# INFILTRATION AND WATER ADVANCE STUDIES UNDER SURGE FLOW FURROW IRRIGATION

By

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## THESIS

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requirement for the degree

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# DECLARATION

I hereby declare that this thesis entitled **"Infiltration and Water Advance Studies under Surge Flow Furrow Irrigation"** is a bonafide record of research work done by me during the course of research and that the thesis has not previously formed the basis for the award to me of any degree, diploma, associateship, fellowship or other similar title of any other University or Society.

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Certified that this thesis entitled **"Infiltration and Water Advance Studies under Surge Flow Furrow Irrigation"** is a record of research work done independently by **Miss Rema, K.P.** under my guidance and supervision and that it has not previously formed the basis for the award of any degree, fellowship or associateship to her.

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AC - Alternating Current
Agric. - Agricultural
ASAE - American Society of Agricultural Engineers
ASCE - American Society of Civil Engineers
cm - centimetre(s)
cm$^2$ - Square centimetre(s)
cm/hr - Centimetre per hour
cm/sec$^2$ - Centimetre per square second(s)
CR - Cycle Ratio
d.c - direct current
d.f - degrees of freedom
*et al.* - and others
fig. - figure
ft - feet
gal/m - gallon(s) per minute
gm - gram
ha - hectare(s)
ICAR - Indian Council of Agricultural Research
IS - Indian Standard(s)
J. - Journal
KAU - Kerala Agricultural University
KCAET - Kelappaji College of Agricultural Engineering and Technology

kg/m$^3$ - kilogram per cubic metre

lab. - laboratory

lps - litres per second

lps/m - litres per second per metre

l/min/m - litres per minute per metre

m - metre(s)

Manage. - Management

min - minute(s)

m$^3$ - cubic metre(s)

mm - millimetre(s)

M.S - Mild steel

No. - Number

NCRDC - Northern Colorado Research Demonstration Centre

P - Probability

pp - pages

Proc. - Proceedings

PVC - Poly Vinyl Chloride

S - Surge

USDA-ARS - United States Department of Agriculture - Agricultural Research Service

VSDA-SCS - United States Department of Agriculture - Soil Conservation Service

USU - Utah State University

WRRP - Western Regional Research Project

WSU - Washington State University

' . minute(s)

" - Second(s)

: - is to

/ - per

% - per cent

° - degree

# Introduction

# INTRODUCTION

Human efforts to fight against the nature's niggardiness in the supply of water to agriculture, take the form of irrigation in the first attempt, the main function of which is to nullify the adverse impact of irregular, uneven and inadequate rainfall.

Even with an annual rainfall slightly higher than the global mean, the erratic distribution of rainfall, its uncertainity of occurrence, marked by prolonged dry spells and aberration in the time of commencement and withdrawal, offers serious constraints to agriculturists in India. This explains the dependence of agriculture, on artificial irrigation, and gives an insight into the nature of the country's water resources. There is the urgent need that the available water resources are utilized in the best manner possible, and the development of technology for augmenting the water resources through new methods, such as artificial recharge, recycling of water, desalinization of sea water, and weather modification should also be given constant attention. The expansion of irrigation facilities in order to ensure timely and adequate water supply, has, ever since the inception of planning, been an extremely important means of bringing about agricultural development in the country.

Irrigation, like any other agricultural tool has to be handled properly in order to maximise the benefits and in some instances, to avoid causing damage. The problems can obviously be caused by incorrect scheduling, but they can also be caused through bad control and lack of uniformity, which in certain instances, are interrelated. A lot of time and effort has been devoted to determining accurate scheduling methods but the application methodology seems to have been relegated to the side lines. This is a mistaken approach and efficient control is vital in order to conserve resources, to increase crop quality and quantity and to obtain the maximum benefits from accurate scheduling.

In the surface irrigation Systems, water is directly applied to the surface of the soil and is spread by gravity flow, incidental to the slope of the land. There are several methods in this system, the common being flooding from a ditch, check basin, ring and basin, border strip and furrow. In furrow irrigation, water is applied to the field in furrows between the two ridges and the top of the ridge is not directly wetted. The furrows can be laid along the slope for gently sloping fields and for slopes exceeding three per cent, they are laid on graded contours.

With furrow irrigation on steep slopes and in heavy soils, the tail water in the furrow would accumulate during irrigation and even spill over its boundaries, thus viciating the storage of irrigation water and its uniform distribution. Reducing the flow into a furrow when the advance phase reaches the tail of the furrow, usually reduces tail water losses and increases application efficiency. This process of scuttling the initial stream flow is known as cut back flow. The research at Utah State University by Stringham and Keller in 1979 proposed that it would be more practical to achieve cut back for furrow irrigation with gated pipe by cycling the inflow rather than by partially closing the gate supplying each furrow. When this technique was tested, it was found that less water was required to complete an advance if the inflow were cycled during the advance phase. This was how the innovation of surge irrigation entered into the scene of surface irrigation practices.

Today, surge flow is a management practice that can be applied to many surface irrigated conditions. By definition, surge flow is the intermittent application of irrigation water to irrigation pathways creating a series of 'ON' and 'OFF' periods of constant or variable duration. The sum of these cyclic applications termed "hydraulic surges" is designed to satisfy the antecedent soil moisture deficit. Studies have highlighted the effect that applying water intermittently to a field surface during the advance phase, altered the soil suggesting that the surface layer permeability has been reduced. The effect was widely variable depending on soil composition, prior wetting history, surface water velocities and duration of ON-OFF periods. Although, the exact mechanisms were not discerned, surge flow had the potential for significantly improving the performance and versatility of surface irrigation systems.

Primary causes of non-uniform water application under surface irrigation are spatial variability of infiltration characteristics and non-uniform intake opportunity time. Surge irrigation, characterized by cycled water application, reduces infiltration on many soils. Surging may also homogenize spatially varying infiltration properties and increase the uniformity of application. This gives the irrigator, a less capital and energy intensive alternative for reducing water losses than a pressurized irrigation system. This progressive step in surface irrigation technology, appears to be beneficial in most situations, even in soils with low intake rates. In such cases, a continuous stream for advance and surge for post advance phases may be advantageous. Surge flow can usually provide benefits either by improving the advance time or controlling the tail water. The goal is to minimise the water loss to deep percolation and tail water, and to satisfy the requirement for water within the root zone.

To effectively design and operate surf irrigation systems, the infiltration behaviour of the .1 must be accurately quantified. Infiltration behaviour subject to both temporal and spatial variability. Soil :ure has a major influence on the form of the infiltration characteristic and spatial variation in texture can be large. The determination of a soil's infiltration characteristics by traditional point measurements to account for these variations is laborious and time consuming. To overcome these problems, engineering research has focussed on the evaluation of infiltration over large areas to obtain a spatially integrated measure of infiltration. Data collected during an irrigation event improves the ease with which infiltration can be predicted and indicate where, changes in irrigation management can increase irrigation efficiency. This is particularly important in surge irrigation because the sediment transport and surge flow infiltration are affected significantly by the dewatering of the furrow between surges.

Furrow irrigation is a complex phenomenon, mainly due to the non-uniform medium of soil upon which the water is transported. With surge irrigation the phenomenon is further complicated by the multiple advances and the effect of alternate wetting and dewatering on the soil's infiltration characteristics. The management parameters for surge irrigation include the number of surges, ON-times, OFF-times, furrow stream flow rate, cut back time, cut back method, and total irrigation time. The multitude of possible configurations make optimization of water use, a complex problem. In one and the same irrigation, varying cycle times may have to be worked out for a precise surge flow technology. Also, optimum values of cycle times, cycle ratios, number of surges, stream flow rate etc. need be worked out for each and every soil over different ranges of topographical slope. Any sort of erratic dealing in respect of the parameters might result in insurmountable consequences, than the aberrations encountered in the continuous flow systems. Though appreciable studies on surge irrigation have been made on previous occasions, they are all location specific in view of the involvement of certain local parameters. To elucidate on the behaviour and performance of surge irrigation, in the sandy loam soils of Tavanur region, the present study was conducted with the following specific objectives.

1. To design and develop a surge flow furrow irrigation system.

2. To test the system for 102 m long furrows in the instructional farm of K.C.A.E.T, Tavanur.

3. To study the infiltration characteristics of water under surge flow.
4. To study the advance and recession trajectories of water under surge flow.
5. To determine the optimum stream size and cycle ratio for best efficiency.
6. Verification of surface irrigation hydraulic models with the help of field data.

# Review of Literature

# REVIEW OF LITERATURE

Competitive pressures from urban, industrial and energy related demands had already resulted in transfer of water from the agricultural sector with a concomitant reduction of irrigated acreage. Surge flow, with its potential for increased irrigation efficiency could help make more efficient use of water resources, thus accommodating other uses, with minimal impact on agricultural production. Several investigators have demonstrated that cycling the application of water in surface irrigation makes it possible to complete the advance phase with less water than required by continuous application, thus increasing uniformity and application efficiency. This so called "surge effect" is the result of reduced intake rate, improved hydraulic section for the previously wetted portions of the furrow, or a combination of both.

## 2.1 Surge irrigation

The concept of surge flow was introduced in the 1979 Irrigation and Drainage speciality conference of the American Society of Civil Engineers. The report was a preliminary discussion of a promising automating technique for achieving cutback in furrow Irrigation. The five years of study under the Utah regional project greatly increased the body of knowledge about surge flow. A detailed review of the work done by earlier researchers in the field of surge irrigation, is presented in this chapter.

### 2.1.1 Conceptual development

Stringham and Keller (1978) attempted to develop a furrow cut-back system, by means of a reduction in furrow flow rate in the post-advance phase, which inturn led to the development of surge irrigation. They concluded that irrigation valves could be operated more effectively in an ON-OFF mode rather than in fully ON, partially OFF modes to obtain cut-back flow streams (Stringhan and Keller, 1979). To obtain cut back flow, the valves were cycled ON and OFF in a manner that achieved 'time averaged' cut back flow without changing instantaneous discharge. A continuous flow of 0.8 lps was compared with two cycled flows of the same instantaneous discharge in both wheel and non-wheel furrows. The advance rates in the cycled flow furrows were about 30 to 40 per cent faster. In one test 33 per cent less water was required to wet the entire length of furrow than with continuous flow. They coined the term "surge flow" to describe the regime of cycling furrow inflows.

Utah State University (1979) conducted field experiments to measure the differences between conventional continuous flow irrigation and surge flow at the same average furrow flows. A flow rate of 0.6 lps was used for the average flow streams with 10 min cycle times in 600 ft furrows. Cycle ratios of one-third, one-half and two-thirds were tested, resulting in instantaneous furrow streams of 0.95 lps, 1.26 lps, and 1.89 lps respectively. A considerable advantage was shown for the surge-flow streams. The average advance time for the continuous flow exceeded 400 min. Whereas the average time for the surge flow stream was about 130 min.

Allen et al. (1980) conducted field trials with a 600 ft long system comprising of piping, valves and controls developed the preceding year. Four tests were conducted in late June and early July with a cycle time of 10 minutes for three surge treatments per test and continuous flow. Cycle-ratios of one-third, one-half and two-thirds were tested with time-averaged discharge of 10 gal/m. An application efficiency of 87 per cent under surge flow and a 9 per cent performance for the continuous flow was obtained. Although, not all the tests were this profound, the promise of surge flow was certainly evident.

USU experiments (1980) involved tests with a constant instantaneous flow of 0.32 lps. Again, continuous flow was compared with surge flow for a large combination of ON-OFF times. The ON-times were 5, 10, and 20 min with OFF-times of 5, 10, 20 and 40 min. Field data indicated that surging even with lower instantaneous flow rates still reduced the advance time. The runoff hydrographs indicated that infiltration rates were significantly lower for the surge-flow regime than for continuous flow. Also surge flow required from 14 to 47 per cent less water to complete the advance.

Coolidge (1981) installed the surge flow system at another USU field having the same soil type but having only 100 m furrows on a 1 per cent slope. The primary objectives were to substantiate the effect of surging on spatial variability and to determine if possible, the relative importance of ON and OFF times. The spatial variability was again significantly lower under a surged regime than under continuous flow. The standard deviations were 53 to 86 per cent lower. The basic intake rate following several surges was approximately one-fourth the value under the continuous flow regime.

Podmore _et_ _al_. (1982) and Walker _et_ _al_. (1982) have supplemented the early field evaluation by numerous other tests on surge flow under a wide range of field conditions. The results have generally been mixed and a few are as significant as those at USU in 1979 and 1980. The following conclusions can be derived from field studies to date:

1. Intermittent flow over the field surface significantly reduces intake. The effect of surging is probably associated with the accelerated development of a thin surface seal comprised of very fine soil particles created by the water movement. During the drainage period, the build up of negative pressure consolidates this thin seal, thereby reducing the permeability.

2. By reducing infiltration rates, it becomes easier to complete the advance phase. Advance rates are very sensitive to the discharge, so that as surge flow reduces infiltration, the hydraulic performance of the system improves.

3. The surge flow regime reduces the temporal and spatial variability exhibited in advance rates. Variations in the field's basic intake rate were often statistically insignificant. The surge flow effect in this regard may therefore be attributed to the lower time required to reach a steady or basic intake rate.

### 2.1.2 Principles of intake rate reduction

Mechanisms by which surge irrigation affect infiltration as proposed by many researchers include:

1. Redistribution of infiltrated water in the soil profile.

2. Surface soil consolidation, as negative hydraulic gradients develop in the soil water during flow interruption.
3. Surface sealing caused by particle migration and reorientation.
4. Air entrapment
5. Filling of cracks, which form in the furrow bed when flow is interrupted, by bed load when water re-enters the furrows.
6. Sealing of the furrow bed as water remaining in the furrow after each flow interruption infiltrates and deposits its fine sediment in large pores or as a fine seal on absorbing surfaces.
7. More complete disintegration of soil particles in the wetted perimeter as a result of faster wetting by the advancing water front and
8. Hydration and expansion of clay particles.

During infiltration, the hydraulic gradient inducing infiltration gradually reduces from some relatively high initial value (due primarily to capillary forces) to nearly unity (due to gravitational forces). During the OFF period of surge irrigation, redistribution of water continues within the soil profile. Soil water tension increases in the soil near the surface and as the wetting front continues to move down, through the soil profile, the water content in the soil above may be reduced. On subsequent rewetting of the soil, the hydraulic gradient is initially large, than at the end of the previous wetting cycle and the conductivity may be reduced. Meanwhile the wetting front continues to move downward. As reinfiltration proceeds, the location of the wetting front has progressively more influence on infiltration rate. Assuming that the tension behind the wetting front is relatively constant, this downward movement of the wetting front during the OFF-time reduces hydraulic gradient later in the surge cycle as the potential differences is spread over a progressively larger elevation difference.

Two phenomena may be included under the category of air entrapment. The first is trapping air between the water layer of successive surges. The second phenomenon is the isolation of large air-filled pores upon rewetting of the soil which blocks liquid-phase flow through those pores that most significantly affect hydraulic conductivity of the soil. Air entrapment in the soil pores reduce intake under surge flow due to differences in conductivity and hydraulic gradients near the wetting front and the rewetting front. The disintegration of soil aggregates, from slaking, clay hydration, or hydraulic impact/shear forces occur during irrigation. This disintegration produces a surface layer of reduced hydraulic conductivity, and is probably, a major reason, why infiltration rates invariably decrease following the first irrigation after tillage. Whether surge irrigation produces a different pattern of migration of these particles during an irrigation is less obvious. Also, consolidation of soil as pore pressure tension increases, is a well-known phenomenon in soil mechanics. Undoubtedly, each of these phenomena, and probably others, contributes to the reduction in infiltration rate attributed to surge irrigation. The relative effect of each probably depends on physical and chemical characteristics of the soil matrix.

Allen (1980) theorized that soil particles were oriented in a plate-like fashion upon dewatering. However, most studies have indicated that there is a greater reduction of infiltration in coarse-textured soils, ie., soils with a smaller fraction of plate-like clay particles.

Lep (1981) conducted laboratory column studies, and found that both air-tight and air-release columns subjected to intermittent ponding had high infiltration rates than columns subjected to continuous ponding, indicating that intermittent applications provide more opportunity for air to escape the infiltration. He presented data for four different soils which showed that, as negative pressures were applied to previously saturated loam, silty clay loam, silt loam and sandy loam soils, the resulting increase in soil bulk density was accompanied by decreases in saturated hydraulic conductivity. They concluded that negative hydraulic gradients which accompany intermittent water applications will increase the instantaneous intake rate of the soil unless the soil's bulk density increases. However, if the bulk density increases during the off-time due to soil consolidation, such that the hydraulic conductivity is decreased enough, to more than offset the increased hydraulic gradient, the effect of surge flow will be a net reduction in infiltration rate.

Kemper et al. (1988) obtained that the high infiltration rate reduction was due to (i) high shear rates late in the season when soil stability was high and (ii) furrows which had been compacted with tractors or other equipment, had low continuous flow infiltration rates. He concluded that, the mechanisms causing reduction in infiltration include (i) consolidation of soil in the furrow bed as tension develops in the soil water during flow interruption (ii) filling of cracks, in the furrow bed formed during flow interruption by bed load, when water re-enters the furrow (iii) surface sealing of the furrow bed as water left in the furrow with each flow interruption, enters the soil and deposits its fine sediment in large pores or forms a fine seal on absorbing surfaces and (iv) more complete disintegration of soil particles in the wetted perimeter as a result of faster wetting.

### 2.1.3 Equipment and controls for surging

Farm irrigation systems must be automated to fully utilize the surge flow technique. Automated equipment and control facilities include gating and valving devices, timers, controllers and distribution systems. Some automated valves and equipment that had been developed or used prior to project initiation were modified or equipped with suitable controllers to accommodate surge irrigation. Research conducted by the Utah research participants contributed to a better understanding of the surge flow process and its potential to increase irrigation efficiency and to help solve problems associated with surface irrigation. This background, coupled with the potential water and cost savings to farmers provided strong economic incentives for the commercial development of automated surge flow equipment.

Surge flow irrigation systems may be separated into three categories, each of which uses equipment suited for that particular system.

(i) Split-set gated pipe systems use conventional gated pipe in a split-set design to distribute water to individual furrows. The gated pipeline for one surge set is divided into two blocks of furrows of equal width with an automated surge valve between the two blocks at the centre of the pipeline. The valve is constructed in a tee configuration and water flow is diverted alternately from one side or section of pipe to the other. Water is normally supplied to the valve from an underground pipeline through an alfalfa valve and hydrant or by a portable supply pipe on the surface.

(ii) Single pipe systems use one pipeline for both the supply pipe to convey water between irrigation sets and to distribute water through outlets in the pipe to individual furrows. A single furrow valve control system uses individually automated outlets, one for each furrow, operated simultaneously in groups or blocks. Individual valves attached to the pipe at each furrow outlet are operated pneumatically. Cablegation is a relatively new system that uses an oversized single pipe line laid on a precise grade; so that water flows below the pipe outlets. A moving plug inserted into the pipe and attached to a cable, checks the water and causes it to flow from the outlets. The cable system can be modified to achieve surge flow, or surging can be accomplished by moving the plug rapidly across the field several times. Modified gated pipe systems use conventional gated pipe with attachments or modifications to close the flow openings in the pipe by automatically moving the gates or by closing the gated openings with a flexible membrane or liner inside the pipe. Surging is accomplished by alternately opening and closing the flow openings in two or more sections of the pipeline.

(iii) Open channel systems: Researchers developed equipment and techniques to achieve surge flow from open channels, however, commercial equipment for these systems is not presently available. An automatic check gate is located between two consecutive bays and alternately releases water to the downstream bay and checks the water in the upstream bay for surge irrigation. In case of borders, two types of control structures were used to accumulate water from small supply streams for surging borders. Water is accumulated in the flow channel, which acts as a temporary storage reservoir from which the water is released as a larger flow over a short time period into borders or basins. Each water release constitutes one surge. The supply streams must be relatively small.

Surge irrigation research at the USDA-ARS Snake River Conservation Research Centre of Idaho largely concerned the development of valves and other control devices for automating and semi-automating surface irrigation systems. Air and water operated irrigation valves were developed for gated pipe systems that can be cycled repeatedly when controlled by appropriate timers. Battery powered pilot valves and mechanical, electro mechanical or electronic timers are used. The water operated valves which are activated with water from the pipeline, may be too slow for short cycle times. However air operated valves are well suited for this application and may use either a portable or permanent air supply.

Haise <u>et</u> <u>al</u>. (1965) has developed pneumatically operated valves for irrigation. He has designed an inflatable '0' ring or doughnut shaped pillow mounted beneath an alfalfa valve lid for the control systems in surge irrigation. He has developed a pillow disk valve which is a single furrow valve for individual gated pipe outlets, attached to gated pipe lines in places of regular pipe gates.

Garton (1966) made the first attempt to automate open ditch irrigation systems. His automatic furrow cutback system consisted of level bays fitted with tubes which extended through the ditch to allow for the discharge of water. An automatic check dam was placed at the end of each bay. Irrigation began in the bay, which had the tubes at the highest elevation. When the furrows for that bay had been irrigated, the check dam was removed. The checks were automated by using mechanical timers which released a lever mechanism, this in turn caused the check dam to collapse, sending the water down the ditch to the next bay.

Flschabach and Godding (1971) attempted to automate surface irrigation by using irrigation valves on buried pipe lines. The automated surface irrigation valve was connected to riser on the buried pipeline. The valve consisted of a casing and a nylon reinforced butyl rubber diaphragm. Air pressure was used to inflate the diaphragm, thus stopping the flow of water. The movement of the diaphragm was controlled by a three-way valve.

Humpherys and Stacey (1975) experimented with water inflatable bladders. One such valve consisted of a housing with a modified small tire inner tube bladder. Water in the pipeline filled the bladder, causing it to expand and seal off the flow area. Draining the bladder allowed water to flow out. A pilot valve was responsible for the filling and emptying of the bladder. Different bladders for varying system pressures were developed.

Haise et al. (1980) devised a tip-down check gate to seat in a trapezoidal concrete lined ditch. The gate was pivoted at the top and counter weighted to maintain its normally open position. A plastic hydraulic cylinder was used to open the gate. They also attempted to automate buried pipelines using inflatable pneumatic O-rings. The same authors developed a pillow disk valve for pipeline risers. Compressed air was used in both cases to operate the valves. They tried to modify pneumatic O-ring at a turnout inlet to control furrow discharge. Butterfly valves and modified butterfly valves were tested, as well. High pressure convoluted cushions and pneumatic pillows were also tried to achieve the desired results.

Northern Colorado Research Demonstration Centre (NCRDC) (1981) conducted surge irrigation trials in collaboration with USU. Before irrigation season, a surge controller for previously developed individual furrow valves for gated pipe was developed. The controller provided a variable cycle time of 1 to 60 min in 1 min increments and with a cycle ratio of 0.5. Switching solenoid valves controlled two banks of pneumatically operated furrow valves. Activation of the valve inflated a pillow that closed off flow to the furrow. An adjusting plot allowed the flow to be set for each furrow.

Malano . (1982) suggested that some of the existing timer controlled systems fitted with multiple cycle controllers have the potential to be adopted for use in surge irrigation. Automated surge flow irrigation requires both timer controlled outlet structures and water sensors to cut off irrigation supply. The only automatic system that is commercially available for surge flow in border irrigation consists of a typical butterfly valve which allows the flow to be cycled between two adjacent borders. This device is used in pipeline systems and does not have automatic flow shut-off control. Water application is limited to cycle ratios of 0.5 i.e., ratio of ON-time to cycle-time length. An automatic system for surge flow in border irrigation would require to integrate both, the capacity to handle cycled applications and automatic shut-off. Systems currently available in the market can perform only one of these functions.

Humpherys (1983) used butterfly valves in gravity pipeline irrigation distribution systems. These valves could be operated using springs or pneumatic methods. Air cylinders or rotary actuators were used to operate the butterfly valves. A four-way pilot valve was used to apply air-pressure to either one side or the other of the butterfly valve. He suggested using solenoid pilot valves in conjunction with the double acting air cylinders or rotary actuators. The battery powered solenoid valves, used to operate the pilot valve, normally require an electrical impulse rather than a continuous supply of electricity. This electrical impulse can be obtained through the discharging of a capacitor. Humpherys used 12 volt AC solenoids which operated on the dc voltage for the pulsing application. Mechanical and electronic timers were used to control the automated valves.

Kemper et al. (1985) has found a new system called cablegation' at the soil and water management research unit of agricultural research, Kimberly. This uses an oversized single pipeline laid on a precise grade, so that water flows below the pipe outlets. A moving plug inserted into the pipe and attached to a cable, checks the water and causes it to flow from the outlets. Surging can be accomplished by moving the plug several times.

Humpherys (1986) has developed a gated pipe with tube liner inside and equipped with automated diverter valves. The diverter valves direct water either through the tube liner to downstream pipe sections where water is distributed through the pipe gates. Surging is accomplished by alternating positions of diverter valves located at the upstream end of the two sets such that irrigation is alternatively shifted from one pipe section to another.

### 2.1.4 Evaluation for optimisation and management

Although most of the research and publicity about surge irrigation has stressed the potential for increasing the advance rates, several other performance factors may justify implementation of surge irrigation.

Stringham and Keller (1979) conducted research at USU on sandy loam soils and obtained a several-fold increase in advance rates with surge flow. In many areas, the potential to reduce runoff by cycling inflows to achieve a time-averaged cutback flow rate in the post advance phase may be more important than the ability to increase the advance rate. This was of course the original goal of Stringham and Keller. Reducing the volume of water required to complete an advance resulted in more uniform infiltration along the furrow length, thus potentially improving water use efficiency.

USU (1980) experimented surge flow with instantaneous rates of 0.32 lps and cycle times of 5, 10 and 20 minutes. Field data have indicated that surge flow required substantially less value to complete the advance. It required from 14 to 47 per cent less water.

Bishop et al. (1981) conducted field tests on a silt loam soil using variable cycle time and ratio. The stream advance under surge flow conditions in non-wheel tract furrows was three to four times faster than continuous flow. In 1981, the field studies also included a new furrow infiltrometer developed at Utah State University. The data clearly indicated that surge flow reduced the intake rates, but did not identify the specific processes responsible.

NCRDC (1981) conducted tests on a 500 m long field of 0.6 per cent slope. Corn was grown in the silt loam soil and two surge treatments were compared with a conventional continuous flow irrigation. For the first three irrigations, the instantaneous flow rate per furrow was set at 1.9 lps, the design flow for continuous irrigation. The continuous flow advanced faster than the 60 minute surge cycle and somewhat faster than that of the 20 minute cycle. For the last three irrigations, the surge instantaneous rates remained at 1.9 lps while the continuous flow furrow discharge was reduced to 0.95 lps. Under these conditions, the 60 minute cycle surge flow advanced faster than continuous flow; but the 20 minute cycle treatment was still slower than the continuous flow.

WSU (1981) conducted three different experiments concerning surge flow at the irrigated Agriculture Research and Extension Centre at Prosser. One experiment involved four tree rows in a mature cherry orchard and the other two were conducted in newly made furrows. With furrow inflows of 0.16 lps and 0.22 lps, slope of 2 per cent and irrigation runs of 180 m, experiments were done for a cycle time ranging from 30 min to 130 minutes. Sediment yields were negligible, application efficiencies exceeded 80 per cent in all cases and neutron probe data showed high uniformity of application.

Preliminary field tests in 1981 near Twinfalls studied the feasibility of using surge flow with an automated system to minimize variability of soil intake rates during the first irrigations of the season. Researches at Utah and Idaho were done on soils that ranged from a sandy loam to a silty clay loam, slopes were about 0.8 per cent and lengths varied from 140-360 m. Most impressive results were obtained for a sandy loam soil. Surge flow trials completed advance faster and with lesser depth of application than continuous flow.

Coolidge et al. (1982) concluded that surging can improve uniformity of application but that infiltration can be deeper at the tail and the middle of the field than at the head. They noted that surge irrigation reduced the variation in advance time from furrow to furrow and from irrigation to irrigation. The standard deviation of advance time for surge furrows was 14 to 47 per cent, of that for continuously irrigated furrows. Regarding the on-time, they suggested that, it should be long enough to advance beyond the previously wetted section of the furrow and the cycle time has to be less than the time taken to complete the total advance.

Walker _et_ _al_. (1982) concluded that surge flow had more effect on sandy soils than on silt loam or clay loams. Almost without exception, surge irrigation was more effective at reducing volume of water for advance during the first irrigation following tillage than during subsequent irrigations.

Izuno (1984) has proposed that the advance phase and the post advance phase be considered separately. He said that, the stream flow for the advance phase and the post advance phase should be the maximum non-erosive flow possible within the furrow and the water supply using a cycle ratio of 0.5. He has concluded that there was a direct relationship between furrow length and the optimum number of surges, independent of other parameters. In addition, short 'ON' times reduced the chance of serious runoff. He has indicated that surge advantage is not particularly sensitive to furrow slope. However, large changes in slope as water moves down the furrow may produce unpredictable results. A flattened slope downfield meant that surges failed to recede in time thus negating the surge advantage on the lower end of the field. If the wet advance rate varies linearly with time, then the duration of ON times should not exceed the time required for the wet advance to reach the tail of the furrows otherwise tail water will be excessive. The wet advance time is a function of the field length, inflow rate, the slope and the basic infiltration rate. Furrow shape and roughness have some effect but Izuno found that they were insignificant factors.

Walker and Schledgel (1984) demonstrated that improper management of surge irrigation following advance can increase runoff. They found that the soil profile could not be refilled because of reduced intake rate resulting from surge irrigation. Increased automation compensates for this by making it possible to apply more light irrigations or higher levels of uniformity and efficiency.

Izuno et al. (1985) have reported on comparisons between continuous and surge furrows in a silty clay loam, 400 m field length, 60 min cycle time and with 0.5 cycle ratio. The volume of water applied during the advance phase in surged non-wheel track furrows was 36 per cent of that required for continuous streams; while that for surged wheel track furrows was 60 per cent.

Pitts and Ferguson (1985) have said that surge irrigation is of no effect in soils that crack severely due to aggregate stability and high percentage of swelling clays. Their studies in clay soils showed virtually no increase in advance rate.

Evans <u>et</u> <u>al</u>. (1986) have said that irrigation performance under conditions with residue in the furrows was generally better for the surged than the continuous flow. They have also found that residues increase infiltration rates so that irrigation uniformity may be low.

Izuno and Podmore (1986) suggested that the initial infiltration rate is reduced by surging to a value near the soils basic intake rate. Thus during the post-advance or cutback phase, water infiltrates at or near the basic intake rate throughout the furrow length. The optimum cutback stream size can be determined by

$$Q = \frac{1000\ CLW}{60}$$

where,

$q$ - cutback flow stream size in lpm

C - basic infiltration rate, mm/hr

L - furrow length, m

W - furrow spacing, m

The method may be particularly useful for fine textured or consolidated soils with low infiltration rates or for short fields which would normally produce considerable runoff.

Izuno et al. (1986) also stated that for relatively short field lengths, the constant on time/variable distance approach is used. With this, the on times for all surge cycles are the same, while the length of dry furrow wetted with each subsequent surge decreases.

USDA-SCS (1986) suggested a general rule for estimating the initial on-time, from field experience, when 4 to 6 surge cycles are used to advance water to the end of the furrow. Four cycles are usually considered adequate for furrows upto 400 m length, while 4 to 6 cycles are used for furrows over 400 m.

For furrows 400 m or less,

$$\text{Initial on-time} = \frac{\text{Out-time for continuous flow}}{8}$$

For furrows over 400 m long,

$$\text{Initial on-time} = \frac{\text{Out-time for continuous flow}}{12}$$

where, 'out-time' is the time required for the advance to reach the end of the field with continuous streams, and is determined from past experience. The time for water to advance through previously wetted furrows is called 'the wet-advance time'. A rule of thumb for this is 2 to 5 min per 30 m over bare soil and 4 to 8 min when close growing crops are grown in the furrow.

The cycle ON-time is the time required for water to advance approximately 35 to 45 per cent of the total furrow length and is the same for each surge. The cycle time chosen shall allow the design non-erosive stream to advance about 75 per cent of the dry furrow length that was wetted during the previous surge. This approach could result in excessive tail water runoff unless carefully monitored.

Mccornick (1986) determined that the last ON-time need to be about 1.3 times the field wet advance time. For low intake rate soils, where the advancing front 'rolls on' after cutoff, the last ON time may need to be only 0.75 times the wet advance time.

Mccornick *et al*. (1986) proposed a simplified field evaluation procedure for surge irrigation. Soil intake rate data and irrigation advance data were collected on three farms in North east Colorado during the summer. These data and simulated advance data generated using a kinematic wave model, were used to test the adequacy of seven proposed techniques for evaluating surge irrigation. The technique selected consistently resulted in values of application efficiency and distribution uniformity within, three and twenty per cent, respectively of the values given by more complex procedures. This procedure requires determining the time at which water reaches the end of a previously wetted furrow section the distance of advance at the time, inflow stops and the maximum advance distance for each surge. This represents approximately 90 per cent reduction in advance data collection over previous evaluation methods.

Miller _et al_. (1987) studied the relationship between furrow erosion, crop residue and surge irrigation, on a sandy loam soil with a slope of about 3 per cent with surge and continuous flow at different residue levels. Total elapsed times for both furrow streams to advance to the end of the field was approximately the same at the same residue level and inflow rates. Thus, since water was ON, only for half the time with surged streams, only about 50 per cent of the water was used.

Testezlaf _et al_. (1987) reported that surge flow, caused a one-third to two-thirds reduction in infiltration rates on loam, fine sandy loam and clay loam soils, with the greatest reduction on the coarser-textured fine sandy loam.

## 2.2 Studies on infiltration under surface irrigation

Infiltration is defined as the process by which water passes through the soil surface and enters the subsoil, generally the root-zone for applications in irrigation. The rate at which infiltration can be maintained in a particular soil is an extremely important parameter in the design of irrigation systems. This single parameter essentially controls not only the amount of water entering the soil but also the advance rate of the overland flow.

Numerous equations have been developed to represent the infiltration parameters. Most of these equations are empirical in nature and have been developed to match observed data sets. Some of the equations which prove useful in system design include,

(i) Kostiakov equation

This is an early equation to quantify infiltration, developed by Kostiakov (1932) and is given by

$$i = C(t)^{\alpha}$$

where,

$i$ - depth of infiltration, cm

$t$ - time of infiltration, minutes

$C$ and $\alpha$ - empirical constants

This equation has been found to fit field measured infiltration data, especially over relatively short periods -

that is, in the range of a few hours. The equation is particularly adaptable to irrigation system design.

### (ii) Horton's equation

The infiltration equation expressed by Horton is

$$f = fc + (fo - fc)e^{-kt}$$

where,

f - infiltration capacity or the maximum rate at which soil under a given condition can take water through its surface ($LT^{-1}$)

fc - the constant infiltration capacity as t approaches infinity

fo - infiltration capacity at the onset of infiltration

k - a positive constant for a given soil and initial conditions

t - time

### (iii) Green and Ampt equation

This equation is based on the assumption that when infiltration occurs, as the region just below surface gets saturated, the wetting continues downward. This area is the wetting front.

$$L - \phi_L \ln \left(\frac{l+L}{\phi L}\right) = \frac{kt}{f}$$

where,

$L$ - depth till wetting front

$\phi_L$ - matric potential of the wetting front

$K$ - permeability of the soil

$f$ - soil porosity

$t$ - time

(iv) The modified form of Kostiakov-Lewis equation is used for practical purposes

$$Z = kt^a + I_b t$$

where,

$K,a$ - empirically determined constants

$I_b$ - basic infiltration rate

$t$ - intake opportunity time

(v) Philip equation

A slightly more complex, but one which may be derived from the same field data set as the Kostiakov equation is that developed by Philip (1957). It is given as

$$i = S_p(t)^{0.5} + A_p\,(t)$$

where,

$i$ - depth of infiltration, cm

$t$ - time of infiltration, min

$S_p$ - sorptivity constant, $\mathrm{cm/(min)^{0.5}}$

$A_p$ - conductivity constant, cm/min

(vi) The United Nations soil conservation service has made a large number of field trials to measure and categorize infiltration rates. The SCS has used a slightly modified form of Kostiakov equation to represent infiltration. The governing equation is

$$i = a(t)^b + c$$

where,

$i$ - depth of infiltration, cm or inches

$t$ - time of infiltration, min

$a$ and $b$ - empirical constants

(vii) Infiltration into unsaturated soils is defined by the differential equation by Klute.

$$\frac{\partial \theta}{\partial t} = \frac{\partial}{\partial z}\left(K \cdot \frac{\partial \phi}{\partial z}\right) + \frac{\partial}{\partial z}\left(Kg\right).$$

where,

$\theta$ - moisture content in volume of water per unit volume of soil

$K$ - saturated hydraulic conductivity ($LT^{-1}$)

$\phi$ - capillary potential ($-L$)

$g$ - gravitational constant ($LT^{-2}$)

$z$ - co-ordinate in the vertical direction ($L$)

Lep (1981) conducted laboratory studies to compare infiltration for continuous and intermittent ponding conditions in air-tight and air-release columns. Cycle times of 20, 40 and 60 minute with cycle ratios of 0.3 and 0.5 were used in intermittent ponding. The soil bulk density, soil texture, initial soil moisture content, soil temperature, and water depth were constant. Wetting front advance, cumulative intake and instataneous intake rate were determined. He found that intake opportunity time, cumulative intake and instantaneous intake rate were higher with intermittent ponding than with continuous ponding.

Malano *et al*. (1982) used a recirculating furrow infiltrometer on three soils, a sandy loam and two silty clay loam soils. On comparison, they have reported that the infiltration rate decreased more rapidly with surge flow. Under surge flow, they have also reported lower steady state infiltration rates and shorter opportunity times to reach these rates. They have postulated that the movement of dispersed fine particles into large pores reduces infiltration.

Walker *et al*. (1983) developed the kinematic wave furrow model for continuous flow irrigation and surge flow irrigation. They formed two Kostiakov-Lewis equations to evaluate the infiltration rate of surge flow irrigation.

$Z = Kt^a$ ---- (1)

$Z = Kt^a + Ct$ ---- (2) (Extended Kostiakov equation)

where,

$Z$ - cumulative intake, litres per metre of furrow length

$t$ - intake opportunity time in minutes

$K$ - Kostiakov constant (L/min/m)

$a$ - Kostiakov exponent, di~~a~~mensionless

$C$ - basic furrow intake rate (litres/min/metre)

Three infiltration conditions under surge flow were identified as dry, wet and transition. The dry regime was when water advanced over dry soil and the intake rate was time dependent. The wet regime occurred during subsequent surges. The transition regime occurred during subsequent surges, when water was flowing over the section of furrow that was partially wetted during the previous surge and the infiltration was lying between high time dependent rate and the surge lowered basic rate.

Izuno et al. (1985) reported on infiltration studies, in silty clay loam soil, and it has been found that steady state infiltration rates were equal under surge and continuous flow, but that it took only one surge cycle to reach the steady state rate. They identified three infiltration phases in surged furrow irrigation as done by Wynn. R. Walker et al.

Testezlaf et al. (1987) reported that surge flow caused a one-third to two-thirds reduction in infiltration rates on loam, fine sandy loam and clay loam soils with the greatest reduction on the coarse textured fine sandy loam.

Fariba et al. (1988) conducted studies on stochastic infiltration from advance in furrows. The mean and variance of parameters in the Kostiakov-Lewis infiltration equation are approximated from advance data using first order analysis and the results are comparable to the results found by involving the two-point volume balance for each of several furrows. First order analysis can be used to approximate the mean and variance of Kostiakov-Lewis infiltration parameters.

Purkey and Wallender (1988) made studies on surge flow infiltration variability. Infiltration along a set of surge irrigated furrows was studied using field data collected from 49 pairs of Neutron Probe access tubes and blocked furrow infiltrometers for each irrigation method. Surge irrigation reduced the average water application depth and the infiltration variability.

Trout (1990) studied on surface seal influence on surge flow furrow infiltration. The interactive influence of furrow surface seal formation and surge irrigation on furrow infiltration into a portneuff silt loam soil was measured with a recirculating furrow infiltrometer. When the formation of a surface seal was prevented by a layer of cheese cloth laid on the furrow perimeter. The flow interruption increased furrow bed bulk density by 100 kg/m$^3$ and decreased infiltration by 25 per cent compared to constant flow.

Trout (1992) studied the effect of flow velocity and wetted perimeter effects on furrow infiltration. Infiltration theory and previous studies show that furrow infiltration increases with wetted perimeter. This effect can strongly influence water distribution along furrows. Stagnant blocked-furrow infiltrometer measurements supported this relationship. However, both recirculating infiltrometer and field-scale measurements showed no consistent infiltration-wetted perimeter relationships. The infiltrometer data collected using a wide range of flow rates on a wide range of slopes, did show infiltration inversely related to flow velocity. This relationship results from the effect of flow on soil aggregate breakdown, particle movement and depositional seal formation.

Bautista et al. (1993) performed numerical calculation of infiltration in furrow irrigation simulation models. The computation of wetted perimeter dependent intake in a furrow irrigation simulation model using an empirical infiltration formula was examined. Different formulations were applied under increasing and decreasing depth of flow condition. Four computational methods were compared for the former condition and only one was tested for the latter. The merit of the procedures was evaluated in relation to the performance of a finite-difference unsteady surface flow model. Only one of the formulae provided consistent results during storage and recession calculations. Numerical instability resulted as well from the application of the procedures with limited convergence.

Bautista et al. (1993) also studied on the identification of furrow intake parameters from advance times and rates. The paper analyses the convergence of a numerical model for the quantification of lumped furrow infiltration parameters. The three parameters of the empirical extended Kostiakov equation were estimated when non-uniformity of infiltration was the only source of variability in the advance curve. Faster convergence and larger radius of convergence resulted from fitting velocities rather than advance times. Measurement error and system perturbations impeded the simultaneous identification of three parameters, while computation of two coefficients from highly variable velocities required the application of weighted least squares. Similar parameters were obtained from few or many observations but convergence improved with smaller data sets.

Childs et al. (1993) studied the spatial and seasonal variation of furrow infiltration. Infiltration was measured with a newly developed flow-through infiltrometer at 20-27 sites in a 21 ha cotton field in the northern region of the San-Joaquin Valley of California. The results were comparable with infiltration measured with Neutron probe. The infiltrometer allowed water to flow through if when a rate test was not being conducted. Furthermore, the water level and quantity inside the infiltrometer was the same as the water flowing past in the remainder of the furrow. Variability contributed by the soil infiltration characteristics and intake opportunity time was quantified. Because the infiltration pattern was temporarily correlated between post plant irrigations, representative sites rather than a complete field interrogation could be used to determine the mean and variability of infiltration.

Hume (1993) determined the infiltration characteristics by volume balance for border check irrigation. The infiltration characteristics of a cracking clay soil were predicted by a regression approach to the volume balance technique, utilising automatic data gathering techniques. The analysis technique developed enables the fitting of any form of infiltration function by least squares regression. The parameters of three common infiltration equations could be predicted accurately from measured field data, and the best fitting equation identified. However, the parameters of the fitted equations were extremely sensitive to errors in measured field data. The average depth of water flowing over an irrigation border was related to the water depth measured at the head of the border, the flow into the border and the border slope. Rates of irrigation advance approached a linear form, and the rate of advance was strongly influenced by border slope or the stage of crop growth.

## 2.3 Surface irrigation hydraulic models

Many researchers, under the Western regional research project developed reliable software for simulating the surge flow regime under nearly all furrow, border and basin irrigation systems. These models have been verified against a wide range of field data to substantiate interrelationships among physical and operational variables. The principal differences between surge and continuous flow regimes in furrows, borders and basins concern the description of the initial and boundary conditions rather than the basic description of the flow itself. Fundamental surge flow theory, like continuous flow is based on continuity of mass and momentum (or energy). All models solve these two relations simultaneously, the continuity equation preserves a volume balance and the momentum equation describes the shape of the surface flow profile. However, some terms in the momentum equation are smaller and were neglected to simplify the numerical solutions. As a result, we have hydrodynamic models, that solve the complete equations, zero-inertia models that result from neglecting the inertia and acceleration terms in the momentum equation, kinematic-wave models that neglect the inertia, acceleration and pressure gradient terms, and volume balance models that assume the average cross-sectional area is constant. Surge flow versions of each of these models were developed. The research work done on the modeling of surface irrigation are reviewed in this section.

Strelkoff and Katapodes (1977) studied on Border irrigation hydraulics with zero inertia. This model considered only the continuous advance phase and only sloping plane-flow conditions, but it proved the basic numerical scheme for escape from characteristic solutions. Subsequent refinements, expansions and adaptations from researchers throughout the western Unites States made this 'zero inertia' model, the standard surface irrigation analysis for borders and basins.

Essafi (1983) formulated a recursive volume balance model and successfully verified it for surge flow conditions. This is the only complete volume balance model for surge flow; which is more cumbersome than the other types of models and was developed to test the simplest set of hydraulic assumptions.

Essafi showed that the volume balance model could effectively predict the advance trasectory and tail water hydrograph, but recession was so problematic that the model has not been used.

Oweis (1983) modified the zero inertia model developed by A.J. Clemmens and colleagues at the USDA water conservation laboratory in Pheonix for surge flow conditions. Modifications included the hydraulic section parameters for furrows, infiltration functions for surge flow, surge-to-surge time-space grid resolution, and improvements in the estimates of recession. The Oweis model used the three step calculation as the Haie model and maintained the one-step linearized numerical procedure originally outlined by Strelkoff and Katapodes. This model did not include a management system for the computational grid.

Haie (1984) undertook the principal hydrodynamic modelling of surge flow during the W-163 project. This model used an eulerian grid system, like that of the kinematic-wave models, but treated surge flow as three processes. In the first, the advance phase was simulated over the previously wetted region of the field. The wet-dry interface was treated as a pseudo-downstream boundary, and a pseudo tail water hydrograph was computed. The second phase of the analysis repeats the basic advance phase simulation from the wet-dry interface to the stopping point of the surge using the pseudo-tail water hydrograph as an inflow hydrograph. At the time of cutoff, the Haie model combined the previous wet and previously dry sections and considered the recession as the continuous flow models have done.

Glchuki (1985) showed that the kinematic wave model was more accurate with a value of 0.65 for phi and 0.51 for theta. The modifications made it possible to simulate numerous individual surges along the entire furrow length. The model appeared to deal effectively with the highly varied surface profile and closely matched field recorded tail water hydrographs. The major problem with the model was that, predicted hydrograph peaks and measured values were offset in time. Researchers at Utah State University hypothesized that the cause lies with the kinematic-wave model assumptions, although the zero-inertia and hydrodynamic models were not modified to test this theory.

Mostafzadehfard (1985) included wetted perimeter in the calculation of infiltration in the kinematic wave model. The question has not been resolved as to whether or not to add these complications to the solutions. Some researchers pursue a greater degree of precision while others believe the dynamics of surface roughness and shape are intractable and are hence ignored.

Wallender and Rayej (1985) made improvements to the zero inertia type model. The work done at the University of California-Davis uses an implicit, non-linear solution of the lagrangian type for the advance phase and of the eulerian type for recession, once the advancing front has stopped or has reached the downstream field boundary. Wallender <u>et al</u>. included grid management options involving both time and space steps, and provided a transition step over the wet-dry interface that effectively eliminated the wave profiles encountered in other works.

Izuno and Podmore (1986) presented a procedure to determine the best management option for surge irrigation using a kinematic wave simulation model. Using the selected management parameter values, they simulated the surge irrigation during the advance phase and determined the optimum combination of inflow rate and 'ON' time based on distribution uniformity; total volume of water applied and time of advance to the end of the field.

Blair <u>et al</u>. (1987) discussed on the Green-Ampt model to predict surge irrigation phenomena. They found that the consolidation and sealing are incorporated in this model by modifying it. The advantage was that infiltration rates, where hydraulic gradients were very large, could be obtained. Ultimately, they found that the reduction of the hydraulic gradient was not a mechanism for the reduction of infiltration which is often observed in surge irrigation.

Fonteh et al. (1993) studied on the development of a physically based infiltration model for furrow irrigation. Four simple, physically based infiltration models for furrow irrigation were developed and their performance compared. The models were associated with a kinematic wave furrow irrigation model in which infiltration could vary spatially or be constant. These models, all based on the Green and Ampt equation are, (a) The slug-flow model based on implicit solution of the equation, (b) The modified slug-flow model with correction for air flow and resistance effects, (c) The exponential model based on an explicit approximation of the integrated form of the equation and (d) a dimensionless form of the equation. It was found that these simple models predict furrow infiltration satisfactorily in fine-textured soils, and are suitable for practical use. Of the four models tested, the slug flow model was most accurate.

Maheswari et al. (1993) conducted performance evaluation of Border irrigation models for South-East

Australia in two parts. (1) Advance and Recession characteristics, (2) Overall suitability for field applications.

The papers examined six models of Border irrigation, namely Jobling-Turner, Strelkoff, Walker, Jayner, Schmitz and Ross, for their suitability to predict advance and recession times under a range of field conditions. The field experiments were monitored at five locations in South-East Australia and a total of 67 irrigation events were carried out over a period of 4 years. It was concluded that the Walker model was the best for predicting advance times and Strelkoff model, for predicting recession times for the field conditions encountered in the study. All of the models were examined for infiltration and runoff prediction. The Strelkoff and Ross models were examined for the discharge-depth equation as an alternative to the Manning's equation for describing overland flow in surface irrigation. Considering the overall accuracy of the model predictions, output details and user-friendliness, Strelkoff model was concluded to be the most satisfactory for the field conditions of South-East Australia.

# Materials and Methods

# MATERIALS AND METHODS

A majority of the irrigated lands of our country are still under surface irrigation, eventhough the water saving methods of sprinkler and drip are gaining prominence in the irrigated agriculture. A major challenge is to develop systems for greater precision in water and plant nutrient control, so as to increase the use efficiency of soil, water and energy resources and to improve the environment for agricultural activities. Progressive technologies like surge flow, increase the efficiency of surface irrigation systems for borders and furrows and reduce the amount of water required, but still satisfy the crop water requirements. The surge effect depends upon a number of factors such as soil texture and consolidation, prior wetting history, duration of ON and OFF periods and length of furrow, which all determine its potential to improve the surface irrigation performance. A field study to evaluate the infiltration and water advance characteristics under surge flow furrow irrigation was conducted at KCAET, Tavanur. The materials used and the methodology employed for experimentation, data collection and analysis are presented in this chapter.

## 3.1. Location

The experiment was conducted in the Instructional farm, KCAET, Tavanur in Malappuram district. The place is situated at 10°53'30" North latitude and 76° East longitude. The total area of KCAET comes to about 40.99 ha, out of which, the total cropped area comprises 29.65 ha.

## 3.2 Climate

Agroclimatically, the area falls within the border line of Northern zone, Central zone and Kole zone of Kerala. Climatologically, the area is in the low rainfall zone with a rainfall of 1000-2000 mm. The area receives rainfall mainly from the South-West monsoon and to a certain extent from the North-East monsoon.

## 3.3 Soil characteristics

The soil characteristics of the experimental site are found to significantly influence the performance of surface irrigation systems, the extent of infiltration and the uniformity of water distribution along the field.

### 3.3.1 Soil texture

Mechanical composition of the soil at the site influences the infiltration characteristics. The surface soil

(60 cm) at the site was subjected to sieve analysis and the mechanical composition was determined.

### 3.3.2 Infiltration

Infiltration characteristics of the experimental site were analysed using the double ring infiltrometer. The cylinder or ring infiltrometer is a metal cylinder made of 2 mm rolled steel. It is 25 cm deep and is driven into the soil upto about 10 cm for measurement. The inner cylinder from which the infiltration measurements are taken is 30 cm in diameter. The outer cylinder which is used to form the buffer pond to minimise the lateral spreading of water is 60 cm in diameter. The cylinders were driven 10 cm deep into the soil with about 15 cm projecting outside. This was done using a drop weight hammer after keeping a wooden plank on top of the cylinder, with an intention to prevent damage to the edges of the cylinder. The water level in the inner cylinder was read using a scale placed inside the cylinder. Infiltration data is obtained from a cylinder infiltrometer by measuring the depth of ponded water in the cylinder at various time intervals. The depth measurements were done at frequent intervals in the beginning and this data provided the initial infiltration rate. The readings were taken until a constant value was obtained. This data corresponds to the basic infiltration rate of the soil of the site. The procedure was repeated at three locations and the average values were accepted for the analysis.

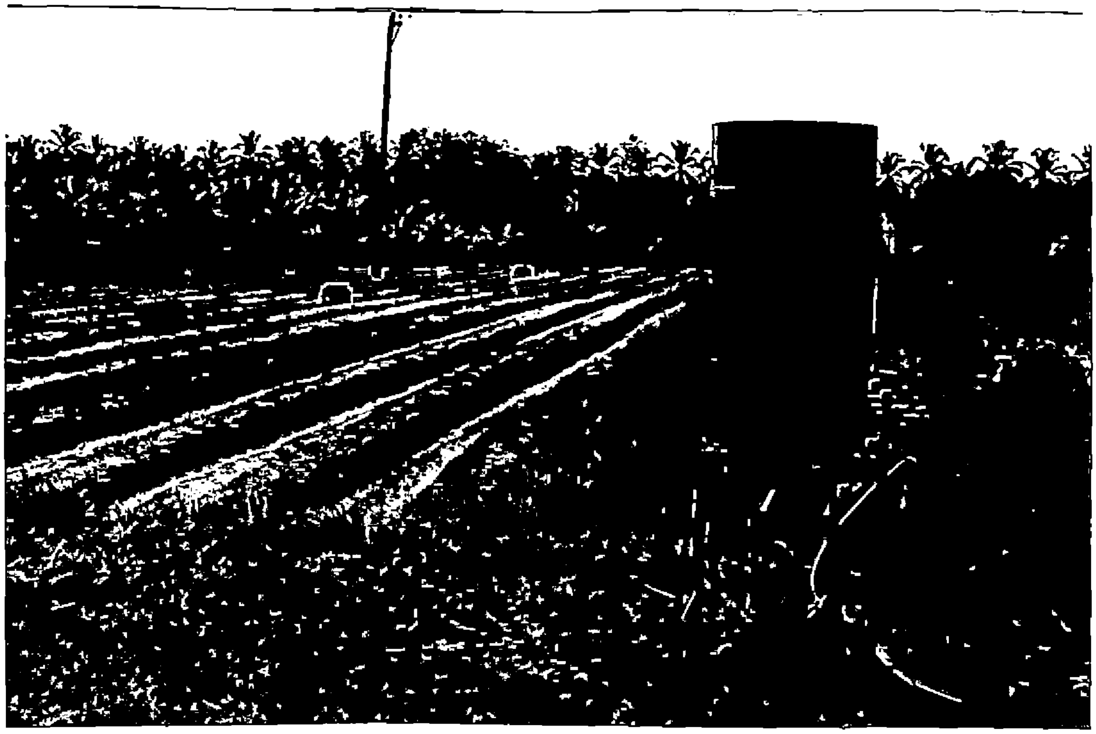
### 3.4 Experimental procedure

A field experiment to study the infiltration and water advance characteristics under surge flow furrow irrigation system, was conducted during the months from December 1992 to May 1993. The system performance was evaluated under varied combinations of operation parameters so as to facilitate comparison of surge and continuous flow systems, and to obtain suitable values of these parameters for best performance. The methodology employed and the various components and equipments used in the system are listed under the following captions. The overall picture of the experimental arrangement is given in Plate I.

#### 3.4.1 Land preparation

The experimental plot was selected in the Instructional farm of KCAET, Tavanur. Three subplots were levelled out to obtain a single stretch of land for laying the irrigation furrows. The bunds were broken using a tractor drawn scraper. The field soil was first ploughed to pulverize the soil and break the clods by using a tractor drawn cultivator. Later, the soil was deep ploughed with a tractor drawn subsoiler to break the hard pan and ensure adequate

Plate I Overall view of the experimental arrangement



infiltration of irrigation water. Finally, the field was levelled to an approximately uniform grade by using the scraper. Thus the land was prepared for laying the irrigation furrows.

### 3.4.2 Layout of the field

The study was conducted in a plot of area 105 m x 15 m. The irrigation furrows were laid along the length of the plot. Twelve furrows of 102 m length and 0.75 m spacing, centre to centre, were laid in the field manually. The furrows had a bottom width of 0.30 m and a side slope of 1.7:1. The ridges were 0.40 m wide and 0.20 m high. Cropping was not done on the ridges and the effect in the bare soil condition was tested. The land slope was determined using a levelling instrument, with the grid points chosen along the furrow length. The slope obtained, ranged between 0.6 to 1 per cent, and to obtain a uniform slope of 0.5 per cent, cut and fill at various grid points were determined. Accordingly, the irrigation furrows were uniformly graded to a slope of 0.5 per cent manually. Layout of the field system is as presented in Fig.1.

### 3.4.3 Water supply

The source of water supply to the plot was an open well in the instructional farm, from which water was pumped to

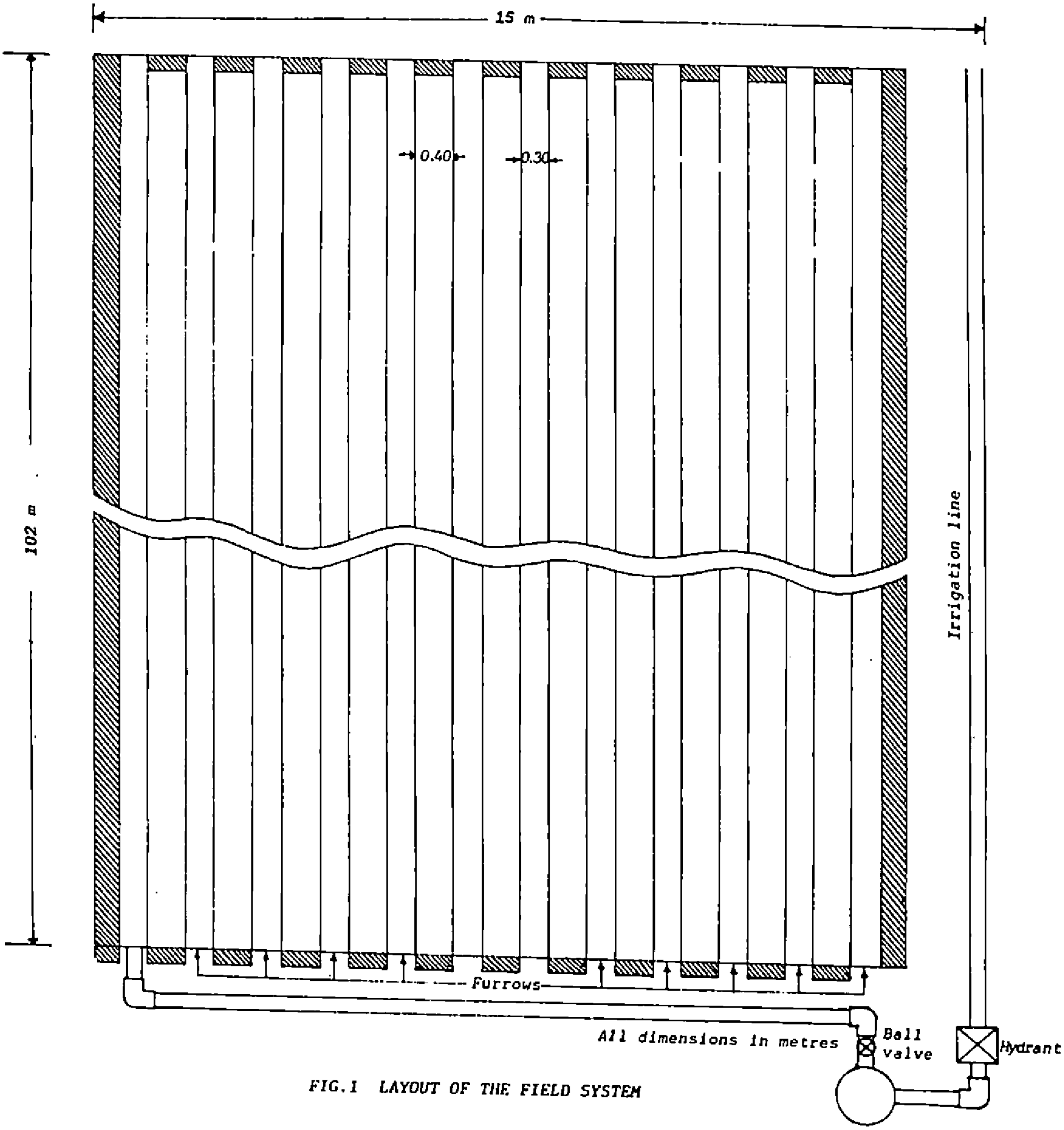


FIG.1 LAYOUT OF THE FIELD SYSTEM

supply lines with hydrants provided at 30 m spacing. The water supply to the experimental system was taken from a hydrant at the end of an irrigation pipe line adjacent to the plot. Water was taken to a supply tank from where it was diverted to the individual furrows according to the system detailed in section 3.5.1.

## 3.5. Plan of the experiment

The study was aimed at comparing the performance of continuous and surge flow systems for furrow irrigation at the site and to obtain suitable values of discharge and cycle ratio for best efficiency, under surge flow. The recommended stream sizes for furrow irrigation usually ranges from 0.5-2.5 lps. To attain a depth of application corresponding to the infiltration characteristics of the soil, and for the adopted values of furrow spacing and length, the stream flow rate in litres per second was computed. Three discharges lying on either sides of this optimum value were chosen as 1.3, 1.7 and 2.1 lps. Trial runs with these discharges for continuous flow were conducted and accordingly the plan for surge irrigation trials was made. The ON times for surge irrigation were chosen such that an optimum of 4 to 6 surges were required to complete the advance. More may result in poor uniformity, and fewer may apply too much water and/or cause too much tail water. As continuous flow required advance time in the range of 20 to 23 minutes, to complete the advance with about 5 surges, the ON time for surge irrigation should be nearly 4 minutes. Values on either sides of this were chosen and hence 3 minutes and 5 minutes ON time were fixed. In one case, the OFF time was kept equal to ON time. In the second case, the OFF time was double the ON time and in the third case, the OFF time was kept half of the ON time. Thus the cycle ratios of 1/2, 1/3 and 2/3 were chosen where, cycle ratio $= \frac{\text{ON time}}{\text{Total cycle time}}$

Thus for cycle ratio 1/2, ON time = 3 min
OFF time = 3 min
For cycle ratio 1/3, ON time = 3 min
OFF time = 6 min
For cycle ratio 2/3, ON time = 5 min
OFF time = 2.5 min

Accordingly surge flow was tested for cycle times of 6, 9 and 7.5 minutes respectively.

The experiment was planned in separate randomized block designs for continuous and surge flow systems. The twelve furrows were divided into four blocks with three furrows per block. The three discharges were randomly allotted to the three furrows and the treatments were replicated four times. The pattern of the experiment was as follows:

$F_1 T_1$ - continuous flow, stream flow rate - 1.3 lps

$F_1 T_2$ - continuous flow, stream flow rate - 1.7 lps

$F_1 T_3$ - continuous flow, stream flow rate - 2.1 lps

$F_2 T_1$ - surge flow, cycle ratio = 1/2, stream flow rate - 1.3 lps

$F_2 T_2$ - surge flow, cycle ratio = 1/2, stream flow rate - 1.7 lps

$F_2T_3$ - surge flow, cycle ratio = 1/2, stream flow rate - 2.1 lps

$F_3 T_1$ - surge flow, cycle ratio = 1/3, stream flow rate - 1.3 lps

$F_3 T_2$ - surge flow, cycle ratio = 1/3, stream flow rate - 1.7 lps

$F_3 T_3$ - surge flow, cycle ratio = 1/3, stream flow rate - 2.1 lps

$F_4 T_1$ - surge flow, cycle ratio = 2/3, stream flow rate - 1.3 lps

$F_4 T_2$ - surge flow, cycle ratio = 2/3, stream flow rate - 1.7 lps

$F_4 T_3$ - surge flow, cycle ratio = 2/3, stream flow rate - 2.1 lps

### 3.5.1 Irrigation system

The water supply from the hydrant was collected in a tank by means of a flexible hose of 2 inch size. The tank was of about 200 litres capacity and height 1 m. The three discharges of 1.3, 1.7 and 2.1 lps were attained by providing three overflow outlets at precalibrated positions in the tank. By supplying an inflow equal to each of the three discharges, the head at which, the inflow became equal to outflow was noted, by trials in the field and these values were maintained to obtain constant discharges. Thus the overflow outlets were provided at 10, 17 and 26 cm respectively from the bottom of the tank. the outlets were of 2 inch size and for a higher value of inflow corresponding to each discharge, the excess water drained off through the respective overflow outlet which was open. The head discharge relationship obtained by calibration is given in Table 1. A quarter-turn ball valve was connected at the outlet of the tank to obtain perfect opening and closure of the supply system for maintaining accurate ON and OFF times. A flexible hose directly connected to this valve supplied water to the individual furrows during irrigation. The calibration was done with this set up, so that the accurate values of discharges could be obtained. The details of the set up in the field is as depicted in Plate 2.

Plate II  Field set up of the irrigation system

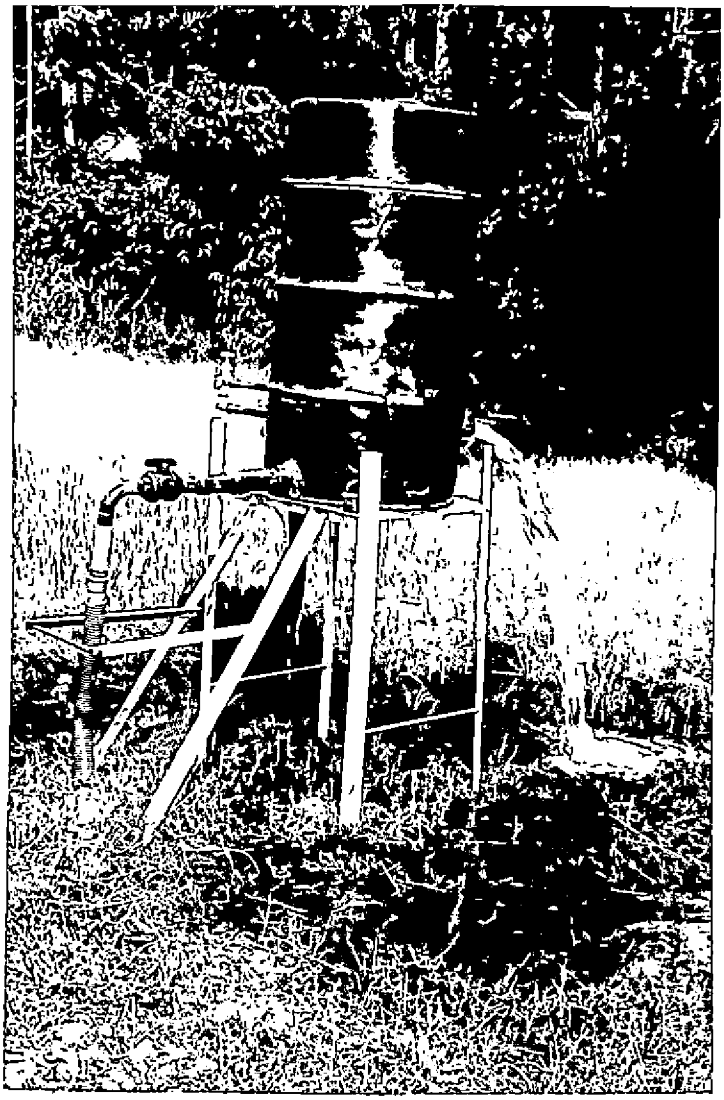


Table 1. Calibration of ball valve

| Sl. No. | Head of water (cm) | Discharge (lps) |
|---|---|---|
| 1. | 10✓ | 1.3✓ |
| 2. | 15 | 1.6 |
| 3. | 17✓ | 1.7✓ |
| 4. | 20 | 1.8 |
| 5. | 24 | 2.0 |
| 6. | 26✓ | 2.1✓ |
| 7. | 28 | 2.2 |
| 8. | 30 | 2.3 |

#### 3.5.1.1 Ball valve

Ball valve produced by the Jain Irrigation Company was used for the study. The valve is injection-moulded from PVC and has a unique design. It has externally adjustable seat at both ends and is available in sizes ranging from 20 mm to 75 mm diameter. The valve used in the present study was 40 mm in size. For installing the valve in the pipe line, both the union nuts were unscrewed from the ends and slid to the pipes. Using PVC cement, the pipe ends were fixed to the threaded socket ends. Now the union nuts were tightened, so that, one was tightened on the upstream side marked 'TIGHTEN' and the other on the downstream side marked 'ADJUST', to obtain optimum valve operation with perfect sealing on valve seats. The valve was installed with the arrow on the body in the direction of the line of flow. To the outlet pipe end, a flexible hose of 2 inch size and 15 m length was connected to supply water to the individual furrows. A view of the ball valve as used in the system is given in Plate 3.

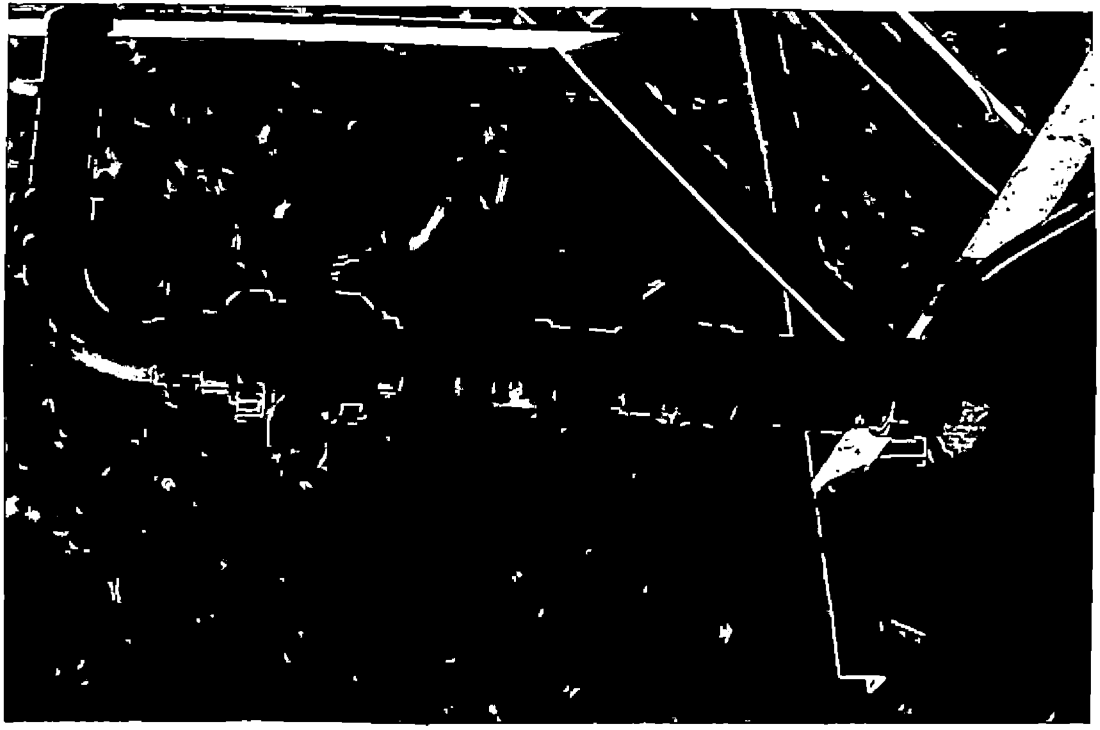
## 3.6 Collection of data

The study was aimed at analysing the infiltration and water advance characteristics under surge and continuous flow furrow irrigation, so as to achieve an effective comparison between the two. Hence, sufficient field data to study the infiltration characteristics and to develop advance trajectories were collected.

### 3.6.1 Continuous flow irrigation

The continuous flow irrigation was tested for the three treatments 1.3, 1.7 and 2.1 lps and replicated in four furrows. Detailed data of the advance time to each 3 m interval and depth of flow at these sections were taken during the irrigation. The inflow in each case was prefixed and the outflow was measured using orifice plates fixed at 102 m distance from the furrow upstream end. At the instance the

Plate III View of the ball valve as used in the system



furrow stream reached the end of the field, the inflow was cut off.

### 3.6.2 Surge flow irrigation

The surge flow system of irrigation was tested for the cycle ratios of 1/2, 1/3 and 2/3 for the three treatments chosen, and were replicated four times. The ON and OFF times of the valve in each case were chosen as detailed in section 3.5. The data on the time of advance of water for each surge in each case at 3 m interval along the furrow length and the data on the depth of flow were collected. The furrow was divided to different sections and orifice plates were fixed at the end of each section to measure the outflow from each surge. The inflow was cut off as soon as the water reached the end of the furrow and the total valve ON-time was recorded.

### 3.6.3 Water advance data

The field was staked at 3 m intervals and the time, the water front advances to each stake was recorded using a stop watch. The inflow was cut off only after the water reached the tail end of the field. Though it is undesirable in furrow irrigation, such a strategy was adopted to ensure easiness of comparison and operation and also as tail water run off was not a factor of importance in the present study.

For surge irrigation, the advance time was noted for each surge until, the water of a particular surge reached the tail end of the field. Detailed data on recession could not be obtained especially for surge irrigation, since the water of a particular surge did not recede completely from the surface of the furrow during the off time and there was overlap between consecutive surges. This could have been remedied if the stream flow rate was reduced considerably but the number of surges in that case exceeded the optimum values thus reducing the effectiveness of surging. Also, if the length of furrows were greater, the effect could have been better, but the maximum available length of plot was 102 m and the testing in this case was subjected to the above said constraints. The advance of water front along the furrow bed is as represented in Plate 4.

### 3.6.4 Data on the depth of flow

The infiltration characteristics under furrow irrigation can be obtained from the advance data by knowing the amount of water stored on the surface at any time interval. For this, the depth of flow of water in the furrow during irrigation was measured using scale at each 3 m interval after the flow reached a steady uniform depth at each point. This data was collected for both continuous and surge flow irrigations. The depth was measured from the furrow bed, keeping the scale at the middle of the furrow cross section. Collection of the data is as shown in Plate 5.

### 3.6.5 Inflow-outflow data

The inflow to irrigation furrows was maintained constant for the three treatments as 1.3, 1.7 and 2.1 lps respectively. Orifice plates were used for measuring the outflow from each furrow during irrigation. In case of continuous flow, the outflow was measured at the tail end of the field, with an orifice plate installed in the furrow. In surge flow trials, the entire furrow length was divided into four sections and orifice plates were installed at 25, 50, 75 and 102 m distances so that outflow from each surge at each section could be quantified.

#### 3.6.5.1 Orifice plate

The orifice plates used for flow measurement were made of 19 gauge MS sheet of 60 cm x 60 cm size. Accurately machined circular openings of 2.5, 5 and 7.5 cm size were provided on each of the plates. The orifices were made by chiseling out the holes of required dimensions in the sheet and then by filing the inner surfaces for ensuring smooth, uniform flow with minimum losses. Plastic scales were fixed on the upstream and downstream faces of the plate with the zero of the scale coinciding with the centre of the orifice.

**Plate IV** Advance of water front along the furrow

A view of the orifice plate used in the study is shown in Plate 6 and Fig 2. The orifice plate as used in the field for flow measurement is shown in Plate 7. The calibration chart for standard orifice dimensions is provided in Appendix-I.

## 3.7 Analysis of field data

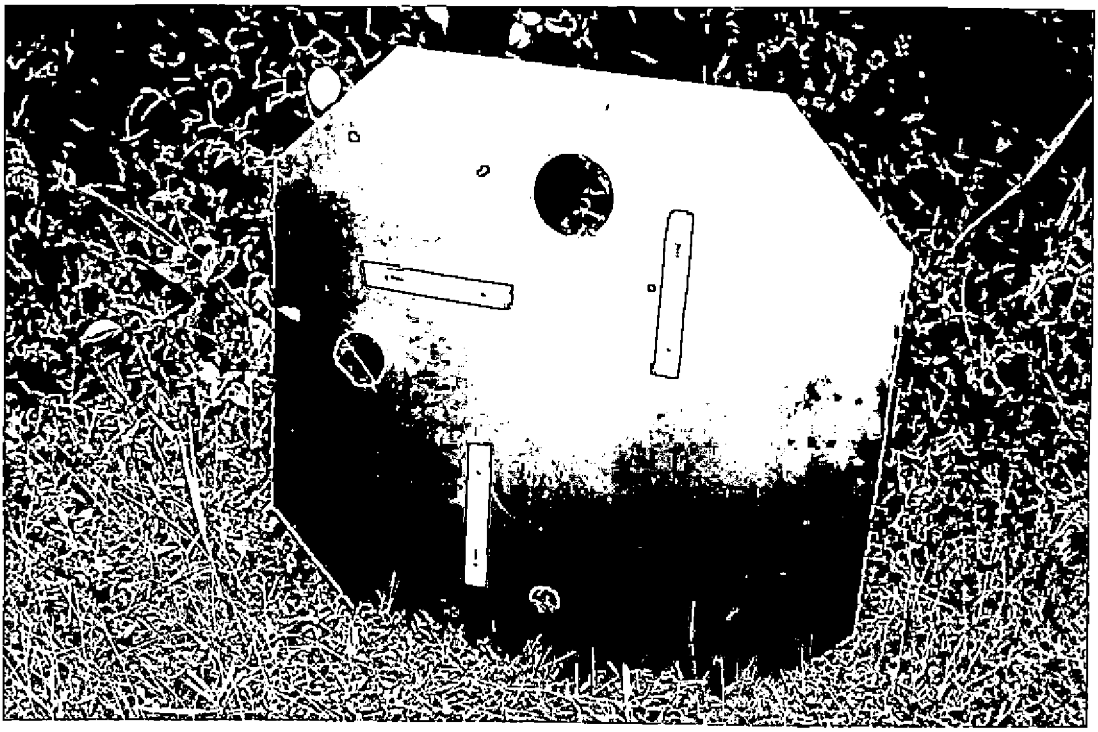
The data collected from the field during various irrigation runs were subjected to analysis for comparing surge and continuous flow irrigation methods.

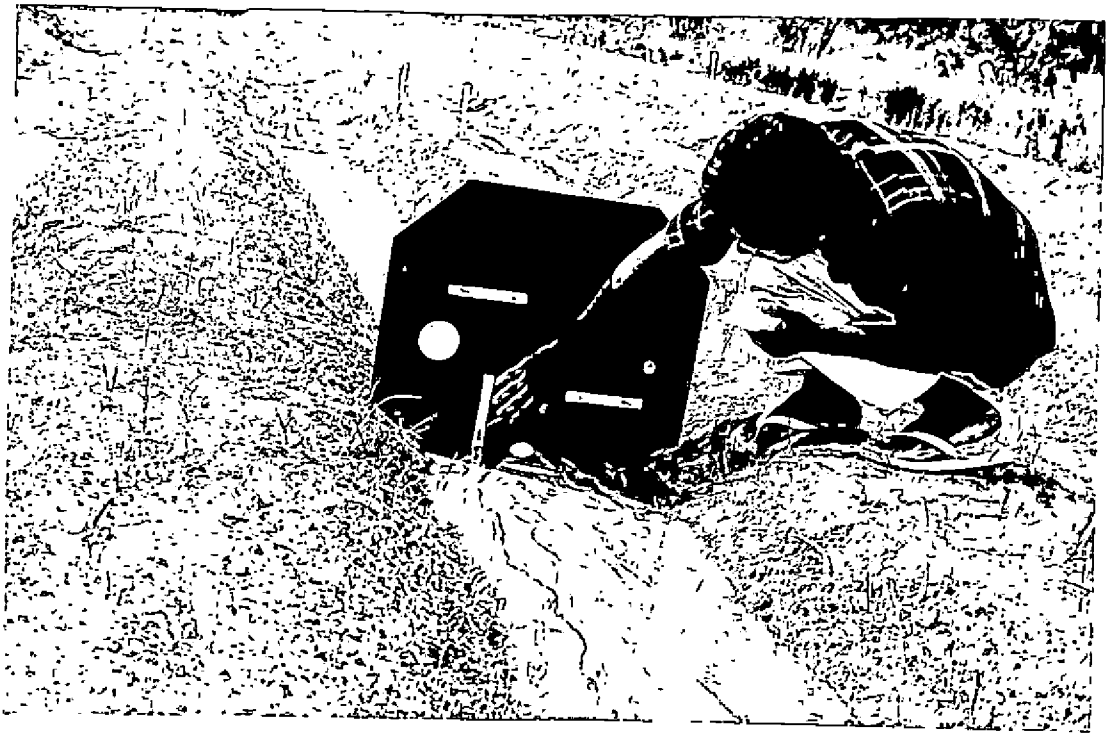
### 3.7.1 Volume-balance calculations

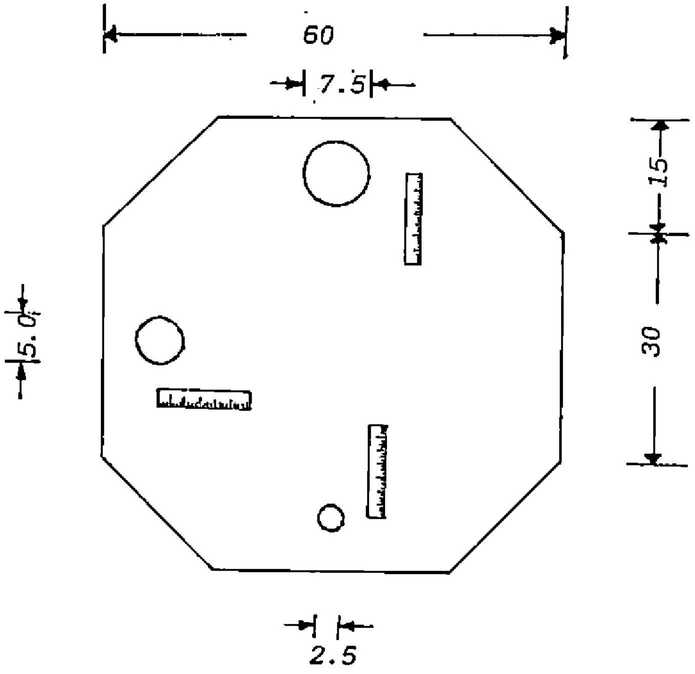
The water advance and depth of flow data collected from the field were used to calculate the infiltrated volume and infiltrated depth in sections of 15 m length along the furrow. The average value of depth of flow in each section was computed and this data was used to calculate the furrow cross-sectional area and wetted perimeter, knowing the values of bottom width, and side slope, of the furrow. With the values of stream flow rate, advance time to each section and the average depth of flow, the infiltration parameters at 15, 30, 45, 60, 75, 90 and 102 m distances were calculated. Accumulated inflow was computed by multiplying the stream flow rate by the advance time to each section. The accumulated storage volume was computed by multiplying the furrow cross-sectional area at each section by the distance travelled by

**Plate VI** View of the orifice plate

**Plate VII** Measurement of outflow using orifice plate







All dimensions in cm

Scale 1:10

FIG.2 ORIFICE PLATE FOR INFLOW-OUTFLOW MEASUREMENTS the furrow stream. Accumulated wetted area was obtained as the product of wetted perimeter and the distance traversed by the furrow stream. The infiltrated volume at each section is the difference of inflow and storage. Infiltrated depth is obtained by dividing the infiltrated volume by the accumulated wetted area.

The calculations were repeated for 15, 30, 45, 60, 75, 90 and 102 m distances to obtain the infiltration parameters. In case of surge irrigation, the calculation was done for each of the surges and the values were added up to obtain the values of the parameters. Comparison of the results obtained for continuous and surge flow trials was done and the results are presented in chapter 4.

### 3.7.2 Analysis of inflow-outflow data

Orifice plate readings obtained during continuous and surge irrigations were used to calculate the infiltration rate in the furrows. The difference of inflow and outflow at each section when divided by the distance between the two points gives the rate of infiltration into the soil in terms of the volume of water per unit time, per unit length of the furrow. In the case of surge flow, the intake rate of each surge in the different sections of furrow length, can be obtained to ensure, effective comparison between surge and continuous flow intake rates and to analyse the promising effect of surge flow in reducing the intake rates. The orifice plate readings were converted to flow rate values by using the equation.

$$Q = 0.61 \times 10^{-3} \; a \; \sqrt{2gh}$$

where,

$Q$ = Discharge through orifice, litres/second

$a$ = Area of cross-section of the orifice, $cm^2$

$g$ = Acceleration due to gravity, $cm/sec^2$

$h$ = Depth of water over the centre of the orifice on the upstream side in the case of free flowing orifice, or the difference in elevation between the water surfaces at the upstream and downstream faces of the orifice plate in case of submerged orifices, cm.

### 3.7.3 Statistical analysis

It has been found by experience that the optimum combination of management parameters for furrow irrigation, results in furrow stream advance with the smallest volume of water. The volume required to complete the advance under each case of surge and continuous flow treatments were calculated from inflow rate and total valve ON-time. The data for the four different flow types $F_1$, $F_2$, $F_3$ and $F_4$ and for the three different discharges $T_1$, $T_2$ and $T_3$ were arranged in the form of a mixed factorial experiment for the analysis. Such an experimental design analyses the effects of two or more sets of variables, their interactions, main effects etc. and ensures better representation of the various treatment effects. The experiment can be conducted in separate randomized block designs and the use of large number of plots can be avoided. For each case, the data corresponding to four replications were taken and analysed for comparison between flow types, discharges and their interactions. Analysis of variance of the volume required to complete the advance, was done to determine whether significant differences existed between continuous and surge flows and between the stream flow rates chosen for the study. Based upon the values of mean volume of water required to complete the advance under each treatment sets, the combination of stream flow rate and cycle ratio for best performance under surge irrigation out of the selected values, could be suggested.

### 3.7.4 Verification of surface irrigation hydraulic models

The usual surface irrigation hydraulic models are modified for surge flow conditions and the modified versions include the kinematic wave model by Walker and Lee (1981), revised kinematic wave model by Walker and Humphery's (1983), recursive volume balance model by Essafi (1983), the zero-inertia model by Oweis (1983) and Haie's Hydrodynamic model

(1984). The surge flow modifications of each of the four models incorporate a common strategy for computing infiltration. Cycled wetting can be represented by two independent functions. But it appeared that neither function adequately represented the second wetting since the wetted perimeter changes significantly between the first and third surges. In a furrow section where the discharge is relatively constant, from surge to surge, infiltration can be evaluated by two Kostiakov-Lewis equations.

$$Z_c = KT^a + fo\ T \quad \text{-----} \quad (1) \quad \text{and}$$

$$Z_s = K'T^{a'} + fo'T \quad \text{-----} \quad (2) \quad \text{where,}$$

'$Z_c$' and '$Z_s$' are the infiltrated volumes per unit of furrow length ($L^2$) for dry, continuous flow conditions and wet intermittent flow conditions respectively. The parameters K, K', a, a', fo and fo' are the empirical parameters particular to the soil type and the effect of cycled wetting and drying. For equation (2), the 'T' is cumulative, i.e., sum of the opportunity times over the number of surges applied. Field observations indicate that the infiltration can be described by a function somewhere between the two equations for the second surge cycle. So in the modified versions of the models, eq. (1) represents dry section, eq. (2) the third and succeeding surges and a transition equation represents the second surge.

If $x_{i-2}$ and $x_{i-1}$ be the advance distances of the i-2 and i-1 surges, the transition function is written as

$$T = \left\{ \begin{array}{ll} \left( \dfrac{x_{i-1} - x}{x_{i-1} - x_{i-2}} \right)^{\lambda} & x_{i-2} \leq x \leq x_{i-1} \\ 0 & x < x_{i-2} \text{ or } x > x_{i-1} \end{array} \right\}$$

in which 'x' is the location of the computational point of interest during the current time step (i) and '$\lambda$' is an empirical nonlinear distribution constant. Then the infiltration equation coefficients for the transition infiltration function are:

$$k'' = k + (k-k')\,T$$

$$a'' = a + (a-a')\,T \text{ and}$$

$$fo'' = fo + (fo-fo')\,T$$

Infiltration equations like equation (1) are based on the cumulative opportunity time. The infiltrated volume added by one particular surge must therefore be computed as a difference. For instance, if at a point x, the opportunity time prior to the on-going surge is $\overline{T}$, the opportunity time created by the present surge is T, the infiltrated volume added by the present surge is

$$Z\ (t) = (\overline{T} + T) - Z\ (T)$$

for verification of models, the input data for surge flow include soil type, inflow (lps), field length, field slope, Manning's 'n', hydraulic section parameters, furrow geometry parameters, continuous flow intake parameters, surge flow intake parameters, cycle time and cycle ratio. A complete analysis of surge flow for model verification should deal in sequence with advance, rear end recession and continued front end advance, rear end recession and front end recession. The two recession phases are more important than the advance phases.

During the course of the present study, the recession data could not be accurately observed and measured in the field as the water from two consecutive surges overlapped in most cases, since the off-time of each surge was not sufficient for the water to recede completely. The off-times could not be increased or the cycle-time varied, since the optimum number of 4-6 surges could not be achieved then. The length of the furrow was a limiting factor and if a longer field could be obtained, the analysis could have been made easier by varying cycle times and OFF times to obtain distinct recession times. Thus the verification of surface irrigation hydraulic models with the field measured infiltration data could not be performed in the absence of adequate data for analysis.

# Results and Discussion

# RESULTS AND DISCUSSION

Surge irrigation, a new innovation to surface irrigation technology was introduced with the objective of minimising the quantity of water utilised, but still satisfying the soil and crop water requirements. The effective management of the system requires feedback on the performance of the system. The information collected during the in-field evaluation of the system may be used for improving the management of the monitored system, for evaluating the system design, for comparing one management system to another or simply for broadening the data base for this type of irrigation system on different soils with a range of management parameters. An accurate and repeatable evaluation of surge irrigation is invaluable for determining whether the application of surge irrigation accomplishes the irrigator's goals. With the objective of obtaining suitable management parameters for surge irrigation in furrows, the present study was conducted in the Instructional farm of KCAET, Tavanur. The results of the experimental study are enunciated in this section.

## 4.1 Analysis of soil characteristics

The soil at the experimental site was analysed for its physical properties like soil texture and infiltration rate. The results of the analysis are as presented below.

### 4.1.1 Soil texture

A representative sample of soil from the experimental site was collected, oven-dried and subjected to sieve analysis. The results of the sieve analysis of the soil are as shown in Table 2.

Table 2. Grain size distribution obtained by sieve analysis

| Soil material | Size range (mm) | Weight of soil retained on the sieve (gm) | % of total weight |
|---|---|---|---|
| Gravel | >4.75 | 60.65 | 4.70 |
|  | Coarse 4.75-2 | 28.65 | 2.22 |
| Sand | Medium 2-0.425 | 147.06 | 11.40 |
|  | Fine 0.425-0.075 | 889.71 | 68.95 |
| Silt and Clay | <0.075 | 164.13 | 12.72 |
| Total |  | 1290.20 |  |

According to Indian Standard's classification, the soil comes under coarse-grained division with more than 75 per cent of the total material by weight larger than 75 micron Is. Sieve size. The particles finer than 75 micron is less than 15 per cent of the total. More than half of the coarse fraction, (>75 micron) is smaller than 4.75 mm Is Sieve size. Gravel comprises only 4.79 per cent of the total. Hence the soil of the experimental site comes under sand subdivision which includes sands and sandy soils. Out of this, the coarse sand fraction comprises 2.22 per cent, medium sand comprises 11.4 per cent and fine sand fraction forms the major portion with 68.95 per cent of the total weight coming under this size group. The soil of the site is thus observed to be a fine sandy soil. It has also considerable percentages of silt and clay amounting to 12.72 per cent. Hence the fine sandy soil with sizeable proportions of silt and clay contained in it can be classified under the group of sandy loam soils.

### 4.1.2 Infiltration

The infiltration characteristics of the soil at the experiment site were analysed according to the procedure explained in section 3.3. The data as presented in Table 3 were obtained from the field experiment. The plot of infiltration rate and accumulated infiltration against elapsed time is given in Fig.3.

Table 3. Sample data on cylinder infiltrometer tests

| Elapsed time | Cylinder - No.1 | | | | Cylinder - No.2 | | | | Cylinder - No.3 | | | | Average infiltration | Average accumulated infiltration |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Distance of water surface from reference | | Infiltration during the period | | Distance of water surface from reference | | Infiltration during the period | | Distance of water surface from reference | | Infiltration during the period | | | |
| min | Before filling cm | After filling cm | Ave. rate cm/hr | Accum. infilling cm | Before filling cm | After filling cm | Ave. rate cm/hr | Accum. infilling cm | Before filling cm | After filling cm | Ave. rate cm/hr | Accum. infilling cm | cm/hr | cm |
| - | - | 5 | - | - | - | 5 | - | - | - | 5 | - | - | | |
| 5 | 5.5 | 5 | 6 | 0.5 | 5.7 | 5 | 8.4 | 0.7 | 5.8 | 5 | 9.6 | 0.8 | 8.0 | 0.67 |
| 10 | 5.5 | 5 | 6 | 1.0 | 5.7 | 5 | 8.4 | 1.4 | 5.8 | 5 | 9.6 | 1.6 | 8.0 | 1.33 |
| 15 | 5.5 | 5 | 6 | 1.5 | 5.8 | 5 | 8.4 | 2.2 | 5.65 | 5 | 7.8 | 2.25 | 7.4 | 1.98 |
| 25 | 5.7 | 5 | 4.2 | 2.2 | 6.0 | 5 | 6.0 | 3.2 | 6.2 | 5 | 7.2 | 3.45 | 5.8 | 3.07 |
| 45 | 6.2 | 5 | 3.6 | 3.4 | 6.3 | 5 | 3.9 | 4.5 | 6.5 | 5 | 4.5 | 4.95 | 4.0 | 4.40 |
| 60 | 5.6 | 5 | 2.4 | 4.0 | 5.9 | 5 | 3.6 | 5.4 | 5.8 | 5 | 3.2 | 5.75 | 3.1 | 5.17 |
| 75 | 5.5 | 5 | 2.0 | 4.5 | 5.7 | 5 | 2.8 | 6.1 | 5.7 | 5 | 2.8 | 6.45 | 2.5 | 5.80 |
| 90 | 5.5 | 5 | 2.0 | 5.0 | 5.7 | 5 | 2.8 | 6.8 | 5.6 | 5 | 2.4 | 7.05 | 2.4 | 6.40 |
| 105 | 5.5 | 5 | 2.0 | 5.5 | 5.7 | 5 | 2.8 | 7.5 | 5.6 | 5 | 2.4 | 7.65 | 2.4 | 7.00 |
| 120 | 5.5 | 5 | 2.0 | 6.0 | 5.7 | 5 | 2.8 | 8.2 | 5.6 | 5 | 2.4 | 8.25 | 2.4 | 7.60 |

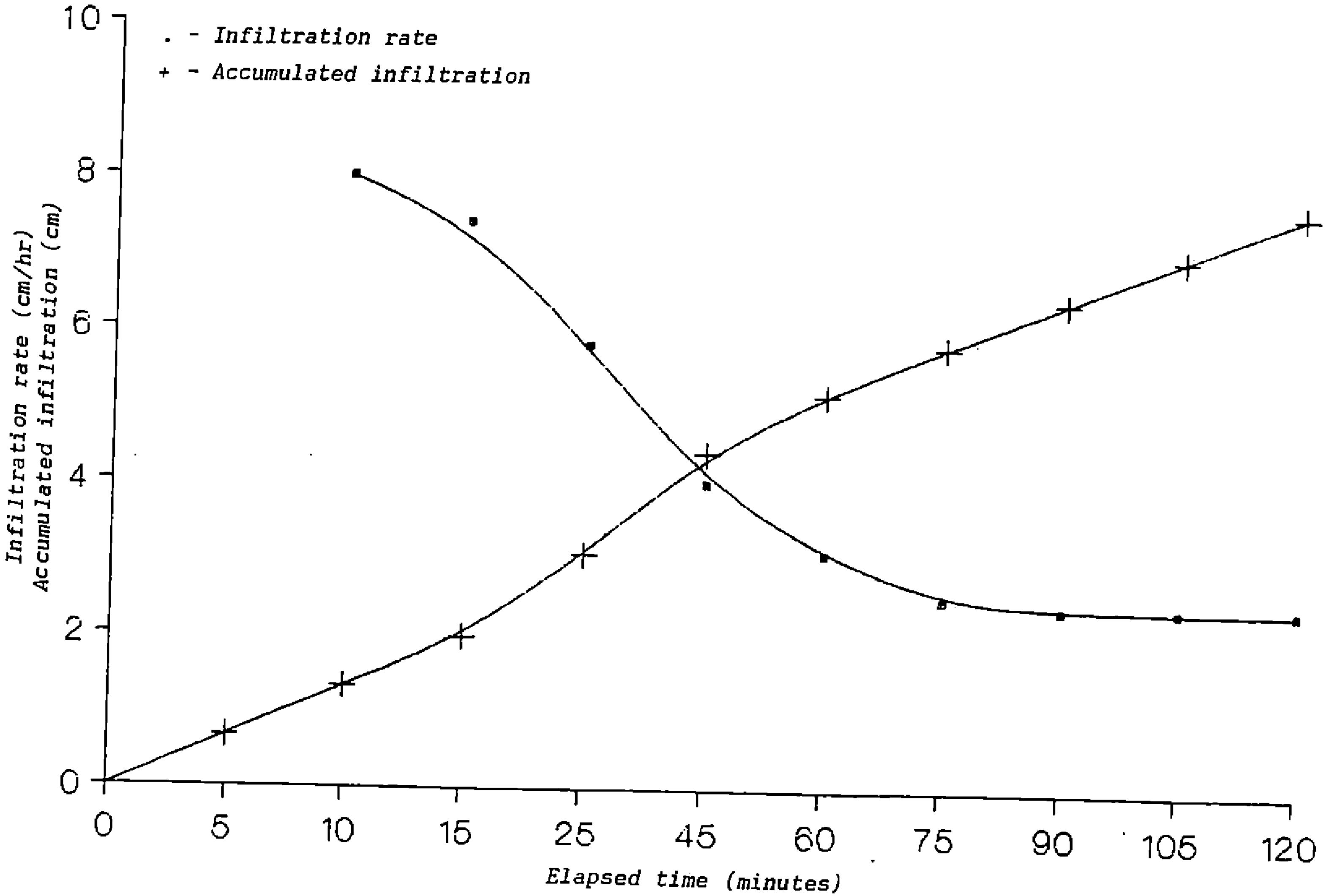


FIG.3 PLOT OF ACCUMULATED INFILTRATION AND AVERAGE INFILTRATION RATE AGAINST ELAPSED TIME

The functional relationship between Accumulated Infiltration (y) and Elapsed time (t) was derived and the equation so obtained was

$$y = 1.047\ (t)^{0.451} - 1.52$$

where,

y - accumulated infiltration (cm)

t - elapsed time (min)

The method of averages used to determine the goodness of fit is presented in the Appendix-II. The goodness of fit was also evaluated.

## 4.2 Evaluation of the system

The experimental set up to accomplish a comparative evaluation of continuous and surge flow furrow irrigation systems and to select suitable management parameters of surge irrigation system was completed according to the methodology detailed in section 3.4. The design and layout of the system in the field was completed by the month of March. The system was analysed for successful operation for a period of two months during which detailed data on advance and infiltration characteristics were collected. Initially, the data was taken for continuous flow irrigation, for stream flow rates of 1.3, 1.7 and 2.1 lps. Following this, the analysis of surge flow with cycle ratios of 1/2, 1/3 and 2/3 was done, for the three discharges as done under continuous flow. The experiments were repeated in the same set of furrows with sufficient time gap between readings to eliminate the influence of one irrigation on the other. Detailed analysis of the collected data and the results so obtained are presented below under the various captions.

### 4.2.1 Water front advance data

Data on the time taken for the advance of water front to every 3 m interval was collected from the field during continuous flow and surge flow irrigations for three discharge rates of 1.3, 1.7 and 2.1 lps. The readings obtained for the various cases were tabulated to enable comparison between treatment combinations and between replications. For continuous flow furrow irrigation, the total time taken for the water to advance upto the tail end of the field was noted for each treatment combination, and the data is presented in Table 4.

Table 4. Continuous flow advance time data

| Sl. No. | | Advance time in minutes | | | | |
|---|---|---|---|---|---|---|
| | | $R_1$ | $R_2$ | $R_3$ | $R_4$ | Mean |
| 1. | $T_1$ | 23.24 | 22.20 | 22.50 | 23.38 | 22.83 |
| 2. | $T_2$ | 21.73 | 22.01 | 21.95 | 22.15 | 21.96 |
| 3. | $T_3$ | 19.63 | 19.52 | 18.96 | 19.34 | 19.36 |

From the data, it was found that the advance time decreased with the increase in stream flow rate. The mean value of advance time for the lowest discharge of 1.3 lps was 22.83 minutes, whereas for 1.7 lps, the value reduced to 21.96 minutes. The value was still lesser for the highest discharge of 2.1 lps with 19.36 minutes taken to cover a distance of 102 m. The values varied less between replications and the mean values were taken for analysis. In the case of surge flow, the total time of irrigation including the valve ON times and OFF times is greater than that for continuous flow. But the total ON time of valve, which represents the time when inflow to the furrow takes place, is considered for comparison with continuous flow. The data for surge flow with cycle ratio = 1/2 is given in Table 5.

Table 5. Data of valve ON-time for surge flow, cycle ratio=1/2

| Sl. No. | | Valve ON-time in minutes | | | | |
|---|---|---|---|---|---|---|
| | | $R_1$ | $R_2$ | $R_3$ | $R_4$ | Mean |
| 1. | $T_1$ | 18.0 | 18.0 | 21.0 | 21.0 | 19.50 |
| 2. | $T_2$ | 15.5 | 16.3 | 18.0 | 18.0 | 16.95 |
| 3. | $T_3$ | 15.0 | 15.0 | 18.0 | 18.0 | 16.50 |

In this case also, the total valve ON time was found to decrease with increase in stream flow rate. The decrease was significant between 1.3 and 1.7 lps than between 1.7 and 2.1 lps. When compared with continuous flow, there was significant reduction in the time of advance. For a discharge of 1.3 lps, there was 14.59 per cent reduction in ON time. In the case of 1.7 lps, the reduction in ON time was still higher, coming to about 22.8 per cent. For the highest discharge, the reduction was 14.77 per cent. Thus in all three cases, the surge effect was pronounced with significant reduction in advance time. The data of total valve ON time for surge flow of cycle ratio 1/3, is presented in Table 6.

Table 6. Data of valve ON-time for surge flow, cycle ratio=1/3

| Sl. No. | Valve ON-time in minutes | | | | |
|---|---|---|---|---|---|
| | $R_1$ | $R_2$ | $R_3$ | $R_4$ | Mean |
| 1. $T_1$ | 15.0 | 15.0 | 12.0 | 15.0 | 14.25 |
| 2. $T_2$ | 12.0 | 12.0 | 12.0 | 15.0 | 12.75 |
| 3. $T_3$ | 12.0 | 12.0 | 12.0 | 12.0 | 12.00 |

The data indicates that the total valve ON time decreases with increase in stream flow rate, though the decrease is less pronounced at higher values of discharge of 1.7 lps and 2.1 lps. Comparison with continuous flow indicates more significant reduction in advance time than in the case of surge flow with cycle ratio = 1/2. Percentage reduction in time was as high as 37.6 per cent for treatment 1. It was still higher as 41.94 per cent in case of treatment 2, and was 38.01 per cent for treatment 3. In all three treatments, surge flow with cycle ratio 1/3 proved more advantageous than that with cycle ratio 1/2 in reducing the time required to complete the advance. The data for surge flow with cycle ratio = 2/3 is presented in Table 7.

Table 7. Data of valve ON-time for surge flow, cycle ratio=2/3

| Sl. No. | | Valve ON-time in minutes | | | | |
|---|---|---|---|---|---|---|
| | | $R_1$ | $R_2$ | $R_3$ | $R_4$ | Mean |
| 1. | $T_1$ | 15.0 | 15.0 | 15.0 | 15.0 | 15.00 |
| 2. | $T_2$ | 15.0 | 15.0 | 14.0 | 15.0 | 14.75 |
| 3. | $T_3$ | 15.0 | 15.0 | 14.83 | 15.0 | 14.96 |

In this case, the total valve ON time was highest for the lowest discharge. For higher discharges the values were almost equal, of which the value was highest for the highest discharge. The variation in treatments 2 and 3 are not significant and it can be concluded that there is no considerable variation in the effects produced by the higher discharges chosen for the study. The ON-time was much less compared to continuous flow and slightly higher compared to surge flow with cycle ratio 1/3. The effect was however better than the case with surge flow of cycle ratio 1/2. The reduction in ON-time varied as 34.29 per cent for treatment 1, 32.83 per cent for treatment 2, and 22.73 per cent for treatment 3, when compared with continuous flow. Thus from the analysis of valve ON-time, it can be observed that surge flow with cycle ratio 1/3 proves the most advantageous in reducing the ON-time of valve, and surge effect in reducing the advance time is significant in the soil of the study area. The detailed data on advance time at every 3 m interval along the furrow for each treatment combination is presented in the Appendix-III.

### 4.2.2 Development of advance trajectories

With the detailed data on advance of water front, advance trajectories were developed for the various treatment combinations, with advance time in minutes along the Y-axis and distance from the furrow end in metres along the X-axis. The data of the corresponding continuous and surge flow treatments were plotted in the same graph to enable an effective comparison between the two. Figure 4 shows the advance trajectories for continuous flow and surge flow with cycle ratio = 1/2 for a discharge of 1.3 lps for one of the cases. Fig.5 gives the curves for another case under the same treatment combination. In case 1, only six surges were used to complete the advance whereas in the other seven surges were needed. In both the cases it was found that the advance curves for the first surge and the continuous flow closely coincided for the distance upto which, the first surge advanced. For each surge, the time required for water to advance through the initially wet portions of the furrow was much less compared to the previous surge. The advance time

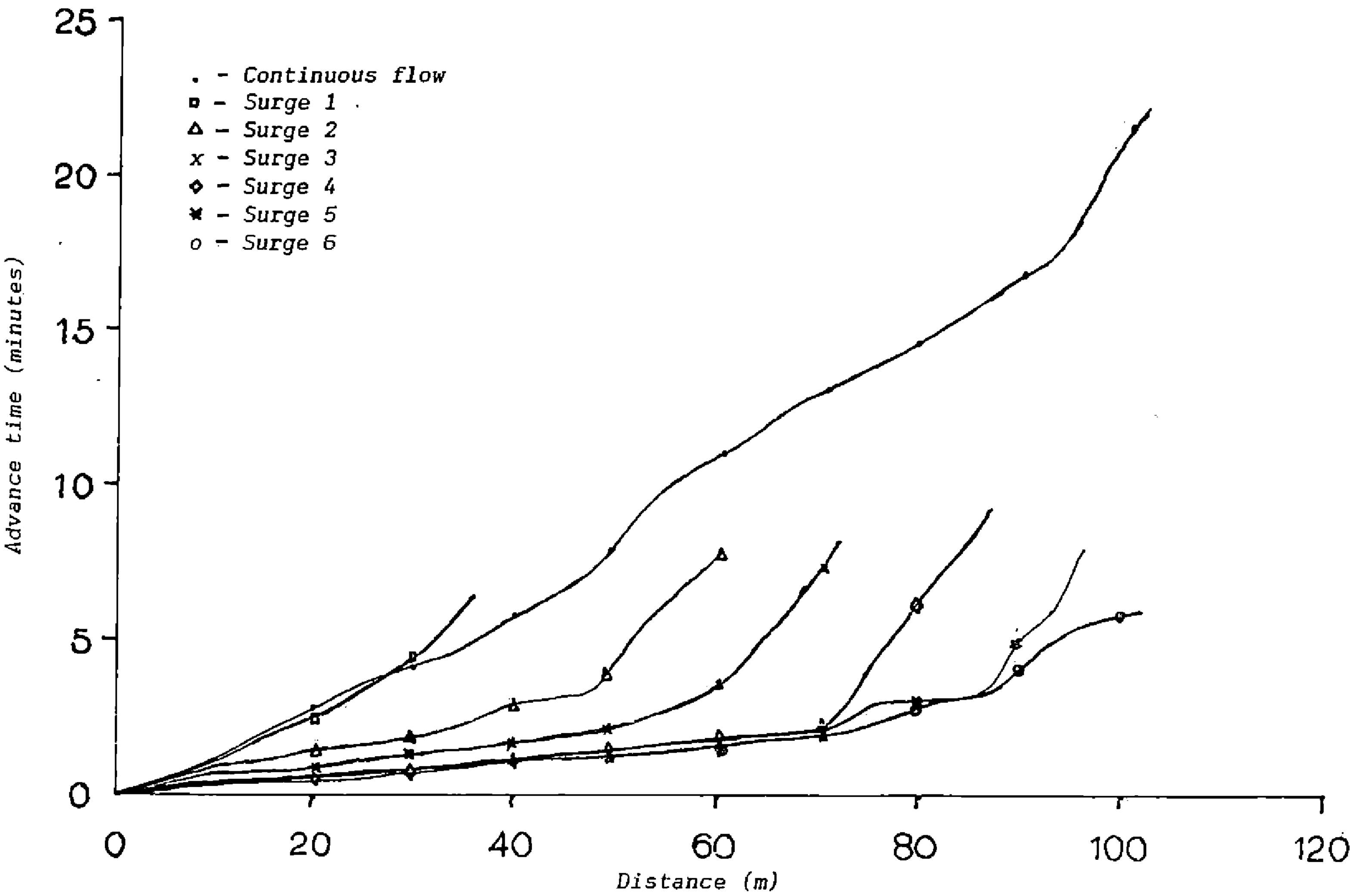


*FIG.4 ADVANCE TRAJECTORIES FOR CONTINUOUS FLOW AND SURGE FLOW (CR=1/2) FOR A DISCHARGE OF 1.3 lps*

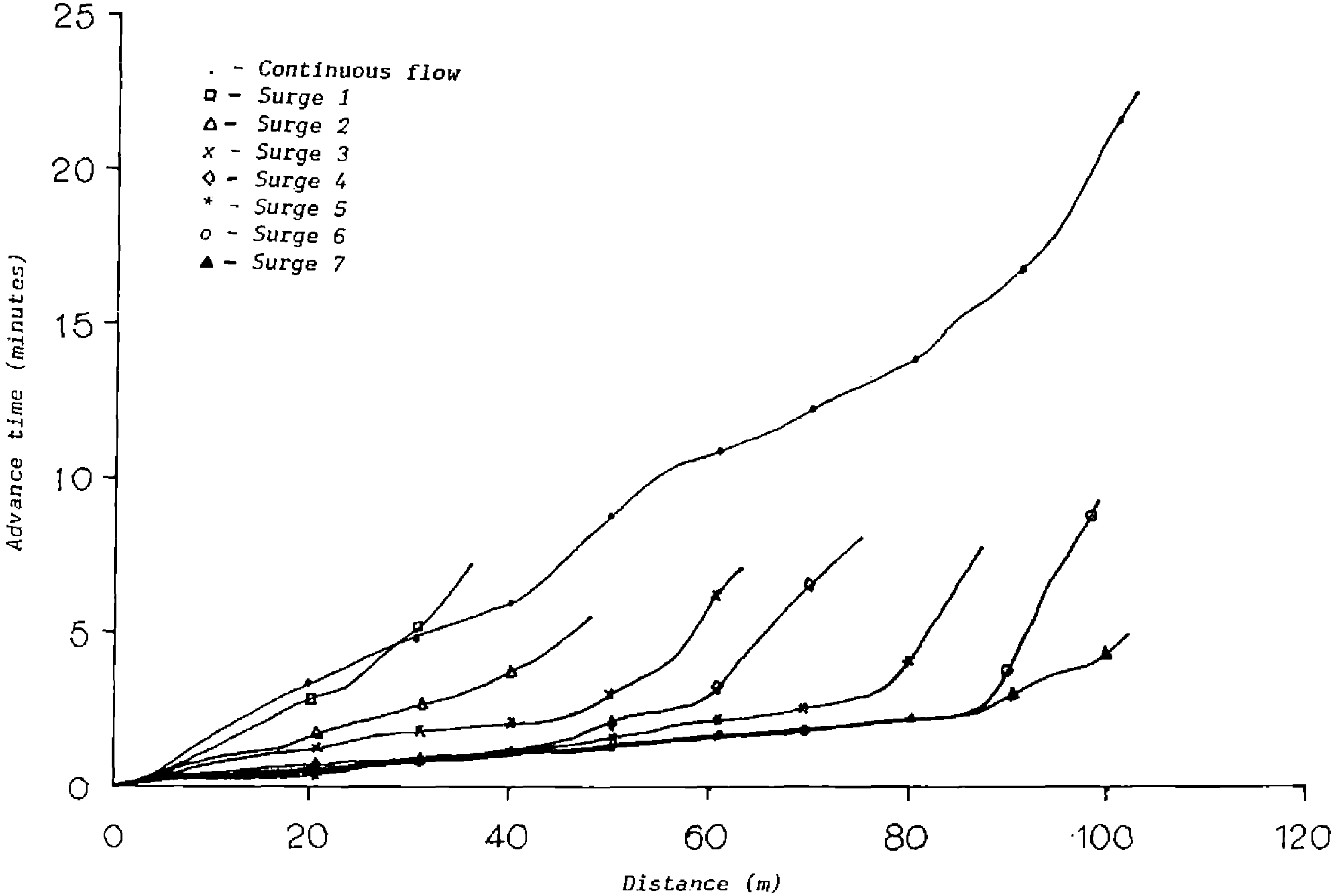


**FIG.5 ADVANCE TRAJECTORIES FOR CONTINUOUS FLOW AND SURGE FLOW (CR=1/2) FOR A DISCHARGE OF 1.3 lps**

significantly increased after this distance. The sixth surge travelled through the whole length of the furrow with an advance time of 5.94 minutes in the first case. The surges 1, 2, 3, 4, 5 and 6 respectively covered 36, 60, 72, 87, 96 and 102 m of the furrow length. Continuous flow took 22.2 minutes to cover the full length of the furrow. In the second case, the surges 1, 2, 3, 4, 5, 6 and 7 covered 36, 48, 63, 75, 87, 99 and 102 m respectively and the seventh surge travelled the entire distance within 5.02 minutes. Continuous flow in this case took 22.5 minutes to complete the advance.

The advance trajectories for continuous flow and surge flow with cycle ratio = 1/2 for a discharge of 1.7 lps is given in Fig.6 and Fig.7. Though the curves for first surge and continuous flow, closely coincided, in the first case, (Fig.6), there was a slight decrease in advance time of the first surge, which may be attributed to a higher initial moisture content in the furrow before the surge irrigation evaluation. The surges 1, 2, 3, 4 and 5 covered respectively 33, 54, 69, 87 and 102 m of the furrow length. In the second case, the surges 1, 2, 3, 4 and 5 covered 42, 60, 78, 93 and 102 m respectively. Continuous flow in these two cases took 21.73 and 22.01 minutes respectively, to complete the advance.

The advance trajectories for continuous flow and surge flow of cycle ratio = 1/2 for a discharge of 2.1 lps is given

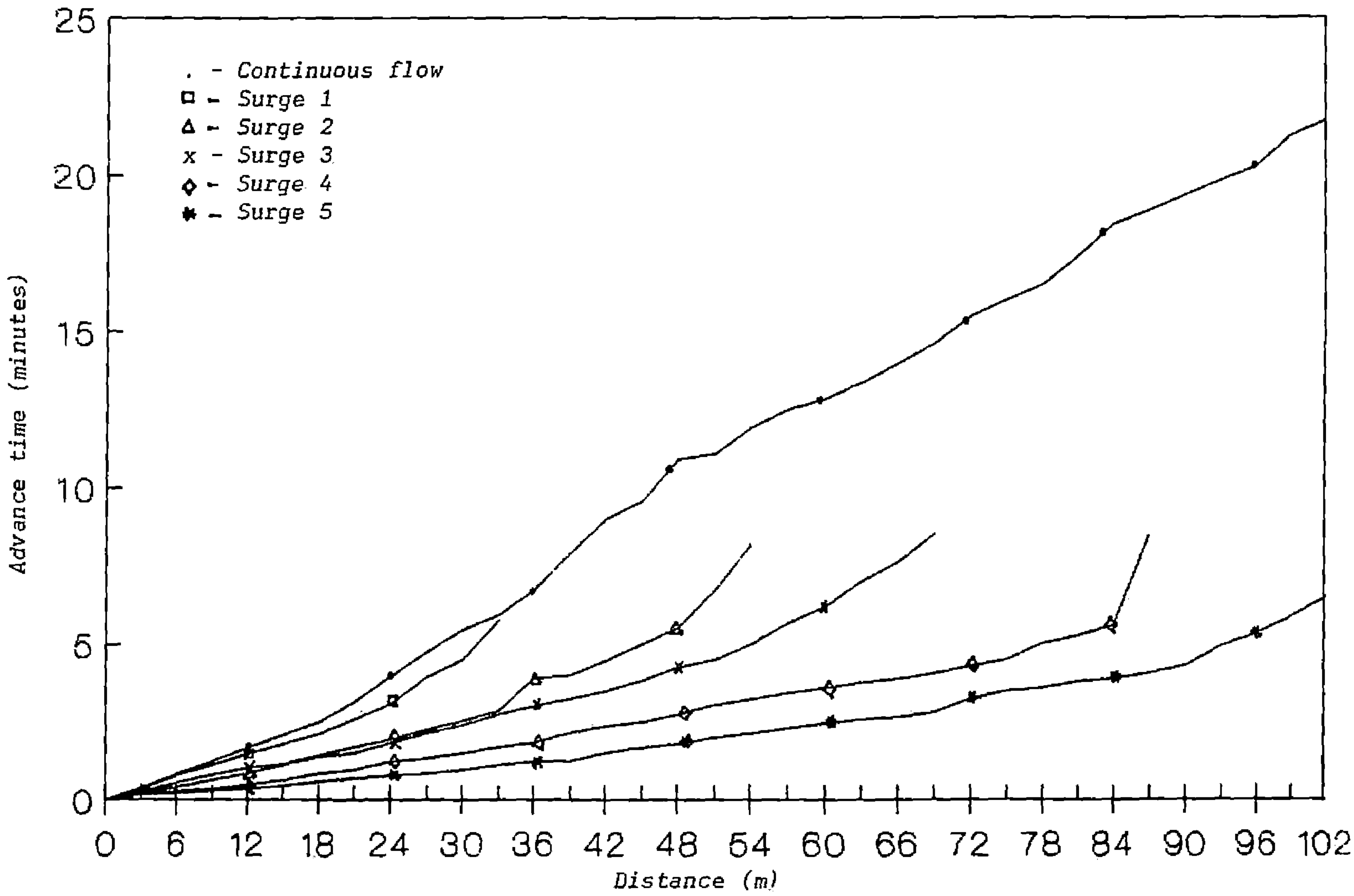


FIG.6 ADVANCE TRAJECTORIES FOR CONTINUOUS FLOW AND SURGE FLOW (CR=1/2) FOR A DISCHARGE OF 1.7 lps

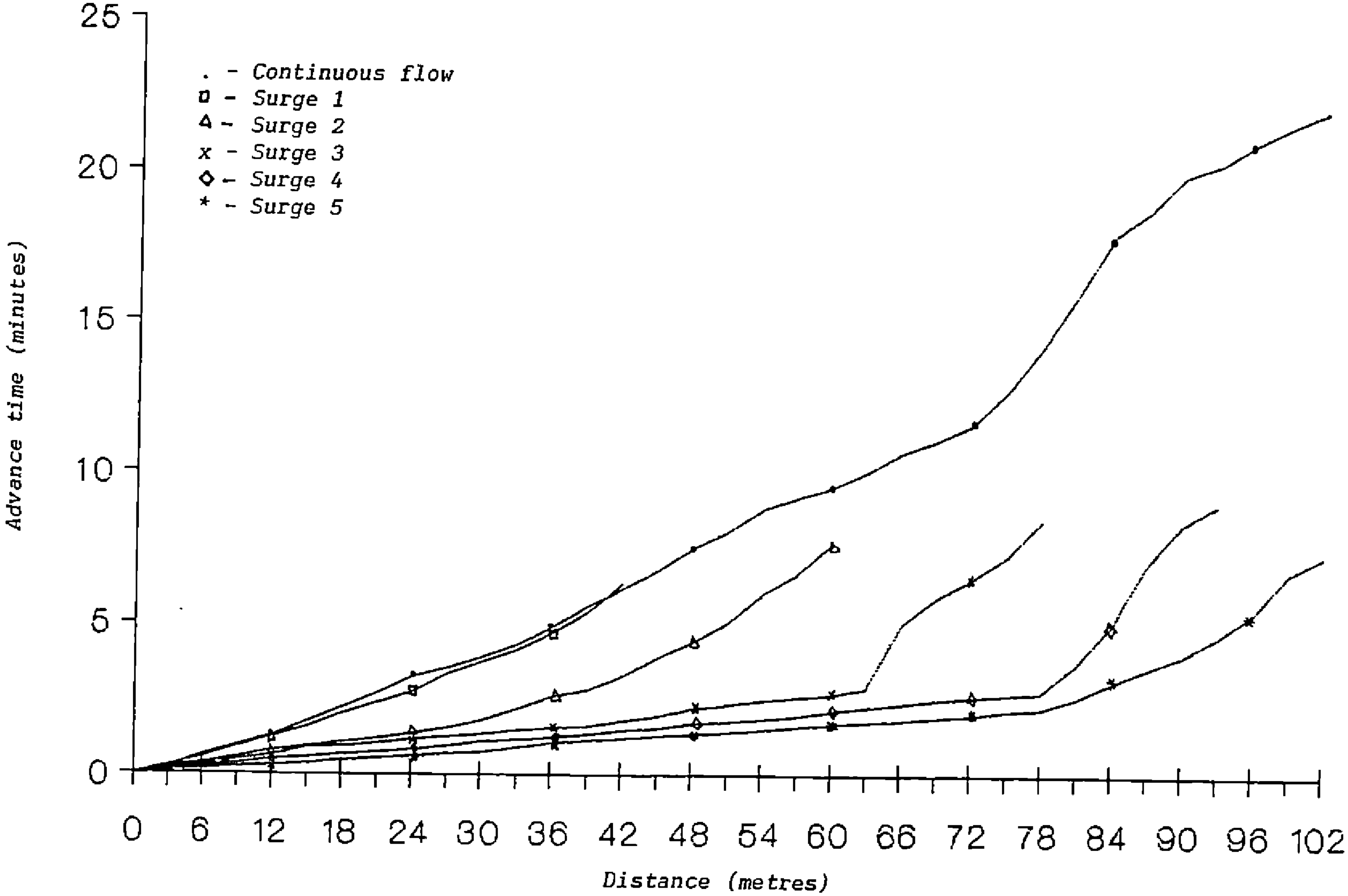


*FIG.7 ADVANCE TRAJECTORIES FOR CONTINUOUS FLOW AND SURGE FLOW (CYCLE RATIO = 1/2) FOR A DISCHARGE OF 1.7 lps*

in Fig.8. Surge flow in this case took six surges to complete the advance. The advance time at each 3 m interval for the first surge was slightly lesser than the continuous flow advance time which may be due to a higher initial moisture content in the furrows prior to surge irrigation evaluation. The surges 1, 2, 3, 4, 5 and 6 travelled 36, 48, 66, 78, 99 and 102 m respectively. Continuous flow in this case took 19.52 minutes to reach a distance of 102 m. Figures 9 and 10 represent the advance trajectories for continuous flow and surge flow of cycle ratio = 1/3 and a discharge of 1.3 lps. Surge flow completed the advance with five surges in one case. Whereas it took only four surges for the advance in the second case. The coincidence of advance curves for continuous flow and the first surge was more pronounced in the first case. According to Fig.9, the surges 1, 2, 3, 4 and 5 travelled 42, 66, 81, 93 and 102 m. Whereas the surges 1, 2, 3 and 4 travelled 45, 72, 96 and 102 m in the second case (Fig.10). The time taken for advance under continuous flow was 22.2 and 22.5 minutes respectively for the two cases considered.

The advance curves for continuous flow and surge flow of cycle ratio 1/3 and a discharge of 1.7 lps is given in Fig.11. Surge flow completed the advance with four surges. There was close resemblance between the curves for continuous flow and the first surge. The respective surges covered 51,

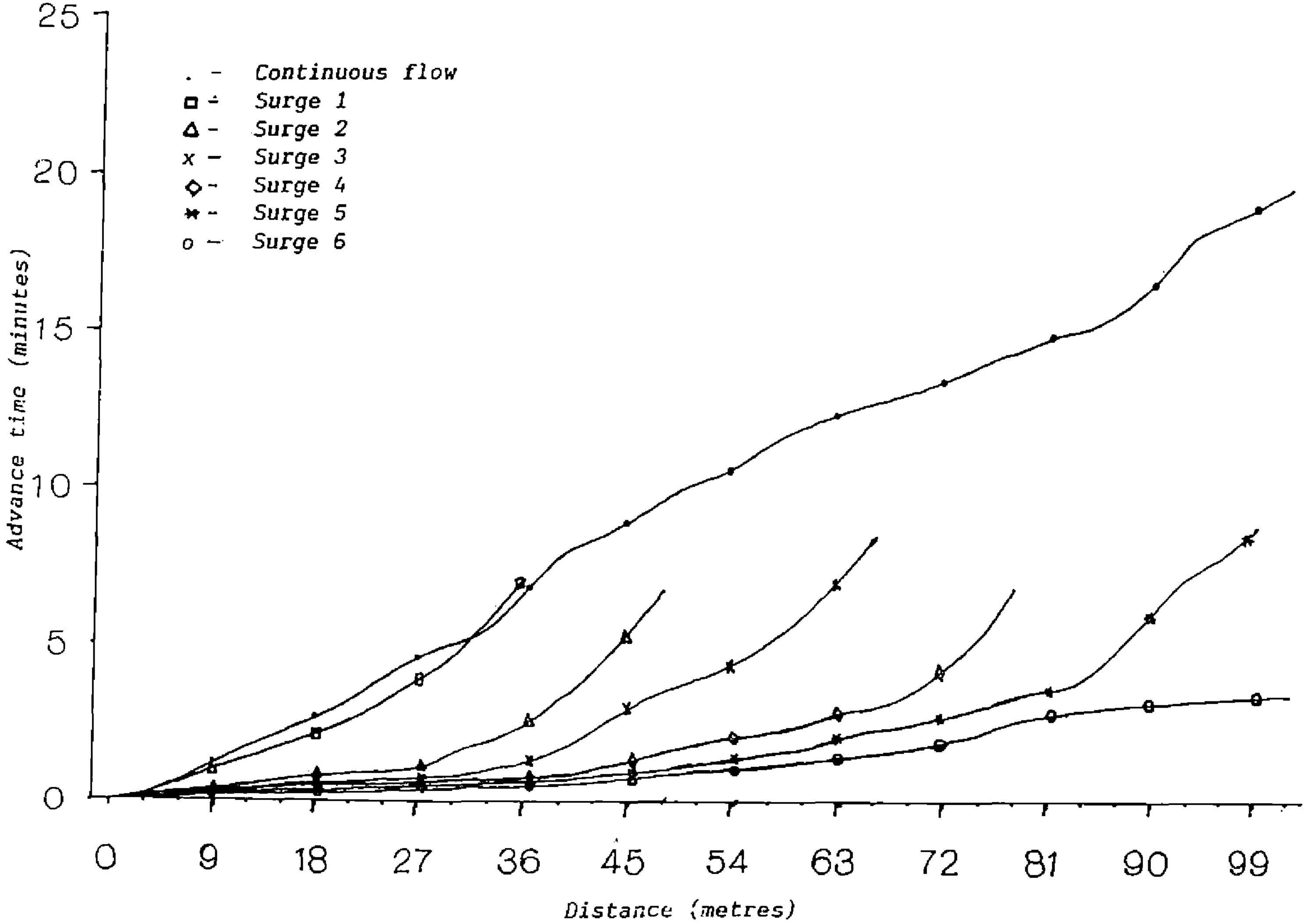


FIG.8 ADVANCE TRAJECTORIES FOR CONTINUOUS FLOW AND SURGE FLOW (CR = 1/2) FOR A DISCHARGE OF 2.1 lps

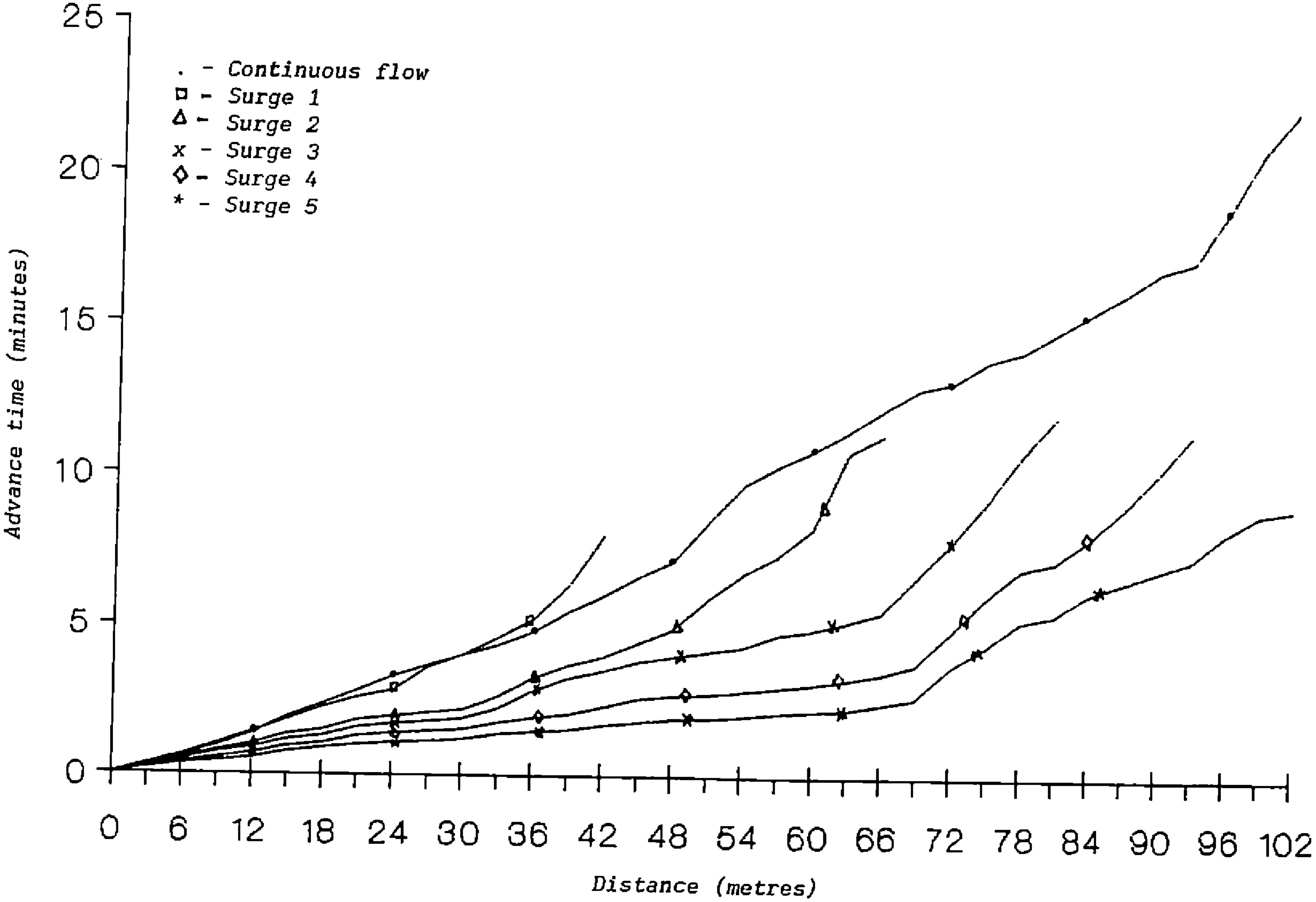


FIG.9 ADVANCE TRAJECTORIES FOR CONTINUOUS FLOW AND SURGE FLOW (CYCLE RATIO = 1/3) FOR A DISCHARGE OF 1.3 lps

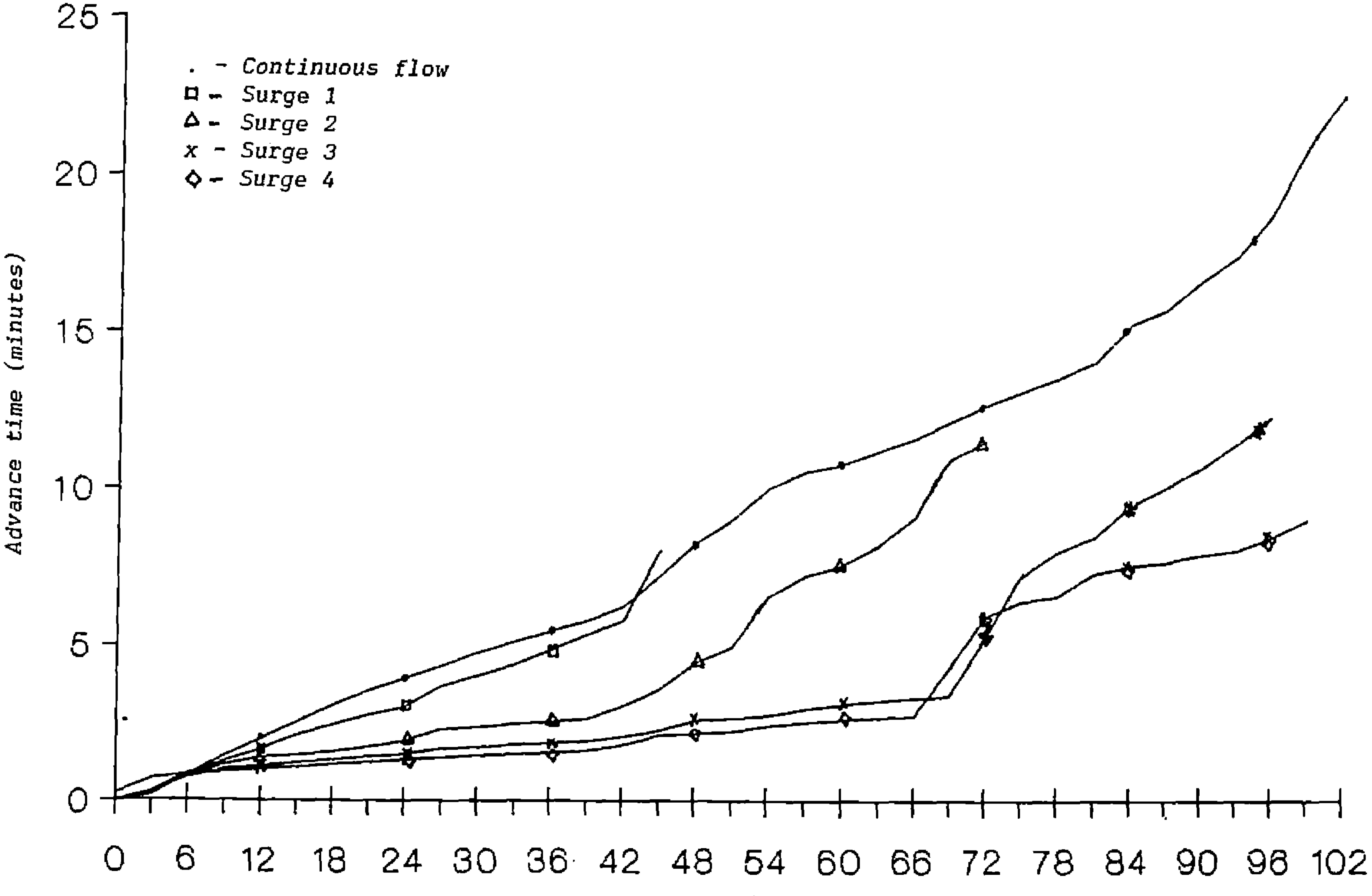


FIG.10 ADVANCE TRAJECTORIES FOR CONTINUOUS FLOW AND SURGE FLOW (CYCLE RATIO = 1/3) FOR A DISCHARGE OF 1.3 lps

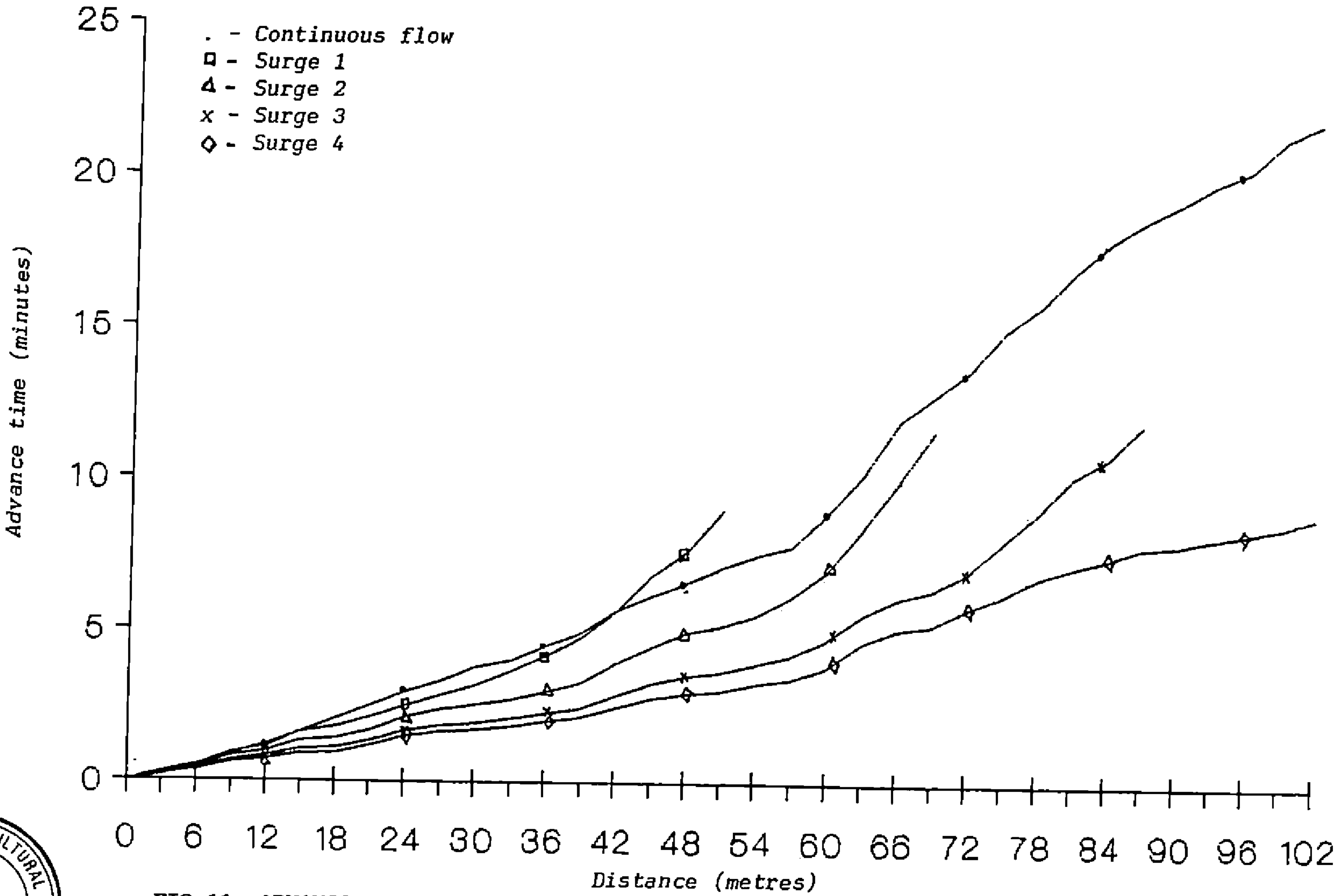


FIG.11 ADVANCE TRAJECTORIES FOR CONTINUOUS FLOW AND SURGE FLOW (CYCLE RATIO = 1/3) FOR A DISCHARGE OF 1.7 lps

69, 87 and 102 m, of the furrow length. The advance time for continuous flow was 21.95 minutes.

Figure 12 represents the advance trajectories for continuous flow and surge flow of cycle ratio = 1/3 for a discharge of 2.1 lps. The curves for the continuous flow and the first surge varied considerably in this set. The reduction in advance time during the period when the first surge travelled upto 39 m from one end, may be due to higher value of moisture content in the soil. Premonsoon shower had occurred in between the evaluation, and eventhough sufficient time gap was given, the soil had a higher moisture content compared to the condition before the evaluation of continuous flow. Beyond 39 m, the advance time increased for each intervel since it occurred during the off time of the surge and the stream size had reduced considerably. The advance was completed in 4 surges, which travelled 48, 69, 87 and 102 m respectively. The advance time for continuous flow was 18.96 minutes.

Figure 13 shows the advance curves for continuous flow and surge flow of cycle ratio 2/3, for a discharge of 1.3 lps. The curves for the continuous flow and the first surge closely coincided and the advance was completed in 3 surges. The surges travelled 60, 96 and 102 m respectively taking advance times of 9.18, 9.73 and 7.36 minutes, to travel these

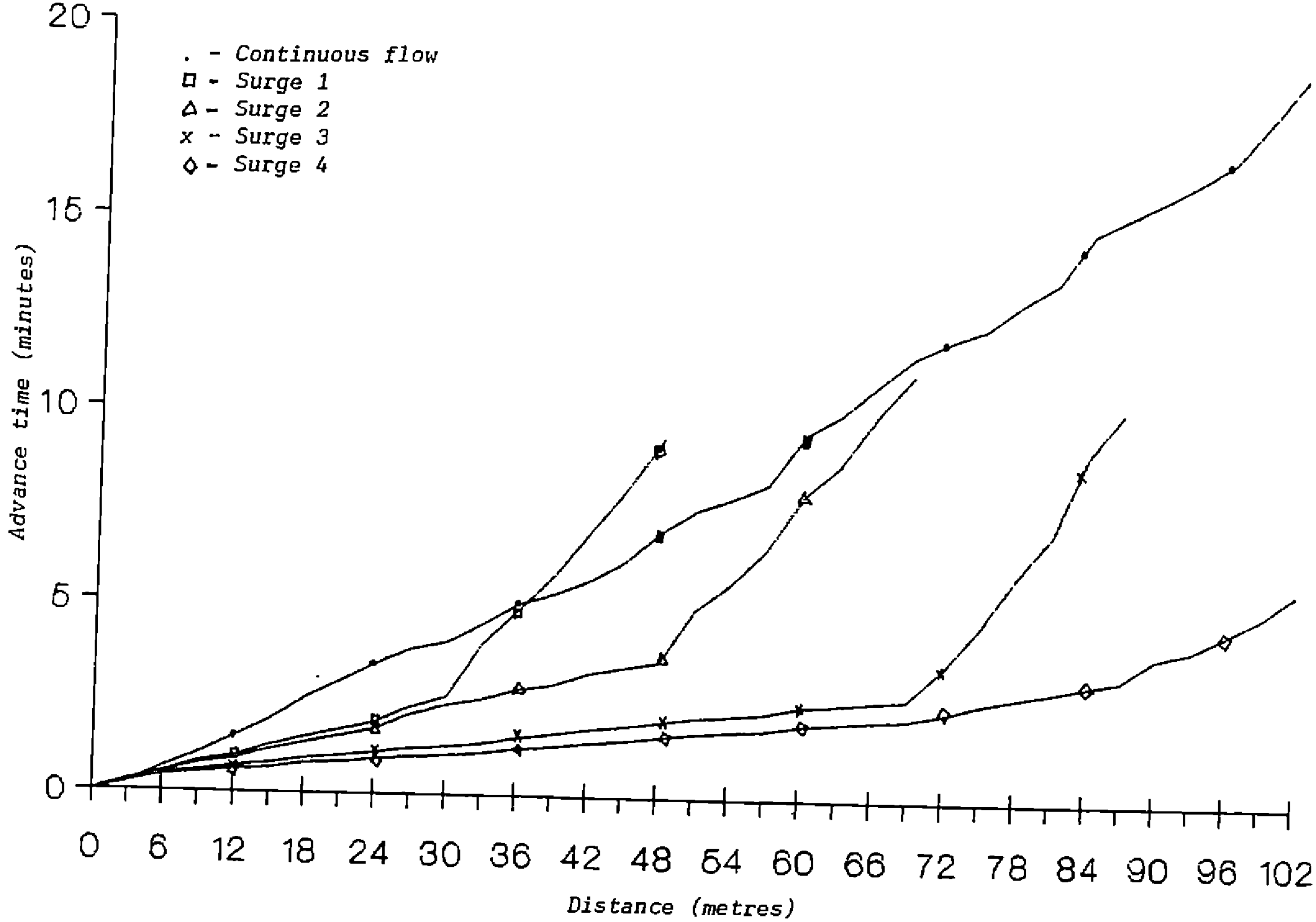


FIG.12 ADVANCE TRAJECTORIES FOR CONTINUOUS FLOW AND SURGE FLOW (CYCLE RATIO = 1/3) FOR A DISCHARGE OF 2.1 lps

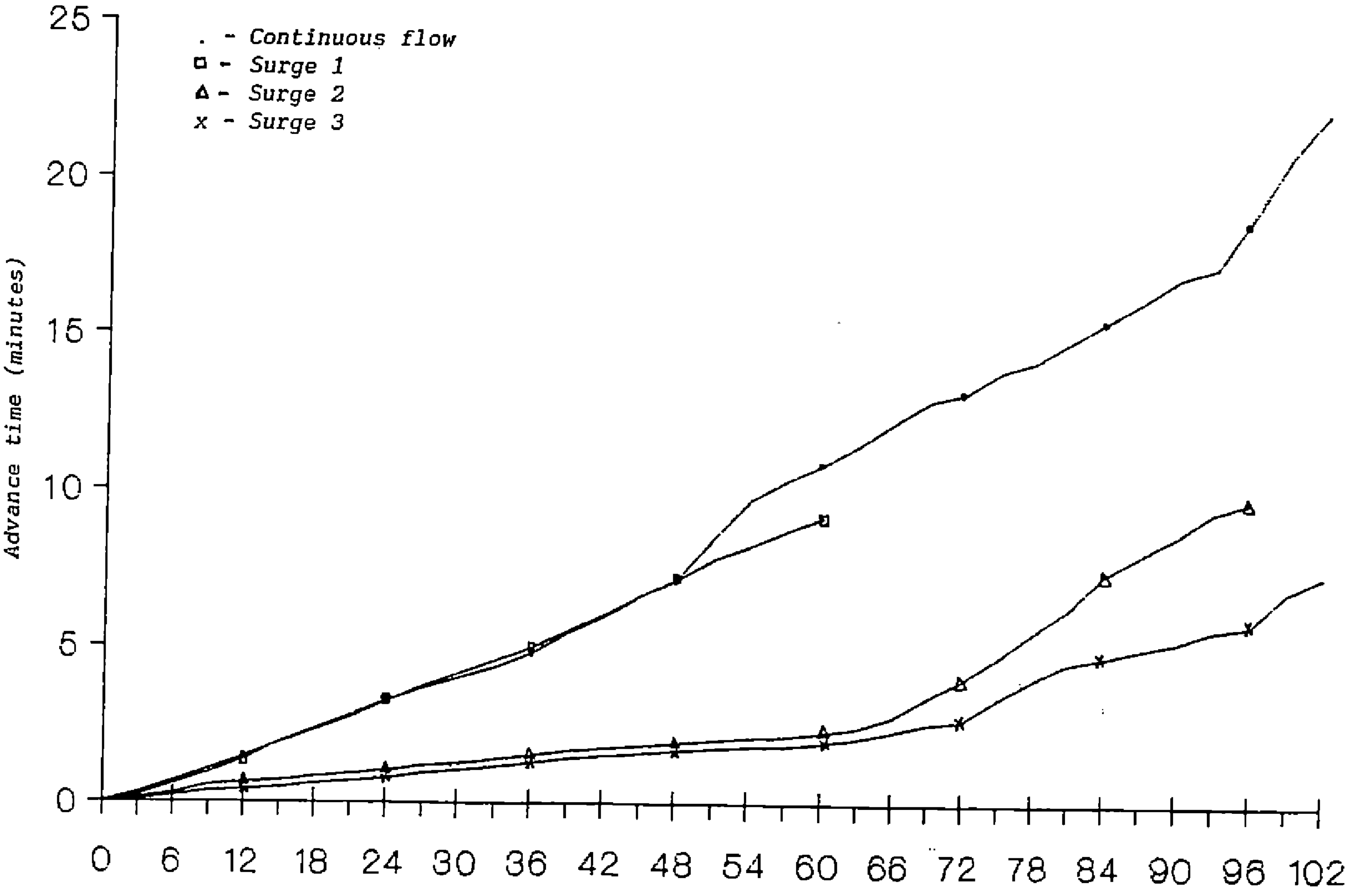


FIG.13 ADVANCE TRAJECTORIES FOR CONTINUOUS FLOW AND SURGE FLOW (CYCLE RATIO = 2/3) FOR A DISCHARGE OF 1.3 lps

distances. Continuous flow in this case took 22.2 minutes. Advance trajectories for continuous flow and surge flow of cycle ratio 2/3 for a discharge of 1.7 lps is presented in Fig.14. Very close resemblance between continuous flow and the first surge advance curves was obtained and the advance was completed in 3 surges. The surges covered 57, 90 and 102 m distances in 8.8, 9.97 and 4.0 minutes. Continuous flow took 21.95 minutes to complete the advance. Figure 15 represents the advance curves for continuous flow and surge flow of cycle ratio 2/3 for a discharge of 2.1 lps. In this case also, the advance was completed in 3 surges and the curve for continuous flow resembled that of the first surge, considerably. The surges travelled 60, 93 and 102 m in 8.7, 7.6 and 4.83 minutes respectively. The advance time for continuous flow was 18.96 minutes, in this case.

The analysis of advance trajectories in all cases indicates close coincidence between curves for the first surge and continuous flow. In one or two cases of exception, the reason was attributed to the changes in initial moisture content and the advance of surge during the off time with reduced stream flow. The time taken for advance in the initially wet portions of the furrow was less and advance times significantly increased beyond the overlapping distance. The faster advance of successive surges is caused by a

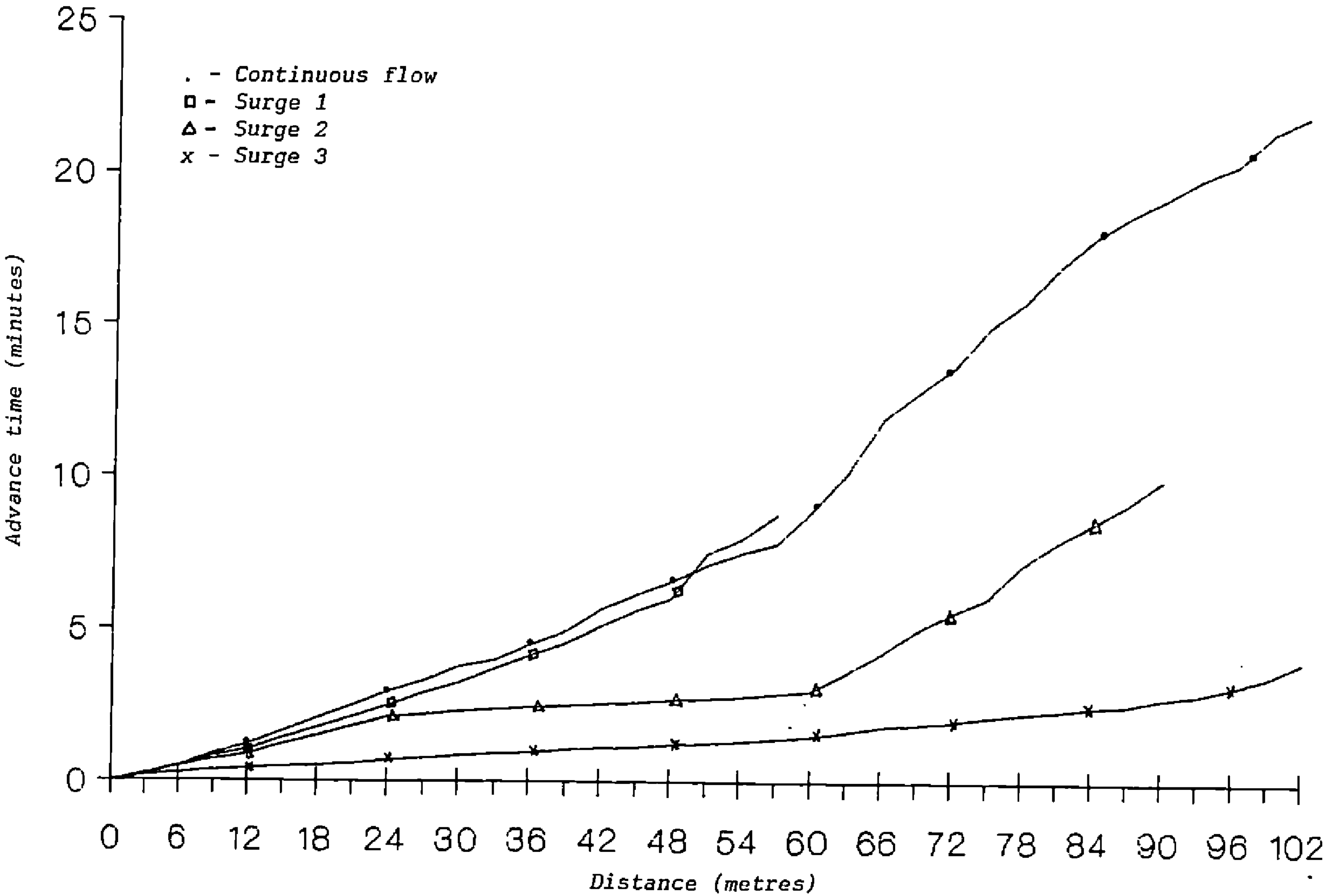


FIG.14 ADVANCE TRAJECTORIES FOR CONTINUOUS FLOW AND SURGE FLOW (CYCLE RATIO = 2/3) FOR A DISCHARGE OF 1.7 lps

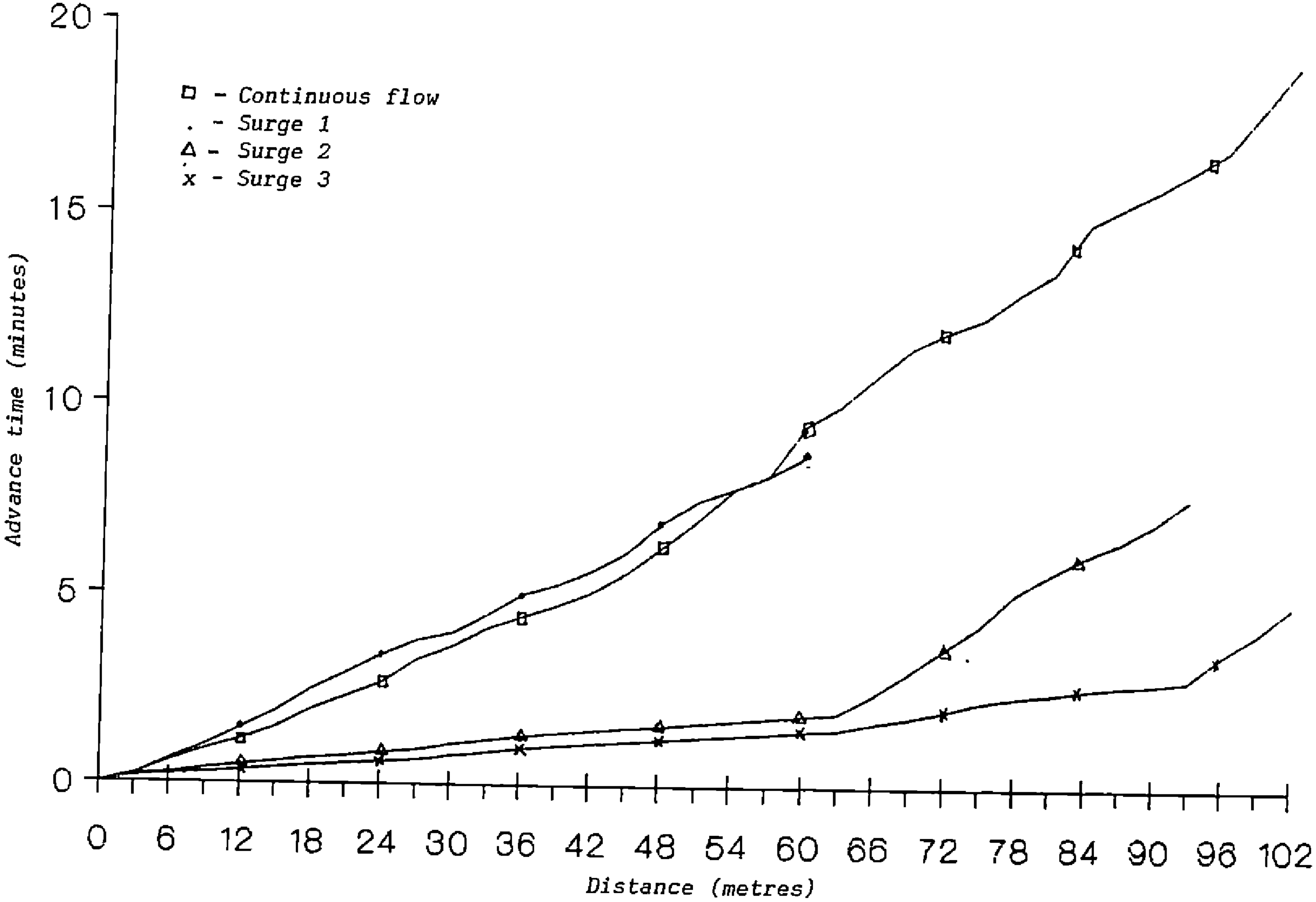


FIG.15 ADVANCE TRAJECTORIES FOR CONTINUOUS FLOW AND SURGE FLOW (CYCLE RATIO = 2/3) FOR A DISCHARGE OF 2.1 lps

reduction in the intake rate of the soil that occurred due to surging. Thus the pronounced effect of surging in affecting the pattern of water front advance in furrows was clearly depicted by the advance trajectories.

### 4.2.3 Data on the depth of flow

The depth of flow data collected from the field was used to calculate the infiltration parameters by volume-balance method. The average value of depth of flow in each section of furrow length was used to calculate the furrow cross section parameters and the surface storage. The detailed data on the depth of flow is presented in the Appendix-III for the different treatment combinations.

### 4.2.4 Volume-balance analysis

The determination of infiltration parameters were done with the data on advance time and depth of flow, according to the procedure explained in section 3.7.1. The values of infiltrated volume and infiltrated depth at different sections of 15 m length along the furrow were tabulated for the different treatment combinations and the corresponding replications. Infiltrated volume in litres and infiltrated depth in cm for the different discharges and various replications under continuous flow is presented in Table 8. The values of infiltrated volume ranged from 50 to 1000 litres

Table 8. Infiltration parameters for continuous flow

| Discharge lps | Distance m | Infiltrated volume Litres | | | | Infiltrated depth cm | | | |
|---|---|---|---|---|---|---|---|---|---|
| | | $R_1$ | $R_2$ | $R_3$ | $R_4$ | $R_1$ | $R_2$ | $R_3$ | $R_4$ |
| 1.3 | 15 | 188.44 | 59.1 | 93.82 | 231.13 | 3.44 | 1.05 | 1.64 | 4.24 |
| | 30 | 544.68 | 192.57 | 219.81 | 482.31 | 5.16 | 1.84 | 2.03 | 4.32 |
| | 45 | 641.83 | 362.43 | 158.89 | 618.75 | 2.07 | 2.35 | 0.88 | 3.59 |
| | 60 | 1056.30 | 584.22 | 587.28 | 1110.48 | 5.07 | 2.75 | 2.79 | 5.52 |
| | 75 | 1119.15 | 786.82 | 807.39 | 1173.72 | 4.10 | 3.01 | 3.21 | 4.42 |
| | 90 | 1093.32 | 1062.00 | 1005.03 | 1357.35 | 3.20 | 3.52 | 3.28 | 4.35 |
| | 102 | 1496.21 | 1415.09 | 1202.87 | 1142.28 | 4.33 | 4.10 | 3.23 | 2.96 |
| 1.7 | 15 | 113.07 | 80.51 | 60.61 | 75.15 | 1.99 | 1.40 | 1.06 | 1.25 |
| | 30 | 346.44 | 190.95 | 162.87 | 180.15 | 3.02 | 1.67 | 1.40 | 1.50 |
| | 45 | 679.89 | 538.84 | 441.93 | 406.91 | 3.99 | 3.50 | 2.80 | 2.54 |
| | 60 | 998.82 | 728.04 | 636.72 | 612.78 | 4.59 | 3.47 | 2.98 | 2.84 |
| | 75 | 1183.33 | 869.35 | 1021.41 | 743.77 | 4.24 | 3.14 | 3.59 | 2.56 |
| | 90 | 1491.81 | 1670.49 | 1122.99 | 1159.86 | 4.55 | 5.32 | 3.07 | 3.16 |
| | 102 | 1635.16 | 1582.43 | 1333.96 | 1622.72 | 4.35 | 4.12 | 3.25 | 4.25 |

Contd.

Table 8 (Contd.)

| Discharge lps | Distance m | Infiltrated volume Litres | | | | Infiltrated depth cm | | | |
|---|---|---|---|---|---|---|---|---|---|
| | | $R_1$ | $R_2$ | $R_3$ | $R_4$ | $R_1$ | $R_2$ | $R_3$ | $R_4$ |
| 2.1 | 15 | 178.21 | 153.90 | 125.81 | 115.38 | 3.24 | 2.57 | 2.16 | 2.06 |
| | 30 | 327.57 | 423.30 | 285.81 | 452.00 | 2.99 | 3.72 | 2.47 | 4.19 |
| | 45 | 700.45 | 844.79 | 623.20 | 692.23 | 4.44 | 5.06 | 4.05 | 4.47 |
| | 60 | 848.94 | 1120.50 | 835.62 | 780.42 | 3.85 | 5.00 | 3.75 | 3.32 |
| | 75 | 1172.03 | 1309.75 | 1036.00 | 1262.53 | 4.40 | 4.70 | 3.62 | 4.73 |
| | 90 | 1466.91 | 1484.46 | 1519.74 | 1339.92 | 4.36 | 4.36 | 4.66 | 3.84 |
| | 102 | 1448.70 | 1979.41 | 1933.82 | 1818.82 | 3.43 | 5.43 | 5.35 | 4.7 |

at various sections for the discharges of 1.3 and 1.7 lps, while the range was 110 to 2000 litres in the case of the highest discharge treatment. Wide variability in infiltration parameters was experienced at different sections of the furrow length for all treatment combinations. The infiltrated depth ranged from 0.8 to 5.6 cm in treatment 1, 1 to 5.5 cm in treatment 2 and 2 to 5.4 cm in treatment 3. The infiltration parameters for surge flow of cycle ratio 1/2 is presented in Table 9. Infiltrated volume ranged between 18 to 515 litres for treatment 1, 7 to 480 litres for treatment 2 and 16 to 750 litres for treatment 3, when the various cases under each treatment combination was considered. The values of infiltrated depth varied as 0.01 to 3.6 cm in treatment 1, 0.02 to 3.1 cm in treatment 2, and 0.1 to 5.6 cm in treatment 3. Thus for the lesser values of discharge, the infiltrated depth was lesser, when compared to the highest discharge treatment. The infiltration parameters obtained with surge flow of cycle ratio 1/2 were much less compared to that under continuous flow.

The calculated values of infiltration parameters for surge flow of cycle ratio 1/3 are presented in Table 10. The values of infiltrated volume in the various sections of the furrow length ranged from 3 to 670 litres for treatment 1, 9 to 915 litres for treatment 2, and 8 to 910 litres for

Table 9. Infiltration parameters for surge flow (CR = 1/2)

| Discharge lps | Distance m | Infiltrated volume Litres | | | | Infiltrated depth cm | | | |
|---|---|---|---|---|---|---|---|---|---|
| | | $R_1$ | $R_2$ | $R_3$ | $R_4$ | $R_1$ | $R_2$ | $R_3$ | $R_4$ |
| 1.3 | 15 | 20.36 | 18.80 | 64.09 | 24.00 | 0.37 | 0.32 | 1.15 | 0.42 |
| | 30 | 172.80 | 177.13 | 258.41 | 367.04 | 1.55 | 1.63 | 2.45 | 3.55 |
| | 45 | 71.01 | 24.46 | 203.38 | 1.96 | 0.46 | 0.11 | 1.32 | 0.012 |
| | 60 | 420.91 | 446.10 | 254.68 | 54.00 | 2.09 | 2.23 | 1.22 | 0.26 |
| | 75 | 376.99 | 59.58 | 514.55 | 135.27 | 1.44 | 0.23 | 2.15 | 0.52 |
| | 90 | 213.24 | 6.91 | 82.77 | 211.21 | 0.71 | 0.02 | 0.28 | 0.69 |
| | 102 | 160.09 | 232.36 | 222.08 | 378.77 | 0.47 | 0.69 | 0.68 | 1.20 |
| 1.7 | 15 | 81.36 | 30.55 | 27.85 | 14.10 | 1.43 | 0.51 | 0.48 | 0.26 |
| | 30 | 327.17 | 153.27 | 214.21 | 63.16 | 3.08 | 1.32 | 1.90 | 0.54 |
| | 45 | 245.46 | 88.52 | 283.96 | 113.68 | 1.47 | 0.52 | 1.75 | 0.67 |
| | 60 | 204.96 | 480.95 | 50.95 | 126.62 | 0.89 | 2.22 | 0.23 | 0.53 |
| | 75 | 11.67 | 163.84 | 67.47 | 294.65 | 0.04 | 0.56 | 0.18 | 1.07 |
| | 90 | 6.51 | 460.39 | 171.45 | 16.95 | 0.02 | 1.45 | 0.50 | 0.05 |
| | 102 | 147.04 | 108.87 | 60.80 | 39.65 | 0.40 | 0.29 | 0.16 | 0.11 |

Contd.

Table 9 (Contd.)

| Discharge lps | Distance m | Infiltrated volume Litres | | | | Infiltrated depth cm | | | |
|---|---|---|---|---|---|---|---|---|---|
| | | $R_1$ | $R_2$ | $R_3$ | $R_4$ | $R_1$ | $R_2$ | $R_3$ | $R_4$ |
| 2.1 | 15 | 102.69 | 102.37 | 36.48 | 97.04 | 1.85 | 1.74 | 0.60 | 1.75 |
| | 30 | 314.95 | 360.96 | 197.01 | 422.06 | 2.84 | 3.14 | 1.62 | 3.86 |
| | 45 | 929.76 | 561.11 | 186.99 | 122.99 | 5.61 | 3.64 | 1.14 | 0.69 |
| | 60 | 750.79 | 407.67 | 16.61 | 350.07 | 3.68 | 1.86 | 0.07 | 1.53 |
| | 75 | 63.47 | 279.56 | 502.49 | 536.25 | 0.20 | 0.92 | 1.81 | 1.75 |
| | 90 | 36.86 | 40.42 | 75.07 | 118.42 | 0.11 | 0.11 | 0.21 | 0.37 |
| | 102 | 217.18 | 94.98 | 497.58 | 569.28 | 0.59 | 0.27 | 1.47 | 1.73 |

Table 10. Infiltration parameters for surge flow (CR = 1/3)

| Discharge lps | Distance m | Infiltrated volume Litres | | | | Infiltrated depth cm | | | |
|---|---|---|---|---|---|---|---|---|---|
| | | $R_1$ | $R_2$ | $R_3$ | $R_4$ | $R_1$ | $R_2$ | $R_3$ | $R_4$ |
| 1.3 | 15 | 21.73 | 3.04 | 77.78 | 14.48 | 0.36 | 0.05 | 1.41 | 0.25 |
| | 30 | 101.18 | 104.96 | 144.26 | 15.43 | 0.88 | 0.92 | 1.31 | 0.13 |
| | 45 | 343.75 | 35.64 | 388.42 | 322.22 | 1.97 | 0.18 | 2.38 | 1.84 |
| | 60 | 181.74 | 480.50 | 12.84 | 321.26 | 0.79 | 2.24 | 0.05 | 1.45 |
| | 75 | 71.13 | 508.42 | 369.06 | 370.10 | 0.24 | 2.00 | 1.41 | 1.34 |
| | 90 | 76.11 | 662.12 | 397.20 | 195.13 | 0.22 | 2.12 | 1.22 | 0.56 |
| | 102 | 28.45 | 512.94 | 307.49 | 317.73 | 0.07 | 1.55 | 0.87 | 0.90 |
| 1.7 | 15 | 102.45 | 62.95 | 19.25 | 8.54 | 1.76 | 1.06 | 0.31 | 0.14 |
| | 30 | 217.11 | 137.98 | 145.84 | 119.25 | 1.95 | 1.20 | 1.31 | 0.98 |
| | 45 | 575.11 | 455.75 | 514.41 | 513.54 | 3.26 | 2.75 | 3.27 | 3.12 |
| | 60 | 557.79 | 911.92 | 340.28 | 818.99 | 2.53 | 4.29 | 1.51 | 3.89 |
| | 75 | 126.45 | 828.40 | 276.11 | 393.05 | 0.42 | 3.25 | 0.96 | 2.56 |
| | 90 | 383.05 | 760.57 | 74.77 | 535.84 | 2.77 | 2.34 | 0.21 | 1.59 |
| | 102 | 365.11 | 822.61 | 525.33 | 433.15 | 1.06 | 2.41 | 1.49 | 1.21 |

Contd.

Table 10 (Contd.)

| Discharge lps | Distance m | Infiltrated volume Litres | | | | Infiltrated depth cm | | | |
|---|---|---|---|---|---|---|---|---|---|
| | | $R_1$ | $R_2$ | $R_3$ | $R_4$ | $R_1$ | $R_2$ | $R_3$ | $R_4$ |
| | 15 | 48.60 | 102.58 | 44.76 | 136.59 | 0.87 | 1.78 | 0.77 | 2.42 |
| | 30 | 264.41 | 269.89 | 153.93 | 394.15 | 2.22 | 2.37 | 1.39 | 3.46 |
| | 45 | 850.32 | 800.92 | 776.86 | 852.53 | 4.34 | 4.87 | 4.76 | 4.81 |
| 2.1 | 60 | 651.77 | 453.27 | 587.01 | 371.87 | 2.93 | 2.03 | 2.57 | 1.57 |
| | 75 | 318.17 | 906.87 | 52.13 | 42.75 | 1.10 | 3.38 | 0.18 | 0.16 |
| | 90 | 8.71 | 693.78 | 12.67 | 24.30 | 0.03 | 2.10 | 0.04 | 0.08 |
| | 102 | 620.80 | 114.04 | 378.48 | 446.77 | 1.85 | 0.31 | 1.09 | 1.30 |

treatment 3 for the various cases. Infiltrated depth ranged as 0.05 to 2.4 cm for treatment 1, 0.1 to 3.9 cm for treatment 2 and 0.03 to 4.8 cm for treatment 3. The infiltration parameters obtained in this case also were much less compared to the values under continuous flow. Also the values were found to be lesser than in the case of surge flow with cycle ratio 1/2. Thus cycle ratio 1/3 proves more advantageous in reducing the infiltrated depth and volume than the surge flow of cycle ratio 1/2.

Table 11 presents the values of infiltration data for surge flow of cycle ratio 2/3. For a discharge of 1.3 lps, infiltrated volume ranges from 5 litres to 450 litres along the various sections of the furrow. The value ranges as 0.8 to 570 litres for treatment 2, and 4 to 815 litres in treatment 3, for the various cases considered. Infiltrated depth varied in the range of 0.05 to 2.4 cm for treatment 1, 0.01 to 2.7 cm for treatment 2 and 0.02 to 3.8 cm for treatment 3. There was considerable reduction in infiltration values compared to continuous flow and surge flow with cycle ratios of 1/2 and 1/3. The sample calculation for the data for continuous flow is given in Appendix-VII.

The mean values of infiltrated depth at various sections for the different treatment combinations were calculated and line graphs were plotted. For each of the

Table 11. Infiltration parameters for surge flow (CR = 2/3)

| Discharge lps | Distance m | Infiltrated volume Litres | | | | Infiltrated depth cm | | | |
|---|---|---|---|---|---|---|---|---|---|
| | | $R_1$ | $R_2$ | $R_3$ | $R_4$ | $R_1$ | $R_2$ | $R_3$ | $R_4$ |
| 1.3 | 15 | 15.83 | 25.51 | 16.39 | 5.28 | 0.27 | 0.43 | 0.28 | 0.09 |
| | 30 | 128.97 | 89.72 | 106.71 | 25.04 | 1.09 | 0.77 | 0.88 | 0.19 |
| | 45 | 393.35 | 186.23 | 389.70 | 395.21 | 2.23 | 1.07 | 2.29 | 2.37 |
| | 60 | 11.30 | 444.05 | 17.85 | 21.62 | 0.05 | 2.08 | 0.08 | 0.09 |
| | 75 | 395.55 | 30.58 | 315.33 | 310.89 | 1.49 | 0.31 | 1.17 | 1.12 |
| | 90 | 39.96 | 201.19 | 19.65 | 66.18 | 0.13 | 0.62 | 0.07 | 0.21 |
| | 102 | 226.65 | 216.50 | 355.28 | 196.18 | 0.65 | 0.62 | 1.06 | 0.56 |
| 1.7 | 15 | 44.01 | 20.32 | 2.71 | 2.65 | 0.78 | 0.36 | 0.04 | 0.05 |
| | 30 | 74.14 | 19.03 | 152.98 | 0.80 | 0.64 | 0.17 | 1.37 | 0.007 |
| | 45 | 357.89 | 46.54 | 392.01 | 342.23 | 2.13 | 0.25 | 2.49 | 1.93 |
| | 60 | 6.84 | 570.05 | 54.76 | 38.45 | 0.03 | 2.61 | 0.26 | 0.18 |
| | 75 | 394.35 | 17.87 | 268.70 | 469.59 | 1.44 | 0.06 | 1.00 | 1.71 |
| | 90 | 42.57 | 7.36 | 701.43 | 9.55 | 0.14 | 0.02 | 2.27 | 0.03 |
| | 102 | 142.82 | 165.68 | 15.83 | 48.71 | 0.40 | 0.47 | 0.04 | 0.13 |

Contd.

Table 11 (Contd.)

| Discharge lps | Distance m | Infiltrated volume Litres | | | | Infiltrated depth cm | | | |
|---|---|---|---|---|---|---|---|---|---|
| | | $R_1$ | $R_2$ | $R_3$ | $R_4$ | $R_1$ | $R_2$ | $R_3$ | $R_4$ |
| 2.1 | 15 | 55.88 | 38.73 | 46.39 | 80.73 | 0.99 | 0.67 | 0.76 | 1.41 |
| | 30 | 189.25 | 163.27 | 234.70 | 233.95 | 1.66 | 1.49 | 2.02 | 2.08 |
| | 45 | 348.23 | 271.09 | 418.20 | 369.90 | 1.86 | 1.54 | 2.47 | 2.14 |
| | 60 | 721.86 | 341.52 | 815.85 | 627.86 | 3.18 | 1.39 | 3.81 | 2.73 |
| | 75 | 31.03 | 173.09 | 42.53 | 33.23 | 0.11 | 0.62 | 0.15 | 0.12 |
| | 90 | 4.81 | 805.57 | 317.80 | 711.18 | 0.02 | 2.64 | 0.94 | 2.32 |
| | 102 | 381.31 | 471.97 | 327.55 | 476.03 | 1.12 | 1.38 | 0.96 | 1.43 |

| Infiltrated depth cm | | | |
|---|---|---|---|
| $R_1$ | $R_2$ | $R_3$ | $R_4$ |
| 0.99 | 0.67 | 0.76 | 1.41 |
| 1.66 | 1.49 | 2.02 | 2.08 |
| 1.86 | 1.54 | 2.47 | 2.14 |
| 3.18 | 1.39 | 3.81 | 2.73 |
| 0.11 | 0.62 | 0.15 | 0.12 |
| 0.02 | 2.64 | 0.94 | 2.32 |
| 1.12 | 1.38 | 0.96 | 1.43 |

three stream flow rates, the values were plotted for all the four different types of flow, so as to enable an effective comparison between the treatment combinations. The graphical representation gives a clear picture of the variability of infiltration under each cases along the different sections of the furrow length.

The comparison of infiltrated depth in cm for continuous flow and surge flows for a discharge of 1.3 lps is shown in Fig.16. For continuous flow, the values of infiltrated depth varies from 2.22 cm to 4.03 cm, with all the values above 2 cm for the various sections. For surge flow of cycle ratio = 1/2, the values ranged between 0.43 cm to 2.3 cm. In the case of surge flow of cycle ratio 1/3, the range was 0.52 to 1.59 cm. For surge flow of cycle ratio 2/3, the values ranged between 0.26 cm to 1.99 cm. The infiltrated depth steadily increases in case of continuous flow as the distance from the furrow end increases, except for a decrease in the section between 30 to 45 cm. In case of surge flow of cycle ratio 1/2, the values increased in the initial sections of the furrow and beyond 60 m the value goes on decreasing. In the case of surge flow of cycle ratio 1/3, the value progressively increases upto 45 m distance, beyond which the value goes on decreasing. In the case of surge flow of cycle ratio = 2/3, as in the previous case the value increases upto

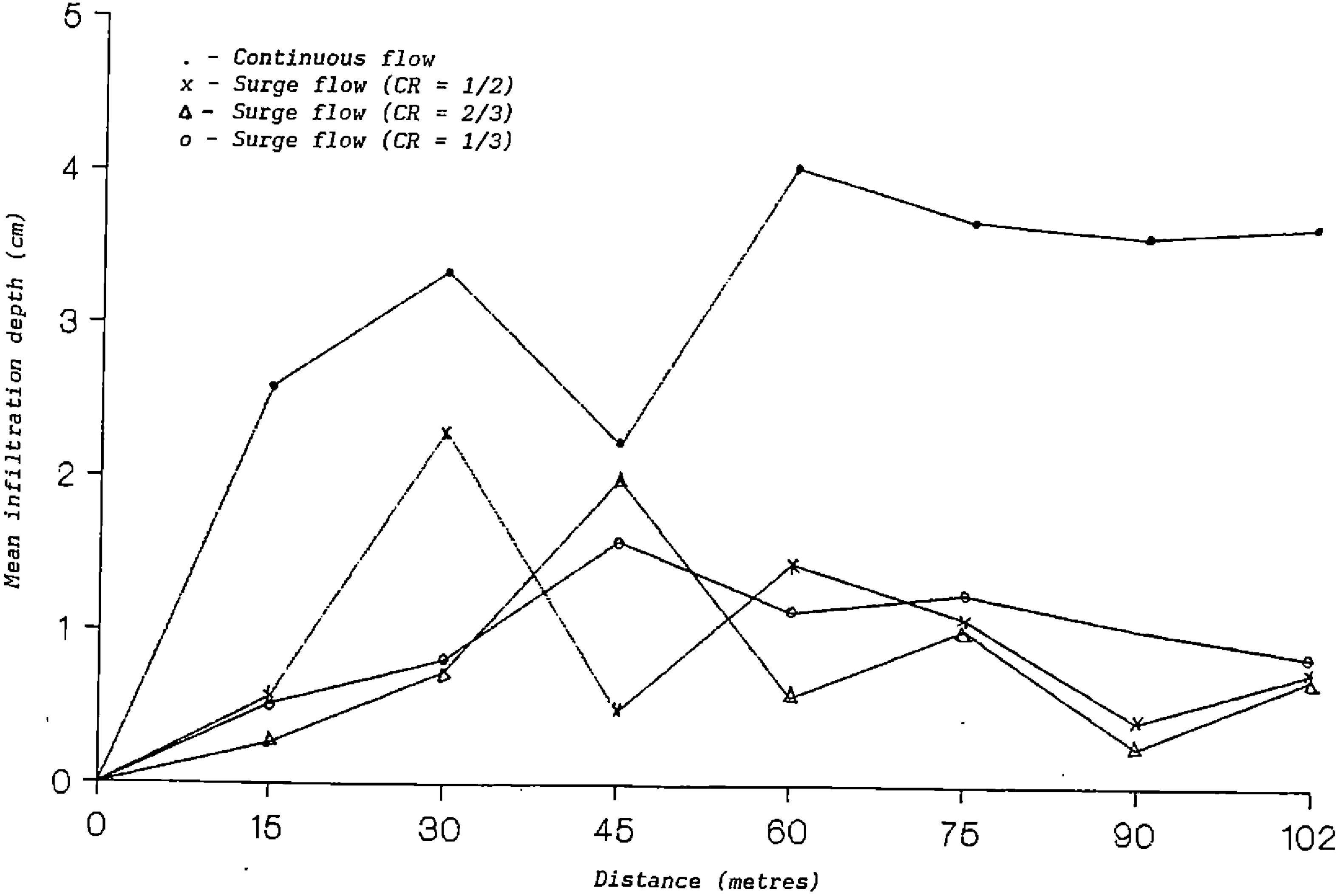


**FIG.16 COMPARISON OF INFILTRATED DEPTH FOR CONTINUOUS FLOW AND SURGE FLOW FOR A DISCHARGE OF 1.3 lps**

45 m and then goes on decreasing. The variability was found to be the least in this case for surge flow of cycle ratio 1/3 and more uniformity of application with lesser value of infiltrated depth compared to continuous flow was obtained.

For a discharge of 1.7 lps, the comparison of surge and continuous flow is represented in Fig.17. The range of values of infiltrated depth for continuous flow was 1.43 cm to 4.03 cm. For surge flow of cycle ratio 1/2, the range is 0.24 to 1.7 cm and for surge flow of cycle ratio 1/3, the range is 0.82 to 3.1 cm. In case of surge flow of cycle ratio 2/3, the values of infiltrated depth vary between 0.26 to 1.7 cm. The values were progressively increasing for continuous flow. For cycle ratio 1/2, the value increased in the sections upto 30 cm and beyond that the values decreased significantly and the minimum values of infiltration depth were obtained. In the case of cycle ratio 1/3, the variability was high and the values were high upto 60 m beyond which there was a decrease in infiltrated depth. The reduction in infiltration depth when compared to continuous flow was much less and the ratio was not advantageous for the discharge of 1.7 lps. Surge flow with cycle ratio 2/3 produced better results and the values decreased considerably beyond 45 m. Thus in this case, cycle ratio 2/3 showed the least variability and the result was almost similar for cycle ratio 1/2 also. Cycle ratio 1/3

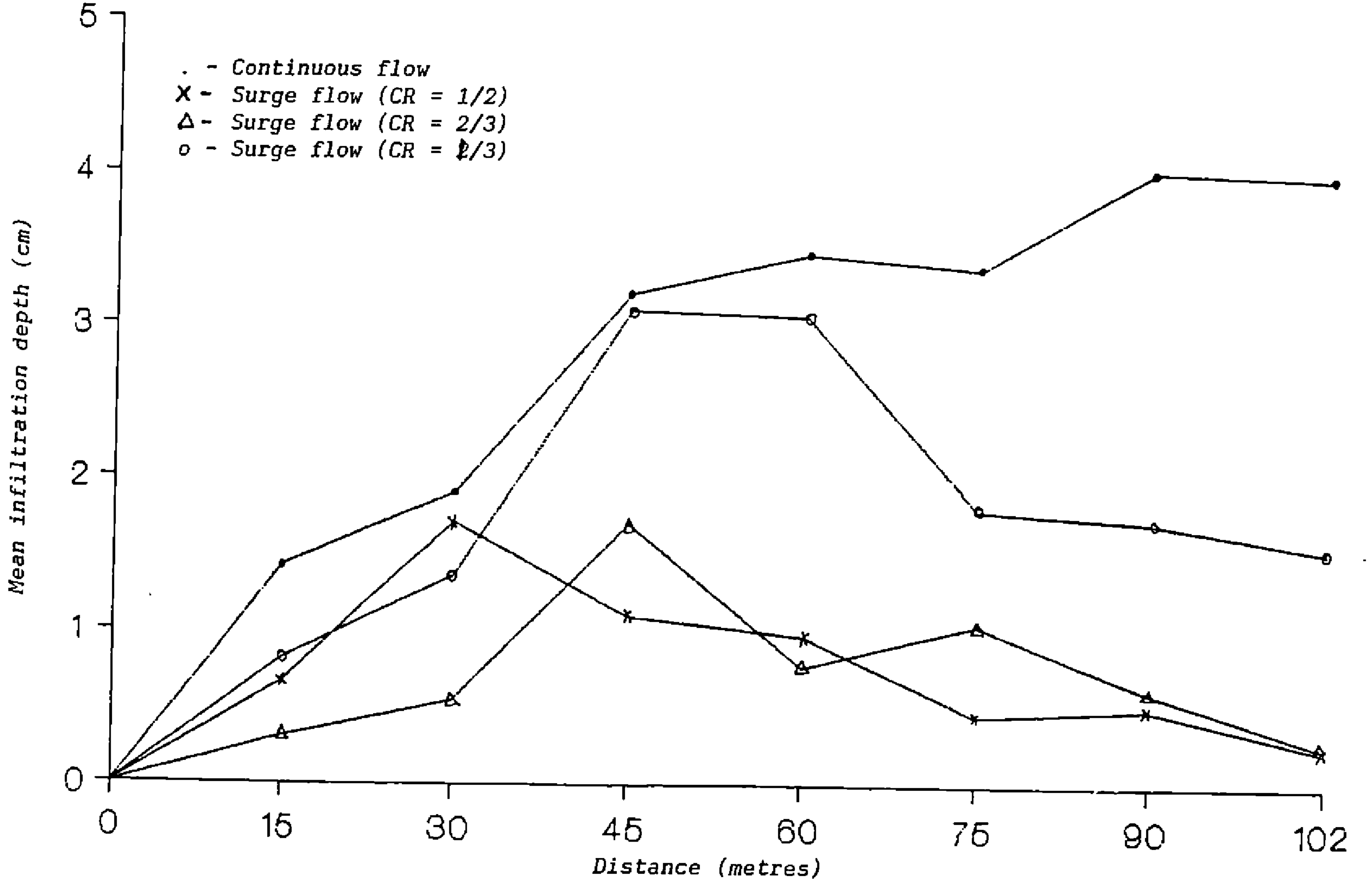


FIG.17 COMPARISON OF INFILTRATED DEPTH FOR CONTINUOUS FLOW AND SURGE FLOW FOR A DISCHARGE OF 1.7 lps

showed high variability though in all cases, the uniformity was much better than continuous flow.

The continuous flow and surge flow infiltrated depths for the discharge of 2.1 lps is presented in Fig.18. The range of values for continuous flow was 2.51 to 4.75 cm. For surge flow of cycle ratio 1/2 the range was 0.21 to 2.87 cm. In the case of surge flow of cycle ratio 1/3, the values varied from 0.56 to 4.7 cm and for a cycle ratio 2/3, the range was 0.25 to 2.78 cm. The variability was least in the case of cycle ratio 2/3. The uniformity of application in all cases was much less compared to the two lower discharge treatments.

The values progressively increased for continuous flow. In the case of cycle ratio 1/2, the values decreased beyond 45 m though there was considerable variability. Cycle ratio 1/3 provided poor results with high value of infiltrated depth at 45 m distance and high variability eventhough the values decreased beyond 45 m. Cycle ratio 2/3 also produced non-uniform results with values increasing and decreasing unevenly.

In analysing the curves for all the three discharges and for all treatment combinations it is found that the cycle ratio 1/3 with a discharge of 1.3 lps provided the best results with the least variability in infiltration depth

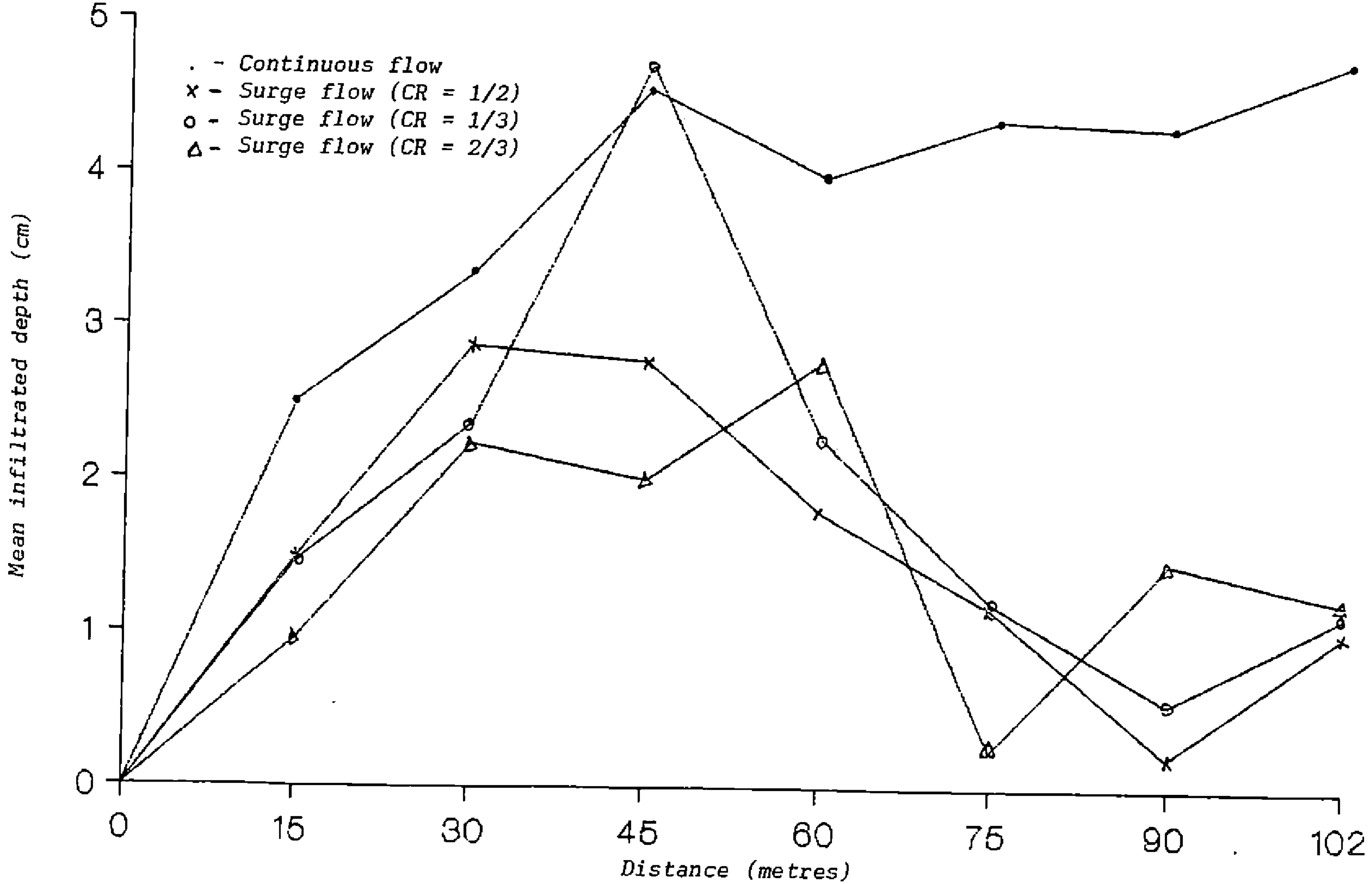


**FIG.18 COMPARISON OF INFILTRATED DEPTH FOR CONTINUOUS AND SURGE FLOWS FOR A DISCHARGE OF 2.1 lps**

values. However, it could be observed that the soil of the study area exhibited significant surge effect with marked reduction in infiltration parameter values compared to continuous flow. The result is due to the reduction of intake rate due to the reduction in effective porosity caused by consolidation effects, particle migration and reorientation and air entrapment. The mean values of infiltrated depth for the three discharges and the different flow conditions are given in Appendix-V.

### 4.2.5 Analysis of infiltration rate

The analysis of the rate of intake of water in litres per second per metre length of furrow for the different treatment combinations were done using the inflow-outflow data obtained by using the orifice plates. The values were calculated according to the procedure, detailed in section 3.7.2. The data on the total intake rate per metre length of the furrow in case of continuous flow is given in Table 12.

The intake rate in lps per metre length of furrow was found to remain the same for the two treatments of 1.3 and 1.7 lps. Thus no significant difference existed between the two treatments for small values of discharge. In the case of higher discharge, the intake rate per metre length of furrow

Table 12. Infiltration rate per metre length - Continuous flow

| Treatment combination | Replication | Total intake rate (lps/m) | Mean (lps/m) |
|---|---|---|---|
| $F_1T_1$ | $R_1$ | 0.0095 | 0.0094 |
| | $R_2$ | 0.0095 | |
| | $R_3$ | 0.0094 | |
| | $R_4$ | 0.0091 | |
| $F_1T_2$ | $R_1$ | 0.0093 | 0.0094 |
| | $R_2$ | 0.0095 | |
| | $R_3$ | 0.0095 | |
| | $R_4$ | 0.0091 | |
| $F_1T_3$ | $R_1$ | 0.011 | 0.012 |
| | $R_2$ | 0.011 | |
| | $R_3$ | 0.012 | |
| | $R_4$ | 0.012 | |

was high and the value was 0.012 lps. Table 13 represents, the intake rate per metre length for surge flow of cycle ratio 1/2 for a discharge of 1.3 lps. The intake rate of each surge in various sections and the total intake rate in each case were determined. The intake rate steadily decreased from the first surge to the last surge in each section for all cases. The total intake rate of each surge was also found to decrease steadily. The last surge which travels the 102 m length, showed an intake rate almost constant for all cases. The value was 0.009 lps/m on an average. This was almost similar to the value obtained for continuous flow.

The infiltration rate per metre length of furrow for a discharge of 1.7 lps, under surge flow of cycle ratio 1/2 is given in Table 14. In this case also, the value of intake rate decreased from surge 1 to the last surge for each section of furrow length. The values decreased along the furrow length for each surge too, except in the case of the last surge which reached the last 25 m section of the furrow. In this case, the majority of water from that surge infiltrated in the last section of furrow, and the rate was found to be high in all cases. Thus the last surge did not cause excess run-off at the tail end, but infiltrated considerably in the last section of the furrow. The value of total intake rate of the last surge which travelled the full

Table 13. Infiltration rate per metre length - surge flow (CR=1/2), discharge - 1.3 lps

| Distance | | Intake rate lps/m 0-25 | 25-50 | 50-75 | 75-102 | Total intake rate |
|---|---|---|---|---|---|---|
| Replication | Surge | m | m | m | m | lps/m |
| $R_1$ | S-1 | --* | | | | -- |
| | S-2 | 0.026 | | | | 0.026 |
| | S-3 | 0.023 | 0.023 | | | 0.023 |
| | S-4 | 0.021 | 0.010 | | | 0.015 |
| | S-5 | 0.018 | 0.008 | 0.004 | | 0.010 |
| | S-6 | 0.015 | 0.007 | 0.006 | 0.009 | 0.009 |
| $R_2$ | S-1 | 0.045 | | | | 0.045 |
| | S-2 | 0.018 | 0.017 | | | 0.018 |
| | S-3 | 0.017 | 0.009 | | | 0.013 |
| | S-4 | 0.013 | 0.009 | 0.006 | | 0.009 |
| | S-5 | 0.013 | 0.006 | 0.004 | | 0.007 |
| | S-6 | 0.012 | 0.004 | 0.006 | 0.016 | 0.009 |

Contd.

Table 13 (Contd.)

| Distance | | Intake rate lps/m | | | | Total intake rate |
|---|---|---|---|---|---|---|
| | | 0-25 | 25-50 | 50-75 | 75-102 | |
| Replication | Surge | m | m | m | m | lps/m |
| R$_3$ | S-1 | --* | | | | -- |
| | S-2 | 0.022 | | | | 0.022 |
| | S-3 | 0.021 | 0.022 | | | 0.021 |
| | S-4 | 0.016 | 0.011 | | | 0.013 |
| | S-5 | 0.015 | 0.011 | 0.011 | | 0.012 |
| | S-6 | 0.014 | 0.012 | 0.005 | | 0.010 |
| | S-7 | 0.013 | 0.012 | 0.005 | 0.011 | 0.010 |
| R$_4$ | S-1 | --* | | | | -- |
| | S-2 | 0.032 | | | | 0.032 |
| | S-3 | 0.023 | --* | | | 0.023 |
| | S-4 | 0.021 | 0.008 | --* | | 0.014 |
| | S-5 | 0.018 | 0.004 | --* | | 0.011 |
| | S-6 | 0.016 | 0.005 | 0.009 | | 0.010 |
| | S-7 | 0.014 | 0.006 | 0.008 | 0.009 | 0.009 |

* Head too low to be measured by orifice plate.

Table 14. Infiltration rate per metre length - surge flow (CR=1/2), discharge - 1.7 lps

| | | Intake rate | | | | Total intake rate |
|---|---|---|---|---|---|---|
| | | lps/m | | | | |
| Distance | | 0-25 | 25-50 | 50-75 | 75-102 | |
| Replication | Surge | m | m | m | m | lps/m |
| $R_1$ | S-1 | 0.053 | | | | 0.053 |
| | S-2 | 0.035 | 0.029 | | | 0.032 |
| | S-3 | 0.034 | 0.028 | | | 0.031 |
| | S-4 | 0.034 | 0.028 | 0.003 | | 0.021 |
| | S-5 | 0.033 | 0.027 | 0.002 | 0.004 | 0.016 |
| $R_2$ | S-1 | 0.039 | | | | 0.039 |
| | S-2 | 0.031 | 0.018 | | | 0.025 |
| | S-3 | 0.031 | 0.011 | 0.011 | | 0.018 |
| | S-4 | 0.030 | 0.010 | 0.009 | | 0.016 |
| | S-5 | 0.028 | 0.010 | 0.000 | 0.021 | 0.014 |
| $R_3$ | S-1 | 0.053 | | | | 0.053 |
| | S-2 | 0.037 | | | | 0.037 |
| | S-3 | 0.032 | 0.032 | | | 0.032 |
| | S-4 | 0.032 | 0.028 | | | 0.030 |
| | S-5 | 0.028 | 0.031 | 0.0002 | | 0.020 |
| | S-6 | 0.027 | 0.032 | 0.0001 | 0.006 | 0.016 |

Contd.

Table 14 (Contd.)

| Distance | | Intake rate lps/m 0-25 | 25-50 | 50-75 | 75-102 | Total intake rate |
|---|---|---|---|---|---|---|
| Repli-cation | Surge | m | m | m | m | lps/m |
| $R_4$ | S-1 | 0.044 | | | | 0.044 |
| | S-2 | 0.034 | | | | 0.034 |
| | S-3 | 0.032 | 0.017 | | | 0.025 |
| | S-4 | 0.032 | 0.006 | 0.015 | | 0.018 |
| | S-5 | 0.026 | 0.009 | 0.014 | | 0.016 |
| | S-6 | 0.024 | 0.007 | 0.015 | 0.017 | 0.016 |

length of furrow averaged to 0.016 lps/m length. The value was higher than for continuous flow showing that reduced value of run-off occurred at the tail end of the furrow. Table 15 represents the data for a discharge of 2.1 lps for surge flow of cycle rate 1/2. The intake rate decreases along the furrow length for each surge and also from the first surge to the last surge. The total intake rate of each surge was also found to decrease considerably. The value of intake rate for the last surge travelling 102 m length of the furrow averaged to 0.015 lps/m length. The value was 0.012 lps/m length for continuous flow. The higher value of intake rate for the last surge indicates that lesser run-off occurred at the tail end.

Tables 16, 17 and 18 represent the data of infiltration rate per metre length of the furrow for discharges of 1.3, 1.7 and 2.1 lps under surge flow of cycle ratio 1/3. The variation of infiltration rate for each surge along the length of furrow and from the first surge to the last surge followed the same pattern as in the case of surge flow of cycle ratio 1/2. The mean value of total intake rate for the last surge travelling 102 m length was found to be 0.011 lps/m, 0.015 lps/m and 0.019 lps/m for the three consecutive discharges. For every section along the furrow length, the values of intake rate decreased for the consecutive surges. The data of intake rate for the three

Table 15. Infiltration rate per metre length - surge flow (CR=1/2), discharge - 2.1 lps

| Distance | | Intake rate lps/m | | | | Total intake rate |
|---|---|---|---|---|---|---|
| | | 0-25 | 25-50 | 50-75 | 75-102 | |
| Replication | Surge | m | m | m | m | lps/m |
| $R_1$ | S-1 | 0.045 | | | | 0.054 |
| | S-2 | 0.042 | 0.030 | | | 0.035 |
| | S-3 | 0.038 | 0.015 | | | 0.030 |
| | S-4 | 0.037 | 0.012 | 0.014 | | 0.021 |
| | S-5 | 0.037 | 0.010 | 0.008 | 0.008 | 0.015 |
| $R_2$ | S-1 | 0.064 | | | | 0.064 |
| | S-2 | 0.047 | | | | 0.047 |
| | S-3 | 0.044 | 0.025 | | | 0.035 |
| | S-4 | 0.042 | 0.017 | 0.010 | | 0.023 |
| | S-5 | 0.041 | 0.013 | 0.006 | | 0.020 |
| | S-6 | 0.041 | 0.013 | 0.001 | 0.018 | 0.018 |
| $R_3$ | S-1 | 0.058 | | | | 0.058 |
| | S-2 | 0.044 | 0.024 | | | 0.034 |
| | S-3 | 0.042 | 0.016 | 0.006 | | 0.021 |
| | S-4 | 0.040 | 0.016 | 0.003 | | 0.019 |
| | S-5 | 0.038 | 0.016 | 0.003 | 0.015 | 0.018 |

Contd.

Table 15 (Contd.)

| Distance |  | Intake rate lps/m |  |  |  | Total intake rate |
|---|---|---|---|---|---|---|
|  |  | 0-25 | 25-50 | 50-75 | 75-102 |  |
| Repli- cation | Surge | m | m | m | m | lps/m |
| $R_4$ | S-1 | 0.045 |  |  |  | 0.045 |
|  | S-2 | 0.018 | 0.017 |  |  | 0.018 |
|  | S-3 | 0.017 | 0.009 |  |  | 0.013 |
|  | S-4 | 0.013 | 0.009 | 0.006 |  | 0.009 |
|  | S-5 | 0.013 | 0.006 | 0.004 |  | 0.007 |
|  | S-6 | 0.012 | 0.004 | 0.006 | 0.016 | 0.009 |

Table 16. Infiltration rate per metre length - surge flow (CR=1/3), discharge - 1.3 lps

| Distance | | Intake rate lps/m | | | | Total intake rate |
|---|---|---|---|---|---|---|
| Replication | Surge | 0-25 m | 25-50 m | 50-75 m | 75-102 m | lps/m |
| $R_1$ | S-1 | 0.033 | | | | 0.033 |
| | S-2 | 0.024 | 0.007 | | | 0.015 |
| | S-3 | 0.020 | 0.006 | 0.004 | | 0.010 |
| | S-4 | 0.018 | 0.005 | 0.002 | | 0.009 |
| | S-5 | 0.017 | 0.005 | 0.003 | 0.019 | 0.011 |
| $R_2$ | S-1 | 0.031 | | | | 0.031 |
| | S-2 | 0.023 | | | | 0.023 |
| | S-3 | 0.020 | 0.017 | | | 0.019 |
| | S-4 | 0.019 | 0.016 | 0.003 | | 0.013 |
| | S-5 | 0.018 | 0.015 | 0.004 | 0.011 | 0.012 |
| $R_3$ | S-1 | 0.037 | | | | 0.037 |
| | S-2 | 0.023 | 0.009 | | | 0.016 |
| | S-3 | 0.021 | 0.008 | 0.002 | | 0.010 |
| | S-4 | 0.010 | 0.009 | 0.001 | 0.015 | 0.011 |

Contd.

Table 16 (Contd.)

| Distance | | Intake rate<br>lps/m<br>0-25 | <br><br>25-50 | <br><br>50-75 | <br><br>75-102 | Total intake rate |
|---|---|---|---|---|---|---|
| Repli- cation | Surge | m | m | m | m | lps/m |
| $R_4$ | S-1 | 0.034 | | | | 0.034 |
| | S-2 | 0.026 | 0.007 | | | 0.017 |
| | S-3 | 0.022 | 0.009 | 0.002 | | 0.011 |
| | S-4 | 0.021 | 0.009 | 0.001 | | 0.010 |
| | S-5 | 0.019 | 0.010 | 0.001 | 0.014 | 0.011 |

Table 17. Infiltration rate per metre length - surge flow (CR=1/3), discharge - 1.7 lps

| | | Intake rate | | | | Total intake rate |
|---|---|---|---|---|---|---|
| | | lps/m | | | | |
| Distance | | 0-25 | 25-50 | 50-75 | 75-102 | |
| Replication | Surge | m | m | m | m | lps/m |
| $R_1$ | S-1 | 0.036 | | | | 0.036 |
| | S-2 | 0.030 | 0.018 | 0.011 | | 0.020 |
| | S-3 | 0.029 | 0.014 | 0.013 | | 0.019 |
| | S-4 | 0.028 | 0.014 | 0.010 | 0.010 | 0.015 |
| $R_2$ | S-1 | 0.034 | | | | 0.034 |
| | S-2 | 0.029 | 0.014 | | | 0.022 |
| | S-3 | 0.028 | 0.013 | 0.020 | | 0.020 |
| | S-4 | 0.026 | 0.011 | 0.012 | 0.013 | 0.015 |
| $R_3$ | S-1 | 0.041 | | | | 0.041 |
| | S-2 | 0.034 | 0.012 | | | 0.023 |
| | S-3 | 0.032 | 0.013 | 0.009 | | 0.018 |
| | S-4 | 0.031 | 0.010 | 0.008 | 0.010 | 0.015 |
| $R_4$ | S-1 | 0.044 | | | | 0.044 |
| | S-2 | 0.042 | 0.011 | | | 0.044 |
| | S-3 | 0.038 | 0.010 | 0.017 | | 0.027 |
| | S-4 | 0.036 | 0.007 | 0.018 | | 0.020 |
| | S-5 | 0.033 | 0.005 | 0.022 | 0.002 | 0.015 |

Table 18. Infiltration rate per metre length - surge flow (CR=1/3), discharge - 2.1 lps

| Distance | | Intake rate lps/m 0-25 | 25-50 | 50-75 | 75-102 | Total intake rate |
|---|---|---|---|---|---|---|
| Replication | Surge | m | m | m | m | lps/m |
| $R_1$ | S-1 | 0.058 | | | | 0.058 |
| | S-2 | 0.049 | 0.020 | | | 0.035 |
| | S-3 | 0.047 | 0.016 | 0.002 | | 0.022 |
| | S-4 | 0.046 | 0.013 | 0.004 | 0.013 | 0.019 |
| $R_2$ | S-1 | 0.045 | | | | 0.045 |
| | S-2 | 0.018 | 0.017 | | | 0.018 |
| | S-3 | 0.017 | 0.009 | | | 0.013 |
| | S-4 | 0.013 | 0.009 | 0.006 | | 0.009 |
| | S-5 | 0.013 | 0.006 | 0.004 | | 0.007 |
| | S-6 | 0.012 | 0.004 | 0.006 | 0.016 | 0.009 |
| $R_3$ | S-1 | 0.057 | | | | 0.057 |
| | S-2 | 0.047 | 0.019 | 0.003 | | 0.023 |
| | S-3 | 0.047 | 0.013 | 0.003 | | 0.021 |
| | S-4 | 0.045 | 0.013 | 0.005 | 0.013 | 0.019 |
| $R_4$ | S-1 | 0.056 | | | | 0.056 |
| | S-2 | 0.048 | 0.019 | | | 0.034 |
| | S-3 | 0.047 | 0.015 | 0.002 | | 0.021 |
| | S-4 | 0.045 | 0.013 | 0.003 | 0.014 | 0.019 |

treatments in the case of surge flow with cycle ratio 2/3, is presented in Tables 19, 20 and 21. The intake rate decreased steadily in all three cases for the consecutive surges for each section of furrow. The total intake rate was also found to decrease from the first surge to the last surge. The mean value of total intake rate for the last surge was found to be 0.011 lps/m, 0.014 lps/m and 0.018 lps/m for the three discharges considered. The orifice plate readings and the corresponding discharges are given in Appendix-IV.

The total intake rate in lps per metre length was found to be the least in the case of surge flow of cycle ratio 1/3 and the discharge of 1.3 lps. The intake rate reduction due to surging can be attributed to the phenomena of consolidation of soil, air entrapment, surface sealing caused by particle migration and reorientation and the hydration and expansion of clay particles. The downward movement of the wetting front during the OFF time of surges causes reduction of hydraulic gradient later in the surge cycle and thus reduces intake rate. This may be because the potential difference occurs over a larger elevation difference when the wetting front has moved down considerably. The soil bulk density increases during the OFF time due to soil consolidation after the initial wetting and this causes reduced porosity. The disintegration of soil aggregates occur

Table 19. Infiltration rate per metre length - surge flow (CR=2/3), discharge - 1.3 lps

| Distance | | Intake rate lps/m 0-25 | 25-50 | 50-75 | 75-102 | Total intake rate |
|---|---|---|---|---|---|---|
| Replication | Surge | m | m | m | m | lps/m |
| $R_1$ | S-1 | 0.021 | | | | 0.021 |
| | S-2 | 0.011 | 0.012 | 0.016 | | 0.013 |
| | S-3 | 0.010 | 0.012 | 0.005 | 0.018 | 0.011 |
| $R_2$ | S-1 | 0.017 | 0.020 | | | 0.019 |
| | S-2 | 0.011 | 0.011 | 0.014 | | 0.012 |
| | S-3 | 0.010 | 0.010 | 0.009 | 0.015 | 0.011 |
| $R_3$ | S-1 | 0.018 | 0.020 | | | 0.019 |
| | S-2 | 0.010 | 0.016 | 0.007 | | 0.011 |
| | S-3 | 0.009 | 0.013 | 0.007 | 0.015 | 0.011 |
| $R_4$ | S-1 | 0.019 | | | | 0.019 |
| | S-2 | 0.018 | 0.013 | 0.006 | | 0.012 |
| | S-3 | 0.010 | 0.012 | 0.008 | 0.205 | 0.010 |

Table 20. Infiltration rate per metre length - surge flow (CR=2/3), discharge - 1.7 lps

| Distance | | Intake rate lps/m | | | | Total intake rate |
|---|---|---|---|---|---|---|
| | | 0-25 | 25-50 | 50-75 | 75-102 | |
| Repli- cation | Surge | m | m | m | m | lps/m |
| $R_1$ | S-1 | 0.037 | 0.009 | | | 0.023 |
| | S-2 | 0.027 | 0.015 | 0.008 | | 0.017 |
| | S-3 | 0.026 | 0.009 | 0.003 | 0.021 | 0.014 |
| $R_2$ | S-1 | 0.038 | 0.004 | | | 0.021 |
| | S-2 | 0.030 | 0.006 | 0.010 | | 0.016 |
| | S-3 | 0.026 | 0.008 | 0.008 | 0.017 | 0.014 |
| $R_3$ | S-1 | 0.031 | 0.013 | | | 0.022 |
| | S-2 | 0.023 | 0.019 | 0.006 | | 0.016 |
| | S-3 | 0.022 | 0.016 | 0.0007 | 0.019 | 0.014 |
| $R_4$ | S-1 | 0.034 | 0.013 | | | 0.023 |
| | S-2 | 0.029 | 0.015 | 0.009 | | 0.018 |
| | S-3 | 0.026 | 0.009 | 0.003 | 0.020 | 0.014 |

Table 21. Infiltration rate per metre length - surge flow (CR=2/3), discharge - 2.1 lps

| Distance | | Intake rate<br>lps/m<br>0-25 | <br><br>25-50 | <br><br>50-75 | <br><br>75-102 | Total intake rate |
|---|---|---|---|---|---|---|
| Repli- cation | Surge | m | m | m | m | lps/m |
| | S-1 | 0.050 | 0.014 | | | 0.032 |
| $R_1$ | S-2 | 0.039 | 0.007 | 0.006 | | 0.018 |
| | S-3 | 0.036 | 0.009 | 0.005 | 0.025 | 0.018 |
| | S-1 | 0.051 | 0.009 | | | 0.030 |
| $R_2$ | S-2 | 0.038 | 0.010 | 0.008 | | 0.019 |
| | S-3 | 0.034 | 0.010 | 0.010 | 0.020 | 0.018 |
| | S-1 | 0.047 | 0.018 | | | 0.033 |
| $R_3$ | S-2 | 0.038 | 0.010 | 0.007 | | 0.018 |
| | S-3 | 0.037 | 0.008 | 0.006 | 0.023 | 0.018 |
| | S-1 | 0.056 | | | | 0.056 |
| $R_4$ | S-2 | 0.048 | 0.019 | | | 0.034 |
| | S-3 | 0.047 | 0.015 | 0.002 | | 0.021 |
| | S-4 | 0.045 | 0.013 | 0.003 | 0.014 | 0.019 |

during irrigation and this produces a surface layer of reduced conductivity. Entrapment of air within the soil mass reduces the effective porosity and blocks the liquid flow thus reducing infiltration. Swelling of clay particles and organic matter content also causes reduction in porosity and reduces infiltration.

In the case of surge flow of cycle ratio 1/3, the OFF time is double that of ON time and the effect of redistribution of water is more pronounced. The changes occurring within the soil profile following the initial wetting takes place over a larger time period than in the case of other cycle ratios. Hence the surge effect is more pronounced in this case. Though the values of total intake rate in all surge flow cases exceeded the values for continuous flow, this basic rate was attained in a much lesser time under surge flow compared to continuous flow. Tail water run-off was also lesser in surge flow cases. The final surge completed the advance through 102 m length and attained the final intake rate with much lesser time when compared to continuous flow in all the different treatment combinations.

## 4.3 Statistical analysis

The volume of water required to complete the advance under different treatment combinations was determined from inflow rate and total valve ON-time. This data was subjected to statistical analysis arranging the data as in a mixed factorial experiment, to determine whether significant differences existed between treatments and to obtain the suitable combination of management parameters. The volume of water required to complete the advance in cubic metres for various treatment combinations is presented in Appendix-VI.

The data was taken and arranged to from a two way table for finding the main effects and the interaction sum of squares. The table so obtained is given in Appendix-VI. From the values arranged in tabular form, the calculation of the sum of squares due to replications, treatments, their interactions and the error sum of squares was done. Anova table for the obtained values was prepared and the Fisher's 'F' test was conducted. Table 22 represents the analysis of variance of the volume of water to complete the advance in the furrows.

The analysis of variance of the volume of water required to complete the advance indicates that the difference between replications was significant at 5 per cent level. The difference between the different types of flow was significant at 1 per cent and 5 per cent levels. Also the variation between discharges was significant at 1 per cent and

Table 22. Analysis of variance of volume of water to complete the advance

| Source | d.f | S.S | M.S | F Calculated | F table p=0.01 | F table p=0.05 |
|---|---|---|---|---|---|---|
| Replication | 3 | 0.08 | 0.03 | 3.33* | 4.49 | 2.897 |
| Treatments | 11 | | | | | |
| F | 3 | 4.79 | 1.60 | 177.8** | 4.49 | 2.897 |
| T | 2 | 2.72 | 1.36 | 151.11** | 5.33 | 3.29 |
| FT | 6 | 0.18 | 0.03 | 3.33* | 3.42 | 2.40 |
| Error | 33 | 0.30 | 0.009 | | | |
| Total | 47 | 8.07 | | | | |

5 per cent levels of significance. The interaction between flow types and discharges indicated variation which was insignificant at 1 per cent level but significant at 5 per cent level. The high F value obtained in calculation for the variation between flow types and discharges indicated significant differences in the effect under continuous flow and different surge flow regimes. The mean of the volume required to complete the advance for the various cases in each treatment combination is given in Table 23. The calculation performed for preparing the Anova table is presented in Appendix-VI.

Table 23. Mean of the volume required to complete the advance in cubic metres

| | $T_1$ | $T_2$ | $T_3$ |
|---|---|---|---|
| $F_1$ | 1.78 | 2.24 | 2.44 |
| $F_2$ | 1.52 | 1.73 | 2.08 |
| $F_3$ | 1.11 | 1.30 | 1.51 |
| $F_4$ | 1.17 | 1.51 | 1.89 |

The volume required to complete the advance was the least in the case of surge flow of cycle ratio 1/3 of which the minimum value was obtained for the least discharge of 1.3 lps. The continuous flow indicated the highest values of the volume required to complete the advance. Surge flow of cycle ratio 2/3 was advantageous than with cycle ratio 1/2 in reducing the volume required for advance. The analysis of infiltrated volume, infiltrated depth and reduction of intake rate in lps per metre length of furrow have all indicated that surge flow of cycle ratio 1/3 for a discharge of 1.3 lps was the best combination for attaining greatest uniformity of application with less volume, reduced infiltration, lesser tail water run-off and deep percolation losses. Hence it is concluded that surge flow with cycle ratio 1/3 and discharge of 1.3 lps proved the most suitable combination for best performance among the various treatment combinations analysed in the study. Surge effect was found to be significant in the sandy loam soils of Tavanur region.

# Summary

# SUMMARY AND CONCLUSION

Surface irrigation methods are the most common for artificially applying water to agricultural lands and world wide, the vast majority of irrigation projects existing, planned or under development involves surface systems. Recent developments in surface irrigation technology have commendable irrigation efficiency advantage and an array of automating devices have reduced labour requirements. Surge irrigation ranks as the foremost among the latest developments in surface irrigation technology, and has emerged from researches at Utah State University. Though the new generation of surface irrigation methods prove to be attractive alternatives to older practices, their associated engineering and management practices are much more difficult to define and implement. With the objective of studying the infiltration and water advance characteristics under surge flow furrow irrigation system, to compare the system with continuous flow and to select suitable management parameters for the sandy loam soils of the area a study was conducted at K.C.A.E.T. Tavanur during the months from December 1992 to May 1993.

The experimental plot was 105 m x 15 m size and twelve furrows of 102 m length were laid for the analysis.

Continuous flow irrigation data was compared with data from surge flows of cycle ratio 1/2, 1/3 and 2/3, with cycle times ranging as 6, 9 and 7.5 minutes respectively. The three levels of discharge 1.3, 1.7 and 2.1 lps were obtained by using a constant head supply tank provided with three overflow outlets at precalibrated positions. A 40 mm quarter-turn ball valve was used to regulate the supply of water to the irrigation line and to maintain accurate ON and OFF times. The twelve furrows were divided to four blocks with three furrows per block and the experiment was performed in continuous flow and three surge flows as separate randomized block designs. Water advance and depth of flow data were collected during the irrigation events and recession data could not be obtained accurately. The inflow-outflow data was taken by using orifice plates for both continuous and surge flow furrow irrigation runs. Advance trajectories were developed and the volume balance calculations were performed using the water front advance and the depth of flow data, to obtain the infiltrated volume and infiltrated depth at sections of 15 m length along the furrow. The inflow-outflow data was used to determine the infiltration rate in litres per second per metre length of furrow. Statistical analysis was performed for the data on volume required to complete the advance under each case and the analysis of variance table was prepared. The analysis of the experimental results evolved the following conclusions.

1. The textural analysis indicated that the soil of the study area was sandy loam with 4.7 per cent gravel, 2.22 per cent coarse sand, 11.4 per cent medium sand, 68.95 per cent fine sand and silt and clay comprising 12.72 per cent of the total weight.

2. Analysis of infiltration rate of the soil by cylinder infiltrometer tests resulted in the generation of curves for infiltration rate and accumulated infiltration vs elapsed time. The infiltration equation obtained from the analysis was $y = 1.047 (t)^{0.451} -1.52$. The goodness of fit was evaluated and the average deviation from observed values was obtained as 2.43.

3. The advance time for continuous and surge flow irrigations decreased with increase in stream flow rate. For surge flow of cycle ratio 1/2, the reduction in advance times when compared to continuous flow ranged as 14.59 per cent, 22.8 per cent and 14.77 per cent respectively for the discharges of 1.3, 1.7 and 2.1 lps. In the case of surge flow of cycle ratio 1/3, the percentage reduction was 37.6 per cent, 41.94 per cent and 38.01 per cent for treatments 1, 2 and 3. For the

surge flow of cycle ratio 2/3, the reduction in advance time was 34.29 per cent, 32.83 per cent and 22.73 per cent for 1.3, 1.7 and 2.1 lps respectively. Surge flow of cycle ratio 1/3 proved the best alternative to continuous flow irrigation in reducing the advance time, along the furrow length.

4. The analysis of advance trajectories in all cases depicted close resemblance between curves for the first surge and continuous flow. The time taken for water to advance through the initially wet portions of the furrow was less and advance time significantly increased beyond the overlapping range. Surge effect was found pronounced in the soil of the site with the advance time decreasing for successive surges at each 3 m intervals.

5. Analysis of infiltration parameters by volume-balance method indicates that the variability of infiltration was significantly lesser in surge flow when compared to continuous flow. Infiltrated volume and depth values were lesser for all cases of surge flow when compared to continuous flow and the values were the least for surge flow of cycle ratio 2/3. However, on analysing the curves for mean value of infiltrated depth for all the treatment combinations, it was found that surge flow of cycle ratio 1/3 and a discharge of 1.3 lps showed the

least variability in infiltrated depth, along the furrow length. Uniformity of application was the best under this treatment combination.

6. From the inflow-outflow readings, the calculation of infiltration rate in lps per metre length of furrow was done for all cases for the various surges and for each surge along various sections of the furrow length. Marked reduction in infiltration rate along the length of the furrow for each surge was obtained. The intake rate also decreased for the consecutive surges in all cases. The last surge in each case attained a final intake rate with much less time as compared to continuous flow. The values of final intake rate were higher than for continuous flow, indicating lesser tail water run-off and considerable infiltration in the last section of the furrow length. The total intake rate of the last surge was found to be the least in the case of surge flow of cycle ratio 1/3 and a discharge of 1.3 lps.

7. The analysis of variance of the volume required to complete the advance, indicates significant difference between flow types at 5 per cent and 1 per cent levels. The variation between discharges was significant at 5 per cent and 1 per cent levels. The interaction between flow types and discharges showed variations significant at

5 per cent level and insignificant at 1 per cent level. Thus surge effect was proved to be significant in the sandy loam soils of Tavanur region.

8. Mean value of the volume required to complete the advance in cubic metres was analysed for each treatment combination and it was found that surge flow with cycle ratio 1/3 and a discharge of 1.3 lps, completed the advance with the least volume of 1.11 $m^3$ compared to all the other treatments.

Thus it was concluded that surge effect was pronounced in the soil of the experimental site and surge flow of cycle ratio 1/3 and a lower value of discharge of 1.3 lps proved the most suitable combination for best performance in the sandy loam soils of Tavanur region out of the various treatment combinations tested during the study.

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* Originals not seen

# *Appendices*

# APPENDIX-I

## Calibration chart for discharge through a circular orifice

| Height of water over centre of orifice cm | Discharge rate, lps | | |
|---|---|---|---|
| | 2.5 cm | 5.0 cm | 7.5 cm |
| 1 | 2 | 3 | 4 |
| 1.0 | 0.13 | 3.53 | 1.2 |
| 1.5 | 0.16 | 0.64 | 1.4 |
| 2.0 | 0.19 | 0.74 | 1.7 |
| 2.5 | 0.21 | 0.81 | 1.8 |
| 3.0 | 0.23 | 0.91 | 2.1 |
| 3.5 | 0.25 | 0.99 | 2.2 |
| 4.0 | 0.26 | 1.15 | 2.4 |
| 4.5 | 0.28 | 1.20 | 2.5 |
| 5.0 | 0.30 | 5.21 | 2.7 |
| 5.5 | 0.31 | 1.23 | 2.8 |
| 6.0 | 0.32 | 1.30 | 2.9 |
| 6.5 | 0.33 | 1.34 | 3.0 |
| 7.0 | 0.35 | 1.39 | 3.1 |
| 7.5 | 0.36 | 1.45 | 3.3 |
| 8.0 | 0.38 | 1.50 | 3.4 |
| 8.5 | 0.39 | 1.53 | 3.5 |
| 9.0 | 0.40 | 1.60 | 3.6 |
| 9.5 | 0.41 | 1.62 | 3.7 |
| 10.0 | 0.42 | 1.70 | 3.8 |
| 10.5 | 0.43 | 1.72 | 3.9 |
| 11.0 | 0.44 | 1.75 | 3.9 |
| 11.5 | 0.45 | 1.80 | 4.0 |
| 12.0 | 0.46 | 1.83 | 4.1 |
| 12.5 | 0.47 | 1.87 | 4.2 |
| 13.0 | 0.48 | 1.90 | 4.3 |
| 13.5 | 0.49 | 1.93 | 4.4 |
| 14.0 | 0.50 | 1.96 | 4.5 |
| 14.5 | 0.50 | 2.10 | 4.5 |

Contd.

APPENDIX-I (Contd.)

| 1 | 2 | 3 | 4 |
|---|---|---|---|
| 15.0 | 0.51 | 2.50 | 4.60 |
| 15.5 | 0.52 | 2.80 | 4.70 |
| 16.0 | 0.53 | 2.10 | 4.80 |
| 16.5 | 0.54 | 2.15 | 4.83 |
| 17.0 | 0.54 | 2.20 | 4.92 |
| 17.5 | 0.55 | 2.22 | 5.00 |
| 18.0 | 0.56 | 2.25 | 5.13 |
| 18.5 | 0.57 | 2.30 | 5.15 |
| 19.0 | 0.58 | 2.31 | 5.20 |
| 19.5 | 0.58 | 2.33 | 5.30 |
| 20.0 | 0.59 | 2.37 | 5.32 |
| 20.5 | 0.60 | 2.40 | 5.40 |
| 21.0 | 0.60 | 2.42 | 5.47 |
| 21.5 | 0.61 | 2.45 | 5.53 |
| 22.0 | 0.62 | 2.50 | 5.60 |
| 22.5 | 0.63 | 2.51 | 5.65 |
| 23.0 | 0.63 | 2.53 | 5.70 |
| 25.5 | 0.64 | 2.57 | 5.77 |
| 24.0 | 0.65 | 2.60 | 5.83 |
| 24.5 | 0.66 | 2.62 | 5.92 |
| 25.0 | 0.66 | 2.63 | 5.95 |
| 25.5 | 0.66 | 2.65 | 6.00 |
| 26.0 | 0.67 | 2.67 | 6.10 |
| 26.5 | 0.68 | 2.70 | 6.12 |
| 27.0 | 0.69 | 2.75 | 6.18 |
| 27.5 | 0.69 | 2.80 | 6.23 |
| 28.0 | 0.70 | 2.81 | 6.30 |
| 28.5 | 0.71 | 2.82 | 6.37 |
| 29.0 | 0.71 | 2.83 | 6.40 |
| 29.5 | 0.72 | 2.87 | 6.47 |
| 30.0 | 0.72 | 2.90 | 6.53 |

# APPENDIX-II

## Method of averages to obtain infiltration parameters of the soil at the site

For $t_1 = 5$ min, $Y_1 = 0.67$ cm, $t_2 = 120$ min, $y_2 = 7.6$ cm

$$t_3 = \sqrt{t_1 x t_2} = \sqrt{5x120} = 24.49 \text{ min}$$

Corresponding value of $Y_3$ from graph = 2.95 cm

$$\therefore \quad b = \frac{y_1 y_2 - y_3^2}{y_1 + y_2 - 2y_3} = -1.52$$

Evaluation of goodness of fit:

| Sl. No. | Time t min | Observed accum infil-tration y cm | y-b | log (y-b) | log t | y calcu-lated cm | Devi-ation % |
|---|---|---|---|---|---|---|---|
| 1. | 5 | 0.67 | 2.19 | 0.3404 | 0.6990 | 0.64 | -4.48 |
| 2. | 10 | 1.33 | 2.85 | 0.4548 | 1.0000 | 1.44 | +8.27 |
| 3. | 15 | 1.98 | 3.50 | 0.5441 | 1.1761 | 2.03 | +2.53 |
| 4. | 25 | 3.07 | 4.59 | 0.6618 | 1.3979 | 2.95 | -3.91 |
| 5. | 45 | 4.40 | 5.92 | 0.7723 | 1.6532 | 4.31 | -2.05 |
| 6. | 60 | 5.17 | 6.69 | 0.8254 | 1.7782 | 5.12 | -0.97 |
| 7. | 75 | 5.80 | 7.32 | 0.8645 | 1.8751 | 5.82 | +0.34 |
| 8. | 90 | 6.40 | 7.92 | 0.8987 | 1.9542 | 6.45 | +0.78 |
| 9. | 105 | 7.00 | 8.52 | 0.9304 | 2.0212 | 7.02 | +0.29 |
| 10. | 120 | 7.60 | 9.12 | 0.9599 | 2.0790 | 7.55 | -0.66 |

Average = 2.43

$$\log (y + 1.52) = \log a + \alpha \log t$$

Forming 10 equations and adding 5 together, the following two equations are obtained.

$$2.7734 = 5 \log a + 5.9262\alpha$$

$$4.4789 = 5 \log a + 9.7077\alpha$$

$$1.7055 = 3.7815\alpha$$

$$\therefore \alpha = \underline{\underline{0.451}}$$

$$\log a = 0.0201$$

$$\therefore a = \underline{\underline{1.047}}$$

The functional relationship between accumulated infiltration (cm) and elapsed time (minutes) was obtained as

$$y = 1.047 (t)^{0.451} - 1.52$$

# APPENDIX-III

Advance time and depth of flow data for continuous flow-Discharge - 1.3 lps

| Sl. No. | Distance | Replication-1 | | Replication-2 | | Replication-3 | | Replication-4 | |
|---|---|---|---|---|---|---|---|---|---|
| | m | Advance time min | Depth of flow cm | Advance time min | Depth of flow cm | Advance time min | Depth of flow cm | Advance time min | Depth of flow cm |
| 1. | 3 | 0.22 | 1.4 | 0.20 | 1.5 | 0.17 | 2.0 | 0.17 | 2.5 |
| 2. | 6 | 0.63 | 2.1 | 0.58 | 2.5 | 0.82 | 2.5 | 0.65 | 1.5 |
| 3. | 9 | 1.54 | 2.5 | 0.95 | 2.5 | 1.42 | 2.5 | 1.65 | 1.0 |
| 4. | 12 | 2.98 | 1.0 | 1.37 | 1.5 | 1.98 | 0.8 | 3.25 | 2.0 |
| 5. | 15 | 3.45 | 1.2 | 1.93 | 1.2 | 2.53 | 2.5 | 3.97 | 1.0 |
| 6. | 18 | 4.36 | 1.5 | 2.37 | 1.3 | 3.05 | 0.5 | 4.50 | 2.5 |
| 7. | 21 | 5.73 | 1.0 | 2.80 | 1.3 | 3.52 | 3.2 | 5.92 | 2.9 |
| 8. | 24 | 6.43 | 1.6 | 3.30 | 1.1 | 3.92 | 1.0 | 6.53 | 0.7 |
| 9. | 27 | 7.54 | 1.0 | 3.67 | 1.5 | 4.33 | 1.0 | 7.75 | 1.0 |
| 10. | 30 | 8.62 | 1.5 | 4.00 | 1.0 | 4.75 | 2.0 | 8.50 | 2.0 |
| 11. | 33 | 9.13 | 2.0 | 4.35 | 1.0 | 5.10 | 2.0 | 9.02 | 1.0 |
| 12. | 36 | 10.32 | 2.1 | 4.80 | 1.0 | 5.43 | 4.5 | 10.17 | 1.5 |
| 13. | 39 | 10.95 | 2.5 | 5.47 | 1.5 | 5.77 | 3.0 | 10.97 | 4.5 |
| 14. | 42 | 11.79 | 2.0 | 6.00 | 1.0 | 6.22 | 1.0 | 11.83 | 2.0 |
| 15. | 45 | 12.21 | 1.7 | 6.63 | 0.9 | 7.20 | 2.5 | 12.00 | 1.5 |
| 16. | 48 | 12.95 | 1.0 | 7.17 | 1.4 | 8.25 | 1.0 | 12.75 | 1.0 |
| 17. | 51 | 13.99 | 0.9 | 8.50 | 1.2 | 9.00 | 1.5 | 14.00 | 1.0 |
| 18. | 54 | 14.74 | 1.2 | 9.71 | 2.0 | 10.00 | 1.5 | 14.85 | 0.5 |
| 19. | 57 | 15.53 | 1.5 | 10.35 | 1.2 | 10.50 | 1.5 | 15.62 | 1.0 |
| 20. | 60 | 16.50 | 1.4 | 10.87 | 1.0 | 10.75 | 1.0 | 16.42 | 1.0 |
| 21. | 63 | 17.03 | 2.1 | 11.49 | 1.0 | 11.17 | 1.0 | 16.92 | 0.5 |
| 22. | 66 | 17.81 | 2.0 | 12.23 | 1.0 | 11.58 | 1.5 | 17.70 | 1.0 |
| 23. | 69 | 18.47 | 1.6 | 12.89 | 1.5 | 12.12 | 0.5 | 18.39 | 1.5 |
| 24. | 72 | 18.74 | 1.4 | 13.15 | 1.1 | 12.62 | 1.0 | 18.88 | 2.0 |
| 25. | 75 | 19.45 | 1.0 | 13.85 | 1.5 | 13.08 | 0.5 | 19.34 | 1.9 |
| 26. | 78 | 19.97 | 1.2 | 14.19 | 1.2 | 13.50 | 1.5 | 19.88 | 1.5 |
| 27. | 81 | 20.43 | 2.0 | 14.83 | 1.0 | 14.00 | 1.3 | 20.33 | 1.0 |
| 28. | 84 | 20.95 | 2.1 | 15.50 | 0.8 | 15.20 | 1.0 | 20.89 | 0.9 |
| 29. | 87 | 21.24 | 2.3 | 16.15 | 0.5 | 15.67 | 0.6 | 21.31 | 1.5 |
| 30. | 90 | 21.81 | 2.5 | 16.89 | 1.0 | 16.62 | 0.7 | 21.76 | 1.0 |
| 31. | 93 | 22.21 | 1.0 | 17.23 | 0.8 | 17.37 | 2.1 | 22.15 | 2.5 |
| 32. | 96 | 22.79 | 0.8 | 18.95 | 1.0 | 18.70 | 2.0 | 22.63 | 2.0 |
| 33. | 99 | 22.99 | 1.0 | 20.85 | 0.9 | 20.90 | 1.6 | 22.91 | 1.6 |
| 34. | 102 | 23.24 | 1.1 | 22.20 | 1.2 | 22.50 | 0.9 | 23.38 | 1.9 |

APPENDIX-III (Contd.)

Advance time and depth of flow data for continuous flow-Discharge - 1.7 lps

| Sl. No. | Distance | Replication-1 | | Replication-2 | | Replication-3 | | Replication-4 | |
|---|---|---|---|---|---|---|---|---|---|
| | m | Advance time min | Depth of flow cm | Advance time min | Depth of flow cm | Advance time min | Depth of flow cm | Advance time min | Depth of flow cm |
| 1. | 3 | 0.38 | 2.0 | 0.22 | 1.5 | 0.15 | 2.5 | 0.13 | 3.5 |
| 2. | 6 | 0.82 | 1.5 | 0.60 | 2.5 | 0.50 | 2.9 | 0.53 | 2.0 |
| 3. | 9 | 1.23 | 1.8 | 0.95 | 2.2 | 0.87 | 1.5 | 1.13 | 2.3 |
| 4. | 12 | 1.67 | 1.9 | 1.28 | 2.1 | 1.20 | 1.5 | 1.53 | 2.5 |
| 5. | 15 | 2.08 | 2.7 | 1.75 | 1.5 | 1.62 | 2.0 | 2.03 | 2.5 |
| 6. | 18 | 2.50 | 2.4 | 2.20 | 1.5 | 2.07 | 2.0 | 2.52 | 2.4 |
| 7. | 21 | 3.15 | 2.4 | 2.67 | 3.0 | 2.50 | 2.3 | 2.85 | 2.5 |
| 8. | 24 | 3.97 | 2.5 | 3.23 | 1.7 | 2.97 | 2.0 | 3.27 | 2.5 |
| 9. | 27 | 4.75 | 2.0 | 3.52 | 2.0 | 3.32 | 3.0 | 3.80 | 2.8 |
| 10. | 30 | 5.47 | 1.2 | 3.88 | 2.0 | 3.78 | 1.7 | 4.33 | 2.5 |
| 11. | 33 | 5.93 | 1.9 | 4.30 | 1.0 | 4.0 | 1.5 | 4.67 | 1.6 |
| 12. | 36 | 2.73 | 2.5 | 4.87 | 1.0 | 4.5 | 1.0 | 5.03 | 1.5 |
| 13. | 39 | 7.92 | 1.3 | 5.57 | 0.8 | 4.95 | 1.5 | 5.45 | 1.0 |
| 14. | 42 | 9.00 | 2.5 | 6.15 | 1.0 | 5.68 | 1.0 | 5.67 | 1.5 |
| 15. | 45 | 9.58 | 1.0 | 6.77 | 1.5 | 6.18 | 1.5 | 6.02 | 1.5 |
| 16. | 48 | 10.92 | 1.5 | 7.50 | 1.0 | 6.60 | 1.2 | 6.67 | 2.0 |
| 17. | 51 | 11.08 | 1.7 | 8.07 | 1.4 | 7.12 | 1.1 | 7.7 | 1.0 |
| 18. | 54 | 11.92 | 1.5 | 8.80 | 1.0 | 7.53 | 1.2 | 8.25 | 1.5 |
| 19. | 57 | 12.50 | 1.5 | 9.17 | 1.5 | 7.85 | 1.9 | 8.53 | 2.0 |
| 20. | 60 | 12.83 | 1.7 | 9.52 | 1.4 | 8.95 | 1.7 | 8.88 | 1.0 |
| 21. | 63 | 13.33 | 1.5 | 10.03 | 2.4 | 10.23 | 2.0 | 9.35 | 2.5 |
| 22. | 66 | 13.97 | 1.2 | 10.67 | 1.5 | 11.99 | 1.4 | 9.80 | 2.5 |
| 23. | 69 | 14.60 | 2.5 | 11.07 | 1.8 | 12.83 | 2.0 | 10.33 | 2.0 |
| 24. | 72 | 15.50 | 1.9 | 11.60 | 1.2 | 13.67 | 2.2 | 11.67 | 1.5 |
| 25. | 75 | 16.03 | 2.0 | 12.74 | 1.8 | 14.98 | 2.5 | 12.75 | 2.5 |
| 26. | 78 | 16.50 | 1.5 | 14.23 | 1.2 | 15.82 | 3.5 | 14.45 | 2.0 |
| 27. | 81 | 17.38 | 2.0 | 15.99 | 1.5 | 17.01 | 2.5 | 15.89 | 3.0 |
| 28. | 84 | 18.43 | 1.5 | 17.91 | 1.0 | 17.99 | 1.5 | 17.82 | 3.2 |
| 29. | 87 | 18.87 | 1.5 | 18.71 | 1.1 | 18.68 | 2.5 | 18.98 | 3.5 |
| 30. | 90 | 19.37 | 1.7 | 19.89 | 1.4 | 19.25 | 3.5 | 19.75 | 2.0 |
| 31. | 93 | 19.83 | 1.0 | 20.25 | 2.0 | 19.91 | 1.5 | 20.29 | 1.5 |
| 32. | 96 | 20.28 | 1.5 | 20.97 | 1.3 | 20.37 | 2.5 | 20.99 | 2.0 |
| 33. | 99 | 21.25 | 1.4 | 21.54 | 1.5 | 21.42 | 3.3 | 21.63 | 2.1 |
| 34. | 102 | 21.73 | 3.0 | 22.01 | 3.0 | 21.95 | 3.0 | 22.15 | 1.9 |

APPENDIX-III (Contd.)

Advance time and depth of flow data for continuous flow-Discharge - 2.1 lps

| Sl. No. | Distance m | Replication-1 | | Replication-2 | | Replication-3 | | Replication-4 | |
|---|---|---|---|---|---|---|---|---|---|
| | | Advance time min | Depth of flow cm | Advance time min | Depth of flow cm | Advance time min | Depth of flow cm | Advance time min | Depth of flow cm |
| 1. | 3 | 0.22 | 1.5 | 0.15 | 2.5 | 0.20 | 2.0 | 0.17 | 2.3 |
| 2. | 6 | 0.75 | 1.5 | 0.60 | 2.0 | 0.63 | 2.4 | 0.58 | 2.8 |
| 3. | 9 | 1.45 | 1.5 | 1.25 | 2.5 | 1.00 | 2.0 | 0.95 | 1.5 |
| 4. | 12 | 1.78 | 2.0 | 1.75 | 2.6 | 1.47 | 3.0 | 1.30 | 1.2 |
| 5. | 15 | 2.08 | 2.0 | 2.25 | 3.0 | 1.90 | 1.8 | 1.65 | 1.5 |
| 6. | 18 | 2.48 | 1.9 | 2.67 | 5.5 | 2.50 | 2.0 | 2.30 | 1.5 |
| 7. | 21 | 2.85 | 2.3 | 3.17 | 2.0 | 2.95 | 2.0 | 3.10 | 1.5 |
| 8. | 24 | 3.25 | 1.5 | 4.01 | 0.5 | 3.40 | 2.8 | 3.67 | 1.5 |
| 9. | 27 | 3.60 | 1.5 | 4.62 | 1.5 | 3.80 | 2.0 | 4.40 | 2.0 |
| 10. | 30 | 3.88 | 1.0 | 4.95 | 0.5 | 4.0 | 2.0 | 4.75 | 1.0 |
| 11. | 33 | 4.15 | 2.0 | 5.37 | 1.0 | 4.48 | 1.0 | 5.08 | 0.8 |
| 12. | 36 | 4.58 | 0.9 | 6.50 | 2.0 | 5.0 | 1.1 | 5.53 | 0.9 |
| 13. | 39 | 5.35 | 1.0 | 7.93 | 2.0 | 5.28 | 1.1 | 5.95 | 1.0 |
| 14. | 42 | 6.08 | 1.5 | 8.25 | 2.0 | 5.65 | 0.9 | 6.50 | 1.0 |
| 15. | 45 | 7.03 | 1.0 | 8.83 | 2.0 | 6.15 | 1.2 | 6.77 | 1.9 |
| 16. | 48 | 7.67 | 1.5 | 9.62 | 3.0 | 6.93 | 1.8 | 7.59 | 2.9 |
| 17. | 51 | 8.12 | 2.0 | 10.15 | 1.5 | 7.5 | 1.5 | 8.21 | 2.5 |
| 18. | 54 | 8.70 | 2.0 | 10.50 | 1.5 | 7.83 | 1.5 | 8.92 | 2.5 |
| 19. | 57 | 9.12 | 1.0 | 11.40 | 0.8 | 8.20 | 1.8 | 9.35 | 2.0 |
| 20. | 60 | 9.40 | 2.0 | 11.83 | 2.5 | 9.5 | 2.5 | 9.98 | 1.8 |
| 21. | 63 | 9.87 | 1.5 | 12.37 | 2.0 | 10.03 | 2.0 | 10.47 | 1.5 |
| 22. | 66 | 10.27 | 1.5 | 12.65 | 1.5 | 10.81 | 2.0 | 10.89 | 1.5 |
| 23. | 69 | 10.87 | 1.5 | 13.00 | 1.3 | 11.54 | 2.5 | 11.63 | 1.0 |
| 24. | 72 | 11.37 | 1.5 | 13.42 | 1.8 | 11.98 | 2.0 | 12.05 | 1.6 |
| 25. | 75 | 12.00 | 1.0 | 13.98 | 2.5 | 12.33 | 1.8 | 12.76 | 1.5 |
| 26. | 78 | 12.58 | 0.9 | 14.25 | 3.1 | 13.00 | 1.8 | 13.33 | 2.0 |
| 27. | 81 | 13.50 | 1.5 | 14.83 | 2.3 | 13.55 | 1.0 | 14.12 | 2.1 |
| 28. | 84 | 14.45 | 2.0 | 15.0 | 0.6 | 14.83 | 2.0 | 14.87 | 2.5 |
| 29. | 87 | 15.38 | 1.0 | 15.5 | 2.3 | 15.30 | 1.5 | 15.35 | 2.5 |
| 30. | 90 | 16.10 | 3.0 | 16.5 | 1.6 | 15.75 | 1.6 | 15.99 | 2.0 |
| 31. | 93 | 17.12 | 2.5 | 18.0 | 0.3 | 16.25 | 1.5 | 16.65 | 2.2 |
| 32. | 96 | 18.37 | 5.0 | 18.4 | 1.6 | 16.79 | 1.5 | 11.15 | 1.5 |
| 33. | 99 | 18.95 | 1.5 | 18.9 | 1.6 | 17.88 | 1.0 | 18.23 | 1.7 |
| 34. | 102 | 19.63 | 2.5 | 19.52 | 2.3 | 18.96 | 1.5 | 19.34 | 1.9 |

APPENDIX-III (Contd.)

Advance time and depth of flow data-surge flow (CR=1/2), Discharge - 1.3 lps, Replication-1

| Sl. No. | Distance | S-1 | | S-2 | | S-3 | | S-4 | | S-5 | | S-6 | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | m | Time min | Depth cm | Time min | Depth cm | Time min | Depth cm | Time min | Depth cm | Time min | Depth cm | Time min | Depth cm |
| 1. | 3 | 0.32 | 1.5 | 0.30 | 1.7 | 0.28 | 2.0 | 0.25 | 3.5 | 0.17 | 4.0 | 0.15 | 4.5 |
| 2. | 6 | 0.64 | 1.5 | 0.41 | 2.0 | 0.35 | 2.5 | 0.29 | 3.5 | 0.23 | 3.9 | 0.19 | 4.0 |
| 3. | 9 | 0.95 | 2.0 | 0.52 | 2.1 | 0.42 | 2.9 | 0.36 | 3.0 | 0.29 | 3.5 | 0.23 | 4.2 |
| 4. | 12 | 1.16 | 2.1 | 0.79 | 2.0 | 0.55 | 3.0 | 0.42 | 3.0 | 0.34 | 3.5 | 0.28 | 4.2 |
| 5. | 15 | 1.35 | 1.5 | 0.92 | 2.5 | 0.64 | 3.2 | 0.49 | 2.5 | 0.41 | 3.0 | 0.35 | 4.5 |
| 6. | 18 | 1.68 | 2.0 | 1.15 | 2.2 | 0.72 | 3.2 | 0.57 | 2.5 | 0.49 | 3.0 | 0.40 | 4.0 |
| 7. | 21 | 2.18 | 2.5 | 1.29 | 3.0 | 0.81 | 3.0 | 0.65 | 2.5 | 0.57 | 2.9 | 0.48 | 3.5 |
| 8. | 24 | 2.54 | 1.9 | 1.43 | 2.5 | 0.89 | 2.9 | 0.71 | 2.0 | 0.64 | 2.5 | 0.54 | 3.5 |
| 9. | 27 | 3.61 | 1.5 | 1.62 | 2.5 | 0.97 | 2.5 | 0.79 | 2.0 | 0.71 | 2.5 | 0.60 | 3.2 |
| 10. | 30 | 4.50 | 1.1 | 1.79 | 1.9 | 1.12 | 2.5 | 0.87 | 1.9 | 0.78 | 2.0 | 0.67 | 3.2 |
| 11. | 33 | 4.99 | 0.9 | 1.91 | 1.5 | 1.24 | 2.2 | 0.93 | 2.0 | 0.85 | 2.0 | [illegible] | [illegible] |
| 12. | 36 | 5.71 | 0.5 | 2.03 | 1.1 | 1.36 | 2.0 | 1.03 | 2.2 | 0.91 | 1.9 | 0.79 | 2.5 |
| 13. | 39 | 6.29 | 0.5 | 2.25 | 1.2 | 1.54 | 1.5 | 1.15 | 2.0 | 0.98 | 1.5 | 0.85 | 2.5 |
| 14. | 42 | | | 2.79 | 1.0 | 1.78 | 1.7 | 1.26 | 2.1 | 1.09 | 1.5 | 0.91 | 2.0 |
| 15. | 45 | | | 3.05 | 1.0 | 1.95 | 2.0 | 1.38 | 2.0 | 1.17 | 2.0 | 0.98 | 2.5 |
| 16. | 48 | | | 3.46 | 0.9 | 2.29 | 2.2 | 1.45 | 2.2 | 1.23 | 2.5 | 1.07 | 2.5 |
| 17. | 51 | | | 4.91 | 1.5 | 2.58 | 2.5 | 1.59 | 2.2 | 1.34 | 2.5 | 1.15 | 3.0 |
| 18. | 54 | | | 5.89 | 1.2 | 2.89 | 1.5 | 1.71 | 2.1 | 1.42 | 2.4 | 1.21 | 3.2 |
| 19. | 57 | | | 6.61 | 0.5 | 3.26 | 1.5 | 1.94 | 2.0 | 1.57 | 2.2 | 1.34 | 2.5 |
| 20. | 60 | | | 7.63 | 0.5 | 3.56 | 1.0 | 2.13 | 1.5 | 1.75 | 2.5 | 1.52 | 2.5 |
| 21. | 63 | | | | | 4.23 | 1.5 | 2.24 | 1.9 | 1.93 | 2.0 | 1.67 | 2.0 |
| 22. | 66 | | | | | 5.61 | 1.2 | 2.39 | 1.4 | 2.07 | 1.2 | 1.75 | 1.5 |
| 23. | 69 | | | | | 6.81 | 1.1 | 2.54 | 1.5 | 2.21 | 1.0 | 1.83 | 1.5 |
| 24. | 72 | | | | | 7.42 | 0.8 | 3.14 | 1.1 | 2.55 | 1.1 | 1.99 | 1.2 |
| 25. | 75 | | | | | 8.01 | 0.6 | 3.72 | 1.0 | 2.98 | 0.9 | 2.23 | 1.5 |
| 26. | 78 | | | | | | | 5.21 | 0.8 | 3.19 | 1.0 | 2.39 | 1.9 |
| 27. | 81 | | | | | | | 7.53 | 0.4 | 3.38 | 1.1 | 2.54 | 2.0 |
| 28. | 84 | | | | | | | 8.19 | 0.3 | 3.54 | 0.8 | 2.69 | 1.5 |
| 29. | 87 | | | | | | | | | 4.89 | 0.7 | 2.98 | 1.2 |
| 30. | 90 | | | | | | | | | 5.78 | 0.6 | 3.39 | 1.1 |
| 31. | 93 | | | | | | | | | 7.85 | 0.5 | 4.95 | 1.1 |
| 32. | 96 | | | | | | | | | | | 5.31 | 1.0 |
| 33. | 99 | | | | | | | | | | | 5.54 | 0.9 |
| 34. | 102 | | | | | | | | | | | 5.98 | 0.8 |

APPENDIX-III (Contd.)

Advance time and depth of flow data-surge flow (CR=1/2), Discharge - 1.3 lps, Replication-2

| Sl. No. | Distance | S-1 | | S-2 | | S-3 | | S-4 | | S-5 | | S-6 | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | m | Time min | Depth cm | Time min | Depth cm | Time min | Depth cm | Time min | Depth cm | Time min | Depth cm | Time min | Depth cm |
| 1. | 3 | 0.30 | 1.6 | 0.25 | 2.0 | 0.17 | 1.1 | 0.17 | 1.2 | 0.15 | 1.5 | 0.09 | 2.5 |
| 2. | 6 | 0.60 | 2.6 | 0.54 | 2.6 | 0.35 | 4.0 | 0.23 | 4.3 | 0.19 | 4.0 | 0.14 | 3.5 |
| 3. | 9 | 0.93 | 3.2 | 0.85 | 3.5 | 0.54 | 4.5 | 0.35 | 4.2 | 0.25 | 4.0 | 0.19 | 3.8 |
| 4. | 12 | 1.28 | 2.3 | 0.96 | 2.2 | 0.63 | 3.5 | 0.41 | 3.8 | 0.31 | 3.9 | 0.26 | 4.0 |
| 5. | 15 | 1.77 | 2.0 | 1.07 | 2.0 | 0.69 | 3.8 | 0.49 | 3.6 | 0.39 | 4.0 | 0.30 | 4.2 |
| 6. | 18 | 2.20 | 2.0 | 1.25 | 2.3 | 0.75 | 3.5 | 0.53 | 3.9 | 0.46 | 3.9 | 0.35 | 3.5 |
| 7. | 21 | 2.57 | 1.9 | 1.36 | 2.0 | 0.82 | 3.3 | 0.58 | 3.4 | 0.55 | 3.5 | 0.39 | 3.5 |
| 8. | 24 | 3.12 | 2.3 | 1.48 | 3.0 | 0.98 | 3.9 | 0.64 | 4.4 | 0.61 | 3.9 | 0.42 | 3.0 |
| 9. | 27 | 3.75 | 1.0 | 1.63 | 1.0 | 1.17 | 1.1 | 0.71 | 1.5 | 0.69 | 1.0 | 0.54 | 2.5 |
| 10. | 30 | 4.23 | 0.6 | 1.77 | 1.0 | 1.22 | 1.0 | 0.77 | 1.4 | 0.75 | 0.8 | 0.68 | 2.0 |
| 11. | 33 | 5.1 | 0.8 | 1.98 | 1.1 | 1.38 | 2.2 | 0.82 | 1.6 | 0.80 | 2.9 | 0.73 | 2.6 |
| 12. | 36 | 6.35 | 0.7 | 2.30 | 1.5 | 1.44 | 3.5 | 0.95 | 3.3 | 0.93 | 3.9 | 0.85 | 2.5 |
| 13. | 39 | | | 2.80 | 1.5 | 1.59 | 3.0 | 1.03 | 3.0 | 1.0 | 3.1 | 0.96 | 3.3 |
| 14. | 42 | | | 2.99 | 2.0 | 1.65 | 3.0 | 1.18 | 3.0 | 1.09 | 3.7 | 0.01 | 3.0 |
| 15. | 45 | | | 3.09 | 1.3 | 1.78 | 2.9 | 1.26 | 2.7 | 1.17 | 3.2 | 1.08 | 3.0 |
| 16. | 48 | | | 3.17 | 1.4 | 1.95 | 3.4 | 1.35 | 5.0 | 1.31 | 5.0 | 1.13 | 2.5 |
| 17. | 51 | | | 4.83 | 0.5 | 2.16 | 1.2 | 1.42 | 1.5 | 1.40 | 1.5 | 1.20 | 2.0 |
| 18. | 54 | | | 6.00 | 1.0 | 2.55 | 1.0 | 1.59 | 1.0 | 1.52 | 1.6 | 1.31 | 2.0 |
| 19. | 57 | | | 6.67 | 0.7 | 3.01 | 1.0 | 1.68 | 0.9 | 1.65 | 1.5 | 1.45 | 1.1 |
| 20. | 60 | | | 7.75 | 0.6 | 0.37 | 1.0 | 1.84 | 1.1 | 1.79 | 1.4 | 1.59 | 1.0 |
| 21. | 63 | | | | | 4.38 | 1.1 | 1.92 | 1.4 | 1.81 | 1.8 | 1.65 | 1.1 |
| 22. | 66 | | | | | 5.62 | 1.0 | 1.97 | 1.4 | 1.96 | 1.8 | 1.73 | 1.5 |
| 23. | 69 | | | | | 6.70 | 1.2 | 2.06 | 1.5 | 2.04 | 3.5 | 1.89 | 1.5 |
| 24. | 72 | | | | | 8.13 | 1.1 | 2.25 | 0.6 | 2.21 | 3.5 | 1.98 | 2.0 |
| 25. | 75 | | | | | | | 4.33 | 0.9 | 2.98 | 2.6 | 2.23 | 2.1 |
| 26. | 78 | | | | | | | 5.18 | 0.7 | 3.02 | 1.0 | 2.54 | 2.0 |
| 27. | 81 | | | | | | | 6.83 | 0.6 | 3.07 | 1.0 | 3.01 | 0.9 |
| 28. | 84 | | | | | | | 7.83 | 0.6 | 3.10 | 1.8 | 3.09 | 1.0 |
| 29. | 87 | | | | | | | 9.25 | 0.6 | 3.17 | 1.9 | 3.13 | 1.1 |
| 30. | 90 | | | | | | | | | 5.48 | 1.5 | 4.05 | 1.0 |
| 31. | 93 | | | | | | | | | 5.53 | 1.7 | 4.97 | 0.9 |
| 32. | 96 | | | | | | | | | 7.90 | 0.4 | 5.58 | 0.8 |
| 33. | 99 | | | | | | | | | | | 5.79 | 0.6 |
| 34. | 102 | | | | | | | | | | | 5.94 | 0.6 |

APPENDIX-III (Contd.)

Advance time and depth of flow data-surge flow (CR=1/2), Discharge - 1.3 lps, Replication-3

| Sl. No. | Distance m | S-1 Time min | S-1 Depth cm | S-2 Time min | S-2 Depth cm | S-3 Time min | S-3 Depth cm | S-4 Time min | S-4 Depth cm | S-5 Time min | S-5 Depth cm | S-6 Time min | S-6 Depth cm | S-7 Time min | S-7 Depth cm |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1. | 3 | 0.17 | 1.5 | 0.15 | 4.5 | 0.16 | 4.6 | 0.17 | 5.0 | 0.09 | 6.0 | 0.05 | 5.0 | 0.04 | 5.5 |
| 2. | 6 | 0.62 | 1.8 | 0.37 | 3.0 | 0.28 | 4.0 | 0.25 | 2.0 | 0.16 | 3.0 | 0.12 | 2.0 | 0.11 | 3.0 |
| 3. | 9 | 1.0 | 2.5 | 0.82 | 3.0 | 0.65 | 2.9 | 0.39 | 3.0 | 0.23 | 4.5 | 0.19 | 3.0 | 0.17 | 4.2 |
| 4. | 12 | 1.52 | 2.8 | 0.98 | 3.2 | 0.84 | 4.5 | 0.46 | 3.5 | 0.34 | 4.0 | 0.28 | 3.5 | 0.22 | 3.8 |
| 5. | 15 | 1.98 | 0.5 | 1.09 | 1.0 | 0.97 | 4.0 | 0.57 | 1.0 | 0.49 | 1.50 | 0.35 | 1.0 | 0.29 | 1.1 |
| 6. | 18 | 2.52 | 2.3 | 1.27 | 2.0 | 1.08 | 1.1 | 0.63 | 3.0 | 0.58 | 4.1 | 0.47 | 3.0 | 0.34 | 2.1 |
| 7. | 21 | 2.97 | 1.5 | 1.78 | 3.0 | 1.19 | 4.0 | 0.71 | 4.0 | 0.65 | 5.2 | 0.55 | 4.0 | 0.42 | 2.0 |
| 8. | 24 | 3.18 | 2.1 | 2.00 | 4.5 | 1.47 | 5.3 | 0.78 | 6.7 | 0.72 | 7.8 | 0.67 | 6.3 | 0.57 | 4.0 |
| 9. | 27 | 4.17 | 0.4 | 2.19 | 0.5 | 1.63 | 4.4 | 0.82 | 1.5 | 0.79 | 1.1 | 0.71 | 1.5 | 0.65 | 0.9 |
| 10. | 30 | 4.95 | 0.3 | 2.54 | 1.0 | 1.71 | 1.5 | 0.87 | 1.5 | 0.84 | 1.0 | 0.79 | 1.5 | 0.74 | 0.9 |
| 11. | 33 | 5.67 | 0.1 | 2.75 | 1.0 | 1.83 | 1.2 | 0.94 | 1.0 | 0.91 | 1.0 | 0.83 | 1.0 | 0.79 | 1.3 |
| 12. | 36 | 7.18 | 0.1 | 3.00 | 1.0 | 1.91 | 1.2 | 0.99 | 1.0 | 0.97 | 1.5 | 0.88 | 1.0 | 0.85 | 1.8 |
| 13. | 39 | | | 3.57 | 0.5 | 2.0 | 1.1 | 1.13 | 3.0 | 1.08 | 3.7 | 0.95 | 3.5 | 0.90 | 4.0 |
| 14. | 42 | | | 3.97 | 2.0 | 2.05 | 2.0 | 1.28 | 5.7 | 1.17 | 4.5 | 1.12 | 6.0 | 1.05 | 4.5 |
| 15. | 45 | | | 4.63 | 1.0 | 2.17 | 5.0 | 1.35 | 3.5 | 1.24 | 4.3 | 1.19 | 4.0 | 1.13 | 4.9 |
| 16. | 48 | | | 5.50 | 1.0 | 2.50 | 2.5 | 1.89 | 2.7 | 1.43 | 3.0 | 1.23 | 2.5 | 1.19 | 3.5 |
| 17. | 51 | | | | | 3.17 | 2.0 | 2.19 | 2.8 | 1.62 | 3.2 | 1.38 | 3.0 | 1.22 | 3.7 |
| 18. | 54 | | | | | 3.67 | 0.4 | 2.36 | 0.8 | 1.84 | 1.6 | 1.46 | 2.0 | 1.39 | 0.5 |
| 19. | 57 | | | | | 4.08 | 0.5 | 2.59 | 0.3 | 2.02 | 1.7 | 1.54 | 1.0 | 1.48 | 1.0 |
| 20. | 60 | | | | | 6.17 | 0.5 | 2.72 | 0.5 | 2.17 | 1.0 | 1.65 | 1.0 | 1.56 | 1.0 |
| 21. | 63 | | | | | 7.07 | 0.2 | 4.17 | 0.5 | 2.21 | 1.5 | 1.73 | 1.5 | 1.71 | 1.0 |
| 22. | 66 | | | | | | | 5.13 | 1.0 | 2.39 | 0.9 | 1.81 | 2.0 | 1.79 | 1.5 |
| 23. | 69 | | | | | | | 6.30 | 0.3 | 2.54 | 0.4 | 1.89 | 2.5 | 1.87 | 1.1 |
| 24. | 72 | | | | | | | 7.18 | 0.5 | 2.77 | 1.4 | 1.97 | 1.0 | 1.95 | 1.5 |
| 25. | 75 | | | | | | | 8.08 | 0.2 | 2.92 | 1.1 | 2.05 | 0.5 | 2.02 | 1.8 |
| 26. | 78 | | | | | | | | | 3.17 | 1.6 | 2.18 | 0.5 | 2.17 | 1.7 |
| 27. | 81 | | | | | | | | | 4.85 | 0.7 | 2.25 | 0.5 | 2.23 | 1.1 |
| 28. | 84 | | | | | | | | | 6.02 | 0.6 | 2.29 | 1.0 | 2.28 | 2.0 |
| 29. | 87 | | | | | | | | | 7.75 | 0.5 | 2.39 | 0.5 | 2.38 | 2.1 |
| 30. | 90 | | | | | | | | | | | 3.58 | 1.0 | 2.97 | 0.9 |
| 31. | 93 | | | | | | | | | | | 6.27 | 1.5 | 3.57 | 0.7 |
| 32. | 96 | | | | | | | | | | | 7.52 | 1.0 | 3.52 | 0.7 |
| 33. | 99 | | | | | | | | | | | 9.32 | 0.5 | 4.00 | 0.5 |
| 34. | 102 | | | | | | | | | | | | | 5.02 | 0.3 |

APPENDIX-III (Contd.)

Advance time and depth of flow data-surge flow (CR=1/2), Discharge - 1.3 lps, Replication-4

| Sl. No. | Distance m | S-1 |  | S-2 |  | S-3 |  | S-4 |  | S-5 |  | S-6 |  | S-7 |  |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
|  |  | Time min | Depth cm | Time min | Depth cm | Time min | Depth cm | Time min | Depth cm | Time min | Depth cm | Time min | Depth cm | Time min | Depth cm |
| 1. | 3 | 0.25 | 1.3 | 0.15 | 3.5 | 0.14 | 4.5 | 0.13 | 5.0 | 0.11 | 4.2 | 0.09 | 5.0 | 0.07 | 5.0 |
| 2. | 6 | 0.52 | 2.6 | 0.44 | 2.0 | 0.28 | 3.1 | 0.23 | 3.0 | 0.19 | 3.9 | 0.14 | 4.9 | 0.11 | 5.2 |
| 3. | 9 | 0.85 | 2.0 | 0.52 | 3.0 | 0.46 | 6.3 | 0.29 | 3.5 | 0.25 | 4.3 | 0.19 | 3.5 | 0.17 | 4.5 |
| 4. | 12 | 1.05 | 1.2 | 0.68 | 4.5 | 0.55 | 7.2 | 0.36 | 7.0 | 0.32 | 7.5 | 0.26 | 3.0 | 0.22 | 4.5 |
| 5. | 15 | 1.55 | 2.6 | 0.79 | 6.0 | 0.67 | 5.1 | 0.41 | 7.5 | 0.38 | 9.0 | 0.33 | 4.0 | 0.28 | 4.5 |
| 6. | 18 | 2.08 | 1.1 | 0.95 | 4.0 | 0.82 | 6.2 | 0.48 | 5.5 | 0.45 | 6.5 | 0.41 | 4.5 | 0.35 | 4.6 |
| 7. | 21 | 2.75 | 1.6 | 1.07 | 5.5 | 0.95 | 5.6 | 0.57 | 7.0 | 0.51 | 7.6 | 0.48 | 4.2 | 0.42 | 4.2 |
| 8. | 24 | 3.08 | 2.6 | 1.27 | 4.5 | 1.15 | 1.8 | 0.64 | 5.5 | 0.59 | 6.5 | 0.56 | 5.0 | 0.49 | 5.0 |
| 9. | 27 | 5.25 | 0.2 | 1.77 | 0.5 | 1.53 | 1.0 | 0.76 | 2.0 | 0.68 | 2.0 | 0.62 | 4.5 | 0.53 | 4.9 |
| 10. | 30 | 6.08 | 0.1 | 2.30 | 2.0 | 1.72 | 2.1 | 0.83 | 3.0 | 0.76 | 2.5 | 0.68 | 4.0 | 0.59 | 4.5 |
| 11. | 33 |  |  | 2.98 | 1.0 | 1.81 | 1.4 | 0.95 | 2.0 | 0.82 | 2.3 | 0.75 | 4.2 | 0.65 | 4.5 |
| 12. | 36 |  |  | 3.73 | 1.0 | 1.94 | 1.6 | 1.02 | 2.0 | 0.94 | 2.3 | 0.88 | 4.3 | 0.71 | 4.9 |
| 13. | 39 |  |  | 4.47 | 1.0 | 2.04 | 2.1 | 1.10 | 4.0 | 1.03 | 5.0 | 0.94 | 5.0 | 0.77 | 5.2 |
| 14. | 42 |  |  | 5.75 | 1.0 | 2.17 | 2.4 | 1.25 | 5.5 | 1.17 | 4.9 | 1.01 | 5.2 | 0.84 | 5.3 |
| 15. | 45 |  |  |  |  | 3.50 | 1.6 | 1.36 | 3.5 | 1.29 | 4.7 | 1.13 | 5.3 | 0.90 | 5.5 |
| 16. | 48 |  |  |  |  | 4.17 | 2.1 | 1.54 | 1.5 | 1.37 | 4.9 | 1.20 | 5.0 | 0.98 | 5.2 |
| 17. | 51 |  |  |  |  | 6.00 | 2.7 | 1.79 | 1.0 | 1.48 | 2.1 | 1.35 | 3.2 | 1.03 | 4.0 |
| 18. | 54 |  |  |  |  | 6.83 | 4.7 | 2.0 | 1.5 | 1.58 | 1.9 | 1.42 | 3.1 | 1.10 | 4.0 |
| 19. | 57 |  |  |  |  | 7.75 | 0.8 | 2.37 | 1.5 | 1.69 | 2.5 | 1.48 | 2.9 | 1.15 | 4.5 |
| 20. | 60 |  |  |  |  |  |  | 3.65 | 0.5 | 1.76 | 2.0 | 1.54 | 2.5 | 1.21 | 3.9 |
| 21. | 63 |  |  |  |  |  |  | 4.43 | 0.5 | 1.94 | 1.2 | 1.63 | 1.5 | 1.29 | 3.5 |
| 22. | 66 |  |  |  |  |  |  | 5.08 | 1.0 | 2.13 | 2.0 | 1.72 | 1.5 | 1.35 | 3.0 |
| 23. | 69 |  |  |  |  |  |  | 6.17 | 0.4 | 2.25 | 1.7 | 1.79 | 1.5 | 1.40 | 3.0 |
| 24. | 72 |  |  |  |  |  |  | 7.98 | 0.2 | 3.75 | 0.4 | 1.85 | 1.5 | 1.46 | 2.4 |
| 25. | 75 |  |  |  |  |  |  |  |  | 5.17 | 0.3 | 1.92 | 1.5 | 1.52 | 2.5 |
| 26. | 78 |  |  |  |  |  |  |  |  | 5.54 | 0.2 | 2.06 | 1.2 | 1.68 | 2.0 |
| 27. | 81 |  |  |  |  |  |  |  |  | 6.82 | 0.2 | 2.15 | 1.1 | 1.79 | 2.1 |
| 28. | 84 |  |  |  |  |  |  |  |  | 7.21 | 0.1 | 2.21 | 1.0 | 1.87 | 2.0 |
| 29. | 87 |  |  |  |  |  |  |  |  |  |  | 3.64 | 1.0 | 2.51 | 2.1 |
| 30. | 90 |  |  |  |  |  |  |  |  |  |  | 6.52 | 0.9 | 2.93 | 0.9 |
| 31. | 93 |  |  |  |  |  |  |  |  |  |  | 6.81 | 0.5 | 3.53 | 0.4 |
| 32. | 96 |  |  |  |  |  |  |  |  |  |  | 7.98 | 0.3 | 3.84 | 0.2 |
| 33. | 99 |  |  |  |  |  |  |  |  |  |  |  |  | 4.31 | 0.2 |
| 34. | 102 |  |  |  |  |  |  |  |  |  |  |  |  | 5.75 | 0.1 |

APPENDIX-III (Contd.)

Advance time and depth of flow data-surge flow (CR=1/2), Discharge - 1.7 lps, Replication-1

| Sl. No. | Distance | S-1 | | S-2 | | S-3 | | S-4 | | S-5 | | S-6 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | m | Time min | Depth cm | Time min | Depth cm | Time min | Depth cm | Time min | Depth cm | Time min | Depth cm | |
| 1. | 3 | 0.33 | 2.5 | 0.27 | 3.0 | 0.22 | 3.3 | 0.19 | 3.5 | 0.15 | 3.5 | Was 'ON' for 30 sec. Advance readings were not taken |
| 2. | 6 | 0.78 | 2.0 | 0.53 | 2.6 | 0.40 | 2.5 | 0.27 | 3.0 | 0.20 | 3.8 | |
| 3. | 9 | 1.13 | 1.5 | 0.80 | 2.4 | 0.63 | 2.7 | 0.35 | 2.6 | 0.29 | 3.2 | |
| 4. | 12 | 1.47 | 2.2 | 1.02 | 3.0 | 3.85 | 3.3 | 0.47 | 2.5 | 0.36 | 3.1 | |
| 5. | 15 | 1.78 | 1.8 | 1.15 | 2.1 | 1.12 | 2.6 | 0.62 | 2.0 | 0.45 | 3.1 | |
| 6. | 18 | 1.13 | 1.5 | 0.80 | 2.4 | 0.63 | 2.7 | 0.35 | 2.6 | 0.29 | 3.2 | |
| 7. | 21 | 2.58 | 1.4 | 1.69 | 1.8 | 1.50 | 2.8 | 0.97 | 2.0 | 0.65 | 2.4 | |
| 8. | 24 | 3.08 | 1.2 | 1.95 | 3.2 | 1.83 | 3.4 | 1.23 | 3.5 | 0.79 | 3.6 | |
| 9. | 27 | 3.95 | 1.2 | 2.26 | 3.0 | 2.15 | 1.9 | 1.35 | 1.5 | 0.86 | 2.6 | |
| 10. | 30 | 4.50 | 1.1 | 2.54 | 2.3 | 2.40 | 2.4 | 1.50 | 1.5 | 0.97 | 3.4 | |
| 11. | 33 | 5.75 | 0.8 | 2.85 | 2.5 | 2.75 | 3.5 | 1.69 | 4.3 | 1.13 | 5.0 | |
| 12. | 36 | | | 3.90 | 1.3 | 3.0 | 2.8 | 1.83 | 2.5 | 1.24 | 3.1 | |
| 13. | 39 | | | 4.02 | 1.3 | 3.25 | 2.7 | 2.17 | 2.0 | 1.36 | 2.9 | |
| 14. | 42 | | | 4.47 | 1.8 | 3.50 | 2.6 | 2.37 | 3.5 | 1.52 | 3.0 | |
| 15. | 45 | | | 5.0 | 2.0 | 3.83 | 1.8 | 2.50 | 2.5 | 1.68 | 3.0 | |
| 16. | 48 | | | 5.53 | 1.3 | 4.25 | 2.9 | 2.75 | 5.0 | 1.79 | 4.4 | |
| 17. | 51 | | | 6.73 | 1.8 | 4.50 | 2.1 | 3.05 | 1.5 | 2.00 | 2.1 | |
| 18. | 54 | | | 8.18 | 1.0 | 5.00 | 2.0 | 3.24 | 1.5 | 2.15 | 2.0 | |
| 19. | 57 | | | | | 5.67 | 2.0 | 3.43 | 2.4 | 2.30 | 2.6 | |
| 20. | 60 | | | | | 6.20 | 1.6 | 3.60 | 2.0 | 2.45 | 2.4 | |
| 21. | 63 | | | | | 7.00 | 1.4 | 3.76 | 2.0 | 2.59 | 2.3 | |
| 22. | 66 | | | | | 7.62 | 1.7 | 3.88 | 2.0 | 2.66 | 2.3 | |
| 23. | 69 | | | | | 8.50 | 0.9 | 4.05 | 1.7 | 2.82 | 2.2 | |
| 24. | 72 | | | | | | | 4.30 | 1.7 | 3.25 | 4.4 | |
| 25. | 75 | | | | | | | 4.49 | 1.6 | 3.49 | 4.9 | |
| 26. | 78 | | | | | | | 5.01 | 3.5 | 3.60 | 1.7 | |
| 27. | 81 | | | | | | | 5.25 | 2.0 | 3.79 | 1.2 | |
| 28. | 84 | | | | | | | 5.59 | 1.5 | 3.87 | 1.4 | |
| 29. | 87 | | | | | | | 8.48 | 1.5 | 4.06 | 1.5 | |
| 30. | 90 | | | | | | | | | 4.31 | 1.6 | |
| 31. | 93 | | | | | | | | | 4.92 | 1.9 | |
| 32. | 96 | | | | | | | | | 5.32 | 1.9 | |
| 33. | 99 | | | | | | | | | 5.86 | 1.5 | |
| 34. | 102 | | | | | | | | | 6.50 | 1.5 | |

APPENDIX-III (Contd.)

Advance time and depth of flow data-Surge flow (CR=1/2), Discharge - 1.7 lps, Replication-2

| Sl. No. | Distance | S-1 | | S-2 | | S-3 | | S-4 | | S-5 | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | m | Time min | Depth cm | Time min | Depth cm | Time min | Depth cm | Time min | Depth cm | Time min | Depth cm |
| 1. | 3 | 0.25 | 2.5 | 0.22 | 2.7 | 0.17 | 2.9 | 0.13 | 3.0 | 0.09 | 3.0 |
| 2. | 6 | 0.55 | 2.4 | 0.35 | 2.0 | 0.28 | 2.3 | 0.22 | 2.5 | 0.15 | 2.5 |
| 3. | 9 | 0.90 | 2.5 | 0.55 | 2.9 | 0.45 | 3.0 | 0.34 | 3.5 | 0.22 | 3.5 |
| 4. | 12 | 1.25 | 2.6 | 0.78 | 3.3 | 0.62 | 3.0 | 0.49 | 3.4 | 0.30 | 8.6 |
| 5. | 15 | 1.57 | 2.6 | 0.91 | 3.3 | 0.89 | 3.1 | 0.57 | 3.6 | 0.37 | 3.5 |
| 6. | 18 | 2.0 | 2.1 | 1.07 | 3.2 | 0.94 | 2.7 | 0.68 | 3.1 | 0.48 | 3.4 |
| 7. | 21 | 2.37 | 2.9 | 1.18 | 3.9 | 1.02 | 3.0 | 0.75 | 2.9 | 0.55 | 3.5 |
| 8. | 24 | 2.73 | 2.2 | 1.37 | 4.6 | 1.17 | 4.5 | 0.83 | 4.4 | 0.61 | 5.1 |
| 9. | 27 | 3.32 | 2.1 | 1.54 | 2.5 | 1.26 | 2.6 | 0.94 | 2.5 | 0.69 | 3.0 |
| 10. | 30 | 3.73 | 1.9 | 1.79 | 2.7 | 1.35 | 2.5 | 1.09 | 2.4 | 0.75 | 3.0 |
| 11. | 33 | 4.12 | 1.5 | 2.17 | 2.3 | 1.48 | 2.5 | 1.17 | 2.2 | 0.89 | 2.1 |
| 12. | 36 | 4.67 | 1.1 | 2.59 | 2.0 | 1.53 | 3.0 | 1.24 | 2.0 | 1.04 | 2.1 |
| 13. | 39 | 5.38 | 1.0 | 2.82 | 1.9 | 1.61 | 2.0 | 1.35 | 1.9 | 1.15 | 3.1 |
| 14. | 42 | 6.32 | 1.0 | 3.25 | 2.1 | 1.78 | 3.0 | 1.48 | 2.7 | 1.20 | 2.5 |
| 15. | 45 | | | 3.88 | 1.9 | 1.95 | 2.9 | 1.54 | 2.3 | 1.29 | 3.9 |
| 16. | 48 | | | 4.38 | 1.9 | 2.19 | 3.1 | 1.69 | 3.1 | 1.35 | 3.3 |
| 17. | 51 | | | 5.03 | 2.1 | 2.31 | 3.3 | 1.76 | 3.2 | 1.41 | 2.1 |
| 18. | 54 | | | 6.00 | 1.5 | 2.47 | 1.5 | 1.85 | 1.7 | 1.50 | 3.0 |
| 19. | 57 | | | 6.67 | 1.2 | 2.59 | 2.1 | 1.97 | 2.5 | 1.61 | 2.9 |
| 20. | 60 | | | 7.67 | 1.0 | 2.68 | 1.4 | 2.11 | 1.5 | 1.69 | 2.5 |
| 21. | 63 | | | | | 2.88 | 3.0 | 2.25 | 2.5 | 1.76 | 2.0 |
| 22. | 66 | | | | | 4.97 | 1.8 | 2.37 | 1.7 | 1.84 | 2.0 |
| 23. | 69 | | | | | 5.85 | 2.5 | 2.49 | 2.2 | 1.91 | 1.5 |
| 24. | 72 | | | | | 6.48 | 1.5 | 2.58 | 1.8 | 1.99 | 5.0 |
| 25. | 75 | | | | | 7.23 | 2.5 | 2.68 | 2.8 | 2.15 | 1.3 |
| 26. | 78 | | | | | 8.45 | 1.0 | 2.75 | 0.9 | 2.22 | 2.1 |
| 27. | 81 | | | | | | | 3.67 | 1.7 | 2.56 | 1.7 |
| 28. | 84 | | | | | | | 5.00 | 1.7 | 3.07 | 2.0 |
| 29. | 87 | | | | | | | 7.00 | 1.1 | 3.54 | 3.0 |
| 30. | 90 | | | | | | | 8.33 | 1.3 | 3.97 | 1.5 |
| 31. | 93 | | | | | | | 8.97 | 0.6 | 4.60 | 1.0 |
| 32. | 96 | | | | | | | | | 5.37 | 3.1 |
| 33. | 99 | | | | | | | | | 6.70 | 2.5 |
| 34. | 102 | | | | | | | | | 7.29 | 0.9 |

APPENDIX-III (Contd.)

Advance time and depth of flow data-Surge flow (CR=1/2), Discharge - 1.7 lps, Replication-3

| Sl. No. | Distance | S-1 | | S-2 | | S-3 | | S-4 | | S-5 | | S-6 | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | m | Time min | Depth cm | Time min | Depth cm | Time min | Depth cm | Time min | Depth cm | Time min | Depth cm | Time min | depth cm |
| 1. | 3 | 0.25 | 2.5 | 0.15 | 3.0 | 0.17 | 5.0 | 0.10 | 4.5 | 0.09 | 5.6 | 0.05 | 5.5 |
| 2. | 6 | 0.56 | 2.5 | 0.25 | 4.0 | 0.21 | 4.6 | 0.17 | 4.5 | 0.14 | 5.1 | 0.09 | 5.5 |
| 3. | 9 | 0.78 | 2.6 | 0.69 | 3.0 | 0.65 | 4.2 | 0.30 | 4.3 | 0.25 | 4.6 | 0.16 | 4.5 |
| 4. | 12 | 1.05 | 2.4 | 1.00 | 4.4 | 0.82 | 5.0 | 0.45 | 5.5 | 0.37 | 5.6 | 0.25 | 6.0 |
| 5. | 15 | 1.42 | 1.5 | 1.03 | 4.0 | 0.92 | 5.1 | 0.57 | 5.5 | 0.43 | 6.0 | 0.32 | 6.5 |
| 6. | 18 | 1.83 | 2.6 | 1.13 | 3.0 | 1.00 | 4.6 | 0.70 | 4.5 | 0.54 | 4.6 | 0.41 | 5.5 |
| 7. | 21 | 2.17 | 2.6 | 1.25 | 3.8 | 1.13 | 5.1 | 0.80 | 5.2 | 0.61 | 5.5 | 0.53 | 6.0 |
| 8. | 24 | 2.62 | 2.9 | 1.37 | 4.8 | 1.20 | 5.9 | 1.00 | 6.3 | 0.72 | 6.1 | 0.63 | 7.0 |
| 9. | 27 | 3.50 | 0.9 | 1.50 | 1.2 | 1.35 | 2.0 | 1.05 | 2.0 | 0.91 | 2.6 | 0.75 | 2.5 |
| 10. | 30 | 4.00 | 0.7 | 1.63 | 1.0 | 1.42 | 2.1 | 1.22 | 2.0 | 1.15 | 2.0 | 0.82 | 2.0 |
| 11. | 33 | 6.00 | 0.2 | 1.80 | 1.6 | 1.61 | 1.5 | 1.30 | 1.5 | 1.20 | 1.6 | 0.95 | 1.0 |
| 12. | 36 | | | 2.47 | 1.5 | 1.82 | 2.0 | 1.45 | 2.5 | 1.30 | 3.5 | 1.07 | 2.5 |
| 13. | 39 | | | 3.00 | 1.5 | 1.94 | 3.1 | 1.62 | 4.5 | 1.48 | 3.6 | 1.11 | 3.5 |
| 14. | 42 | | | 4.10 | 1.6 | 2.25 | 2.1 | 1.78 | 4.0 | 1.59 | 4.0 | 1.17 | 2.5 |
| 15. | 45 | | | 5.00 | 1.5 | 3.16 | 2.4 | 1.94 | 5.0 | 1.68 | 4.5 | 1.20 | 3.5 |
| 16. | 48 | | | 6.20 | 1.0 | 3.74 | 4.0 | 2.62 | 4.0 | 1.80 | 6.0 | 1.23 | 4.5 |
| 17. | 51 | | | | | 4.08 | 0.9 | 3.00 | 1.5 | 2.14 | 2.6 | 1.25 | 2.5 |
| 18. | 54 | | | | | 5.32 | 0.8 | 3.28 | 1.5 | 2.35 | 3.4 | 1.31 | 2.5 |
| 19. | 57 | | | | | 7.00 | 0.5 | 3.62 | 1.0 | 2.84 | 2.8 | 1.45 | 2.5 |
| 20. | 60 | | | | | | | 4.00 | 1.0 | 3.09 | 1.5 | 1.57 | 2.0 |
| 21. | 63 | | | | | | | 5.00 | 1.5 | 3.35 | 2.0 | 1.72 | 2.0 |
| 22. | 66 | | | | | | | 6.50 | 1.0 | 3.56 | 2.0 | 1.91 | 4.0 |
| 23. | 69 | | | | | | | 7.31 | 1.0 | 3.98 | 4.0 | 2.14 | 6.5 |
| 24. | 72 | | | | | | | 8.20 | 0.9 | 4.15 | 4.0 | 2.30 | 6.5 |
| 25. | 75 | | | | | | | | | 4.56 | 1.5 | 2.69 | 6.0 |
| 26. | 78 | | | | | | | | | 5.47 | 4.6 | 2.84 | 3.2 |
| 27. | 81 | | | | | | | | | 6.30 | 1.8 | 3.01 | 1.0 |
| 28. | 84 | | | | | | | | | 6.94 | 1.6 | 3.54 | 1.5 |
| 29. | 87 | | | | | | | | | 7.32 | 1.5 | 3.86 | 1.5 |
| 30. | 90 | | | | | | | | | 7.64 | 0.6 | 4.03 | 2.5 |
| 31. | 93 | | | | | | | | | | | 5.54 | 1.5 |
| 32. | 96 | | | | | | | | | | | 5.31 | 1.5 |
| 33. | 99 | | | | | | | | | | | 5.59 | 2.0 |
| 34. | 102 | | | | | | | | | | | 5.92 | 1.5 |

APPENDIX-III (Contd.)

Advance time and depth of flow data-Surge flow (CR=1/2), Discharge - 1.7 lps, Replication-4

| Sl. No. | Distance m | S-1 | | S-2 | | S-3 | | S-4 | | S-5 | | S-6 | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | Time min | Depth cm | Time min | Depth cm | Time min | Depth cm | Time min | Depth cm | Time min | Depth cm | Time min | Depth cm |
| 1. | 3 | 0.25 | 2.5 | 0.20 | 6.0 | 0.17 | 6.7 | 0.12 | 6.5 | 0.08 | 6.8 | 0.06 | 7.0 |
| 2. | 6 | 0.44 | 1.5 | 0.37 | 3.5 | 0.25 | 4.0 | 0.18 | 3.0 | 0.12 | 3.5 | 0.09 | 4.0 |
| 3. | 9 | 0.66 | 1.4 | 0.50 | 2.8 | 0.42 | 3.1 | 0.23 | 2.5 | 0.17 | 2.9 | 0.12 | 3.5 |
| 4. | 12 | 0.80 | 2.0 | 0.62 | 1.5 | 0.51 | 2.5 | 0.38 | 1.5 | 0.25 | 2.0 | 0.17 | 2.5 |
| 5. | 15 | 0.95 | 1.0 | 0.80 | 1.5 | 0.65 | 2.3 | 0.47 | 1.5 | 0.36 | 2.0 | 0.22 | 2.5 |
| 6. | 18 | 1.07 | 2.0 | 1.00 | 1.5 | 0.73 | 3.0 | 0.55 | 2.5 | 0.42 | 2.7 | 0.26 | 2.5 |
| 7. | 21 | 1.22 | 3.4 | 1.15 | 3.5 | 0.86 | 5.2 | 0.61 | 5.5 | 0.47 | 6.0 | 0.29 | 5.5 |
| 8. | 24 | 1.56 | 3.6 | 1.25 | 1.5 | 0.97 | 4.4 | 0.69 | 5.0 | 0.53 | 5.5 | 0.35 | 6.0 |
| 9. | 27 | 2.49 | 2.0 | 1.43 | 1.5 | 1.09 | 1.8 | 0.76 | 1.5 | 0.59 | 2.0 | 0.39 | 2.5 |
| 10. | 30 | 2.98 | 0.8 | 1.60 | 1.0 | 1.15 | 1.1 | 0.81 | 1.5 | 0.63 | 2.5 | 0.46 | 3.0 |
| 11. | 33 | 3.50 | 0.7 | 1.83 | 1.0 | 1.29 | 1.0 | 0.87 | 1.0 | 0.68 | 2.0 | 0.51 | 2.5 |
| 12. | 36 | | | 2.10 | 1.5 | 1.36 | 2.5 | 0.92 | 3.5 | 0.72 | 4.0 | 0.54 | 4.5 |
| 13. | 39 | | | 2.40 | 2.5 | 1.48 | 5.6 | 1.01 | 6.5 | 0.79 | 5.5 | 0.59 | 6.0 |
| 14. | 42 | | | 2.65 | 3.0 | 1.61 | 7.5 | 1.15 | 6.5 | 0.85 | 5.0 | 0.63 | 5.5 |
| 15. | 45 | | | 3.90 | 1.5 | 1.75 | 8.1 | 1.25 | 8.0 | 0.91 | 7.5 | 0.68 | 6.5 |
| 16. | 48 | | | 4.42 | 1.0 | 2.93 | 5.4 | 1.34 | 6.5 | 0.99 | 7.0 | 0.74 | 6.0 |
| 17. | 51 | | | | | 3.48 | 3.4 | 1.46 | 3.0 | 1.07 | 4.0 | 0.81 | 4.5 |
| 18. | 54 | | | | | 3.89 | 1.8 | 1.59 | 1.5 | 1.16 | 2.5 | 0.88 | 3.0 |
| 19. | 57 | | | | | 5.75 | 1.2 | 1.71 | 1.0 | 1.24 | 2.0 | 0.95 | 2.5 |
| 20. | 60 | | | | | 6.46 | 1.1 | 1.82 | 1.0 | 1.31 | 2.0 | 1.08 | 2.5 |
| 21. | 63 | | | | | 7.82 | 1.1 | 2.05 | 1.0 | 1.45 | 2.5 | 1.15 | 3.0 |
| 22. | 66 | | | | | | | 2.99 | 3.5 | 1.59 | 2.5 | 1.21 | 3.5 |
| 23. | 69 | | | | | | | 3.72 | 2.0 | 1.73 | 2.5 | 1.33 | 3.6 |
| 24. | 72 | | | | | | | 5.63 | 1.0 | 1.86 | 1.5 | 1.42 | 4.0 |
| 25. | 75 | | | | | | | 7.00 | 1.0 | 2.00 | 1.5 | 1.53 | 2.0 |
| 26. | 78 | | | | | | | | | 4.10 | 1.6 | 1.95 | 1.2 |
| 27. | 81 | | | | | | | | | 5.25 | 0.9 | 2.36 | 1.2 |
| 28. | 84 | | | | | | | | | 6.50 | 1.0 | 2.50 | 1.0 |
| 29. | 87 | | | | | | | | | 8.10 | 0.8 | 2.90 | 1.0 |
| 30. | 90 | | | | | | | | | | | 3.20 | 1.0 |
| 31. | 93 | | | | | | | | | | | 4.03 | 2.5 |
| 32. | 96 | | | | | | | | | | | 4.98 | 2.6 |
| 33. | 99 | | | | | | | | | | | 5.36 | 1.5 |
| 34. | 102 | | | | | | | | | | | 5.98 | 1.0 |

APPENDIX-III (Contd.)

Advance time and depth of flow data-Surge flow (CR=1/2), Discharge - 2.1 lps, Replication-1

| Sl. No. | Distance | S-1 | | S-2 | | S-3 | | S-4 | | S-5 | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | m | Time min | Depth cm | Time min | Depth cm | Time min | Depth cm | Time min | Depth cm | Time min | Depth cm |
| 1. | 3 | 0.35 | 2.0 | 0.33 | 3.5 | 0.25 | 4.1 | 0.19 | 4.0 | 0.15 | 5.0 |
| 2. | 6 | 0.74 | 1.5 | 0.42 | 2.0 | 0.31 | 2.5 | 0.24 | 2.3 | 0.19 | 2.4 |
| 3. | 9 | 0.95 | 1.5 | 0.60 | 2.0 | 0.42 | 2.0 | 0.31 | 2.5 | 0.24 | 2.0 |
| 4. | 12 | 1.25 | 2.0 | 0.82 | 2.5 | 0.54 | 3.0 | 0.40 | 2.5 | 0.31 | 3.0 |
| 5. | 15 | 1.48 | 1.8 | 1.00 | 2.0 | 0.65 | 2.8 | 0.49 | 3.0 | 0.38 | 2.5 |
| 6. | 18 | 1.75 | 1.5 | 1.22 | 2.0 | 0.79 | 2.5 | 0.56 | 2.4 | 0.42 | 2.0 |
| 7. | 21 | 2.13 | 2.0 | 1.50 | 3.5 | 0.85 | 3.1 | 0.60 | 4.5 | 0.45 | 4.0 |
| 8. | 24 | 2.47 | 2.0 | 1.79 | 1.3 | 0.91 | 4.5 | 0.65 | 6.8 | 0.49 | 5.8 |
| 9. | 27 | 2.78 | 1.4 | 2.06 | 1.3 | 1.02 | 2.5 | 0.71 | 2.5 | 0.53 | 3.0 |
| 10. | 30 | 3.11 | 1.4 | 2.33 | 2.2 | 1.16 | 2.2 | 0.79 | 2.5 | 0.59 | 2.3 |
| 11. | 33 | 3.65 | 1.9 | 2.57 | 1.5 | 1.23 | 3.5 | 0.84 | 4.0 | 0.63 | 4.0 |
| 12. | 36 | 4.36 | 1.8 | 3.13 | 1.3 | 1.35 | 2.5 | 0.89 | 2.5 | 0.67 | 2.0 |
| 13. | 39 | 5.12 | 2.0 | 3.63 | 1.6 | 1.46 | 3.5 | 0.97 | 4.2 | 0.72 | 4.0 |
| 14. | 42 | 6.76 | 1.8 | 3.83 | 1.7 | 1.55 | 2.8 | 1.04 | 3.5 | 0.76 | 4.5 |
| 15. | 45 | 7.03 | 1.7 | 4.32 | 1.6 | 1.72 | 2.8 | 1.12 | 3.5 | 0.81 | 3.8 |
| 16. | 48 | | | 4.87 | 2.0 | 1.91 | 2.8 | 1.20 | 3.0 | 0.87 | 3.8 |
| 17. | 51 | | | 5.30 | 1.0 | 2.13 | 2.8 | 1.27 | 6.5 | 0.91 | 4.0 |
| 18. | 54 | | | 7.24 | 0.7 | 2.35 | 2.8 | 1.31 | 2.5 | 0.95 | 2.7 |
| 19. | 57 | | | 7.43 | 0.7 | 2.49 | 1.5 | 1.45 | 2.5 | 1.04 | 2.5 |
| 20. | 60 | | | 7.50 | 0.7 | 2.57 | 1.0 | 1.51 | 2.0 | 1.09 | 1.8 |
| 21. | 63 | | | | | 3.96 | 1.8 | 1.96 | 1.5 | 1.15 | 2.8 |
| 22. | 66 | | | | | 5.01 | 1.5 | 2.24 | 1.8 | 1.23 | 2.0 |
| 23. | 69 | | | | | 6.25 | 1.8 | 2.65 | 1.5 | 1.37 | 2.8 |
| 24. | 72 | | | | | 7.34 | 0.9 | 2.93 | 2.0 | 1.49 | 3.8 |
| 25. | 75 | | | | | | | 3.96 | 2.0 | 1.58 | 5.0 |
| 26. | 78 | | | | | | | 4.63 | 1.5 | 1.97 | 1.7 |
| 27. | 81 | | | | | | | 5.80 | 1.0 | 2.35 | 1.5 |
| 28. | 84 | | | | | | | 6.50 | 0.5 | 2.98 | 1.5 |
| 29. | 87 | | | | | | | 8.58 | 1.0 | 3.34 | 1.0 |
| 30. | 90 | | | | | | | | | 3.78 | 1.8 |
| 31. | 93 | | | | | | | | | 4.52 | 3.8 |
| 32. | 96 | | | | | | | | | 4.92 | 1.5 |
| 33. | 99 | | | | | | | | | 5.35 | 0.5 |
| 34. | 102 | | | | | | | | | 5.89 | 0.5 |

APPENDIX-III (Contd.)

Advance time and depth of flow data-Surge flow (CR=1/2), Discharge - 2.1 lps, Replication-2

| Sl. No. | Distance | S-1 | | S-2 | | S-3 | | S-4 | | S-5 | | S-6 | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | m | Time min | Depth cm | Time min | Depth cm | Time min | Depth cm | Time min | Depth cm | Time min | Depth cm | Time min | Depth cm |
| 1. | 3 | 0.22 | 1.8 | 0.19 | 3.0 | 0.17 | 4.2 | 0.15 | 4.0 | 0.11 | 5.5 | 0.07 | 4.6 |
| 2. | 6 | 0.50 | 3.0 | 0.23 | 3.5 | 0.20 | 4.3 | 0.18 | 4.0 | 0.13 | 5.0 | 0.09 | 4.0 |
| 3. | 9 | 1.00 | 2.0 | 0.33 | 2.0 | 0.26 | 3.4 | 0.24 | 3.0 | 0.17 | 4.0 | 0.12 | 4.0 |
| 4. | 12 | 1.33 | 2.8 | 0.50 | 3.5 | 0.35 | 5.1 | 0.29 | 3.5 | 0.21 | 6.5 | 0.15 | 6.0 |
| 5. | 15 | 1.75 | 2.0 | 0.67 | 5.0 | 0.41 | 5.3 | 0.35 | 4.5 | 0.26 | 6.3 | 0.19 | 5.0 |
| 6. | 18 | 2.08 | 3.5 | 3.75 | 2.0 | 0.48 | 6.3 | 0.40 | 7.0 | 0.31 | 7.5 | 0.23 | 7.5 |
| 7. | 21 | 2.55 | 2.4 | 0.86 | 3.5 | 0.54 | 3.4 | 0.45 | 3.5 | 0.34 | 4.8 | 0.26 | 4.0 |
| 8. | 24 | 3.17 | 2.4 | 0.95 | 1.0 | 0.61 | 5.0 | 0.51 | 5.0 | 0.39 | 6.5 | 0.30 | 5.0 |
| 9. | 27 | 3.88 | 1.0 | 1.00 | 1.0 | 0.69 | 1.8 | 0.57 | 1.5 | 0.44 | 2.0 | 0.34 | 1.0 |
| 10. | 30 | 4.42 | 1.4 | 1.49 | 1.0 | 0.78 | 2.2 | 0.63 | 1.0 | 0.49 | 2.0 | 0.68 | 1.0 |
| 11. | 33 | 5.5 | 1.1 | 1.87 | 1.0 | 0.41 | 1.0 | 0.69 | 1.0 | 0.53 | 1.0 | 0.41 | 1.0 |
| 12. | 36 | 7.08 | 0.5 | 2.27 | 0.5 | 1.25 | 4.5 | 0.74 | 3.0 | 0.58 | 4.5 | 0.46 | 3.5 |
| 13. | 39 | | | 3.23 | 1.5 | 1.54 | 1.3 | 0.85 | 3.0 | 0.67 | 4.6 | 0.53 | 3.5 |
| 14. | 42 | | | 4.00 | 1.00 | 2.25 | 2.6 | 0.97 | 3.5 | 0.75 | 4.6 | 0.60 | 5.0 |
| 15. | 45 | | | 5.32 | 1.0 | 2.97 | 1.8 | 1.21 | 3.0 | 0.89 | 5.0 | 0.72 | 4.0 |
| 16. | 48 | | | 6.67 | 1.0 | 3.46 | 2.5 | 1.53 | 4.5 | 0.96 | 5.5 | 0.78 | 5.0 |
| 17. | 51 | | | | | 3.87 | 1.7 | 1.77 | 3.5 | 1.13 | 2.0 | 0.89 | 5.0 |
| 18. | 54 | | | | | 4.17 | 1.3 | 1.92 | 1.0 | 1.21 | 1.2 | 0.95 | 2.0 |
| 19. | 57 | | | | | 5.00 | 1.8 | 2.15 | 1.0 | 1.42 | 1.0 | 1.08 | 1.0 |
| 20. | 60 | | | | | 5.83 | 1.0 | 2.34 | 1.5 | 1.59 | 1.6 | 1.22 | 1.0 |
| 21. | 63 | | | | | 7.02 | 0.8 | 2.78 | 1.0 | 1.97 | 1.2 | 1.29 | 1.0 |
| 22. | 66 | | | | | 8.42 | 0.3 | 2.91 | 0.2 | 0.20 | 1.0 | 1.50 | 1.0 |
| 23. | 69 | | | | | | | 3.30 | 0.5 | 2.35 | 2.5 | 1.61 | 2.0 |
| 24. | 72 | | | | | | | 4.23 | 3.5 | 2.62 | 3.5 | 1.86 | 6.0 |
| 25. | 75 | | | | | | | 5.0 | 2.0 | 2.91 | 5.0 | 2.14 | 5.0 |
| 26. | 78 | | | | | | | 6.8 | 1.0 | 3.34 | 4.5 | 2.53 | 2.5 |
| 27. | 81 | | | | | | | | | 3.49 | 2.5 | 2.68 | 2.0 |
| 28. | 84 | | | | | | | | | 3.67 | 1.5 | 2.87 | 1.0 |
| 29. | 87 | | | | | | | | | 4.75 | 2.0 | 2.94 | 2.0 |
| 30. | 90 | | | | | | | | | 6.00 | 1.2 | 3.02 | 2.0 |
| 31. | 93 | | | | | | | | | 7.16 | 1.2 | 3.16 | 1.5 |
| 32. | 96 | | | | | | | | | 7.67 | 1.0 | 3.21 | 0.9 |
| 33. | 99 | | | | | | | | | 8.58 | 1.2 | 3.29 | 0.8 |
| 34. | 102 | | | | | | | | | | | 3.32 | 0.8 |

APPENDIX-III (Contd.)

Advance time and depth of flow data-Surge flow (CR=1/2), Discharge - 2.1 lps, Replication-3

| Sl. No. | Distance | S-1 | | S-2 | | S-3 | | S-4 | | S-5 | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | m | Time min | Depth cm | Time min | Depth cm | Time min | Depth cm | Time min | Depth cm | Time min | Depth cm |
| 1. | 3 | 0.18 | 3.5 | 0.13 | 3.5 | 0.12 | 5.0 | 0.12 | 3.4 | 0.10 | 4.5 |
| 2. | 6 | 0.48 | 2.5 | 0.25 | 2.0 | 0.21 | 3.0 | 0.18 | 2.5 | 0.15 | 4.0 |
| 3. | 9 | 0.83 | 2.5 | 0.42 | 2.0 | 0.32 | 4.0 | 0.26 | 3.5 | 0.21 | 3.75 |
| 4. | 12 | 1.08 | 2.2 | 0.55 | 3.5 | 0.43 | 7.0 | 0.33 | 4.5 | 0.26 | 5.5 |
| 5. | 15 | 1.42 | 3.0 | 0.70 | 3.0 | 0.54 | 4.5 | 0.40 | 4.0 | 0.30 | 4.5 |
| 6. | 18 | 1.98 | 2.6 | 0.80 | 2.0 | 0.61 | 4.2 | 0.46 | 3.5 | 0.35 | 4.0 |
| 7. | 21 | 2.38 | 2.5 | 0.90 | 2.5 | 0.69 | 4.5 | 0.52 | 4.5 | 0.40 | 4.25 |
| 8. | 24 | 2.72 | 5.5 | 1.00 | 5.5 | 0.75 | 8.0 | 0.57 | 6.5 | 0.44 | 6.5 |
| 9. | 27 | 3.35 | 1.5 | 1.07 | 0.1 | 0.80 | 2.0 | 0.65 | 1.5 | 0.51 | 2.0 |
| 10. | 30 | 3.75 | 1.2 | 1.35 | 0.5 | 1.01 | 1.2 | 0.76 | 1.5 | 0.60 | 1.0 |
| 11. | 33 | 4.52 | 0.9 | 1.75 | 1.3 | 1.25 | 1.7 | 0.81 | 1.5 | 0.64 | 1.0 |
| 12. | 36 | 5.43 | 0.8 | 2.09 | 1.0 | 1.36 | 2.0 | 0.87 | 2.0 | 0.70 | 1.4 |
| 13. | 39 | 6.83 | 0.2 | 2.47 | 2.0 | 1.43 | 2.0 | 0.92 | 3.0 | 0.74 | 3.0 |
| 14. | 42 | | | 2.72 | 2.0 | 1.56 | 4.5 | 0.97 | 5.0 | 0.77 | 4.0 |
| 15. | 45 | | | 3.43 | 2.0 | 1.68 | 3.2 | 1.04 | 4.0 | 0.81 | 4.0 |
| 16. | 48 | | | 4.65 | 2.0 | 1.75 | 3.5 | 1.12 | 3.5 | 0.86 | 5.0 |
| 17. | 51 | | | 6.10 | 2.0 | 1.87 | 1.2 | 1.22 | 4.5 | 0.91 | 1.0 |
| 18. | 54 | | | 6.98 | 0.3 | 1.96 | 1.7 | 1.29 | 1.0 | 0.97 | 1.0 |
| 19. | 57 | | | | | 2.08 | 1.2 | 1.37 | 1.0 | 1.03 | 1.0 |
| 20. | 60 | | | | | 3.00 | 1.5 | 1.64 | 1.0 | 1.17 | 1.0 |
| 21. | 63 | | | | | 4.00 | 1.2 | 1.83 | 1.0 | 1.25 | 2.25 |
| 22. | 66 | | | | | 5.00 | 2.0 | 2.01 | 1.0 | 1.39 | 2.0 |
| 23. | 69 | | | | | 6.08 | 2.2 | 2.17 | 1.0 | 1.51 | 2.6 |
| 24. | 72 | | | | | 6.17 | 1.7 | 2.36 | 2.0 | 1.68 | 1.2 |
| 25. | 75 | | | | | 7.02 | 0.7 | 2.50 | 3.0 | 1.80 | 0.8 |
| 26. | 78 | | | | | | | 4.45 | 1.0 | 1.96 | 1.0 |
| 27. | 81 | | | | | | | 5.58 | 0.5 | 2.07 | 1.1 |
| 28. | 84 | | | | | | | 6.55 | 0.5 | 2.34 | 0.6 |
| 29. | 87 | | | | | | | 7.53 | 0.5 | 2.45 | 0.8 |
| 30. | 90 | | | | | | | | | 2.67 | 1.1 |
| 31. | 93 | | | | | | | | | 3.67 | 1.1 |
| 32. | 96 | | | | | | | | | 4.83 | 0.6 |
| 33. | 99 | | | | | | | | | 5.17 | 0.8 |
| 34. | 102 | | | | | | | | | 5.98 | 0.7 |

APPENDIX-III (Contd.)

Advance time and depth of flow data-Surge flow (CR=1/2), Discharge - 2.1 lps, Replication-4

| Sl. No. | Distance | S-1 | | S-2 | | S-3 | | S-4 | | S-5' | | S-6 | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | m | Time min | Depth cm | Time min | Depth cm | Time min | Depth cm | Time min | Depth cm | Time min | Depth cm | Time min | Depth cm |
| 1. | 3 | 0.33 | 1.8 | 0.23 | 3.5 | 0.20 | 3.6 | 0.15 | 4.2 | 0.12 | 4.2 | 0.09 | 4.5 |
| 2. | 6 | 0.62 | 1.9 | 0.38 | 3.0 | 0.26 | 3.8 | 0.22 | 4.0 | 0.16 | 4.9 | 0.11 | 5.1 |
| 3. | 9 | 0.92 | 1.4 | 0.53 | 3.0 | 0.32 | 3.8 | 0.26 | 3.8 | 0.20 | 4.7 | 0.14 | 4.8 |
| 4. | 12 | 1.15 | 1.9 | 0.61 | 5.0 | 0.37 | 5.9 | 0.31 | 6.7 | 0.24 | 7.1 | 0.19 | 7.3 |
| 5. | 15 | 1.47 | 1.9 | 0.73 | 5.0 | 0.45 | 6.1 | 0.37 | 6.7 | 0.29 | 7.6 | 0.21 | 8.0 |
| 6. | 18 | 2.25 | 3.1 | 0.84 | 5.0 | 0.49 | 5.4 | 0.41 | 4.3 | 0.31 | 5.4 | 0.25 | 5.5 |
| 7. | 21 | 2.67 | 1.7 | 0.90 | 2.5 | 0.53 | 5.1 | 0.43 | 5.0 | 0.35 | 4.9 | 0.28 | 5.0 |
| 8. | 24 | 3.08 | 2.1 | 0.95 | 3.0 | 0.58 | 5.1 | 0.47 | 5.0 | 0.39 | 5.0 | 0.31 | 5.2 |
| 9. | 27 | 3.92 | 0.8 | 1.23 | 1.0 | 0.64 | 2.1 | 0.53 | 1.5 | 0.43 | 1.6 | 0.34 | 2.0 |
| 10. | 30 | 4.63 | 0.5 | 1.53 | 0.5 | 0.69 | 1.4 | 0.56 | 1.2 | 0.46 | 1.2 | 0.37 | 1.5 |
| 11. | 33 | 5.97 | 1.0 | 1.94 | 2.6 | 0.74 | 2.9 | 0.6 | 1.2 | 0.49 | 1.3 | 0.40 | 1.5 |
| 12. | 36 | 7.20 | 1.9 | 2.17 | 1.8 | 0.83 | 2.1 | 0.64 | 1.8 | 0.53 | 2.9 | 0.43 | 3.0 |
| 13. | 39 | | | 2.83 | 1.8 | 0.92 | 2.4 | 0.73 | 3.5 | 0.57 | 4.9 | 0.47 | 5.0 |
| 14. | 42 | | | 3.27 | 2.5 | 1.24 | 5.5 | 0.85 | 7.0 | 0.62 | 8.1 | 0.51 | 8.1 |
| 15. | 45 | | | 3.87 | 6.2 | 1.48 | 5.2 | 0.96 | 6.2 | 0.69 | 6.9 | 0.56 | 7.0 |
| 16. | 48 | | | | | 1.60 | 3.2 | 1.05 | 5.2 | 0.75 | 5.0 | 0.61 | 5.0 |
| 17. | 51 | | | | | 2.50 | 2.8 | 1.29 | 1.5 | 0.81 | 2.0 | 0.65 | 2.5 |
| 18. | 54 | | | | | 3.02 | 2.7 | 1.56 | 1.0 | 0.93 | 1.3 | 0.69 | 1.5 |
| 19. | 57 | | | | | 5.0 | 0.8 | 1.98 | 1.5 | 1.07 | 1.4 | 0.83 | 1.5 |
| 20. | 60 | | | | | 6.10 | 0.9 | 2.23 | 1.5 | 1.18 | 1.6 | 0.92 | 1.9 |
| 21. | 63 | | | | | 7.02 | 0.8 | 2.42 | 2.0 | 1.36 | 1.3 | 1.11 | 1.5 |
| 22. | 66 | | | | | 7.67 | 0.9 | 2.67 | 1.5 | 1.50 | 2.1 | 1.23 | 2.5 |
| 23. | 69 | | | | | | | 4.32 | 2.0 | 1.92 | 2.9 | 1.37 | 3.0 |
| 24. | 72 | | | | | | | 5.32 | 1.5 | 2.18 | 4.6 | 1.50 | 5.0 |
| 25. | 75 | | | | | | | 7.33 | 0.9 | 2.65 | 3.0 | 1.72 | 3.0 |
| 26. | 78 | | | | | | | | | 3.00 | 2.5 | 1.98 | 2.5 |
| 27. | 81 | | | | | | | | | 5.03 | 2.0 | 2.27 | 1.5 |
| 28. | 84 | | | | | | | | | 6.54 | 1.4 | 2.49 | 1.0 |
| 29. | 87 | | | | | | | | | 7.01 | 0.6 | 3.54 | 0.9 |
| 30. | 90 | | | | | | | | | | | 3.98 | 0.7 |
| 31. | 93 | | | | | | | | | | | 4.23 | 0.7 |
| 32. | 96 | | | | | | | | | | | 5.03 | 0.6 |
| 33. | 99 | | | | | | | | | | | 5.75 | 0.5 |
| 34. | 102 | | | | | | | | | | | 5.96 | 0.5 |

APPENDIX-III (Contd.)

Advance time and depth of flow data-Surge flow (CR=1/3), Discharge - 1.3 lps, Replication-1

| Sl. No. | Distance | S-1 | | S-2 | | S-3 | | S-4 | | S-5 | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | m | Time min | Depth cm | Time min | Depth cm | Time min | Depth cm | Time min | Depth cm | Time min | Depth cm |
| 1. | 3 | 0.33 | 2.5 | 0.31 | 3.5 | 0.26 | 4.9 | 0.25 | 5.5 | 0.22 | 6.0 |
| 2. | 6 | 0.69 | 3.0 | 3.63 | 4.5 | 0.55 | 5.5 | 0.51 | 5.9 | 0.45 | 5.8 |
| 3. | 9 | 1.03 | 2.6 | 0.84 | 5.0 | 0.73 | 5.8 | 0.66 | 5.0 | 0.59 | 5.5 |
| 4. | 12 | 1.48 | 2.5 | 0.99 | 5.9 | 0.82 | 6.0 | 0.74 | 4.8 | 0.63 | 5.0 |
| 5. | 15 | 1.94 | 2.0 | 1.38 | 4.8 | 1.19 | 4.9 | 0.98 | 4.5 | 0.85 | 5.4 |
| 6. | 18 | 2.23 | 2.5 | 1.59 | 4.7 | 1.32 | 4.0 | 1.10 | 4.5 | 0.93 | 4.9 |
| 7. | 21 | 2.56 | 2.5 | 1.85 | 4.5 | 1.49 | 4.5 | 1.23 | 3.9 | 1.02 | 4.5 |
| 8. | 24 | 2.91 | 2.0 | 2.16 | 4.0 | 1.71 | 4.6 | 1.42 | 3.0 | 1.20 | 4.8 |
| 9. | 27 | 3.54 | 1.9 | 2.34 | 4.5 | 1.85 | 4.1 | 1.53 | 4.2 | 1.29 | 4.9 |
| 10. | 30 | 3.98 | 1.5 | 2.76 | 5.0 | 2.14 | 4.0 | 1.78 | 4.6 | 1.45 | 5.5 |
| 11. | 33 | 4.36 | 1.4 | 3.14 | 3.5 | 2.36 | 3.9 | 1.95 | 4.0 | 1.60 | 6.0 |
| 12. | 36 | 5.36 | 1.2 | 3.35 | 2.0 | 2.54 | 3.5 | 2.09 | 4.0 | 1.71 | 6.1 |
| 13. | 39 | 6.71 | 1.1 | 3.59 | 1.5 | 2.76 | 3.7 | 2.26 | 4.1 | 1.86 | 5.9 |
| 14. | 42 | 8.12 | 0.9 | 3.86 | 1.5 | 2.98 | 3.6 | 2.37 | 4.2 | 1.94 | 6.2 |
| 15. | 45 | | | 4.13 | 1.5 | 3.09 | 3.5 | 2.46 | 4.0 | 2.01 | 5.9 |
| 16. | 48 | | | 4.45 | 1.2 | 3.48 | 3.5 | 2.79 | 3.8 | 2.31 | 5.0 |
| 17. | 51 | | | 4.99 | 2.0 | 3.96 | 2.5 | 3.17 | 3.9 | 2.62 | 4.9 |
| 18. | 54 | | | 5.36 | 2.9 | 4.26 | 2.9 | 3.38 | 3.5 | 2.81 | 4.8 |
| 19. | 57 | | | 6.54 | 2.5 | 4.54 | 2.5 | 3.64 | 3.5 | 3.01 | 4.0 |
| 20. | 60 | | | 7.81 | 2.0 | 4.98 | 3.0 | 3.98 | 2.9 | 3.29 | 4.5 |
| 21. | 63 | | | 8.98 | 1.9 | 5.31 | 2.5 | 4.29 | 2.9 | 3.54 | 4.5 |
| 22. | 66 | | | 10.35 | 1.0 | 5.71 | 2.9 | 4.68 | 2.5 | 3.91 | 3.9 |
| 23. | 69 | | | | | 6.83 | 2.5 | 5.31 | 2.9 | 4.33 | 4.0 |
| 24. | 72 | | | | | 7.72 | 2.0 | 5.85 | 2.4 | 4.79 | 4.0 |
| 25. | 75 | | | | | 8.63 | 1.9 | 6.16 | 2.0 | 4.89 | 4.2 |
| 26. | 78 | | | | | 10.16 | 1.1 | 6.36 | 2.5 | 5.15 | 3.8 |
| 27. | 81 | | | | | 11.59 | 0.9 | 6.76 | 2.5 | 5.43 | 3.5 |
| 28. | 84 | | | | | | | 7.45 | 2.0 | 5.96 | 3.5 |
| 29. | 87 | | | | | | | 8.03 | 2.0 | 6.47 | 3.0 |
| 30. | 90 | | | | | | | 9.11 | 1.5 | 6.81 | 2.9 |
| 31. | 93 | | | | | | | 10.01 | 0.9 | 7.06 | 2.5 |
| 32. | 96 | | | | | | | | | 7.28 | 2.0 |
| 33. | 99 | | | | | | | | | 8.01 | 1.9 |
| 34. | 102 | | | | | | | | | 8.98 | 1.5 |

APPENDIX-III (Contd.)

Advance time and depth of flow data-Surge flow (CR=1/3), Discharge - 1.3 lps, Replication-2

| Sl. No. | Distance | S-1 | | S-2 | | S-3 | | S-4 | | S-5 | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | m | Time min | Depth cm | Time min | Depth cm | Time min | Depth cm | Time min | Depth cm | Time min | Depth cm |
| 1. | 3 | 0.32 | 3.0 | 0.29 | 3.1 | 0.25 | 2.6 | 0.22 | 3.3 | 0.18 | 2.4 |
| 2. | 6 | 0.62 | 3.0 | 0.51 | 5.0 | 0.47 | 3.5 | 0.39 | 4.9 | 0.34 | 3.6 |
| 3. | 9 | 1.00 | 2.0 | 0.79 | 5.9 | 0.71 | 4.0 | 0.55 | 5.1 | 0.42 | 3.9 |
| 4. | 12 | 1.40 | 2.8 | 1.01 | 4.2 | 0.90 | 3.4 | 0.69 | 4.3 | 0.54 | 3.1 |
| 5. | 15 | 1.82 | 2.6 | 1.33 | 4.2 | 1.16 | 3.6 | 0.93 | 4.5 | 0.77 | 2.9 |
| 6. | 18 | 2.25 | 2.7 | 1.50 | 4.3 | 1.30 | 3.7 | 1.05 | 4.6 | 0.90 | 3.1 |
| 7. | 21 | 2.58 | 2.1 | 1.83 | 3.9 | 1.59 | 3.4 | 1.29 | 4.0 | 1.01 | 2.6 |
| 8. | 24 | 2.83 | 2.6 | 1.96 | 4.1 | 1.72 | 3.5 | 1.40 | 4.0 | 1.10 | 3.4 |
| 9. | 27 | 3.62 | 1.6 | 2.09 | 2.0 | 1.81 | 1.2 | 1.48 | 2.0 | 1.15 | 1.5 |
| 10. | 30 | 4.00 | 1.3 | 2.18 | 1.1 | 1.89 | 0.8 | 1.53 | 1.5 | 1.20 | 0.8 |
| 11. | 33 | 4.58 | 0.6 | 2.63 | 1.4 | 2.24 | 1.8 | 1.76 | 1.6 | 1.38 | 1.6 |
| 12. | 36 | 5.22 | 1.8 | 3.25 | 2.3 | 2.84 | 2.9 | 1.95 | 3.5 | 1.48 | 3.2 |
| 13. | 39 | 6.33 | 0.4 | 3.67 | 1.9 | 3.25 | 1.7 | 2.06 | 2.1 | 1.55 | 2.0 |
| 14. | 42 | 8.00 | 0.4 | 3.97 | 3.0 | 3.50 | 2.2 | 2.29 | 2.3 | 1.69 | 3.3 |
| 15. | 45 | | | 4.43 | 1.8 | 3.82 | 1.4 | 2.58 | 2.1 | 1.81 | 1.0 |
| 16. | 48 | | | 4.90 | 3.0 | 3.99 | 3.2 | 2.71 | 3.5 | 1.91 | 2.9 |
| 17. | 51 | | | 5.92 | 1.3 | 4.17 | 1.0 | 2.74 | 1.1 | 1.94 | 0.9 |
| 18. | 54 | | | 6.75 | 1.0 | 4.33 | 1.1 | 2.85 | 1.2 | 2.02 | 0.7 |
| 19. | 57 | | | 7.38 | 1.1 | 4.74 | 0.7 | 2.99 | 1.0 | 2.15 | 0.8 |
| 20. | 60 | | | 8.28 | 1.1 | 4.91 | 0.6 | 3.09 | 1.0 | 2.20 | 0.7 |
| 21. | 63 | | | 10.75 | 1.0 | 5.18 | 0.8 | 3.25 | 0.9 | 2.25 | 0.9 |
| 22. | 66 | | | 11.37 | 0.9 | 5.50 | 0.6 | 3.45 | 1.0 | 2.45 | 1.0 |
| 23. | 69 | | | | | 6.67 | 1.8 | 3.76 | 2.5 | 2.65 | 2.4 |
| 24. | 72 | | | | | 7.83 | 1.0 | 4.85 | 2.0 | 3.71 | 2.6 |
| 25. | 75 | | | | | 9.17 | 0.6 | 5.99 | 2.6 | 4.36 | 2.4 |
| 26. | 78 | | | | | 10.75 | 0.5 | 6.95 | 2.0 | 5.21 | 1.4 |
| 27. | 81 | | | | | 12.0 | 0.5 | 7.20 | 1.0 | 5.43 | 0.6 |
| 28. | 84 | | | | | | | 7.98 | 0.9 | 6.15 | 0.5 |
| 29. | 87 | | | | | | | 8.97 | 1.3 | 6.52 | 0.9 |
| 30. | 90 | | | | | | | 10.15 | 1.8 | 6.92 | 1.2 |
| 31. | 93 | | | | | | | 11.45 | 0.8 | 7.29 | 0.9 |
| 32. | 96 | | | | | | | | | 8.17 | 0.6 |
| 33. | 99 | | | | | | | | | 8.85 | 0.4 |
| 34. | 102 | | | | | | | | | 9.01 | 0.5 |

APPENDIX-III (Contd.)

Advance time and depth of flow data-Surge flow (CR=1/3), Discharge - 1.3 lps, Replication-3

| Sl. No. | Distance | S-1 | | S-2 | | S-3 | | S-4 | |
|---|---|---|---|---|---|---|---|---|---|
| | m | Time min | Depth cm | Time min | Depth cm | Time min | Depth cm | Time min | Depth cm |
| 1. | 3 | 0.28 | 2.0 | 0.27 | 4.7 | 0.26 | 5.0 | 0.24 | 5.9 |
| 2. | 6 | 0.87 | 1.5 | 0.81 | 2.3 | 0.75 | 2.0 | 0.69 | 3.9 |
| 3. | 9 | 1.25 | 2.3 | 1.14 | 4.2 | 1.01 | 3.5 | 0.85 | 4.9 |
| 4. | 12 | 1.65 | 2.0 | 1.39 | 4.3 | 1.10 | 3.2 | 0.91 | 4.5 |
| 5. | 15 | 2.10 | 0.9 | 1.43 | 1.5 | 1.21 | 1.0 | 1.01 | 2.0 |
| 6. | 18 | 2.43 | 2.0 | 1.57 | 3.6 | 1.29 | 2.0 | 1.07 | 3.2 |
| 7. | 21 | 2.75 | 2.1 | 1.71 | 4.8 | 1.40 | 2.8 | 1.16 | 4.0 |
| 8. | 24 | 3.00 | 2.5 | 1.91 | 6.2 | 1.50 | 5.6 | 1.22 | 5.0 |
| 9. | 27 | 3.67 | 1.0 | 2.29 | 0.5 | 1.67 | 0.2 | 1.31 | 0.7 |
| 10. | 30 | 4.00 | 0.9 | 2.36 | 1.0 | 1.72 | 1.0 | 1.39 | 0.6 |
| 11. | 33 | 4.37 | 2.5 | 2.48 | 1.8 | 1.81 | 1.5 | 1.46 | 1.0 |
| 12. | 36 | 4.83 | 1.5 | 2.55 | 2.5 | 1.86 | 1.5 | 1.50 | 2.0 |
| 13. | 39 | 5.33 | 1.5 | 2.64 | 3.6 | 1.93 | 3.0 | 1.55 | 3.3 |
| 14. | 42 | 5.78 | 1.5 | 3.03 | 5.9 | 2.05 | 6.0 | 1.61 | 6.0 |
| 15. | 45 | 8.00 | 1.0 | 3.57 | 3.9 | 2.26 | 4.0 | 1.79 | 4.0 |
| 16. | 48 | | | 4.42 | 3.0 | 2.59 | 2.3 | 2.10 | 2.2 |
| 17. | 51 | | | 4.92 | 3.3 | 2.66 | 3.0 | 2.16 | 4.0 |
| 18. | 54 | | | 6.53 | 3.0 | 2.74 | 1.0 | 2.23 | 1.5 |
| 19. | 57 | | | 7.20 | 3.3 | 2.95 | 1.0 | 2.40 | 1.0 |
| 20. | 60 | | | 7.53 | 1.2 | 3.11 | 1.0 | 2.53 | 1.5 |
| 21. | 63 | | | 8.18 | 1.2 | 3.20 | 1.5 | 2.60 | 1.9 |
| 22. | 66 | | | 9.07 | 2.0 | 3.29 | 1.8 | 2.67 | 1.6 |
| 23. | 69 | | | 10.92 | 1.7 | 3.37 | 0.5 | 2.73 | 1.0 |
| 24. | 72 | | | 11.50 | 1.3 | 5.18 | 0.5 | 4.23 | 1.5 |
| 25. | 75 | | | | | 7.17 | 1.5 | 5.89 | 1.6 |
| 26. | 78 | | | | | 7.95 | 1.5 | 6.38 | 2.0 |
| 27. | 81 | | | | | 8.42 | 2.5 | 6.54 | 1.5 |
| 28. | 84 | | | | | 9.42 | 1.5 | 7.26 | 2.4 |
| 29. | 87 | | | | | 10.0 | 1.5 | 7.50 | 1.9 |
| 30. | 90 | | | | | 10.63 | 1.0 | 7.62 | 1.5 |
| 31. | 93 | | | | | 11.38 | 0.5 | 7.87 | 1.4 |
| 32. | 96 | | | | | 12.25 | 0.5 | 8.00 | 1.1 |
| 33. | 99 | | | | | | | 8.42 | 1.4 |
| 34. | 102 | | | | | | | 8.97 | 0.9 |

APPENDIX-III (Contd.)

Advance time and depth of flow data-Surge flow (CR=1/3), Discharge - 1.3 lps, Replication-4

| Sl. No. | Distance | S-1 | | S-2 | | S-3 | | S-4 | | S-5 | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | m | Time min | Depth cm | Time min | Depth cm | Time min | Depth cm | Time min | Depth cm | Time min | Depth cm |
| 1. | 3 | 0.30 | 3.0 | 0.28 | 3.5 | 0.26 | 3.2 | 0.25 | 2.5 | 0.22 | 2.8 |
| 2. | 6 | 0.65 | 3.0 | 0.58 | 3.2 | 0.51 | 3.0 | 0.48 | 3.0 | 0.45 | 3.5 |
| 3. | 9 | 0.99 | 2.1 | 0.88 | 4.5 | 0.77 | 3.5 | 0.74 | 3.9 | 0.69 | 4.5 |
| 4. | 12 | 1.38 | 1.6 | 1.17 | 4.0 | 1.03 | 3.5 | 0.96 | 4.5 | 0.88 | 4.5 |
| 5. | 15 | 1.57 | 1.0 | 1.30 | 3.5 | 1.14 | 4.0 | 1.02 | 5.0 | 0.92 | 5.0 |
| 6. | 18 | 1.91 | 1.5 | 1.61 | 2.8 | 1.41 | 3.0 | 1.26 | 7.0 | 1.11 | 5.5 |
| 7. | 21 | 2.36 | 2.5 | 2.00 | 3.0 | 1.78 | 2.9 | 1.53 | 6.8 | 1.34 | 6.0 |
| 8. | 24 | 2.65 | 2.9 | 2.25 | 3.0 | 1.96 | 2.5 | 1.70 | 5.3 | 1.48 | 6.5 |
| 9. | 27 | 2.91 | 3.0 | 2.48 | 3.0 | 2.15 | 3.0 | 1.86 | 6.5 | 1.61 | 6.9 |
| 10. | 30 | 3.61 | 3.0 | 2.57 | 3.5 | 2.21 | 3.2 | 1.90 | 6.0 | 1.65 | 5.5 |
| 11. | 33 | 3.98 | 2.9 | 2.71 | 3.0 | 2.31 | 3.3 | 1.98 | 5.9 | 1.71 | 5.0 |
| 12. | 36 | 4.51 | 2.5 | 2.95 | 3.0 | 2.51 | 3.0 | 2.05 | 5.3 | 1.48 | 4.9 |
| 13. | 39 | 5.32 | 3.0 | 3.09 | 2.9 | 2.64 | 2.9 | 2.13 | 4.9 | 1.84 | 4.8 |
| 14. | 42 | 6.83 | 1.9 | 3.34 | 1.9 | 2.85 | 2.0 | 2.31 | 4.0 | 1.98 | 4.5 |
| 15. | 45 | 8.50 | 0.9 | 3.85 | 1.5 | 3.16 | 2.0 | 2.58 | 5.2 | 2.21 | 4.2 |
| 16. | 48 | | | 4.06 | 2.0 | 3.31 | 2.5 | 2.68 | 5.0 | 2.30 | 4.0 |
| 17. | 51 | | | 4.95 | 2.1 | 3.64 | 2.5 | 2.97 | 4.9 | 2.55 | 4.0 |
| 18. | 54 | | | 6.48 | 1.9 | 4.03 | 2.0 | 3.31 | 4.8 | 2.71 | 3.5 |
| 19. | 57 | | | 7.69 | 1.5 | 4.26 | 2.0 | 3.51 | 4.0 | 2.88 | 3.9 |
| 20. | 60 | | | 8.53 | 1.2 | 4.66 | 3.0 | 3.87 | 3.5 | 3.14 | 3.0 |
| 21. | 63 | | | 10.15 | 0.9 | 4.91 | 2.5 | 3.98 | 3.5 | 3.20 | 3.0 |
| 22. | 66 | | | | | 5.76 | 2.1 | 4.31 | 3.2 | 3.49 | 3.0 |
| 23. | 69 | | | | | 6.81 | 1.9 | 4.84 | 3.0 | 3.57 | 3.5 |
| 24. | 72 | | | | | 8.06 | 1.0 | 5.07 | 2.9 | 3.76 | 4.0 |
| 25. | 75 | | | | | 10.19 | 1.1 | 5.26 | 2.5 | 3.91 | 4.1 |
| 26. | 78 | | | | | 11.96 | 0.9 | 5.64 | 3.0 | 4.08 | 3.9 |
| 27. | 81 | | | | | | | 6.89 | 2.0 | 4.52 | 3.5 |
| 28. | 84 | | | | | | | 8.03 | 2.5 | 4.97 | 2.9 |
| 29. | 87 | | | | | | | 9.54 | 1.9 | 5.13 | 2.5 |
| 30. | 90 | | | | | | | 10.98 | 1.5 | 5.43 | 3.0 |
| 31. | 93 | | | | | | | | | 6.54 | 2.9 |
| 32. | 96 | | | | | | | | | 7.63 | 0.8 |
| 33. | 99 | | | | | | | | | 8.31 | 0.6 |
| 34. | 102 | | | | | | | | | 8.99 | 0.5 |

APPENDIX-III (Contd.)

Advance time and depth of flow data-Surge flow (CR=1/3), Discharge - 1.7 lps, Replication-1

| Sl. No. | Distance | S-1 | | S-2 | | S-3 | | S-4 | |
|---|---|---|---|---|---|---|---|---|---|
| | m | Time min | Depth cm | Time min | Depth cm | Time min | Depth cm | Time min | Depth cm |
| 1. | 3 | 0.35 | 2.0 | 0.30 | 3.0 | 0.27 | 3.0 | 0.20 | 3.3 |
| 2. | 6 | 0.80 | 2.5 | 0.64 | 2.8 | 0.60 | 2.6 | 0.51 | 3.3 |
| 3. | 9 | 1.23 | 2.0 | 0.92 | 2.8 | 0.85 | 2.1 | 0.68 | 3.0 |
| 4. | 12 | 1.60 | 2.5 | 1.13 | 2.6 | 1.03 | 2.0 | 0.76 | 3.1 |
| 5. | 15 | 1.90 | 1.9 | 1.42 | 2.6 | 1.32 | 1.8 | 1.01 | 3.1 |
| 6. | 18 | 2.2 | 2.2 | 1.69 | 3.0 | 1.43 | 2.5 | 1.10 | 4.0 |
| 7. | 21 | 2.60 | 1.5 | 1.97 | 2.9 | 1.75 | 1.6 | 1.35 | 2.8 |
| 8. | 24 | 2.98 | 2.8 | 2.17 | 4.7 | 1.94 | 2.1 | 1.47 | 4.3 |
| 9. | 27 | 3.57 | 1.5 | 2.50 | 1.6 | 2.29 | 1.1 | 1.65 | 2.0 |
| 10. | 30 | 3.90 | 1.1 | 2.83 | 2.2 | 2.57 | 1.5 | 1.77 | 2.2 |
| 11. | 33 | 4.38 | 3.0 | 2.95 | 4.2 | 2.65 | 2.5 | 1.84 | 4.3 |
| 12. | 36 | 5.20 | 2.5 | 3.25 | 2.3 | 2.87 | 2.0 | 1.96 | 2.2 |
| 13. | 39 | 6.08 | 2.3 | 3.77 | 3.0 | 2.98 | 2.1 | 2.05 | 2.8 |
| 14. | 42 | 6.92 | 1.9 | 4.33 | 2.6 | 3.06 | 3.0 | 2.11 | 2.8 |
| 15. | 45 | 8.15 | 1.5 | 4.97 | 1.5 | 3.19 | 1.1 | 2.20 | 1.6 |
| 16. | 48 | 9.10 | 0.7 | 5.52 | 2.5 | 3.36 | 2.9 | 2.35 | 2.8 |
| 17. | 51 | | | 6.00 | 1.5 | 3.67 | 1.0 | 2.64 | 1.2 |
| 18. | 54 | | | 6.42 | 1.7 | 3.91 | 1.0 | 2.85 | 1.6 |
| 19. | 57 | | | 6.80 | 2.2 | 4.17 | 1.1 | 3.05 | 2.5 |
| 20. | 60 | | | 7.22 | 1.2 | 4.54 | 1.2 | 3.11 | 1.8 |
| 21. | 63 | | | 8.00 | 1.5 | 5.29 | 1.8 | 3.21 | 2.0 |
| 22. | 66 | | | 8.55 | 1.0 | 5.82 | 1.0 | 3.28 | 1.2 |
| 23. | 69 | | | 9.30 | 2.2 | 6.27 | 3.0 | 3.36 | 3.3 |
| 24. | 72 | | | 9.95 | 1.3 | 6.91 | 3.5 | 3.45 | 3.3 |
| 25. | 75 | | | 10.87 | 2.2 | 7.82 | 3.7 | 3.59 | 3.5 |
| 26. | 78 | | | 11.25 | 0.9 | 8.16 | 1.6 | 3.68 | 1.5 |
| 27. | 81 | | | | | 10.12 | 1.0 | 3.76 | 1.0 |
| 28. | 84 | | | | | 10.68 | 1.3 | 3.85 | 1.1 |
| 29. | 87 | | | | | 11.13 | 1.0 | 4.05 | 1.8 |
| 30. | 90 | | | | | 12.00 | 2.0 | 4.23 | 1.2 |
| 31. | 93 | | | | | 12.68 | 1.9 | 4.59 | 0.9 |
| 32. | 96 | | | | | 13.88 | 1.8 | 4.83 | 0.8 |
| 33. | 99 | | | | | | | 5.67 | 0.8 |
| 34. | 102 | | | | | | | 6.50 | 1.8 |

APPENDIX-III (Contd.)

Advance time and depth of flow data-Surge flow (CR=1/3), Discharge - 1.7 lps, Replication-2

| Sl. No. | Distance | S-1 | | S-2 | | S-3 | | S-4 | |
|---|---|---|---|---|---|---|---|---|---|
| | m | Time min | Depth cm | Time min | Depth cm | Time min | Depth cm | Time min | Depth cm |
| 1. | 3 | 0.22 | 3.8 | 0.20 | 5.0 | 0.18 | 5.0 | 0.15 | 5.0 |
| 2. | 6 | 0.78 | 1.8 | 0.68 | 2.3 | 0.42 | 3.1 | 0.35 | 2.5 |
| 3. | 9 | 1.18 | 2.0 | 1.05 | 2.0 | 0.72 | 2.5 | 0.59 | 2.5 |
| 4. | 12 | 1.58 | 2.0 | 1.36 | 3.0 | 0.92 | 3.0 | 0.69 | 3.0 |
| 5. | 15 | 1.82 | 2.4 | 1.55 | 3.0 | 1.18 | 3.1 | 0.93 | 3.0 |
| 6. | 18 | 2.13 | 2.3 | 1.78 | 2.5 | 1.35 | 2.1 | 1.07 | 2.0 |
| 7. | 21 | 2.59 | 2.1 | 2.19 | 4.0 | 1.62 | 4.1 | 1.30 | 4.5 |
| 8. | 24 | 2.83 | 3.8 | 2.41 | 6.0 | 1.92 | 5.4 | 1.55 | 6.0 |
| 9. | 27 | 3.02 | 1.1 | 2.53 | 2.0 | 2.08 | 1.9 | 1.68 | 2.0 |
| 10. | 30 | 3.47 | 1.4 | 2.89 | 1.5 | 2.38 | 1.9 | 1.85 | 1.5 |
| 11. | 33 | 3.77 | 2.1 | 3.16 | 3.5 | 2.65 | 3.6 | 2.09 | 4.0 |
| 12. | 36 | 4.13 | 1.5 | 3.49 | 1.0 | 2.75 | 2.0 | 2.15 | 2.0 |
| 13. | 39 | 4.80 | 1.2 | 3.85 | 2.5 | 3.00 | 2.5 | 2.38 | 2.7 |
| 14. | 42 | 5.33 | 2.1 | 4.05 | 3.0 | 3.13 | 3.5 | 2.47 | 3.0 |
| 15. | 45 | 6.00 | 1.2 | 4.25 | 1.5 | 3.58 | 2.2 | 2.77 | 3.0 |
| 16. | 48 | 6.65 | 1.9 | 4.54 | 2.5 | 3.75 | 2.5 | 2.89 | 2.0 |
| 17. | 51 | 7.75 | 1.7 | 4.77 | 2.7 | 3.86 | 2.5 | 2.96 | 2.0 |
| 18. | 54 | 8.67 | 1.2 | 5.25 | 2.5 | 4.01 | 2.3 | 3.07 | 2.0 |
| 19. | 57 | 9.17 | 0.9 | 5.57 | 2.3 | 4.29 | 2.2 | 3.31 | 1.5 |
| 20. | 60 | 10.00 | 0.5 | 5.87 | 1.5 | 4.48 | 2.0 | 3.48 | 2.0 |
| 21. | 63 | | | 6.27 | 1.0 | 4.79 | 1.9 | 3.76 | 1.7 |
| 22. | 66 | | | 6.73 | 1.0 | 5.23 | 1.6 | 3.98 | 1.5 |
| 23. | 69 | | | 7.28 | 1.0 | 5.59 | 1.8 | 4.31 | 3.0 |
| 24. | 72 | | | 7.80 | 0.5 | 6.00 | 3.8 | 4.68 | 0.5 |
| 25. | 75 | | | 8.50 | 1.0 | 6.54 | 3.7 | 5.07 | 0.5 |
| 26. | 78 | | | 10.02 | 0.7 | 7.00 | 1.1 | 5.51 | 2.0 |
| 27. | 81 | | | 10.98 | 0.5 | 7.50 | 1.0 | 5.99 | 2.0 |
| 28. | 84 | | | 12.05 | 0.5 | 8.25 | 2.0 | 6.65 | 3.0 |
| 29. | 87 | | | | | 9.92 | 1.3 | 8.27 | 4.0 |
| 30. | 90 | | | | | 11.03 | 1.8 | 8.79 | 2.5 |
| 31. | 93 | | | | | 12.00 | 2.4 | 9.16 | 1.5 |
| 32. | 96 | | | | | | | 9.40 | 1.0 |
| 33. | 99 | | | | | | | 9.88 | 0.5 |
| 34. | 102 | | | | | | | 10.82 | 0.5 |

APPENDIX-III (Contd.)

Advance time and depth of flow data-Surge flow (CR=1/3), Discharge - 1.7 lps, Replication-3

| Sl. No. | Distance | S-1 | | S-2 | | S-3 | | S-4 | |
|---|---|---|---|---|---|---|---|---|---|
| | m | Time min | Depth cm | Time min | Depth cm | Time min | Depth cm | Time min | Depth cm |
| 1. | 3 | 0.28 | 3.0 | 0.25 | 4.8 | 0.22 | 5.0 | 0.20 | 5.5 |
| 2. | 6 | 0.52 | 3.0 | 0.45 | 4.2 | 0.39 | 5.0 | 0.35 | 5.2 |
| 3. | 9 | 0.92 | 3.0 | 0.81 | 3.5 | 0.67 | 3.0 | 0.60 | 4.9 |
| 4. | 12 | 1.15 | 2.5 | 0.98 | 4.8 | 0.82 | 5.5 | 0.72 | 5.0 |
| 5. | 15 | 1.62 | 2.5 | 1.34 | 4.7 | 1.06 | 5.5 | 0.97 | 5.0 |
| 6. | 18 | 1.80 | 2.0 | 1.42 | 4.2 | 1.11 | 5.5 | 0.95 | 5.0 |
| 7. | 21 | 2.12 | 1.5 | 1.68 | 4.1 | 1.34 | 5.0 | 1.18 | 4.8 |
| 8. | 24 | 2.50 | 3.0 | 2.13 | 4.8 | 1.68 | 5.5 | 1.49 | 4.8 |
| 9. | 27 | 2.85 | 1.5 | 2.38 | 1.1 | 1.86 | 1.5 | 1.65 | 4.0 |
| 10. | 30 | 3.18 | 1.0 | 2.54 | 1.1 | 1.95 | 1.5 | 1.72 | 3.9 |
| 11. | 33 | 3.65 | 1.0 | 2.73 | 1.7 | 2.09 | 2.0 | 1.83 | 3.5 |
| 12. | 36 | 4.17 | 1.0 | 2.99 | 2.7 | 2.27 | 3.0 | 2.00 | 3.5 |
| 13. | 39 | 4.80 | 2.0 | 3.31 | 3.8 | 2.46 | 4.2 | 2.17 | 4.8 |
| 14. | 42 | 5.67 | 1.0 | 3.95 | 3.6 | 2.87 | 3.8 | 2.47 | 4.5 |
| 15. | 45 | 6.83 | 1.3 | 4.48 | 4.1 | 3.28 | 4.4 | 2.79 | 4.5 |
| 16. | 48 | 7.67 | 3.0 | 4.97 | 5.5 | 3.54 | 5.7 | 2.96 | 6.0 |
| 17. | 51 | 9.00 | 0.5 | 5.20 | 1.0 | 3.67 | 2.0 | 3.05 | 3.5 |
| 18. | 54 | | | 5.55 | 1.0 | 3.95 | 2.5 | 3.29 | 3.5 |
| 19. | 57 | | | 6.17 | 1.0 | 4.23 | 2.2 | 3.46 | 3.6 |
| 20. | 60 | | | 7.05 | 1.0 | 4.76 | 2.8 | 3.86 | 3.9 |
| 21. | 63 | | | 8.43 | 1.2 | 5.58 | 2.9 | 4.65 | 4.9 |
| 22. | 66 | | | 9.98 | 1.1 | 6.13 | 1.8 | 5.10 | 2.5 |
| 23. | 69 | | | 11.65 | 0.5 | 6.42 | 1.5 | 5.26 | 2.00 |
| 24. | 72 | | | | | 7.00 | 2.0 | 5.81 | 2.5 |
| 25. | 75 | | | | | 8.00 | 2.5 | 6.24 | 3.0 |
| 26. | 78 | | | | | 9.00 | 4.0 | 6.83 | 4.5 |
| 27. | 81 | | | | | 10.17 | 2.0 | 7.19 | 2.5 |
| 28. | 84 | | | | | 10.83 | 1.0 | 7.48 | 2.0 |
| 29. | 87 | | | | | 11.92 | 0.5 | 7.87 | 1.5 |
| 30. | 90 | | | | | | | 7.95 | 1.5 |
| 31. | 93 | | | | | | | 8.17 | 1.9 |
| 32. | 96 | | | | | | | 8.36 | 1.1 |
| 33. | 99 | | | | | | | 8.58 | 0.9 |
| 34. | 102 | | | | | | | 8.91 | 0.8 |

APPENDIX-III (Contd.)

Advance time and depth of flow data-Surge flow (CR=1/3), Discharge - 2.1 lps, Replication-4

| Sl. No. | Distance | S-1 | | S-2 | | S-3 | | S-4 | |
|---|---|---|---|---|---|---|---|---|---|
| | m | Time min | Depth cm | Time min | Depth cm | Time min | Depth cm | Time min | Depth cm |
| 1. | 3 | 0.27 | 2.5 | 0.24 | 2.5 | 0.21 | 4.5 | 0.19 | 5.0 |
| 2. | 6 | 0.51 | 1.4 | 0.46 | 3.0 | 0.40 | 4.0 | 0.27 | 5.0 |
| 3. | 9 | 0.89 | 1.2 | 0.82 | 3.5 | 0.49 | 4.2 | 0.35 | 4.9 |
| 4. | 12 | 1.36 | 2.0 | 1.21 | 3.2 | 0.53 | 3.9 | 0.39 | 4.8 |
| 5. | 15 | 1.65 | 1.9 | 1.32 | 2.0 | 0.61 | 3.8 | 0.46 | 4.5 |
| 6. | 18 | 2.12 | 1.8 | 1.48 | 2.2 | 0.76 | 3.6 | 0.60 | 4.5 |
| 7. | 21 | 2.77 | 2.0 | 1.57 | 2.5 | 0.83 | 3.5 | 0.66 | 4.0 |
| 8. | 24 | 3.28 | 2.5 | 1.69 | 2.4 | 0.93 | 3.3 | 0.74 | 3.9 |
| 9. | 27 | 3.91 | 1.9 | 1.81 | 2.1 | 1.03 | 3.2 | 0.82 | 3.8 |
| 10. | 30 | 4.72 | 1.9 | 2.00 | 3.0 | 1.20 | 2.9 | 0.95 | 3.5 |
| 11. | 33 | 6.10 | 3.5 | 2.26 | 3.5 | 1.41 | 2.5 | 1.14 | 3.6 |
| 12. | 36 | 7.23 | 2.5 | 2.48 | 3.0 | 1.60 | 2.8 | 1.23 | 3.7 |
| 13. | 39 | 7.89 | 2.9 | 2.78 | 3.2 | 1.82 | 2.5 | 1.36 | 2.9 |
| 14. | 42 | 8.64 | 1.5 | 2.97 | 3.1 | 1.98 | 2.1 | 1.50 | 3.0 |
| 15. | 45 | 9.66 | 1.5 | 3.23 | 3.0 | 2.06 | 2.1 | 1.57 | 3.1 |
| 16. | 48 | 10.11 | 0.9 | 3.39 | 3.0 | 2.15 | 3.0 | 3.64 | 3.2 |
| 17. | 51 | 11.34 | 0.8 | 3.56 | 2.1 | 2.27 | 2.5 | 1.74 | 3.1 |
| 18. | 54 | | | 4.31 | 2.5 | 2.38 | 3.0 | 1.81 | 3.0 |
| 19. | 57 | | | 5.78 | 2.4 | 2.45 | 3.2 | 1.87 | 2.5 |
| 20. | 60 | | | 6.81 | 1.9 | 2.56 | 3.0 | 1.96 | 2.9 |
| 21. | 63 | | | 8.43 | 1.5 | 2.61 | 2.0 | 2.01 | 2.5 |
| 22. | 66 | | | 9.91 | 1.0 | 2.69 | 1.7 | 2.07 | 2.4 |
| 23. | 69 | | | 10.78 | 0.9 | 2.73 | 1.5 | 2.10 | 2.7 |
| 24. | 72 | | | 11.85 | 0.8 | 2.78 | 1.5 | 2.14 | 3.0 |
| 25. | 75 | | | | | 3.54 | 1.5 | 2.56 | 3.1 |
| 26. | 78 | | | | | 5.77 | 1.5 | 2.79 | 1.5 |
| 27. | 81 | | | | | 7.61 | 1.1 | 2.83 | 1.5 |
| 28. | 84 | | | | | 8.98 | 1.0 | 3.21 | 1.5 |
| 29. | 87 | | | | | 10.15 | 0.9 | 3.42 | 1.5 |
| 30. | 90 | | | | | | | 3.63 | 1.4 |
| 31. | 93 | | | | | | | 3.96 | 1.0 |
| 32. | 96 | | | | | | | 4.56 | 1.1 |
| 33. | 99 | | | | | | | 5.13 | 0.9 |
| 34. | 102 | | | | | | | 5.91 | 0.7 |

APPENDIX-III (Contd.)

Advance time and depth of flow data-Surge flow (CR=1/3), Discharge - 2.1lps, Replication-1

| Sl. No. | Distance | S-1 | | S-2 | | S-3 | | S-4 | |
|---|---|---|---|---|---|---|---|---|---|
| | m | Time min | Depth cm | Time min | Depth cm | Time min | Depth cm | Time min | Depth cm |
| 1. | 3 | 0.26 | 2.0 | 0.25 | 2.5 | 0.22 | 3.5 | 0.20 | 4.0 |
| 2. | 6 | 0.48 | 2.1 | 0.45 | 3.0 | 0.41 | 4.0 | 0.34 | 4.5 |
| 3. | 9 | 0.64 | 1.9 | 0.58 | 3.2 | 0.52 | 4.5 | 0.45 | 4.9 |
| 4. | 12 | 0.89 | 1.8 | 0.79 | 3.1 | 0.71 | 4.0 | 0.63 | 4.5 |
| 5. | 15 | 1.12 | 1.5 | 0.96 | 2.5 | 0.85 | 3.9 | 0.76 | 4.0 |
| 6. | 18 | 1.56 | 1.8 | 1.36 | 2.2 | 0.91 | 3.5 | 0.81 | 4.0 |
| 7. | 21 | 1.87 | 2.0 | 1.61 | 2.0 | 0.96 | 4.0 | 1.05 | 4.5 |
| 8. | 24 | 2.36 | 2.5 | 1.87 | 2.5 | 1.12 | 4.2 | 1.20 | 4.5 |
| 9. | 27 | 2.87 | 3.0 | 2.24 | 2.6 | 1.29 | 4.3 | 1.36 | 4.5 |
| 10. | 30 | 3.34 | 3.1 | 2.69 | 2.5 | 1.36 | 4.5 | 1.42 | 5.0 |
| 11. | 33 | 4.82 | 2.8 | 2.81 | 2.6 | 1.48 | 3.0 | 1.54 | 3.5 |
| 12. | 36 | 5.75 | 3.0 | 2.99 | 3.0 | 1.56 | 3.5 | 1.61 | 4.0 |
| 13. | 39 | 6.83 | 3.0 | 3.56 | 3.1 | 1.67 | 3.5 | 1.71 | 4.0 |
| 14. | 42 | 8.03 | 2.5 | 3.74 | 3.0 | 1.82 | 3.0 | 1.85 | 3.5 |
| 15. | 45 | 9.66 | 2.9 | 3.91 | 2.9 | 1.95 | 2.5 | 1.95 | 3.0 |
| 16. | 48 | | | 4.36 | 1.8 | 2.03 | 2.9 | 2.02 | 3.0 |
| 17. | 51 | | | 5.17 | 2.5 | 2.16 | 3.0 | 2.14 | 3.0 |
| 18. | 54 | | | 5.98 | 2.5 | 2.27 | 3.2 | 2.21 | 4.0 |
| 19. | 57 | | | 6.83 | 1.5 | 2.38 | 3.1 | 2.30 | 4.0 |
| 20. | 60 | | | 8.11 | 1.0 | 2.51 | 2.9 | 2.41 | 3.0 |
| 21. | 63 | | | 9.00 | 0.8 | 2.69 | 2.5 | 2.56 | 3.5 |
| 22. | 66 | | | 10.17 | 0.8 | 2.76 | 2.4 | 2.62 | 3.5 |
| 23. | 69 | | | 11.75 | 0.5 | 2.82 | 2.3 | 2.67 | 2.5 |
| 24. | 72 | | | | | 4.05 | 2.0 | 2.78 | 2.9 |
| 25. | 75 | | | | | 6.81 | 1.5 | 2.91 | 2.1 |
| 26. | 78 | | | | | 7.91 | 1.2 | 3.05 | 2.0 |
| 27. | 81 | | | | | 8.78 | 1.0 | 3.14 | 1.8 |
| 28. | 84 | | | | | 9.33 | 0.9 | 3.36 | 1.9 |
| 29. | 87 | | | | | 10.17 | 0.8 | 3.54 | 1.5 |
| 30. | 90 | | | | | | | 3.91 | 1.0 |
| 31. | 93 | | | | | | | 4.82 | 0.9 |
| 32. | 96 | | | | | | | 5.15 | 0.8 |
| 33. | 99 | | | | | | | 5.68 | 0.7 |
| 34. | 102 | | | | | | | 6.76 | 0.5 |

APPENDIX-III (Contd.)

Advance time and depth of flow data-Surge flow (CR=1/3), Discharge - 2.1 lps, Replication-2

| Sl. No. | Distance | S-1 | | S-2 | | S-3 | | S-4 | |
|---|---|---|---|---|---|---|---|---|---|
| | m | Time min | Depth cm | Time min | Depth cm | Time min | Depth cm | Time min | Depth cm |
| 1. | 3 | 0.25 | 2.0 | 0.24 | 4.0 | 0.21 | 3.7 | 0.19 | 4.0 |
| 2. | 6 | 0.60 | 2.8 | 0.55 | 3.6 | 0.49 | 3.4 | 0.28 | 4.0 |
| 3. | 9 | 1.00 | 1.0 | 0.86 | 3.5 | 0.64 | 3.0 | 0.30 | 3.8 |
| 4. | 12 | 1.28 | 3.0 | 1.09 | 4.3 | 0.76 | 4.1 | 0.41 | 4.8 |
| 5. | 15 | 1.68 | 2.0 | 1.49 | 4.2 | 0.89 | 4.1 | 0.52 | 4.3 |
| 6. | 18 | 2.00 | 3.5 | 1.69 | 5.7 | 0.97 | 6.0 | 0.59 | 6.2 |
| 7. | 21 | 2.40 | 1.5 | 1.83 | 3.3 | 1.16 | 3.0 | 0.74 | 3.0 |
| 8. | 24 | 2.87 | 2.1 | 1.95 | 3.8 | 1.23 | 4.1 | 0.80 | 4.0 |
| 9. | 27 | 3.37 | 1.5 | 2.25 | 2.2 | 1.29 | 2.1 | 0.85 | 2.3 |
| 10. | 30 | 3.75 | 1.5 | 2.45 | 2.0 | 1.37 | 2.0 | 0.91 | 2.0 |
| 11. | 33 | 4.13 | 1.8 | 2.81 | 2.5 | 1.44 | 1.5 | 0.96 | 2.2 |
| 12. | 36 | 4.67 | 1.8 | 2.97 | 2.6 | 1.56 | 3.2 | 2.04 | 3.5 |
| 13. | 39 | 5.47 | 1.7 | 3.11 | 2.0 | 1.68 | 2.5 | 2.14 | 2.8 |
| 14. | 42 | 6.37 | 1.5 | 3.36 | 3.0 | 1.76 | 3.3 | 2.21 | 3.8 |
| 15. | 45 | 8.00 | 1.3 | 3.42 | 2.8 | 1.84 | 2.8 | 2.26 | 3.0 |
| 16. | 48 | 9.85 | 0.9 | 3.50 | 2.6 | 1.93 | 3.8 | 2.31 | 4.0 |
| 17. | 51 | | | 4.68 | 2.6 | 1.99 | 3.0 | 2.36 | 3.5 |
| 18. | 54 | | | 5.17 | 1.6 | 2.16 | 1.5 | 2.40 | 2.3 |
| 19. | 57 | | | 5.75 | 1.4 | 2.25 | 1.8 | 2.44 | 2.0 |
| 20. | 60 | | | 6.50 | 1.0 | 2.34 | 2.1 | 2.51 | 2.5 |
| 21. | 63 | | | 7.27 | 1.5 | 2.40 | 1.0 | 2.58 | 2.0 |
| 22. | 66 | | | 8.00 | 0.6 | 2.48 | 1.0 | 2.63 | 1.3 |
| 23. | 69 | | | 8.68 | 1.0 | 2.53 | 1.5 | 2.69 | 2.2 |
| 24. | 72 | | | 9.50 | 1.0 | 2.59 | 1.5 | 2.74 | 1.6 |
| 25. | 75 | | | 10.02 | 3.2 | 2.65 | 5.8 | 2.79 | 4.8 |
| 26. | 78 | | | 11.32 | 1.0 | 2.70 | 3.0 | 2.83 | 3.8 |
| 27. | 81 | | | | | 4.67 | 1.0 | 2.86 | 2.0 |
| 28. | 84 | | | | | 7.38 | 2.1 | 2.91 | 4.3 |
| 29. | 87 | | | | | 8.58 | 1.0 | 2.94 | 1.3 |
| 30. | 90 | | | | | 9.50 | 1.4 | 2.99 | 1.5 |
| 31. | 93 | | | | | 10.05 | 1.5 | 3.06 | 1.5 |
| 32. | 96 | | | | | 11.75 | 1.0 | 3.61 | 2.2 |
| 33. | 99 | | | | | | | 4.76 | 1.6 |
| 34. | 102 | | | | | | | 5.00 | 0.9 |

APPENDIX-III (Contd.)

Advance time and depth of flow data-Surge flow (CR=1/3), Discharge - 2.1 lps, Replication-3

| Sl. No. | Distance | S-1 | | S-2 | | S-3 | | S-4 | |
|---|---|---|---|---|---|---|---|---|---|
| | m | Time min | Depth cm | Time min | Depth cm | Time min | Depth cm | Time min | Depth cm |
| 1. | 3 | 0.27 | 2.5 | 0.25 | 4.0 | 0.24 | 4.5 | 0.22 | 4.0 |
| 2. | 6 | 0.51 | 2.4 | 0.48 | 3.5 | 0.45 | 3.7 | 0.41 | 4.5 |
| 3. | 9 | 0.79 | 2.1 | 0.74 | 3.6 | 0.56 | 3.6 | 0.50 | 4.0 |
| 4. | 12 | 0.95 | 2.0 | 0.87 | 4.2 | 0.68 | 3.5 | 0.59 | 4.2 |
| 5. | 15 | 1.23 | 1.9 | 1.13 | 4.1 | 0.77 | 4.0 | 0.65 | 4.5 |
| 6. | 18 | 1.46 | 1.8 | 1.32 | 5.1 | 0.91 | 4.2 | 0.78 | 4.2 |
| 7. | 21 | 1.66 | 1.8 | 1.50 | 4.8 | 0.98 | 3.3 | 0.83 | 4.1 |
| 8. | 24 | 1.87 | 1.6 | 1.69 | 3.9 | 1.10 | 3.9 | 0.92 | 4.0 |
| 9. | 27 | 2.29 | 1.5 | 2.09 | 3.8 | 1.19 | 3.5 | 0.99 | 3.9 |
| 10. | 30 | 2.57 | 1.9 | 2.35 | 3.5 | 1.26 | 3.0 | 1.04 | 3.8 |
| 11. | 33 | 3.96 | 1.8 | 2.57 | 3.5 | 1.35 | 3.0 | 1.11 | 3.5 |
| 12. | 36 | 4.84 | 1.8 | 2.78 | 3.0 | 1.57 | 2.9 | 1.23 | 3.2 |
| 13. | 39 | 5.76 | 1.5 | 2.91 | 3.1 | 1.63 | 2.5 | 1.31 | 3.3 |
| 14. | 42 | 6.91 | 1.9 | 3.23 | 3.0 | 1.77 | 2.5 | 1.41 | 3.1 |
| 15. | 45 | 8.01 | 0.9 | 3.38 | 2.9 | 1.86 | 2.5 | 1.49 | 3.0 |
| 16. | 48 | 9.34 | 0.8 | 3.54 | 2.2 | 1.99 | 2.3 | 1.59 | 3.0 |
| 17. | 51 | | | 4.91 | 2.1 | 2.11 | 2.5 | 1.70 | 2.5 |
| 18. | 54 | | | 5.63 | 2.0 | 2.18 | 2.2 | 1.76 | 2.8 |
| 19. | 57 | | | 6.52 | 2.0 | 2.25 | 2.1 | 1.81 | 2.5 |
| 20. | 60 | | | 7.91 | 1.9 | 2.42 | 2.5 | 1.95 | 2.0 |
| 21. | 63 | | | 8.72 | 1.8 | 2.50 | 2.0 | 2.01 | 2.1 |
| 22. | 66 | | | 10.01 | 1.5 | 2.58 | 1.9 | 2.09 | 2.2 |
| 23. | 69 | | | 11.06 | 1.0 | 2.65 | 2.0 | 2.14 | 2.1 |
| 24. | 72 | | | | | 3.52 | 2.5 | 2.31 | 2.0 |
| 25. | 75 | | | | | 4.61 | 2.1 | 2.56 | 2.0 |
| 26. | 78 | | | | | 5.92 | 1.8 | 2.74 | 1.9 |
| 27. | 81 | | | | | 7.01 | 1.5 | 2.91 | 1.6 |
| 28. | 84 | | | | | 9.11 | 0.9 | 3.08 | 1.5 |
| 29. | 87 | | | | | 10.25 | 0.8 | 3.24 | 1.5 |
| 30. | 90 | | | | | | | 3.84 | 1.5 |
| 31. | 93 | | | | | | | 4.05 | 1.5 |
| 32. | 96 | | | | | | | 4.47 | 0.9 |
| 33. | 99 | | | | | | | 4.94 | 0.8 |
| 34. | 102 | | | | | | | 5.57 | 0.8 |

|  | m | Time min | Depth cm | Time min | Depth cm | Time min | Depth cm |
|---|---|---|---|---|---|---|---|
| 1. | 3 | 0.27 | 3.0 | 0.25 | 5.5 | 0.20 | 7.0 |
| 2. | 6 | 0.63 | 2.9 | 0.34 | 6.0 | 0.28 | 7.5 |
| 3. | 9 | 0.99 | 2.5 | 0.46 | 6.1 | 0.35 | 7.0 |
| 4. | 12 | 1.34 | 2.0 | 0.58 | 5.9 | 0.41 | 7.0 |
| 5. | 15 | 1.82 | 1.9 | 0.71 | 5.8 | 0.48 | 7.0 |
| 6. | 18 | 2.31 | 1.9 | 0.90 | 5.5 | 0.53 | 6.5 |
| 7. | 21 | 2.79 | 2.0 | 1.00 | 5.4 | 0.59 | 6.5 |
| 8. | 24 | 3.65 | 2.5 | 1.17 | 4.9 | 0.64 | 6.0 |
| 9. | 27 | 4.05 | 3.0 | 1.28 | 4.8 | 0.71 | 5.5 |
| 10. | 30 | 4.77 | 2.5 | 1.37 | 4.8 | 0.76 | 5.5 |
| 11. | 33 | 5.82 | 2.8 | 1.46 | 4.5 | 0.82 | 5.0 |
| 12. | 36 | 6.94 | 2.9 | 1.54 | 4.5 | 0.88 | 5.1 |
| 13. | 39 | 7.87 | 2.5 | 1.69 | 4.2 | 0.94 | 5.2 |
| 14. | 42 | 8.81 | 2.0 | 1.78 | 4.0 | 0.99 | 4.5 |
| 15. | 45 | 9.63 | 1.5 | 1.83 | 3.9 | 1.03 | 4.0 |
| 16. | 48 | 10.11 | 1.1 | 1.96 | 2.5 | 1.10 | 4.0 |
| 17. | 51 |  |  | 2.82 | 2.1 | 1.24 | 4.5 |
| 18. | 54 |  |  | 3.64 | 2.0 | 1.36 | 4.5 |
| 19. | 57 |  |  | 4.72 | 1.9 | 1.43 | 4.0 |
| 20. | 60 |  |  | 5.34 | 1.6 | 1.48 | 4.0 |
| 21. | 63 |  |  | 5.91 | 1.9 | 1.56 | 3.9 |
| 22. | 66 |  |  | 6.82 | 1.5 | 1.63 | 3.5 |
| 23. | 69 |  |  | 7.65 | 1.4 | 1.69 | 3.5 |
| 24. | 72 |  |  | 8.31 | 1.0 | 1.74 | 3.0 |
| 25. | 75 |  |  | 9.23 | 0.9 | 1.82 | 3.0 |
| 26. | 78 |  |  |  |  | 2.45 | 1.3 |
| 27. | 81 |  |  |  |  | 2.99 | 1.2 |
| 28. | 84 |  |  |  |  | 3.63 | 1.2 |
| 29. | 87 |  |  |  |  | 4.12 | 1.1 |
| 30. | 90 |  |  |  |  | 4.87 | 1.1 |
| 31. | 93 |  |  |  |  | 5.73 | 1.5 |
| 32. | 96 |  |  |  |  | 6.34 | 1.1 |
| 33. | 99 |  |  |  |  | 6.91 | 0.9 |
| 34. | 102 |  |  |  |  | 7.38 | 0.8 |

APPENDIX-III (Contd.)

Advance time and depth of flow data-Surge flow (CR=2/3), Discharge - 1.3 lps, Replication-3

| Sl. No. | Distance | S-1 | | S-2 | | S-3 | |
|---|---|---|---|---|---|---|---|
| | m | Time min | Depth cm | Time min | Depth cm | Time min | Depth cm |
| 1. | 3 | 0.29 | 2.5 | 0.16 | 5.5 | 0.11 | 6.0 |
| 2. | 6 | 0.71 | 2.0 | 0.27 | 5.1 | 0.20 | 5.5 |
| 3. | 9 | 0.99 | 1.9 | 0.39 | 5.1 | 0.28 | 5.5 |
| 4. | 12 | 1.25 | 2.0 | 0.51 | 5.0 | 0.36 | 5.5 |
| 5. | 15 | 1.71 | 3.1 | 0.73 | 4.9 | 0.42 | 5.0 |
| 6. | 18 | 2.21 | 4.0 | 0.94 | 5.0 | 0.48 | 5.1 |
| 7. | 21 | 2.72 | 2.9 | 1.07 | 5.5 | 0.54 | 6.0 |
| 8. | 24 | 3.86 | 2.9 | 1.19 | 6.0 | 0.60 | 6.5 |
| 9. | 27 | 4.35 | 1.8 | 1.28 | 6.7 | 0.68 | 6.9 |
| 10. | 30 | 4.84 | 1.5 | 1.35 | 6.5 | 0.72 | 6.9 |
| 11. | 33 | 5.91 | 2.0 | 1.42 | 6.3 | 0.78 | 7.0 |
| 12. | 36 | 6.78 | 2.1 | 1.48 | 6.2 | 0.83 | 7.1 |
| 13. | 39 | 7.45 | 2.5 | 1.54 | 5.5 | 0.88 | 7.0 |
| 14. | 42 | 7.89 | 1.9 | 1.61 | 5.0 | 0.93 | 6.5 |
| 15. | 45 | 8.85 | 1.5 | 1.74 | 4.5 | 1.05 | 6.5 |
| 16. | 48 | 9.63 | 1.1 | 1.83 | 2.0 | 1.11 | 6.2 |
| 17. | 51 | 10.03 | 1.0 | 1.98 | 2.0 | 1.16 | 5.5 |
| 18. | 54 | | | 2.61 | 1.8 | 1.25 | 5.0 |
| 19. | 57 | | | 3.76 | 1.5 | 1.34 | 4.5 |
| 20. | 60 | | | 4.42 | 1.0 | 1.41 | 4.5 |
| 21. | 63 | | | 4.97 | 1.9 | 1.47 | 4.0 |
| 22. | 66 | | | 5.51 | 1.5 | 1.52 | 3.9 |
| 23. | 69 | | | 6.82 | 1.0 | 1.59 | 3.5 |
| 24. | 72 | | | 7.76 | 1.5 | 1.63 | 3.5 |
| 25. | 75 | | | 8.67 | 1.5 | 1.74 | 3.0 |
| 26. | 78 | | | 9.81 | 0.9 | 1.86 | 1.0 |
| 27. | 81 | | | | | 2.14 | 0.9 |
| 28. | 84 | | | | | 2.36 | 0.9 |
| 29. | 87 | | | | | 2.91 | 0.8 |
| 30. | 90 | | | | | 3.45 | 0.8 |
| 31. | 93 | | | | | 4.82 | 0.9 |
| 32. | 96 | | | | | 5.63 | 0.8 |
| 33. | 99 | | | | | 6.71 | 0.5 |
| 34. | 102 | | | | | 7.41 | 0.6 |

APPENDIX-III (Contd.)

Advance time and depth of flow data-Surge flow (CR=2/3), Discharge - 1.3 lps, Replication-4

| Sl. No. | Distance | S-1 | | S-2 | | S-3 | |
|---|---|---|---|---|---|---|---|
| | m | Time min | Depth cm | Time min | Depth cm | Time min | Depth cm |
| 1. | 3 | 0.22 | 2.0 | 0.12 | 5.1 | 0.09 | 6.0 |
| 2. | 6 | 0.60 | 2.5 | 0.27 | 3.5 | 0.19 | 4.5 |
| 3. | 9 | 0.97 | 2.5 | 0.51 | 3.5 | 0.28 | 6.0 |
| 4. | 12 | 1.28 | 2.0 | 0.68 | 6.7 | 0.36 | 7.5 |
| 5. | 15 | 1.67 | 2.5 | 0.77 | 7.7 | 0.43 | 8.5 |
| 6. | 18 | 2.25 | 3.0 | 0.89 | 6.0 | 0.51 | 6.5 |
| 7. | 21 | 2.73 | 4.5 | 0.97 | 6.8 | 0.56 | 7.0 |
| 8. | 24 | 3.25 | 4.5 | 1.09 | 5.5 | 0.62 | 6.0 |
| 9. | 27 | 4.35 | 3.0 | 1.18 | 3.0 | 0.69 | 1.5 |
| 10. | 30 | 5.00 | 2.0 | 1.31 | 3.0 | 0.77 | 1.5 |
| 11. | 33 | 5.50 | 2.5 | 1.42 | 1.5 | 0.84 | 2.5 |
| 12. | 36 | 6.12 | 2.1 | 1.57 | 1.5 | 0.95 | 2.0 |
| 13. | 39 | 6.67 | 2.0 | 1.69 | 3.8 | 1.07 | 5.0 |
| 14. | 42 | 7.00 | 1.5 | 1.78 | 5.5 | 1.11 | 7.0 |
| 15. | 45 | 8.50 | 0.9 | 1.86 | 3.5 | 1.16 | 5.0 |
| 16. | 48 | 10.00 | 0.8 | 1.93 | 3.0 | 1.22 | 5.1 |
| 17. | 51 | | | 3.78 | 1.5 | 1.28 | 5.5 |
| 18. | 54 | | | 4.63 | 1.5 | 1.34 | 3.5 |
| 19. | 57 | | | 5.20 | 2.0 | 1.39 | 1.5 |
| 20. | 60 | | | 5.70 | 2.5 | 1.44 | 1.5 |
| 21. | 63 | | | 6.55 | 2.5 | 1.48 | 2.0 |
| 22. | 66 | | | 7.17 | 2.0 | 1.54 | 3.5 |
| 23. | 69 | | | 7.85 | 1.8 | 1.59 | 3.0 |
| 24. | 72 | | | 8.65 | 1.5 | 1.63 | 4.0 |
| 25. | 75 | | | 9.50 | 0.9 | 1.74 | 4.5 |
| 26. | 78 | | | | | 2.96 | 1.2 |
| 27. | 81 | | | | | 3.85 | 1.1 |
| 28. | 84 | | | | | 5.01 | 1.2 |
| 29. | 87 | | | | | 5.34 | 1.5 |
| 30. | 90 | | | | | 5.68 | 1.5 |
| 31. | 93 | | | | | 5.91 | 1.5 |
| 32. | 96 | | | | | 6.28 | 1.1 |
| 33. | 99 | | | | | 6.59 | 1.0 |
| 34. | 102 | | | | | 7.21 | 0.9 |

APPENDIX-III (Contd.)

Advance time and depth of flow data-Surge flow (CR=2/3), Discharge - 1.7 lps, Replication-1

| Sl. No. | Distance | S-1 | | S-2 | | S-3 | |
|---|---|---|---|---|---|---|---|
| | m | Time min | Depth cm | Time min | Depth cm | Time min | Depth cm |
| 1. | 3 | 0.26 | 2.5 | 0.24 | 5.1 | 0.21 | 5.5 |
| 2. | 6 | 0.51 | 2.0 | 0.39 | 5.0 | 0.35 | 5.5 |
| 3. | 9 | 0.82 | 1.9 | 0.50 | 4.9 | 0.42 | 5.0 |
| 4. | 12 | 0.05 | 1.5 | 0.63 | 4.8 | 0.50 | 5.0 |
| 5. | 15 | 1.36 | 1.6 | 0.84 | 4.5 | 0.63 | 5.1 |
| 6. | 18 | 1.62 | 1.9 | 0.95 | 4.5 | 0.71 | 5.0 |
| 7. | 21 | 1.89 | 2.0 | 1.11 | 4.0 | 0.82 | 4.5 |
| 8. | 24 | 2.06 | 2.2 | 1.29 | 3.9 | 0.96 | 4.5 |
| 9. | 27 | 2.54 | 2.5 | 1.37 | 3.6 | 1.03 | 4.0 |
| 10. | 30 | 2.91 | 2.4 | 1.49 | 3.3 | 1.11 | 4.0 |
| 11. | 33 | 3.48 | 2.1 | 1.54 | 3.5 | 1.19 | 4.1 |
| 12. | 36 | 3.86 | 2.0 | 1.71 | 3.0 | 1.29 | 4.5 |
| 13. | 39 | 4.41 | 1.9 | 1.92 | 3.1 | 1.36 | 4.2 |
| 14. | 42 | 4.77 | 1.8 | 2.15 | 3.2 | 4.49 | 4.1 |
| 15. | 45 | 6.23 | 1.5 | 2.28 | 3.0 | 1.61 | 3.9 |
| 16. | 48 | 6.75 | 1.5 | 2.42 | 2.5 | 1.75 | 3.5 |
| 17. | 51 | 7.79 | 1.2 | 2.76 | 2.0 | 1.84 | 3.5 |
| 18. | 54 | 8.76 | 1.0 | 2.91 | 1.9 | 1.93 | 3.6 |
| 19. | 57 | | | 3.36 | 1.9 | 2.01 | 3.6 |
| 20. | 60 | | | 3.91 | 1.5 | 2.16 | 3.5 |
| 21. | 63 | | | 4.53 | 2.2 | 2.28 | 3.5 |
| 22. | 66 | | | 4.84 | 1.9 | 2.34 | 3.2 |
| 23. | 69 | | | 5.21 | 1.5 | 2.38 | 3.1 |
| 24. | 72 | | | 5.99 | 1.5 | 2.49 | 3.0 |
| 25. | 75 | | | 7.82 | 1.1 | 2.55 | 3.0 |
| 26. | 78 | | | 8.63 | 1.0 | 2.64 | 1.5 |
| 27. | 81 | | | 9.84 | 0.9 | 2.71 | 1.2 |
| 28. | 84 | | | | | 2.98 | 1.1 |
| 29. | 87 | | | | | 3.31 | 1.1 |
| 30. | 90 | | | | | 3.69 | 0.9 |
| 31. | 93 | | | | | 3.98 | 1.9 |
| 32. | 96 | | | | | 4.34 | 1.5 |
| 33. | 99 | | | | | 4.91 | 1.1 |
| 34. | 102 | | | | | 5.76 | 0.9 |

APPENDIX-III (Contd.)

Advance time and depth of flow data-Surge flow (CR=2/3),
Discharge - 1.7 lps, Replication-2

| Sl. No. | Distance | S-1 | | S-2 | | S-3 | |
|---|---|---|---|---|---|---|---|
| | m | Time min | Depth cm | Time min | Depth cm | Time min | Depth cm |
| 1. | 3 | 0.26 | 2.5 | 0.23 | 4.9 | 0.20 | 5.5 |
| 2. | 6 | 0.41 | 1.8 | 0.36 | 4.5 | 0.31 | 5.0 |
| 3. | 9 | 0.68 | 2.0 | 0.45 | 4.5 | 0.39 | 5.0 |
| 4. | 12 | 0.92 | 2.0 | 0.59 | 4.0 | 0.48 | 5.1 |
| 5. | 15 | 1.16 | 1.5 | 0.73 | 4.2 | 0.55 | 5.5 |
| 6. | 18 | 1.37 | 1.9 | 0.84 | 4.1 | 0.62 | 5.2 |
| 7. | 21 | 1.54 | 2.1 | 0.91 | 3.9 | 0.68 | 4.9 |
| 8. | 24 | 1.72 | 2.0 | 1.05 | 3.5 | 0.81 | 4.0 |
| 9. | 27 | 1.93 | 2.0 | 1.16 | 4.0 | 0.90 | 4.5 |
| 10. | 30 | 2.26 | 2.5 | 1.29 | 4.0 | 0.99 | 4.5 |
| 11. | 33 | 2.54 | 2.5 | 1.38 | 3.9 | 1.05 | 4.0 |
| 12. | 36 | 2.91 | 2.6 | 1.46 | 3.5 | 1.10 | 4.1 |
| 13. | 39 | 3.43 | 3.0 | 1.59 | 3.5 | 1.19 | 3.9 |
| 14. | 42 | 3.91 | 3.1 | 1.74 | 3.0 | 1.28 | 3.5 |
| 15. | 45 | 4.82 | 3.0 | 1.98 | 2.9 | 1.41 | 3.0 |
| 16. | 48 | 5.54 | 2.5 | 2.24 | 2.9 | 1.59 | 3.0 |
| 17. | 51 | 6.32 | 2.0 | 2.49 | 2.5 | 1.74 | 2.9 |
| 18. | 54 | 6.87 | 1.5 | 2.64 | 3.0 | 1.86 | 3.5 |
| 19. | 57 | 7.84 | 1.1 | 2.83 | 3.1 | 1.99 | 3.5 |
| 20. | 60 | 8.71 | 1.0 | 2.94 | 3.0 | 2.06 | 3.5 |
| 21. | 63 | | | 3.61 | 2.5 | 2.15 | 3.0 |
| 22. | 66 | | | 4.27 | 2.5 | 2.24 | 3.0 |
| 23. | 69 | | | 4.86 | 2.5 | 2.30 | 3.0 |
| 24. | 72 | | | 5.52 | 2.0 | 2.36 | 2.5 |
| 25. | 75 | | | 5.91 | 2.0 | 2.41 | 2.9 |
| 26. | 78 | | | 6.84 | 1.9 | 2.46 | 1.2 |
| 27. | 81 | | | 7.77 | 1.5 | 2.51 | 1.1 |
| 28. | 84 | | | 8.63 | 1.1 | 2.57 | 1.1 |
| 29. | 87 | | | 9.91 | 0.9 | 2.70 | 0.9 |
| 30. | 90 | | | | | 2.99 | 0.9 |
| 31. | 93 | | | | | 3.36 | 1.5 |
| 32. | 96 | | | | | 3.81 | 1.1 |
| 33. | 99 | | | | | 4.67 | 1.0 |
| 34. | 102 | | | | | 5.13 | 0.8 |

APPENDIX-III (Contd.)

Advance time and depth of flow data-Surge flow (CR=2/3),
Discharge - 1.7 lps, Replication-3

| Sl. No. | Distance | S-1 | | S-2 | | S-3 | |
|---|---|---|---|---|---|---|---|
| | m | Time min | Depth cm | Time min | Depth cm | Time min | Depth cm |
| 1. | 3 | 0.23 | 3.0 | 0.21 | 4.8 | 0.16 | 5.0 |
| 2. | 6 | 0.50 | 2.9 | 0.48 | 4.2 | 0.26 | 5.0 |
| 3. | 9 | 0.80 | 2.6 | 0.69 | 3.5 | 0.35 | 3.0 |
| 4. | 12 | 1.03 | 2.5 | 0.88 | 4.8 | 0.41 | 5.5 |
| 5. | 15 | 1.40 | 2.5 | 1.21 | 4.7 | 0.48 | 5.5 |
| 6. | 18 | 1.77 | 2.0 | 1.49 | 4.2 | 0.52 | 5.5 |
| 7. | 21 | 2.12 | 1.5 | 1.81 | 4.1 | 0.59 | 5.0 |
| 8. | 24 | 2.50 | 3.0 | 2.11 | 4.8 | 0.69 | 5.5 |
| 9. | 27 | 2.93 | 1.5 | 2.22 | 1.1 | 0.77 | 1.5 |
| 10. | 30 | 3.25 | 1.0 | 2.31 | 1.1 | 0.85 | 1.5 |
| 11. | 33 | 3.72 | 1.0 | 2.38 | 1.7 | 0.91 | 2.0 |
| 12. | 36 | 4.15 | 1.0 | 2.45 | 2.7 | 0.97 | 3.0 |
| 13. | 39 | 4.55 | 2.0 | 2.50 | 3.8 | 1.06 | 4.2 |
| 14. | 42 | 5.12 | 1.0 | 2.56 | 3.6 | 1.11 | 3.8 |
| 15. | 45 | 5.63 | 1.3 | 2.61 | 4.1 | 1.15 | 4.4 |
| 16. | 48 | 6.03 | 3.0 | 2.69 | 2.5 | 1.23 | 5.7 |
| 17. | 51 | 7.50 | 1.5 | 2.75 | 1.0 | 1.28 | 2.0 |
| 18. | 54 | 8.00 | 1.5 | 2.82 | 1.0 | 1.35 | 2.5 |
| 19. | 57 | 8.80 | 0.9 | 2.91 | 1.0 | 1.44 | 2.2 |
| 20. | 60 | | | 3.00 | 1.0 | 1.52 | 2.8 |
| 21. | 63 | | | 3.62 | 1.2 | 1.68 | 3.9 |
| 22. | 66 | | | 4.25 | 1.1 | 1.85 | 3.8 |
| 23. | 69 | | | 4.98 | 1.4 | 1.92 | 5.3 |
| 24. | 72 | | | 5.57 | 1.7 | 2.00 | 6.0 |
| 25. | 75 | | | 6.07 | 1.8 | 2.17 | 6.3 |
| 26. | 78 | | | 7.18 | 1.5 | 2.28 | 4.0 |
| 27. | 81 | | | 7.90 | 1.5 | 2.36 | 2.0 |
| 28. | 84 | | | 8.52 | 0.9 | 2.49 | 2.0 |
| 29. | 87 | | | 9.17 | 0.8 | 2.57 | 5.0 |
| 30. | 90 | | | 9.97 | 0.8 | 2.79 | 3.5 |
| 31. | 93 | | | | | 2.93 | 1.6 |
| 32. | 96 | | | | | 3.19 | 1.2 |
| 33. | 99 | | | | | 3.50 | 1.1 |
| 34. | 102 | | | | | 4.00 | 0.9 |

APPENDIX-III (Contd.)

Advance time and depth of flow data-Surge flow (CR=2/3), Discharge - 1.7 lps, Replication-4

| Sl. No. | Distance | S-1 | | S-2 | | S-3 | |
|---|---|---|---|---|---|---|---|
| | m | Time min | Depth cm | Time min | Depth cm | Time min | Depth cm |
| 1. | 3 | 0.28 | 2.0 | 0.25 | 4.5 | 0.19 | 5.5 |
| 2. | 6 | 0.41 | 2.0 | 0.36 | 4.3 | 0.20 | 5.2 |
| 3. | 9 | 0.63 | 2.2 | 0.51 | 4.2 | 0.30 | 5.1 |
| 4. | 12 | 0.82 | 2.2 | 0.63 | 4.0 | 0.40 | 5.0 |
| 5. | 15 | 1.03 | 1.8 | 0.75 | 4.1 | 0.48 | 4.9 |
| 6. | 18 | 1.24 | 2.1 | 0.86 | 3.9 | 0.56 | 4.5 |
| 7. | 21 | 1.58 | 2.2 | 0.99 | 3.5 | 0.65 | 4.0 |
| 8. | 24 | 1.94 | 2.5 | 1.15 | 3.6 | 0.73 | 4.0 |
| 9. | 27 | 2.31 | 3.0 | 1.28 | 3.5 | 0.81 | 4.1 |
| 10. | 30 | 2.64 | 3.2 | 1.37 | 3.3 | 0.89 | 4.5 |
| 11. | 33 | 3.02 | 3.1 | 1.46 | 3.0 | 0.95 | 4.1 |
| 12. | 36 | 3.53 | 2.5 | 1.61 | 3.0 | 1.08 | 4.0 |
| 13. | 39 | 4.82 | 2.2 | 1.82 | 2.9 | 1.19 | 3.9 |
| 14. | 42 | 5.71 | 2.1 | 2.03 | 2.8 | 1.26 | 3.5 |
| 15. | 45 | 6.93 | 2.0 | 2.27 | 2.5 | 1.41 | 3.5 |
| 16. | 48 | 7.31 | 1.9 | 2.49 | 1.9 | 1.59 | 3.8 |
| 17. | 51 | 7.98 | 1.8 | 2.62 | 1.8 | 1.71 | 3.9 |
| 18. | 54 | 8.54 | 1.5 | 2.78 | 1.5 | 1.85 | 4.0 |
| 19. | 57 | 8.91 | 1.1 | 2.86 | 1.5 | 1.91 | 4.1 |
| 20. | 60 | | | 3.54 | 1.5 | 2.11 | 3.8 |
| 21. | 63 | | | 4.82 | 2.1 | 2.29 | 3.5 |
| 22. | 66 | | | 5.91 | 1.9 | 2.41 | 3.0 |
| 23. | 69 | | | 6.88 | 1.8 | 2.52 | 2.9 |
| 24. | 72 | | | 7.54 | 1.5 | 2.59 | 2.5 |
| 25. | 75 | | | 8.61 | 1.0 | 2.66 | 2.5 |
| 26. | 78 | | | 9.71 | 0.9 | 2.74 | 1.7 |
| 27. | 81 | | | | | 2.98 | 1.6 |
| 28. | 84 | | | | | 3.25 | 1.2 |
| 29. | 87 | | | | | 3.63 | 1.1 |
| 30. | 90 | | | | | 3.91 | 1.1 |
| 31. | 93 | | | | | 4.34 | 1.9 |
| 32. | 96 | | | | | 4.75 | 1.7 |
| 33. | 99 | | | | | 4.99 | 1.5 |
| 34. | 102 | | | | | 5.36 | 0.9 |

APPENDIX-III (Contd.)

Advance time and depth of flow data-Surge flow (CR=2/3), Discharge - 2.1 lps, Replication-1

| Sl. No. | Distance | S-1 | | S-2 | | S-3 | |
|---|---|---|---|---|---|---|---|
| | m | Time min | Depth cm | Time min | Depth cm | Time min | Depth cm |
| 1. | 3 | 0.23 | 2.9 | 0.21 | 6.0 | 0.20 | 7.5 |
| 2. | 6 | 0.48 | 2.5 | 0.36 | 5.9 | 0.32 | 7.1 |
| 3. | 9 | 0.63 | 2.0 | 0.45 | 5.5 | 0.39 | 6.5 |
| 4. | 12 | 0.91 | 1.5 | 0.58 | 6.1 | 0.41 | 6.1 |
| 5. | 15 | 1.23 | 1.0 | 0.65 | 6.2 | 0.47 | 6.2 |
| 6. | 18 | 1.49 | 1.1 | 0.74 | 6.0 | 0.53 | 6.0 |
| 7. | 21 | 1.55 | 1.5 | 0.80 | 5.8 | 0.58 | 5.9 |
| 8. | 24 | 2.06 | 2.0 | 0.86 | 5.5 | 0.63 | 5.0 |
| 9. | 27 | 2.78 | 2.5 | 0.95 | 5.5 | 0.71 | 5.1 |
| 10. | 30 | 3.11 | 3.0 | 1.01 | 5.3 | 0.76 | 5.5 |
| 11. | 33 | 3.68 | 2.8 | 1.13 | 5.0 | 0.85 | 4.8 |
| 12. | 36 | 4.83 | 2.9 | 1.24 | 5.1 | 0.94 | 4.9 |
| 13. | 39 | 5.31 | 3.1 | 1.38 | 4.9 | 1.05 | 5.0 |
| 14. | 42 | 5.79 | 3.0 | 1.45 | 4.8 | 1.10 | 5.1 |
| 15. | 45 | 6.41 | 2.8 | 1.59 | 4.5 | 1.23 | 5.2 |
| 16. | 48 | 6.89 | 2.5 | 7.71 | 4.5 | 1.34 | 5.1 |
| 17. | 51 | 7.31 | 2.1 | 1.78 | 4.0 | 1.40 | 5.0 |
| 18. | 54 | 7.94 | 2.0 | 1.85 | 3.9 | 1.46 | 5.0 |
| 19. | 57 | 8.33 | 1.9 | 1.96 | 3.9 | 1.56 | 3.1 |
| 20. | 60 | 8.91 | 1.5 | 2.01 | 3.8 | 1.61 | 3.5 |
| 21. | 63 | | | 2.42 | 2.5 | 1.74 | 3.1 |
| 22. | 66 | | | 3.01 | 2.5 | 1.91 | 3.2 |
| 23. | 69 | | | 3.57 | 2.0 | 2.00 | 2.5 |
| 24. | 72 | | | 4.12 | 2.0 | 2.19 | 2.1 |
| 25. | 75 | | | 4.62 | 1.9 | 2.28 | 2.0 |
| 26. | 78 | | | 5.43 | 1.5 | 2.34 | 1.5 |
| 27. | 81 | | | 5.97 | 1.4 | 2.38 | 1.5 |
| 28. | 84 | | | 6.71 | 1.1 | 2.47 | 1.2 |
| 29. | 87 | | | 7.68 | 0.9 | 2.56 | 1.1 |
| 30. | 90 | | | | | 2.98 | 1.1 |
| 31. | 93 | | | | | 3.34 | 0.9 |
| 32. | 96 | | | | | 3.81 | 1.0 |
| 33. | 99 | | | | | 4.58 | 0.8 |
| 34. | 102 | | | | | 5.19 | 0.7 |

APPENDIX-III (Contd.)

Advance time and depth of flow data-Surge flow (CR=2/3), Discharge - 2.1 lps, Replication-2

| Sl. No. | Distance | S-1 | | S-2 | | S-3 | |
|---|---|---|---|---|---|---|---|
| | m | Time min | Depth cm | Time min | Depth cm | Time min | Depth cm |
| 1. | 3 | 0.30 | 2.0 | 0.11 | 3.6 | 0.08 | 4.0 |
| 2. | 6 | 0.68 | 2.5 | 0.27 | 5.0 | 0.21 | 5.5 |
| 3. | 9 | 1.05 | 2.5 | 0.54 | 5.1 | 0.33 | 6.0 |
| 4. | 12 | 1.45 | 2.5 | 0.63 | 4.5 | 0.41 | 4.5 |
| 5. | 15 | 1.90 | 3.0 | 0.70 | 4.2 | 0.48 | 4.5 |
| 6. | 18 | 2.32 | 3.5 | 0.83 | 4.1 | 0.61 | 4.5 |
| 7. | 21 | 2.75 | 3.0 | 0.91 | 3.6 | 0.68 | 3.5 |
| 8. | 24 | 3.28 | 3.0 | 1.03 | 3.8 | 0.79 | 3.5 |
| 9. | 27 | 3.75 | 1.0 | 1.19 | 1.5 | 0.93 | 1.0 |
| 10. | 30 | 4.15 | 1.0 | 1.28 | 1.2 | 1.05 | 3.0 |
| 11. | 33 | 4.57 | 3.0 | 1.40 | 2.1 | 1.16 | 4.5 |
| 12. | 36 | 4.97 | 1.5 | 1.54 | 4.1 | 1.30 | 3.0 |
| 13. | 39 | 5.52 | 3.0 | 1.68 | 2.2 | 1.43 | 3.5 |
| 14. | 42 | 6.03 | 1.5 | 1.77 | 3.0 | 1.51 | 2.5 |
| 15. | 45 | 6.67 | 2.0 | 1.86 | 1.9 | 1.66 | 4.0 |
| 16. | 48 | 7.15 | 1.0 | 1.95 | 3.1 | 1.69 | 2.0 |
| 17. | 51 | 7.82 | 1.5 | 2.04 | 1.4 | 1.76 | 1.0 |
| 18. | 54 | 8.25 | 1.9 | 2.12 | 1.2 | 1.82 | 0.5 |
| 19. | 57 | 8.73 | 1.5 | 2.17 | 1.0 | 1.86 | 1.5 |
| 20. | 60 | 9.18 | 1.1 | 2.29 | 1.0 | 1.96 | 1.0 |
| 21. | 63 | | | 2.45 | 1.1 | 2.11 | 1.0 |
| 22. | 66 | | | 2.82 | 1.1 | 2.35 | 3.0 |
| 23. | 69 | | | 3.43 | 1.5 | 2.59 | 2.5 |
| 24. | 72 | | | 4.00 | 1.2 | 2.70 | 3.5 |
| 25. | 75 | | | 4.73 | 1.1 | 3.41 | 3.0 |
| 26. | 78 | | | 5.52 | 1.7 | 4.00 | 1.0 |
| 27. | 81 | | | 6.27 | 1.3 | 4.53 | 1.5 |
| 28. | 84 | | | 7.38 | 1.3 | 4.72 | 1.0 |
| 29. | 87 | | | 8.00 | 1.8 | 4.98 | 2.5 |
| 30. | 90 | | | 8.62 | 1.9 | 5.21 | 1.5 |
| 31. | 93 | | | 9.38 | 1.1 | 5.59 | 1.0 |
| 32. | 96 | | | 9.73 | 1.0 | 5.76 | 1.5 |
| 33. | 99 | | | | | 6.83 | 1.0 |
| 34. | 102 | | | | | 7.36 | 0.9 |

APPENDIX-III (Contd.)

Advance time and depth of flow data-Surge flow (CR=2/3),
Discharge - 2.1 lps, Replication-3

| Sl. No. | Distance | S-1 | | S-2 | | S-3 | |
|---|---|---|---|---|---|---|---|
| | m | Time min | Depth cm | Time min | Depth cm | Time min | Depth cm |
| 1. | 3 | 0.22 | 2.0 | 0.20 | 6.0 | 0.17 | 7.0 |
| 2. | 6 | 0.57 | 2.5 | 0.26 | 3.3 | 0.21 | 4.5 |
| 3. | 9 | 0.90 | 2.0 | 0.37 | 4.1 | 0.27 | 5.0 |
| 4. | 12 | 1.17 | 4.0 | 0.48 | 6.1 | 0.34 | 7.0 |
| 5. | 15 | 1.48 | 3.0 | 0.57 | 5.2 | 0.41 | 6.0 |
| 6. | 18 | 1.97 | 2.0 | 0.69 | 5.2 | 0.48 | 5.5 |
| 7. | 21 | 2.32 | 2.0 | 0.74 | 5.1 | 0.53 | 5.5 |
| 8. | 24 | 2.67 | 4.5 | 0.85 | 6.9 | 0.60 | 7.0 |
| 9. | 27 | 3.28 | 1.0 | 0.92 | 1.0 | 0.65 | 2.0 |
| 10. | 30 | 3.63 | 1.5 | 1.07 | 1.2 | 0.77 | 1.0 |
| 11. | 33 | 4.12 | 1.0 | 1.18 | 1.4 | 0.86 | 1.0 |
| 12. | 36 | 4.42 | 2.0 | 1.29 | 2.8 | 0.97 | 3.5 |
| 13. | 39 | 4.73 | 2.0 | 1.37 | 3.3 | 1.04 | 4.5 |
| 14. | 42 | 5.08 | 2.3 | 1.45 | 5.4 | 1.11 | 6.0 |
| 15. | 45 | 5.60 | 2.3 | 1.51 | 4.1 | 1.16 | 5.0 |
| 16. | 48 | 6.28 | 1.5 | 1.58 | 4.0 | 1.21 | 4.5 |
| 17. | 51 | 7.00 | 1.9 | 1.66 | 1.3 | 1.28 | 2.0 |
| 18. | 54 | 7.80 | 1.8 | 1.74 | 2.0 | 1.34 | 1.0 |
| 19. | 57 | 8.18 | 1.1 | 1.86 | 2.2 | 1.40 | 1.0 |
| 20. | 60 | 8.70 | 0.9 | 1.88 | 1.0 | 1.46 | 0.5 |
| 21. | 63 | | | 1.95 | 2.0 | 1.51 | 1.0 |
| 22. | 66 | | | 2.45 | 1.5 | 1.69 | 1.5 |
| 23. | 69 | | | 3.03 | 1.18 | 1.84 | 3.0 |
| 24. | 72 | | | 3.68 | 2.1 | 2.03 | 3.5 |
| 25. | 75 | | | 4.27 | 2.5 | 2.27 | 2.0 |
| 26. | 78 | | | 5.13 | 2.1 | 2.41 | 2.0 |
| 27. | 81 | | | 5.65 | 3.7 | 2.50 | 1.5 |
| 28. | 84 | | | 6.13 | 1.6 | 2.62 | 2.0 |
| 29. | 87 | | | 6.48 | 1.0 | 2.71 | 1.0 |
| 30. | 90 | | | 6.98 | 1.0 | 2.76 | 1.0 |
| 31. | 93 | | | 7.63 | 1.0 | 2.87 | 1.5 |
| 32. | 96 | | | | | 3.56 | 0.8 |
| 33. | 99 | | | | | 4.12 | 0.7 |
| 34. | 102 | | | | | 4.83 | 0.5 |

APPENDIX-III (Contd.)

Advance time and depth of flow data-Surge flow (CR=2/3), Discharge - 2.1 lps, Replication-4

| Sl. No. | Distance | S-1 | | S-2 | | S-3 | |
|---|---|---|---|---|---|---|---|
| | m | Time min | Depth cm | Time min | Depth cm | Time min | Depth cm |
| 1. | 3 | 0.20 | 2.5 | 0.19 | 5.9 | 0.16 | 7.0 |
| 2. | 6 | 0.58 | 2.1 | 0.22 | 6.0 | 0.19 | 6.9 |
| 3. | 9 | 0.93 | 2.0 | 0.35 | 4.5 | 0.29 | 6.0 |
| 4. | 12 | 1.27 | 2.0 | 0.48 | 4.0 | 0.40 | 5.5 |
| 5. | 15 | 1.48 | 1.9 | 0.56 | 5.1 | 0.45 | 5.9 |
| 6. | 18 | 1.61 | 1.5 | 0.69 | 5.1 | 0.56 | 6.1 |
| 7. | 21 | 1.97 | 2.0 | 0.77 | 4.5 | 0.61 | 5.5 |
| 8. | 24 | 2.31 | 2.1 | 0.86 | 4.0 | 0.68 | 5.0 |
| 9. | 27 | 2.75 | 2.6 | 0.97 | 3.9 | 0.73 | 5.0 |
| 10. | 30 | 3.36 | 1.9 | 1.07 | 3.5 | 0.81 | 3.5 |
| 11. | 33 | 3.75 | 2.0 | 1.17 | 3.5 | 0.90 | 4.0 |
| 12. | 36 | 3.98 | 2.1 | 1.29 | 3.0 | 1.00 | 4.2 |
| 13. | 39 | 4.32 | 2.3 | 1.36 | 4.1 | 1.05 | 4.9 |
| 14. | 42 | 4.71 | 2.2 | 1.49 | 4.0 | 1.14 | 3.5 |
| 15. | 45 | 5.48 | 2.0 | 1.56 | 4.0 | 1.19 | 3.0 |
| 16. | 48 | 5.93 | 2.5 | 1.68 | 3.9 | 1.30 | 2.9 |
| 17. | 51 | 6.41 | 2.5 | 1.73 | 3.5 | 1.35 | 2.6 |
| 18. | 54 | 7.03 | 2.1 | 1.77 | 3.5 | 1.38 | 2.5 |
| 19. | 57 | 7.81 | 1.9 | 1.84 | 1.1 | 1.43 | 2.7 |
| 20. | 60 | 8.34 | 1.5 | 1.89 | 3.9 | 1.47 | 2.5 |
| 21. | 63 | 8.85 | 1.0 | 1.99 | 2.0 | 1.55 | 2.0 |
| 22. | 66 | | | 2.41 | 1.9 | 1.95 | 2.1 |
| 23. | 69 | | | 3.34 | 1.9 | 2.06 | 1.9 |
| 24. | 72 | | | 3.72 | 1.5 | 2.19 | 1.5 |
| 25. | 75 | | | 4.32 | 1.5 | 2.31 | 1.5 |
| 26. | 78 | | | 4.73 | 1.1 | 2.48 | 1.3 |
| 27. | 81 | | | 5.51 | 0.9 | 2.59 | 1.1 |
| 28. | 84 | | | 6.82 | 0.9 | 2.70 | 1.0 |
| 29. | 87 | | | 7.51 | 0.8 | 2.81 | 1.0 |
| 30. | 90 | | | | | 2.91 | 0.9 |
| 31. | 93 | | | | | 3.37 | 0.8 |
| 32. | 96 | | | | | 3.93 | 0.7 |
| 33. | 99 | | | | | 4.81 | 0.7 |
| 34. | 102 | | | | | 5.48 | 0.5 |

## APPENDIX-IV

### Orifice plate data for infiltration rate calculations
Surge flow (CR=1/2), Discharge - 1.3 lps

| Replication | Surge | Section of furrow length | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | | 0-25 (m) | | 25-50 (m) | | 50-75 (m) | | 75-102 (m) | |
| | | Head cm | Discharge lps | Head cm | Discharge lps | Head cm | Discharge lps | Head cm | Discharge lps |
| | S-1 | -- | -- | | | | | | |
| | S-2 | 1.5 | 0.650 | | | | | | |
| $R_1$ | S-3 | 1.9 | 0.731 | 0.1 | 0.168 | | | | |
| | S-4 | 2.2 | 0.79 | 1.0 | 0.531 | | | | |
| | S-5 | 2.5 | 0.84 | 1.5 | 0.65 | 1.1 | 0.56 | | |
| | S-6 | 3.0 | 0.92 | 2.0 | 0.750 | 1.3 | 0.61 | 0.5 | 0.38 |
| | S-1 | 0.1 | 0.168 | | | | | | |
| | S-2 | 2.5 | 0.84 | 0.6 | 0.411 | | | | |
| $R_2$ | S-3 | 2.7 | 0.87 | 1.5 | 0.650 | | | | |
| | S-4 | 3.3 | 0.96 | 2.0 | 0.750 | 1.3 | 0.61 | | |
| | S-5 | 3.4 | 0.98 | 2.5 | 0.84 | 2.0 | 0.75 | | |
| | S-6 | 3.6 | 1.01 | 3.0 | 0.919 | 2.1 | 0.77 | 0.5 | 0.38 |
| | S-1 | -- | -- | | | | | | |
| | S-2 | 2.0 | 0.75 | | | | | | |
| $R_3$ | S-3 | 2.2 | 0.79 | 0.2 | 0.24 | | | | |
| | S-4 | 2.9 | 0.903 | 1.4 | 0.63 | | | | |
| | S-5 | 3.0 | 0.92 | 1.5 | 0.65 | 0.5 | 0.375 | | |
| | S-6 | 3.2 | 0.95 | 1.5 | 0.65 | 1.0 | 0.531 | | |
| | S-7 | 3.4 | 0.98 | 1.6 | 0.671 | 1.1 | 0.56 | 0.3 | 0.291 |
| | S-1 | -- | -- | | | | | | |
| | S-2 | 0.9 | 0.503 | | | | | | |
| | S-3 | 1.9 | 0.731 | | | | | | |
| | S-4 | 2.2 | 0.78 | 1.2 | 0.581 | | | | |
| | S-5 | 2.6 | 0.86 | 2.0 | 0.75 | | | | |
| | S-6 | 2.9 | 0.903 | 2.2 | 0.79 | 1.1 | 0.56 | | |
| | S-7 | 3.2 | 0.95 | 2.3 | 0.81 | 1.3 | 0.61 | 0.5 | 0.38 |

## APPENDIX-IV (Contd.)

### Orifice plate data for infiltration rate calculations
### Surge flow (CR=1/2), Inflow Discharge - 1.7 lps

| Replication | Surge | Section of furrow length | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | | 0-25 (m) | | 25-50 (m) | | 50-75 (m) | | 75-102 (m) | |
| | | Head cm | Discharge lps | Head cm | Discharge lps | Head cm | Discharge lps | Head cm | Discharge lps |
| $R_1$ | S-1 | 0.5 | 0.375 | | | | | | |
| | S-2 | 2.4 | 0.822 | 0.5 | 0.094 | | | | |
| | S-3 | 2.5 | 0.84 | 1.5 | 0.162 | | | | |
| | S-4 | 2.6 | 0.86 | 1.5 | 0.162 | 0.5 | 0.094 | | |
| | S-5 | 2.7 | 0.872 | 2.3 | 0.20 | 1.5 | 0.162 | 0.3 | 0.073 |
| $R_2$ | S-1 | 1.8 | 0.712 | | | | | | |
| | S-2 | 3.0 | 0.919 | 0.8 | 0.475 | | | | |
| | S-3 | 3.1 | 0.934 | 1.5 | 0.650 | | | | |
| | S-4 | 3.2 | 0.949 | 1.7 | 0.692 | 0.8 | 0.475 | | |
| | S-5 | 3.5 | 0.993 | 2.0 | 0.750 | 2.0 | 0.750 | 0.2 | 0.24 |
| $R_3$ | S-1 | 0.5 | 0.375 | | | | | | |
| | S-2 | 2.1 | 0.769 | | | | | | |
| | S-3 | 2.8 | 0.89 | 0.5 | 0.094 | | | | |
| | S-4 | 2.9 | 0.903 | 2.5 | 0.21 | | | | |
| | S-5 | 3.5 | 0.99 | 2.9 | 0.23 | 2.8 | 0.222 | | |
| | S-6 | 3.7 | 1.02 | 3.0 | 0.23 | 2.84 | 0.224 | 0.4 | 0.084 |
| $R_4$ | S-1 | 1.3 | 0.61 | | | | | | |
| | S-2 | 2.5 | 0.84 | | | | | | |
| | S-3 | 2.8 | 0.89 | 0.8 | 0.475 | | | | |
| | S-4 | 2.9 | 0.903 | 2.1 | 0.75 | 0.5 | 0.375 | | |
| | S-5 | 4.0 | 1.06 | 2.5 | 0.84 | 0.8 | 0.475 | | |
| | S-6 | 4.2 | 1.09 | 2.9 | 0.903 | 1.0 | 0.531 | 0.5 | 0.094 |

APPENDIX-IV (Contd.)

## Orifice plate data for infiltration rate calculations
Surge flow (CR=1/2), Discharge - 2.1 lps

| Replication | Surge | Section of furrow length | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | | 0-25 (m) | | 25-50 (m) | | 50-75 (m) | | 75-102 (m) | |
| | | Head cm | Discharge lps | Head cm | Discharge lps | Head cm | Discharge lps | Head cm | Discharge lps |
| $R_1$ | S-1 | 2.0 | 0.750 | | | | | | |
| | S-2 | 4.0 | 1.061 | 0.5 | 0.38 | | | | |
| | S-3 | 4.7 | 1.15 | 2.2 | 0.79 | | | | |
| | S-4 | 4.9 | 1.17 | 2.7 | 0.87 | 1.0 | 0.53 | | |
| | S-5 | 4.9 | 1.17 | 3.0 | 0.92 | 1.9 | 0.73 | 1.0 | 0.531 |
| $R_2$ | S-1 | 0.9 | 0.503 | | | | | | |
| | S-2 | 3.0 | 0.92 | | | | | | |
| | S-3 | 3.5 | 0.99 | 0.5 | 0.38 | | | | |
| | S-4 | 4.0 | 1.06 | 1.4 | 0.63 | 0.5 | 0.38 | | |
| | S-5 | 4.1 | 1.07 | 2.0 | 0.75 | 1.3 | 0.61 | | |
| | S-6 | 4.2 | 1.09 | 2.1 | 0.78 | 2.0 | 0.75 | 0.3 | 0.291 |
| $R_3$ | S-1 | 1.5 | 0.65 | | | | | | |
| | S-2 | 3.6 | 1.00 | 0.6 | 0.411 | | | | |
| | S-3 | 4.0 | 1.06 | 1.5 | 0.65 | 0.9 | 0.503 | | |
| | S-4 | 4.5 | 1.13 | 1.9 | 0.731 | 1.5 | 0.65 | | |
| | S-5 | 4.8 | 1.16 | 2.0 | 0.75 | 1.6 | 0.67 | 0.3 | 0.291 |
| $R_4$ | S-1 | 0.5 | 0.375 | | | | | | |
| | S-2 | 2.5 | 0.84 | | | | | | |
| | S-3 | 3.0 | 0.92 | 0.5 | 0.38 | | | | |
| | S-4 | 3.5 | 0.99 | 1.8 | 0.71 | 0.5 | 0.38 | | |
| | S-5 | 3.8 | 0.04 | 2.0 | 0.750 | 1.0 | 0.53 | | |
| | S-6 | 4.0 | 1.06 | 2.5 | 0.84 | 2.0 | 0.75 | 0.6 | 0.42 |

APPENDIX-IV (Contd.)

Orifice plate data for infiltration rate calculations
Surge flow (CR=1/3), Discharge ~ 1.3 lps

| Replication | Surge | Section of furrow length | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | | 0-25 (m) | | 25-50 (m) | | 50-75 (m) | | 75-102 (m) | |
| | | Head cm | Discharge lps | Head cm | Discharge lps | Head cm | Discharge lps | Head cm | Discharge lps |
| $R_1$ | S-1 | 0.8 | 0.475 | | | | | | |
| | S-2 | 1.8 | 0.712 | 1.0 | 0.531 | | | | |
| | S-3 | 2.3 | 0.81 | 1.5 | 0.650 | 1.1 | 0.56 | | |
| | S-4 | 2.5 | 0.84 | 1.8 | 0.712 | 1.5 | 0.650 | | |
| | S-5 | 2.7 | 0.872 | 2.0 | 0.750 | 1.6 | 0.671 | 2.4 | 0.21 |
| $R_2$ | S-1 | 1.0 | 0.531 | | | | | | |
| | S-2 | 1.9 | 0.731 | | | | | | |
| | S-3 | 2.3 | 0.81 | 0.5 | 0.38 | | | | |
| | S-4 | 2.4 | 0.822 | 0.6 | 0.411 | 0.4 | 0.34 | | |
| | S-5 | 2.5 | 0.84 | 0.8 | 0.48 | 0.5 | 0.38 | 0.5 | 0.094 |
| $R_3$ | S-1 | 0.5 | 0.38 | | | | | | |
| | S-2 | 1.9 | 0.731 | 0.9 | 0.503 | | | | |
| | S-3 | 2.2 | 0.79 | 1.2 | 0.581 | 1.0 | 0.531 | | |
| | S-4 | 2.4 | 0.82 | 1.3 | 0.61 | 1.2 | 0.581 | 2.3 | 0.201 |
| $R_4$ | S-1 | 0.7 | 0.444 | | | | | | |
| | S-2 | 1.5 | 0.650 | 0.8 | 0.475 | | | | |
| | S-3 | 2.0 | 0.75 | 1.0 | 0.531 | 0.8 | 0.475 | | |
| | S-4 | 2.2 | 0.79 | 1.1 | 0.56 | 1.0 | 0.53 | | |
| | S-5 | 2.4 | 0.82 | 1.2 | 0.58 | 1.1 | 0.56 | 2.5 | 0.210 |

APPENDIX-IV (Contd.)

Orifice plate data for infiltration rate calculations
Surge flow (CR=1/3), Discharge - 1.7 lps

| Repli-cation | Surge | Section of furrow length | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | | 0-25 (m) | | 25-50 (m) | | 50-75 (m) | | 75-102 (m) | |
| | | Head cm | Discharge lps | Head cm | Discharge lps | Head cm | Discharge lps | Head cm | Discharge lps |
| $R_1$ | S-1 | 2.3 | 0.81 | | | | | | |
| | S-2 | 3.2 | 0.95 | 0.9 | 0.503 | 0.2 | 0.24 | | |
| | S-3 | 3.3 | 0.96 | 1.3 | 0.61 | 0.3 | 0.29 | | |
| | S-4 | 3.5 | 0.99 | 1.5 | 0.65 | 0.6 | 0.411 | 0.1 | 0.17 |
| $R_2$ | S-1 | 2.5 | 0.84 | | | | | | |
| | S-2 | 3.3 | 0.96 | 1.3 | 0.61 | | | | |
| | S-3 | 3.5 | 0.99 | 1.6 | 0.671 | 0.1 | 0.17 | | |
| | S-4 | 4.0 | 1.06 | 2.2 | 0.79 | 0.8 | 0.48 | 1.5 | 0.16 |
| $R_3$ | S-1 | 1.6 | 0.671 | | | | | | |
| | S-2 | 2.5 | 0.84 | 1.0 | 0.531 | | | | |
| | S-3 | 2.8 | 0.89 | 1.1 | 0.56 | 0.4 | 0.34 | | |
| | S-4 | 3.0 | 0.92 | 1.6 | 0.671 | 0.8 | 0.48 | 2.7 | 0.22 |
| $R_4$ | S-1 | 1.3 | 0.61 | | | | | | |
| | S-2 | 1.5 | 0.65 | 0.5 | 0.38 | | | | |
| | S-3 | 2.0 | 0.75 | 0.9 | 0.503 | 0.3 | 0.073 | | |
| | S-4 | 2.3 | 0.81 | 1.4 | 0.63 | 106 | 0.17 | | |
| | S-5 | 2.7 | 0.872 | 2.0 | 0.75 | 2.0 | 0.19 | 1.0 | 0.13 |

APPENDIX-IV (Contd.)

Orifice plate data for infiltration rate calculations
Surge flow (CR=1/3), Discharge - 2.1 lps

| Replication | Surge | Section of furrow length | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | | 0-25 (m) | | 25-50 (m) | | 50-75 (m) | | 75-102 (m) | |
| | | Head cm | Discharge lps | Head cm | Discharge lps | Head cm | Discharge lps | Head cm | Discharge lps |
| $R_1$ | S-1 | 1.5 | 0.65 | | | | | | |
| | S-2 | 2.7 | 0.87 | 0.5 | 0.38 | | | | |
| | S-3 | 3.0 | 0.92 | 1.0 | 0.531 | 0.8 | 0.48 | | |
| | S-4 | 3.2 | 0.95 | 1.4 | 0.63 | 1.0 | 0.53 | 2.4 | 0.21 |
| $R_2$ | S-1 | 1.6 | 0.67 | | | | | | |
| | S-2 | 3.0 | 0.92 | 0.7 | 0.44 | 0.5 | 0.38 | | |
| | S-3 | 3.1 | 0.93 | 1.3 | 0.61 | 1.0 | 0.53 | | |
| | S-4 | 3.4 | 0.98 | 1.5 | 0.65 | 1.0 | 0.53 | 2.5 | 0.21 |
| $R_3$ | S-1 | 1.8 | 0.71 | | | | | | |
| | S-2 | 3.2 | 0.95 | 0.8 | 0.48 | | | | |
| | S-3 | 3.5 | 0.99 | 1.2 | 0.58 | 1.0 | 0.53 | | |
| | S-4 | 3.7 | 1.02 | 1.5 | 0.65 | 1.2 | 0.58 | 2.3 | 0.20 |
| $R_4$ | S-1 | 1.7 | 0.69 | | | | | | |
| | S-2 | 2.8 | 0.89 | 0.6 | 0.41 | | | | |
| | S-3 | 3.0 | 0.92 | 1.1 | 0.56 | 0.9 | 0.503 | | |
| | S-4 | 3.3 | 0.96 | 1.4 | 0.63 | 1.1 | 0.56 | 2.4 | 0.21 |

APPENDIX-IV (Contd.)

Orifice plate data for infiltration rate calculations
Surge flow (CR=2/3), Discharge - 1.3 lps

| Replication | Surge | Section of furrow length | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | | 0-25 (m) | | 25-50 (m) | | 50-75 (m) | | 75-102 (m) | |
| | | Head cm | Discharge lps | Head cm | Discharge lps | Head cm | Discharge lps | Head cm | Discharge lps |
| $R_1$ | S-1 | 2.2 | 0.79 | | | | | | |
| | S-2 | 3.8 | 1.03 | 1.9 | 0.73 | 0.4 | 0.34 | | |
| | S-3 | 4.0 | 1.06 | 2.1 | 0.77 | 1.5 | 0.65 | 2.4 | 0.21 |
| $R_2$ | S-1 | 2.7 | 0.87 | 0.5 | 0.38 | | | | |
| | S-2 | 3.8 | 1.03 | 2.0 | 0.75 | 0.6 | 0.41 | | |
| | S-3 | 4.0 | 1.06 | 2.3 | 0.81 | 1.2 | 0.58 | 2.5 | 0.210 |
| $R_3$ | S-1 | 2.5 | 0.84 | 0.4 | 0.34 | | | | |
| | S-2 | 4.0 | 1.06 | 1.6 | 0.67 | 0.9 | 0.50 | | |
| | S-3 | 4.2 | 1.09 | 2.0 | 0.75 | 1.2 | 0.58 | 2.2 | 0.20 |
| $R_4$ | S-1 | 2.4 | 0.82 | | | | | | |
| | S-2 | 2.6 | 0.86 | 1.0 | 0.53 | 0.5 | 0.38 | | |
| | S-3 | 3.9 | 1.05 | 2.0 | 0.75 | 1.1 | 0.56 | 2.4 | 0.210 |

APPENDIX-IV (Contd.)

Orifice plate data for infiltration rate calculations
Surge flow (CR=2/3), Discharge - 1.7 lps

| Replication | Surge | Section of furrow length | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | | 0-25 (m) | | 25-50 (m) | | 50-75 (m) | | 75-102 (m) | |
| | | Head cm | Discharge lps | Head cm | Discharge lps | Head cm | Discharge lps | Head cm | Discharge lps |
| $R_1$ | S-1 | 2.2 | 0.79 | 1.1 | 0.56 | | | | |
| | S-2 | 3.8 | 1.03 | 1.5 | 0.65 | 0.7 | 0.44 | | |
| | S-3 | 4.0 | 1.06 | 2.5 | 0.84 | 2.1 | 0.77 | 3.3 | 0.24 |
| $R_2$ | S-1 | 2.0 | 0.75 | 1.5 | 0.65 | | | | |
| | S-2 | 3.2 | 0.95 | 2.2 | 0.79 | 1.0 | 0.531 | | |
| | S-3 | 3.9 | 1.05 | 2.5 | 0.84 | 1.5 | 0.650 | 3.0 | 0.230 |
| $R_3$ | S-1 | 3.0 | 0.92 | 1.2 | 0.58 | | | | |
| | S-2 | 4.5 | 1.13 | 1.5 | 0.65 | 0.9 | 0.503 | | |
| | S-3 | 4.8 | 1.16 | 2.0 | 0.75 | 1.9 | 0.73 | 4.0 | 0.27 |
| $R_4$ | S-1 | 2.6 | 0.86 | 1.0 | 0.53 | | | | |
| | S-2 | 3.4 | 0.98 | 1.3 | 0.61 | 0.5 | 0.38 | | |
| | S-3 | 3.9 | 1.05 | 2.4 | 0.82 | 2.0 | 0.75 | 3.5 | 0.25 |

## APPENDIX-IV (Contd.)

Orifice plate data for infiltration rate calculations
Surge flow (CR=2/3), Discharge - 2.1 lps

| Replication | Surge | Section of furrow length | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | | 0-25 (m) | | 25-50 (m) | | 50-75 (m) | | 75-102 (m) | |
| | | Head cm | Discharge lps | Head cm | Discharge lps | Head cm | Discharge lps | Head cm | Discharge lps |
| $R_1$ | S-1 | 2.6 | 0.86 | 0.9 | 0.503 | | | | |
| | S-2 | 4.5 | 1.13 | 3.2 | 0.95 | 2.2 | 0.79 | | |
| | S-3 | 5.2 | 1.21 | 3.5 | 0.99 | 2.7 | 0.87 | 3.5 | 0.25 |
| $R_2$ | S-1 | 2.4 | 0.82 | 1.3 | 0.61 | | | | |
| | S-2 | 4.8 | 1.16 | 3.0 | 0.92 | 1.8 | 0.71 | | |
| | S-3 | 5.5 | 1.24 | 3.5 | 0.99 | 2.0 | 0.75 | 3.3 | 0.24 |
| $R_3$ | S-1 | 3.0 | 0.92 | 0.8 | 0.48 | | | | |
| | S-2 | 4.8 | 1.16 | 3.0 | 0.92 | 2.0 | 0.75 | | |
| | S-3 | 5.0 | 1.19 | 3.5 | 0.99 | 2.5 | 0.86 | 3.6 | 0.25 |
| $R_4$ | S-1 | 2.5 | 0.84 | 1.0 | 0.53 | | | | |
| | S-2 | 4.1 | 1.07 | 3.5 | 0.99 | 2.0 | 0.75 | | |
| | S-3 | 5.3 | 1.22 | 3.7 | 1.02 | 2.5 | 0.84 | 3.2 | 0.24 |

APPENDIX-IV (Contd.)

## Orifice plate data for infiltration rate calculations
## Continuous flow

| Sl. No. | Discharge (lps) | Outflow discharge data | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | | $R_1$ | | $R_2$ | | $R_3$ | | $R_4$ | |
| | | Head cm | Discharge lps | Head cm | Discharge lps | Head cm | Discharge lps | Head cm | Discharge lps |
| 1. | 1.3 | 0.4* | 0.335 | 6.3** | 0.335 | 6.5** | 0.338 | 0.5** | 0.375 |
| 2. | 1.7 | 2.0* | 0.75 | 1.9* | 0.731 | 1.9* | 0.731 | 2.1* | 0.77 |
| 3. | 2.1 | 3.2* | 0.95 | 3.2* | 0.95 | 3.0* | 0.92 | 3.0* | 0.92 |

* Orifice diameter - 5 cm

** Orifice diameter - 2.5 cm

## APPENDIX-V

### Mean depth of infiltration at various sections

| Discharge lps | Distance (m) | Type of flow | | | |
|---|---|---|---|---|---|
| | | $F_1$ | $F_2$ | $F_3$ | $F_4$ |
| 1.3 | 15 | 2.59 | 0.57 | 0.52 | 0.27 |
| | 30 | 3.34 | 2.30 | 0.81 | 0.23 |
| | 45 | 2.22 | 0.48 | 1.59 | 1.99 |
| | 60 | 4.03 | 1.45 | 1.13 | 0.58 |
| | 75 | 3.69 | 1.09 | 1.25 | 1.02 |
| | 90 | 3.59 | 0.43 | 1.03 | 0.26 |
| | 102 | 3.66 | 0.76 | 0.85 | 0.72 |
| 1.7 | 15 | 1.43 | 0.67 | 0.82 | 0.31 |
| | 30 | 1.90 | 1.71 | 1.36 | 0.55 |
| | 45 | 3.21 | 1.10 | 3.10 | 1.70 |
| | 60 | 3.47 | 0.97 | 3.06 | 0.77 |
| | 75 | 3.38 | 0.46 | 1.80 | 1.05 |
| | 90 | 4.03 | 0.51 | 1.73 | 0.62 |
| | 102 | 3.99 | 0.24 | 1.54 | 0.26 |
| 2.1 | 15 | 2.51 | 1.49 | 1.46 | 0.96 |
| | 30 | 3.34 | 2.87 | 2.36 | 2.23 |
| | 45 | 4.54 | 2.77 | 4.70 | 2.00 |
| | 60 | 3.98 | 1.79 | 2.27 | 2.78 |
| | 75 | 4.36 | 1.17 | 1.21 | 0.25 |
| | 90 | 4.31 | 0.21 | 0.56 | 1.48 |
| | 102 | 4.75 | 1.02 | 1.14 | 1.22 |

## APPENDIX-VI

Volume of water to complete the advance

| Replication | Volume ($m^3$) | | | | | | | | | | | | Total |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | $F_1T_1$ | $F_1T_2$ | $F_1T_3$ | $F_2T_1$ | $F_2T_2$ | $F_2T_3$ | $F_3T_1$ | $F_3T_2$ | $F_3T_3$ | $F_4T_1$ | $F_4T_2$ | $F_4T_3$ | |
| 1. | 1.81 | 2.22 | 2.47 | 1.40 | 1.58 | 1.89 | 1.17 | 1.22 | 1.51 | 1.17 | 1.53 | 1.89 | 19.86 |
| 2. | 1.73 | 2.25 | 2.46 | 1.40 | 1.66 | 2.27 | 1.17 | 1.22 | 1.51 | 1.17 | 1.53 | 1.89 | 20.26 |
| 3. | 1.76 | 2.24 | 2.39 | 1.64 | 1.84 | 1.89 | 0.94 | 1.22 | 1.51 | 1.17 | 1.43 | 1.87 | 19.90 |
| 4. | 1.82 | 2.26 | 2.44 | 1.64 | 1.84 | 2.27 | 1.17 | 1.53 | 1.51 | 1.17 | 1.53 | 1.89 | 21.07 |
| Total | 7.12 | 8.97 | 9.76 | 6.08 | 6.92 | 8.32 | 4.45 | 5.19 | 6.04 | 4.68 | 6.02 | 7.54 | 81.09 |

APPENDIX-VI (Contd.)

Two-way table for finding the main effects and interaction' sum of squares

| | $T_1$ | $T_2$ | $T_3$ | Total |
|---|---|---|---|---|
| $F_1$ | 7.12 | 8.97 | 9.76 | 25.85 |
| $F_2$ | 6.08 | 6.92 | 8.32 | 21.32 |
| $F_3$ | 4.45 | 5.19 | 6.04 | 15.68 |
| $F_4$ | 4.68 | 6.02 | 7.54 | 18.24 |
| Total | 22.33 | 27.10 | 31.66 | 81.09 |

Correction factor = $(81.09)^2/48 = 136.99$

Total sum of squares = $[(1.81)^2 + (2.22)^2 + ---- + (1.89)^2] - 136.99$
= $\underline{\underline{8.07}}$

Replication sum of squares (RSSO) = $\frac{1}{12}[(19.86)^2 + (20.26)^2 + (21.07)^2] - 136.99$
= $\underline{\underline{0.08}}$

F sum of squares (FSS) = $\frac{1}{12}[(25.85)^2 + ----- ] - 136.99 = \underline{\underline{4.79}}$

T sum of squares (TSS) = $\frac{1}{16}[(22.33)^2 + ----- ] - 136.99 = \underline{\underline{2.72}}$

Two-way table sum of squares = $\frac{1}{4}[(7.12)^2 + ------ + (7.54)^2] - 136.99 = \underline{\underline{7.69}}$

FxT sum of squares = $7.69 - (4.79 + 2.72) = \underline{\underline{0.18}}$

Error sum of squares = Total sum of squares - (R.S.S. + 7.69)
= $8.07 - (0.08 + 7.69) = \underline{\underline{0.3}}$

# APPENDIX-VII

## Sample calculation of infiltration parameters

Flow type - continuous flow Discharge - 1.3 lps

| Distance (m) | Advance time (min) | Mean depth of flow (cm) | Wetted perimeter (cm) | Furrow cross-sectional area ($cm^2$) | Inflow to the section lts | Storage in the section lts | Wetted area of section $cm^2$ | Infiltrated volume lts | Infiltrated depth cm |
|---|---|---|---|---|---|---|---|---|---|
| 15 | 1.93 | 1.84 | 37.26 | 60.96 | 150.54 | 91.44 | 55890 | 59.10 | 1.05 |
| 30 | 4.00 | 1.24 | 34.89 | 39.81 | 312.00 | 119.43 | 104670 | 192.57 | 1.84 |
| 45 | 6.63 | 0.18 | 34.26 | 34.38 | 517.14 | 154.71 | 154170 | 362.43 | 2.35 |
| 60 | 10.87 | 1.36 | 35.36 | 43.94 | 847.86 | 263.64 | 212160 | 584.22 | 2.75 |
| 75 | 13.85 | 1.22 | 34.81 | 39.13 | 1080.30 | 293.48 | 261075 | 786.82 | 3.01 |
| 90 | 16.89 | 0.90 | 33.55 | 28.38 | 1317.42 | 255.42 | 301950 | 1062.00 | 3.52 |
| 102 | 22.20 | 0.98 | 33.87 | 31.03 | 1731.60 | 316.51 | 345474 | 1415.09 | 4.10 |

# INFILTRATION AND WATER ADVANCE STUDIES UNDER SURGE FLOW FURROW IRRIGATION

By

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## ABSTRACT OF A THESIS

Submitted in partial fulfilment of the
requirement for the degree

**Master of Technology in Agricultural Engineering**

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## APPENDIX-VII

Sample calculation of infiltration parameters

Flow type - continuous flow  Discharge - 1.3 lps

| Distance (m) | Advance time (min) | Mean depth of flow (cm) | Wetted perimeter (cm) | Furrow cross-sectional area $(cm^2)$ | Inflow to the section lts | Storage in the section lts | Wetted area of section $cm^2$ | Infiltrated volume lts | Infiltrated depth cm |
|---|---|---|---|---|---|---|---|---|---|
| 15 | 1.93 | 1.84 | 37.26 | 60.96 | 150.54 | 91.44 | 55890 | 59.10 | 1.05 |
| 30 | 4.00 | 1.24 | 34.89 | 39.81 | 312.00 | 119.43 | 104670 | 192.57 | 1.84 |
| 45 | 6.63 | 0.18 | 34.26 | 34.38 | 517.14 | 154.71 | 154170 | 362.43 | 2.35 |
| 60 | 10.87 | 1.36 | 35.36 | 43.94 | 847.86 | 263.64 | 212160 | 584.22 | 2.75 |
| 75 | 13.85 | 1.22 | 34.81 | 39.13 | 1080.30 | 293.48 | 261075 | 786.82 | 3.01 |
| 90 | 16.89 | 0.90 | 33.55 | 28.38 | 1317.42 | 255.42 | 301950 | 1062.00 | 3.52 |
| 102 | 22.20 | 0.98 | 33.87 | 31.03 | 1731.60 | 316.51 | 345474 | 1415.09 | 4.10 |

# ABSTRACT

Furrow irrigation necessitates the wetting of only a part of the surface of land, thus reducing evaporation losses, lessening the puddling of heavy soils and making it possible to cultivate the soil sooner after irrigation. Surge irrigation in furrows possesses the capability to increase irrigation efficiency, by ensuring water saving, better uniformity and reduced tail water losses in different soil and site conditions. To assess the suitability of the system for use in the sandy loam soils of Tavanur region, and to obtain suitable management parameters for surging in the area, a study was conducted at the Instructional Farm of KCAET, Tavanur. Continuous flow was compared with surge flow of cycle ratios 1/2, 1/3 and 2/3 with cycle times 6, 9 and 7.5 minutes for discharges of 1.3, 1.7 and 2.1 lps. Data of advance time, depth of flow and inflow-outflow measurements were collected during field irrigation runs.

Surge flow in all cases advanced faster compared to continuous flow. For cycle ratio 1/2, the reduction in advance time ranged as 14.59, 22.8 and 14.77 per cent for the three discharge rates. In the case of cycle ratio 1/3, the reduction was 37.6, 41.94 and 38.01 per cent respectively,

whereas for cycle ratio 2/3, the reduction was 34.29, 32.83 and 22.73 per cent respectively. Infiltration variability was lesser under surge flow and the values of infiltrated volume and infiltrated depth at various sections along the furrow length was lesser. Surging with cycle ratio 1/3 and a discharge of 1.3 lps showed the least variability in infiltrated depth and the greatest uniformity of application. Infiltration rate was found to decrease significantly along the length of the furrow and between consecutive surges. The lowest intake rate was obtained for surge flow of cycle ratio 1/3. Surging with cycle ratio 1/3, and a discharge of 1.3 lps required only 1.11 $m^3$ of water to complete the advance. This was the least value compared to continuous flow and other surge flow cases. Analysis of variance of the volume required to complete the advance indicated significant difference between flow types at 5 per cent and 1 per cent levels. The variation between discharges was also significant at 5 per cent and 1 per cent levels. Thus surge flow proved advantageous compared to continuous flow in the sandy loam soils of Tavanur region and surging with cycle ratio 1/3 and a discharge of 1.3 lps was chosen as the best out of the selected treatments for the study.