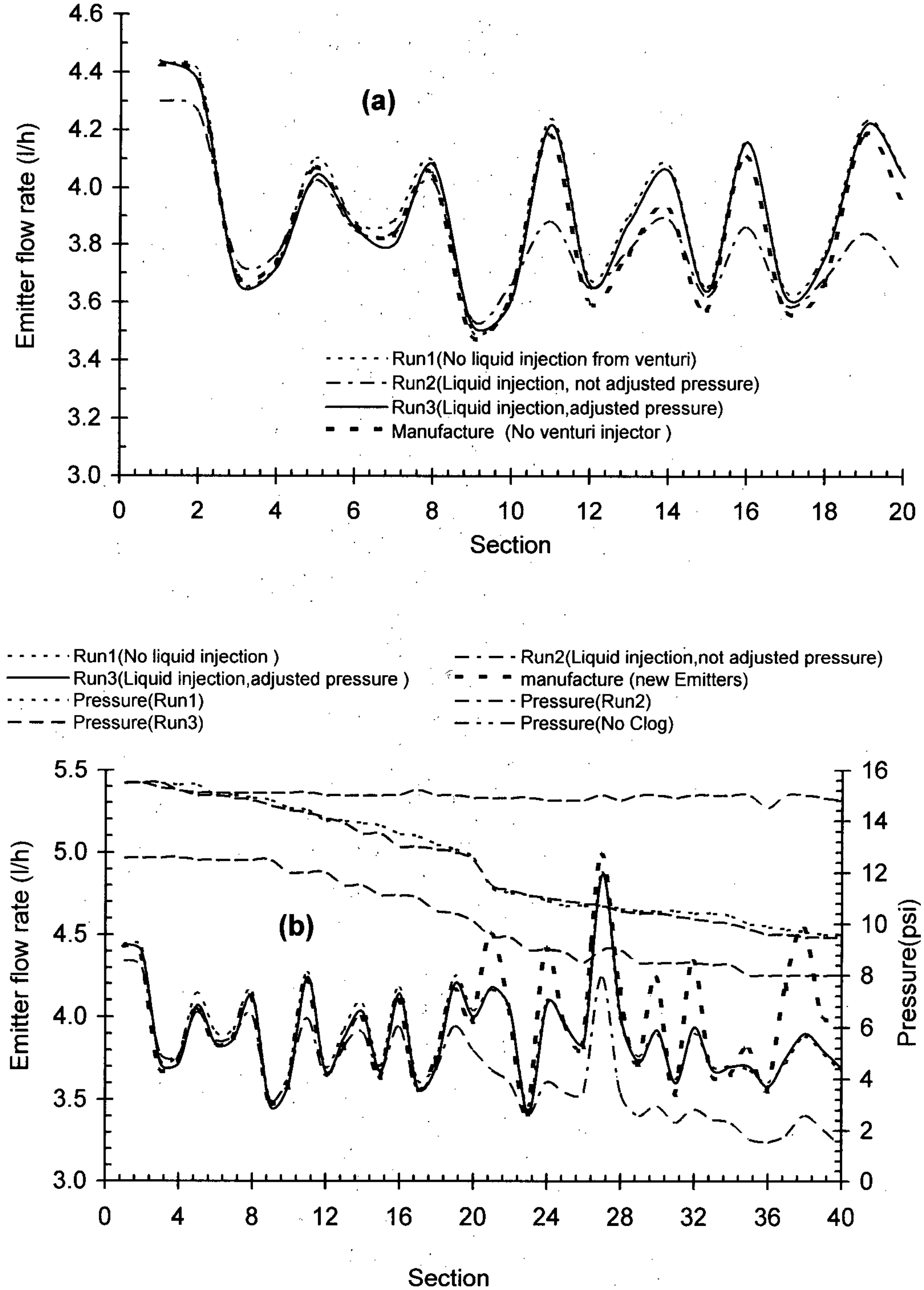


Figure 5. 49 Variation of emitter flow rate and pressure along a 20m (a) and 40m (b) laterals with and without liquid injection using city water and no clogged emitters.

the saline water with a constant salt concentration (electrical conductivity, *EC* = 1.5 and 3 mmhos/cm) was required from the emitters flow along the lateral. When the liquid nutrients are injected into the system, the flow in the lateral is the combination of a portion (%) of liquid injection and a portion of irrigation water (inflow) from the main line. Therefore, the *EC* of the mixed water delivered by the emitters is dependent upon the portion of liquid suction and the portion of inflow from the main line and their electrical conductivity. The injection water has an *EC* of 0.022 mmhos/cm.

To obtain the mixed water (irrigation water and saline water) with *EC* of 3 mmhos/cm, saline water with higher *EC* than the irrigation water is provided. The amount of salt (*g/l*) required to make a saline water an injection liquid can be determined from the portion of liquid suction (%) and its electrical conductivity (EC_L), and the portion of inflow (%) and its electrical conductivity (EC_i). Based on different portions of motive and liquid flow, the values of the total amount of salt (*g/l*) that was needed in the irrigation water to make a saline water of EC_L as an injection liquid were determined and summarised in Table A.5.41 (Appendix A). About 10 to 11 *g/l* and 22 *g/l* salt (table salt or sodium chloride) were required to use saline water as an injection liquid, resulting in the mixed water of EC_m = 1.5 and 3 mmhos/cm delivered by the emitters. Table A.5.41 gives an example of determining the amount of salt for an ideal case of mixed water of EC_m equal to 3 mmhos/cm. Similar calculations as summarised in Table A.5.41 were done for EC_m equal to 1.5 mmhos/cm. The ideal case was simulated similar to the real condition when the irrigation water is provided from two different sources of saline water and a constant value of EC_m at the emitter is desired.

In the conventional case, two different saline waters of EC equal to 1.5 and 3 mmhos/cm were prepared as the injection liquid. To provide the saline injection liquid of EC_L = 1.5 and 3 mmhos/cm, 0.54 and 1.14 *g/l* of table salt were added into the irrigation water. These saline liquids were injected into the microirrigation system and mixed with irrigation water. Under both ideal and conventional cases, the average emitter flow rate and the electrical conductivity of the mixed water along the 20m and 40m laterals were measured. Three different runs similar to those explained in previous sections were done in each case. Tables A.5.42 to A.5.45

(Appendix A) summarised the average emitter flow rate obtained from injection of different saline water (ideal case) in three runs for 20m and 40m laterals. The hydraulic parameters were determined and given in Tables A.5.42 to A.5.45. Results show that about 6.5% of total lateral flow was provided from the liquid injection and 93.5% from the motive flow in the second and third runs for both the 20m and 40m laterals. These proportions of flows were slightly different in the second and third runs. The injection of saline water (as nutrient injection) with EC_L of 27.5, 15 and 13.5 mmhos/cm resulted in mixed water with EC_m of 3, 1.6 and 1.4 mmhos/cm. The EC_m from the emitters along the 20m and 40m laterals were measured and are shown in Tables A.5.42 to A.5.45. It is found that EC_m was constant along the laterals when the injection liquid with EC_L of 27.5, 15 and 13.5 mmhos/cm was injected into the microirrigation system. Results indicated that the flow at the venturi throat was turbulent (Reynolds number greater than 10000). The turbulent condition mixed the liquid and motive flow sufficiently to give a mixed water with a constant EC_m along the lateral. Tables A.5.46 to A.5.49 (Appendix A) show the results of the conventional case of the injected liquid. The EC_m obtained from the mixed water released by the emitters along the laterals was constant over time and equal to 0.11 (when EC_L was 1.5 mmhos/cm) and 0.2 (when EC_L was 3 mmhos/cm) mmhos/cm respectively. The hydraulic parameters in the second run differed from those values obtained from the first and third runs. There were no significant differences between the values of hydraulic parameters in the first and third runs. Figures 5.50 a,b,c,d and 5.51 a,b,c,d show the emitter flow variation along the laterals with injection of different concentrations of saline water and without venturi injector under no-clogged condition for 20m and 40m laterals respectively. The straight line in the figures indicates the nominal emitter flow rate. It was found that the emitter flow along the lateral in the second run differed from that in the first and third runs. It also differed from the emitter flow rates when the venturi injector was not installed. The differences between emitter flow rates under different runs were greater from the middle part up to the end of the lateral and increased as the emitters were closer to the end of lateral. Tables 5.37 and 5.38 summarised the results obtained from the effect of the venturi injector and saline and city water injection on total emitter flow (T.E.F), *CU*, *EU'*, *Ea*, q_{var}, and V_{qs} under seven different conditions and on three different runs for 20m and 40m laterals. The seven different conditions were: (1) natural clogging, water injection, (2) no-clogged (new emitters), water injection, (3) saline water

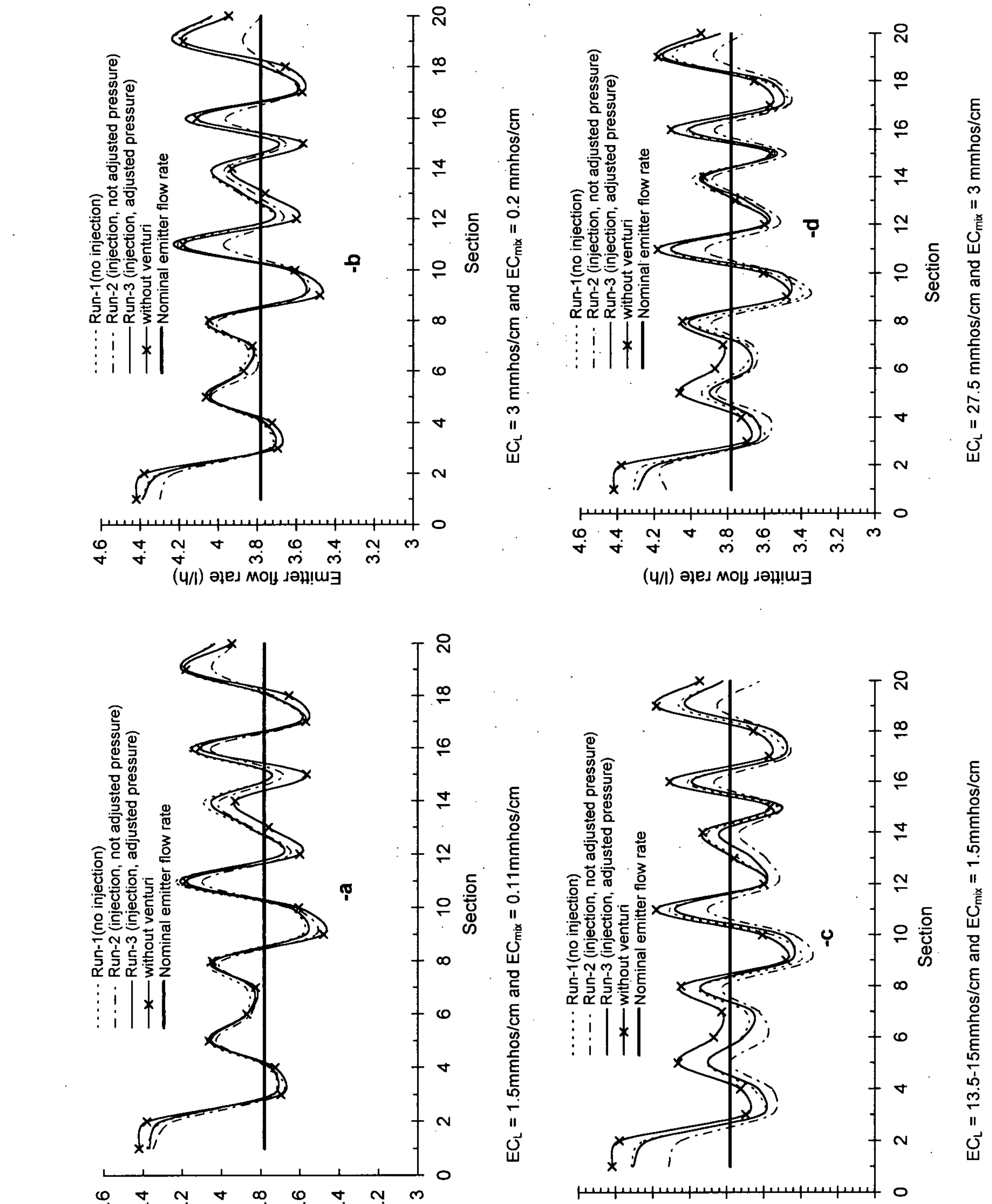


Figure 5. 50 Variation of emitter flow rate along a 20m lateral with and without injection of different saline water under no clogged emitter condition.

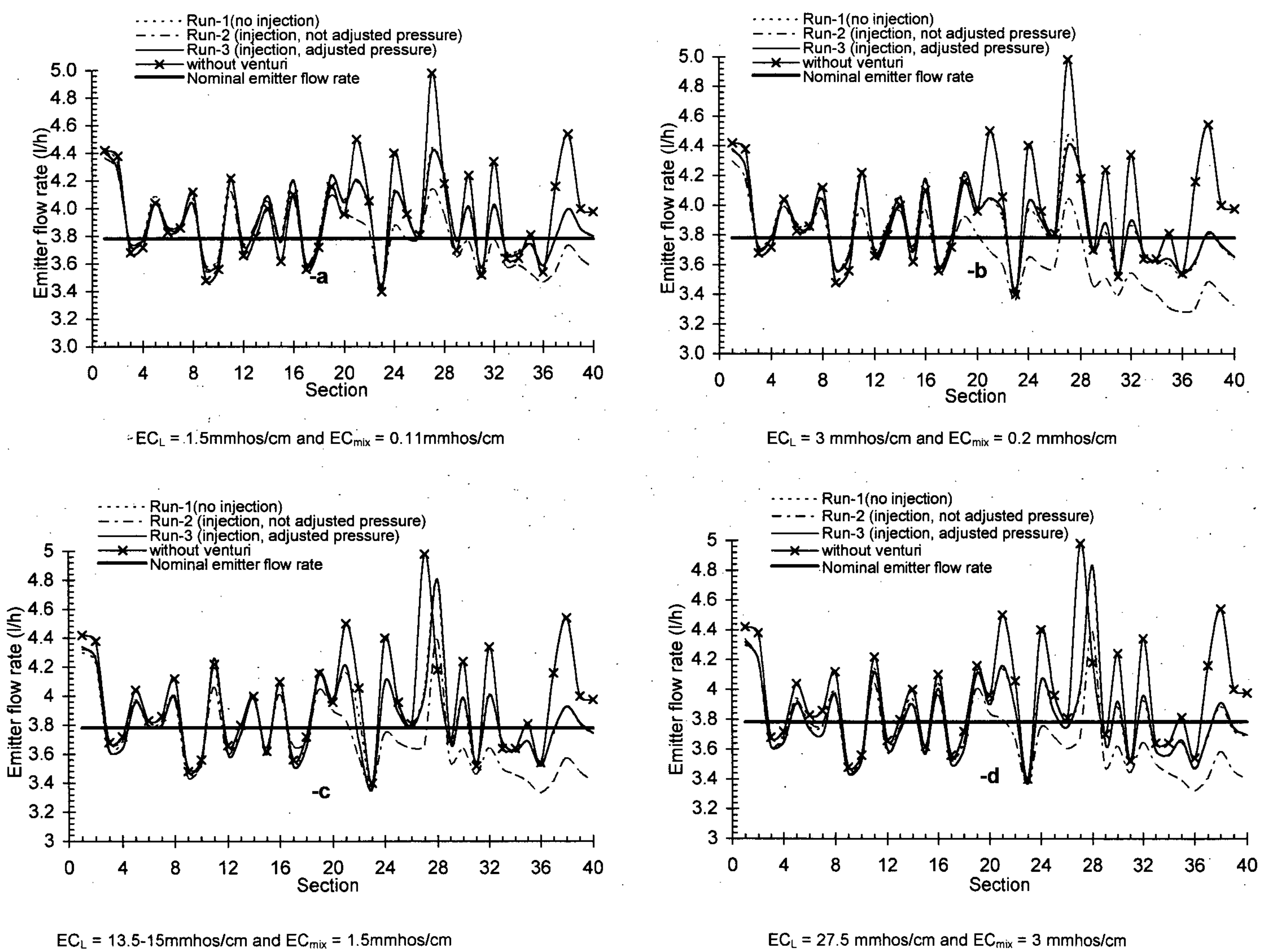


Figure 5. 51 Variation of emitter flow rate along a 40m lateral with and without injection of different saline water under no clogged emitter condition.

Table 5.37 Effect of venturi injector, saline and city water injection on emitter flow rate , CU, EU', Ea, qvar, and Vqs in a **20** meters lateral laid on flat terrain.

Conditions	RUN-1: venturi closed, no liquid injection					
	Total emitter flow (l/h)	CU (%)	EU' (%)	Ea (%)	Vqs (%)	qvar (%)
City water, natural clogging	67.90	86.554	73.108	99.998	24.2123	8.9E-03
City water, new emitters	78.69	94.003	91.956	99.997	6.8083	1.1E-02
City water, ECL=13.5-15	75.85	94.285	92.604	99.997	6.6570	1.0E-02
City water, ECL=27.5	76.13	94.018	92.332	99.997	6.7447	1.0E-02
City water, ECL=1.5	78.66	94.577	92.906	99.997	6.0523	1.1E-02
City water, ECL=3	78.53	94.624	92.625	99.997	6.1374	1.1E-02
City water, no Venturi installed	77.61	94.019	91.860	99.997	6.9764	1.0E-02
Conditions	RUN-2:City water and saline water injection, no adjusted pressure					
	Total emitter flow (l/h)	CU (%)	EU' (%)	Ea (%)	Vqs (%)	qvar (%)
Natural clogging, water injection	67.98	86.190	72.536	99.997	24.3070	1.1E-02
New emitters, water injection	76.49	95.998	94.481	99.996	5.1955	1.3E-02
Saline water injection, ECmix=1.5	73.44	95.301	94.092	99.997	5.4805	1.2E-02
Saline water injection, ECmix=3.0	74.30	95.046	93.285	99.997	5.7909	1.2E-02
Saline water injection, ECmix=0.11	77.50	95.161	93.161	99.997	5.6900	1.3E-02
Saline water injection, ECmix=0.2	76.82	95.829	94.038	99.997	5.1539	1.3E-02
No Venturi (No injection)	77.61	94.019	91.860	99.997	6.9764	1.0E-02
Conditions	RUN-3: City water and saline water injection, adjusted pressure					
	Total emitter flow (l/h)	CU (%)	EU' (%)	Ea (%)	Vqs (%)	qvar (%)
Natural clogging, water injection	67.67	86.648	73.297	99.998	24.2038	8.9E-03
New emitters, water injection	78.36	93.773	91.572	99.997	7.0976	1.1E-02
Saline water injection, ECmix=1.5	75.49	94.372	92.846	99.997	6.4402	9.9E-03
Saline water injection, ECmix=3.0	76.06	94.209	92.660	99.997	6.4598	1.0E-02
Saline water injection, ECmix=0.11	78.47	94.651	93.029	99.997	6.0203	1.1E-02
Saline water injection, ECmix=0.2	78.51	94.573	92.778	99.997	6.1538	1.1E-02
No Venturi (No injection)	77.61	94.019	91.860	99.997	6.9764	1.0E-04

Table 5.38 Effect of venturi injector, saline and city water injection on emitter flow rate , CU, EU', Ea, qvar, and Vqs in a **40** meters lateral laid on flat terrain.

Conditions	Total emitter flow (l/h)	CU (%)	EU' (%)	Ea (%)	Vqs (%)	qvar (%)
	RUN-1: venturi closed, no liquid injection					
City water, natural clogging	137.23	89.394	78.787	99.984	19.0521	6.1E-02
City water, new emitters	156.42	94.162	92.111	99.980	7.4650	7.4E-02
City water, ECL=13.5-15	153.86	94.139	91.898	99.981	7.2352	7.3E-02
City water, ECL=27.5	152.40	94.239	92.310	99.981	7.2903	7.1E-02
City water, ECL=1.5	156.70	94.661	92.788	99.980	6.2372	7.5E-02
City water, ECL=3	154.23	94.786	92.693	99.981	6.4192	7.2E-02
City water, no Venturi installed	158.28	92.877	90.012	99.979	8.6960	7.8E-02
	RUN-2:City water and saline water injection, no adjusted pressure					
Conditions	Total emitter flow (l/h)	CU (%)	EU' (%)	Ea (%)	Vqs (%)	qvar (%)
Natural clogging, water injection	130.39	87.628	76.264	99.982	20.7621	6.6E-02
New emitters, water injection	146.31	93.452	90.821	99.979	7.9485	7.8E-02
Saline water injection, ECmix=1.5	148.55	94.228	92.134	99.978	7.4005	8.2E-02
Saline water injection, ECmix=3.0	147.62	94.504	92.397	99.978	7.0940	8.1E-02
Saline water injection, ECmix=0.11	152.16	95.141	92.908	99.977	5.9352	8.6E-02
Saline water injection, ECmix=0.2	147.03	94.395	91.600	99.979	6.8154	7.9E-02
No Venturi (No injection)	158.28	92.877	90.012	99.979	8.6960	7.8E-02
	RUN-3: City water and saline water injection, adjusted pressure					
Conditions	Total emitter flow (l/h)	CU (%)	EU' (%)	Ea (%)	Vqs (%)	qvar (%)
Natural clogging, water injection	135.36	88.470	76.954	99.984	19.6189	5.8E-02
New emitters, water injection	155.72	94.325	92.385	99.980	7.2797	7.4E-02
Saline water injection, ECmix=1.5	153.88	94.032	92.034	99.981	7.3948	7.3E-02
Saline water injection, ECmix=3.0	152.34	94.161	92.229	99.981	7.3711	7.2E-02
Saline water injection, ECmix=0.11	156.33	94.644	92.516	99.980	6.2489	7.5E-02
Saline water injection, ECmix=0.2	154.50	94.766	92.810	99.981	6.3199	7.3E-02
No Venturi (No injection)	158.28	92.877	90.012	99.979	8.6960	7.8E-02

injection, EC_m = 1.5 mmhos/cm, (4) saline water injection, EC_m = 3 mmhos/cm (5) saline water injection, EC_m = 0.11 mmhos/cm, (6) saline water injection, EC_m = 0.2 mmhos/cm, and (7) no venturi injector, no injection. Results show that the differences between the values of the total emitter flow, V_{qs}, and q_{var} in the second run with those values obtained from the first and third runs under the seven different conditions were significant. For example, the values of total emitter flow under condition (4) were 152.4 *l/h*, 147.62 *l/h*, and 152.34 *l/h*, in the first, second and third runs respectively for the 40m lateral. This means that there was about 5 *l/h* reduction in lateral flow in the second run for the 40m lateral. This amount of reduction is considerable if the growing season, size of cultivated area, and the number of hours of operating the microirrigation system are considered. On the other hand, there were less than 1% to 2% differences between the values of *CU*, and *EU'* under different conditions in three runs. For instance, the values of *CU* under condition (5) were 94.66%, 95.14%, and 94.64% in the first, second and third runs respectively for the 40m lateral. Figures 5.52 a,b,c,d show a comparison of the values of the hydraulic parameters under seven conditions. This clearly demonstrates that the venturi injector has an impact on the hydraulics in a microirrigation system.

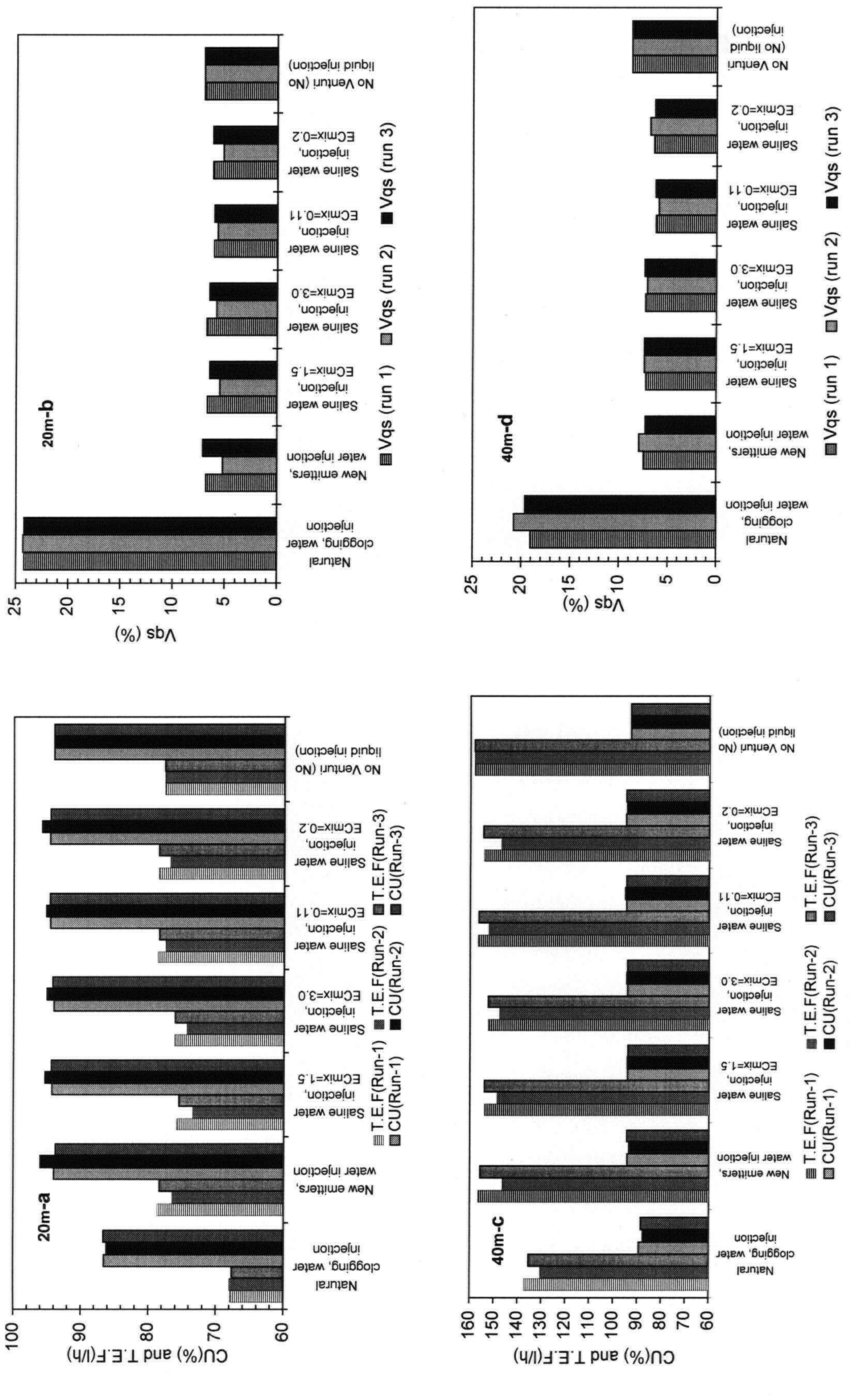


Figure 5. 52 Impact of venturi injector with different inlet pressure and liquid injection on total emitter flow rate (T.E.F), CU and V_{qs} in 20m and 40m laterals.

Chapter 6

SUMMARY AND CONCLUSIONS

6.1 Summary:

A comprehensive study was undertaken to determine the effects on the hydraulics of a microirrigation system of different numbers, degrees and locations of clogged emitters along laterals laid on flat and sloped terrain. Results obtained from the field experiment were compared to the results predicted by a computer simulation program. The effects of air and water temperatures and lateral flushing on emitter flow rates were also investigated in the field. Finally, the impact of injecting saline water (as a nutrient) on the emitter's flow characteristics was examined.

A computer spreadsheet program was constructed to simulate the effect of eight patterns of clogged emitters and five slopes on the hydraulics of the microirrigation system. The computer program was designed according to commonly used theoretical and empirical equations which determine the head loss, pressure and flow rate within a lateral. The program predicts lateral flow rates and variation of individual emitter discharges along the lateral due to pressure changes within the lateral line. The uniformities in a microirrigation system were estimated from the variation of emitter flow rates. The hydraulic parameters (H_f, H_{var}, q_{var}, CU, EU', DU, U_s, V_{qs}, V_{hs}, V_{qh}, U_{sh}, and V_{pf}) were determined and presented in graphical form. The relationships between the hydraulic parameters under different patterns of clogging can be easily compared to each other by using the graphs. The program incorporates the data of coefficient of variation and deficit evapotranspiration adopted from the study made by Sammis and Wu (1985) to estimate the reduction of cotton yield due to emitter clogging.

A field experiment was then conducted to study the effects of the same patterns of clogging and slopes on hydraulic characteristics of a microirrigation system installed on flat and sloped terrains. Five different slopes (0%, and 3% and 7% for both up- and down-slope) were used. The effect of emitter clogging on hydraulics parameters (similar parameters to those in simulation program) was evaluated. The results obtained from the field experiment were compared to the theoretical values obtained from the computer simulation model output. In all slopes and stages studied, the computed results did not deviate more than ±5% from the field observations. Based on data obtained from the field and synthetic data, the effects of different patterns of clogged emitters on reduction of cotton yields were simulated, and the loss to the farmer was estimated.

Under the *no-clogged* condition, the emitter discharge along the lateral varied from the nominal emitter flow rate in all five slopes studied. In the case of *flat terrain*, this variation is mainly due to the emitter manufacturer's coefficient of variation. In the case of *sloped terrain*, the pressure variation along the lateral was the major factor affecting emitter flow rate in addition to the manufacturer coefficient of variation.

The behavior of the hydraulics on flat terrain was slightly different from that on sloped terrain. In the case of *flat terrain*, the number and location of clogged emitters had more impact on H_f, H_{var}, q_{var}, V_{hs}, and V_{qh} than did the degree of clogging. The number and degree of clogging were the major factors affecting uniformities (*CU, EU', DU,* and U_s). For the emitter discharge coefficient of variation, the number of clogged emitters had a higher impact than did the degree and location of clogged emitters.

In the cases of *sloped terrain*, higher values of H_f, q_{var}, V_{qh}, H_{var}, and V_{hs} were obtained in up-slopes than in the down-slopes in all eight stages. The slopes of laterals had a significant effect on V_{qh}, H_{var}, and V_{hs}, but had little impact on uniformities. While the maximum emitter flow variation (q_{var}) occurred in stage 1 in an up-slope, the minimum was found in stage 1 in a down-slope condition. Although the number, degree and location of clogged emitters affected the q_{var}, the last noted was found to have a higher impact than the other two. The number and location of clogged emitters had a significant impact on V_{qs} and V_{pf}, but the location of clogging had a greater effect than the number of clogged emitters. The highest values of V_{qs} and V_{pf} were found in stages 4 and 5 in different slopes. According to the ASAE EP458 (1997) criteria, the emitter performance coefficients of variation were too high to be accepted in all stages with clogged emitters.

On *sloped terrain*, both the number and location of clogged emitters were the major factors affecting uniformities, but the former had a higher impact than the latter. In the *no-clogged situation*, the uniformities in down-slopes were 1 to 4 % higher than that in the up-slope conditions. In the case of *clogged conditions*, the differences between the values of uniformities (*CU, EU', DU,* and U_s) in up- and down-slopes depended upon the number and degree of clogged emitters. It was found that the uniformities were independent of the slopes of the laterals. For each slope there was a linear relationship between the uniformities and the percentage of the total number of partially clogged emitters along the lateral. The relationship between *CU* and average degree of emitter clogging (C_d) obtained from natural, artificial, and synthetic clogging data were plotted and a least-square regression equation was determined. The relationship between *CU* and U_s under different slopes indicated that they were highly correlated. Therefore, either *CU* or U_s can be used for evaluating the system.

Both the field data and simulated results showed that stages 4 and 5 represented the worst emitter clogging patterns affecting the hydraulic parameters. Similar results for all aforementioned parameters were obtained from synthetic data generated by the computer simulation program in all stages and slopes.

The economic effects of different patterns of emitter clogging on crop production were evaluated using the cotton crop as a paradigm. The reduction in yield and the farmer's money loss were highly dependent on the number and location of clogged emitters along the lateral. As the number of clogged emitters increased, the cotton yield decreased. The reduction of yield was independent of the type of lateral slopes (up- or down-slopes). Stages 4 and 5 were the worst stages of emitter clogging affecting the cotton yield.

The effects of air and water temperatures on the hydraulic characteristics of the emitter were examined. It was found that there were no significant differences in emitter flow rate along the lateral under various temperatures at the experimental site. The impact of flushing the lateral on emitter flow rate was also investigated, and results indicated that the flushing improves the emitter flow rate along the lateral. However, the flushing may also create an emitter clogging problem since the small, suspended particles from the lateral may be flushed into the emitter.

The effect on emitter's hydraulic characteristics of injecting different degrees of saline water into the lateral were studied. Two cases were evaluated: (1) in which a constant value of electrical conductivity (*EC*) at the emitter's outlet was maintained and (2) in which a constant *EC* value of the injecting water was maintained. The turbulent flow at the injecting point (venturi throat) allows sufficient mixing of the injected liquid and motive flow. Therefore, a mixed water of almost constant EC_m along the lateral was obtained over time. When the venturi was installed and the liquid was injected, the values of hydraulic parameters (emitter flow rate, emitter coefficient of variations, uniformity, etc.) varied from those values obtained without the injection.

6.2 Conclusions:

The following conclusions can be drawn. The numbers correspond to objective numbers in chapter 1:

1- The emitter flow rate from pressure-compensating emitters and, consequently, the uniformities in a microirrigation system are highly dependent on the number, degree, and location of clogged emitters along the lateral. *Pressure-compensating* emitters do not produce constant and uniform discharge along the lateral. The average deviations of emitter flow rate on flat and sloped terrains from the nominal emitter flow rate were ± 5.9% in flat terrain, ±3.47% and ± 4.51% in 3% and 7% up-slopes, and -6.64% and -5.12% in 3% and 7% down-slopes. There were no significant differences in emitter flow rate along the lateral under various temperatures at the experimental site.

2- Synthetic data showed similar behavior to that of the field study for hydraulic parameters along the 10 to 60 meter laterals under all patterns of emitter clogging. Higher variations in the hydraulic parameters were observed when the length of lateral was increased. The following results were obtained from the field experiment and the computer program:

A- In the case of *flat terrain*, the number and location of partially clogged emitters were the major factors affecting pressure variation, head loss, and emitter coefficient of variations. The number and degree of clogged emitters had a major effect upon the uniformities.

B- In the case of *sloped terrain*, the *location* of clogged emitters and the *slope* of laterals had a significant impact on pressure variation and emitter discharge coefficient of variation due to hydraulics. On sloped terrain the *number of partially clogged* emitters along the lateral had higher impact than the *location* of clogging on *uniformities*. The type of lateral slope (up- or down-slope) had no significant impact on uniformities. The differences observed between the values of unformities obtained from up and down-slopes were insignificant.

3- Stages 4 and 5 (when 30% of the total number of emitters along the lateral were partially clogged and located at the first one-third section or randomly located along the lateral) were the worst situations of emitter clogging.

4- Pressure drop occurred at the lateral inlet when fertilizer or chemical (in this study, saline water) was injected by the venturi injector. Changing the pressure at the lateral inlet caused variation in emitter flows and rate uniformities.

5- Turbulent flow at the venturi throat mixed the liquid injection and motive flow sufficiently to maintain a constant concentration of fertilizer or chemicals (in this study constant *EC* of saline water) at the emitter outlets over time.

6- When chemical is injected by the venturi injector into the lateral, variation of hydraulic parameters is unavoidable. In this case, variation of hydraulic parameters can be minimized if the pressure at the lateral inlet is adjusted to the amount of pressure in the no-liquid injection situation.

7- The reduction of crop (cotton in this study) yields was directly related to the number and degree of clogged emitters in different slopes. The highest yield reduction and farmer's money loss occurred when the partially clogged emitters were located at the first one-third section of the lateral or randomly located along the lateral (stages 4 and 5). Regression equations indicate that as the number of partially clogged emitters along the lateral increased the cotton yield decreased.

8- A computer spreadsheet program (in MS Excel) was constructed and used to predict the effects of emitter clogging on the hydraulics of microirrigation system. In all eight stages of clogged conditions, the theoretical results obtained from the computer program did not deviate more than ±5% from the field results.

From the point of view for future research numbers 1, 2, and 4 and from the point of view of applying these results numbers 2, 3, 5, and 6 are the most important.

6.3 Recommendations:

The hydraulics of a microirrigation system under different patterns of clogging are very complicated, and it is practically impossible to make emitters clog predictably. The present study, the field evaluation of the hydraulics of a microirrigation system, is only a small step toward a better understanding and management of the emitter clogging problem. For extending this research, the following recommendations are made:

1- It is tedious work to measure individual emitter discharges manually with a stop watch, container and graduated cylinder. It would be desirable to utilize an electronic flow meter with a data logger to collect the data.

2- Theoretical results showed similar trends of hydraulic parameters of microirrigation system for 10 to 60 meter laterals under different patterns of emitter clogging. The length of lateral in this study was 20m. Field tests on laterals longer than 20m should be made to confirm this.

3- Only one type of pressure-compensating emitter was used in this study. More confidence could be gained in interpreting the hydraulic characteristics of pressure-compensating emitters affected by clogging, if more pressure-compensating emitters with the same or with different nominal flow rates from different manufacturers were tested.

4- To obtain better evaluations and comparisons of the impact of different patterns of clogging on emitter flow rates, similar field experiments should be made with both *pressure-* and *non-pressure-compensating* emitters.

Recommendations for the application of these results are as follows:

1- Based on the results obtained from this research, and according to the criteria suggested by ASAE EP458 (1997) and ASAE EP405.1 (1997), when 10% or more of the total number of emitters are partially clogged, the uniformities (*CU, EU', DU,* and U_s) are poor or unacceptable. To improve the uniformities, flushing the lateral or replacing the emitters is suggested.

2- Based on the finding of this research, when pressure compensating emitters are used, *three* among the thirteen parameters examined, ***CU*** or $\boldsymbol{U_s}$, ***EU'***, and $\boldsymbol{V_{pf}}$, are the most important parameters for evaluating a microirrigation system.

3- Considering the cost of operating pressure and achieving similar values of uniformities in up- or down-slopes, the installation of microirrigation systems on down-slopes is suggested.

4- Although the flushing of laterals improves the flow rate from most emitters along the lateral, an inspection of emitters along the lateral is suggested because of possible emitter clogging after flushing.

5- When *pressure-compensating* emitters are used, adjustments (using a pressure regulator) should be made to compensate for the effect of different operating pressures (even within the pressure range recommended by the manufacture).

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APPENDIX A.

Table A.3.1 Average emitter discharge(*l/h*) affected by manufacturer's coefficient of variation (synthetic data same degree of clogging as the field experiment, flat terrain)

Emitter #	Stage- 1* q_f (*l/h*)	Stage- 2** q_f (*l/h*)	Stage- 3 q_f (*l/h*)	Stage- 4 q_f (*l/h*)	Stage- 5 q_f (*l/h*)	Stage- 6 q_f (*l/h*)	Stage- 7 q_f (*l/h*)	Stage- 8 q_f (*l/h*)
1	3.687	3.687	3.687	2.612	2.612	3.687	3.687	3.687
2	3.762	3.762	3.762	1.382	3.762	3.762	3.762	3.762
3	3.692	3.692	3.692	0.982	1.382	2.612	3.692	3.692
4	3.762	3.762	3.762	0.282	3.762	3.762	0.982	3.762
5	3.842	3.842	3.842	0.000	0.982	3.842	3.842	3.842
6	3.691	3.692	3.692	1.682	3.692	0.282	3.692	3.692
7	3.711	3.712	2.612	3.712	3.712	3.712	3.712	3.712
8	3.781	3.782	1.382	3.781	3.782	0.982	3.781	3.781
9	3.721	3.722	0.982	3.721	0.282	3.721	3.721	3.721
10	3.801	3.802	0.282	3.801	3.802	3.801	3.801	3.801
11	3.721	3.722	0.000	3.721	0.000	3.721	3.721	3.721
12	3.801	3.802	1.682	3.801	3.801	1.381	3.801	3.801
13	3.761	3.762	3.762	3.761	3.761	3.761	0.281	3.761
14	3.691	3.692	3.692	3.691	3.691	3.691	3.691	3.691
15	3.741	2.612	3.741	3.741	3.741	3.741	3.741	3.741
16	3.841	1.382	3.841	3.841	1.681	3.841	3.841	0.281
17	3.761	0.982	3.761	3.761	3.761	3.761	3.761	3.761
18	3.761	0.282	3.761	3.761	3.761	3.761	3.761	3.761
19	3.731	0.000	3.731	3.731	3.731	3.731	3.731	3.731
20	3.691	1.682	3.691	3.691	3.691	3.691	3.691	3.691

* Stage- 1: no-clogged emitters

** Stage- 2 to 8: with clogged emitters

Table A.3.2 Effect of number, location, and degree of clogged emitters on head loss (H_f) in 10, 20, 30, 40, 50, and 60m length of laterals.

Length (m)	Stage 1	Stage 2	Stage 3	Stage 4	Stage 5	Stage 6	Stage 7	Stage 8
10	0.0021	0.0012	0.0014	0.0018	0.0014	0.0016	0.0018	0.0017
20	0.0139	0.0073	0.0089	0.0116	0.0097	0.0112	0.0120	0.0123
30	0.0433	0.0253	0.0296	0.0379	0.0291	0.0341	0.0357	0.0405
40	0.0971	0.0586	0.0678	0.0847	0.0668	0.0737	0.0861	0.0922
50	0.1821	0.1022	0.1195	0.1562	0.1163	0.1445	0.1566	0.1647
60	0.3050	0.1696	0.1997	0.2609	0.1992	0.2326	0.2537	0.2814

Table A.3.3 Effect of number, location, and degree of clogged emitters on pressure variation (H_{var})

Length (m)	Stage 1	Stage 2	Stage 3	Stage 4	Stage 5	Stage 6	Stage 7	Stage 8
10	0.00020	0.00012	0.00014	0.00017	0.00013	0.00015	0.00017	0.00016
20	0.00132	0.00069	0.00084	0.00110	0.00092	0.00106	0.00114	0.00116
30	0.00410	0.00239	0.00280	0.00359	0.00276	0.00323	0.00338	0.00384
40	0.00920	0.00555	0.00642	0.00802	0.00633	0.00698	0.00816	0.00873
50	0.01724	0.00968	0.01132	0.01479	0.01102	0.01368	0.01483	0.01560
60	0.02888	0.01606	0.01891	0.02471	0.01886	0.02203	0.02403	0.02665

Table A.3.4 Effect of number, location, and degree of clogged emitters on emitter flow variation (q_{var})

Length (m)	Stage 1	Stage 2	Stage 3	Stage 4	Stage 5	Stage 6	Stage 7	Stage 8
10	0.00001	0.00001	0.00001	0.00001	0.00001	0.00001	0.00001	0.00001
20	0.00010	0.00005	0.00006	0.00008	0.00007	0.00008	0.00009	0.00009
30	0.00031	0.00018	0.00021	0.00027	0.00021	0.00024	0.00026	0.00029
40	0.01145	0.00042	0.00049	0.00061	0.00048	0.00053	0.00062	0.00066
50	0.00132	0.00074	0.00086	0.00113	0.00084	0.00104	0.00113	0.00119
60	0.00222	0.00123	0.00144	0.00189	0.00144	0.00168	0.00184	0.00204

Table A.3.5 Effect of number, location, and degree of clogged emitters on coefficient of uniformity (CU)

Length (m)	Stage 1	Stage 2	Stage 3	Stage 4	Stage 5	Stage 6	Stage 7	Stage 8
10	98.81	70.72	70.71	70.56	70.61	78.54	85.68	85.67
20	98.94	63.37	63.38	63.34	63.36	76.11	83.68	90.79
30	99.00	69.98	69.99	69.94	69.96	78.61	85.55	93.59
40	99.05	72.30	72.25	72.28	72.23	77.49	87.86	94.34
50	99.03	68.05	68.03	68.05	68.01	79.71	86.20	91.38
60	99.07	67.42	67.41	67.45	67.41	77.12	86.20	93.61

Table A.3.6 Effect of number, location, and degree of clogged emitters on application efficiency (Ea)

Length (m)	Stage 1	Stage 2	Stage 3	Stage 4	Stage 5	Stage 6	Stage 7	Stage 8
10	99.9996	99.9997	99.9997	99.9996	99.9997	99.9997	99.9996	99.9997
20	99.9973	99.9986	99.9983	99.9977	99.9981	99.9978	99.9977	99.9976
30	99.9917	99.9951	99.9943	99.9927	99.9944	99.9934	99.9931	99.9922
40	99.9814	99.9888	99.9870	99.9838	99.9872	99.9859	99.9835	99.9823
50	99.9650	99.9805	99.9771	99.9700	99.9777	99.9723	99.9699	99.9683
60	99.9409	99.9675	99.9616	99.9496	99.9617	99.9552	99.9510	99.9456

Table A.3.7 Effect of number, location, and degree of clogged emitters on field emission uniformity (EU')

Length (m)	Stage 1	Stage 2	Stage 3	Stage 4	Stage 5	Stage 6	Stage 7	Stage 8
10	98.527	51.201	51.184	50.929	51.019	68.096	80.559	80.420
20	98.474	29.149	29.154	29.105	35.403	54.826	71.811	84.278
30	98.560	44.135	55.000	44.084	44.106	62.819	76.811	89.377
40	98.570	46.164	46.101	46.139	46.077	57.439	78.808	89.824
50	98.533	34.837	34.811	34.835	34.787	59.531	74.770	92.701
60	98.566	35.692	35.678	35.755	35.692	56.702	75.957	88.650

Table A.3.8 Effect of number, location, and degree of clogged emitters on distribution uniformity (DU)

Length (m)	Stage 1	Stage 2	Stage 3	Stage 4	Stage 5	Stage 6	Stage 7	Stage 8
10	98.1108	53.4456	53.4299	53.1866	53.2723	65.8825	77.2246	77.2089
20	98.3138	41.7630	41.7696	41.7068	41.7492	62.0180	74.0467	85.3534
30	98.4065	52.2652	52.2820	52.2077	52.2321	65.9863	77.0255	89.8063
40	98.4845	55.9491	55.8794	55.9198	55.8532	64.2121	80.7052	90.9981
50	98.4589	49.2019	49.1689	49.1916	49.1398	67.7339	78.0594	86.3007
60	98.5166	48.1929	48.1760	48.2529	48.1834	63.6178	78.0584	89.8368

Table A.3.9 Effect of number, location, and degree of clogged emitters on statistical uniformity coefficient (U_s)

Length (m)	Stage 1	Stage 2	Stage 3	Stage 4	Stage 5	Stage 6	Stage 7	Stage 8
10	98.6597	67.0214	67.0230	66.8632	66.9078	72.1297	76.1004	76.0687
20	98.7370	56.8880	56.8892	56.8659	56.8900	67.9400	72.5707	78.8339
30	98.7911	63.2215	63.2289	63.1996	63.2032	71.3177	73.6347	87.0129
40	98.8550	65.8583	65.8256	65.8492	65.8131	68.6801	78.1705	85.3156
50	98.8281	60.5382	60.5219	60.5398	60.5097	70.6745	75.4775	80.1103
60	98.8579	59.5288	59.5207	59.5629	59.5251	67.2262	75.0320	83.8886

Table A.3.10 Effect of number, location, and degree of clogged emitters on statistical uniformity due to hydraulics (U_{sh})

Length (m)	Stage 1	Stage 2	Stage 3	Stage 4	Stage 5	Stage 6	Stage 7	Stage 8
10	99.9995	99.9997	99.9997	99.9996	99.9997	99.9996	99.9996	99.9996
20	99.9969	99.9984	99.9980	99.9975	99.9979	99.9975	99.9974	99.9973
30	99.9907	99.9946	99.9937	99.9919	99.9937	99.9927	99.9923	99.9913
40	99.9793	99.9875	99.9856	99.9819	99.9858	99.9843	99.9816	99.9803
50	99.9612	99.9783	99.9746	99.9667	99.9753	99.9693	99.9667	99.9649
60	99.9347	99.9640	99.9575	99.9443	99.9576	99.9504	99.9458	99.9398

Table A.3.11 Effect of number, location, and degree of clogged emitters on emitter discharge coefficient of variation (V_{qs})

Length (m)	Stage 1	Stage 2	Stage 3	Stage 4	Stage 5	Stage 6	Stage 7	Stage 8
10	0.0134	0.3298	0.3298	0.3314	0.3309	0.2787	0.2390	0.2393
20	0.0126	0.4311	0.4311	0.4313	0.4311	0.3206	0.2743	0.2117
30	0.0121	0.3678	0.3677	0.3680	0.3680	0.2868	0.2637	0.1299
40	0.0114	0.3414	0.3417	0.3415	0.3419	0.3132	0.2183	0.1468
50	0.0117	0.3946	0.3948	0.3946	0.3949	0.2933	0.2452	0.1989
60	0.0114	0.4047	0.4048	0.4044	0.4047	0.3277	0.2497	0.1611

Table A.3.12 Effect of number, location, and degree of clogged emitters on hydraulic design coefficient of variation (V_{hs})

Length (m)	Stage 1	Stage 2	Stage 3	Stage 4	Stage 5	Stage 6	Stage 7	Stage 8
10	0.00006	0.00004	0.00004	0.00005	0.00004	0.00005	0.00005	0.00005
20	0.00040	0.00021	0.00026	0.00034	0.00028	0.00033	0.00035	0.00035
30	0.00123	0.00072	0.00084	0.00108	0.00083	0.00097	0.00101	0.00115
40	0.00274	0.00165	0.00191	0.00239	0.00188	0.00207	0.00243	0.00260
50	0.00513	0.00287	0.00335	0.00439	0.00326	0.00406	0.00440	0.00464
60	0.00863	0.00475	0.00561	0.00736	0.00559	0.00655	0.00715	0.00795

Table A.3.13 Effect of number, location, and degree of clogged emitters on emitter discharge coefficient of variation due to hydraulics (V_{qh})

Length (m)	Stage 1	Stage 2	Stage 3	Stage 4	Stage 5	Stage 6	Stage 7	Stage 8
10	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000
20	0.00003	0.00002	0.00002	0.00003	0.00002	0.00002	0.00003	0.00003
30	0.00009	0.00005	0.00006	0.00008	0.00006	0.00007	0.00008	0.00009
40	0.00021	0.00012	0.00014	0.00018	0.00014	0.00016	0.00018	0.00020
50	0.00039	0.00022	0.00025	0.00033	0.00025	0.00031	0.00033	0.00035
60	0.00065	0.00036	0.00042	0.00056	0.00042	0.00050	0.00054	0.00060

Table A.3.14 Effect of number, location, and degree of clogged emitters on emitter performace coefficient of variation (V_{pf})

Length (m)	Stage 1	Stage 2	Stage 3	Stage 4	Stage 5	Stage 6	Stage 7	Stage 8
10	0.01340	0.32979	0.32977	0.33137	0.33092	0.27870	0.23900	0.23931
20	0.01263	0.43112	0.43111	0.43134	0.43110	0.32060	0.27429	0.21166
30	0.01209	0.36778	0.36771	0.36800	0.36797	0.28682	0.26365	0.12987
40	0.01145	0.34142	0.34174	0.34151	0.34187	0.31320	0.21829	0.14684
50	0.01171	0.39462	0.39478	0.39460	0.39490	0.29325	0.24523	0.19890
60	0.01140	0.40471	0.40479	0.40437	0.40475	0.32774	0.24968	0.16111

Table A.3.15 Values of emitter flow (q_i) due to emitter manufacturer's coefficient of variation and pressure variation along the 10m to 60m laterals

Length of Lateral 10 sections		(10 m) Final	Length of Lateral 20 sections		(20 m) Final	Length of Lateral 30 sections		(30 m) Final	Emitter
qi=khx	qf (final q)	I qf I	qi=khx	qf (final q)	I qf I	qi=khx	qf (final q)	I qf I	Number
3.762	3.687	3.687	3.762	3.687	3.687	3.762	3.687	3.687	1
3.762	3.762	3.762	3.762	3.762	3.762	3.762	3.762	3.762	2
3.762	3.692	3.692	3.762	3.692	3.692	3.761	3.691	3.691	3
3.762	3.762	3.762	3.762	3.762	3.762	3.761	3.761	3.761	4
3.762	3.842	3.842	3.762	3.842	3.842	3.761	3.841	3.841	5
3.762	3.692	3.692	3.761	3.691	3.691	3.761	3.691	3.691	6
3.762	3.712	3.712	3.761	3.711	3.711	3.761	3.711	3.711	7
3.762	3.782	3.782	3.761	3.781	3.781	3.761	3.781	3.781	8
3.762	3.722	3.722	3.761	3.721	3.721	3.761	3.721	3.721	9
3.762	3.802	3.802	3.761	3.801	3.801	3.761	3.801	3.801	10
			3.761	3.721	3.721	3.761	3.721	3.721	11
			3.761	3.801	3.801	3.761	3.801	3.801	12
			3.761	3.761	3.761	3.761	3.761	3.761	13
			3.761	3.691	3.691	3.761	3.691	3.691	14
			3.761	3.741	0.000	3.761	3.741	3.741	15
			3.761	3.841	3.841	3.761	3.841	3.841	16
			3.761	3.761	3.761	3.761	3.761	3.761	17
			3.761	3.761	3.761	3.761	3.761	3.761	18
			3.761	3.731	3.731	3.761	3.731	3.731	19
			3.761	3.691	3.691	3.761	3.691	3.691	20
						3.761	3.761	3.761	21
						3.761	3.761	3.761	22
						3.761	3.721	3.721	23
						3.761	3.691	3.691	24
						3.761	3.781	3.781	25
						3.761	3.761	3.761	26
						3.761	3.711	3.711	27
						3.761	3.731	3.731	28
						3.761	3.841	3.841	29
						3.761	3.781	3.781	30

Length of Lateral 40 sections		(40 m) Final	Length of Lateral 50 sections		(50 m) Final	Length of Lateral 60 sections		(60 m) Final	Emitter
qi=khx	qf (final q)	I qf I	qi=khx	qf (final q)	I qf I	qi=khx	qf (final q)	I qf I	Number
3.762	3.687	3.687	3.761	3.686	3.686	3.761	3.686	3.686	1
3.761	3.761	3.761	3.761	3.761	3.761	3.761	3.761	3.761	2
3.761	3.691	3.691	3.761	3.691	3.691	3.761	3.691	3.691	3
3.761	3.761	3.761	3.761	3.761	3.761	3.760	3.760	3.760	4
3.761	3.841	3.841	3.760	3.840	3.840	3.760	3.840	3.840	5
3.761	3.691	3.691	3.760	3.690	3.690	3.760	3.690	3.690	6
3.761	3.711	3.711	3.760	3.710	3.710	3.759	3.709	3.709	7
3.760	3.780	3.780	3.760	3.780	3.780	3.759	3.779	3.779	8
3.760	3.720	3.720	3.760	3.720	3.720	3.759	3.719	3.719	9
3.760	3.800	3.800	3.759	3.799	3.799	3.758	3.798	3.798	10
3.760	3.720	3.720	3.759	3.719	3.719	3.758	3.718	3.718	11
3.760	3.800	3.800	3.759	3.799	3.799	3.758	3.798	3.798	12
3.760	3.760	3.760	3.759	3.759	3.759	3.758	3.758	3.758	13
3.760	3.690	3.690	3.759	3.689	3.689	3.757	3.687	3.687	14
3.760	3.740	3.740	3.759	3.739	3.739	3.757	3.737	3.737	15
3.760	3.840	3.840	3.758	3.838	3.838	3.757	3.837	3.837	16
3.760	3.760	3.760	3.758	3.758	3.758	3.757	3.757	3.757	17
3.760	3.760	3.760	3.758	3.758	3.758	3.756	3.756	3.756	18
3.760	3.730	3.730	3.758	3.728	3.728	3.756	3.726	3.726	19
3.759	3.689	3.689	3.758	3.688	3.688	3.756	3.686	3.686	20
3.759	3.759	3.759	3.758	3.758	3.758	3.756	3.756	3.756	21
3.759	3.759	3.759	3.758	3.758	3.758	3.756	3.756	3.756	22
3.759	3.719	3.719	3.758	3.718	3.718	3.756	3.716	3.716	23
3.759	3.689	3.689	3.758	3.688	3.688	3.755	3.685	3.685	24
3.759	3.779	3.779	3.757	3.777	3.777	3.755	3.775	3.775	25
3.759	3.759	3.759	3.757	3.757	3.757	3.755	3.755	3.755	26
3.759	3.709	3.709	3.757	3.707	3.707	3.755	3.705	3.705	27
3.759	3.729	3.729	3.757	3.727	3.727	3.755	3.725	3.725	28
3.759	3.839	3.839	3.757	3.837	3.837	3.755	3.835	3.835	29
3.759	3.779	3.779	3.757	3.777	3.777	3.755	3.775	3.775	30
3.759	3.759	3.759	3.757	3.757	3.757	3.754	3.754	3.754	31
3.759	3.759	3.759	3.757	3.757	3.757	3.754	3.754	3.754	32
3.759	3.699	3.699	3.757	3.697	3.697	3.754	3.694	3.694	33
3.759	3.719	3.719	3.757	3.717	3.717	3.754	3.714	3.714	34
3.759	3.689	3.689	3.757	3.687	3.687	3.754	3.684	3.684	35
3.759	3.759	3.759	3.757	3.757	3.757	3.754	3.754	3.754	36
3.759	3.799	3.799	3.757	3.797	3.797	3.754	3.794	3.794	37
3.759	3.789	3.789	3.757	3.787	3.787	3.754	3.784	3.784	38
3.759	3.729	3.729	3.757	3.727	3.727	3.754	3.724	3.724	39
3.759	3.769	3.769	3.757	3.767	3.767	3.754	3.764	3.764	40
			3.757	3.737	3.737	3.754	3.734	3.734	41
			3.757	3.817	3.817	3.754	3.814	3.814	42
			3.757	3.837	3.837	3.754	3.834	3.834	43
			3.757	3.757	3.757	3.754	3.754	3.754	44
			3.757	3.757	3.757	3.754	3.754	3.754	45
			3.757	3.707	3.707	3.754	3.704	3.704	46
			3.757	3.687	3.687	3.754	3.684	3.684	47
			3.757	3.727	3.727	3.753	3.723	3.723	48
			3.757	3.767	3.767	3.753	3.763	3.763	49
			3.757	3.687	3.687	3.753	3.683	3.683	50
						3.753	3.753	3.753	51
						3.753	3.773	3.773	52
						3.753	3.783	3.783	53
						3.753	3.823	3.823	54
						3.753	3.753	3.753	55
						3.753	3.793	3.793	56
						3.753	3.713	3.713	57
						3.753	3.743	3.743	58
						3.753	3.763	3.763	59
						3.753	3.703	3.703	60

Table A.3.16 Initial emitter flow (synthetic data) along the lateral before considering the impact of emitter manufacurer's coefficient of variations and pressure variations

Initial emitter flow along a 10 meter lateral

Emitter #	Stage1	Stage2	Stage3	stage4	stage5	stage6	stage7	stage8
1	3.705	3.705	3.705	1.700	3.705	3.705	3.705	3.705
2	3.780	3.780	3.780	1.000	3.780	3.780	3.780	3.780
3	3.710	3.710	3.710	2.100	3.710	2.100	3.710	3.710
4	3.780	3.780	1.700	3.780	1.700	3.780	3.780	3.780
5	3.860	3.860	1.000	3.860	3.860	3.860	1.000	3.860
6	3.710	3.710	2.100	3.710	3.710	3.710	3.710	3.710
7	3.730	3.730	3.730	3.730	1.000	3.730	3.730	3.730
8	3.800	1.700	3.800	3.800	3.800	1.000	3.800	1.000
9	3.740	1.000	3.740	3.740	2.100	3.740	3.740	3.740
10	3.820	2.100	3.820	3.820	3.820	3.820	3.820	3.820

10 meter

Initial emitter flow along a 20 meter lateral

Emitter #	Stage1	Stage2	Stage3	stage4	stage5	stage6	stage7	stage8
1	3.705	3.705	3.705	2.630	2.630	3.705	3.705	3.705
2	3.780	3.780	3.780	1.400	3.780	3.780	3.780	3.780
3	3.710	3.710	3.710	1.000	1.400	2.630	3.710	3.710
4	3.780	3.780	3.780	0.300	3.780	3.780	1.000	3.780
5	3.860	3.860	3.860	0.000	1.000	3.860	3.860	3.860
6	3.710	3.710	3.710	1.700	3.710	0.300	3.710	3.710
7	3.730	3.730	2.630	3.730	3.730	3.730	3.730	3.730
8	3.800	3.800	1.400	3.800	3.800	1.000	3.800	3.800
9	3.740	3.740	1.000	3.740	0.300	3.740	3.740	3.740
10	3.820	3.820	0.300	3.820	3.820	3.820	3.820	3.820
11	3.740	3.740	0.000	3.740	0.000	3.740	3.740	3.740
12	3.820	3.820	1.700	3.820	3.820	1.400	3.820	3.820
13	3.780	3.780	3.780	3.780	3.780	3.780	0.300	3.780
14	3.710	3.710	3.710	3.710	3.710	3.710	3.710	3.710
15	3.760	2.630	3.760	3.760	3.760	3.760	3.760	3.760
16	3.860	1.400	3.860	3.860	1.700	3.860	3.860	0.300
17	3.780	1.000	3.780	3.780	3.780	3.780	3.780	3.780
18	3.780	0.300	3.780	3.780	3.780	3.780	3.780	3.780
19	3.750	0.000	3.750	3.750	3.750	3.750	3.750	3.750
20	3.710	1.700	3.710	3.710	3.710	3.710	3.710	3.710

20 meter

Initial emitter flow along a 30 meter lateral

Emitter #	Stage1	Stage2	Stage3	stage4	stage5	stage6	stage7	stage8
1	3.705	3.705	3.705	2.630	3.705	3.705	3.705	3.705
2	3.780	3.780	3.780	1.400	2.630	3.780	3.780	3.780
3	3.710	3.710	3.710	1.000	3.710	3.710	3.710	3.710
4	3.780	3.780	3.780	0.300	3.780	3.780	3.780	3.780
5	3.860	3.860	3.860	0.000	3.860	1.400	3.860	3.860
6	3.710	3.710	3.710	2.100	3.710	3.710	3.710	3.710
7	3.730	3.730	3.730	3.000	1.400	1.000	3.730	3.730
8	3.800	3.800	3.800	1.900	3.800	3.800	3.800	3.800
9	3.740	3.740	3.740	1.700	3.740	3.740	3.740	3.740
10	3.820	3.820	3.820	3.820	3.820	3.820	3.820	3.820
11	3.740	3.740	2.630	3.740	3.740	3.740	3.740	3.740
12	3.820	3.820	1.400	3.820	1.000	3.820	3.820	1.700
13	3.780	3.780	1.000	3.780	3.780	3.780	3.780	3.780
14	3.710	3.710	0.300	3.710	3.710	3.710	3.710	3.710
15	3.760	3.760	0.000	3.760	0.300	3.760	2.630	3.760
16	3.860	3.860	2.100	3.860	3.860	2.100	3.860	3.860
17	3.780	3.780	3.000	3.780	3.780	3.780	3.780	3.780
18	3.780	3.780	1.900	3.780	3.780	1.900	3.780	2.100
19	3.750	3.750	1.700	3.750	0.000	3.750	0.300	3.750
20	3.710	3.710	3.710	3.710	2.100	3.710	3.710	3.710
21	3.780	3.780	3.780	3.780	3.780	3.780	3.780	3.780
22	3.780	2.630	3.780	3.780	3.000	2.630	3.780	3.780
23	3.740	1.400	3.740	3.740	3.740	3.740	3.740	3.740
24	3.710	1.000	3.710	3.710	3.710	3.710	3.710	3.710
25	3.800	0.300	3.800	3.800	3.800	3.800	3.800	3.800
26	3.780	0.000	3.780	3.780	3.780	3.780	3.780	3.780
27	3.730	2.100	3.730	3.730	3.730	3.730	0.000	3.730
28	3.750	3.000	3.750	3.750	1.900	0.300	3.750	3.750
29	3.860	1.900	3.860	3.860	3.860	3.860	3.860	3.860
30	3.800	1.700	3.800	3.800	1.700	3.800	3.800	3.800

30 meter

Table A.3.16 (continue)

Emitter #	Initial emitter flow along a 40 meter lateral							
	Stage1	Stage2	Stage3	stage4	stage5	stage6	stage7	stage8
1	3.705	3.705	3.705	2.630	3.705	3.705	3.705	3.705
2	3.780	3.780	3.780	2.800	3.780	3.780	3.780	3.780
3	3.710	3.710	3.710	1.400	3.710	3.710	3.710	3.710
4	3.780	3.780	3.780	1.000	2.630	3.780	3.780	3.780
5	3.860	3.860	3.860	0.300	3.860	2.630	3.860	3.860
6	3.710	3.710	3.710	2.100	3.710	3.710	3.710	3.710
7	3.730	3.730	3.730	3.000	3.730	3.730	3.730	3.730
8	3.800	3.800	3.800	1.900	2.800	1.400	2.800	3.800
9	3.740	3.740	3.740	2.700	1.100	3.740	3.740	3.740
10	3.820	3.820	3.820	1.000	3.820	3.820	3.820	3.820
11	3.740	3.740	3.740	0.500	3.740	3.740	3.740	3.740
12	3.820	3.820	3.820	1.100	3.820	3.820	3.820	3.820
13	3.780	3.780	3.780	3.780	3.780	3.780	1.400	3.780
14	3.710	3.710	2.630	3.710	1.400	2.800	3.710	0.500
15	3.760	3.760	2.800	3.760	3.760	3.760	3.760	3.760
16	3.860	3.860	1.400	3.860	3.860	3.860	0.300	3.860
17	3.780	3.780	1.000	3.780	3.780	3.780	3.780	3.780
18	3.780	3.780	0.300	3.780	3.780	3.780	3.780	3.780
19	3.750	3.750	2.100	3.750	3.750	0.500	3.750	3.750
20	3.710	3.710	3.000	3.710	1.000	3.710	3.710	3.710
21	3.780	3.780	1.900	3.780	0.500	3.780	3.780	3.780
22	3.780	3.780	2.700	3.780	3.780	3.780	3.780	3.780
23	3.740	3.740	1.000	3.740	3.740	0.300	3.740	3.740
24	3.710	3.710	0.500	3.710	3.710	3.710	3.710	3.710
25	3.800	3.800	1.100	3.800	3.800	3.800	3.800	3.800
26	3.780	3.780	3.780	3.780	3.780	3.780	3.780	3.780
27	3.730	3.730	3.730	3.730	0.300	3.730	3.730	3.730
28	3.750	3.750	3.750	3.750	3.750	3.750	3.750	3.750
29	3.860	2.630	3.860	3.860	3.860	3.860	3.860	3.860
30	3.800	2.800	3.800	3.800	2.100	2.100	3.800	3.800
31	3.780	1.400	3.780	3.780	3.780	3.780	3.780	2.700
32	3.780	1.000	3.780	3.780	3.780	3.780	3.780	3.780
33	3.720	0.300	3.720	3.720	3.000	3.720	1.100	3.720
34	3.740	2.100	3.740	3.740	3.740	3.740	3.740	3.740
35	3.710	3.000	3.710	3.710	1.900	3.710	3.710	3.710
36	3.780	1.900	3.780	3.780	3.780	3.780	3.780	3.780
37	3.820	2.700	3.820	3.820	2.700	3.820	3.820	3.820
38	3.810	1.000	3.810	3.810	3.810	3.810	3.810	3.810
39	3.750	0.500	3.750	3.750	3.750	1.900	3.750	3.750
40	3.790	1.100	3.790	3.790	1.000	0.000	3.790	3.790

40 meter

Emitter #	Initial emitter flow along a 50 meter lateral							
	Stage1	Stage2	Stage3	stage4	stage5	stage6	stage7	stage8
1	3.705	3.705	3.705	2.800	3.705	3.705	3.705	3.705
2	3.780	3.780	3.780	1.400	3.780	3.780	3.780	3.780
3	3.710	3.710	3.710	1.000	3.710	3.710	3.710	3.710
4	3.780	3.780	3.780	2.700	3.780	3.780	3.780	3.780
5	3.860	3.860	3.860	0.300	3.860	2.800	3.860	3.860
6	3.710	3.710	3.710	0.500	2.800	3.710	3.710	3.710
7	3.730	3.730	3.730	3.000	3.730	1.400	3.730	3.730
8	3.800	3.800	3.800	2.900	3.800	3.800	3.800	3.800
9	3.740	3.740	3.740	1.900	3.740	3.740	3.740	3.740
10	3.820	3.820	3.820	0.100	3.820	1.000	1.400	3.820
11	3.740	3.740	3.740	2.300	3.740	2.700	3.740	3.740
12	3.820	3.820	3.820	0.800	1.400	3.820	1.000	3.820
13	3.780	3.780	3.780	1.200	3.780	3.780	3.780	3.780
14	3.710	3.710	3.710	0.600	3.710	3.710	3.710	3.710
15	3.760	3.760	3.760	0.200	1.000	3.760	3.760	3.760
16	3.860	3.860	3.860	3.860	3.860	3.860	3.860	3.860
17	3.780	3.780	3.780	3.780	3.780	3.780	3.780	3.780
18	3.780	3.780	2.800	3.780	2.700	3.780	3.780	3.780
19	3.750	3.750	1.400	3.750	3.750	3.750	3.750	3.750
20	3.710	3.710	1.000	3.710	3.710	3.710	3.710	2.700
21	3.780	3.780	2.700	3.780	0.300	1.900	3.780	3.780
22	3.780	3.780	0.300	3.780	3.780	3.780	3.780	3.780
23	3.740	3.740	0.500	3.740	3.740	3.740	2.700	3.740
24	3.710	3.710	3.000	3.710	0.200	3.710	3.710	0.300
25	3.800	3.800	2.900	3.800	3.800	3.800	3.800	3.800
26	3.780	3.780	1.900	3.780	0.500	3.780	3.780	3.780
27	3.730	3.730	0.100	3.730	3.730	3.730	3.730	3.730
28	3.750	3.750	2.300	3.750	3.000	3.750	3.750	3.750
29	3.860	3.860	0.800	3.860	3.860	3.860	3.860	3.860
30	3.800	3.800	1.200	3.800	3.800	3.800	3.800	3.800
31	3.780	3.780	0.600	3.780	3.780	3.780	3.780	3.780
32	3.780	3.780	0.200	3.780	2.900	3.780	3.780	3.780
33	3.720	3.720	3.720	3.720	3.720	3.720	3.720	3.720
34	3.740	3.740	3.740	3.740	3.740	3.740	3.740	3.740
35	3.710	3.710	3.710	3.710	3.710	0.300	3.710	3.710
36	3.780	2.800	3.780	3.780	1.900	3.780	3.780	3.780
37	3.820	1.400	3.820	3.820	3.820	0.500	3.820	3.820
38	3.810	1.000	3.810	3.810	0.100	3.810	3.810	3.810
39	3.750	2.700	3.750	3.750	3.750	3.750	3.750	3.750
40	3.790	0.300	3.790	3.790	3.790	3.790	3.790	3.790
41	3.760	0.500	3.760	3.760	2.300	3.760	3.760	0.100
42	3.840	3.000	3.840	3.840	3.840	3.840	3.840	3.840
43	3.860	2.900	3.860	3.860	3.860	3.860	0.300	3.860
44	3.780	1.900	3.780	3.780	0.800	3.000	3.780	3.780
45	3.780	0.100	3.780	3.780	3.780	3.780	3.780	3.780
46	3.730	2.300	3.730	3.730	3.730	3.730	3.730	3.730
47	3.710	0.800	3.710	3.710	1.200	2.900	0.100	3.710
48	3.750	1.200	3.750	3.750	3.750	3.750	3.750	3.750
49	3.790	0.600	3.790	3.790	3.790	3.790	3.790	3.790
50	3.710	0.200	3.710	3.710	0.600	0.100	3.710	3.710

50 meter

Emitter #	Initial emitter flowalong a 60 meter lateral							
	Stage1	Stage2	Stage3	stage4	stage5	stage6	stage7	stage8
1	3.705	3.705	3.705	2.800	3.705	3.705	3.705	3.705
2	3.780	3.780	3.780	1.400	2.800	3.780	3.780	3.780
3	3.710	3.710	3.710	1.000	3.710	3.710	3.710	3.710
4	3.780	3.780	3.780	2.700	3.780	3.780	3.780	3.780
5	3.860	3.860	3.860	0.300	3.860	2.800	3.860	3.860
6	3.710	3.710	3.710	0.800	1.400	3.710	3.710	3.710
7	3.730	3.730	3.730	3.000	3.730	2.700	3.730	3.730
8	3.800	3.800	3.800	2.900	3.800	3.800	3.800	3.800
9	3.740	3.740	3.740	1.900	3.740	0.300	3.740	3.740
10	3.820	3.820	3.820	0.100	1.000	3.820	3.820	3.820
11	3.740	3.740	3.740	2.300	3.740	3.000	3.740	3.740
12	3.820	3.820	3.820	0.500	3.820	3.820	3.820	3.820
13	3.780	3.780	3.780	1.200	3.780	3.780	3.780	3.780
14	3.710	3.710	3.710	2.900	2.700	3.710	3.710	3.710
15	3.760	3.760	3.760	0.200	3.760	3.760	3.760	3.760
16	3.860	3.860	3.860	1.100	3.860	3.860	3.860	3.860
17	3.780	3.780	3.780	0.000	3.780	3.780	3.780	3.780
18	3.780	3.780	3.780	0.300	3.780	3.780	3.780	3.780
19	3.750	3.750	3.750	3.750	3.750	3.750	3.750	3.750
20	3.710	3.710	3.710	3.710	3.710	3.710	3.710	3.710
21	3.780	3.780	2.800	3.780	0.300	2.900	3.780	3.780
22	3.780	3.780	1.400	3.780	3.780	3.780	3.780	3.780
23	3.740	3.740	1.000	3.740	3.740	0.100	3.740	3.740
24	3.710	3.710	2.700	3.710	0.300	3.710	3.710	3.710
25	3.800	3.800	0.300	3.800	0.800	3.800	3.800	3.800
26	3.780	3.780	0.800	3.780	3.780	3.780	3.780	3.780
27	3.730	3.730	3.000	3.730	3.730	3.730	3.730	1.200
28	3.750	3.750	2.900	3.750	3.000	3.750	1.400	3.750
29	3.860	3.860	1.900	3.860	3.860	3.860	3.860	3.860
30	3.800	3.800	0.100	3.800	3.800	3.800	3.800	3.800
31	3.780	3.780	2.300	3.780	2.900	3.780	3.780	3.780
32	3.780	3.780	0.500	3.780	3.780	3.780	1.900	3.780
33	3.720	3.720	1.200	3.720	3.720	2.300	3.720	3.720
34	3.740	3.740	2.900	3.740	1.900	3.740	3.740	3.740
35	3.710	3.710	0.200	3.710	0.100	3.710	3.710	3.710
36	3.780	3.780	1.100	3.780	3.780	3.780	3.780	3.780
37	3.820	3.820	0.000	3.820	3.820	3.820	3.820	3.820
38	3.810	3.810	0.300	3.810	2.300	3.810	3.810	2.700
39	3.750	3.750	3.750	3.750	3.750	0.500	3.750	3.750
40	3.790	3.790	3.790	3.790	3.790	3.790	3.790	3.790
41	3.760	3.760	3.760	3.760	0.500	3.760	2.900	3.760
42	3.840	3.840	3.840	3.840	3.840	3.840	0.100	3.840
43	3.860	2.800	3.860	3.860	3.860	1.200	3.860	3.860
44	3.780	1.400	3.780	3.780	3.780	3.780	3.780	3.780
45	3.780	1.000	3.780	3.780	3.780	3.780	3.780	3.780
46	3.730	2.700	3.730	3.730	3.730	3.730	3.730	3.730
47	3.710	0.300	3.710	3.710	3.710	3.710	0.300	3.710
48	3.750	0.800	3.750	3.750	1.200	3.750	3.750	3.750
49	3.790	3.000	3.790	3.790	3.790	3.790	3.790	3.790
50	3.710	2.900	3.710	3.710	3.710	0.200	3.710	3.710
51	3.780	1.900	3.780	3.780	0.000	3.780	3.780	3.780
52	3.800	0.100	3.800	3.800	3.800	3.800	3.800	3.800
53	3.810	2.300	3.810	3.810	3.810	3.810	3.810	3.810
54	3.850	0.500	3.850	3.850	2.900	3.850	3.850	3.850
55	3.780	1.200	3.780	3.780	3.780	3.780	0.000	3.780
56	3.820	2.900	3.820	3.820	1.100	1.100	3.820	0.100
57	3.740	0.200	3.740	3.740	3.740	3.740	3.740	3.740
58	3.770	1.100	3.770	3.770	3.770	3.770	3.770	3.770
59	3.790	0.000	3.790	3.790	0.200	3.790	3.790	3.790
60	3.730	0.300	3.730	3.730	3.730	0.000	3.730	3.730

60 meter

Table A.5.1 Values of K%, q%, and C_d% for the 10, 30, 40, 50, and 60 meter laterals on flat terrain, when 30% of emitters are partially clogged and located at one-third from the down stream end (ynthetic data)

10 meters lateral						20 meters lateral						30 meters lateral					
q_i	h_i	k_i	K%	q%	C_d%	q_i	h_i	k_i	K%	q%	Cd%	q_i	h_i	k_i	K%	q%	Cd%
3.69	10.56	3.08	1.99	2.47	1.99	3.69	10.56	3.08	1.99	2.47	1.99	3.69	10.56	3.08	1.99	2.47	1.99
3.76	10.56	3.15	0.00	0.00	0.00	3.76	10.56	3.15	0.00	0.00	0.00	3.76	10.56	3.15	0.00	0.00	0.00
3.69	10.56	3.09	1.86	2.34	1.86	3.69	10.56	3.09	1.86	2.34	1.86	3.69	10.55	3.09	1.86	2.34	1.86
3.76	10.56	3.15	0.00	0.00	0.00	3.76	10.56	3.15	0.00	0.00	0.00	3.76	10.55	3.15	0.00	0.00	0.00
3.84	10.56	3.15	0.00	0.00	0.00	3.84	10.56	3.15	0.00	0.00	0.00	3.84	10.55	3.15	0.00	0.00	0.00
3.69	10.56	3.09	1.86	2.34	1.86	3.69	10.56	3.09	1.86	2.34	1.86	3.69	10.55	3.09	1.86	2.34	1.86
3.71	10.56	3.11	1.33	1.81	1.33	3.71	10.55	3.11	1.33	1.81	1.33	3.71	10.55	3.11	1.33	1.82	1.33
1.68	10.56	1.41	55.29	55.51	55.29	3.78	10.55	3.15	0.00	0.00	0.00	3.78	10.55	3.15	0.00	0.00	0.00
0.98	10.56	0.82	73.90	74.03	73.90	3.72	10.55	3.11	1.06	1.55	1.06	3.72	10.54	3.11	1.06	1.55	1.06
2.08	10.56	1.74	44.66	44.93	44.66	3.80	10.55	3.15	0.00	0.00	0.00	3.80	10.54	3.15	0.00	0.00	0.00
						3.72	10.55	3.11	1.06	1.55	1.06	3.72	10.54	3.11	1.06	1.55	1.06
						3.80	10.55	3.15	0.00	0.00	0.00	3.80	10.54	3.15	0.00	0.00	0.00
						3.76	10.55	3.15	0.00	0.00	0.00	3.76	10.54	3.15	0.00	0.00	0.00
						3.69	10.55	3.09	1.86	2.34	1.86	3.69	10.54	3.09	1.86	2.35	1.86
						2.61	10.55	2.18	30.57	30.91	30.57	3.74	10.54	3.13	0.53	1.03	0.53
						1.38	10.55	1.16	63.27	63.45	63.27	3.84	10.54	3.15	0.00	0.00	0.00
						0.98	10.55	0.82	73.91	74.03	73.91	3.76	10.54	3.15	0.00	0.00	0.00
						0.28	10.55	0.24	92.52	92.55	92.52	3.76	10.54	3.15	0.00	0.00	0.00
						0.00	10.55	0.00	100.00	100.00	100.00	3.73	10.54	3.12	0.80	1.29	0.80
						1.68	10.55	1.41	55.30	55.51	55.30	3.69	10.54	3.09	1.86	2.35	1.86
												3.76	10.54	3.15	0.00	0.00	0.00
												2.61	10.54	2.18	30.58	30.92	30.58
												1.38	10.54	1.16	63.28	63.46	63.28
												0.98	10.53	0.82	73.92	74.05	73.92
												0.28	10.53	0.24	92.53	92.56	92.53
												0.00	10.53	0.00	100.00	100.00	100.00
												2.08	10.53	1.74	44.67	44.95	44.67
												2.98	10.53	2.49	20.74	21.14	20.74
												1.88	10.53	1.57	49.99	50.24	49.99
												1.68	10.53	1.41	55.30	55.53	55.30

Continue (table A.5.1)

40 meters lateral						50 meters lateral						60 meters lateral					
q_i	h_i	k_i	K%	q%	Cd%	q_i	h_i	k_i	K%	q%	Cd%	q_i	h_i	k_i	K%	q%	Cd%
3.69	10.56	3.08	1.99	2.47	1.99	3.69	10.55	3.08	1.99	2.47	1.99	3.69	10.55	3.08	1.99	2.47	1.99
3.76	10.55	3.15	0.00	0.00	0.00	3.76	10.55	3.15	0.00	0.00	0.00	3.76	10.54	3.15	0.00	0.00	0.00
3.69	10.55	3.09	1.86	2.34	1.86	3.69	10.54	3.09	1.86	2.35	1.86	3.69	10.54	3.09	1.86	2.35	1.86
3.76	10.54	3.15	0.00	0.00	0.00	3.76	10.54	3.15	0.00	0.00	0.00	3.76	10.53	3.15	0.00	0.00	0.00
3.84	10.54	3.15	0.00	0.00	0.00	3.84	10.53	3.15	0.00	0.00	0.00	3.84	10.52	3.15	0.00	0.00	0.00
3.69	10.54	3.09	1.86	2.35	1.86	3.69	10.53	3.09	1.86	2.36	1.86	3.69	10.52	3.09	1.86	2.37	1.86
3.71	10.54	3.11	1.33	1.82	1.33	3.71	10.52	3.11	1.33	1.83	1.33	3.71	10.51	3.11	1.33	1.84	1.33
3.78	10.53	3.15	0.00	0.00	0.00	3.78	10.52	3.15	0.00	0.00	0.00	3.78	10.50	3.15	0.00	0.00	0.00
3.72	10.53	3.11	1.06	1.56	1.06	3.72	10.52	3.11	1.06	1.57	1.06	3.72	10.50	3.11	1.06	1.59	1.06
3.80	10.53	3.15	0.00	0.00	0.00	3.80	10.51	3.15	0.00	0.00	0.00	3.80	10.49	3.15	0.00	0.00	0.00
3.72	10.52	3.11	1.06	1.57	1.06	3.72	10.51	3.11	1.06	1.58	1.06	3.72	10.49	3.11	1.06	1.59	1.06
3.80	10.52	3.15	0.00	0.00	0.00	3.80	10.50	3.15	0.00	0.00	0.00	3.80	10.48	3.15	0.00	0.00	0.00
3.76	10.52	3.15	0.00	0.00	0.00	3.76	10.50	3.15	0.00	0.00	0.00	3.76	10.47	3.15	0.00	0.00	0.00
3.69	10.52	3.09	1.86	2.36	1.86	3.69	10.50	3.09	1.86	2.38	1.86	3.69	10.47	3.09	1.86	2.40	1.86
3.74	10.52	3.13	0.53	1.04	0.53	3.74	10.49	3.13	0.53	1.06	0.53	3.74	10.47	3.13	0.53	1.08	0.53
3.84	10.52	3.15	0.00	0.00	0.00	3.84	10.49	3.15	0.00	0.00	0.00	3.84	10.46	3.15	0.00	0.00	0.00
3.76	10.51	3.15	0.00	0.00	0.00	3.76	10.49	3.15	0.00	0.00	0.00	3.76	10.46	3.15	0.00	0.00	0.00
3.76	10.51	3.15	0.00	0.00	0.00	3.76	10.49	3.15	0.00	0.00	0.00	3.76	10.45	3.15	0.00	0.00	0.00
3.73	10.51	3.12	0.80	1.31	0.80	3.73	10.48	3.12	0.80	1.33	0.80	3.73	10.45	3.12	0.80	1.36	0.80
3.69	10.51	3.09	1.86	2.37	1.86	3.69	10.48	3.09	1.86	2.39	1.86	3.69	10.44	3.09	1.86	2.42	1.86
3.76	10.51	3.15	0.00	0.00	0.00	3.76	10.48	3.15	0.00	0.00	0.00	3.76	10.44	3.15	0.00	0.00	0.00
3.76	10.51	3.15	0.00	0.00	0.00	3.76	10.48	3.15	0.00	0.00	0.00	3.76	10.44	3.15	0.00	0.00	0.00
3.72	10.51	3.11	1.06	1.58	1.06	3.72	10.48	3.11	1.06	1.60	1.06	3.72	10.43	3.11	1.06	1.63	1.06
3.69	10.51	3.09	1.86	2.37	1.86	3.69	10.47	3.09	1.86	2.40	1.86	3.69	10.43	3.09	1.86	2.43	1.86
3.78	10.50	3.15	0.00	0.00	0.00	3.78	10.47	3.16	0.00	0.00	0.00	3.78	10.43	3.16	0.00	0.00	0.00
3.76	10.50	3.15	0.00	0.00	0.00	3.76	10.47	3.15	0.00	0.00	0.00	3.76	10.42	3.15	0.00	0.00	0.00
3.71	10.50	3.11	1.33	1.85	1.33	3.71	10.47	3.11	1.33	1.87	1.33	3.71	10.42	3.11	1.33	1.91	1.33
3.73	10.50	3.12	0.80	1.32	0.80	3.73	10.47	3.12	0.80	1.34	0.80	3.73	10.42	3.12	0.80	1.38	0.80
2.61	10.50	2.18	30.58	30.95	30.58	3.84	10.47	3.15	0.00	0.00	0.00	3.84	10.42	3.15	0.00	0.00	0.00
2.78	10.50	2.33	26.06	26.45	26.06	3.78	10.47	3.16	0.00	0.00	0.00	3.78	10.41	3.16	0.00	0.00	0.00
1.38	10.50	1.16	63.29	63.49	63.29	3.76	10.46	3.15	0.00	0.00	0.00	3.76	10.41	3.15	0.00	0.00	0.00
0.98	10.50	0.82	73.93	74.07	73.93	3.76	10.46	3.15	0.00	0.00	0.00	3.76	10.41	3.15	0.00	0.00	0.00
0.28	10.50	0.23	92.55	92.59	92.55	3.70	10.46	3.10	1.60	2.14	1.60	3.70	10.41	3.10	1.60	2.18	1.60
2.08	10.50	1.74	44.68	44.97	44.68	3.72	10.46	3.11	1.06	1.61	1.06	3.72	10.41	3.11	1.06	1.65	1.06
2.98	10.50	2.49	20.74	21.16	20.74	3.69	10.46	3.09	1.86	2.41	1.86	3.69	10.40	3.09	1.86	2.45	1.86
1.88	10.50	1.57	50.00	50.26	50.00	2.78	10.46	2.33	26.07	26.48	26.07	3.76	10.40	3.15	0.00	0.00	0.00
2.68	10.50	2.24	28.72	29.10	28.72	1.38	10.46	1.15	63.31	63.52	63.31	3.80	10.40	3.15	0.00	0.00	0.00
0.98	10.50	0.82	73.93	74.07	73.93	0.98	10.46	0.82	73.96	74.10	73.96	3.79	10.40	3.15	0.00	0.00	0.00
0.48	10.50	0.40	87.23	87.30	87.23	2.68	10.46	2.24	28.73	29.13	28.73	3.73	10.40	3.12	0.80	1.39	0.80
1.08	10.50	0.90	71.27	71.42	71.27	0.28	10.46	0.23	92.58	92.62	92.58	3.77	10.40	3.16	0.00	0.00	0.00
						0.48	10.46	0.40	87.26	87.33	87.26	3.74	10.40	3.13	0.53	1.13	0.53
						2.98	10.46	2.49	20.75	21.19	20.75	3.82	10.40	3.15	0.00	0.00	0.00
						2.88	10.46	2.41	23.41	23.84	23.41	2.78	10.40	2.33	26.08	26.53	26.08
						1.88	10.46	1.57	50.01	50.29	50.01	1.38	10.39	1.15	63.34	63.57	63.34
						0.08	10.46	0.07	97.90	97.91	97.90	0.98	10.39	0.82	73.99	74.15	73.99
						2.28	10.46	1.91	39.37	39.71	39.37	2.68	10.39	2.24	28.74	29.17	28.74
						0.78	10.46	0.65	79.28	79.39	79.28	0.28	10.39	0.23	92.62	92.67	92.62
						1.18	10.46	0.99	68.64	68.81	68.64	0.78	10.39	0.65	79.31	79.44	79.31
						0.58	10.46	0.48	84.60	84.68	84.60	2.98	10.39	2.49	20.76	21.24	20.76
						0.18	10.46	0.15	95.24	95.27	95.24	2.88	10.39	2.41	23.42	23.88	23.42
												1.88	10.39	1.57	50.04	50.34	50.04
												0.08	10.39	0.06	97.95	97.96	97.95
												2.28	10.39	1.91	39.39	39.76	39.39
												0.48	10.39	0.40	87.30	87.38	87.30
												1.18	10.39	0.99	68.67	68.86	68.67
												2.88	10.39	2.41	23.42	23.89	23.42
												0.18	10.39	0.15	95.29	95.31	95.29
												1.08	10.39	0.90	71.33	71.50	71.33
												0.00	10.39	0.00	100.00	100.00	100.00
												0.28	10.39	0.23	92.62	92.67	92.62

Table A.5.2 Comparison of adjusted F factor in multi outlet head loss equations suggested by Christiansen (F), Jensen (F'), Walker (F''), and Gohering (F''').

$F = 1/(m+1) + 1/2N + (m-1)^{0.5}/6N^2$	F by: Christiansen, 1942
$F' = 1/(2N-1) + 2\,[(N-1)^m + (N-2^m + \ldots 1^m]/(2N-1)N$	F' by:Jensen and Fratini,1957
$F'' = [(2N/2N-1)F] - 1/(2N-1)$	F'' by: Walker, 1976
$F''' = 0.63837(N)^{-1.8916} + 0.35929$	F''' by: Gohering, 1976)
N 1 - 200	**m** 1.852

# of emitter	F	F'	F''	F'''
1	1.0045	1.0000	1.0089	0.9977
2	0.6391	0.5180	0.5188	0.5313
3	0.5344	0.4411	0.4413	0.4392
4	0.4852	0.4116	0.4117	0.4057
5	0.4568	0.3964	0.3964	0.3897
6	0.4382	0.3871	0.3872	0.3808
7	0.4252	0.3810	0.3810	0.3754
8	0.4155	0.3766	0.3766	0.3718
9	0.4081	0.3733	0.3733	0.3693
10	0.4022	0.3707	0.3707	0.3675
11	0.3974	0.3687	0.3687	0.3661
12	0.3934	0.3670	0.3670	0.3651
13	0.3900	0.3656	0.3656	0.3643
14	0.3871	0.3644	0.3644	0.3636
15	0.3846	0.3634	0.3634	0.3631
16	0.3825	0.3626	0.3626	0.3627
17	0.3806	0.3618	0.3618	0.3623
18	0.3789	0.3611	0.3611	0.3620
19	0.3774	0.3605	0.3605	0.3617
20	0.3760	0.3600	0.3600	0.3615
21	0.3748	0.3595	0.3595	0.3613
22	0.3737	0.3588	0.3591	0.3611
23	0.3727	0.3587	0.3587	0.3610
24	0.3717	0.3579	0.3584	0.3609
25	0.3709	0.3572	0.3580	0.3607
26	0.3701	0.3565	0.3577	0.3606
27	0.3694	0.3558	0.3575	0.3605
28	0.3687	0.3551	0.3572	0.3605
29	0.3681	0.3544	0.3570	0.3604
30	0.3675	0.3538	0.3567	0.3603
31	0.3669	0.3532	0.3565	0.3603
32	0.3664	0.3527	0.3563	0.3602
33	0.3659	0.3521	0.3562	0.3601
34	0.3655	0.3516	0.3560	0.3601
35	0.3650	0.3510	0.3558	0.3601

Table A.5.2 (continued)

36	0.3646	0.3504	0.3557	0.3600
37	0.3643	0.3551	0.3555	0.3600
38	0.3639	0.3545	0.3554	0.3599
39	0.3636	0.3538	0.3553	0.3599
40	0.3632	0.3533	0.3552	0.3599
41	0.3629	0.3527	0.3551	0.3599
42	0.3626	0.3522	0.3549	0.3598
43	0.3623	0.3516	0.3548	0.3598
44	0.3621	0.3510	0.3547	0.3598
45	0.3618	0.3504	0.3546	0.3598
46	0.3616	0.3552	0.3546	0.3597
47	0.3613	0.3545	0.3545	0.3597
48	0.3611	0.3539	0.3544	0.3597
49	0.3609	0.3533	0.3543	0.3597
50	0.3607	0.3527	0.3542	0.3597
51	0.3605	0.3522	0.3542	0.3597
52	0.3603	0.3516	0.3541	0.3597
53	0.3601	0.3510	0.3540	0.3596
54	0.3599	0.3504	0.3540	0.3596
55	0.3598	0.3552	0.3539	0.3596
56	0.3596	0.3545	0.3538	0.3596
57	0.3595	0.3539	0.3538	0.3596
58	0.3593	0.3533	0.3537	0.3596
59	0.3591	0.3527	0.3537	0.3596
60	0.3590	0.3522	0.3536	0.3596
61	0.3589	0.3516	0.3536	0.3596
62	0.3587	0.3510	0.3535	0.3595
63	0.3586	0.3504	0.3535	0.3595
64	0.3585	0.3552	0.3534	0.3595
65	0.3584	0.3545	0.3534	0.3595
66	0.3582	0.3539	0.3533	0.3595
67	0.3581	0.3533	0.3533	0.3595
68	0.3580	0.3527	0.3533	0.3595
69	0.3579	0.3522	0.3532	0.3595
70	0.3578	0.3516	0.3532	0.3595

Table A.5.2 (continued)

71	0.3577	0.3510	0.3531	0.3595
72	0.3576	0.3504	0.3531	0.3595
73	0.3575	0.3552	0.3531	0.3595
74	0.3574	0.3545	0.3530	0.3595
75	0.3573	0.3539	0.3530	0.3595
76	0.3572	0.3533	0.3530	0.3595
77	0.3572	0.3527	0.3529	0.3595
78	0.3571	0.3522	0.3529	0.3595
79	0.3570	0.3516	0.3529	0.3595
80	0.3569	0.3510	0.3529	0.3595
81	0.3568	0.3504	0.3528	0.3594
82	0.3568	0.3552	0.3528	0.3594
83	0.3567	0.3545	0.3528	0.3594
84	0.3566	0.3539	0.3528	0.3594
85	0.3565	0.3533	0.3527	0.3594
86	0.3565	0.3527	0.3527	0.3594
87	0.3564	0.3522	0.3527	0.3594
88	0.3563	0.3516	0.3527	0.3594
89	0.3563	0.3510	0.3526	0.3594
90	0.3562	0.3504	0.3526	0.3594
91	0.3561	0.3552	0.3526	0.3594
92	0.3561	0.3545	0.3526	0.3594
93	0.3560	0.3539	0.3525	0.3594
94	0.3560	0.3533	0.3525	0.3594
95	0.3559	0.3527	0.3525	0.3594
96	0.3559	0.3522	0.3525	0.3594
97	0.3558	0.3516	0.3525	0.3594
98	0.3557	0.3510	0.3524	0.3594
99	0.3557	0.3504	0.3524	0.3594
100	0.3556	0.3552	0.3524	0.3594
101	0.3556	0.3545	0.3524	0.3594
102	0.3555	0.3539	0.3524	0.3594
103	0.3555	0.3533	0.3524	0.3594
104	0.3555	0.3527	0.3523	0.3594
105	0.3554	0.3522	0.3523	0.3594
106	0.3554	0.3516	0.3523	0.3594
107	0.3553	0.3510	0.3523	0.3594
108	0.3553	0.3504	0.3523	0.3594
109	0.3552	0.3552	0.3523	0.3594
110	0.3552	0.3545	0.3522	0.3594
111	0.3551	0.3539	0.3522	0.3594
112	0.3551	0.3533	0.3522	0.3594
113	0.3551	0.3527	0.3522	0.3594
114	0.3550	0.3522	0.3522	0.3594
115	0.3550	0.3516	0.3522	0.3594
116	0.3550	0.3510	0.3522	0.3594

Table A.5.2 (continued)

117	0.3549	0.3504	0.3521	0.3594
118	0.3549	0.3552	0.3521	0.3594
119	0.3548	0.3545	0.3521	0.3594
120	0.3548	0.3539	0.3521	0.3594
121	0.3548	0.3533	0.3521	0.3594
122	0.3547	0.3527	0.3521	0.3594
123	0.3547	0.3522	0.3521	0.3594
124	0.3547	0.3516	0.3521	0.3594
125	0.3546	0.3510	0.3520	0.3594
126	0.3546	0.3504	0.3520	0.3594
127	0.3546	0.3552	0.3520	0.3594
128	0.3545	0.3545	0.3520	0.3594
129	0.3545	0.3539	0.3520	0.3594
130	0.3545	0.3533	0.3520	0.3594
131	0.3545	0.3527	0.3520	0.3594
132	0.3544	0.3522	0.3520	0.3594
133	0.3544	0.3516	0.3520	0.3594
134	0.3544	0.3510	0.3520	0.3594
135	0.3543	0.3504	0.3519	0.3593
136	0.3543	0.3552	0.3519	0.3593
137	0.3543	0.3545	0.3519	0.3593
138	0.3543	0.3539	0.3519	0.3593
139	0.3542	0.3533	0.3519	0.3593
140	0.3542	0.3527	0.3519	0.3593
141	0.3542	0.3522	0.3519	0.3593
142	0.3542	0.3516	0.3519	0.3593
143	0.3541	0.3510	0.3519	0.3593
144	0.3541	0.3504	0.3519	0.3593
145	0.3541	0.3552	0.3519	0.3593
146	0.3541	0.3545	0.3518	0.3593
147	0.3540	0.3539	0.3518	0.3593
148	0.3540	0.3533	0.3518	0.3593
149	0.3540	0.3527	0.3518	0.3593
150	0.3540	0.3522	0.3518	0.3593
151	0.3539	0.3516	0.3518	0.3593
152	0.3539	0.3510	0.3518	0.3593
153	0.3539	0.3504	0.3518	0.3593
154	0.3539	0.3552	0.3518	0.3593
155	0.3539	0.3545	0.3518	0.3593
156	0.3538	0.3539	0.3518	0.3593
157	0.3538	0.3533	0.3518	0.3593
158	0.3538	0.3527	0.3518	0.3593
159	0.3538	0.3522	0.3517	0.3593
160	0.3538	0.3516	0.3517	0.3593
161	0.3537	0.3510	0.3517	0.3593
162	0.3537	0.3504	0.3517	0.3593

Table A.5.2 (continued)

163	0.3537	0.3552	0.3517	0.3593
164	0.3537	0.3545	0.3517	0.3593
165	0.3537	0.3539	0.3517	0.3593
166	0.3536	0.3533	0.3517	0.3593
167	0.3536	0.3527	0.3517	0.3593
168	0.3536	0.3522	0.3517	0.3593
169	0.3536	0.3516	0.3517	0.3593
170	0.3536	0.3510	0.3517	0.3593
171	0.3536	0.3504	0.3517	0.3593
172	0.3535	0.3552	0.3517	0.3593
173	0.3535	0.3545	0.3517	0.3593
174	0.3535	0.3539	0.3516	0.3593
175	0.3535	0.3533	0.3516	0.3593
176	0.3535	0.3527	0.3516	0.3593
177	0.3535	0.3522	0.3516	0.3593
178	0.3534	0.3516	0.3516	0.3593
179	0.3534	0.3510	0.3516	0.3593
180	0.3534	0.3504	0.3516	0.3593
181	0.3534	0.3552	0.3516	0.3593
182	0.3534	0.3545	0.3516	0.3593
183	0.3534	0.3539	0.3516	0.3593
184	0.3534	0.3533	0.3516	0.3593
185	0.3533	0.3527	0.3516	0.3593
186	0.3533	0.3522	0.3516	0.3593
187	0.3533	0.3516	0.3516	0.3593
188	0.3533	0.3510	0.3516	0.3593
189	0.3533	0.3504	0.3516	0.3593
190	0.3533	0.3552	0.3516	0.3593
191	0.3533	0.3545	0.3516	0.3593
192	0.3532	0.3539	0.3516	0.3593
193	0.3532	0.3533	0.3515	0.3593
194	0.3532	0.3527	0.3515	0.3593
195	0.3532	0.3522	0.3515	0.3593
196	0.3532	0.3516	0.3515	0.3593
197	0.3532	0.3510	0.3515	0.3593
198	0.3532	0.3504	0.3515	0.3593
199	0.3531	0.3552	0.3515	0.3593
200	0.3531	0.3545	0.3515	0.3593

Table A.5.3 Total head loss and pressure per section along the lateral laid on flat terrain under different patterns of clogging

Section	Length Ratio	Stage 1		Stage 2		Stage 3		Stage 4		Stage 5		Stage 6		Stage 7		Stage 8	
		T.Hf(m)*	Hi(m)**	T.Hf(m)	Hi(m)	T.Hf(m)	Hi(m)	T.Hf(m)	Hi(m)	T.Hf(m)	Hi(m)	T.Hf(m)	Hi(m)	T.Hf(m)	Hi(m)	T.Hf(m)	Hi(m)
0	0.00	0.000	10.560	0.000	10.560	0.000	10.560	0.000	10.560	0.000	10.560	0.000	10.560	0.000	10.560	0.000	10.560
1	0.05	0.002	10.558	0.001	10.559	0.001	10.559	0.001	10.558	0.001	10.559	0.001	10.559	0.001	10.559	0.002	10.558
2	0.10	0.003	10.557	0.002	10.558	0.002	10.558	0.002	10.557	0.002	10.557	0.003	10.557	0.003	10.557	0.003	10.557
3	0.15	0.005	10.555	0.003	10.557	0.003	10.556	0.004	10.556	0.003	10.556	0.004	10.556	0.004	10.556	0.004	10.556
4	0.20	0.006	10.554	0.004	10.557	0.004	10.556	0.005	10.555	0.004	10.555	0.005	10.555	0.005	10.555	0.006	10.554
5	0.25	0.007	10.553	0.005	10.556	0.005	10.555	0.006	10.554	0.005	10.555	0.006	10.554	0.006	10.554	0.007	10.553
6	0.30	0.008	10.552	0.005	10.555	0.006	10.554	0.006	10.553	0.006	10.554	0.007	10.553	0.007	10.553	0.008	10.552
7	0.35	0.009	10.551	0.006	10.555	0.006	10.553	0.007	10.552	0.007	10.553	0.007	10.552	0.008	10.552	0.008	10.552
8	0.40	0.010	10.550	0.006	10.554	0.007	10.553	0.008	10.551	0.007	10.552	0.008	10.552	0.008	10.552	0.009	10.551
9	0.45	0.011	10.549	0.006	10.554	0.007	10.552	0.009	10.551	0.008	10.552	0.009	10.551	0.009	10.551	0.010	10.550
10	0.50	0.011	10.549	0.007	10.554	0.008	10.552	0.009	10.550	0.008	10.552	0.009	10.551	0.009	10.551	0.010	10.550
11	0.55	0.012	10.548	0.007	10.553	0.008	10.551	0.010	10.550	0.008	10.551	0.010	10.550	0.010	10.550	0.011	10.549
12	0.60	0.012	10.548	0.007	10.553	0.008	10.551	0.010	10.550	0.009	10.551	0.010	10.550	0.010	10.550	0.011	10.549
13	0.65	0.012	10.547	0.007	10.553	0.009	10.551	0.011	10.549	0.009	10.551	0.010	10.550	0.010	10.550	0.011	10.549
14	0.70	0.013	10.547	0.007	10.553	0.009	10.551	0.011	10.549	0.009	10.551	0.010	10.549	0.010	10.550	0.011	10.548
15	0.75	0.013	10.547	0.007	10.553	0.009	10.551	0.011	10.549	0.010	10.550	0.011	10.549	0.011	10.549	0.012	10.548
16	0.80	0.013	10.547	0.007	10.553	0.009	10.551	0.011	10.549	0.010	10.550	0.011	10.549	0.011	10.549	0.012	10.548
17	0.85	0.013	10.547	0.007	10.553	0.009	10.551	0.011	10.549	0.010	10.550	0.011	10.549	0.011	10.549	0.012	10.548
18	0.90	0.013	10.547	0.007	10.553	0.009	10.551	0.011	10.549	0.010	10.550	0.011	10.549	0.011	10.549	0.012	10.548
19	0.95	0.013	10.547	0.007	10.553	0.009	10.551	0.011	10.549	0.010	10.550	0.011	10.549	0.011	10.549	0.012	10.548
20	1.00	0.013	10.547	0.007	10.553	0.009	10.551	0.011	10.549	0.010	10.550	0.011	10.549	0.011	10.549	0.012	10.548

* Total head loss per section
** pressure per section

Table A.5.4 Energy drop ratio and total pressure drop per section along the lateral laid on flat terrain under different patterns of emitter clogging

Section	dHi/dH* stage 1	dHi (m)**	dHi/dH stage 2	dHi (m)	dHi/dH stage 3	dHi (m)	dHi/dH stage 4	dHi (m)	dHi/dH stage 5	dHi (m)	dHi/dH stage 6	dHi (m)	dHi/dH stage 7	dHi (m)	dHi/dH stage 8	dHi (m)
1	0.1361	0.0018	0.1361	0.0010	0.1361	0.0018	0.1361	0.0018	0.1361	0.0018	0.1361	0.0018	0.1361	0.0018	0.1361	0.0016
2	0.2595	0.0034	0.2595	0.0019	0.2595	0.0034	0.2595	0.0034	0.2595	0.0034	0.2595	0.0034	0.2595	0.0034	0.2595	0.0031
3	0.3709	0.0049	0.3709	0.0027	0.3709	0.0049	0.3709	0.0049	0.3709	0.0049	0.3709	0.0049	0.3709	0.0049	0.3709	0.0044
4	0.4708	0.0062	0.4708	0.0034	0.4708	0.0062	0.4708	0.0062	0.4708	0.0062	0.4708	0.0062	0.4708	0.0062	0.4708	0.0056
5	0.5598	0.0074	0.5598	0.0041	0.5598	0.0074	0.5598	0.0074	0.5598	0.0074	0.5598	0.0074	0.5598	0.0074	0.5598	0.0067
6	0.6384	0.0084	0.6384	0.0047	0.6384	0.0084	0.6384	0.0084	0.6384	0.0084	0.6384	0.0084	0.6384	0.0084	0.6384	0.0076
7	0.7073	0.0093	0.7073	0.0052	0.7073	0.0093	0.7073	0.0093	0.7073	0.0093	0.7073	0.0093	0.7073	0.0093	0.7073	0.0084
8	0.7670	0.0101	0.7670	0.0056	0.7670	0.0101	0.7670	0.0101	0.7670	0.0101	0.7670	0.0101	0.7670	0.0101	0.7670	0.0091
9	0.8182	0.0108	0.8182	0.0060	0.8182	0.0108	0.8182	0.0108	0.8182	0.0108	0.8182	0.0108	0.8182	0.0108	0.8182	0.0098
10	0.8615	0.0114	0.8615	0.0063	0.8615	0.0114	0.8615	0.0114	0.8615	0.0114	0.8615	0.0114	0.8615	0.0114	0.8615	0.0103
11	0.8974	0.0118	0.8974	0.0066	0.8974	0.0118	0.8974	0.0118	0.8974	0.0118	0.8974	0.0118	0.8974	0.0118	0.8974	0.0107
12	0.9267	0.0122	0.9267	0.0068	0.9267	0.0122	0.9267	0.0122	0.9267	0.0122	0.9267	0.0122	0.9267	0.0122	0.9267	0.0110
13	0.9499	0.0125	0.9499	0.0069	0.9499	0.0125	0.9499	0.0125	0.9499	0.0125	0.9499	0.0125	0.9499	0.0125	0.9499	0.0113
14	0.9677	0.0128	0.9677	0.0071	0.9677	0.0128	0.9677	0.0128	0.9677	0.0128	0.9677	0.0128	0.9677	0.0128	0.9677	0.0115
15	0.9808	0.0129	0.9808	0.0072	0.9808	0.0129	0.9808	0.0129	0.9808	0.0129	0.9808	0.0129	0.9808	0.0129	0.9808	0.0117
16	0.9898	0.0131	0.9898	0.0072	0.9898	0.0131	0.9898	0.0131	0.9898	0.0131	0.9898	0.0131	0.9898	0.0131	0.9898	0.0118
17	0.9955	0.0131	0.9955	0.0073	0.9955	0.0131	0.9955	0.0131	0.9955	0.0131	0.9955	0.0131	0.9955	0.0131	0.9955	0.0119
18	0.9986	0.0132	0.9986	0.0073	0.9986	0.0132	0.9986	0.0132	0.9986	0.0132	0.9986	0.0132	0.9986	0.0132	0.9986	0.0119
19	0.9998	0.0132	0.9998	0.0073	0.9998	0.0132	0.9998	0.0132	0.9998	0.0132	0.9998	0.0132	0.9998	0.0132	0.9998	0.0119
20	1.0000	0.0132	1.0000	0.0073	1.0000	0.0132	1.0000	0.0132	1.0000	0.0132	1.0000	0.0132	1.0000	0.0132	1.0000	0.0119

* energy drop ratio
** total pressure drop per section

Table A.5.5 Cotton yield reduction due to different patterns of emitter clogging along a lateral laid on flat terrain (experimental data).

Stage #	Vsh	Vpf	Vt	Increase In Vt	Ky	i/ETm	1-ET/ETm	ET/ETm	Increase In 1-ET/ETm	Yield Reduction 1-Y/Ym	Y.R compare to No clog
1	0.00038	0.04339	0.04339		0.85	1	0.017	0.983	0.017	0.01475	1.4752
2	0.00021	0.39844	0.39844	0.35506	0.85	1	0.159	0.841	0.142	0.13547	12.0719
3	0.00027	0.32131	0.32131	0.27792	0.85	1	0.129	0.871	0.111	0.10925	9.4494
4	0.00033	0.32034	0.32034	0.27695	0.85	1	0.128	0.872	0.111	0.10891	9.4163
5	0.00028	0.35651	0.35651	0.31312	0.85	1	0.143	0.857	0.125	0.12121	10.6461
6	0.00032	0.26174	0.26174	0.21835	0.85	1	0.105	0.895	0.087	0.08899	7.4239
7	0.00031	0.22703	0.22703	0.18364	0.85	1	0.091	0.909	0.073	0.07719	6.2438
8	0.00034	0.11235	0.11235	0.06896	0.85	1	0.045	0.955	0.028	0.03820	2.3447

Table A.5.6 Cottonyield reduction due to different patterns of emitter clogging along a lateral laid on flat terrain (synthetic data).

Stage #	Vsh	Vpf	Vt	Increase In Vt	Ky	i/ETm	1-ET/ETm	ET/ETm	Increase In 1-ET/ETm	Yield Reduction 1-Y/Ym	Y.R compare to No clog
1	0.00040	0.01263	0.01264		0.85	1	0.017	0.983	0.017	0.01475	1.4752
2	0.00022	0.40600	0.40600	0.36261	0.85	1	0.159	0.841	0.142	0.13547	12.0719
3	0.00029	0.32975	0.32975	0.28637	0.85	1	0.129	0.871	0.111	0.10925	9.4494
4	0.00035	0.32963	0.32963	0.28624	0.85	1	0.128	0.872	0.111	0.10891	9.4163
5	0.00030	0.36652	0.36652	0.32313	0.85	1	0.143	0.857	0.125	0.12121	10.6461
6	0.00034	0.26858	0.26858	0.22520	0.85	1	0.105	0.895	0.087	0.08899	7.4239
7	0.00035	0.23258	0.23258	0.18919	0.85	1	0.091	0.909	0.073	0.07719	6.2438
8	0.00035	0.21166	0.21166	0.16827	0.85	1	0.045	0.955	0.028	0.03820	2.3447

Table A.5.7 Cotton yield analysis affect by different patterns of emitter clogging along the lateral laid on flat terrain ***

ASSUMPTIONS:	C .Y/ha (ton)*		C.C/kg ($)**			
Yield and Price--------	0.7076		1.304			
	Area(ha)	1	10	100	1000	10000
	Ave.Yield/ha (ton)	0.7076	7.076	70.76	707.6	7076
Stage #	Yield benefit/ha ($)	922.7	9227.1	92271.0	922710.4	9227104
	Yield reduction (%)	1.4752	1.4752	1.4752	1.4752	1.4752
1	Yield reduction (ton)	0.0104	0.1044	1.0438	10.4384	104.3840
	Effective yield (ton)	0.6972	6.9716	69.7162	697.1616	6971.616
	Money lost ($/Area)	13.6117	136.1167	1361.1668	13611.6684	136116.7
	Yield reduction (%)	13.5471	13.5471	13.5471	13.5471	13.5471
2	Yield reduction (ton)	0.0959	0.9586	9.5859	95.8590	958.5899
	Effective yield (ton)	0.6117	6.1174	61.1741	611.7410	6117.410
	Money lost ($/Area)	125.0001	1250.0012	12500.0124	125000.124	1250001
	Yield reduction (%)	10.9246	10.9246	10.9246	10.9246	10.9246
3	Yield reduction (ton)	0.0773	0.7730	7.7303	77.3026	773.0258
	Effective yield (ton)	0.6303	6.3030	63.0297	630.2974	6302.974
	Money lost ($/Area)	100.8026	1008.0256	10080.2559	100802.559	1008026
	Yield reduction (%)	10.8915	10.8915	10.8915	10.8915	10.8915
4	Yield reduction (ton)	0.0771	0.7707	7.7068	77.0680	770.6798
	Effective yield (ton)	0.6305	6.3053	63.0532	630.5320	6305.320
	Money lost ($/Area)	100.4966	1004.9665	10049.6646	100496.646	1004966
	Yield reduction (%)	12.1213	12.1213	12.1213	12.1213	12.1213
5	Yield reduction (ton)	0.0858	0.8577	8.5770	85.7704	857.7040
	Effective yield (ton)	0.6218	6.2183	62.1830	621.8296	6218.296
	Money lost ($/Area)	111.8446	1118.4461	11184.4606	111844.606	1118446
	Yield reduction (%)	8.8990	8.8990	8.8990	8.8990	8.8990
6	Yield reduction (ton)	0.0630	0.6297	6.2970	62.9696	629.6965
	Effective yield (ton)	0.6446	6.4463	64.4630	644.6304	6446.304
	Money lost ($/Area)	82.1124	821.1242	8211.2417	82112.4174	821124.2
	Yield reduction (%)	7.71898	7.71898	7.71898	7.71898	7.71898
7	Yield reduction (ton)	0.05462	0.54620	5.46195	54.61953	546.1953
	Effective yield (ton)	0.65298	6.52980	65.29805	652.98047	6529.805
	Money lost ($/Area)	71.22386	712.23861	7122.38611	71223.8611	712238.6
	Yield reduction (%)	3.81988	3.81988	3.81988	3.81988	3.81988
8	Yield reduction (ton)	0.02703	0.27029	2.70295	27.02947	270.2947
	Effective yield (ton)	0.68057	6.80571	68.05705	680.57053	6805.705
	Money lost ($/Area)	35.24643	352.46433	3524.64335	35246.4335	352464.3

* C.Y/ha = Average cotton yield per hectare = 0.7076 (ton)

**C.C/Kg ($)= Cotton cost per kg = US $1.304

***Cotton yield and price: adopted from Agric.Statistics US.Dept. of Agric., 1994, pp:50-61

Table A.5.8. Sample data of emitter flow rate measurement in the field with four replications (20m lateral, 30% clogging at the last one-third section, on 7% down-slope terrain

Stage-2	*R1. July 14, 1996			R2. June. 15, 1996			R3. July 16, 1996			R4. July 17 , 1996			
	Ave.P(in)	Ave.P(end)		Ave.P(in)	Ave.P(end)		Ave.P(in)	Ave.P(end)		Ave.P(in)	Ave.P(end)		
	15psi	**17psi**		**15psi**	**17psi**		**15psi**	**17psi**		**15psi**	**17psi**		
Emitter #	T(min)	Vol.(cc)	q (l/h)	T(min)	Vol.(cc)	q (l/h)	T(min)	Vol.(cc)	q (l/h)	T(min)	Vol.(cc)	q (l/h)	Ave.q(l/h)
1	30	1828	3.656	30	1810	3.620	30	1840	3.680	30	1810	3.620	3.64
2	30	1810	3.620	30	1800	3.600	30	1808	3.616	30	1805	3.610	3.61
3	30	1828	3.656	30	1812	3.624	30	1810	3.620	30	1800	3.600	3.63
4	30	1762	3.524	30	1750	3.500	30	1760	3.520	30	1740	3.480	3.51
5	30	1708	3.416	30	1700	3.400	30	1695	3.390	30	1690	3.380	3.40
6	30	1740	3.480	30	1720	3.440	30	1740	3.480	30	1720	3.440	3.46
7	30	1790	3.580	30	1828	3.656	30	1805	3.610	30	1790	3.580	3.61
8	30	1700	3.400	30	1698	3.396	30	1695	3.390	30	1698	3.396	3.40
9	30	1810	3.620	30	1830	3.660	30	1820	3.640	30	1810	3.620	3.64
10	30	1845	3.690	30	1850	3.700	30	1850	3.700	30	1845	3.690	3.70
11	30	1818	3.636	30	1830	3.660	30	1818	3.636	30	1810	3.620	3.64
12	30	1810	3.620	30	1825	3.650	30	1810	3.620	30	1810	3.620	3.63
13	30	1800	3.600	30	1780	3.560	30	1800	3.600	30	1785	3.570	3.58
14	30	1830	3.660	30	1815	3.630	30	1830	3.660	30	1830	3.660	3.65
15	30	1440	2.880	30	1440	2.880	30	1438	2.876	30	1435	2.870	2.88
16	30	45	0.090	30	35	0.070	30	35	0.070	30	25	0.050	0.07
17	30	1310	2.620	30	1300	2.600	30	1298	2.596	30	1285	2.570	2.60
18	30	1200	2.400	30	1200	2.400	30	1180	2.360	30	1180	2.360	2.38
19	30	1330	2.660	30	1330	2.660	30	1325	2.650	30	1325	2.650	2.66
20	30	0	0.000	30	0	0.000	30	0	0.000	30	0	0.000	0.00

*R1, R2, R3, R4 indicate four REPLICATION in the experiment as under same condition for lateral A
1psi=0,704 meter

Table A.5.9 Average Emitter Flow Rate (l/h)along the laterals under 8 different stages in the field experiment(down slope, slope=+7%).

Pin (m) =	10.56	10.56	10.56	10.56	10.56	10.56	10.56	10.56
Pout(m) =	11.97	11.97	11.97	11.97	11.97	11.97	11.97	11.97
Emitter #	Stage- 1 q (l/h)	Stage- 2 q (l/h)	Stage- 3 q (l/h)	Stage- 4 q (l/h)	Stage- 5 q (l/h)	Stage- 6 q (l/h)	Stage- 7 q (l/h)	Stage- 8 q (l/h)
1	3.81	3.64	3.69	1.21	0.70	3.79	3.74	3.70
2	3.71	3.61	3.64	2.26	3.49	3.50	3.54	3.54
3	3.75	3.63	3.62	0.64	0.37	0.35	3.30	3.34
4	3.64	3.51	3.50	2.03	3.35	3.36	0.85	3.46
5	3.50	3.40	3.39	0.00	0.00	3.44	3.44	3.50
6	3.57	3.46	3.53	0.64	3.37	1.91	3.30	3.38
7	3.79	3.61	1.86	3.23	3.21	3.23	3.25	3.32
8	3.50	3.40	2.65	3.41	3.41	0.97	3.40	3.50
9	3.78	3.64	1.10	3.76	0.57	3.58	3.60	3.68
10	3.62	3.70	0.00	3.67	3.67	3.73	3.55	3.61
11	3.72	3.64	1.75	3.76	1.37	3.70	3.77	3.81
12	3.76	3.63	1.28	3.85	3.87	2.05	3.63	3.67
13	3.67	3.58	3.57	3.60	3.56	3.55	0.59	3.64
14	3.78	3.65	3.68	3.71	3.61	3.67	3.66	3.71
15	3.61	2.88	3.69	3.57	3.52	3.48	3.45	3.57
16	3.72	0.07	3.63	3.55	1.24	3.50	3.56	0.35
17	3.64	2.60	3.67	3.66	3.62	3.61	3.66	3.83
18	3.72	2.38	3.84	3.95	4.04	3.69	3.66	4.04
19	3.78	2.66	3.50	3.52	3.58	3.93	3.83	3.87
20	3.76	0.00	3.68	4.02	3.64	3.66	3.66	3.71
lateral,Q	73.82	60.65	59.27	58.05	54.16	62.72	65.41	69.24

Table A.5.10 Dimensionless values of K%, q%, and C_d% for 20m lateral laid on 7% down-slope, stage 2 (field data).

Emitter discharge q_i (1)	Operating pressure H_i (2)	Emit.Dis Coeff. K_i (3)	Dimenssion-less K% (4)	Reduction in q q% (5)	Percent clog C_d% (6)
3.64	10.63	3.04	3.28	3.70	3.28
3.61	10.70	3.02	4.13	4.50	4.13
3.63	10.77	3.03	3.64	3.97	3.64
3.51	10.84	2.93	6.87	7.14	6.87
3.40	10.91	2.84	9.84	10.05	9.84
3.46	10.97	2.89	8.29	8.47	8.29
3.61	11.04	3.01	4.36	4.50	4.36
3.40	11.11	2.83	9.97	10.05	9.97
3.64	11.18	3.03	3.66	3.70	3.66
3.70	11.25	3.08	2.11	2.12	2.11
3.64	11.32	3.03	3.75	3.70	3.75
3.63	11.39	3.02	4.05	3.97	4.05
3.58	11.46	2.98	5.42	5.29	5.42
3.65	11.53	3.03	3.61	3.44	3.61
2.88	11.60	2.39	23.98	23.81	23.98
0.07	11.67	0.06	98.15	98.15	98.15
2.60	11.74	2.16	31.44	31.22	31.44
2.38	11.81	1.97	37.27	37.04	37.27
2.66	11.88	2.21	29.92	29.63	29.92
0.00	11.95	0.00	100.00	100.00	100.00

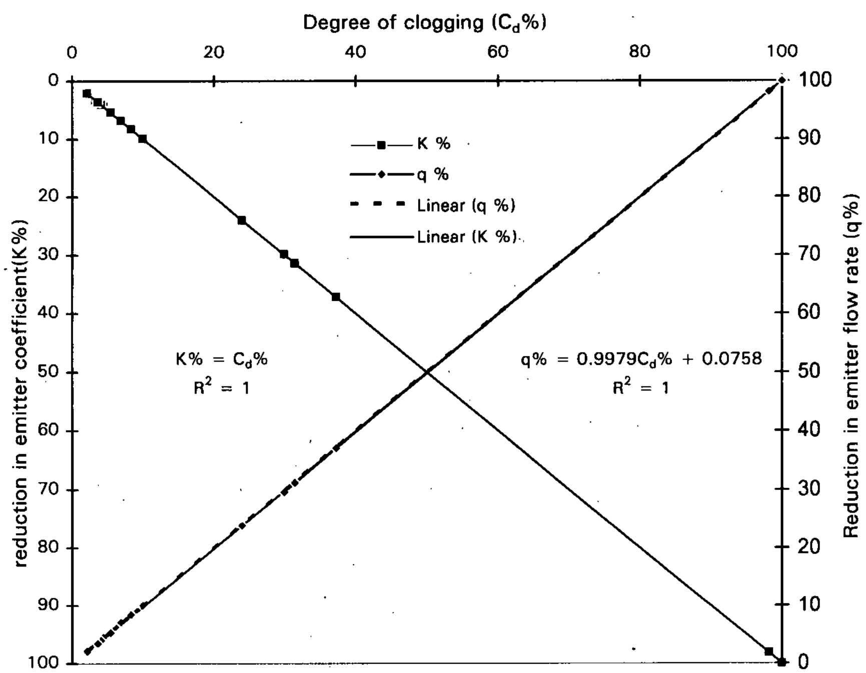


Figure A.5.1 Relationship between K%, q%, and C_d%, for 20m lateral laid on 7% down-slope, stage 2 (field data).

Table A.5.11 Head loss and pressure in each section along the lateral laid on 7% down-slope

Section	Length Ratio(i)	T.Hf(m) Stage 1	Hi(m) Stage 1	T.Hf(m) Stage 2	Hi(m) Stage 2	T.Hf(m) Stage 3	Hi(m) Stage 3	T.Hf(m) Stage 4	Hi(m) Stage 4	T.Hf(m) Stage 5	Hi(m) Stage 5	T.Hf(m) Stage 6	Hi(m) Stage 6	T.Hf(m) Stage 7	Hi(m) Stage 7	T.Hf(m) Stage 8	Hi(m) Stage 8
0	0.0000	0.0000	10.5600	0.0000	10.5600	0.0000	10.5600	0.0000	10.5600	0.0000	10.5600	0.0000	10.5600	0.0000	10.5600	0.0000	10.5600
1	0.0500	0.0018	10.6282	0.0013	10.6289	0.0012	10.6288	0.0012	10.6285	0.0010	10.6288	0.0013	10.6285	0.0014	10.6285	0.0016	10.6284
2	0.1000	0.0034	10.6965	0.0024	10.6979	0.0023	10.6977	0.0023	10.6971	0.0020	10.6976	0.0025	10.6972	0.0027	10.6971	0.0030	10.6969
3	0.1500	0.0049	10.7650	0.0034	10.7670	0.0032	10.7667	0.0033	10.7658	0.0029	10.7666	0.0036	10.7660	0.0039	10.7659	0.0043	10.7656
4	0.2000	0.0062	10.8336	0.0042	10.8362	0.0040	10.8358	0.0043	10.8347	0.0037	10.8357	0.0046	10.8349	0.0049	10.8347	0.0055	10.8344
5	0.2500	0.0074	10.9024	0.0050	10.9054	0.0047	10.9050	0.0052	10.9037	0.0045	10.9049	0.0055	10.9039	0.0059	10.9038	0.0066	10.9033
6	0.3000	0.0085	10.9713	0.0056	10.9748	0.0053	10.9743	0.0062	10.9728	0.0053	10.9742	0.0064	10.9731	0.0068	10.9729	0.0075	10.9724
7	0.3500	0.0094	11.0404	0.0062	11.0442	0.0059	11.0437	0.0071	11.0421	0.0059	11.0436	0.0071	11.0423	0.0076	11.0421	0.0083	11.0416
8	0.4000	0.0102	11.1096	0.0067	11.1138	0.0063	11.1131	0.0079	11.1114	0.0065	11.1130	0.0078	11.1117	0.0083	11.1114	0.0090	11.1109
9	0.4500	0.0109	11.1789	0.0071	11.1833	0.0068	11.1827	0.0086	11.1808	0.0070	11.1826	0.0084	11.1811	0.0089	11.1809	0.0097	11.1803
10	0.5000	0.0115	11.2483	0.0074	11.2530	0.0072	11.2523	0.0092	11.2503	0.0074	11.2522	0.0090	11.2506	0.0094	11.2504	0.0102	11.2498
11	0.5500	0.0120	11.3178	0.0076	11.3227	0.0075	11.3219	0.0097	11.3199	0.0078	11.3218	0.0094	11.3203	0.0098	11.3200	0.0106	11.3193
12	0.6000	0.0124	11.3874	0.0078	11.3925	0.0079	11.3917	0.0101	11.3896	0.0082	11.3916	0.0098	11.3899	0.0101	11.3897	0.0110	11.3890
13	0.6500	0.0128	11.4571	0.0079	11.4623	0.0082	11.4615	0.0105	11.4593	0.0084	11.4614	0.0101	11.4597	0.0104	11.4594	0.0112	11.4587
14	0.7000	0.0130	11.5269	0.0080	11.5321	0.0085	11.5313	0.0107	11.5291	0.0087	11.5312	0.0103	11.5295	0.0107	11.5292	0.0114	11.5285
15	0.7500	0.0132	11.5967	0.0081	11.6020	0.0087	11.6012	0.0109	11.5990	0.0088	11.6011	0.0105	11.5994	0.0108	11.5991	0.0116	11.5983
16	0.8000	0.0134	11.6666	0.0081	11.6719	0.0088	11.6711	0.0110	11.6689	0.0089	11.6710	0.0107	11.6693	0.0110	11.6690	0.0117	11.6682
17	0.8500	0.0135	11.7365	0.0081	11.7419	0.0089	11.7411	0.0111	11.7388	0.0090	11.7409	0.0108	11.7392	0.0111	11.7389	0.0118	11.7382
18	0.9000	0.0135	11.8065	0.0081	11.8119	0.0089	11.8110	0.0112	11.8088	0.0091	11.8109	0.0108	11.8092	0.0111	11.8089	0.0118	11.8081
19	0.9500	0.0135	11.8765	0.0081	11.8819	0.0090	11.8810	0.0112	11.8788	0.0091	11.8809	0.0109	11.8791	0.0112	11.8788	0.0119	11.8781
20	1.0000	0.0136	11.9464	0.0081	11.9519	0.0090	11.9510	0.0112	11.9488	0.0091	11.9509	0.0109	11.9491	0.0112	11.9488	0.0119	11.9481

Table A.5.12 Pressure drop along a lateral laid on 7% down-slope under eight different stages studied

Section	dHi/dH	dHi (m) T. P.drop	dHi/dH	dHi (m) T. P.drop	dHi/dH	dHi (m) T. P.drop	dHi/dH	dHi (m) T. P.drop	dHi/dH	dHi (m) T. P.drop	dHi/dH	dHi (m) T. P.drop	dHi/dH	dHi (m) T. P.drop	dHi/dH	dHi (m) T. P.drop
	Stage 1		Stage 2		Stage 3		Stage 4		Stage 5		Stage 6		Stage 7		Stage 8	
1	0.1360915	0.0018443	0.1360915	0.0011081	0.1360915	0.0012211	0.136091549	0.0015293	0.136092	0.001239	0.136092	0.001478	0.1360915	0.001519	0.136092	0.001617
2	0.2595434	0.0035172	0.2595434	0.0021132	0.2595434	0.0023288	0.259543352	0.0029165	0.259543	0.002362	0.259543	0.002818	0.2595434	0.002897	0.259543	0.003084
3	0.3709245	0.0050266	0.3709245	0.0030201	0.3709245	0.0033282	0.370924493	0.0041681	0.370924	0.003376	0.370924	0.004027	0.3709245	0.004141	0.370924	0.004407
4	0.4708088	0.0063802	0.4708088	0.0038333	0.4708088	0.0042244	0.470808764	0.0052905	0.470809	0.004285	0.470809	0.005112	0.4708088	0.005256	0.470809	0.005594
5	0.559775	0.0075859	0.559775	0.0045577	0.559775	0.0050227	0.559774979	0.0062903	0.559775	0.005095	0.559775	0.006077	0.559775	0.006249	0.559775	0.006651
6	0.6384073	0.0086515	0.6384073	0.0051979	0.6384073	0.0057283	0.638407337	0.0071739	0.638407	0.005811	0.638407	0.006931	0.6384073	0.007127	0.638407	0.007585
7	0.7072958	0.009585	0.7072958	0.0057588	0.7072958	0.0063464	0.707295841	0.007948	0.707296	0.006438	0.707296	0.007679	0.7072958	0.007896	0.707296	0.008404
8	0.7670368	0.0103946	0.7670368	0.0062452	0.7670368	0.0068824	0.767036777	0.0086193	0.767037	0.006982	0.767037	0.008328	0.7670368	0.008562	0.767037	0.009114
9	0.8182333	0.0110884	0.8182333	0.0066621	0.8182333	0.0073418	0.818233272	0.0091946	0.818233	0.007448	0.818233	0.008883	0.8182333	0.009134	0.818233	0.009722
10	0.861496	0.0116747	0.861496	0.0070143	0.861496	0.00773	0.861495957	0.0096808	0.861496	0.007841	0.861496	0.009353	0.861496	0.009617	0.861496	0.010236
11	0.8974438	0.0121618	0.8974438	0.007307	0.8974438	0.0080525	0.89744376	0.0100847	0.897444	0.008168	0.897444	0.009743	0.8974438	0.010018	0.897444	0.010663
12	0.9267049	0.0125584	0.9267049	0.0075452	0.9267049	0.0083151	0.926704874	0.0104135	0.926705	0.008435	0.926705	0.010061	0.9267049	0.010345	0.926705	0.011011
13	0.949918	0.012873	0.949918	0.0077342	0.949918	0.0085234	0.949917954	0.0106744	0.949918	0.008646	0.949918	0.010313	0.949918	0.010604	0.949918	0.011286
14	0.9677337	0.0131144	0.9677337	0.0078793	0.9677337	0.0086832	0.967733652	0.0108746	0.967734	0.008808	0.967734	0.010507	0.9677337	0.010803	0.967734	0.011498
15	0.9808166	0.0132917	0.9808166	0.0079858	0.9808166	0.0088006	0.98081663	0.0110216	0.980817	0.008927	0.980817	0.010649	0.9808166	0.010949	0.980817	0.011654
16	0.9898483	0.0134141	0.9898483	0.0080593	0.9898483	0.0088817	0.989848329	0.0111231	0.989848	0.00901	0.989848	0.010747	0.9898483	0.01105	0.989848	0.011761
17	0.995531	0.0134911	0.995531	0.0081056	0.995531	0.0089326	0.99553098	0.0111869	0.995531	0.009061	0.995531	0.010808	0.995531	0.011113	0.995531	0.011828
18	0.998594	0.0135326	0.998594	0.0081305	0.998594	0.0089601	0.998593952	0.0112214	0.998594	0.009089	0.998594	0.010842	0.998594	0.011147	0.998594	0.011865
19	0.9998053	0.013549	0.9998053	0.0081404	0.9998053	0.008971	0.999805257	0.011235	0.999805	0.0091	0.999805	0.010855	0.9998053	0.011161	0.999805	0.011879
20	1	0.0135517	1	0.008142	1	0.0089727	1	0.0112372	1	0.009102	1	0.010857	1	0.011163	1	0.011881

Table A.5.13 Summary of hydraulic parameters resulted from field experiment in stage 2 when lateral laid on 7% down-slope

Stage # 2	L(m)	I.D (m)	P(inlet)m		SEC.(m)	N.E/Sec.	**Slope(%)**	
30%,1/3L,DC	20	0.015	10.56		1	1	**0.07**	
Section	qi (l/h)	Hf (m)	T.Hf from inlet	Hi	dHi/dH	qi - qave.	Hydraulic Parameters	**Stage # 2**
1	3.64	0.00125	0.00125	10.6289	0.136092	0.6055	**Hf (m)**	0.00814
2	3.61	0.00112	0.00237	10.6979	0.259543	0.5755	**Stan. devia(qs)**	1.07338
3	3.63	0.00099	0.00336	10.7670	0.370924	0.5955	**Sum qi**	60.69000
4	3.51	0.00087	0.00422	10.8362	0.470809	0.4755	**qmax(field)**	3.70000
5	3.40	0.00076	0.00498	10.9054	0.559775	0.3655	**qmin(field)**	0.00000
6	3.46	0.00066	0.00564	10.9748	0.638407	0.4255	**qave(field)**	3.03450
7	3.61	0.00056	0.00620	11.0442	0.707296	0.5755	**sum l(qi-qave)l**	15.23400
8	3.40	0.00047	0.00667	11.1138	0.767037	0.3655	**Vqs**	0.35373
9	3.64	0.00039	0.00707	11.1833	0.818233	0.6055	**Hmax(field)**	11.95186
10	3.70	0.00031	0.00738	11.2530	0.861496	0.6655	**Hmin(field)**	10.56000
11	3.64	0.00024	0.00762	11.3227	0.897444	0.6055	**Have(field)**	11.25407
12	3.63	0.00018	0.00781	11.3925	0.926705	0.5955	**H (var)**	0.11646
13	3.58	0.00013	0.00794	11.4623	0.949918	0.5455	**Stan.Dev.(Sh)**	0.42158
14	3.65	0.00009	0.00802	11.5321	0.967734	0.6155	**Vhs**	0.03746
15	2.88	0.00005	0.00807	11.6020	0.980817	0.1545	**Vqh**	0.00284
16	0.07	0.00003	0.00810	11.6719	0.989848	2.9645	**Vpf**	0.35371
17	2.60	0.00003	0.00813	11.7419	0.995531	0.4345	**qi (lowest 1/4)**	1.54200
18	2.38	0.00001	0.00814	11.8119	0.998594	0.6545	**EU'(fiield)%**	50.81562
19	2.66	0.00000	0.00814	11.8819	0.999805	0.3745	**CU% or Ed%**	74.89867
20	0.00	0.00000	0.00814	11.9519	1.000000	3.0345	**DU%**	60.08888
							Ea %	99.51928
							Us	64.62745
							Ush	99.71642
							qvar	0.00933

Table A.5.14 Cotton yield reduction due to different patterns of emitter clogging along a lateral laid on 3% down-slope (experimental data).

Stage #	Vsh	Vpf	Vt	Increase In Vt	Ky	I/ETm	1-ET/ETm	ET/ETm	Increase In 1-ET/ETm	Yield Reduction 1-Y/Ym	Y.R compare to No clog
1	0.0164	0.0283	0.0327		0.85	1	0.013	0.987	0.013	0.01113	1.1132
2	0.0165	0.3312	0.3316	0.2989	0.85	1	0.133	0.867	0.120	0.11276	10.1627
3	0.0165	0.3842	0.3845	0.3518	0.85	1	0.154	0.846	0.141	0.13074	11.9608
4	0.0165	0.4394	0.4397	0.4070	0.85	1	0.176	0.824	0.163	0.14950	13.8372
5	0.0165	0.4178	0.4181	0.3854	0.85	1	0.167	0.833	0.154	0.14216	13.1031
6	0.0165	0.3396	0.3400	0.3073	0.85	1	0.136	0.864	0.123	0.11560	10.4467
7	0.0165	0.2971	0.2976	0.2649	0.85	1	0.119	0.881	0.106	0.10118	9.0049
8	0.0164	0.1753	0.1761	0.1433	0.85	1	0.070	0.930	0.057	0.05986	4.8730

Table A.5.15 Cottonyield reduction due to different patterns of emitter clogging along a lateral laid on 3% down-slope (synthetic data).

Stage #	Vsh	Vpf	Vt	Increase In Vt	Ky	I/ETm	1-ET/ETm	ET/ETm	Increase In 1-ET/ETm	Yield Reduction 1-Y/Ym	Y.R compare to No clog
1	0.0164	0.0124	0.0206		0.85	1	0.013	0.987	0.013	0.01113	1.1132
2	0.0165	0.3426	0.3430	0.3103	0.85	1	0.133	0.867	0.120	0.11276	10.1627
3	0.0165	0.3901	0.3904	0.3577	0.85	1	0.154	0.846	0.141	0.13074	11.9608
4	0.0164	0.4392	0.4395	0.4067	0.85	1	0.176	0.824	0.163	0.14950	13.8372
5	0.0165	0.4252	0.4255	0.3928	0.85	1	0.167	0.833	0.154	0.14216	13.1031
6	0.0165	0.3421	0.3425	0.3098	0.85	1	0.136	0.864	0.123	0.11560	10.4467
7	0.0164	0.2958	0.2963	0.2636	0.85	1	0.119	0.881	0.106	0.10118	9.0049
8	0.0164	0.1744	0.1752	0.1424	0.85	1	0.070	0.930	0.057	0.05986	4.8730

Table A.5.16 Cotton yield reduction due to different patterns of emitter clogging along a lateral laid on 3% up-slope (experimental data).

Stage #	Vsh	Vpf	Vt	Increase In Vt	Ky	i/ETm	1-ET/ETm	ET/ETm	Increase In 1-ET/ETm	Yield Reduction 1-Y/Ym	Y.R compare to No clog
1	0.0181	0.0365	0.0408		0.85	1	0.016	0.984	0.016	0.01386	1.3862
2	0.0180	0.3310	0.3315	0.2907	0.85	1	0.133	0.867	0.116	0.11271	9.8850
3	0.0180	0.3330	0.3335	0.2927	0.85	1	0.133	0.867	0.117	0.11339	9.9529
4	0.0181	0.4425	0.4429	0.4021	0.85	1	0.177	0.823	0.161	0.15059	13.6724
5	0.0180	0.4856	0.4859	0.4452	0.85	1	0.194	0.806	0.178	0.16521	15.1352
6	0.0181	0.2590	0.2596	0.2188	0.85	1	0.104	0.896	0.088	0.08826	7.4402
7	0.0181	0.2098	0.2105	0.1698	0.85	1	0.084	0.916	0.068	0.07158	5.7720
8	0.0181	0.1816	0.1825	0.1417	0.85	1	0.073	0.927	0.057	0.06205	4.8190

Table A.5.17 Cottonyield reduction due to different patterns of emitter clogging along a lateral laid on 3% up-slope (synthetic data).

Stage #	Vsh	Vpf	Vt	Increase In Vt	Ky	i/ETm	1-ET/ETm	ET/ETm	Increase In 1-ET/ETm	Yield Reduction 1-Y/Ym	Y.R compare to No clog
1	0.0181	0.0125	0.0220		0.85	1	0.016	0.984	0.016	0.01386	1.3862
2	0.0180	0.3300	0.3305	0.2897	0.85	1	0.133	0.867	0.116	0.11271	9.8850
3	0.0180	0.3320	0.3325	0.2917	0.85	1	0.133	0.867	0.117	0.11339	9.9529
4	0.0180	0.4410	0.4414	0.4006	0.85	1	0.177	0.823	0.161	0.15059	13.6724
5	0.0180	0.4858	0.4862	0.4454	0.85	1	0.194	0.806	0.178	0.16521	15.1352
6	0.0180	0.2570	0.2577	0.2169	0.85	1	0.104	0.896	0.088	0.08826	7.4402
7	0.0181	0.2069	0.2077	0.1670	0.85	1	0.084	0.916	0.068	0.07158	5.7720
8	0.0181	0.1813	0.1822	0.1414	0.85	1	0.073	0.927	0.057	0.06205	4.8190

Table A.5.18 Cotton yield reduction due to different patterns of emitter clogging along a lateral laid on 7% down-slope (experimental data)

Stage #	Vsh	Vpf	Vt	Increase In Vt	Ky	i/ETm	1-ET/ETm	ET/ETm	Increase In 1-ET/ETm	Yield Reduction 1-Y/Ym	Y.R compare to No clog
1	0.0373	0.0247	0.0448		0.85	1	0.018	0.982	0.018	0.01522	1.5222
2	0.0375	0.3537	0.3557	0.3109	0.85	1	0.142	0.858	0.124	0.12094	10.5714
3	0.0374	0.3697	0.3716	0.3268	0.85	1	0.149	0.851	0.131	0.12634	11.1115
4	0.0374	0.4313	0.4329	0.3881	0.85	1	0.173	0.827	0.155	0.14718	13.1958
5	0.0374	0.4970	0.4984	0.4536	0.85	1	0.199	0.801	0.181	0.16945	15.4226
6	0.0374	0.3097	0.3120	0.2672	0.85	1	0.125	0.875	0.107	0.10608	9.0854
7	0.0374	0.2645	0.2672	0.2224	0.85	1	0.107	0.893	0.089	0.09084	7.5616
8	0.0374	0.2125	0.2158	0.1710	0.85	1	0.086	0.914	0.068	0.07338	5.8154

Table A.5.19 Cottonyield reduction due to different patterns of emitter clogging along a lateral laid on 7% down-slope (synthetic data).

Stage #	Vsh	Vpf	Vt	Increase In Vt	Ky	I/ETm	1-ET/ETm	ET/ETm	Increase In 1-ET/ETm	Yield Reduction 1-Y/Ym	Y.R compare to No clog
1	0.0373	0.0120	0.0392		0.85	1	0.018	0.982	0.018	0.01522	1.5222
2	0.0374	0.3588	0.3608	0.3160	0.85	1	0.142	0.858	0.124	0.12094	10.5714
3	0.0374	0.3767	0.3785	0.3337	0.85	1	0.149	0.851	0.131	0.12634	11.1115
4	0.0374	0.4309	0.4325	0.3878	0.85	1	0.173	0.827	0.155	0.14718	13.1958
5	0.0374	0.4992	0.5006	0.4558	0.85	1	0.199	0.801	0.181	0.16945	15.4226
6	0.0374	0.3130	0.3153	0.2705	0.85	1	0.125	0.875	0.107	0.10608	9.0854
7	0.0374	0.2640	0.2666	0.2218	0.85	1	0.107	0.893	0.089	0.09084	7.5616
8	0.0374	0.2067	0.2101	0.1653	0.85	1	0.086	0.914	0.068	0.07338	5.8154

Table A.5.20 Cotton yield reduction due to different patterns of emitter clogging along a lateral laid on 7% up-slope (experimental data).

Stage #	Vsh	Vpf	Vt	Increase In Vt	Ky	i/ETm	1-ET/ETm	ET/ETm	Increase In 1-ET/ETm	Yield Reduction 1-Y/Ym	Y.R compare to No clog
1	0.0435	0.0439	0.0618		0.85	1	0.025	0.975	0.025	0.02101	2.1011
2	0.0433	0.2960	0.2991	0.2373	0.85	1	0.120	0.880	0.095	0.10171	8.0694
3	0.0433	0.3804	0.3828	0.3210	0.85	1	0.153	0.847	0.128	0.13016	10.9152
4	0.0434	0.4111	0.4134	0.3516	0.85	1	0.165	0.835	0.141	0.14056	11.9553
5	0.0433	0.4024	0.4048	0.3430	0.85	1	0.162	0.838	0.137	0.13762	11.6608
6	0.0434	0.2916	0.2948	0.2330	0.85	1	0.118	0.882	0.093	0.10024	7.9230
7	0.0434	0.1983	0.2030	0.1412	0.85	1	0.081	0.919	0.056	0.06901	4.8000
8	0.0434	0.1495	0.1557	0.0939	0.85	1	0.062	0.938	0.038	0.05292	3.1913

Table A.5.21 Cottonyield reduction due to different patterns of emitter clogging along a lateral laid on 7% up-slope (synthetic data).

Stage #	Vsh	Vpf	Vt	Increase In Vt	Ky	i/ETm	1-ET/ETm	ET/ETm	Increase In 1-ET/ETm	Yield Reduction 1-Y/Ym	Y.R compare to No clog
1	0.0434	0.0124	0.0452		0.85	1	0.025	0.975	0.025	0.02101	2.1011
2	0.0433	0.2956	0.2988	0.2370	0.85	1	0.120	0.880	0.095	0.10171	8.0694
3	0.0433	0.3791	0.3815	0.3197	0.85	1	0.153	0.847	0.128	0.13016	10.9152
4	0.0434	0.4093	0.4116	0.3498	0.85	1	0.165	0.835	0.141	0.14056	11.9553
5	0.0433	0.4010	0.4033	0.3415	0.85	1	0.162	0.838	0.137	0.13762	11.6608
6	0.0433	0.2882	0.2914	0.2297	0.85	1	0.118	0.882	0.093	0.10024	7.9230
7	0.0434	0.1903	0.1952	0.1334	0.85	1	0.081	0.919	0.056	0.06901	4.8000
8	0.0434	0.1452	0.1516	0.0898	0.85	1	0.062	0.938	0.038	0.05292	3.1913

Table A.5.22 Emitter flow rate along a 20 meters lateral(**A**) consist of naturally clogged emitters laid on flat terrain.

R1. June 5, 1997				**R2. June 5, 1997**			**R3. June 5, 1997**			**R4.June 5, 1997**			Average
Pinlet = 15psi		Pend =14.85psi		Pinlet = 15psi	Pend =14.85psi		Pinlet = 15psi	Pend =14.85psi		Pinlet = 15psi	Pend =14.85psi		discharge
Emitter #	Timie (minute)	Volume (cc)	q (l/h)	Emitter #	Timie (minute)	Volume (cc)	Emitter #	Timie (minute)	Volume (cc)	Emitter #	Timie (minute)	Volume (cc)	q (l/h)
1	30	1435.00	2.87	30	1370.00	2.74	30	1330.00	2.66	30	1330.00	2.66	**2.73**
2	30	1700.00	3.40	30	1710.00	3.42	30	1700.00	3.40	30	1695.00	3.39	**3.40**
3	30	1918.00	3.84	30	1910.00	3.82	30	1890.00	3.78	30	1880.00	3.76	**3.80**
4	30	1800.00	3.60	30	1795.00	3.59	30	1785.00	3.57	30	1785.00	3.57	**3.58**
5	30	1770.00	3.54	30	1770.00	3.54	30	1760.00	3.52	30	1755.00	3.51	**3.53**
6	30	1800.00	3.60	30	1790.00	3.58	30	1780.00	3.56	30	1780.00	3.56	**3.58**
7	30	1910.00	3.82	30	1900.00	3.80	30	1890.00	3.78	30	1885.00	3.77	**3.79**
8	30	1798.00	3.60	30	1790.00	3.58	30	1785.00	3.57	30	1780.00	3.56	**3.58**
9	30	1690.00	3.38	30	1685.00	3.37	30	1670.00	3.34	30	1670.00	3.34	**3.36**
10	30	1830.00	3.66	30	1830.00	3.66	30	1815.00	3.63	30	1810.00	3.62	**3.64**
11	30	1818.00	3.64	30	1818.00	3.64	30	1810.00	3.62	30	1810.00	3.62	**3.63**
12	30	1728.00	3.46	30	1722.00	3.44	30	1720.00	3.44	30	1715.00	3.43	**3.44**
13	30	1730.00	3.46	30	1712.00	3.42	30	1700.00	3.40	30	1700.00	3.40	**3.42**
14	30	1700.00	3.40	30	1710.00	3.42	30	1700.00	3.40	30	1705.00	3.41	**3.41**
15	30	1930.00	3.86	30	1920.00	3.84	30	1915.00	3.83	30	1920.00	3.84	**3.84**
16	30	1745.00	3.49	30	1745.00	3.49	30	1730.00	3.46	30	1735.00	3.47	**3.48**
17	30	1810.00	3.62	30	1820.00	3.64	30	1810.00	3.62	30	1815.00	3.63	**3.63**
18	30	1560.00	3.12	30	1550.00	3.10	30	1540.00	3.08	30	1540.00	3.08	**3.10**
19	30	1780.00	3.56	30	1780.00	3.56	30	1760.00	3.52	30	1755.00	3.51	**3.54**
20	30	1800.00	3.60	30	1762.00	3.52	30	1750.00	3.50	30	1758.00	3.52	**3.54**

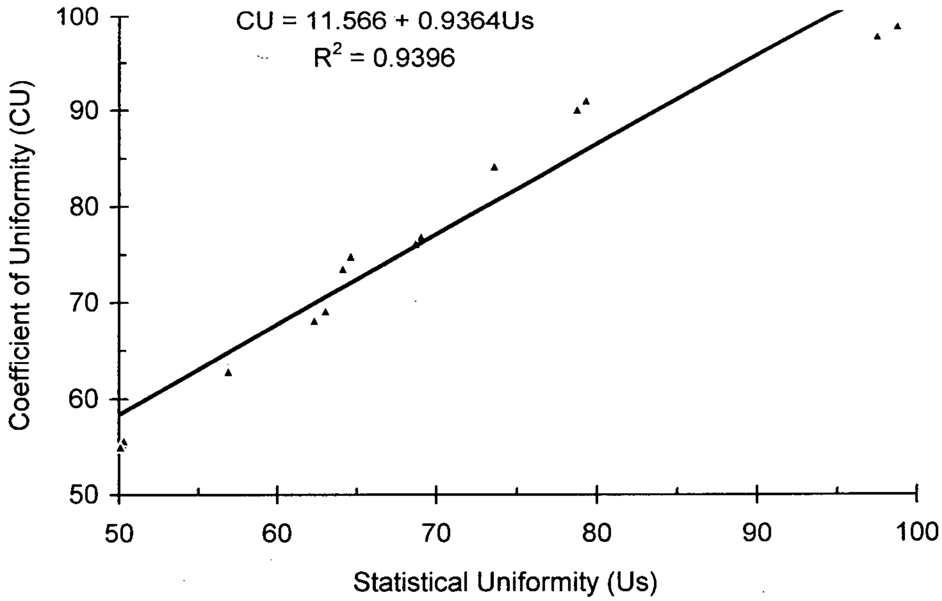


Figure A.5.2 Relationship between CU and U_s under different stages in 7% down-slope (experimental and theoretical results

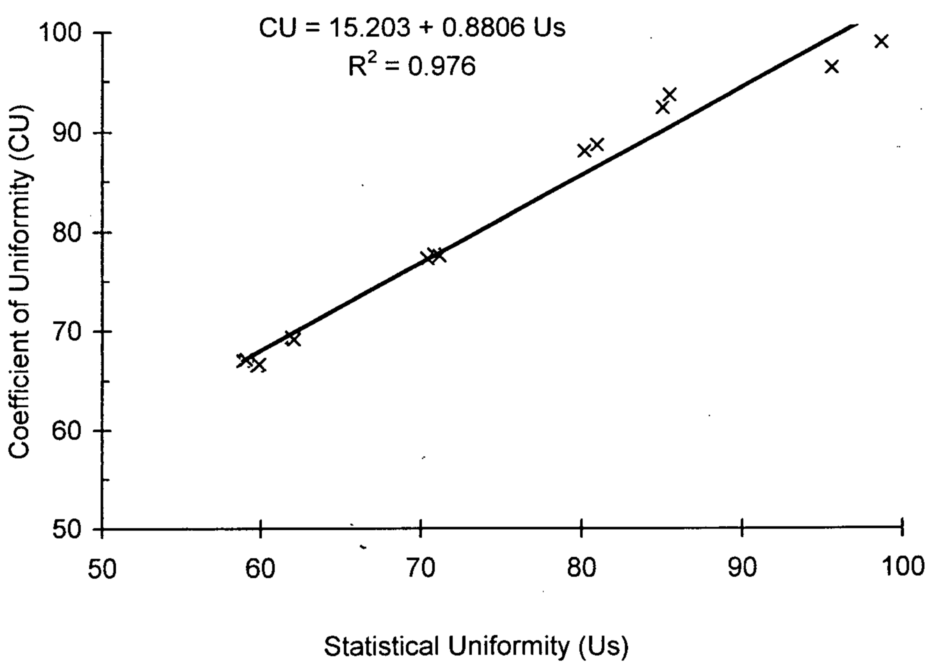


Figure A.5.3 Relationship between CU and U_s under different stages in 7% up-slope (experimental and theoretical results

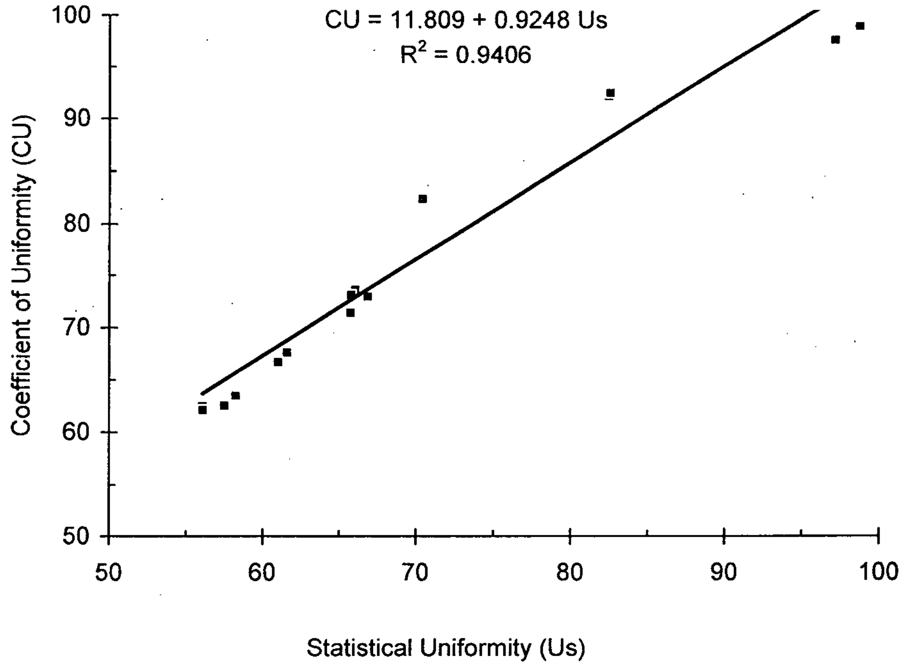


Figure A.5.4 Relationship between CU and U_s under different stages in 3% down-slope (experimental and theoretical results

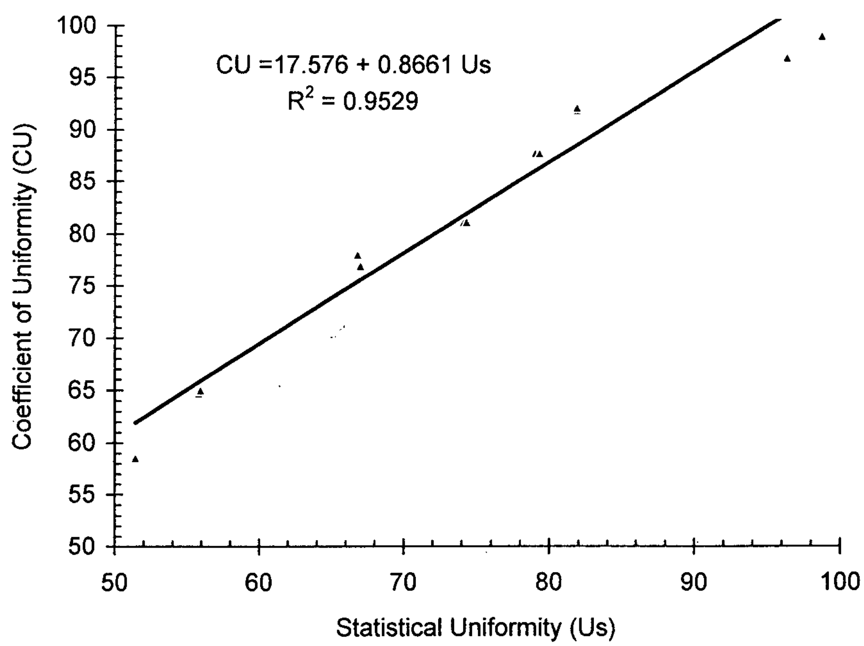


Figure A.5.5 Relationship between CU and U_s under different stages in 3% up-slope (experimental and theoretical results

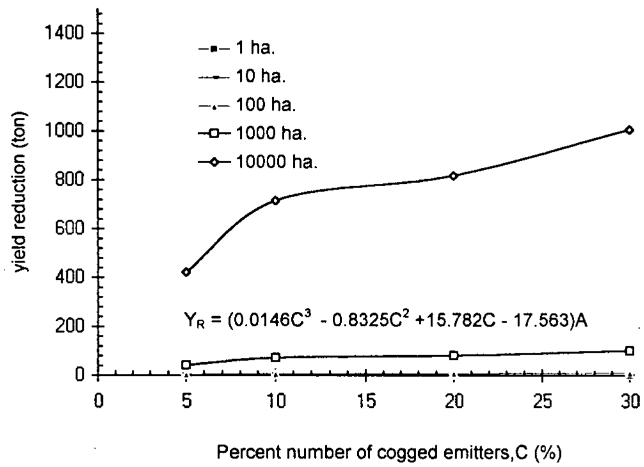


Figure A.5.6 Cotton yield reduction at differernt areas under different randomly clogged emitters along the lateral (3% down-slope)

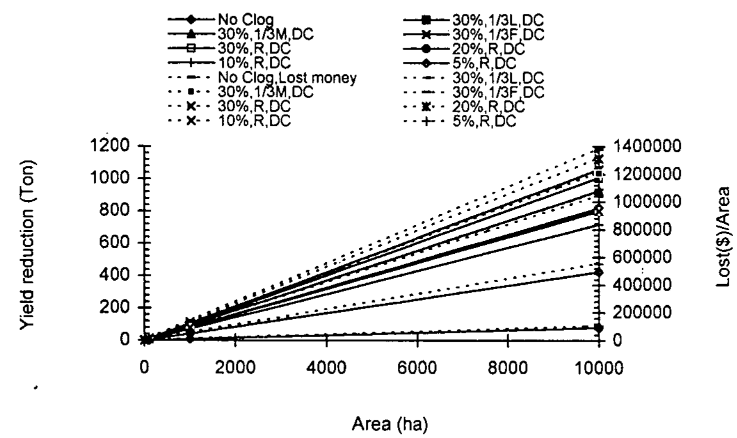


Figure A.5. 7 Cotton yield reduction and money lost in different areas under different patterns of clogging (3% down-slop)

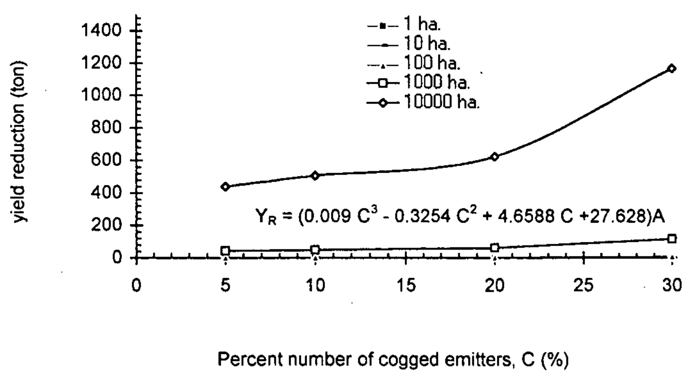


Figure A.5.8 Cotton yield reduction at differernt areas under different randomly clogged emitters along the lateral (3% up-slope)

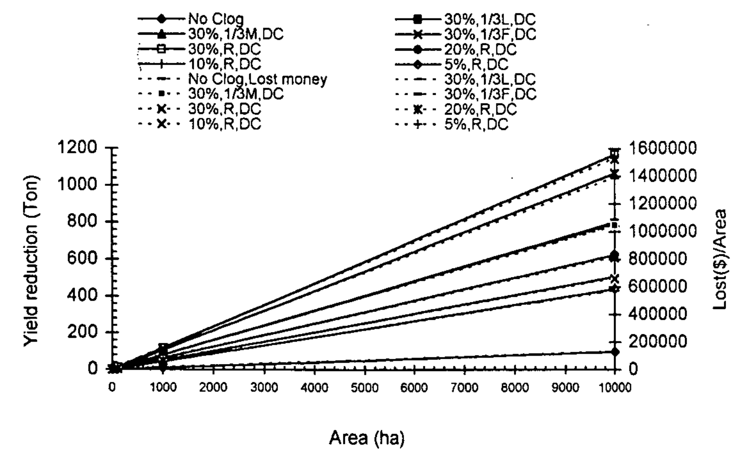


Figure A.5.9 Cotton yield reduction and money lost in different areas under different patterns of clogging (3% up-slop)

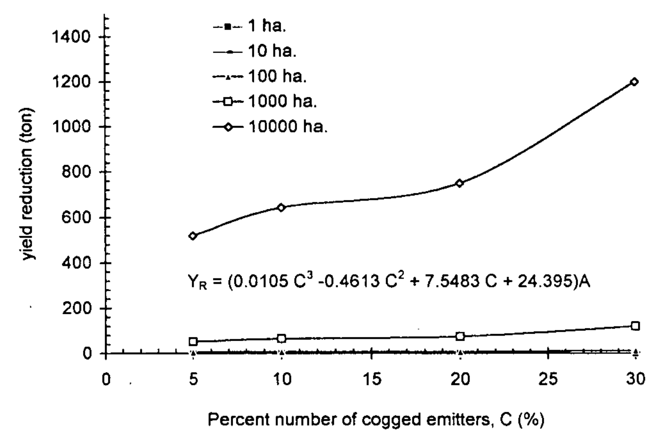


Figure A.5.10 Cotton yield reduction at differernt areas under different randomly clogged emitters along the lateral (7% down-slope)

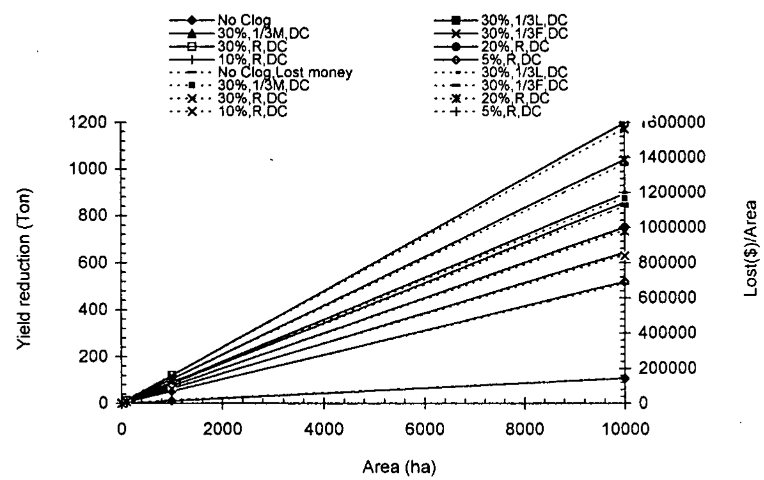


Figure A.5.11 Cotton yield reduction and money lost in different areas under different patterns of clogging (7% down-slop)

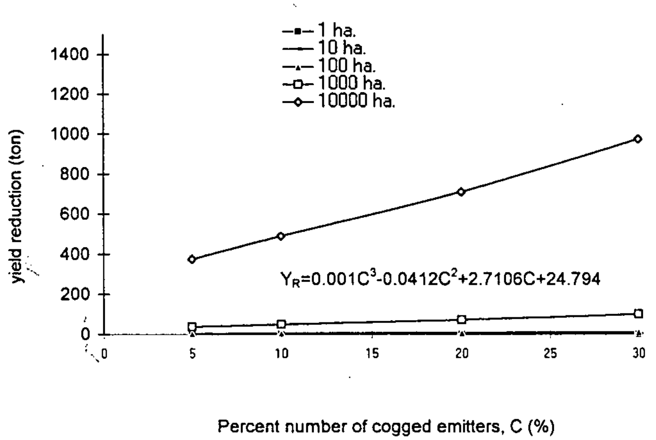


Figure A.5.12 Cotton yield reduction at differernt areas under different randomly clogged emitters along the lateral (7% up-slope)

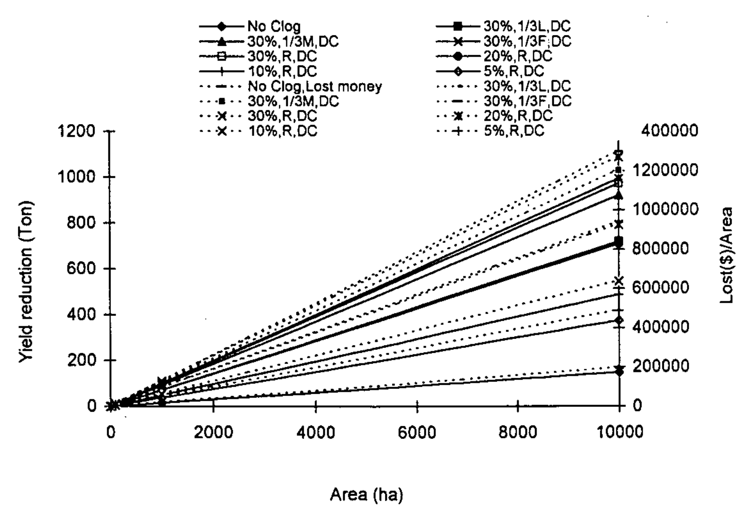


Figure A.5.13 Cotton yield reduction and money lost in different areas under different patterns of clogging (7% down-slop)

Table A.5.23 Emitter flow rate along a 20 meters lateral(**B**) consist of naturally clogged emitters laid on flat terrain.

R1. June 5, 1997 Pinlet = 15psi Pend =14.85psi				**R2. June 5, 1997** Pinlet = 15psi Pend =14.85psi			**R3. June 5, 1997** Pinlet = 15psi Pend =14.85psi			**R4.June 5, 1997** Pinlet = 15psi Pend =14.85psi			Average discharge
Emitter #	Timie (minute)	Volume (cc)	q (l/h)	Emitter #	Timie (minute)	Volume (cc)	Emitter #	Timie (minute)	Volume (cc)	Emitter #	Timie (minute)	Volume (cc)	q (l/h)
1	30	1765.00	3.53	30	1760.00	3.52	30	1755.00	3.51	30	1700.00	3.40	**3.49**
2	30	1650.00	3.30	30	1660.00	3.32	30	1655.00	3.31	30	1650.00	3.30	**3.31**
3	30	1728.00	3.46	30	1718.00	3.44	30	1720.00	3.44	30	1725.00	3.45	**3.45**
4	30	1770.00	3.54	30	1770.00	3.54	30	1765.00	3.53	30	1760.00	3.52	**3.53**
5	30	1708.00	3.42	30	1700.00	3.40	30	1705.00	3.41	30	1700.00	3.40	**3.41**
6	30	1810.00	3.62	30	1800.00	3.60	30	1805.00	3.61	30	1805.00	3.61	**3.61**
7	30	1800.00	3.60	30	1790.00	3.58	30	1795.00	3.59	30	1790.00	3.58	**3.59**
8	30	1892.00	3.78	30	1877.00	3.75	30	1880.00	3.76	30	1875.00	3.75	**3.76**
9	30	1740.00	3.48	30	1745.00	3.49	30	1745.00	3.49	30	1740.00	3.48	**3.49**
10	30	1700.00	3.40	30	1680.00	3.36	30	1690.00	3.38	30	1685.00	3.37	**3.38**
11	30	1818.00	3.64	30	1805.00	3.61	30	1810.00	3.62	30	1800.00	3.60	**3.62**
12	30	1710.00	3.42	30	1710.00	3.42	30	1720.00	3.44	30	1715.00	3.43	**3.43**
13	30	1600.00	3.20	30	1580.00	3.16	30	1590.00	3.18	30	1585.00	3.17	**3.18**
14	30	1800.00	3.60	30	1800.00	3.60	30	1805.00	3.61	30	1805.00	3.61	**3.61**
15	30	1855.00	3.71	30	1840.00	3.68	30	1840.00	3.68	30	1835.00	3.67	**3.69**
16	30	1700.00	3.40	30	1700.00	3.40	30	1695.00	3.39	30	1690.00	3.38	**3.39**
17	30	1640.00	3.28	30	1620.00	3.24	30	1630.00	3.26	30	1625.00	3.25	**3.26**
18	30	3230.00	6.46	30	3190.00	6.38	30	3200.00	6.40	30	3190.00	6.38	**6.41**
19	30	1850.00	3.70	30	1840.00	3.68	30	1845.00	3.69	30	1840.00	3.68	**3.69**
20	30	2230.00	4.46	30	2190.00	4.38	30	2190.00	4.38	30	2185.00	4.37	**4.40**

Table A.5.24 Emitter flow rate along a 40 meters lateral consist of naturally clogged emitters laid on flat terrain (First operation).

R1. June 24, 1997 Pinlet = 15psi Pend =14.8psi				R2. June 24, 1997 Pinlet = 15psi Pend =14.8psi			R3. June 24, 1997 Pinlet = 15psi Pend =14.8psi			R4.June 24, 1997 Pinlet = 15psi Pend =14.8psi			Average discharge
Emitter #	Timie (minute)	Volume (cc)	q (l/h)	Emitter #	Timie (minute)	Volume (cc)	Emitter #	Timie (minute)	Volume (cc)	Emitter #	Timie (minute)	Volume (cc)	q (l/h)
1	30	1400	2.80	30	1390	2.78	30	1400	2.80	30	1390	2.78	**2.79**
2	30	1710	3.42	30	1720	3.44	30	1710	3.42	30	1720	3.44	**3.43**
3	30	1868	3.74	30	1810	3.62	30	1868	3.74	30	1810	3.62	**3.68**
4	30	1855	3.71	30	1835	3.67	30	1855	3.71	30	1835	3.67	**3.69**
5	30	1742	3.48	30	1740	3.48	30	1742	3.48	30	1740	3.48	**3.48**
6	30	1780	3.56	30	1765	3.53	30	1780	3.56	30	1765	3.53	**3.55**
7	30	1870	3.74	30	1850	3.70	30	1870	3.74	30	1850	3.70	**3.72**
8	30	1780	3.56	30	1770	3.54	30	1780	3.56	30	1770	3.54	**3.55**
9	30	1688	3.38	30	1670	3.34	30	1688	3.38	30	1670	3.34	**3.36**
10	30	1605	3.21	30	1590	3.18	30	1605	3.21	30	1590	3.18	**3.20**
11	30	1790	3.58	30	1780	3.56	30	1790	3.58	30	1780	3.56	**3.57**
12	30	1700	3.40	30	1695	3.39	30	1700	3.40	30	1695	3.39	**3.40**
13	30	1510	3.02	30	1490	2.98	30	1510	3.02	30	1490	2.98	**3.00**
14	30	1695	3.39	30	1690	3.38	30	1695	3.39	30	1690	3.38	**3.39**
15	30	1885	3.77	30	1870	3.74	30	1885	3.77	30	1870	3.74	**3.76**
16	30	1730	3.46	30	1725	3.45	30	1730	3.46	30	1725	3.45	**3.46**
17	30	1770	3.54	30	1762	3.52	30	1770	3.54	30	1762	3.52	**3.53**
18	30	2012	4.02	30	1990	3.98	30	2012	4.02	30	1990	3.98	**4.00**
19	30	1735	3.47	30	1710	3.42	30	1735	3.47	30	1710	3.42	**3.45**
20	30	1810	3.62	30	1780	3.56	30	1810	3.62	30	1780	3.56	**3.59**
21	30	875	1.75	30	760	1.52	30	875	1.75	30	760	1.52	**1.64**
22	30	1780	3.56	30	1770	3.54	30	1780	3.56	30	1770	3.54	**3.55**
23	30	1605	3.21	30	1592	3.18	30	1605	3.21	30	1592	3.18	**3.20**
24	30	1795	3.59	30	1780	3.56	30	1795	3.59	30	1780	3.56	**3.58**
25	30	1720	3.44	30	1715	3.43	30	1720	3.44	30	1715	3.43	**3.44**
26	30	1865	3.73	30	1850	3.70	30	1865	3.73	30	1850	3.70	**3.72**
27	30	1808	3.62	30	1790	3.58	30	1808	3.62	30	1790	3.58	**3.60**
28	30	1510	3.02	30	1500	3.00	30	1510	3.02	30	1500	3.00	**3.01**
29	30	1720	3.44	30	1705	3.41	30	1720	3.44	30	1705	3.41	**3.43**
30	30	1830	3.66	30	1820	3.64	30	1830	3.66	30	1820	3.64	**3.65**
31	30	1715	3.43	30	1700	3.40	30	1715	3.43	30	1700	3.40	**3.42**
32	30	1740	3.48	30	1730	3.46	30	1740	3.48	30	1730	3.46	**3.47**
33	30	1890	3.78	30	1870	3.74	30	1890	3.78	30	1870	3.74	**3.76**
34	30	1840	3.68	30	1830	3.66	30	1840	3.68	30	1830	3.66	**3.67**
35	30	1850	3.70	30	1835	3.67	30	1850	3.70	30	1835	3.67	**3.69**
36	30	1728	3.46	30	1705	3.41	30	1728	3.46	30	1705	3.41	**3.43**
37	30	1730	3.46	30	1728	3.46	30	1730	3.46	30	1728	3.46	**3.46**
38	30	1808	3.62	30	1795	3.59	30	1808	3.62	30	1795	3.59	**3.60**
39	30	1698	3.40	30	1695	3.39	30	1698	3.40	30	1695	3.39	**3.39**
40	30	1850	3.70	30	1840	3.68	30	1850	3.70	30	1840	3.68	**3.69**

Table A.5.25 Emitter flow rate along a 40 meters lateral consist of naturally clogged emitters laid on flat terrain (second operation).

R1. June 24, 1997				R2. June 24, 1997			R3. June 24, 1997			R4.June 24, 1997			Average
Pinlet = 15psi		Pend =14.8psi		Pinlet = 15psi	Pend =14.8psi		Pinlet = 15psi	Pend =14.8psi		Pinlet = 15psi	Pend =14.8psi		discharge
Emitter #	Timie (minute)	Volume (cc)	q (l/h)	Emitter #	Timie (minute)	Volume (cc)	Emitter #	Timie (minute)	Volume (cc)	Emitter #	Timie (minute)	Volume (cc)	q (l/h)
1	30	1394	2.79	30	1392	2.78	30	1394	2.79	30	1392	2.78	**2.79**
2	30	1747	3.49	30	1745	3.49	30	1747	3.49	30	1745	3.49	**3.49**
3	30	1914	3.83	30	1895	3.79	30	1914	3.83	30	1895	3.79	**3.81**
4	30	1882	3.76	30	1870	3.74	30	1882	3.76	30	1870	3.74	**3.75**
5	30	1771	3.54	30	1760	3.52	30	1771	3.54	30	1760	3.52	**3.53**
6	30	1819	3.64	30	1810	3.62	30	1819	3.64	30	1810	3.62	**3.63**
7	30	1957	3.91	30	1930	3.86	30	1957	3.91	30	1930	3.86	**3.89**
8	30	1829	3.66	30	1820	3.64	30	1829	3.66	30	1820	3.64	**3.65**
9	30	1698	3.40	30	1708	3.42	30	1698	3.40	30	1688	3.38	**3.40**
10	30	1616	3.23	30	1605	3.21	30	1616	3.23	30	1605	3.21	**3.22**
11	30	1824	3.65	30	1810	3.62	30	1824	3.65	30	1810	3.62	**3.63**
12	30	1732	3.46	30	1725	3.45	30	1732	3.46	30	1725	3.45	**3.46**
13	30	1510	3.02	30	1500	3.00	30	1510	3.02	30	1500	3.00	**3.01**
14	30	1718	3.44	30	1710	3.42	30	1718	3.44	30	1710	3.42	**3.43**
15	30	1926	3.85	30	1910	3.82	30	1926	3.85	30	1910	3.82	**3.84**
16	30	1761	3.52	30	1755	3.51	30	1761	3.52	30	1755	3.51	**3.52**
17	30	1810	3.62	30	1800	3.60	30	1810	3.62	30	1800	3.60	**3.61**
18	30	2066	4.13	30	2035	4.07	30	2066	4.13	30	2035	4.07	**4.10**
19	30	1781	3.56	30	1770	3.54	30	1781	3.56	30	1770	3.54	**3.55**
20	30	1829	3.66	30	1810	3.62	30	1829	3.66	30	1810	3.62	**3.64**
21	30	850	1.70	30	790	1.58	30	850	1.70	30	790	1.58	**1.64**
22	30	1815	3.63	30	1810	3.62	30	1815	3.63	30	1810	3.62	**3.63**
23	30	1781	3.56	30	1760	3.52	30	1781	3.56	30	1760	3.52	**3.54**
24	30	1529	3.06	30	1470	2.94	30	1529	3.06	30	1470	2.94	**3.00**
25	30	1737	3.47	30	1730	3.46	30	1737	3.47	30	1730	3.46	**3.47**
26	30	1907	3.81	30	1890	3.78	30	1907	3.81	30	1890	3.78	**3.80**
27	30	1839	3.68	30	1830	3.66	30	1839	3.68	30	1830	3.66	**3.67**
28	30	1573	3.15	30	1540	3.08	30	1573	3.15	30	1540	3.08	**3.11**
29	30	1740	3.48	30	1735	3.47	30	1740	3.48	30	1735	3.47	**3.48**
30	30	1863	3.73	30	1855	3.71	30	1863	3.73	30	1855	3.71	**3.72**
31	30	1742	3.48	30	1740	3.48	30	1742	3.48	30	1740	3.48	**3.48**
32	30	1781	3.56	30	1775	3.55	30	1781	3.56	30	1775	3.55	**3.56**
33	30	1918	3.84	30	1910	3.82	30	1918	3.84	30	1910	3.82	**3.83**
34	30	1834	3.67	30	1825	3.65	30	1834	3.67	30	1825	3.65	**3.66**
35	30	1858	3.72	30	1850	3.70	30	1858	3.72	30	1850	3.70	**3.71**
36	30	1771	3.54	30	1760	3.52	30	1771	3.54	30	1760	3.52	**3.53**
37	30	1839	3.68	30	1828	3.66	30	1839	3.68	30	1828	3.66	**3.67**
38	30	1916	3.83	30	1910	3.82	30	1916	3.83	30	1910	3.82	**3.83**
39	30	1708	3.42	30	1700	3.40	30	1708	3.42	30	1700	3.40	**3.41**
40	30	1873	3.75	30	1865	3.73	30	1873	3.75	30	1865	3.73	**3.74**

Table A.5.26 Total percentage of clogging (TC%), degree of clogging (C_d%), and coefficient of uniformity under different numbers and degrees of clogged emitters along a 20 meter lateral obtained from synthetic data (flat terrain)

5% number of emitters are partially clogged

Emitter #	Emitter Flow rate l/h	Degree of Clogging C_d%	Cumulative Percent (TC%)
16	0.28	92.56	**92.56**
CU = 90.79		**TC =** 92.56	
Ave C_d = 4.63			

Ave.C_d = Average degree of clogging along the latera

10% number of emitters are partially clogged

Emitter #	Emitter Flow rate l/h	Degree of Clogging C_d%	Cumulative Percent (TC%)
4	0.98	73.95	**73.95**
13	0.28	92.56	**166.51**
CU = 86.96		**TC =** 166.51	
Ave.C_d = 8.33			

20% number of emitters are partially clogged

Emitter #	Emitter Flow rate l/h	Degree of Clogging C_d%	Cumulative Percent (TC%)
3	2.61	30.62	**30.62**
6	0.28	92.56	**123.17**
8	0.98	73.95	**197.12**
12	1.38	63.32	**260.44**
CU =76.11	**TC** =260.44	**Ave.C_d** =13.022	

30% number of emitters are partially clogged

Emitter #	Emitter Flow rate l/h	Degree of Clogging C_d%	Cumulative Percent (TC%)
1	2.61	30.62	**30.62**
3	1.38	63.32	**93.93**
5	0.98	73.95	**167.88**
9	0.28	92.56	**260.44**
11	0.00	100.00	**360.44**
16	1.68	55.34	**415.78**
CU = 63.36		**TC =** 415.78	
Ave. C_d = 20.79			

40% number of emitters are partially clogged

Emitter #	Emitter Flow rate l/h	Degree of Clogging C_d%	Cumulative Percent (TC%)
2	2.00	46.83	**46.83**
3	1.68	55.34	**102.17**
7	1.98	47.36	**149.54**
9	1.88	50.02	**199.56**
12	0.93	75.28	**274.84**
15	1.28	65.97	**340.81**
17	1.6	57.47	**398.28**
18	0	100.00	**498.28**
CU = 59.83		**TC =** 498.28	
Ave. C_d = 24.91			

50% number of emitters are partially clogged

Emitter #	Emitter Flow rate l/h	Degree of Clogging C_d%	Cumulative Percent (TC%)
2	1.10	70.76	**70.76**
3	1.70	54.81	**125.57**
7	2.00	46.83	**172.40**
9	1.90	49.49	**221.89**
11	2.00	46.83	**268.72**
12	0.95	74.75	**343.47**
15	1.30	65.44	**408.91**
17	1.70	54.81	**463.72**
18	1.00	73.42	**537.14**
19	1.10	70.76	**607.90**
CU =55.9	**TC** =607.9	**Ave.C_d** = 30.39	

Table A.5.26 (continue)

60% number of emitters are partially clogged

Emitter #	Emitter Flow rate l/h	Degree of Clogging C_d %	Cumulative Percent (TC%)
2	1.08	71.29	**71.29**
3	1.68	55.34	**126.63**
5	1.78	52.68	**179.31**
7	0.98	73.95	**253.26**
9	1.88	50.02	**303.28**
10	0.88	76.61	**379.89**
11	0.98	73.95	**453.84**
12	0.93	75.28	**529.12**
15	1.28	65.97	**595.10**
17	0.50	86.71	**681.81**
18	0.60	84.05	**765.86**
19	1.00	73.42	**839.28**
CU = 41.7		**TC =** 839.28	
Ave. C_d = 41.96			

70% number of emitters are partially clogged

Emitter #	Emitter Flow rate l/h	Degree of Clogging C_d %	Cumulative Percent (TC%)
1	1.10	70.76	**70.76**
2	0.08	97.88	**168.64**
3	1.60	57.47	**226.10**
6	1.70	54.81	**280.91**
8	1.90	49.49	**330.40**
9	1.80	52.15	**382.55**
10	0.68	81.93	**464.48**
12	0.98	73.95	**538.43**
13	0.93	75.28	**613.71**
14	1.90	49.49	**663.20**
16	0.68	81.93	**745.12**
17	0.40	89.37	**834.49**
19	0.00	100.00	**934.49**
20	0.90	76.08	**1010.57**
CU = 37.63		**TC =** 1010.57	
Ave. C_d = 50.53			

80% number of emitters are partially clogged

Emitter #	Emitter Flow rate l/h	Degree of Clogging C_d %	Cumulative Percent (TC%)
1	0.10	97.34	**97.34**
2	1.08	71.29	**168.64**
3	0.90	76.08	**244.71**
5	1.01	73.15	**317.86**
6	0.63	83.25	**401.12**
8	1.08	71.29	**472.41**
9	2.10	44.17	**516.58**
10	0.88	76.61	**593.19**
12	1.00	73.42	**666.61**
13	0.88	73.42	**740.03**
14	0.92	76.61	**816.64**
15	1.90	75.54	**892.18**
16	0.00	49.49	**941.67**
17	0.98	100.00	**1041.68**
19	1.78	52.68	**1094.36**
20	0.80	78.73	**1173.09**
CU = 35.32		**TC =** 1173.09	
Ave. C_d = 58.65			

90% number of emitters are partially clogged

Emitter #	Emitter Flow rate l/h	Degree of Clogging C_d %	Cumulative Percent (TC%)
1	0.70	81.39	**81.39**
2	0.08	97.88	**179.27**
3	0.04	98.94	**278.21**
5	0.98	73.95	**352.16**
6	1.63	56.67	**408.83**
7	0.93	75.28	**484.11**
8	1.08	71.29	**555.40**
9	1.60	57.47	**612.87**
10	0.88	76.61	**689.47**
11	0.08	97.88	**787.35**
12	0.98	73.95	**861.30**
13	1.00	73.42	**934.72**
14	1.01	73.15	**1007.87**
15	0.00	100.00	**1107.87**
16	1.00	73.42	**1181.29**
17	0.00	100.00	**1281.29**
19	0.08	97.88	**1379.17**
20	0.03	99.21	**1478.38**
CU = 25.67		**TC =** 1478.38	
Ave. C_d = 73.92			

100% number of emitters are partially clogged

Emitter #	Emitter Flow rate l/h	Degree of Clogging C_d %	Cumulative Percent (TC%)
1	0.10	97.34	**97.34**
2	1.03	72.62	**169.97**
3	0.88	76.61	**246.57**
4	0.08	97.88	**344.45**
5	1.98	47.36	**391.81**
6	1.63	56.67	**448.48**
7	1.00	73.42	**521.90**
8	0.08	97.88	**619.78**
9	1.08	71.29	**691.07**
10	0.78	79.27	**770.34**
11	0.00	100.00	**870.34**
12	0.88	76.61	**946.95**
13	0.93	75.28	**1022.23**
14	0.08	97.88	**1120.10**
15	0.00	100.00	**1220.11**
16	1.60	57.47	**1277.57**
17	0.56	85.12	**1362.69**
18	0.08	97.88	**1460.56**
19	0.07	98.14	**1558.71**
20	0.01	99.74	**1658.44**
CU =14.72	TC =1658.4	**Ave.C_d** =82.92	

Table A.5.27 CU%, C_d%, and TC% obtained from natural, artificial, and synthetic data of partiallty clogged emitters along the 20m lateral (flat terrain)

CU, C_d, and TC from the synthetic data when 5% to 100% of emitters along the lateral are partially clogged				CU, C_d, and TC under Natural and Artificial clogged emitters along the lateral				CU, C_d, and TC under Natural, Artificial and Synthetic clogged emitters		
Percentage of clogging	TC% obtained from synth.data	$C_{d\%}$ obtained from synth.data	CU% obtained from synth.data	Percentage of clogging	TC% obtained from Nat.or Art.	$C_{d\%}$ obtained from Natu. or Art.	CU% obtained from Natu. or Art.	TC% obtained from Nat.,Art.,Syn.	$C_{d\%}$ obtained from Nat.,Art.,Syn.	CU% obtained from Nat.,Art.,Syn.
0	0.00	0.00	98.94	0%	0.00	0.00	96.21	0.00	0.00	96.26
5%	92.56	4.63	90.79	20% N	50.95	2.55	90.43	50.95	2.55	90.43
10%	166.51	8.33	86.96	30% N	154.18	7.71	93.20	92.56	4.63	90.79
20%	260.44	13.02	76.11	20% A	212.32	10.62	81.77	154.18	7.71	93.20
30%	415.78	20.79	63.36	30% A	368.73	18.44	69.44	166.51	8.33	86.96
40%	498.28	24.91	59.83					212.32	10.62	81.77
50%	607.90	30.40	55.90					260.44	13.02	76.11
60%	839.28	41.96	41.70					368.73	18.44	69.44
70%	1010.57	50.53	37.63					415.78	20.79	63.36
80%	1173.09	58.65	35.32					498.28	24.91	59.83
90%	1478.38	73.92	25.67					607.90	30.40	55.90
100%	1658.44	82.92	14.72					839.28	41.96	41.70
								1010.57	50.53	37.63
								1173.09	58.65	35.32
								1478.38	73.92	25.67
								1658.44	82.92	14.72
								2000.00	100.00	0.00

Table A.5.28 Emitter flow rate after flushing a 20 meters lateral(**A**) consist of naturally clogged emitters (laid on flat terrain).

	R1. July 10, 1997			**R2. July 10, 1997**			**R3. July 11, 1997**			**R4.July 11, 1997**			Average
	Pinlet = 15psi	Pend =14.85psi		Pinlet = 15psi	Pend =14.85psi		Pinlet = 15psi	Pend =14.85psi		Pinlet = 15psi	Pend =14.85psi		discharge
Emitter #	Timie (minute)	Volume (cc)	q (l/h)	Timie (minute)	Volume (cc)	q (l/h)	Timie (minute)	Volume (cc)	q (l/h)	Timie (minute)	Volume (cc)	q (l/h)	q (l/h)
1	30	258.00	0.52	30	258.00	0.52	30	195.00	0.39	30	195.00	0.39	**0.45**
2	30	1760.00	3.52	30	1760.00	3.52	30	1740.00	3.48	30	1740.00	3.48	**3.50**
3	30	1930.00	3.86	30	1930.00	3.86	30	1920.00	3.84	30	1920.00	3.84	**3.85**
4	30	1880.00	3.76	30	1880.00	3.76	30	1865.00	3.73	30	1865.00	3.73	**3.75**
5	30	1800.00	3.60	30	1800.00	3.60	30	1800.00	3.60	30	1800.00	3.60	**3.60**
6	30	1770.00	3.54	30	1770.00	3.54	30	1841.00	3.68	30	1841.00	3.68	**3.61**
7	30	1880.00	3.76	30	1880.00	3.76	30	1875.00	3.75	30	1875.00	3.75	**3.76**
8	30	1842.00	3.68	30	1842.00	3.68	30	1822.00	3.64	30	1822.00	3.64	**3.66**
9	30	1740.00	3.48	30	1740.00	3.48	30	1725.00	3.45	30	1725.00	3.45	**3.47**
10	30	1510.00	3.02	30	1510.00	3.02	30	1480.00	2.96	30	1480.00	2.96	**2.99**
11	30	1828.00	3.66	30	1828.00	3.66	30	1815.00	3.63	30	1815.00	3.63	**3.64**
12	30	1682.00	3.36	30	1682.00	3.36	30	1680.00	3.36	30	1680.00	3.36	**3.36**
13	30	1660.00	3.32	30	1660.00	3.32	30	1590.00	3.18	30	1590.00	3.18	**3.25**
14	30	1730.00	3.46	30	1730.00	3.46	30	1720.00	3.44	30	1720.00	3.44	**3.45**
15	30	1935.00	3.87	30	1935.00	3.87	30	1925.00	3.85	30	1925.00	3.85	**3.86**
16	30	1750.00	3.50	30	1750.00	3.50	30	1755.00	3.51	30	1755.00	3.51	**3.51**
17	30	1810.00	3.62	30	1810.00	3.62	30	1815.00	3.63	30	1815.00	3.63	**3.63**
18	30	2037.00	4.07	30	2037.00	4.07	30	2035.00	4.07	30	2035.00	4.07	**4.07**
19	30	1905.00	3.81	30	1905.00	3.81	30	1895.00	3.79	30	1895.00	3.79	**3.80**
20	30	1770.00	3.54	30	1770.00	3.54	30	1810.00	3.62	30	1810.00	3.62	**3.58**

Table A.5.29 Emitter flow rate after flushing a 20 meters lateral(**B**) consist of naturally clogged emitters (laid on flat terrain).

Emitter	**R1. July 10, 1997** Pinlet = 15psi Pend =14.85psi			**R2. July 10, 1997** Pinlet = 15psi Pend =14.85psi			**R3. July 11, 1997** Pinlet = 15psi Pend =14.85psi			**R4.July 11, 1997** Pinlet = 15psi Pend =14.85psi			Average discharge
#	Timie (minute)	Volume (cc)	q (l/h)	Timie (minute)	Volume (cc)	q (l/h)	Timie (minute)	Volume (cc)	q (l/h)	Timie (minute)	Volume (cc)	q (l/h)	q (l/h)
1	30	1828.00	3.66	30	1828.00	3.66	30	1760.00	3.52	30	1760.00	3.52	**3.59**
2	30	1730.00	3.46	30	1730.00	3.46	30	1690.00	3.38	30	1690.00	3.38	**3.42**
3	30	1860.00	3.72	30	1860.00	3.72	30	1815.00	3.63	30	1815.00	3.63	**3.68**
4	30	1878.00	3.76	30	1878.00	3.76	30	1830.00	3.66	30	1830.00	3.66	**3.71**
5	30	1760.00	3.52	30	1760.00	3.52	30	1730.00	3.46	30	1730.00	3.46	**3.49**
6	30	1868.00	3.74	30	1868.00	3.74	30	1830.00	3.66	30	1830.00	3.66	**3.70**
7	30	1800.00	3.60	30	1800.00	3.60	30	1760.00	3.52	30	1760.00	3.52	**3.56**
8	30	1915.00	3.83	30	1915.00	3.83	30	1870.00	3.74	30	1870.00	3.74	**3.79**
9	30	1780.00	3.56	30	1780.00	3.56	30	1752.00	3.50	30	1752.00	3.50	**3.53**
10	30	1740.00	3.48	30	1740.00	3.48	30	1715.00	3.43	30	1715.00	3.43	**3.46**
11	30	1860.00	3.72	30	1860.00	3.72	30	1835.00	3.67	30	1835.00	3.67	**3.70**
12	30	1760.00	3.52	30	1760.00	3.52	30	1730.00	3.46	30	1730.00	3.46	**3.49**
13	30	1557.00	3.11	30	1557.00	3.11	30	1520.00	3.04	30	1520.00	3.04	**3.08**
14	30	1850.00	3.70	30	1850.00	3.70	30	1830.00	3.66	30	1830.00	3.66	**3.68**
15	30	1808.00	3.62	30	1808.00	3.62	30	1780.00	3.56	30	1780.00	3.56	**3.59**
16	30	1755.00	3.51	30	1755.00	3.51	30	1738.00	3.48	30	1738.00	3.48	**3.49**
17	30	1400.00	2.80	30	1400.00	2.80	30	1395.00	2.79	30	1395.00	2.79	**2.80**
18	30	1815.00	3.63	30	1815.00	3.63	30	1790.00	3.58	30	1790.00	3.58	**3.61**
19	30	1790.00	3.58	30	1790.00	3.58	30	1820.00	3.64	30	1820.00	3.64	**3.61**
20	30	860.00	1.72	30	860.00	1.72	30	915.00	1.83	30	915.00	1.83	**1.78**

Table A.5.30 Emitter flow rate after flushing a 40 meters lateral consist of naturally clogged emitters (laid on flat terrain).

Emitter #	R1. July 3, 1997 Pinlet = 15psi Timie (minute)	Volume (cc)	Pend =14.8p q (l/h)	R2. July 7, 1997 Pinlet = 15psi Timie (minute)	Pend =14.8psi Volume (cc)	q (l/h)	R3. July 7, 1997 Pinlet = 15psi Timie (minute)	Pend =14.8psi Volume (cc)	q (l/h)	R4.July 7, 1997 Pinlet = 15psi Timie (minute)	Pend =14.8psi Volume (cc)	q (l/h)	Average discharge q (l/h)
1	30	850	1.70	30	720	1.44	30	850	1.70	30	720	1.44	**1.57**
2	30	1760	3.52	30	1750	3.50	30	1760	3.52	30	1750	3.50	**3.51**
3	30	1925	3.85	30	1910	3.82	30	1925	3.85	30	1910	3.82	**3.84**
4	30	1890	3.78	30	1880	3.76	30	1890	3.78	30	1880	3.76	**3.77**
5	30	1845	3.69	30	1820	3.64	30	1845	3.69	30	1820	3.64	**3.67**
6	30	1820	3.64	30	1805	3.61	30	1820	3.64	30	1805	3.61	**3.63**
7	30	1888	3.78	30	1898	3.80	30	1888	3.78	30	1898	3.80	**3.79**
8	30	1835	3.67	30	1830	3.66	30	1835	3.67	30	1830	3.66	**3.67**
9	30	1698	3.40	30	1698	3.40	30	1698	3.40	30	1698	3.40	**3.40**
10	30	1610	3.22	30	1540	3.08	30	1610	3.22	30	1540	3.08	**3.15**
11	30	1830	3.66	30	1800	3.60	30	1830	3.66	30	1800	3.60	**3.63**
12	30	1720	3.44	30	1700	3.40	30	1720	3.44	30	1700	3.40	**3.42**
13	30	1720	3.44	30	1655	3.31	30	1720	3.44	30	1655	3.31	**3.38**
14	30	1712	3.42	30	1720	3.44	30	1712	3.42	30	1720	3.44	**3.43**
15	30	1920	3.84	30	1908	3.82	30	1920	3.84	30	1908	3.82	**3.83**
16	30	1760	3.52	30	1750	3.50	30	1760	3.52	30	1750	3.50	**3.51**
17	30	1810	3.62	30	1808	3.62	30	1810	3.62	30	1808	3.62	**3.62**
18	30	2054	4.11	30	2010	4.02	30	2054	4.11	30	2010	4.02	**4.06**
19	30	1780	3.56	30	1760	3.52	30	1780	3.56	30	1760	3.52	**3.54**
20	30	1790	3.58	30	1730	3.46	30	1790	3.58	30	1730	3.46	**3.52**
21	30	795	1.59	30	550	1.10	30	795	1.59	30	550	1.10	**1.35**
22	30	1868	3.74	30	1808	3.62	30	1868	3.74	30	1808	3.62	**3.68**
23	30	1680	3.36	30	1770	3.54	30	1680	3.36	30	1770	3.54	**3.45**
24	30	1735	3.47	30	1745	3.49	30	1735	3.47	30	1745	3.49	**3.48**
25	30	1730	3.46	30	1728	3.46	30	1730	3.46	30	1728	3.46	**3.46**
26	30	1865	3.73	30	1760	3.52	30	1865	3.73	30	1760	3.52	**3.63**
27	30	1830	3.66	30	1838	3.68	30	1830	3.66	30	1838	3.68	**3.67**
28	30	1600	3.20	30	1490	2.98	30	1600	3.20	30	1490	2.98	**3.09**
29	30	1740	3.48	30	1735	3.47	30	1740	3.48	30	1735	3.47	**3.48**
30	30	1860	3.72	30	1840	3.68	30	1860	3.72	30	1840	3.68	**3.70**
31	30	1755	3.51	30	1730	3.46	30	1755	3.51	30	1730	3.46	**3.49**
32	30	1770	3.54	30	1735	3.47	30	1770	3.54	30	1735	3.47	**3.51**
33	30	1912	3.82	30	1920	3.84	30	1912	3.82	30	1920	3.84	**3.83**
34	30	1820	3.64	30	1800	3.60	30	1820	3.64	30	1800	3.60	**3.62**
35	30	1862	3.72	30	1850	3.70	30	1862	3.72	30	1850	3.70	**3.71**
36	30	1850	3.70	30	1718	3.44	30	1850	3.70	30	1718	3.44	**3.57**
37	30	1855	3.71	30	1830	3.66	30	1855	3.71	30	1830	3.66	**3.69**
38	30	1862	3.72	30	1810	3.62	30	1862	3.72	30	1810	3.62	**3.67**
39	30	1710	3.42	30	1690	3.38	30	1710	3.42	30	1690	3.38	**3.40**
40	30	1840	3.68	30	1830	3.66	30	1840	3.68	30	1830	3.66	**3.67**

Table A.5.31 Effect of air and water temperature on emitter flow rate along the 20m lateral (**A**) after flushing the lateral (flat terrain).

Emitter # along the lateral	Air Temp.=17.5c, Cloudy Water temp.(first sec. 15.5c) Water temp.(midle sec. 15.9c) Water temp.(last sec. 17c) R1. July 21, 1997 Pinlet = 15psi Pend =14.85psi			Air Temp.=21.8c, sunny(4PM) Water temp.(first sec. 19.2c) Water temp.(midle sec. 19.8c) Water temp.(last sec. 21.5c) R2. July 22, 1997 Pinlet = 15psi Pend =14.85psi			Air Temp.=16c, sunset(10PM) Water temp.(first sec. 14c) Water temp.(midle sec. 14c) Water temp.(last sec. 15c) R3. July 22 , 1997 Pinlet = 15psi Pend =14.85psi			Air Temp.=15.5c, sunrise(6 AM) Water temp.(first sec. 14.2c) Water temp.(midle sec. 14.5c) Water temp.(last sec. 15.3c) R4.July 23, 1997 Pinlet = 15psi Pend =14.85psi			Air Temp.=20.2c, sunny(3 PM) Water temp.(first sec. 19c) Water temp.(midle sec. 19.5c) Water temp.(last sec. 21.5c) R4.July 23, 1997 Pinlet = 15psi Pend =14.85psi			Average discharge q (l/h)
	Time (min)	Vol.(cc)	q (l/h)	Time (min)	Vol.(cc)	q (l/h)	Time (min)	Vol.(cc)	q (l/h)	Time (min)	Vol.(cc)	q (l/h)	Time (min)	Vol.(cc)	q (l/h)	
1	30	190.00	0.38	30	170.00	0.34	30	110.00	0.22	30	165.00	0.33	30	160	0.32	0.32
2	30	1750.00	3.50	30	1728.00	3.46	30	1710.00	3.42	30	1740.00	3.48	30	1720	3.44	3.46
3	30	1918.00	3.84	30	1895.00	3.79	30	1840.00	3.68	30	1898.00	3.80	30	1898	3.80	3.78
4	30	1865.00	3.73	30	1840.00	3.68	30	1790.00	3.58	30	1860.00	3.72	30	1848	3.70	3.68
5	30	1750.00	3.50	30	1810.00	3.62	30	1760.00	3.52	30	1805.00	3.61	30	1800	3.60	3.57
6	30	1900.00	3.80	30	1855.00	3.71	30	1810.00	3.62	30	1878.00	3.76	30	1875	3.75	3.73
7	30	1930.00	3.86	30	1850.00	3.70	30	1810.00	3.62	30	1885.00	3.77	30	1875	3.75	3.74
8	30	1840.00	3.68	30	1812.00	3.62	30	1770.00	3.54	30	1810.00	3.62	30	1808	3.62	3.62
9	30	1749.00	3.50	30	1725.00	3.45	30	1675.00	3.35	30	1710.00	3.42	30	1715	3.43	3.43
10	30	1610.00	3.22	30	1555.00	3.11	30	1510.00	3.02	30	1520.00	3.04	30	1530	3.06	3.09
11	30	1850.00	3.70	30	1810.00	3.62	30	1772.00	3.54	30	1825.00	3.65	30	1802	3.60	3.62
12	30	1680.00	3.36	30	1670.00	3.34	30	1642.00	3.28	30	1685.00	3.37	30	1678	3.36	3.34
13	30	1545.00	3.09	30	1580.00	3.16	30	1510.00	3.02	30	1570.00	3.14	30	1570	3.14	3.11
14	30	1738.00	3.48	30	1720.00	3.44	30	1695.00	3.39	30	1705.00	3.41	30	1718	3.44	3.43
15	30	1950.00	3.90	30	1915.00	3.83	30	1868.00	3.74	30	1920.00	3.84	30	1910	3.82	3.83
16	30	1742.00	3.48	30	1750.00	3.50	30	1718.00	3.44	30	1755.00	3.51	30	1748	3.50	3.49
17	30	1810.00	3.62	30	1810.00	3.62	30	1775.00	3.55	30	1815.00	3.63	30	1792	3.58	3.60
18	30	2008.00	4.02	30	2015.00	4.03	30	1930.00	3.86	30	1990.00	3.98	30	1970	3.94	3.97
19	30	1995.00	3.99	30	1915.00	3.83	30	1850.00	3.70	30	1930.00	3.86	30	1948	3.90	3.86
20	30	1810.00	3.62	30	1815.00	3.63	30	1745.00	3.49	30	1803.00	3.61	30	1830	3.66	3.60

Table A.5.32 Effect of air and water temperature on emitter flow rate along the 20m lateral (B) after flushing the lateral (flat terrain).

Emitter # along the lateral	Air Temp.=17.5c, Cloudy Water temp.(first sec. 15.5c) Water temp.(midle sec. 15.9c) Water temp.(last sec. 17c) R1. July 21, 1997 Pinlet = 15psi Pend =14.85psi			Air Temp.=21.8c, sunny (10 AM) Water temp.(first sec. 19.2c) Water temp.(midle sec. 19.8c) Water temp.(last sec. 21.5c) R2. July 22, 1997 Pinlet = 15psi Pend =14.85psi			Air Temp.=16c, sunset(10PM) Water temp.(first sec. 14c) Water temp.(midle sec. 14c) Water temp.(last sec. 15c) R3. July 22 , 1997 Pinlet = 15psi Pend =14.85psi			Air Temp.=15.5c, sunrise(6 AM) Water temp.(first sec. 14.2c) Water temp.(midle sec. 14.5c) Water temp.(last sec. 15.3c) R3. July 23 , 1997 Pinlet = 15psi Pend =14.85psi			Air Temp.=20.2c, sunny(3 PM) Water temp.(first sec. 19c) Water temp.(midle sec. 19.5c) Water temp.(last sec. 21.5c) R3. July 23 , 1997 Pinlet = 15psi Pend =14.85psi			Average discharge q
	Time (min)	Vol.(cc)	q (l/h)	Time (min)	Vol.(cc)	q (l/h)	Time (min)	Vol.(cc)	q (l/h)	Time (min)	Vol.(cc)	q (l/h)	Time (min)	Vol.(cc)	q (l/h)	(l/h)
1	30	1775.00	3.55	30	1730.00	3.46	30	1695.00	3.39	30	1750.00	3.50	30	1740	3.48	3.48
2	30	1705.00	3.41	30	1680.00	3.36	30	1655.00	3.31	30	1675.00	3.35	30	1670	3.34	3.36
3	30	1792.00	3.58	30	1730.00	3.46	30	1710.00	3.42	30	1758.00	3.52	30	1725	3.45	3.50
4	30	1850.00	3.70	30	1820.00	3.64	30	1782.00	3.56	30	1840.00	3.68	30	1810	3.62	3.65
5	30	1740.00	3.48	30	1715.00	3.43	30	1700.00	3.40	30	1720.00	3.44	30	1710	3.42	3.44
6	30	1850.00	3.70	30	1820.00	3.64	30	1780.00	3.56	30	1829.00	3.66	30	1820	3.64	3.64
7	30	1770.00	3.54	30	1730.00	3.46	30	1698.00	3.40	30	1740.00	3.48	30	1730	3.46	3.47
8	30	1915.00	3.83	30	1880.00	3.76	30	1848.00	3.70	30	1910.00	3.82	30	1890	3.78	3.78
9	30	1760.00	3.52	30	1730.00	3.46	30	1700.00	3.40	30	1735.00	3.47	30	1725	3.45	3.46
10	30	1700.00	3.40	30	1660.00	3.32	30	1622.00	3.24	30	1685.00	3.37	30	1665	3.33	3.33
11	30	1850.00	3.70	30	1810.00	3.62	30	1778.00	3.56	30	1830.00	3.66	30	1815	3.63	3.63
12	30	1730.00	3.46	30	1710.00	3.42	30	1680.00	3.36	30	1720.00	3.44	30	1710	3.42	3.42
13	30	1510.00	3.02	30	1505.00	3.01	30	1450.00	2.90	30	1495.00	2.99	30	1480	2.96	2.98
14	30	1780.00	3.56	30	1800.00	3.60	30	1765.00	3.53	30	1825.00	3.65	30	1810	3.62	3.59
15	30	1782.00	3.56	30	1770.00	3.54	30	1710.00	3.42	30	1790.00	3.58	30	1770	3.54	3.53
16	30	1710.00	3.42	30	1700.00	3.40	30	1675.00	3.35	30	1698.00	3.40	30	1700	3.40	3.39
17	30	1342.00	2.68	30	1315.00	2.63	30	1260.00	2.52	30	1070.00	2.14	30	1090	2.18	2.49
18	30	1780.00	3.56	30	1780.00	3.56	30	1738.00	3.48	30	1768.00	3.54	30	1760	3.52	3.53
19	30	1815.00	3.63	30	1800.00	3.60	30	1750.00	3.50	30	1780.00	3.56	30	1770	3.54	3.57
20	30	847.00	1.69	30	860.00	1.72	30	800.00	1.60	30	792.00	1.58	30	820	1.64	1.65

Table A.5.33 Comparison of hydraulic parameters under artificially, synthetically, and naturally clogged emitters (20m lateral, flat terrain)

	A.C	P.C	N.C,lat. A	N.C,lat. B
Hvar	0.0009	0.0009	0.0012	0.0013
Hf(m)	0.0098	0.0097	0.0124	0.0142
	A.C	**P.C**	**N.C,lat. A**	**N.C,lat. B**
CU(%)	69.44	63.36	95.24	90.43
EU'(%)	43.72	35.40	91.40	89.66
	A.C	**P.C**	**N.C,lat. A**	**N.C,lat. B**
qvar (%)	0.00702	0.00694	0.00889	0.01015
Hvar (%)	0.09270	0.09169	0.11740	0.13401
	A.C	**P.C**	**N.C,lat. A**	**N.C,lat. B**
Vqs (%)	35.651	43.110	6.9008	18.2236
Vhs (%)	0.028	0.028	0.0359	0.0410
Vqh (%)	0.002	0.002	0.0027	0.0031
Vpf (%)	35.651	43.110	6.9008	18.2236

A.C: artificial clogging
P.C: predict or synthetic data of clogging
N.C: natural clogging

Table A.5.34 Emitter flow rate along the lateral (20m) under artificial, synthetic and natural clogging (flat terrain)

Emitter #	Flow rate (l/h) A.C(stage 5)	Flow rate (l/h) P.C(stage 5)	Flow rate (l/h) N.C.,Lat A	Flow rate (l/h) N.C.,Lat B
1	1.99	2.61	2.73	3.49
2	3.46	3.76	3.40	3.31
3	1.72	1.38	3.80	3.45
4	3.76	3.76	3.58	3.53
5	0.26	0.98	3.53	3.41
6	3.73	3.69	3.58	3.61
7	3.66	3.71	3.79	3.59
8	3.92	3.78	3.58	3.76
9	1.32	0.28	3.36	3.49
10	3.49	3.80	3.64	3.38
11	1.17	0.00	3.63	3.62
12	3.42	3.80	3.44	3.43
13	3.37	3.76	3.42	3.18
14	3.61	3.69	3.41	3.61
15	3.59	3.74	3.84	3.69
16	2.24	1.68	3.48	3.39
17	3.53	3.76	3.63	3.26
18	3.57	3.76	3.10	6.41
19	3.64	3.73	3.54	3.69
20	3.66	3.69	3.54	4.40
Lat. flow	59.09	59.39	70.00	73.66

Table A.5.35 The value of venturi throat diameter,d (cm) under differents pressures (psi) and required lateral inflow (L/M).

Lat.flow *Q (L/M)	coefficient C (Constant)	inlet diam. D (cm)	inlet press. P1 (psi)	Throat press. P2 (psi)	conversion K (Constant)	Throat diam. d (cm)
2.52	0.98	1.5	60	15	6.66	0.148
2.52	0.98	1.5	60	25	6.66	0.158
2.52	0.98	1.5	60	30	6.66	0.164
2.52	0.98	1.5	50	15	6.66	0.158
2.52	0.98	1.5	50	25	6.66	0.172
2.52	0.98	1.5	50	30	6.66	0.182
2.52	0.98	1.5	40	15	6.66	0.172
2.52	0.98	1.5	40	25	6.66	0.196
2.52	0.98	1.5	40	30	6.66	0.217
2.52	0.98	1.5	30	15	6.66	0.196
2.52	0.98	1.5	30	25	6.66	0.258
2.52	0.98	1.5	30	30	6.66	#DIV/0.0
2.52	0.98	1.5	15	15	6.66	#DIV/0.0
2.52	0.98	1.5	20	15	6.66	0.258
2.52	0.98	1.5	30	15	6.66	0.196
2.52	0.98	1.5	40	15	6.66	0.172
2.52	0.98	1.5	50	15	6.66	0.158
2.52	0.98	1.5	60	15	6.66	0.148
2.52	0.98	1.5	70	15	6.66	0.141
2.52	0.98	1.5	15	10	6.66	0.258
2.52	0.98	1.5	20	10	6.66	0.217
2.52	0.98	1.5	30	10	6.66	0.182
2.52	0.98	1.5	40	10	6.66	0.164
2.52	0.98	1.5	50	10	6.66	0.153
2.52	0.98	1.5	60	10	6.66	0.145
2.52	0.98	1.5	70	10	6.66	0.138
2.52	0.98	1.5	60	30	6.66	0.164
2.52	0.98	1.5	60	20	6.66	0.153
2.52	0.98	1.5	60	15	6.66	0.148
2.52	0.98	1.5	50	30	6.66	0.182
2.52	0.98	1.5	50	20	6.66	0.164
2.52	0.98	1.5	50	15	6.66	0.158
2.52	0.98	1.5	40	30	6.66	0.217
2.52	0.98	1.5	40	20	6.66	0.182
2.52	0.98	1.5	40	15	6.66	0.172

***: $Q = Cd^2 K (P1 - P2)^{1/2} / [1 - (d/D)^2]^{1/2}$**

Q=lateral flow (L/min, gal/min)

C= flow coefficient

d= throat diameter in cm, inches

P1 = pressure in upstrem section (Kpa, lb/in^2)

P2 = pressure in contractioin (Kpa, lb/in^2)

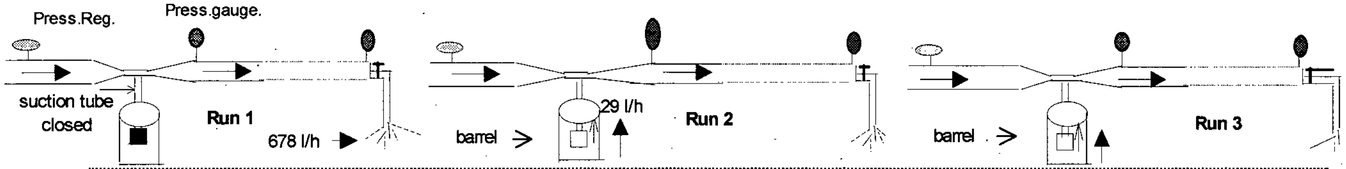
K = unit constant (K = 6.66 for Q in L/min, d and D in cm, P1 , P2 , in Kpa

OR, K = 29.86 for Q in gal/min, d and D in inches, and P1 , P2 , in lb/ft^2)

Table A.5.36 Required lateral inflow (Q) under different values of inlet pressure (P_1) and outlet pressure (P_2) in psi of a venturi injector.

Required flow **Q** L/min	Coefficient **C** Constant	inlte diam. **D** cm	inlet press. **P1** psi	throat press. **P2** psi	corec.fact. **K** 6.66	throat.diam. **d** cm
2.496	0.98	1.5	60	15	6.66	0.147
2.202	0.98	1.5	60	25	6.66	0.147
2.038	0.98	1.5	60	30	6.66	0.147
2.202	0.98	1.5	50	15	6.66	0.147
1.861	0.98	1.5	50	25	6.66	0.147
1.664	0.98	1.5	50	30	6.66	0.147
1.861	0.98	1.5	40	15	6.66	0.147
1.441	0.98	1.5	40	25	6.66	0.147
1.177	0.98	1.5	40	30	6.66	0.147
1.441	0.98	1.5	30	15	6.66	0.147
1.177	0.98	1.5	30	20	6.66	0.147
0.832	0.98	1.5	30	25	6.66	0.147
0.000	0.98	1.5	30	30	6.66	0.147

Table A.5.37 Variations in emitter flow rate in different runs when venturi injector installed and city water is injected (20m, naturally clogged, flat terrain).



Run1: No injection of water from barrel
Liquid suction tube closed
Water passes through the venturi into the entire length of lateral(Q= 678 L/h)

Pregulator (injector inlet)=24.5-25psi — Diff.in Press. 10psi
Pinjector outlet(lateral inlet)=14.5-15psi
Pend of lateral= 12-12.2 psi

Run2: With injection of water from barrel
Liquid suction 28.3 l/h,Q from connected pipe 725 L/h
Water mixed from main hose and venturi injector, flow into the lateral (Not adjusted pressure)

Pregulator (injector inlet)=25-26psi — Diff.in Press. 13.5psi
Pinjector outlet(lateral inlet)=11.5-12.5psi
Pend of lateral= 9-9.5 psi

Run3: With injection of water from bucket(26 l/h)
Suction opened (adjusted lateral inlet pressure to 15 psi by decreasing Q (716 l/h) from a hose connected at the end of 20 m lateral.

Pregulator (injector inlet)=24.5-25psi — Diff.in Pres. 10psi
Pinjector outlet(lateral inlet)=14.5-15psi
Pend of lateral= 12-12.2 psi

Emitter #	Timie (min)	Ave.Vol.(cc)	q (l/h)	Emitter #	Timie (min)	Ave.Vol.(cc)	q (l/h)	Emitter #	Timie (min)	Ave.Vol.(cc)	q (l/h)
1	30	40.00	0.08	1	30	46.00	0.09	1	30	41.00	0.08
2	30	1730.00	3.46	2	30	1760.00	3.52	2	30	1720.00	3.44
3	30	1905.00	3.81	3	30	1920.00	3.84	3	30	1900.00	3.80
4	30	1870.00	3.74	4	30	1895.00	3.79	4	30	1865.00	3.73
5	30	1815.00	3.63	5	30	1848.00	3.70	5	30	1810.00	3.62
6	30	1900.00	3.80	6	30	1925.00	3.85	6	30	1900.00	3.80
7	30	1920.00	3.84	7	30	1925.00	3.85	7	30	1920.00	3.84
8	30	1790.00	3.58	8	30	1825.00	3.65	8	30	1790.00	3.58
9	30	1738.00	3.48	9	30	1780.00	3.56	9	30	1725.00	3.45
10	30	1495.00	2.99	10	30	1470.00	2.94	10	30	1495.00	2.99
11	30	1838.00	3.68	11	30	1850.00	3.70	11	30	1820.00	3.64
12	30	1580.00	3.16	12	30	1565.00	3.13	12	30	1570.00	3.14
13	30	1742.00	3.48	13	30	1720.00	3.44	13	30	1730.00	3.46
14	30	1670.00	3.34	14	30	1720.00	3.44	14	30	1678.00	3.36
15	30	1920.00	3.84	15	30	1885.00	3.77	15	30	1910.00	3.82
16	30	1710.00	3.42	16	30	1728.00	3.46	16	30	1710.00	3.42
17	30	1810.00	3.62	17	30	1810.00	3.62	17	30	1800.00	3.60
18	30	1965.00	3.93	18	30	1950.00	3.90	18	30	1945.00	3.89
19	30	2090.00	4.18	19	30	2000.00	4.00	19	30	2090.00	4.18
20	30	1420.00	2.84	20	30	1370.00	2.74	20	30	1415.00	2.83
CU =	86.554	Ea =	99.998	CU =	86.190	Ea =	99.997	CU =	86.648	Ea =	99.998
EU'=	73.108	qvar =	0.000089	EU'=	72.536	qvar =	0.0001113	EU'=	73.297	qvar =	0.0000887
						Percent water				Percent water	
Total emitters flow(L/h):			67.90	Total emitters flow(L/h):			67.98	Total emitters flow(L/h):			67.67
Q from connected pipe (L/h):			678	Q from connected pipe (L/h):			725	Q from connected pipe (L/h):			716
Total Q in the system(L/h):			745.90	**Q from injector =3.56%(2**		3.569	28.3	**Q from injector =3.31%(26**		3.318	26
				Total Q in the system (L/h):			792.98	Total Q in the system (L/h):			783.67
				Q from main line=96.43%		96.431	764.68	**Q from main line=96.68%**		96.682	757.67
		Vqs	0.2421			**Vqs**	0.2431			**Vqs**	0.2420

Table A.5.38 Variation in emitter flow ratein different runs when venturi injector installed and city water is injected (40m lateral, naturally clogged, flat terrain)

Run1: No injection of water from barrel
Liquid suction tube closed
Water passes through the venturi into the lateral(Q connection pipe=607.62 L/h)

Pregulator (injector inlet)=24.5-25.5 psi — Diff.in Press. 10psi
Pinjector outlet(lateral inlet)=14.5-15.5psi
Pend of lateral= 8-8.5 psi

Run2: With injection of water from barrel
Liquid suction 42.4 l/h,Q from connected pipe 534 L/h
Water mixed from main hose and venturi injector, flow into the lateral (Not adjusted pres.)

Pregulator (injector inlet)=25-26 psi — Diff.in Press. 13.25 psi
Pinjector outlet(lateral inlet)=12-12.5psi
Pend of lateral= 6.5-7 psi (Not adjusted pressure)

Run3:Injection water (48 l/h) from bucket, Q from connected pipe= 615.6 l/h
Suction opened & adjusted lateral inlet pressure to 14.5-15.5 psi by increasing the press. regul. to 33-34 psi. (Adjusted Pressure)

Pregulator (injector inlet)=33.5-34.5 psi — Diff.in Press. 19psi
Pinjector outlet(lateral inlet)=14.5-15.5psi
Pend of lateral= 8-8.5 psi

Run1 Emitter #	Timie (min)	Ave.Vol.(cc)	q (l/h)	Run2 Emitter #	Timie (min)	Ave.Vol.(cc)	q (l/h)	Run3 Emitter #	Timie (min)	Ave.Vol.(cc)	q (l/h)
1	30	370.00	0.74	1	30	300.00	0.60	1	30	350.00	0.70
2	30	1740.00	3.48	2	30	1730.00	3.46	2	30	1730.00	3.46
3	30	1940.00	3.88	3	30	1920.00	3.84	3	30	1910.00	3.82
4	30	1720.00	3.44	4	30	1680.00	3.36	4	30	1690.00	3.38
5	30	1835.00	3.67	5	30	1810.00	3.62	5	30	1815.00	3.63
6	30	1945.00	3.89	6	30	1925.00	3.85	6	30	1935.00	3.87
7	30	1935.00	3.87	7	30	1920.00	3.84	7	30	1915.00	3.83
8	30	1830.00	3.66	8	30	1830.00	3.66	8	30	1835.00	3.67
9	30	1760.00	3.52	9	30	1760.00	3.52	9	30	1740.00	3.48
10	30	1505.00	3.01	10	30	1470.00	2.94	10	30	1498.00	3.00
11	30	1860.00	3.72	11	30	1840.00	3.68	11	30	1840.00	3.68
12	30	1640.00	3.28	12	30	1610.00	3.22	12	30	1600.00	3.20
13	30	1518.00	3.04	13	30	1435.00	2.87	13	30	1480.00	2.96
14	30	1710.00	3.42	14	30	1710.00	3.42	14	30	1690.00	3.38
15	30	1940.00	3.88	15	30	1900.00	3.80	15	30	1920.00	3.84
16	30	1765.00	3.53	16	30	1730.00	3.46	16	30	1740.00	3.48
17	30	1840.00	3.68	17	30	1810.00	3.62	17	30	1830.00	3.66
18	30	2110.00	4.22	18	30	2115.00	4.23	18	30	2100.00	4.20
19	30	2110.00	4.22	19	30	2080.00	4.16	19	30	2105.00	4.21
20	30	1980.00	3.96	20	30	1920.00	3.84	20	30	1865.00	3.73
21	30	550.00	1.10	21	30	475.00	0.95	21	30	535.00	1.07
22	30	1900.00	3.80	22	30	1785.00	3.57	22	30	1860.00	3.72
23	30	1700.00	3.40	23	30	1560.00	3.12	23	30	1600.00	3.20
24	30	1240.00	2.48	24	30	1130.00	2.26	24	30	1190.00	2.38
25	30	1740.00	3.48	25	30	1690.00	3.38	25	30	1720.00	3.44
26	30	1800.00	3.60	26	30	1660.00	3.32	26	30	1780.00	3.56
27	30	1820.00	3.64	27	30	1660.00	3.32	27	30	1815.00	3.63
28	30	1570.00	3.14	28	30	1410.00	2.82	28	30	1535.00	3.07
29	30	1750.00	3.50	29	30	1630.00	3.26	29	30	1730.00	3.46
30	30	1850.00	3.70	30	30	1700.00	3.40	30	30	1840.00	3.68
31	30	1780.00	3.56	31	30	1630.00	3.26	31	30	1770.00	3.54
32	30	1850.00	3.70	32	30	1700.00	3.40	32	30	1820.00	3.64
33	30	1830.00	3.66	33	30	1645.00	3.29	33	30	1830.00	3.66
34	30	1745.00	3.49	34	30	1570.00	3.14	34	30	1720.00	3.44
35	30	1720.00	3.44	35	30	1560.00	3.12	35	30	1710.00	3.42
36	30	1730.00	3.46	36	30	1600.00	3.20	36	30	1720.00	3.44
37	30	1790.00	3.58	37	30	1600.00	3.20	37	30	1780.00	3.56
38	30	1760.00	3.52	38	30	1595.00	3.19	38	30	1750.00	3.50
39	30	1710.00	3.42	39	30	1580.00	3.16	39	30	1690.00	3.38
40	30	1725.00	3.45	40	30	1520.00	3.04	40	30	1698.00	3.40
CU =	89.394	Ea =	99.984	CU =	87.628	Ea =	99.982	CU =	88.470	Ea =	99.984
EU'=	78.787	qvar =	0.0006059	EU'=	76.264	qvar =	0.0006583	EU'=	76.954	qvar =	0.00058276

Run1

Total emitters flow(L/h):	137.23
Q from connected pipe (L/h):	607.62
Total Q in the system(L/h):	744.85
Vqs	0.1905

Run2

	Percent water	
Total emitters flow(L/h):		130.39
Q from connected pipe (L/h):		534
Q from injector =6.38%(42.4	6.382	42.4
Total Q in the system (L/h):		664.39
Q from main line=93.62%	93.618	621.99
Vqs		0.2076

Run3

	Percent water	
Total emitters flow(L/h):		135.36
Q from connected pipe (L/h):		615.6
Q from injector =6.4%(48L/t	6.392	48
Total Q in the system (L/h):		750.96
Q from main line=93.6%	93.608	702.96
Vqs		0.1962

Table A.5.39 Variations in emitter flow rate in different runs when venturi injector installed and city water is injected (20m, no clogged, flat terrain)

Run1: No injection of water from barrel
Liquid suction tube closed
Water passes through the venturi into the lateral(Q from the connection pipe 672 L/h)
Pregulator (injector inlet)=24.5-25.5psi — Diff.in Press. 10psi
Pinjector outlet(lateral inlet)=14.5-15.5psi
Pend of lateral= 12-12.5 psi

Emitter #	Timie (min)	Ave.Vol.(cc)	q (l/h)
1	30	2210.00	4.42
2	30	2200.00	4.40
3	30	1840.00	3.68
4	30	1860.00	3.72
5	30	2050.00	4.10
6	30	1940.00	3.88
7	30	1940.00	3.88
8	30	2045.00	4.09
9	30	1750.00	3.50
10	30	1810.00	3.62
11	30	2120.00	4.24
12	30	1840.00	3.68
13	30	1950.00	3.90
14	30	2040.00	4.08
15	30	1825.00	3.65
16	30	2080.00	4.16
17	30	1820.00	3.64
18	30	1885.00	3.77
19	30	2115.00	4.23
20	30	2024.00	4.05
CU=	94.003	Ea=	99.997
EU'=	91.956	qvar =	0.0001078
Total emitters flow(L/h):			78.69
Q from connected pipe (L/h):			672
Total Q in the system(L/h):			750.69
		Vqs	0.0681

Run2: With injection of water from barrel
Liquid suction 48.9 l/h,Q from connected pipe 608 L/h
Water mixed from main hose and venturi injector, flow into the lateral (Not adjusted pres.)
Pregulator (injector inlet)=25-26psi — Diff.in Press. 13.75
Pinjector outlet(lateral inlet)=11.5-12psi
Pend of lateral= 9-9.5 psi

Emitter #	Timie (min)	Ave.Vol.(cc)	q (l/h)
1	30	2150.00	4.30
2	30	2130.00	4.26
3	30	1870.00	3.74
4	30	1880.00	3.76
5	30	2012.00	4.02
6	30	1925.00	3.85
7	30	1920.00	3.84
8	30	2012.00	4.02
9	30	1770.00	3.54
10	30	1830.00	3.66
11	30	1940.00	3.88
12	30	1825.00	3.65
13	30	1890.00	3.78
14	30	1945.00	3.89
15	30	1810.00	3.62
16	30	1930.00	3.86
17	30	1795.00	3.59
18	30	1840.00	3.68
19	30	1920.00	3.84
20	30	1850.00	3.70
CU =	95.998	Ea =	99.996
EU'=	94.481	qvar =	0.0001288
		Percent water	
Total emitters flow(L/h):			76.49
Q from connected pipe (L/h):			672
Q from injector =6.53%(48.9		6.533	48.9
Total Q in the system (L/h):			748.49
Q from main line=93.46%		93.467	699.59
		Vqs	0.0520

Run3:Injection water(52.7L/h), Q connectedpipe=683.5L
Suction opened & adjusted lateral inlet pressure to 14.5-15.5 psi by increasing the pressure regulator to 34 psi. (Adjusted Pressure)
Pregulator (injector inlet)=33.5-34.5psi — Diff.in Press. 19.25psi
Pinjector outlet(lateral inlet)=14.5-15.psi
Pend of lateral= 12-12.5 psi

Emitter #	Timie (min)	Ave.Vol.(cc)	q (l/h)
1	30	2220.00	4.44
2	30	2180.00	4.36
3	30	1835.00	3.67
4	30	1860.00	3.72
5	30	2022.00	4.04
6	30	1930.00	3.86
7	30	1900.00	3.80
8	30	2040.00	4.08
9	30	1760.00	3.52
10	30	1805.00	3.61
11	30	2110.00	4.22
12	30	1830.00	3.66
13	30	1940.00	3.88
14	30	2030.00	4.06
15	30	1820.00	3.64
16	30	2080.00	4.16
17	30	1810.00	3.62
18	30	1880.00	3.76
19	30	2110.00	4.22
20	30	2020.00	4.04
CU =	93.773	Ea =	99.997
EU'=	91.572	qvar =	0.0001064
		Percent water	
Total emitters flow(L/h):			78.36
Q from connected pipe (L/h):			683.5
Q from injector =6.92%(52.7		6.917	52.7
Total Q in the system (L/h):			761.86
Q from main line=93.08%		93.083	709.16
		Vqs	0.0710

Nominal Emitter flow rate = 3.78l/h
Operating M.I.S
New Emitters
Without venturi Injector
P(lateral inlet)=14.5-15.5psi
Pend of lateral= 14.4-15.4psi

Emitter #	Timie (min)	Ave.Vol.(cc)	q (l/h)
1	30	2210.00	4.42
2	30	2190.00	4.38
3	30	1848.00	3.70
4	30	1863.00	3.73
5	30	2031.00	4.06
6	30	1935.00	3.87
7	30	1913.00	3.83
8	30	2023.00	4.05
9	30	1740.00	3.48
10	30	1803.00	3.61
11	30	2090.00	4.18
12	30	1800.00	3.60
13	30	1880.00	3.76
14	30	1965.00	3.93
15	30	1783.00	3.57
16	30	2054.00	4.11
17	30	1785.00	3.57
18	30	1828.00	3.66
19	30	2090.00	4.18
20	30	1973.00	3.95
CU =	94.019	Ea =	99.997
EU'=	91.860	qvar =	0.000104
Total emitters flow(L/h):			77.61
		Vqs	0.0698

Table A.5.40 Variations in emitter flow rate in different runs when venturi injector installed and city water is injected (40m, no clogged, flat terrain)

Run1: No injection of water from barrel
Liquid suction tube closed
Water passes through the venturi into the lateral(Q from the connection pipe 558 L/h)

Pregulator (injector inlet)=24.5-25.5 psi — Diff.in Press. 10psi
Pinjector outlet(lateral inlet)=14.5-15.5psi
Pend of lateral= 9-9.5 psi

Emitter #	Timie (min)	Ave.Vol.(cc)	q (l/h)	Pressure from indivisual emitter at each (psi)
1	30	2220.00	4.44	15.50
2	30	2210.00	4.42	15.50
3	30	1870.00	3.74	15.50
4	30	1880.00	3.76	15.40
5	30	2070.00	4.14	15.40
6	30	1955.00	3.91	15.00
7	30	1960.00	3.92	15.00
8	30	2075.00	4.15	14.90
9	30	1750.00	3.50	14.80
10	30	1820.00	3.64	14.50
11	30	2135.00	4.27	14.40
12	30	1850.00	3.70	14.00
13	30	1960.00	3.92	14.00
14	30	2040.00	4.08	13.90
15	30	1850.00	3.70	13.80
16	30	2090.00	4.18	13.50
17	30	1808.00	3.62	13.40
18	30	1860.00	3.72	13.10
19	30	2120.00	4.24	12.90
20	30	2018.00	4.04	12.60
21	30	2080.00	4.16	11.40
22	30	2025.00	4.05	11.20
23	30	1730.00	3.46	11.10
24	30	2044.00	4.09	10.90
25	30	1980.00	3.96	10.70
26	30	1925.00	3.85	10.70
27	30	2440.00	4.88	10.70
28	30	1990.00	3.98	10.60
29	30	1880.00	3.76	10.50
30	30	1950.00	3.90	10.50
31	30	1810.00	3.62	10.50
32	30	1950.00	3.90	10.40
33	30	1850.00	3.70	10.40
34	30	1850.00	3.70	10.30
35	30	1840.00	3.68	10.00
36	30	1800.00	3.60	9.90
37	30	1860.00	3.72	9.80
38	30	1940.00	3.88	9.70
39	30	1890.00	3.78	9.60
40	30	1835.00	3.67	9.60
CU =	94.162	Ea =	99.980	
EU'=	92.111	qvar =	0.0007436	

Total emitters flow(L/h):	156.42
Q from connected pipe (L/h):	672
Total Q in the system(L/h):	828.42
Vqs	0.0747

Run2: With injection of water from barrel
Liquid suction 40 l/h,Q from connected pipe 513 L/h
Water mixed from main hose and venturi injector, flow into the lateral (Not adjusted pres.)

Pregulator (injector inlet)=25-26 psi — Diff.in Press. 13.25
Pinjector outlet(lateral inlet)=12-12.5psi
Pend of lateral= 8-8.5 psi (Not adjusted pressure)

Emitter #	Timie (min)	Ave.Vol.(cc)	q (l/h)	Pressure From indivisual emitter at each section (psi)
1	30	2170.00	4.34	12.60
2	30	2150.00	4.30	12.60
3	30	1890.00	3.78	12.60
4	30	1880.00	3.76	12.60
5	30	2013.00	4.03	12.50
6	30	1930.00	3.86	12.50
7	30	1940.00	3.88	12.50
8	30	2005.00	4.01	12.50
9	30	1750.00	3.50	12.50
10	30	1820.00	3.64	12.00
11	30	1995.00	3.99	12.00
12	30	1820.00	3.64	12.00
13	30	1910.00	3.82	11.50
14	30	1955.00	3.91	11.50
15	30	1835.00	3.67	11.10
16	30	1970.00	3.94	11.10
17	30	1780.00	3.56	11.00
18	30	1840.00	3.68	10.50
19	30	1970.00	3.94	10.40
20	30	1900.00	3.80	10.10
21	30	1840.00	3.68	9.50
22	30	1800.00	3.60	9.50
23	30	1700.00	3.40	9.00
24	30	1800.00	3.60	9.00
25	30	1770.00	3.54	8.90
26	30	1770.00	3.54	8.50
27	30	2120.00	4.24	9.00
28	30	1770.00	3.54	9.00
29	30	1700.00	3.40	8.50
30	30	1730.00	3.46	8.50
31	30	1680.00	3.36	8.50
32	30	1720.00	3.44	8.50
33	30	1690.00	3.38	8.40
34	30	1680.00	3.36	8.40
35	30	1630.00	3.26	8.00
36	30	1620.00	3.24	8.00
37	30	1640.00	3.28	8.00
38	30	1700.00	3.40	8.00
39	30	1660.00	3.32	8.00
40	30	1610.00	3.22	8.00
CU =	93.452	Ea =	99.979	
EU'=	90.821	qvar =	0.0007784	

	Percent water	
Total emitters flow(L/h):		146.31
Q from connected pipe (L/h):		513
Q from injector =6.07%(40L/	6.067	40
Total Q in the system (L/h):		659.31
Q from main line=93.93%	93.933	619.31
Vqs		0.0795

Run3: Injection water(44L/h), Q =558L/h
Suction opened & adjusted lateral inlet pres.
to 14.5-15.5 psi by increasing the pressure regul.
to 29.5-31 psi. (Adjusted Pressure)

Pregulator (injector inlet)=29.5-31 psi — Diff.in Press. 15.25psi
Pinjector outlet(lateral inlet)=14.5-15.5psi
Pend of lateral= 9-9.5 psi

Emitter #	Timie (min)	Ave.Vol.(cc)	q (l/h)	Pressure From indivisual emitter at each section (psi)
1	30	2220.00	4.44	15.50
2	30	2195.00	4.39	15.50
3	30	1860.00	3.72	15.30
4	30	1860.00	3.72	15.20
5	30	2035.00	4.07	15.00
6	30	1920.00	3.84	15.00
7	30	1935.00	3.87	14.90
8	30	2060.00	4.12	14.80
9	30	1730.00	3.46	14.60
10	30	1800.00	3.60	14.40
11	30	2120.00	4.24	14.30
12	30	1835.00	3.67	14.10
13	30	1940.00	3.88	13.90
14	30	2015.00	4.03	13.50
15	30	1835.00	3.67	13.50
16	30	2070.00	4.14	13.00
17	30	1785.00	3.57	13.00
18	30	1850.00	3.70	12.90
19	30	2100.00	4.20	12.80
20	30	2000.00	4.00	12.50
21	30	2090.00	4.18	11.50
22	30	2020.00	4.04	11.30
23	30	1710.00	3.42	11.10
24	30	2040.00	4.08	11.00
25	30	1975.00	3.95	10.90
26	30	1925.00	3.85	10.80
27	30	2435.00	4.87	10.70
28	30	2000.00	4.00	10.50
29	30	1865.00	3.73	10.40
30	30	1960.00	3.92	10.40
31	30	1800.00	3.60	10.30
32	30	1970.00	3.94	10.20
33	30	1840.00	3.68	10.10
34	30	1850.00	3.70	10.00
35	30	1850.00	3.70	9.80
36	30	1790.00	3.58	9.60
37	30	1880.00	3.76	9.60
38	30	1950.00	3.90	9.50
39	30	1900.00	3.80	9.50
40	30	1845.00	3.69	9.50
CU =	94.325	Ea =	99.980	
EU'=	92.385	qvar =	0.0007401	

	Percent water	
Total emitters flow(L/h):		155.72
Q from connected pipe (L/h):		558
Q from injector =6.17%(44 L	6.165	44
Total Q in the system (L/h):		713.72
Q from main line=93.83%	93.835	669.72
Vqs		0.0728

Nominal Emitter flow rate = 3.78l/h
Operating M.I.S
New Emitters
Without Venturi Injector

P(lateral inlet)=14.5-15.5psi
Pend of lateral= 14-14.8 psi

Emitter #	Timie (min)	Ave.Vol.(cc)	q (l/h)	emitter Pressure at each section (psi)
1	30	2210.00	4.42	15.50
2	30	2190.00	4.38	15.50
3	30	1840.00	3.68	15.50
4	30	1860.00	3.72	15.20
5	30	2020.00	4.04	15.10
6	30	1915.00	3.83	15.10
7	30	1930.00	3.86	15.10
8	30	2060.00	4.12	15.10
9	30	1740.00	3.48	15.10
10	30	1780.00	3.56	15.10
11	30	2110.00	4.22	15.10
12	30	1830.00	3.66	15.00
13	30	1900.00	3.80	15.00
14	30	2000.00	4.00	15.00
15	30	1810.00	3.62	15.00
16	30	2050.00	4.10	15.00
17	30	1780.00	3.56	15.20
18	30	1860.00	3.72	15.00
19	30	2080.00	4.16	15.00
20	30	1980.00	3.96	14.90
21	30	2250.00	4.50	14.90
22	30	2028.00	4.06	14.90
23	30	1700.00	3.40	14.90
24	30	2200.00	4.40	14.80
25	30	1980.00	3.96	14.80
26	30	1905.00	3.81	14.80
27	30	2490.00	4.98	15.00
28	30	2090.00	4.18	14.80
29	30	1850.00	3.70	15.00
30	30	2120.00	4.24	15.00
31	30	1760.00	3.52	14.90
32	30	2170.00	4.34	15.00
33	30	1820.00	3.64	15.00
34	30	1820.00	3.64	15.00
35	30	1905.00	3.81	15.00
36	30	1770.00	3.54	14.50
37	30	2080.00	4.16	15.00
38	30	2270.00	4.54	15.00
39	30	2000.00	4.00	14.90
40	30	1988.00	3.98	14.80
CU =	92.877	Ea =	99.979	
EU'=	90.012	qvar =	0.0007760	

Total emitters flow(L/h):	158.28
Vqs	0.0870

Table A.5.41 Total amount of salt to be added to the irrigation water of EC=0.022 mmhos/cm as the injection liquid

EC_I mmhos/cm	inflow %	iquid suctio %	EC_L mmhos/cm	Req. flow %	*EC_m mmhos/cm	**Total salt g/L
0.022	0.000	1.000	3.000	1	3	1.9059
0.022	0.005	0.995	3.015	1	3	1.9155
0.022	0.010	0.990	3.030	1	3	1.9252
0.022	0.015	0.985	3.045	1	3	1.9349
0.022	0.020	0.980	3.061	1	3	1.9448
0.022	0.025	0.975	3.076	1	3	1.9548
0.022	0.030	0.970	3.092	1	3	1.9649
0.022	0.035	0.965	3.108	1	3	1.9750
0.022	0.040	0.960	3.124	1	3	1.9853
0.022	0.045	0.955	3.140	1	3	1.9957
0.022	0.050	0.950	3.157	1	3	2.0062
0.022	0.055	0.945	3.173	1	3	2.0168
0.022	0.060	0.940	3.190	1	3	2.0276
0.022	0.065	0.935	3.207	1	3	2.0384
0.022	0.070	0.930	3.224	1	3	2.0494
0.022	0.075	0.925	3.241	1	3	2.0605
0.022	0.080	0.920	3.259	1	3	2.0717
0.022	0.085	0.915	3.277	1	3	2.0830
0.022	0.090	0.910	3.295	1	3	2.0944
0.022	0.095	0.905	3.313	1	3	2.1060
0.022	0.100	0.900	3.331	1	3	2.1177
0.022	0.105	0.895	3.349	1	3	2.1295
0.022	0.110	0.890	3.368	1	3	2.1415
0.022	0.115	0.885	3.387	1	3	2.1536
0.022	0.120	0.880	3.406	1	3	2.1658
0.022	0.125	0.875	3.425	1	3	2.1782
0.022	0.130	0.870	3.445	1	3	2.1907
0.022	0.135	0.865	3.465	1	3	2.2034
0.022	0.140	0.860	3.485	1	3	2.2162
0.022	0.145	0.855	3.505	1	3	2.2291
0.022	0.150	0.850	3.526	1	3	2.2423
0.022	0.155	0.845	3.546	1	3	2.2555
0.022	0.160	0.840	3.567	1	3	2.2690
0.022	0.165	0.835	3.588	1	3	2.2825
0.022	0.170	0.830	3.610	1	3	2.2963
0.022	0.175	0.825	3.632	1	3	2.3102
0.022	0.180	0.820	3.654	1	3	2.3243
0.022	0.185	0.815	3.676	1	3	2.3386
0.022	0.190	0.810	3.699	1	3	2.3530
0.022	0.195	0.805	3.721	1	3	2.3676
0.022	0.200	0.800	3.745	1	3	2.3824
0.022	0.205	0.795	3.768	1	3	2.3974
0.022	0.210	0.790	3.792	1	3	2.4126

EC_I mmhos/cm	inflow %	iquid suctio %	EC_L mmhos/cm	Req. flow %	EC_m mmhos/cm	Total salt g/L
0.022	0.215	0.785	3.8156	1	3	2.4279
0.022	0.220	0.780	3.8399	1	3	2.4435
0.022	0.225	0.775	3.8646	1	3	2.4593
0.022	0.230	0.770	3.8895	1	3	2.4752
0.022	0.235	0.765	3.9148	1	3	2.4914
0.022	0.240	0.760	3.9404	1	3	2.5078
0.022	0.245	0.755	3.9664	1	3	2.5244
0.022	0.250	0.750	3.9927	1	3	2.5412
0.022	0.255	0.745	4.0193	1	3	2.5583
0.022	0.260	0.740	4.0463	1	3	2.5756
0.022	0.265	0.735	4.0737	1	3	2.5931
0.022	0.270	0.730	4.1015	1	3	2.6108
0.022	0.275	0.725	4.1296	1	3	2.6289
0.022	0.280	0.720	4.1581	1	3	2.6471
0.022	0.285	0.715	4.1870	1	3	2.6656
0.022	0.290	0.710	4.2164	1	3	2.6844
0.022	0.295	0.705	4.2461	1	3	2.7034
0.022	0.300	0.700	4.2763	1	3	2.7227
0.022	0.305	0.695	4.3069	1	3	2.7423
0.022	0.310	0.690	4.3379	1	3	2.7622
0.022	0.315	0.685	4.3694	1	3	2.7824
0.022	0.320	0.680	4.4014	1	3	2.8028
0.022	0.325	0.675	4.4339	1	3	2.8236
0.022	0.330	0.670	4.4668	1	3	2.8447
0.022	0.335	0.665	4.5002	1	3	2.8660
0.022	0.340	0.660	4.5341	1	3	2.8878
0.022	0.345	0.655	4.5686	1	3	2.9098
0.022	0.350	0.650	4.6035	1	3	2.9322
0.022	0.355	0.645	4.6391	1	3	2.9549
0.022	0.360	0.640	4.6751	1	3	2.9780
0.022	0.365	0.635	4.7118	1	3	3.0014
0.022	0.370	0.630	4.7490	1	3	3.0253
0.022	0.375	0.625	4.7868	1	3	3.0495
0.022	0.380	0.620	4.8252	1	3	3.0741
0.022	0.385	0.615	4.8643	1	3	3.0991
0.022	0.390	0.610	4.9040	1	3	3.1245
0.022	0.395	0.605	4.9443	1	3	3.1503
0.022	0.400	0.600	4.9853	1	3	3.1765
0.022	0.405	0.595	5.0270	1	3	3.2032
0.022	0.410	0.590	5.0695	1	3	3.2304
0.022	0.415	0.585	5.1126	1	3	3.2580
0.022	0.420	0.580	5.1565	1	3	3.2861
0.022	0.425	0.575	5.2011	1	3	3.3146

EC_I mmhos/cm	inflow %	liquid suctior %	EC_L mmhos/cm	Req. flow %	EC_m mmhos/cm	Total salt g/L
0.022	0.430	0.570	5.24656	1	3	3.344
0.022	0.435	0.565	5.29280	1	3	3.373
0.022	0.440	0.560	5.33986	1	3	3.403
0.022	0.445	0.555	5.38777	1	3	3.434
0.022	0.450	0.550	5.43655	1	3	3.465
0.022	0.455	0.545	5.48622	1	3	3.497
0.022	0.460	0.540	5.53681	1	3	3.529
0.022	0.465	0.535	5.58836	1	3	3.562
0.022	0.470	0.530	5.64087	1	3	3.596
0.022	0.475	0.525	5.69438	1	3	3.630
0.022	0.480	0.520	5.74892	1	3	3.665
0.022	0.485	0.515	5.80452	1	3	3.701
0.022	0.490	0.510	5.86122	1	3	3.737
0.022	0.495	0.505	5.91903	1	3	3.774
0.022	0.500	0.500	5.97800	1	3	3.812
0.022	0.505	0.495	6.03816	1	3	3.850
0.022	0.510	0.490	6.09955	1	3	3.890
0.022	0.515	0.485	6.16221	1	3	3.930
0.022	0.520	0.480	6.22617	1	3	3.971
0.022	0.525	0.475	6.29147	1	3	4.012
0.022	0.530	0.470	6.35817	1	3	4.055
0.022	0.535	0.465	6.42630	1	3	4.099
0.022	0.540	0.460	6.49591	1	3	4.143
0.022	0.545	0.455	6.56705	1	3	4.189
0.022	0.550	0.450	6.63978	1	3	4.235
0.022	0.555	0.445	6.71413	1	3	4.283
0.022	0.560	0.440	6.79018	1	3	4.332
0.022	0.565	0.435	6.86798	1	3	4.381
0.022	0.570	0.430	6.94758	1	3	4.432
0.022	0.575	0.425	7.02906	1	3	4.485
0.022	0.580	0.420	7.11248	1	3	4.538
0.022	0.585	0.415	7.19790	1	3	4.593
0.022	0.590	0.410	7.28541	1	3	4.649
0.022	0.595	0.405	7.37509	1	3	4.706
0.022	0.600	0.400	7.46700	1	3	4.765
0.022	0.605	0.395	7.56124	1	3	4.825
0.022	0.610	0.390	7.65790	1	3	4.887
0.022	0.615	0.385	7.75706	1	3	4.950
0.022	0.620	0.380	7.85884	1	3	5.016
0.022	0.625	0.375	7.96333	1	3	5.082
0.022	0.630	0.370	8.07065	1	3	5.151
0.022	0.635	0.365	8.18090	1	3	5.222
0.022	0.640	0.360	8.29422	1	3	5.294

*EC_m = EC_I portion of inflow + EC_L * portion of liquid suction

**Total salt required to be added into the source water =mg/L= (640 * EC_L) - (640 * EC_I) EC_I= Electrical conductivity of irrigation water EC_L = Electrical conductivity of saline water EC_m = Electrical conductivity of mixture water

Table A.5.41 (continue)

EC_i mmhos/cm	inflow %	iquid suctior %	EC_L mmhos/cm	Req. flow %	EC_m mmhos/cm	Total salt g/L	EC_i mmhos/cm	inflow %	iquid suctior %	EC_L mmhos/cm	Req. flow %	EC_m mmhos/cm	Total salt g/L
0.022	0.645	0.3550	8.4107	1	3	5.36879	0.022	0.865	0.1350	22.0813	1	3	14.1179
0.022	0.650	0.3500	8.5306	1	3	5.44549	0.022	0.870	0.1300	22.9297	1	3	14.6609
0.022	0.655	0.3450	8.6539	1	3	5.52441	0.022	0.875	0.1250	23.8460	1	3	15.2474
0.022	0.660	0.3400	8.7808	1	3	5.60565	0.022	0.880	0.1200	24.8387	1	3	15.8827
0.022	0.665	0.3350	8.9116	1	3	5.68931	0.022	0.885	0.1150	25.9177	1	3	16.5732
0.022	0.670	0.3300	9.0462	1	3	5.77552	0.022	0.890	0.1100	27.0947	1	3	17.3265
0.022	0.675	0.3250	9.1851	1	3	5.86437	0.022	0.895	0.1050	28.3839	1	3	18.1516
0.022	0.680	0.3200	9.3283	1	3	5.95600	0.022	0.900	0.1000	29.8020	1	3	19.0592
0.022	0.685	0.3150	9.4760	1	3	6.05054	0.022	0.905	0.0950	31.3694	1	3	20.0623
0.022	0.690	0.3100	9.6285	1	3	6.14813	0.022	0.910	0.0900	33.1109	1	3	21.1769
0.022	0.695	0.3050	9.7859	1	3	6.24892	0.022	0.915	0.0850	35.0573	1	3	22.4226
0.022	0.700	0.3000	9.9487	1	3	6.35307	0.022	0.920	0.0800	37.2470	1	3	23.8240
0.022	0.705	0.2950	10.1169	1	3	6.46075	0.022	0.925	0.0750	39.7287	1	3	25.4123
0.022	0.710	0.2900	10.2910	1	3	6.57214	0.022	0.930	0.0700	42.5649	1	3	27.2274
0.022	0.715	0.2850	10.4711	1	3	6.68744	0.022	0.935	0.0650	45.8374	1	3	29.3218
0.022	0.720	0.2800	10.6577	1	3	6.80686	0.022	0.940	0.0600	49.6553	1	3	31.7653
0.022	0.725	0.2750	10.8511	1	3	6.93062	0.022	0.945	0.0550	54.1675	1	3	34.6531
0.022	0.730	0.2700	11.0516	1	3	7.05896	0.022	0.950	0.0500	59.5820	1	3	38.1184
0.022	0.735	0.2650	11.2597	1	3	7.19215	0.022	0.955	0.0450	66.1998	1	3	42.3538
0.022	0.740	0.2600	11.4758	1	3	7.33046	0.022	0.960	0.0400	74.4720	1	3	47.6480
0.022	0.745	0.2550	11.7004	1	3	7.47420	0.022	0.965	0.0350	85.1077	1	3	54.4549
0.022	0.750	0.2500	11.9340	1	3	7.62368	0.022	0.970	0.0300	99.2887	1	3	63.5307
0.022	0.755	0.2450	12.1771	1	3	7.77927	0.022	0.975	0.0250	119.1420	1	3	76.2368
0.022	0.760	0.2400	12.4303	1	3	7.94133	0.022	0.980	0.0200	148.9220	1	3	95.2960
0.022	0.765	0.2350	12.6943	1	3	8.11030	0.022	0.985	0.0150	198.5553	1	3	127.0613
0.022	0.770	0.2300	12.9698	1	3	8.28661	0.022	0.990	0.0100	297.8220	1	3	190.5920
0.022	0.775	0.2250	13.2576	1	3	8.47076	0.022	0.995	0.0050	595.6220	1	3	381.1840
0.022	0.780	0.2200	13.5584	1	3	8.66327	0.022	1.000	0.0000	########	1	3	########
0.022	0.785	0.2150	13.8732	1	3	8.86474							
0.022	0.790	0.2100	14.2030	1	3	9.07581							
0.022	0.795	0.2050	14.5488	1	3	9.29717							
0.022	0.800	0.2000	14.9120	1	3	9.52960							
0.022	0.805	0.1950	15.2938	1	3	9.77395							
0.022	0.810	0.1900	15.6957	1	3	10.03116							
0.022	0.815	0.1850	16.1193	1	3	10.30227							
0.022	0.820	0.1800	16.5664	1	3	10.58844							
0.022	0.825	0.1750	17.0391	1	3	10.89097							
0.022	0.830	0.1700	17.5396	1	3	11.21129							
0.022	0.835	0.1650	18.0705	1	3	11.55103							
0.022	0.840	0.1600	18.6345	1	3	11.91200							
0.022	0.845	0.1550	19.2349	1	3	12.29626							
0.022	0.850	0.1500	19.8753	1	3	12.70613							
0.022	0.855	0.1450	20.5599	1	3	13.14428							
0.022	0.860	0.1400	21.2934	1	3	13.61371							

Table A.5.42 Emitter flow variation under saline water injection (EC_L=27.5 mmhos/cm), average Ec_m= 3 mmhos/cm, no-clogged condition, and **20m** lateral laid on flat terrain

Run1: No injection of saline water from the barrel
ECl =0.022 mmhos/cm, Air.T=23c, Water.T=15c
Liquid suction tube closed
Water passes through the venturi into the entire length of lateral(Q from the connection pipe 662.4 L/h)
Pregulator (injector inlet)=24.5 Diff.in Press.
Pinjector outlet(lateral inlet)=1· 10psi
Pend of lateral= 12-12.5 psi

Emitter #	Timie (min)	Volume (cc) run1	Volume (cc) run2	Average q (l/h)
1	30	2130.00	2180.00	4.31
2	30	2120.00	2130.00	4.25
3	30	1800.00	1820.00	3.62
4	30	1820.00	1840.00	3.66
5	30	1960.00	1980.00	3.94
6	30	1860.00	1860.00	3.72
7	30	1850.00	1840.00	3.69
8	30	1980.00	1980.00	3.96
9	30	1700.00	1700.00	3.40
10	30	1780.00	1780.00	3.56
11	30	2052.00	2056.00	4.11
12	30	1800.00	1800.00	3.60
13	30	1880.00	1860.00	3.74
14	30	1996.00	1990.00	3.99
15	30	1780.00	1760.00	3.54
16	30	2010.00	2010.00	4.02
17	30	1740.00	1740.00	3.48
18	30	1800.00	1800.00	3.60
19	30	2046.00	2044.00	4.09
20	30	1920.00	1940.00	3.86
CU =	94.018	Ea =	99.997	
EU'=	92.332	qvar =	0.000101	

Total emitters flow(L/h): 76.13
Q from connected pipe (L/h): 662.4
Total Q in the system(L/h): 738.53
Vqs 0.0674

Run2: With injection of saline water (40.92 l/h) from the barrel
ECl =0.022 mmhos/cm, ECL=27.5mmhos/cm, Air.T=23c, Water T.= 15c
Liquid suction 40.92 l/h,Q from connected pipe 600 L/h
Water mixed (ECmix = 3mmhos/cm) from main hose and venturi injector, flow into the lateral (Not adjusted pressure)
Pregulator (injector inlet)=25-26 psi Diff.in Press.
Pinjector outlet(lateral inlet)=11.9-12.5psi 13.25
Pend of lateral= 9.5-10.5 psi (Not adjusted pressure)

Emitter #	Timie (min)	Volume (cc) run1	*ECmix. (mmhos/cm)	Volume (cc) run2	**ECmix. (mmhos/cm)	Ave.ECmix. (mmhos/cm)	Average q (l/h)
1	30	2060.00	3.00	2070.00	3	3	4.13
2	30	2080.00	3.00	2066.00	3	3	4.15
3	30	1820.00	3.00	1800.00	3	3	3.62
4	30	1780.00	3.00	1790.00	3	3	3.57
5	30	1940.00	3.00	1920.00	3	3	3.86
6	30	1840.00	3.00	1820.00	3	3	3.66
7	30	1840.00	3.00	1820.00	3	3	3.66
8	30	1940.00	3.00	1940.00	3	3	3.88
9	30	1680.00	3.00	1680.00	3	3	3.36
10	30	1760.00	3.00	1740.00	3	3	3.50
11	30	1960.00	3.00	1960.00	3	3	3.92
12	30	1760.00	3.00	1760.00	3	3	3.52
13	30	1840.00	3.00	1820.00	3	3	3.66
14	30	1940.00	3.00	1940.00	3	3	3.88
15	30	1740.00	3.00	1740.00	3	3	3.48
16	30	1930.00	3.00	1940.00	3	3	3.87
17	30	1740.00	3.00	1730.00	3	3	3.47
18	30	1770.00	3.00	1760.00	3	3	3.53
19	30	1930.00	3.00	1940.00	3	3	3.87
20	30	1856.00	3.00	1860.00	3	3	3.72
CU =	95.046	Ea =	99.997				
EU'=	93.285	qvar =	0.0001211				

	Percent water	
Total emitters flow(L/h):		74.30
Q from connected pipe (L/h):		600
Q from injector =6.06%(40.9	6.068	40.92
Total Q in the system (L/h):		674.30
Q from main line=93.93%	93.932	633.38
Vqs		0.0579

* 22 gr. NaCl / liter of irrigation water in barrel
** 22 gr. NaCl / liter of irrigation water in barrel

Run3:Injection saline water(49.8L/h), Q connectedpipe=669.8L/h
ECl =0.022 mmhos/cm, ECL=27.5mmhos/cm, Air.T=23c, Water T.= 15c
Suction opened & adjusted lateral inlet pressure to 14.5-15.5 psi by increasing the pressure regulator to 33.5-34.5 psi. (Adjusted Pressure)
Pregulator (injector inlet)=33.5-34.5 psi Diff.in Press.
Pinjector outlet(lateral inlet)=14.5-15.5psi 19 psi
Pend of lateral= 12-12.5 psi

Emitter #	Timie (min)	Volume (cc) run1	*ECmix. (mmhos/cm)	Volume (cc) run2	**ECmix. (mmhos/cm)	Ave.ECmix. (mmhos/cm)	Average q (l/h)
1	30	2150.00	3.00	2140.00	3.00	3	4.29
2	30	2100.00	3.00	2090.00	3.00	3	4.19
3	30	1840.00	3.00	1810.00	3.00	3	3.65
4	30	1840.00	3.00	1820.00	3.00	3	3.66
5	30	1960.00	3.00	1940.00	3.00	3	3.90
6	30	1860.00	3.00	1820.00	3.00	3	3.68
7	30	1880.00	3.00	1840.00	3.00	3	3.72
8	30	2020.00	3.00	1990.00	3.00	3	4.01
9	30	1750.00	3.00	1730.00	3.00	3	3.48
10	30	1770.00	3.00	1740.00	3.00	3	3.51
11	30	2060.00	3.00	2050.00	3.00	3	4.11
12	30	1800.00	3.00	1790.00	3.00	3	3.59
13	30	1860.00	3.00	1840.00	3.00	3	3.70
14	30	1980.00	3.00	1970.00	3.00	3	3.95
15	30	1780.00	3.00	1750.00	3.00	3	3.53
16	30	2010.00	3.00	2000.00	3.00	3	4.01
17	30	1770.00	3.00	1740.00	3.00	3	3.51
18	30	1800.00	3.00	1780.00	3.00	3	3.58
19	30	2070.00	3.00	2080.00	3.00	3	4.15
20	30	1920.00	3.00	1920.00	3.00	3	3.84
CU =	94.209	Ea =	99.997				
EU'=	92.660	qvar =	0.000101				

	Percent water	
Total emitters flow(L/h):		76.06
Q from connected pipe (L/h):		669.8
Q from injector =6.68%(49.8 L	6.677	49.8
Total Q in the system (L/h):		745.86
Q from main line=93.32%	93.323	696.06
Vqs		0.0646

* 22 gr. NaCl / liter of irrigation water in barrel
** 22 gr. NaCl / liter of irrigation water in barrel

Nominal Emitter flow rate = 3.78l/h
Operating M.I.S
New Emitters
Without venturi Injector
P(lateral inlet)=14.5-15.5psi
Pend of lateral= 14-14.8 psi

Emitter #	Timie (min)	Ave.Volume (cc)	Average q (l/h)	emitter Pressure at each section (psi)
1	30	2210.00	4.42	15.50
2	30	2190.00	4.38	15.50
3	30	1848.00	3.70	15.50
4	30	1863.00	3.73	15.20
5	30	2031.00	4.06	15.10
6	30	1935.00	3.87	15.10
7	30	1913.00	3.83	15.10
8	30	2023.00	4.05	15.10
9	30	1740.00	3.48	15.10
10	30	1803.00	3.61	15.10
11	30	2090.00	4.18	15.10
12	30	1800.00	3.60	15.00
13	30	1880.00	3.76	15.00
14	30	1965.00	3.93	15.00
15	30	1783.00	3.57	15.00
16	30	2054.00	4.11	15.00
17	30	1785.00	3.57	15.20
18	30	1828.00	3.66	15.00
19	30	2090.00	4.18	15.00
20	30	1973.00	3.95	14.90
CU =	94.019	Ea =	99.997	
EU'=	91.860	qvar =	0.000104	

Total emitters flow(L/h): 77.61
Vqs 0.0698

Table A.5.43 Emitter flow variation under saline water injection (EC_L=13.5-15 mmhos/cm), average EC_m= 1.5 mmhos/cm, no-clogged condition, and **20m** lateral laid on flat terrain

Run1: No injection of saline water from the barrel
ECi =0.022 mmhos/cm, Air.T=23c, Water.T=15c
Liquid suction tube closed
Water passes through the venturi into the entire length of lateral(Q from the connection pipe 646.8 L/h)
Pregulator (injector inlet)=24.5 Diff.in Press.
Pinjector outlet(lateral inlet)=1· 10psi
Pend of lateral= 12-12.5 psi

Emitter #	Timie (min)	Volume (cc) run1	Volume (cc) run2	Average q (l/h)
1	30	2160.00	2155.00	4.32
2	30	2120.00	2130.00	4.25
3	30	1800.00	1810.00	3.61
4	30	1820.00	1830.00	3.65
5	30	1960.00	1940.00	3.90
6	30	1860.00	1860.00	3.72
7	30	1850.00	1840.00	3.69
8	30	1960.00	1980.00	3.94
9	30	1700.00	1700.00	3.40
10	30	1780.00	1760.00	3.54
11	30	2052.00	2056.00	4.11
12	30	1790.00	1800.00	3.59
13	30	1870.00	1860.00	3.73
14	30	1940.00	1960.00	3.90
15	30	1760.00	1760.00	3.52
16	30	2000.00	2010.00	4.01
17	30	1760.00	1750.00	3.51
18	30	1800.00	1790.00	3.59
19	30	2024.00	2030.00	4.05
20	30	1900.00	1920.00	3.82
CU =	94.285	Ea =	99.997	
EU'=	92.604	qvar =	0.000100	

Total emitters flow(L/h): 75.85
Q from connected pipe (L/h): 646.8
Total Q in the system(L/h): 722.65
Vqs 0.0666

Run2: With injection of saline water (40.68 l/h) from the barrel
ECi =0.022 mmhos/cm, ECL=13.5-15 mmhos/cm, Air.T=23c, Water T.= 15c
Liquid suction 40.68 l/h,Q from connected pipe 589.2 L/h
Water mixed (ECmix = 1.5mmhos/cm) from main hose and venturi injector, flow into the lateral (Not adjusted pressure)
Pregulator (injector inlet)=25-26 psi Diff.in Press.
Pinjector outlet(lateral inlet)=12-12.5psi 13.25
Pend of lateral= 9.5-10.5 psi (Not adjusted pressure)

Emitter #	Timie (min)	Volume (cc) run1	*ECmix. (mmhos/cm)	Volume (cc) run2	**ECmix. (mmhos/cm)	Ave.ECmix. (mmhos/cm)	Average q (l/h)
1	30	2060.00	1.60	2054.00	1.4	1.5	4.11
2	30	2020.00	1.60	2030.00	1.4	1.5	4.05
3	30	1780.00	1.60	1780.00	1.4	1.5	3.56
4	30	1780.00	1.60	1770.00	1.4	1.5	3.55
5	30	1880.00	1.60	1900.00	1.4	1.5	3.78
6	30	1790.00	1.60	1790.00	1.4	1.5	3.58
7	30	1800.00	1.60	1820.00	1.4	1.5	3.62
8	30	1920.00	1.60	1900.00	1.4	1.5	3.82
9	30	1680.00	1.60	1670.00	1.4	1.5	3.35
10	30	1710.00	1.60	1720.00	1.4	1.5	3.43
11	30	1960.00	1.60	1940.00	1.4	1.5	3.90
12	30	1770.00	1.60	1760.00	1.4	1.5	3.53
13	30	1780.00	1.60	1800.00	1.4	1.5	3.58
14	30	1860.00	1.60	1870.00	1.4	1.5	3.73
15	30	1740.00	1.60	1760.00	1.4	1.5	3.50
16	30	1925.00	1.60	1940.00	1.4	1.5	3.87
17	30	1740.00	1.60	1730.00	1.4	1.5	3.47
18	30	1780.00	1.60	1760.00	1.4	1.5	3.54
19	30	1920.00	1.60	1930.00	1.4	1.5	3.85
20	30	1800.00	1.60	1820.00	1.4	1.5	3.62
CU =	95.301	Ea =	99.997				
EU'=	94.092	qvar =	0.0001158				

	Percent water		
Total emitters flow(L/h):		73.44	* 11 gr. NaCl / liter of irrigation water in barrel
Q from connected pipe (L/h):		589.2	** 10 gr. NaCl / liter of irrigation water in barrel
Q from injector =6.13%(40.6	6.139	40.68	
Total Q in the system (L/h):		662.64	
Q from main line=93.87%	93.861	621.96	
Vqs		0.0548	

Run3:Injection saline water(44.56L/h), Q connectedpipe=655.8L/h
ECi =0.022 mmhos/cm, ECL=13.5-15 mmhos/cm, Air.T=23c, Water T.= 15c
Suction opened & adjusted lateral inlet pressure to 14.5-15.5 psi by increasing the pressure regulator to 33.5-34.5 psi. (Adjusted Pressure)
Pregulator (injector inlet)=33.5-34.5 psi Diff.in Press.
Pinjector outlet(lateral inlet)=14.5-15.5psi 19 psi
Pend of lateral= 12-12.5 psi

Emitter #	Timie (min)	Volume (cc) run1	*ECmix. (mmhos/cm)	Volume (cc) run2	**ECmix. (mmhos/cm)	Ave.ECmix. (mmhos/cm)	Average q (l/h)
1	30	2150.00	1.60	2155.00	1.4	1.5	4.31
2	30	2110.00	1.60	2115.00	1.4	1.5	4.23
3	30	1800.00	1.60	1810.00	1.4	1.5	3.61
4	30	1810.00	1.60	1820.00	1.4	1.5	3.63
5	30	1960.00	1.60	1940.00	1.4	1.5	3.90
6	30	1850.00	1.60	1860.00	1.4	1.5	3.71
7	30	1820.00	1.60	1840.00	1.4	1.5	3.66
8	30	1960.00	1.60	1980.00	1.4	1.5	3.94
9	30	1725.00	1.60	1730.00	1.4	1.5	3.46
10	30	1760.00	1.60	1740.00	1.4	1.5	3.50
11	30	2030.00	1.60	2050.00	1.4	1.5	4.08
12	30	1800.00	1.60	1800.00	1.4	1.5	3.60
13	30	1820.00	1.60	1840.00	1.4	1.5	3.66
14	30	1920.00	1.60	1920.00	1.4	1.5	3.84
15	30	1750.00	1.60	1750.00	1.4	1.5	3.50
16	30	2000.00	1.60	1990.00	1.4	1.5	3.99
17	30	1760.00	1.60	1740.00	1.4	1.5	3.50
18	30	1760.00	1.60	1780.00	1.4	1.5	3.54
19	30	2020.00	1.60	2000.00	1.4	1.5	4.02
20	30	1900.00	1.60	1920.00	1.4	1.5	3.82
CU =	94.372	Ea =	99.997				
EU'=	92.846	qvar =	0.000099				

	Percent water		
Total emitters flow(L/h):		75.49	* 11 gr. NaCl / liter of irrigation water in barrel
Q from connected pipe (L/h):		655.8	** 10 gr. NaCl / liter of irrigation water in barrel
Q from injector =6.09%(44 L/	6.093	44.56	
Total Q in the system (L/h):		731.29	
Q from main line=93.91%	93.907	686.73	
Vqs		0.0644	

Nominal Emitter flow rate = 3.78l/h
Operating M.I.S
New Emitters
Without venturi injector
P(lateral inlet)=14.5-15.5psi
Pend of lateral= 14-14.8 psi

Emitter #	Timie (min)	Ave.Volume (cc)	Average q (l/h)	emitter Pressure at each section (psi)
1	30	2210.00	4.42	15.50
2	30	2190.00	4.38	15.50
3	30	1848.00	3.70	15.50
4	30	1863.00	3.73	15.20
5	30	2031.00	4.06	15.10
6	30	1935.00	3.87	15.10
7	30	1913.00	3.83	15.10
8	30	2023.00	4.05	15.10
9	30	1740.00	3.48	15.10
10	30	1803.00	3.61	15.10
11	30	2090.00	4.18	15.10
12	30	1800.00	3.60	15.00
13	30	1880.00	3.76	15.00
14	30	1965.00	3.93	15.00
15	30	1783.00	3.57	15.00
16	30	2054.00	4.11	15.00
17	30	1785.00	3.57	15.20
18	30	1828.00	3.66	15.00
19	30	2090.00	4.18	15.00
20	30	1973.00	3.95	14.90
CU =	94.019	Ea =	99.997	
EU'=	91.860	qvar =	0.000104	

Total emitters flow(L/h): 77.61
Vqs 0.0698

Table A.5.44 Emitter flow variation under saline water injection (EC_L=27.5 mmhos/cm), average Ec_m= 3 mmhos/cm, no-clogged condition, and **40m** lateral laid on flat terrain

Run1: No injection of saline water from the barrel
ECl =0.022 mmhos/cm, Air.T=20c, Water.T=15c
Liquid suction tube closed
Water passes through the venturi into the entire length of lateral(Q from the connection pipe 561.6 L/h)
Pregulator (injector inlet)=24.5-: Diff.in Press.
Pinjector outlet(lateral inlet)=14. 10psi
Pend of lateral= 9-9.5 psi

Emitter #	Timie (min)	Volume (cc) run1	Volume (cc) run2	Average q (l/h)
1	30	2160.00	2140.00	4.30
2	30	2120.00	2100.00	4.22
3	30	1820.00	1800.00	3.62
4	30	1820.00	1840.00	3.66
5	30	1980.00	1960.00	3.94
6	30	1890.00	1860.00	3.75
7	30	1890.00	1860.00	3.75
8	30	1980.00	2000.00	3.98
9	30	1720.00	1720.00	3.44
10	30	1780.00	1760.00	3.54
11	30	2080.00	2060.00	4.14
12	30	1800.00	1800.00	3.60
13	30	1880.00	1860.00	3.74
14	30	1980.00	1960.00	3.94
15	30	1770.00	1790.00	3.56
16	30	2030.00	2010.00	4.04
17	30	1780.00	1750.00	3.53
18	30	1836.00	1800.00	3.64
19	30	2074.00	2050.00	4.12
20	30	1970.00	1950.00	3.92
21	30	2060.00	2076.00	4.14
22	30	1950.00	1930.00	3.88
23	30	1690.00	1680.00	3.37
24	30	2016.00	2024.00	4.04
25	30	1920.00	1920.00	3.84
26	30	1880.00	1860.00	3.74
27	30	1980.00	1990.00	3.97
28	30	2420.00	2400.00	4.82
29	30	1820.00	1820.00	3.64
30	30	1940.00	1940.00	3.88
31	30	1760.00	1750.00	3.51
32	30	1960.00	1960.00	3.92
33	30	1800.00	1796.00	3.60
34	30	1780.00	1770.00	3.55
35	30	1820.00	1820.00	3.64
36	30	1740.00	1730.00	3.47
37	30	1840.00	1840.00	3.68
38	30	1940.00	1940.00	3.88
39	30	1860.00	1860.00	3.72
40	30	1844.00	1840.00	3.68
CU=	94.239	Ea =	99.981	
EU'=	92.310	qvar =	0.000714	
Total emitters flow(L/h):			152.40	
Q from connected pipe (L/h):			561.6	
Total Q in the system(L/h):			714.00	
		Vqs	0.0729	

Run2: With injection of saline water (40.46 l/h) from the barrel
ECl =0.022 mmhos/cm, ECL=27.5 mmhos/cm, Air.T=20c, Water T.= 15c
Liquid suction 40.46 l/h,Q from connected pipe 522 L/h
Water mixed (ECmix = 3mmhos/cm) from main hose and venturi injector, flow into the lateral (Not adjusted pressure)
Pregulator (injector inlet)=25-26 psi Diff.in Press.
Pinjector outlet(lateral inlet)=12-12.5psi 13.25psi
Pend of lateral= 8-8.5 psi (Not adjusted pressure)

Emitter #	Timie (min)	Volume (cc) run1	*ECmix. (mmhos/cm)	Volume (cc) run2	**ECmix. (mmhos/cm)	Ave.ECmix. (mmhos/cm)	Average q (l/h)
1	30	2180.00	3.00	2160.00	3.00	3.00	4.34
2	30	2100.00	3.00	2100.00	3.00	3.00	4.20
3	30	1800.00	3.00	1820.00	3.00	3.00	3.62
4	30	1840.00	3.00	1840.00	3.00	3.00	3.68
5	30	1960.00	3.00	1960.00	3.00	3.00	3.92
6	30	1880.00	3.00	1900.00	3.00	3.00	3.78
7	30	1880.00	3.00	1880.00	3.00	3.00	3.76
8	30	1980.00	3.00	1980.00	3.00	3.00	3.96
9	30	1720.00	3.00	1720.00	3.00	3.00	3.44
10	30	1776.00	3.00	1760.00	3.00	3.00	3.54
11	30	2020.00	3.00	2020.00	3.00	3.00	4.04
12	30	1790.00	3.00	1790.00	3.00	3.00	3.58
13	30	1870.00	3.00	1860.00	3.00	3.00	3.73
14	30	1940.00	3.00	1960.00	3.00	3.00	3.90
15	30	1780.00	3.00	1800.00	3.00	3.00	3.58
16	30	1980.00	3.00	1980.00	3.00	3.00	3.96
17	30	1770.00	3.00	1770.00	3.00	3.00	3.54
18	30	1820.00	3.00	1820.00	3.00	3.00	3.64
19	30	2000.00	3.00	2000.00	3.00	3.00	4.00
20	30	1920.00	3.00	1920.00	3.00	3.00	3.84
21	30	1900.00	3.00	1900.00	3.00	3.00	3.80
22	30	1830.00	3.00	1840.00	3.00	3.00	3.67
23	30	1680.00	3.00	1680.00	3.00	3.00	3.36
24	30	1870.00	3.00	1870.00	3.00	3.00	3.74
25	30	1840.00	3.00	1840.00	3.00	3.00	3.68
26	30	1800.00	3.00	1800.00	3.00	3.00	3.60
27	30	1830.00	3.00	1840.00	3.00	3.00	3.67
28	30	2200.00	3.00	2190.00	3.00	3.00	4.39
29	30	1740.00	3.00	1740.00	3.00	3.00	3.48
30	30	1820.00	3.00	1800.00	3.00	3.00	3.62
31	30	1720.00	3.00	1720.00	3.00	3.00	3.44
32	30	1820.00	3.00	1820.00	3.00	3.00	3.64
33	30	1760.00	3.00	1740.00	3.00	3.00	3.50
34	30	1720.00	3.00	1720.00	3.00	3.00	3.44
35	30	1700.00	3.00	1690.00	3.00	3.00	3.39
36	30	1660.00	3.00	1660.00	3.00	3.00	3.32
37	30	1700.00	3.00	1700.00	3.00	3.00	3.40
38	30	1800.00	3.00	1780.00	3.00	3.00	3.58
39	30	1730.00	3.00	1720.00	3.00	3.00	3.45
40	30	1700.00	3.00	1700.00	3.00	3.00	3.40
CU =	94.504	Ea =	99.978				
EU'=	92.397	qvar =	0.0008074				
		Percent water					
Total emitters flow(L/h):			147.62	* 22 gr. NaCl / liter of irrigation water in barrel			
Q from connected pipe (L/h):			522	** 22 gr. NaCl / liter of irrigation water in barrel			
Q from injector =6.04%(40.4		6.042	40.46				
Total Q in the system (L/h):			669.62				
Q from main line=93.96%		93.958	629.16				
		Vqs	0.0709				

Run3:Injection saline water(47.08 L/h), Q connectedpipe 572.4 L/h
ECl =0.022 mmhos/cm, ECL=27.5 mmhos/cm, Air.T=20c, Water T.= 15c
Suction opened & adjusted lateral inlet pressure to 14.5-15.5 psi by increasing the pressure regulator to 33.5-34.5 psi. (Adjusted Pressure)
Pregulator (injector inlet)=33.5-34.5 psi Diff.in Press.
Pinjector outlet(lateral inlet)=14.5-15.5p: 19 psi
Pend of lateral= 9-9.5 psi

Emitter #	Timie (min)	Volume (cc) run1	*ECmix. (mmhos/cm)	Volume (cc) run2	**ECmix. (mmhos/cm)	Ave.ECmix. (mmhos/cm)	Average q (l/h)
1	30	2160.00	3.00	2160.00	3.00	3.00	4.32
2	30	2100.00	3.00	2100.00	3.00	3.00	4.20
3	30	1800.00	3.00	1820.00	3.00	3.00	3.62
4	30	1825.00	3.00	1820.00	3.00	3.00	3.65
5	30	1960.00	3.00	1950.00	3.00	3.00	3.91
6	30	1855.00	3.00	1880.00	3.00	3.00	3.74
7	30	1860.00	3.00	1840.00	3.00	3.00	3.70
8	30	1990.00	3.00	1980.00	3.00	3.00	3.97
9	30	1710.00	3.00	1730.00	3.00	3.00	3.44
10	30	1760.00	3.00	1760.00	3.00	3.00	3.52
11	30	2060.00	3.00	2060.00	3.00	3.00	4.12
12	30	1800.00	3.00	1800.00	3.00	3.00	3.60
13	30	1865.00	3.00	1860.00	3.00	3.00	3.73
14	30	1960.00	3.00	1940.00	3.00	3.00	3.90
15	30	1790.00	3.00	1780.00	3.00	3.00	3.57
16	30	2005.00	3.00	2000.00	3.00	3.00	4.01
17	30	1740.00	3.00	1760.00	3.00	3.00	3.50
18	30	1800.00	3.00	1800.00	3.00	3.00	3.60
19	30	2050.00	3.00	2060.00	3.00	3.00	4.11
20	30	1950.00	3.00	1950.00	3.00	3.00	3.90
21	30	2060.00	3.00	2100.00	3.00	3.00	4.16
22	30	1930.00	3.00	1940.00	3.00	3.00	3.87
23	30	1680.00	3.00	1690.00	3.00	3.00	3.37
24	30	2020.00	3.00	2040.00	3.00	3.00	4.06
25	30	1920.00	3.00	1920.00	3.00	3.00	3.84
26	30	1870.00	3.00	1880.00	3.00	3.00	3.75
27	30	2000.00	3.00	2020.00	3.00	3.00	4.02
28	30	2410.00	3.00	2420.00	3.00	3.00	4.83
29	30	1820.00	3.00	1820.00	3.00	3.00	3.64
30	30	1950.00	3.00	1970.00	3.00	3.00	3.92
31	30	1760.00	3.00	1750.00	3.00	3.00	3.51
32	30	1960.00	3.00	2000.00	3.00	3.00	3.96
33	30	1790.00	3.00	1800.00	3.00	3.00	3.59
34	30	1780.00	3.00	1780.00	3.00	3.00	3.56
35	30	1820.00	3.00	1840.00	3.00	3.00	3.66
36	30	1730.00	3.00	1740.00	3.00	3.00	3.47
37	30	1840.00	3.00	1860.00	3.00	3.00	3.70
38	30	1960.00	3.00	1950.00	3.00	3.00	3.91
39	30	1860.00	3.00	1880.00	3.00	3.00	3.74
40	30	1844.00	3.00	1850.00	3.00	3.00	3.69
CU =	94.161	Ea =	99.981				
EU'=	92.229	qvar =	0.000715				
			Percent water				
Total emitters flow(L/h):			152.34	* 22 gr. NaCl / liter of irrigation water in barrel			
Q from connected pipe (L/h):			572.4	** 22 gr. NaCl / liter of irrigation water in barrel			
Q from injector =6.5%(47.08 L/h)		6.496	47.08				
Total Q in the system (L/h):			724.74				
Q from main line=93.5%		93.504	677.66				
		Vqs	0.0737				

Nominal Emitter flow rate = 3.78l/h
Operating M.I.S
New Emitters
Without venturi Injector
P(lateral inlet)=14.5-15.5psi
Pend of lateral= 14-14.8 psi

Emitter #	Timie (min)	Ave.Volume (cc)	Average q (l/h)	emitter Pressure at each section (psi)
1	30	2210.00	4.42	15.50
2	30	2190.00	4.38	15.50
3	30	1840.00	3.68	15.50
4	30	1860.00	3.72	15.20
5	30	2020.00	4.04	15.10
6	30	1915.00	3.83	15.10
7	30	1930.00	3.86	15.10
8	30	2060.00	4.12	15.10
9	30	1740.00	3.48	15.10
10	30	1780.00	3.56	15.10
11	30	2110.00	4.22	15.10
12	30	1830.00	3.66	15.00
13	30	1900.00	3.80	15.00
14	30	2000.00	4.00	15.00
15	30	1810.00	3.62	15.00
16	30	2050.00	4.10	15.00
17	30	1780.00	3.56	15.20
18	30	1860.00	3.72	15.00
19	30	2080.00	4.16	15.00
20	30	1980.00	3.96	14.90
21	30	2250.00	4.50	14.90
22	30	2028.00	4.06	14.90
23	30	1700.00	3.40	14.90
24	30	2200.00	4.40	14.80
25	30	1980.00	3.96	14.80
26	30	1905.00	3.81	14.80
27	30	2490.00	4.98	15.00
28	30	2090.00	4.18	14.80
29	30	1850.00	3.70	15.00
30	30	2120.00	4.24	15.00
31	30	1760.00	3.52	14.90
32	30	2170.00	4.34	15.00
33	30	1820.00	3.64	15.00
34	30	1820.00	3.64	15.00
35	30	1905.00	3.81	15.00
36	30	1770.00	3.54	14.50
37	30	2080.00	4.16	15.00
38	30	2270.00	4.54	15.00
39	30	2000.00	4.00	14.90
40	30	1988.00	3.98	14.80
CU =	92.877	Ea =	99.979	
EU'=	90.012	qvar =	0.000776	
Total emitters flow(L/h):			158.28	
Total Q in the system (L/h):			158.28	
			Vqs	0.0870

Table A.5.45 Emitter flow variation under saline water injection (EC_L=13.5-15 mmhos/cm), average EC_m= 1.5 mmhos/cm, no-clogged condition, and **40m** lateral laid on flat terrain

Run1: No injection of saline water from the barrel
ECI =0.022 mmhos/cm, Air.T=20c, Water.T=15c
Liquid suction tube closed
Water passes through the venturi into the entire length of lateral(Q from the connection pipe 560 L/h)
Pregulator (injector inlet)=24.5 Diff.in Press.
Pinjector outlet(lateral inlet)=1· 10psi
Pend of lateral= 9-9.5 psi

Emitter #	Timie (min)	Volume (cc) run1	Volume (cc) run2	Average q (l/h)
1	30	2160.00	2140.00	4.30
2	30	2140.00	2100.00	4.24
3	30	1820.00	1800.00	3.62
4	30	1840.00	1840.00	3.68
5	30	1980.00	1990.00	3.97
6	30	1900.00	1900.00	3.80
7	30	1895.00	1900.00	3.80
8	30	2000.00	2000.00	4.00
9	30	1736.00	1740.00	3.48
10	30	1750.00	1760.00	3.51
11	30	2100.00	2095.00	4.20
12	30	1800.00	1810.00	3.61
13	30	1880.00	1860.00	3.74
14	30	2000.00	2010.00	4.01
15	30	1800.00	1795.00	3.60
16	30	2044.00	2040.00	4.08
17	30	1760.00	1755.00	3.52
18	30	1820.00	1830.00	3.65
19	30	2085.00	2080.00	4.17
20	30	1990.00	1995.00	3.99
21	30	2086.00	2076.00	4.16
22	30	1950.00	1930.00	3.88
23	30	1690.00	1680.00	3.37
24	30	2040.00	2035.00	4.08
25	30	1960.00	1970.00	3.93
26	30	1900.00	1880.00	3.78
27	30	2010.00	2020.00	4.03
28	30	2400.00	2398.00	4.80
29	30	1840.00	1850.00	3.69
30	30	1990.00	1995.00	3.99
31	30	1760.00	1750.00	3.51
32	30	2000.00	2010.00	4.01
33	30	1830.00	1840.00	3.67
34	30	1800.00	1810.00	3.61
35	30	1840.00	1845.00	3.69
36	30	1760.00	1765.00	3.53
37	30	1870.00	1870.00	3.74
38	30	1960.00	1965.00	3.93
39	30	1900.00	1910.00	3.81
40	30	1860.00	1870.00	3.73
CU =	94.139	Ea =	99.981	
EU'=	91.898	qvar =	0.000730	

Total emitters flow(L/h): 153.86
Q from connected pipe (L/h): 560
Total Q in the system(L/h): 713.86
Vqs 0.0724

Run2: With injection of saline water (44.16 l/h) from the barrel
ECI =0.022 mmhos/cm, ECL=13.5-15 mmhos/cm, Air.T=20c, Water T.= 15c
Liquid suction 44.16 l/h,Q from connected pipe 523.2 L/h
Water mixed (ECmix = 1.5mmhos/cm) from main hose and venturi injector, flow into the lateral (Not adjusted pressure)
Pregulator (injector inlet)=25-26 psi Diff.in Press.
Pinjector outlet(lateral inlet)=12-12.5psi 13.25psi
Pend of lateral= 8-8.5 psi (Not adjusted pressure)

Emitter #	Timie (min)	Volume (cc) run1	*ECmix. (mmhos/cm)	Volume (cc) run2	**ECmix. (mmhos/cm)	Ave.ECmix. (mmhos/cm)	Average q (l/h)
1	30	2160.00	1.40	2160.00	1.6	1.5	4.32
2	30	2140.00	1.40	2140.00	1.6	1.5	4.28
3	30	1840.00	1.40	1840.00	1.6	1.5	3.68
4	30	1840.00	1.40	1840.00	1.6	1.5	3.68
5	30	1990.00	1.40	1970.00	1.6	1.5	3.96
6	30	1910.00	1.40	1880.00	1.6	1.5	3.79
7	30	1900.00	1.40	1920.00	1.6	1.5	3.82
8	30	2000.00	1.40	1980.00	1.6	1.5	3.98
9	30	1720.00	1.40	1720.00	1.6	1.5	3.44
10	30	1760.00	1.40	1760.00	1.6	1.5	3.52
11	30	2020.00	1.40	2040.00	1.6	1.5	4.06
12	30	1800.00	1.40	1800.00	1.6	1.5	3.60
13	30	1900.00	1.40	1880.00	1.6	1.5	3.78
14	30	2000.00	1.40	1980.00	1.6	1.5	3.98
15	30	1800.00	1.40	1840.00	1.6	1.5	3.64
16	30	2000.00	1.40	2010.00	1.6	1.5	4.01
17	30	1780.00	1.40	1880.00	1.6	1.5	3.66
18	30	1840.00	1.40	1840.00	1.6	1.5	3.68
19	30	2020.00	1.40	2020.00	1.6	1.5	4.04
20	30	1940.00	1.40	1960.00	1.6	1.5	3.90
21	30	1910.00	1.40	1920.00	1.6	1.5	3.83
22	30	1780.00	1.40	1800.00	1.6	1.5	3.58
23	30	1680.00	1.40	1680.00	1.6	1.5	3.36
24	30	1870.00	1.40	1870.00	1.6	1.5	3.74
25	30	1840.00	1.40	1840.00	1.6	1.5	3.68
26	30	1820.00	1.40	1820.00	1.6	1.5	3.64
27	30	1840.00	1.40	1820.00	1.6	1.5	3.66
28	30	2200.00	1.40	2190.00	1.6	1.5	4.39
29	30	1760.00	1.40	1780.00	1.6	1.5	3.54
30	30	1820.00	1.40	1820.00	1.6	1.5	3.64
31	30	1720.00	1.40	1740.00	1.6	1.5	3.46
32	30	1820.00	1.40	1820.00	1.6	1.5	3.64
33	30	1760.00	1.40	1740.00	1.6	1.5	3.50
34	30	1720.00	1.40	1740.00	1.6	1.5	3.46
35	30	1700.00	1.40	1710.00	1.6	1.5	3.41
36	30	1660.00	1.40	1670.00	1.6	1.5	3.33
37	30	1710.00	1.40	1700.00	1.6	1.5	3.41
38	30	1780.00	1.40	1790.00	1.6	1.5	3.57
39	30	1750.00	1.40	1730.00	1.6	1.5	3.48
40	30	1700.00	1.40	1710.00	1.6	1.5	3.41
CU =	94.228	Ea =	99.978				
EU'=	92.134	qvar =	#######				

Percent water
Total emitters flow(L/h): 148.55 * 10 gr. NaCl / liter of irrigation water in barrel
Q from connected pipe (L/h): 523.2 ** 11 gr. NaCl / liter of irrigation water in barrel
Q from injector =6.57%(44.1 6.574 44.16
Total Q in the system (L/h): 671.75
Q from main line=93.43% 93.426 627.59
Vqs 0.0740

Run3:Injection saline water(47.5 L/h), Q connectedpipe 574.42 L/h
ECI =0.022 mmhos/cm, ECL=(13.5-15) mmhos/cm, Air.T=20c, Water T.= 15c
Suction opened & adjusted lateral inlet pressure to 14.5-15.5 psi by increasing the pressure regulator to 33.5-34.5 psi. (Adjusted Pressure)
Pregulator (injector inlet)=33.5-34. Diff.in Press.
Pinjector outlet(lateral inlet)=14.5-· 19 psi
Pend of lateral= 9-9.5 psi

Emitter #	Timie (min)	Volume (cc) run1	*ECmix. (mmhos/cm)	Volume (cc) run2	**ECmix. (mmhos/cm)	Ave.ECmix. (mmhos/cm)	Average q (l/h)
1	30	2180.00	1.40	2160.00	1.6	1.5	4.34
2	30	2120.00	1.40	2140.00	1.6	1.5	4.26
3	30	1800.00	1.40	1820.00	1.6	1.5	3.62
4	30	1820.00	1.40	1820.00	1.6	1.5	3.64
5	30	1980.00	1.40	1980.00	1.6	1.5	3.96
6	30	1900.00	1.40	1900.00	1.6	1.5	3.80
7	30	1900.00	1.40	1900.00	1.6	1.5	3.80
8	30	2000.00	1.40	2000.00	1.6	1.5	4.00
9	30	1760.00	1.40	1740.00	1.6	1.5	3.50
10	30	1760.00	1.40	1770.00	1.6	1.5	3.53
11	30	2140.00	1.40	2120.00	1.6	1.5	4.26
12	30	1800.00	1.40	1800.00	1.6	1.5	3.60
13	30	1880.00	1.40	1860.00	1.6	1.5	3.74
14	30	1995.00	1.40	2000.00	1.6	1.5	4.00
15	30	1800.00	1.40	1800.00	1.6	1.5	3.60
16	30	2050.00	1.40	2050.00	1.6	1.5	4.10
17	30	1760.00	1.40	1760.00	1.6	1.5	3.52
18	30	1820.00	1.40	1825.00	1.6	1.5	3.65
19	30	2070.00	1.40	2084.00	1.6	1.5	4.15
20	30	1980.00	1.40	1990.00	1.6	1.5	3.97
21	30	2110.00	1.40	2100.00	1.6	1.5	4.21
22	30	1840.00	1.40	1840.00	1.6	1.5	3.68
23	30	1680.00	1.40	1680.00	1.6	1.5	3.36
24	30	2040.00	1.40	2060.00	1.6	1.5	4.10
25	30	1940.00	1.40	1950.00	1.6	1.5	3.89
26	30	1900.00	1.40	1880.00	1.6	1.5	3.78
27	30	2005.00	1.40	2015.00	1.6	1.5	4.02
28	30	2400.00	1.40	2405.00	1.6	1.5	4.81
29	30	1840.00	1.40	1840.00	1.6	1.5	3.68
30	30	1996.00	1.40	1996.00	1.6	1.5	3.99
31	30	1780.00	1.40	1760.00	1.6	1.5	3.54
32	30	2010.00	1.40	2000.00	1.6	1.5	4.01
33	30	1845.00	1.40	1840.00	1.6	1.5	3.69
34	30	1820.00	1.40	1800.00	1.6	1.5	3.62
35	30	1850.00	1.40	1840.00	1.6	1.5	3.69
36	30	1760.00	1.40	1760.00	1.6	1.5	3.52
37	30	1880.00	1.40	1885.00	1.6	1.5	3.77
38	30	1970.00	1.40	1960.00	1.6	1.5	3.93
39	30	1910.00	1.40	1910.00	1.6	1.5	3.82
40	30	1870.00	1.40	1875.00	1.6	1.5	3.75
CU =	94.032	Ea =	99.981				
EU'=	92.034	qvar =	0.000729				

Percent water
Total emitters flow(L/h): 153.88 * 10 gr. NaCl / liter of irrigation water in barrel
Q from connected pipe (L/h): 574.42 ** 11 gr. NaCl / liter of irrigation water in barrel
Q from injector =6.52%(47.5 L 6.522 47.5
Total Q in the system (L/h): 728.30
Q from main line=93.48% 93.478 680.80
Vqs 0.0739

Nominal Emitter flow rate = 3.78l/h
Operating M.I.S
New Emitters
Without venturi Injector

P(lateral inlet)=14.5-15.5psi
Pend of lateral= 14-14.8 psi

Emitter #	Timie (min)	Ave.Volume (cc)	Average q (l/h)	emitter Pressure at each section (psi)
1	30	2210.00	4.42	15.50
2	30	2190.00	4.38	15.50
3	30	1840.00	3.68	15.50
4	30	1860.00	3.72	15.20
5	30	2020.00	4.04	15.10
6	30	1915.00	3.83	15.10
7	30	1930.00	3.86	15.10
8	30	2060.00	4.12	15.10
9	30	1740.00	3.48	15.10
10	30	1780.00	3.56	15.10
11	30	2110.00	4.22	15.10
12	30	1830.00	3.66	15.00
13	30	1900.00	3.80	15.00
14	30	2000.00	4.00	15.00
15	30	1810.00	3.62	15.00
16	30	2050.00	4.10	15.00
17	30	1780.00	3.56	15.20
18	30	1860.00	3.72	15.00
19	30	2080.00	4.16	15.00
20	30	1980.00	3.96	14.90
21	30	2250.00	4.50	14.90
22	30	2028.00	4.06	14.90
23	30	1700.00	3.40	14.90
24	30	2200.00	4.40	14.80
25	30	1980.00	3.96	14.80
26	30	1905.00	3.81	14.80
27	30	2490.00	4.98	15.00
28	30	2090.00	4.18	14.80
29	30	1850.00	3.70	15.00
30	30	2120.00	4.24	15.00
31	30	1760.00	3.52	14.90
32	30	2170.00	4.34	15.00
33	30	1820.00	3.64	15.00
34	30	1820.00	3.64	15.00
35	30	1905.00	3.81	15.00
36	30	1770.00	3.54	14.50
37	30	2080.00	4.16	15.00
38	30	2270.00	4.54	15.00
39	30	2000.00	4.00	14.90
40	30	1988.00	3.98	14.80
CU =	92.877	Ea =	99.979	
EU'=	90.012	qvar =	0.000776	

Total emitters flow(L/h): 158.28
Vqs 0.0870

Table A.5.46 Emitter flow variation under saline water injection (EC_L=1.5 mmhos/cm), average EC_m= 0.11 mmhos/cm, no-clogged condition, and **20m** lateral laid on flat terrain

Run1: No injection of saline water from the barrel
ECl =0.022 mmhos/cm, Air.T=20c, Water.T=15c
Liquid suction tube closed
Water passes through the venturi into the entire length of lateral(Q from the connection pipe 604.14 L/h)
Pregulator (injector inlet)=24.5 Diff.in Press.
Pinjector outlet(lateral inlet)=1- 10psi
Pend of lateral= 12-12.5 psi

Emitter #	Time (min)	Volume (cc) run1	Volume (cc) run2	Average q (l/h)
1	30	2190.00	2190.00	4.38
2	30	2150.00	2150.00	4.30
3	30	1880.00	1870.00	3.75
4	30	1880.00	1870.00	3.75
5	30	2030.00	2040.00	4.07
6	30	1940.00	1940.00	3.88
7	30	1930.00	1940.00	3.87
8	30	2036.00	2026.00	4.06
9	30	1800.00	1790.00	3.59
10	30	1830.00	1820.00	3.65
11	30	2110.00	2120.00	4.23
12	30	1850.00	1840.00	3.69
13	30	1930.00	1930.00	3.86
14	30	2036.00	2046.00	4.08
15	30	1870.00	1870.00	3.74
16	30	2080.00	2080.00	4.16
17	30	1800.00	1800.00	3.60
18	30	1880.00	1870.00	3.75
19	30	2100.00	2096.00	4.20
20	30	2022.00	2024.00	4.05
CU=	94.577	Ea =	99.997	
EU'=	92.906	qvar =	0.000108	

Total emitters flow(L/h): 78.66
Q from connected pipe (L/h): 604.14
Total Q in the system(L/h): 682.80
Vqs 0.0605

Run2: With injection of saline water (33.6 l/h) from the barrel
ECl =0.022 mmhos/cm, *ECL=1.5mmhos/cm, Air.T=20c, Water T.= 15c
Liquid suction 33.6 l/h,Q from connected pipe 567.6 L/h
Water mixed (ECmix = 0.12mmhos/cm) from main hose and venturi injector, flow into the lateral (Not adjusted pressure)
Pregulator (injector inlet)=25-26 psi Diff.in Press.
Pinjector outlet(lateral inlet)=12-12.5psi 13.25
Pend of lateral= 9.5-10.5 psi (Not adjusted pressure)

Emitter #	Time (min)	Volume (cc) run1	ECmix. (mmhos/cm)	Volume (cc) run2	ECmix. (mmhos/cm)	Ave.ECmix. (mmhos/cm)	Average q (l/h)
1	30	2180.00	0.11	2170.00	0.11	0.11	4.35
2	30	2130.00	0.11	2120.00	0.11	0.11	4.25
3	30	1860.00	0.11	1840.00	0.11	0.11	3.70
4	30	1870.00	0.11	1870.00	0.11	0.11	3.74
5	30	2024.00	0.11	2000.00	0.11	0.11	4.02
6	30	1930.00	0.11	1920.00	0.11	0.11	3.85
7	30	1920.00	0.11	1920.00	0.11	0.11	3.84
8	30	2000.00	0.11	2000.00	0.11	0.11	4.00
9	30	1760.00	0.11	1760.00	0.11	0.11	3.52
10	30	1800.00	0.11	1820.00	0.11	0.11	3.62
11	30	2056.00	0.11	2040.00	0.11	0.11	4.10
12	30	1830.00	0.11	1820.00	0.11	0.11	3.65
13	30	1920.00	0.11	1920.00	0.11	0.11	3.84
14	30	2010.00	0.11	2000.00	0.11	0.11	4.01
15	30	1840.00	0.11	1840.00	0.11	0.11	3.68
16	30	2028.00	0.11	2024.00	0.11	0.11	4.05
17	30	1790.00	0.11	1790.00	0.11	0.11	3.58
18	30	1870.00	0.11	1860.00	0.11	0.11	3.73
19	30	2020.00	0.11	2020.00	0.11	0.11	4.04
20	30	1960.00	0.11	1970.00	0.11	0.11	3.93
CU =	95.161	Ea =	99.997				
EU'=	93.161	qvar =	0.000128				

Percent water
Total emitters flow(L/h): 77.50
Q from connected pipe (L/h): 567.6
Q from injector =5.2%(33.6L 5.208 33.6
Total Q in the system (L/h): 645.10
Q from main line=94.8% 94.792 611.50
Vqs 0.0569

* 0.54 gr. NaCl / liter of irrigation water in barrel to make saline water with EC=1.5 mmhos/cm

Run3:Injection saline water(35.74L/h), Q connectedpipe=609L/h
ECl =0.022 mmhos/cm, *ECL=1.5mmhos/cm, Air.T=20c, Water T.= 15c
Suction opened & adjusted lateral inlet pressure to 14.5-15.5 psi by increasing the pressure regulator to 33.5-34.5 psi. (Adjusted Pressure)
Pregulator (injector inlet)=33.5-34.5 psi Diff.in Press.
Pinjector outlet(lateral inlet)=14.5-15.5psi 19 psi
Pend of lateral= 12-12.5 psi

Emitter #	Time (min)	Volume (cc) run1	ECmix. (mmhos/cm)	Volume (cc) run2	ECmix. (mmhos/cm)	Ave.ECmix. (mmhos/cm)	Average q (l/h)
1	30	2190.00	0.11	2180.00	0.11	0.11	4.37
2	30	2150.00	0.11	2160.00	0.11	0.11	4.31
3	30	1870.00	0.11	1870.00	0.11	0.11	3.74
4	30	1870.00	0.11	1880.00	0.11	0.11	3.75
5	30	2028.00	0.11	2024.00	0.11	0.11	4.05
6	30	1940.00	0.11	1930.00	0.11	0.11	3.87
7	30	1920.00	0.11	1920.00	0.11	0.11	3.84
8	30	2020.00	0.11	2016.00	0.11	0.11	4.04
9	30	1780.00	0.11	1790.00	0.11	0.11	3.57
10	30	1830.00	0.11	1820.00	0.11	0.11	3.65
11	30	2100.00	0.11	2110.00	0.11	0.11	4.21
12	30	1850.00	0.11	1840.00	0.11	0.11	3.69
13	30	1920.00	0.11	1940.00	0.11	0.11	3.86
14	30	2020.00	0.11	2030.00	0.11	0.11	4.05
15	30	1870.00	0.11	1870.00	0.11	0.11	3.74
16	30	2070.00	0.11	2080.00	0.11	0.11	4.15
17	30	1800.00	0.11	1800.00	0.11	0.11	3.60
18	30	1870.00	0.11	1880.00	0.11	0.11	3.75
19	30	2100.00	0.11	2100.00	0.11	0.11	4.20
20	30	2014.00	0.11	2020.00	0.11	0.11	4.03
CU =	94.651	Ea =	99.997				
EU'=	93.029	qvar =	0.000107				

Percent water
Total emitters flow(L/h): 78.47
Q from connected pipe (L/h): 609
Q from injector =5.20%(35.74 5.199 35.74
Total Q in the system (L/h): 687.47
Q from main line=94.8% 94.801 651.73
Vqs 0.0602

* 0.54 gr. NaCl / liter of irrigation water in barrel to make saline water with EC=1.5 mmhos/cm

Nominal Emitter flow rate = 3.78l/h
Operating M.I.S
New Emitters
Without venturi Injector
P(lateral inlet)=14.5-15.5psi
Pend of lateral= 14-14.8 psi

Emitter #	Time (min)	Ave.Volume (cc)	Average q (l/h)	emitter Pressure at each section (psi)
1	30	2210.00	4.42	15.50
2	30	2190.00	4.38	15.50
3	30	1848.00	3.70	15.50
4	30	1863.00	3.73	15.20
5	30	2031.00	4.06	15.10
6	30	1935.00	3.87	15.10
7	30	1913.00	3.83	15.10
8	30	2023.00	4.05	15.10
9	30	1740.00	3.48	15.10
10	30	1803.00	3.61	15.10
11	30	2090.00	4.18	15.10
12	30	1800.00	3.60	15.00
13	30	1880.00	3.76	15.00
14	30	1965.00	3.93	15.00
15	30	1783.00	3.57	15.00
16	30	2054.00	4.11	15.00
17	30	1785.00	3.57	15.20
18	30	1828.00	3.66	15.00
19	30	2090.00	4.18	15.00
20	30	1973.00	3.95	14.90
CU =	94.019	Ea =	99.997	
EU'=	91.860	qvar =	0.000104	

Total emitters flow(L/h): 77.81
Vqs 0.0698

Table A.5.47 Emitter flow variation under saline water injection (EC_L=3 mmhos/cm), average EC_m= 0.22 mmhos/cm, no-clogged condition, and **20m** lateral laid on flat terrain

Run1: No injection of saline water from the barrel
ECl =0.022 mmhos/cm, Air.T=19c, Water.T=15c
Liquid suction tube closed
Water passes through the venturi into the entire length of lateral(Q from the connection pipe 636.6 L/h)
Pregulator (injector inlet)=24.5 Diff.in Press.
Pinjector outlet(lateral inlet)=1· 10psi
Pend of lateral= 12-12.5 psi

Emitter #	Time (min)	Volume (cc) run1	Volume (cc) run2	Average q (l/h)
1	30	2200.00	2190.00	4.39
2	30	2154.00	2150.00	4.30
3	30	1872.00	1870.00	3.74
4	30	1890.00	1880.00	3.77
5	30	2034.00	2020.00	4.05
6	30	1950.00	1940.00	3.89
7	30	1932.00	1920.00	3.85
8	30	2034.00	2020.00	4.05
9	30	1788.00	1780.00	3.57
10	30	1812.00	1800.00	3.61
11	30	2106.00	2100.00	4.21
12	30	1860.00	1860.00	3.72
13	30	1944.00	1940.00	3.88
14	30	2016.00	2016.00	4.03
15	30	1842.00	1840.00	3.68
16	30	2082.00	2080.00	4.16
17	30	1800.00	1800.00	3.60
18	30	1884.00	1880.00	3.76
19	30	2100.00	2120.00	4.22
20	30	2016.00	2010.00	4.03
CU =	94.624	Ea =	99.997	
EU'=	92.625	qvar =	0.000107	

Total emitters flow(L/h): 78.53
Q from connected pipe (L/h): 636.6
Total Q in the system(L/h): 715.13
Vqs 0.0614

Run2: With injection of saline water (40.8 l/h) from the barrel
ECl =0.022 mmhos/cm, *ECL=3.00mmhos/cm, Air.T=19c, Water T.= 15c
Liquid suction 40.8 l/h,Q from connected pipe 585 L/h
Water mixed (ECmix = 0.27mmhos/cm) from main hose and venturi injector, flow into the lateral (Not adjusted pressure)
Pregulator (injector inlet)=25-26 psi Diff.in Press.
Pinjector outlet(lateral inlet)=12-12.5psi 13.25
Pend of lateral= 9.5-10.5 psi (Not adjusted pressure)

Emitter #	Time (min)	Volume (cc) run1	ECmix. (mmhos/cm)	Volume (cc) run2	ECmix. (mmhos/cm)	Ave.ECmix. (mmhos/cm)	Average q (l/h)
1	30	2160.00	0.20	2140.00	0.20	0.2	4.30
2	30	2120.00	0.20	2110.00	0.20	0.2	4.23
3	30	1870.00	0.20	1860.00	0.20	0.2	3.73
4	30	1880.00	0.20	1880.00	0.20	0.2	3.76
5	30	2016.00	0.20	2020.00	0.20	0.2	4.04
6	30	1910.00	0.20	1900.00	0.20	0.2	3.81
7	30	1920.00	0.20	1910.00	0.20	0.2	3.83
8	30	2000.00	0.20	2000.00	0.20	0.2	4.00
9	30	1780.00	0.20	1780.00	0.20	0.2	3.56
10	30	1800.00	0.20	1790.00	0.20	0.2	3.59
11	30	1990.00	0.20	1980.00	0.20	0.2	3.97
12	30	1830.00	0.20	1834.00	0.20	0.2	3.66
13	30	1910.00	0.20	1900.00	0.20	0.2	3.81
14	30	1980.00	0.20	1984.00	0.20	0.2	3.96
15	30	1830.00	0.20	1820.00	0.20	0.2	3.65
16	30	1980.00	0.20	1980.00	0.20	0.2	3.96
17	30	1800.00	0.20	1800.00	0.20	0.2	3.60
18	30	1860.00	0.20	1850.00	0.20	0.2	3.71
19	30	1940.00	0.20	1930.00	0.20	0.2	3.87
20	30	1900.00	0.20	1880.00	0.20	0.2	3.78
CU =	95.829	Ea =	99.997				
EU'=	94.038	qvar =	0.000125				

	Percent water	
Total emitters flow(L/h):		76.82
Q from connected pipe (L/h):		586
Q from injector =6.15%(40.8	6.155	40.8
Total Q in the system (L/h):		662.82
Q from main line=93.84%	93.845	622.02
Vqs		0.0515

* 1.14 gr. NaCl / liter of irrigation water in barrel to make saline water with EC=3.00 mmhos/cm

Run3:Injection saline water(44.4L/h), Q connectedpipe=645L/h
ECl =0.022 mmhos/cm, *ECL=3.00mmhos/cm, Air.T=19c, Water T.= 15c
Suction opened & adjusted lateral inlet pressure to 14.5-15.5 psi by increasing the pressure regulator to 33.5-34.5 psi. (Adjusted Pressure)
Pregulator (injector inlet)=33.5-34.5 psi Diff.in Press.
Pinjector outlet(lateral inlet)=14.5-15.5psi 19 psi
Pend of lateral= 12-12.5 psi

Emitter #	Time (min)	Volume (cc) run1	ECmix. (mmhos/cm)	Volume (cc) run2	ECmix. (mmhos/cm)	Ave.ECmix. (mmhos/cm)	Average q (l/h)
1	30	2200.00	0.20	2190.00	0.20	0.2	4.39
2	30	2150.00	0.20	2140.00	0.20	0.2	4.29
3	30	1870.00	0.20	1860.00	0.20	0.2	3.73
4	30	1880.00	0.20	1880.00	0.20	0.2	3.76
5	30	2024.00	0.20	2020.00	0.20	0.2	4.04
6	30	1940.00	0.20	1930.00	0.20	0.2	3.87
7	30	1920.00	0.20	1910.00	0.20	0.2	3.83
8	30	2030.00	0.20	2024.00	0.20	0.2	4.05
9	30	1784.00	0.20	1780.00	0.20	0.2	3.56
10	30	1820.00	0.20	1816.00	0.20	0.2	3.64
11	30	2120.00	0.20	2110.00	0.20	0.2	4.23
12	30	1860.00	0.20	1860.00	0.20	0.2	3.72
13	30	1940.00	0.20	1936.00	0.20	0.2	3.88
14	30	2020.00	0.20	2010.00	0.20	0.2	4.03
15	30	1850.00	0.20	1840.00	0.20	0.2	3.69
16	30	2086.00	0.20	2080.00	0.20	0.2	4.17
17	30	1800.00	0.20	1800.00	0.20	0.2	3.60
18	30	1880.00	0.20	1888.00	0.20	0.2	3.77
19	30	2120.00	0.20	2110.00	0.20	0.2	4.23
20	30	2024.00	0.20	2010.00	0.20	0.2	4.03
CU =	94.573	Ea =	99.997				
EU'=	92.778	qvar =	0.0001075				

	Percent water	
Total emitters flow(L/h):		78.51
Q from connected pipe (L/h):		645
Q from injector =6.13%(44.4 L	6.137	44.4
Total Q in the system (L/h):		723.51
Q from main line=93.86%	93.863	679.11
Vqs		0.0615

* 1.14 gr. NaCl / liter of irrigation water in barrel to make saline water with EC=3.00 mmhos/cm

Nominal Emitter flow rate = 3.78l/h
Operating M.I.S
New Emitters
Without venturi injector
P(lateral inlet)=14.5-15.5psi
Pend of lateral= 14-14.8 psi

Emitter #	Time (min)	Ave.Volume (cc)	Average q (l/h)	emitter Pressure at each section (psi)
1	30	2210.00	4.42	15.50
2	30	2190.00	4.38	15.50
3	30	1848.00	3.70	15.50
4	30	1863.00	3.73	15.20
5	30	2031.00	4.06	15.10
6	30	1935.00	3.87	15.10
7	30	1913.00	3.83	15.10
8	30	2023.00	4.05	15.10
9	30	1740.00	3.48	15.10
10	30	1803.00	3.61	15.10
11	30	2090.00	4.18	15.10
12	30	1800.00	3.60	15.00
13	30	1880.00	3.76	15.00
14	30	1965.00	3.93	15.00
15	30	1783.00	3.57	15.00
16	30	2054.00	4.11	15.00
17	30	1785.00	3.57	15.20
18	30	1828.00	3.66	15.00
19	30	2090.00	4.18	15.00
20	30	1973.00	3.95	14.90
CU =	94.019	Ea =	99.997	
EU'=	91.860	qvar =	0.000104	

Total emitters flow(L/h): 77.61
Vqs 0.0698

Table A.5.48 Emitter flow variation under saline water injection (EC_L=1.5 mmhos/cm), average EC_m= 0.11 mmhos/cm, no-clogged condition, and **40m** lateral laid on flat terrain

Run1: No injection of saline water from the barrel
ECl =0.022 mmhos/cm, Air.T=20c, Water.T=14c
Liquid suction tube closed
Water passes through the venturi into the entire length of lateral(Q from the connection pipe 535.8 L/h)
Pregulator (injector inlet)=24.5 Diff.in Press.
Pinjector outlet(lateral inlet)=1· 10psi
Pend of lateral= 9-9.5 psi

Emitter #	Timie (min)	Volume (cc) run1	Volume (cc) run2	Average q (l/h)
1	30	2220.00	2216.00	4.44
2	30	2160.00	2170.00	4.33
3	30	1880.00	1870.00	3.75
4	30	1890.00	1880.00	3.77
5	30	2046.00	2040.00	4.09
6	30	1940.00	1930.00	3.87
7	30	1940.00	1930.00	3.87
8	30	2040.00	2036.00	4.08
9	30	1790.00	1800.00	3.59
10	30	1810.00	1816.00	3.63
11	30	2120.00	2110.00	4.23
12	30	1880.00	1870.00	3.75
13	30	1940.00	1936.00	3.88
14	30	2040.00	2044.00	4.08
15	30	1900.00	1880.00	3.78
16	30	2100.00	2100.00	4.20
17	30	1800.00	1800.00	3.60
18	30	1890.00	1888.00	3.78
19	30	2116.00	2120.00	4.24
20	30	2038.00	2020.00	4.06
21	30	2096.00	2100.00	4.20
22	30	2024.00	2010.00	4.03
23	30	1720.00	1720.00	3.44
24	30	2056.00	2060.00	4.12
25	30	1980.00	1980.00	3.96
26	30	1920.00	1900.00	3.82
27	30	2210.00	2216.00	4.43
28	30	2140.00	2120.00	4.26
29	30	1880.00	1880.00	3.76
30	30	1990.00	2016.00	4.01
31	30	1790.00	1780.00	3.57
32	30	2000.00	2010.00	4.01
33	30	1850.00	1840.00	3.69
34	30	1850.00	1840.00	3.69
35	30	1870.00	1870.00	3.74
36	30	1790.00	1790.00	3.58
37	30	1880.00	1888.00	3.77
38	30	1990.00	2004.00	3.99
39	30	1930.00	1924.00	3.85
40	30	1890.00	1900.00	3.79
CU =	94.661	Ea =	99.980	
EU'=	92.788	qvar =	0.000751	

Total emitters flow(L/h):		156.70
Q from connected pipe (L/h):		535.8
Total Q in the system(L/h):		692.50
	Vqs	0.0624

Run2: With injection of saline water (37.2 l/h) from the barrel
ECl =0.022 mmhos/cm, *ECL=1.5mmhos/cm, Air.T=20c, Water T.= 14c
Liquid suction 37.2 l/h,Q from connected pipe 505.2 L/h
Water mixed (ECmix = 0.12mmhos/cm) from main hose and venturi injector, flow into the lateral (Not adjusted pressure)
Pregulator (injector inlet)=25-26 psi Diff.in Press.
Pinjector outlet(lateral inlet)=12-12.5psi 13.25psi
Pend of lateral= 8-8.5 psi (Not adjusted pressure)

Emitter #	Timie (min)	Volume (cc) run1	ECmix. (mmhos/cm)	Volume (cc) run2	ECmix. (mmhos/cm)	Ave.ECmix. (mmhos/cm)	Average q (l/h)
1	30	2190.00	0.11	2180.00	0.11	0.11	4.37
2	30	2140.00	0.11	2130.00	0.11	0.11	4.27
3	30	1880.00	0.11	1870.00	0.11	0.11	3.75
4	30	1890.00	0.11	1880.00	0.11	0.11	3.77
5	30	2020.00	0.11	2024.00	0.11	0.11	4.04
6	30	1940.00	0.11	1930.00	0.11	0.11	3.87
7	30	1940.00	0.11	1930.00	0.11	0.11	3.87
8	30	2020.00	0.11	2010.00	0.11	0.11	4.03
9	30	1780.00	0.11	1770.00	0.11	0.11	3.55
10	30	1810.00	0.11	1800.00	0.11	0.11	3.61
11	30	2060.00	0.11	2064.00	0.11	0.11	4.12
12	30	1840.00	0.11	1850.00	0.11	0.11	3.69
13	30	1940.00	0.11	1936.00	0.11	0.11	3.88
14	30	2030.00	0.11	2020.00	0.11	0.11	4.05
15	30	1870.00	0.11	1880.00	0.11	0.11	3.75
16	30	2040.00	0.11	2040.00	0.11	0.11	4.08
17	30	1800.00	0.11	1800.00	0.11	0.11	3.60
18	30	1890.00	0.11	1880.00	0.11	0.11	3.77
19	30	2050.00	0.11	2040.00	0.11	0.11	4.09
20	30	1990.00	0.11	1980.00	0.11	0.11	3.97
21	30	1970.00	0.11	1950.00	0.11	0.11	3.92
22	30	1930.00	0.11	1912.00	0.11	0.11	3.84
23	30	1700.00	0.11	1720.00	0.11	0.11	3.42
24	30	1940.00	0.11	1924.00	0.11	0.11	3.86
25	30	1880.00	0.11	1900.00	0.11	0.11	3.78
26	30	1880.00	0.11	1900.00	0.11	0.11	3.78
27	30	2076.00	0.11	2060.00	0.11	0.11	4.14
28	30	1990.00	0.11	1970.00	0.11	0.11	3.96
29	30	1830.00	0.11	1820.00	0.11	0.11	3.65
30	30	1890.00	0.11	1870.00	0.11	0.11	3.76
31	30	1740.00	0.11	1760.00	0.11	0.11	3.50
32	30	1890.00	0.11	1880.00	0.11	0.11	3.77
33	30	1800.00	0.11	1780.00	0.11	0.11	3.58
34	30	1800.00	0.11	1790.00	0.11	0.11	3.59
35	30	1770.00	0.11	1760.00	0.11	0.11	3.53
36	30	1740.00	0.11	1724.00	0.11	0.11	3.46
37	30	1760.00	0.11	1780.00	0.11	0.11	3.54
38	30	1870.00	0.11	1860.00	0.11	0.11	3.73
39	30	1830.00	0.11	1808.00	0.11	0.11	3.64
40	30	1790.00	0.11	1780.00	0.11	0.11	3.57
CU =	95.141	Ea =	99.977				
EU'=	92.908	qvar =	0.00086				

	Percent water		
Total emitters flow(L/h):		152.16	* 0.54 gr. NaCl / liter of irrigation water in barrel to make saline water with EC=1.5 mmhos/cm
Q from connected pipe (L/h):		505.2	
Q from injector =5.66%(37.2	5.659	37.2	
Total Q in the system (L/h):		657.36	
Q from main line=94.34%	94.341	620.16	
	Vqs	0.0594	

Run3:Injection saline water(39.72 L/h), Q connectedpipe 534 L/h
ECl =0.022 mmhos/cm, *ECL=1.5mmhos/cm, Air.T=20c, Water T.= 14c
Suction opened & adjusted lateral inlet pressure to 14.5-15.5 psi by increasing the pressure regulator to 33.5-34.5 psi. (Adjusted Pressure)
Pregulator (injector inlet)=33.5-34. Diff.in Press.
Pinjector outlet(lateral inlet)=14.5-· 19 psi
Pend of lateral= 9-9.5 psi

Emitter #	Timie (min)	Volume (cc) run1	ECmix. (mmhos/cm)	Volume (cc) run2	ECmix. (mmhos/cm)	Ave.ECmix. (mmhos/cm)	Average q (l/h)
1	30	2210.00	0.11	2200.00	0.11	0.11	4.41
2	30	2150.00	0.11	2130.00	0.11	0.11	4.28
3	30	1860.00	0.11	1870.00	0.11	0.11	3.73
4	30	1880.00	0.11	1890.00	0.11	0.11	3.77
5	30	2020.00	0.11	2028.00	0.11	0.11	4.05
6	30	1930.00	0.11	1930.00	0.11	0.11	3.86
7	30	1930.00	0.11	1930.00	0.11	0.11	3.86
8	30	2020.00	0.11	2016.00	0.11	0.11	4.04
9	30	1790.00	0.11	1780.00	0.11	0.11	3.57
10	30	1800.00	0.11	1800.00	0.11	0.11	3.60
11	30	2110.00	0.11	2100.00	0.11	0.11	4.21
12	30	1860.00	0.11	1870.00	0.11	0.11	3.73
13	30	1930.00	0.11	1936.00	0.11	0.11	3.87
14	30	2040.00	0.11	2050.00	0.11	0.11	4.09
15	30	1880.00	0.11	1880.00	0.11	0.11	3.76
16	30	2100.00	0.11	2104.00	0.11	0.11	4.20
17	30	1800.00	0.11	1800.00	0.11	0.11	3.60
18	30	1880.00	0.11	1880.00	0.11	0.11	3.76
19	30	2120.00	0.11	2116.00	0.11	0.11	4.24
20	30	2020.00	0.11	2024.00	0.11	0.11	4.04
21	30	2100.00	0.11	2110.00	0.11	0.11	4.21
22	30	2000.00	0.11	2010.00	0.11	0.11	4.01
23	30	1700.00	0.11	1720.00	0.11	0.11	3.42
24	30	2056.00	0.11	2050.00	0.11	0.11	4.11
25	30	1980.00	0.11	1976.00	0.11	0.11	3.96
26	30	1910.00	0.11	1900.00	0.11	0.11	3.81
27	30	2200.00	0.11	2210.00	0.11	0.11	4.41
28	30	2120.00	0.11	2110.00	0.11	0.11	4.23
29	30	1880.00	0.11	1890.00	0.11	0.11	3.77
30	30	2000.00	0.11	2016.00	0.11	0.11	4.02
31	30	1790.00	0.11	1780.00	0.11	0.11	3.57
32	30	2010.00	0.11	2020.00	0.11	0.11	4.03
33	30	1840.00	0.11	1830.00	0.11	0.11	3.67
34	30	1840.00	0.11	1836.00	0.11	0.11	3.68
35	30	1870.00	0.11	1874.00	0.11	0.11	3.74
36	30	1790.00	0.11	1800.00	0.11	0.11	3.59
37	30	1890.00	0.11	1900.00	0.11	0.11	3.79
38	30	2000.00	0.11	2000.00	0.11	0.11	4.00
39	30	1930.00	0.11	1924.00	0.11	0.11	3.85
40	30	1900.00	0.11	1900.00	0.11	0.11	3.80
CU =	94.644	Ea =	99.980				
EU'=	92.516	qvar =	0.000748				

	Percent water		
Total emitters flow(L/h):		156.33	* 0.54 gr. NaCl / liter of irrigation water in barrel to make saline water with EC=1.5 mmhos/cm
Q from connected pipe (L/h):		534	
Q from injector =5.75%(39.72	5.754	39.72	
Total Q in the system (L/h):		690.33	
Q from main line=94.24%	94.246	650.61	
	Vqs	0.0625	

Nominal Emitter flow rate = 3.78l/h
Operating M.I.S
New Emitters
Without venturi Injector
P(lateral inlet)=14.5-15.5psi
Pend of lateral= 14-14.8 psi

Emitter #	Timie (min)	Ave.Volume (cc)	Average q (l/h)	emitter Pressure at each section (psi)
1	30	2210.00	4.42	15.50
2	30	2190.00	4.38	15.50
3	30	1840.00	3.68	15.50
4	30	1860.00	3.72	15.20
5	30	2020.00	4.04	15.10
6	30	1915.00	3.83	15.10
7	30	1930.00	3.86	15.10
8	30	2060.00	4.12	15.10
9	30	1740.00	3.48	15.10
10	30	1780.00	3.56	15.10
11	30	2110.00	4.22	15.10
12	30	1830.00	3.66	15.00
13	30	1900.00	3.80	15.00
14	30	2000.00	4.00	15.00
15	30	1810.00	3.62	15.00
16	30	2050.00	4.10	15.00
17	30	1780.00	3.56	15.20
18	30	1860.00	3.72	15.00
19	30	2080.00	4.16	15.00
20	30	1980.00	3.96	14.90
21	30	2250.00	4.50	14.90
22	30	2028.00	4.06	14.90
23	30	1700.00	3.40	14.90
24	30	2200.00	4.40	14.80
25	30	1980.00	3.96	14.80
26	30	1905.00	3.81	14.80
27	30	2490.00	4.98	15.00
28	30	2090.00	4.18	14.80
29	30	1850.00	3.70	15.00
30	30	2120.00	4.24	15.00
31	30	1760.00	3.52	14.90
32	30	2170.00	4.34	15.00
33	30	1820.00	3.64	15.00
34	30	1820.00	3.64	15.00
35	30	1905.00	3.81	15.00
36	30	1770.00	3.54	14.50
37	30	2080.00	4.16	15.00
38	30	2270.00	4.54	15.00
39	30	2000.00	4.00	14.90
40	30	1988.00	3.98	14.80
CU =	92.877	Ea =	99.979	
EU'=	90.012	qvar =	0.00078	

Total emitters flow(L/h):		158.28
	Vqs	0.0870

Table A.5.49 Emitter flow variation under saline water injection (EC_L=3 mmhos/cm), average EC_m= 0.22 mmhos/cm, no-clogged condition, and **40m** lateral laid on flat terrain

Run1: No injection of saline water from the barrel
ECl =0.022 mmhos/cm, Air.T=20c, Water.T=14c
Liquid suction tube closed
Water passes through the venturi into the entire length of lateral(Q from the connection pipe 544.4 L/h)
Pregulator (injector inlet)=24.5 Diff.in Press.
Pinjector outlet(lateral inlet)=1· 10psi
Pend of lateral= 9-9.5 psi

Emitter #	Timie (min)	Volume (cc) run1	Volume (cc) run2	Average q (l/h)
1	30	2180.00	2190.00	4.37
2	30	2130.00	2140.00	4.27
3	30	1870.00	1860.00	3.73
4	30	1900.00	1880.00	3.78
5	30	2030.00	2010.00	4.04
6	30	1940.00	1940.00	3.88
7	30	1940.00	1930.00	3.87
8	30	2034.00	2010.00	4.04
9	30	1790.00	1780.00	3.57
10	30	1840.00	1820.00	3.66
11	30	2120.00	2110.00	4.23
12	30	1860.00	1850.00	3.71
13	30	1940.00	1920.00	3.86
14	30	2036.00	2030.00	4.07
15	30	1860.00	1860.00	3.72
16	30	2080.00	2080.00	4.16
17	30	1800.00	1800.00	3.60
18	30	1900.00	1880.00	3.78
19	30	2100.00	2090.00	4.19
20	30	1990.00	1980.00	3.97
21	30	2016.00	2024.00	4.04
22	30	1960.00	1960.00	3.92
23	30	1720.00	1710.00	3.43
24	30	1980.00	1980.00	3.96
25	30	1920.00	1940.00	3.86
26	30	1880.00	1900.00	3.78
27	30	2230.00	2230.00	4.46
28	30	2120.00	2110.00	4.23
29	30	1840.00	1850.00	3.69
30	30	1900.00	1920.00	3.82
31	30	1760.00	1760.00	3.52
32	30	1920.00	1940.00	3.86
33	30	1840.00	1840.00	3.68
34	30	1800.00	1810.00	3.61
35	30	1800.00	1800.00	3.60
36	30	1760.00	1760.00	3.52
37	30	1800.00	1800.00	3.60
38	30	1900.00	1900.00	3.80
39	30	1860.00	1860.00	3.72
40	30	1820.00	1810.00	3.63
CU =	94.786	Ea =	99.981	
EU'=	92.693	qvar =	0.000723	
Total emitters flow(L/h):			154.23	
Q from connected pipe (L/h):			544.5	
Total Q in the system(L/h):			698.73	
		Vqs	0.0642	

Run2: With injection of saline water (41.75 l/h) from the barrel
ECl =0.022 mmhos/cm, *ECL=3mmhos/cm, Air.T=20c, Water T.= 14c
Liquid suction 41.75 l/h,Q from connected pipe 507.2 L/h
Water mixed (ECmix = 0.27mmhos/cm) from main hose and venturi injector, flow into the lateral (Not adjusted pressure)
Pregulator (injector inlet)=25-26 psi Diff.in Press.
Pinjector outlet(lateral inlet)=12-12.5psi 13 25psi
Pend of lateral= 8-8.5 psi (Not adjusted pressure)

Emitter #	Timie (min)	Volume (cc) run1	ECmix. (mmhos/cm)	Volume (cc) run2	ECmix. (mmhos/cm)	Ave.ECmix. (mmhos/cm)	Average q (l/h)
1	30	2160.00	0.20	2140.00	0.20	0.2	4.30
2	30	2100.00	0.20	2080.00	0.20	0.2	4.18
3	30	1860.00	0.20	1860.00	0.20	0.2	3.72
4	30	1880.00	0.20	1880.00	0.20	0.2	3.76
5	30	2000.00	0.20	1990.00	0.20	0.2	3.99
6	30	1920.00	0.20	1910.00	0.20	0.2	3.83
7	30	1920.00	0.20	1910.00	0.20	0.2	3.83
8	30	1990.00	0.20	1980.00	0.20	0.2	3.97
9	30	1780.00	0.20	1780.00	0.20	0.2	3.56
10	30	1840.00	0.20	1820.00	0.20	0.2	3.66
11	30	2000.00	0.20	1980.00	0.20	0.2	3.98
12	30	1830.00	0.20	1820.00	0.20	0.2	3.65
13	30	1900.00	0.20	1910.00	0.20	0.2	3.81
14	30	1980.00	0.20	1980.00	0.20	0.2	3.96
15	30	1840.00	0.20	1840.00	0.20	0.2	3.68
16	30	1980.00	0.20	1990.00	0.20	0.2	3.97
17	30	1800.00	0.20	1790.00	0.20	0.2	3.59
18	30	1860.00	0.20	1860.00	0.20	0.2	3.72
19	30	1960.00	0.20	1960.00	0.20	0.2	3.92
20	30	1900.00	0.20	1900.00	0.20	0.2	3.80
21	30	1850.00	0.20	1840.00	0.20	0.2	3.69
22	30	1800.00	0.20	1800.00	0.20	0.2	3.60
23	30	1680.00	0.20	1680.00	0.20	0.2	3.36
24	30	1820.00	0.20	1820.00	0.20	0.2	3.64
25	30	1800.00	0.20	1790.00	0.20	0.2	3.59
26	30	1790.00	0.20	1790.00	0.20	0.2	3.58
27	30	2036.00	0.20	2000.00	0.20	0.2	4.04
28	30	1910.00	0.20	1900.00	0.20	0.2	3.81
29	30	1740.00	0.20	1720.00	0.20	0.2	3.46
30	30	1760.00	0.20	1750.00	0.20	0.2	3.51
31	30	1700.00	0.20	1690.00	0.20	0.2	3.39
32	30	1770.00	0.20	1770.00	0.20	0.2	3.54
33	30	1730.00	0.20	1720.00	0.20	0.2	3.45
34	30	1700.00	0.20	1700.00	0.20	0.2	3.40
35	30	1660.00	0.20	1650.00	0.20	0.2	3.31
36	30	1640.00	0.20	1640.00	0.20	0.2	3.28
37	30	1660.00	0.20	1640.00	0.20	0.2	3.30
38	30	1740.00	0.20	1740.00	0.20	0.2	3.48
39	30	1700.00	0.20	1700.00	0.20	0.2	3.40
40	30	1660.00	0.20	1660.00	0.20	0.2	3.32
CU =	94.395	Ea =	99.979				
EU'=	91.600	qvar =	0.000792				
		Percent water					
Total emitters flow(L/h):			147.03	* 1.14 gr. NaCl / liter of irrigation water in barr			
Q from connected pipe (L/h):			507.2	to make saline water with EC=3 mmhos/cm			
Q from injector =6.38%(41.7		6.382	41.75				
Total Q in the system (L/h):			654.23				
Q from main line=93.62%		93.618	612.48				
		Vqs	0.0682				

Run3:Injection saline water(45.56 L/h), Q connectedpipe 562.2 L/h
ECl =0.022 mmhos/cm, *ECL=3mmhos/cm, Air.T=20c, Water T.= 14c
Suction opened & adjusted lateral inlet pressure to 14.5-15.5 psi by increasing the pressure regulator to 33.5-34.5 psi. (Adjusted Pressure)
Pregulator (injector inlet)=33.5-34. Diff.in Press.
Pinjector outlet(lateral inlet)=14.5-' 19 psi
Pend of lateral= 9-9.5 psi

Emitter #	Timie (min)	Volume (cc) run1	ECmix. (mmhos/cm)	Volume (cc) run2	ECmix. (mmhos/cm)	Ave.ECmix. (mmhos/cm)	Average q (l/h)
1	30	2200.00	0.20	2180.00	0.20	0.2	4.38
2	30	2120.00	0.20	2140.00	0.20	0.2	4.26
3	30	1850.00	0.20	1860.00	0.20	0.2	3.71
4	30	1880.00	0.20	1900.00	0.20	0.2	3.78
5	30	2010.00	0.20	2020.00	0.20	0.2	4.03
6	30	1920.00	0.20	1940.00	0.20	0.2	3.86
7	30	1920.00	0.20	1930.00	0.20	0.2	3.85
8	30	2020.00	0.20	2020.00	0.20	0.2	4.04
9	30	1780.00	0.20	1785.00	0.20	0.2	3.57
10	30	1840.00	0.20	1810.00	0.20	0.2	3.65
11	30	2130.00	0.20	2100.00	0.20	0.2	4.23
12	30	1840.00	0.20	1850.00	0.20	0.2	3.69
13	30	1920.00	0.20	1930.00	0.20	0.2	3.85
14	30	2020.00	0.20	2030.00	0.20	0.2	4.05
15	30	1850.00	0.20	1850.00	0.20	0.2	3.70
16	30	2100.00	0.20	2080.00	0.20	0.2	4.18
17	30	1790.00	0.20	1800.00	0.20	0.2	3.59
18	30	1880.00	0.20	1900.00	0.20	0.2	3.78
19	30	2120.00	0.20	2100.00	0.20	0.2	4.22
20	30	1990.00	0.20	1990.00	0.20	0.2	3.98
21	30	2040.00	0.20	2010.00	0.20	0.2	4.05
22	30	2000.00	0.20	1960.00	0.20	0.2	3.96
23	30	1720.00	0.20	1700.00	0.20	0.2	3.42
24	30	2040.00	0.20	1980.00	0.20	0.2	4.02
25	30	1960.00	0.20	1940.00	0.20	0.2	3.90
26	30	1900.00	0.20	1900.00	0.20	0.2	3.80
27	30	2200.00	0.20	2200.00	0.20	0.2	4.40
28	30	2100.00	0.20	2120.00	0.20	0.2	4.22
29	30	1860.00	0.20	1840.00	0.20	0.2	3.70
30	30	1940.00	0.20	1940.00	0.20	0.2	3.88
31	30	1780.00	0.20	1760.00	0.20	0.2	3.54
32	30	1960.00	0.20	1940.00	0.20	0.2	3.90
33	30	1860.00	0.20	1820.00	0.20	0.2	3.68
34	30	1820.00	0.20	1800.00	0.20	0.2	3.62
35	30	1840.00	0.20	1800.00	0.20	0.2	3.64
36	30	1780.00	0.20	1760.00	0.20	0.2	3.54
37	30	1830.00	0.20	1800.00	0.20	0.2	3.63
38	30	1920.00	0.20	1900.00	0.20	0.2	3.82
39	30	1890.00	0.20	1840.00	0.20	0.2	3.73
40	30	1830.00	0.20	1820.00	0.2	0.2	3.65
CU =	94.766	Ea =	99.981				
EU'=	92.810	qvar =	0.000727				
			Percent water				
Total emitters flow(L/h):			154.50	* 1.14 gr. NaCl / liter of irrigation water in barr			
Q from connected pipe (L/h):			562.2	to make saline water with EC=3 mmhos/cm			
Q from injector =6.36%(45.56		6.357	45.56				
Total Q in the system (L/h):			716.70				
Q from main line=93.64%		93.643	671.14				
		Vqs	0.0632				

Nominal Emitter flow rate = 3.78l/h
Operating M.I.S
New Emitters
Without venturi Injector

P(lateral inlet)=14.5-15.5psi
Pend of lateral= 14-14.8 psi

Emitter #	Timie (min)	Ave.Volume (cc)	Average q (l/h)	emitter Pressure at each section (psi)
1	30	2210.00	4.42	15.50
2	30	2190.00	4.38	15.50
3	30	1840.00	3.68	15.50
4	30	1860.00	3.72	15.20
5	30	2020.00	4.04	15.10
6	30	1915.00	3.83	15.10
7	30	1930.00	3.86	15.10
8	30	2060.00	4.12	15.10
9	30	1740.00	3.48	15.10
10	30	1780.00	3.56	15.10
11	30	2110.00	4.22	15.10
12	30	1830.00	3.66	15.00
13	30	1900.00	3.80	15.00
14	30	2000.00	4.00	15.00
15	30	1810.00	3.62	15.00
16	30	2050.00	4.10	15.00
17	30	1780.00	3.56	15.20
18	30	1860.00	3.72	15.00
19	30	2080.00	4.16	15.00
20	30	1980.00	3.96	14.90
21	30	2250.00	4.50	14.90
22	30	2028.00	4.06	14.90
23	30	1700.00	3.40	14.90
24	30	2200.00	4.40	14.80
25	30	1980.00	3.96	14.80
26	30	1905.00	3.81	14.80
27	30	2490.00	4.98	15.00
28	30	2090.00	4.18	14.80
29	30	1850.00	3.70	15.00
30	30	2120.00	4.24	15.00
31	30	1760.00	3.52	14.90
32	30	2170.00	4.34	15.00
33	30	1820.00	3.64	15.00
34	30	1820.00	3.64	15.00
35	30	1905.00	3.81	15.00
36	30	1770.00	3.54	14.50
37	30	2080.00	4.16	15.00
38	30	2270.00	4.54	15.00
39	30	2000.00	4.00	14.90
40	30	1988.00	3.98	14.80
CU =	92.877	Ea =	99.979	
EU'=	90.012	qvar =	0.000776	
Total emitters flow(L/h):			158.28	
			Vqs	0.0870