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The Effect of Raindrop Impact and Surface Roughness on Sheet Flow

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ABSTRACT

THE EFFECT OF RAINDROP IMPACT AND SURFACE ROUGHNESS ON SHEET FLOW

An experimental and analytical study was conducted to investigate the mechanics of sheet flow as it is affected by rainfall. Water surface profile data were taken in a laboratory flume using artificially generated rainfall and a hydraulically smooth surface. The one-dimensional spatially varied flow equation as developed from the momentum approach was then used to compute the boundary shear stress and subsequently a Weisbach type friction factor. It was found that the results below a Reynolds number of approximately 1000 could be expressed as $f = C/N_R$ where C increases with increasing rainfall intensity and surface slope. Velocity profile studies show that velocity in the surface region is retarded by the rainfall. Turbulence intensity measurements indicate that turbulence is generated at the surface due to the rainfall and also at the boundary for flow which would normally be laminar without rainfall. Spectral analysis of the turbulent measurements indicates that the rainfall shifts the turbulent energy to higher frequencies than would be the case without rainfall. Analysis of flow over rough surfaces taken by the Corps of Engineers shows that rainfall has little effect on resistance beyond the transition region and the transition point may be lowered by the presence of rainfall.

A separate study of a single drop striking a stagnant water layer shows that the velocity and pressure field can be computed using a Synthetic-Cell-Fluid scheme to solve the Navier-Stokes equations for this case. A dimensionless maximum impact pressure model was developed and the velocity field and free surface configuration were studied. It was found that surface tension is significant, the diameter of the region of disturbance was approximately one inch, and that locally high shear stress are generated. These stresses could easily cause soil erosion.

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This study has supported two research assistants, Dr. Raymond C. T. Wang and Dr. Yong Nam Yoon, whose doctoral theses represent a significant portion of the work. In addition the apparatus was used by another graduate student, Mr. Terry Sturm, as part of a special problem on turbulence. Furthermore, four undergraduates were supported by the project during its three year duration.

The author sincerely appreciates the significant work done by Drs. Wang and Yoon. Appreciation is also extended to Professor V. J. McDonald for his assistance on the electronic aspects of the turbulence measurements and to Mr. Jay W. Miller for his help in the design and construction of the apparatus. The author also wishes to thank Mrs. Dorothy Dilley and Mrs. Joanne Garth for typing the manuscript.

Fig. 1 RAINFALL IMPACT

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NOTATION

C = constant depending on the channel slope and rainfall intensity

d = raindrop size

$E(n)$ = one-dimensional energy function

$F(n)$ = normalized energy function, $E(n)/u'^2$

f = Darcy-Weisbach friction factor

g = acceleration due to gravity

i = lateral inflow per unit length in the x direction or rainfall intensity

k_s = equivalent sand grain roughness

L_x = macroscale of turbulence

ℓ = Prandtl's mixing length

N_R = Reynolds number, VY_o/ν

n = frequency

n_g = unit outward normal

n_{50} = frequency which corresponds to the value where the 50% of the turbulence energy lies at frequencies less than this under the spectral curve

P = gage pressure

q = local flow rate per unit width of channel

q_o = base flow rate per unit width of channel

R_1, R_2 = principle radii of curvature of the free surface

r = radial direction

S_f = friction slope

S_o = channel slope

T = temperature

t = time

U = velocity of the raindrops as they enter the main flow

u = local point mean velocity in the x direction

$\underline{u}$ = instantaneous total velocity in x direction

u' = RMS velocity fluctuation

u'' = fluctuating component of $\overline{u}$

V = local mean velocity

V_r = radial (r) velocity component at any time t

V_z = axial (z) velocity component at any time t

x = direction of mean flow

y = direction normal to x in a vertical plane

y_o = local depth measured normal to the channel bottom

y_{max} = position of maximum point mean velocity u_{max}

z = vertical direction

β = momentum correction factor

Γ = survace tension force per unit length

γ = specific weight of water

ε = equivalent surface roughness

η = dimensionless parameter describing drop impact pattern

θ = angle between the x direction and the horizontal

κ = Karman's universal constant

λ = dimensionless parameter describing drop shape

μ = dynamic viscosity

ν = absolute viscosity

ρ = density of water

σ_{ij} = stress tensor

τ = local mean shear stress

τ_{ox} = average boundary shear stress in the x direction at any x position

Ψ = angle between the velocity vector U and the x direction

1. INTRODUCTION

1.1 - Objectives

The observation of raindrops striking a thin layer of water as it flows from a sidewalk or street creates an intuitive feeling that the drops must have some effect on the characteristics of flow. With the growing awareness of the importance of urban hydrology it is necessary to gain a better understanding of the runoff process so that more intelligent design procedures can be developed. Sheet flow is the initial phase of surface runoff and in impervious urban areas it is a very significant one. The effects of rainfall on sheet flow have not been thoroughly studied and it is the overall objective of this study to contribute to the understanding of this phenomenon. Another area in which this knowledge is of value is that of soil erosion.

The specific objectives of the study are:

1. To experimentally investigate and describe the effect of rainfall on the resistance to sheet flow.
2. To obtain a better understanding of the mechanics of sheet flow under the action of simulated rainfall.

The second objective has resulted in doctoral disserations by Wang (1) and Yoon (2), the results of which are summarized in this report.

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1. Numbers in parentheses refer to corresponding items in References.

1.2 - Previous Study

A detailed discussion of previous work related to this study was presented by Wang (1) and Yoon (2) and only a summary is presented here. The first experimental work directly concerned with the resistance to flow due to rainfall was done by Izzard (3, 4) who presented a design procedure for impervious surfaces which recognizes the effect of rainfall. Just after this initial work Keulegan (5) presented the one-dimensional equation for spatially varied flow which has served as a theoretical basis for many subsequent studies. This equation has recently been discussed in further detail by Yen and Wenzel (6). In the light of Keulegan's work Izzard developed a relationship between friction coefficient and Reynolds number for paved and turfed surfaces (7, 8) which is in qualitative agreement with more recent studies. Perhaps the most extensive study to date was reported by Woo and Brater (9) who reported the results of the effect of rainfall intensity, surface roughness, and slope on the resistance coefficient. The Los Angeles District of the Corps of Engineers obtained surface profiles and runoff hydrographs from 500 ft long concrete and turfed surfaces (10). Part of this data was analyzed by Yu and McKnown (11) who concluded that the effect of rainfall decreased and became insignificant as the Reynolds number exceeded 2,000. Robertson <u>et al</u> (12) performed overland flow tests using a gravel surface and a channel slope of 0.05 and obtained very high resistance coefficients.

Smerdon (13) first reported the results of velocity profile measurements of shallow sediment laden flow with rainfall using pitot tubes. Subsequent work by Glass and Smerdon (14) on concrete and plywood surfaces led to the conclusion that the velocity distribution under rainfall was logarithmic with the value of the von Karman constant being higher than the value without rainfall. The first use of the hot film anemometer for velocity profile measurements with rainfall was reported by Threadgill and Hermanson (15) using a triangular open channel. Their results agreed approximately with those of Glass and Smerdon.

The determination of boundary shear stress is of basic importance in this study. Various methods of accomplishing this are discussed by Yoon (2). The two methods used here are the solution of the one-dimensional spatially varied flow equation for the resistance term (6) and the semi-direct method of the flush mounted hot film probe. Threadgill and Hermanson (15) first used the surface probe method but difficulties with calibration made their results questionable.

Although considerable use of the hot film anemometer has been made in measuring turbulence characteristics in water, the only application to flow with rainfall was reported by Barfield (16). Although his range of flow parameters was limited, he reported relative turbulence intensity profiles, Eulerian time scale and diffusion coefficient values.

A single drop striking a fluid has aroused the interest of researchers since the time of Reynolds (17). The work by Wang (1) presents a summary of the previous work in this area as well as the numerical procedures used in recent times to treat such problems mathematically.

2. THEORY

2.1 - Spatially Varied Flow

The theoretical approach used in the present analysis of the steady state resistance to flow caused by rainfall is to treat the rainfall as a uniformly distributed lateral inflow to a two-dimensional channel flow. The general equation which describes this type of flow can be derived from either a momentum or energy approach (6). When the boundary shear is of interest the momentum approach is more appropriate, and if the pressure distribution is assumed to be hydrostatic and the momentum coefficient is constant the result is

$$\frac{dy_o}{dx} = \frac{S_o - \frac{\tau_{ox}}{\gamma y_o} + \frac{i}{g y_o}(U \cos \psi - 2\beta V)}{\cos \theta - \frac{\beta V^2}{g y_o}} \tag{2.1}$$

where y_o = the local depth measured normal to the channel bottom, x = the direction of mean flow, θ = the angle between the x direction and the horizontal, $S_o = \sin \theta$, V = the local mean velocity, τ_{ox} = the average boundary shear stress in the x direction at any x position, i = the lateral inflow per unit length in the x direction which in this case is the rainfall intensity, U = the velocity of the raindrops as they enter the main flow, ψ = the angle between the velocity vector U and the x direction, β = the conventional momentum correction factor (β = 1.20 for two-dimensional laminar sheet flow), γ = the specific weight of water and g = the acceleration due to gravity. The resistance term is sometimes referred to as the friction slope S_f. It is expressed here, as others have done, in terms of a friction factor f such that

$$S_f = \frac{\tau_{ox}}{\gamma y_o} = \frac{fV^2}{8gy_o} \tag{2.2}$$

It should be emphasized that the friction factor definition is based on the momentum rather than the energy approach and should be used in that context.

It would be useful at this point to identify the variables which may affect τ_o and hence f.

$$\tau_o = F(V,\ y_o,\ S_o,\ \mu,\ \varepsilon,\ U,\ i,\ d,\ \eta,\ \lambda,\ \rho,\ g) \tag{2.3}$$

where ε = the equivalent surface roughness, d = the drop size and η and λ = dimensionless parameters describing the drop impact pattern and shape, respectively. Application of dimensional analysis leads to

$$\frac{\tau_o}{\rho V^2} = F_1\left(\frac{\rho V y_o}{\mu},\ \frac{V}{\sqrt{gy_o}},\ \frac{i}{V},\ \frac{U}{V},\ \frac{d}{y_o},\ \frac{\varepsilon}{y_o},\ S_o,\ \eta,\ \lambda\right) \tag{2.4}$$

The parameters in Eq. 2.4 can be combined in a more useful form

$$\frac{\tau_o}{\rho V^2} = F_2\left(\frac{\rho V y_o}{\mu},\ \frac{V}{\sqrt{gy_o}},\ \frac{\rho i y_o}{\mu},\ \frac{U}{\sqrt{gy_o}},\ \frac{\rho i d}{\mu},\ \frac{\varepsilon}{y_o},\ S_o,\ \eta,\ \lambda\right) \tag{2.5}$$

In addition to the conventional Reynolds and Froude numbers, channel slope and relative roughness, Eq. 2.5 contains rainfall parameters in the form of Reynolds or Froude numbers as well as η and λ. The parameter η could be regarded as the ratio between drop diameter and average horizontal spacing between drops while λ could represent a mean aspect ratio of the drops.

2.2 - Velocity Profile

One of the objectives of Yoon's work (2) was to investigate the velocity profile with rainfall. The two part mathematical model which resulted was based on von Karman's mixing length assumption

$$\ell = \kappa \left| \frac{du/dy}{d^2u/dy^2} \right| \tag{2.6}$$

where u = local point mean velocity in the x direction, y = the direction normal to x in a vertical plane, ℓ = Prandtl's mixing length and κ = von Karman's so called universal constant. Yoon found that the velocity profile could be characterized by a lower region starting at the boundary and extending to a point of maximum velocity, y_{max}. This was followed by a region of velocity retardation from y_{max} to the surface, y_o.

The lower part of the profile ($0 < y < y_{max}$) is described by the conventional universal velocity distribution relationship

$$\frac{u_{max} - u}{\sqrt{\tau_o/\rho}} = -\frac{1}{\kappa}\left[\log_e\left(1-\sqrt{1-\frac{y}{y_{max}}}\right) + \sqrt{1-\frac{y}{y_{max}}}\right] \tag{2.7}$$

The additional assumption leading to Eq. 2.7 is that a linear distribution of turbulent shear stress exists. Of course Eq. 2.7 is not valid in the viscous sublayer region where viscous shear predominates nor at a free surface where the vertical mixing must essentially vanish. Although a free surface does not exist at $y = y_{max}$, the velocity gradient is zero there which is not in agreement with the model. However, this difficiency is not unique and is not regarded as serious.

The upper portion of the profile is also a von Karman model with shear stress distribution given by a linear extrapolation of the shear distribution used for the lower part.

$$\tau = \tau_o\left(\frac{y}{y_{max}} - 1\right) \qquad y_{max} < y < y_o \tag{2.8}$$

Upon substituting Eq. 2.8 into von Karman's similarity hypothesis

$$\tau = \rho \ell^2 \left(\frac{du}{dy}\right)^2 \tag{2.9}$$

together with Eq. 2.6 and integrating twice the velocity profile equation becomes

$$\frac{u - u_{max}}{u^*} = \frac{1}{\kappa}\left[\sqrt{y-y_{max}} + \left(\sqrt{y_o-y_{max}} + D\right) \log_e \left(1-\frac{\sqrt{y-y_{max}}}{\sqrt{y_o-y_{max}}+D}\right)\right] \tag{2.10}$$

where

$$u^* = \sqrt{\frac{\tau_o}{\rho y_{max}}} \tag{2.11}$$

$$D = -\frac{u^*}{2\kappa\left(\left.\frac{du}{dy}\right|_{y = y_o}\right)} \tag{2.12}$$

The parameter D is introduced to permit a finite velocity gradient to exist at the free surface.

2.3 - Turbulence Parameters

In order to further describe the nature of the flow Yoon obtained turbulence intensity profiles. If the instantaneous total velocity component $\underline{u}$ is considered to be composed of a steady and a fluctuating component

$$\underline{u} = u + u'' \tag{2.13}$$

such that $\overline{u''} = 0$, the turbulence intensity, u', is defined as

$$u' = \left[\frac{1}{t}\int_0^t (\underline{u}-u)^2 dt\right]^{1/2} = \sqrt{\overline{u''^2}} \tag{2.14}$$

where t = time.

Additional description of the turbulence is given by examining the distribution of kinetic energy per unit mass among the various fluctuation frequencies present in the flow. If 1/2 E(n)dn represents the kinetic energy per unit mass in the frequency range n - n + dn associated with the longitudinal component of velocity then

$$u'^2 = \int_0^\infty E(n)\ dn \tag{2.15}$$

where E(n) = the one-dimensional energy function and n = frequency. Examination of the spectral function with and without rainfall shows how the additional energy supplied by the flow is distributed throughout the various frequencies.

The normalized energy function, F(n), is similarly defined as

$$F(n) = \frac{E(n)}{u'^2} \tag{2.16}$$

Except for the region of high frequencies, the normalized energy function is assumed to have the form (21, 22)

$$F(n) = \frac{4 \frac{L_x}{u}}{1 + \left[\frac{2\pi n L_x}{u}\right]^2} \tag{2.17}$$

where L_x = the macroscale of turbulence. Equation 2.17 allows to estimate the macroscale by fitting a curve of the form to the data. However, a more convenient method was suggested by Raichlen (20), namely,

$$L_x = \frac{u}{2\pi\ n_{50}} \tag{2.18}$$

where n_{50} = the frequency below which 50% of the turbulence energy lies.

2.4 - Single Drop Analysis

The previous discussion was based on a quasi-steady approach, treating the rainfall as a uniform lateral inflow which creates effects which can be considered as steady on the average. As an alternative approach which is much more complex and difficult, Wang (1) has examined the impact of a single drop on a stagnant water layer using a numerical solution of the Navier-Stokes equations with appropriate boundary conditions. This is a simplified model of the natural phenomenon since the water layer was not initially flowing and only one drop was considered. However, it represents a first step in a detailed analysis of the real unsteady flow field and provides some perspective from which further extensions of the approach can be made. The results, although limited by available funds for computer time, are of interest and provide support for the large scale resistance measurements.

The details of the theoretical approach and the numerical scheme are described by Wang (1) and only a brief summary is presented here. The drop impact phenomenon is assumed to be axisymmetric with constant fluid temperature and density and no interfacial tension between the drop fluid and the fluid layer is considered. The equation of continuity and equations of motion which govern the phenomenon after impact are therefore

$$\frac{1}{r}\,\frac{\partial(rV_r)}{\partial r} + \frac{\partial V_z}{\partial z} = 0 \qquad (2.19)$$

$$\frac{\partial V_r}{\partial t} + \frac{1}{r}\,\frac{\partial(rV_r^{\,2})}{\partial r} + \frac{(V_r V_z)}{\partial r} = -\frac{1}{\rho}\,\frac{\partial P}{\partial r} + \nu\frac{\partial}{\partial z}\left[\frac{\partial V_r}{\partial z} - \frac{\partial V_z}{\partial r}\right] \qquad (2.20)$$

$$\frac{\partial V_z}{\partial t} + \frac{1}{r}\,\frac{\partial(rV_r V_t)}{\partial r} + \frac{\partial V_z^{\,2}}{\partial t} = -\,g - \frac{1}{\rho}\,\frac{\partial P}{\partial z} - \frac{\nu}{r}\,\frac{\partial}{\partial r}\left[r\left(\frac{\partial V_r}{\partial z} - \frac{\partial V_z}{\partial r}\right)\right] \qquad (2.21)$$

where V_r and V_z = the radial (r) and axial (z) velocity components at any time t, and P = the gage pressure.

The boundary conditions include zero radial velocity, velocity gradient and pressure gradient along the z axis which is located along the drop centerline, a no slip condition along the bottom of the fluid layer (a free slip condition was also studied), a circular wall at some radial distance from the impact point to limit the computational field, and a set of equations to account for surface tension at the free surface. This latter boundary condition is expressed as

$$\Gamma\left(\frac{1}{R_1} + \frac{1}{R_2}\right) = - \sigma_{ij} n_j \qquad (2.22)$$

where F = the surface tension force per unit length, R_1 and R_2 = the principal radii of curvature of the free surface, σ_{ij} = the stress tensor and n_g = unit outward normal. The initial conditions required are the drop shape and velocity at the instant of impact.

The numerical method employs a Synthetic-Cell-Fluid scheme which conserves mass and momentum. The computational field is divided into a series of cells which are considered to be either empty or filled with a "synthetic-cell-fluid." Initially this fluid corresponds to the real fluid and physically represents the fractional part of a cell which is occupied by the real fluid. The movement of the synthetic fluid is governed by the continuity equation for compressible flow. If a cell contains a volume of synthetic fluid which is greater than a specified amount it is assumed to be filled with real fluid, otherwise it is empty. In this way the free surface is determined. The numerical scheme proceeds in two steps. In the first step Eqs. 2.20 and 2.21 are combined to yield a relationship which permits the pressure to be computed if the velocity field is known.

$$\frac{1}{\rho} \quad \frac{\partial^2 P}{\partial x^2} + \frac{1}{r}\frac{\partial}{\partial r}\left(r\frac{\partial P}{\partial r}\right) = -\frac{\partial}{\partial t}\left[\frac{1}{r}\frac{\partial(rV_r)}{\partial r} + \frac{\partial V_z}{\partial z}\right] - \frac{1}{r}\frac{\partial^2(V_r{}^2)}{\partial r^2} - \frac{2\partial^2(rV_rV_z)}{\partial r\partial z} - \frac{\partial^2(V_z{}^2)}{\partial z^2} \qquad (2.23)$$

Equation 2.23, in finite difference form is used with the known velocity field at time t to compute the change in the pressure field, starting at the free surface and proceeding inward. The synthetic fluid is then moved using the velocity field at time t together with the continuity equation for compressible flow. This defines the fluid domain at t + Δt. Then Eqs. 2.20 and 2.21, in finite difference form, are used to evaluate the velocity field at t + Δt. This completes the cycle which is then repeated.

3. EXPERIMENTAL EQUIPMENT AND PROCEDURE

3.1 - Rainfall-Runoff System

The laboratory flume used for the flow resistance experiments consisted of a 3 ft wide, 24 ft long flume with a 1/4 in. thick plate glass bottom and two 8 in. high plywood walls painted with epoxy. A schematic diagram of the system is shown in Fig. 2 and a general photograph in Fig. 3. The plate glass was laid directly on top of a 1/8 in. thick stainless steel plate which was supported by three 1 in. square steel bars which were glued by epoxy along the centerline and two edges of the plate. Eleven pairs of steel channel stringers, each of which was bolted by two 1/2 in. threaded rods near both ends, were connected to each of the 1 in. square steel bars by three 1/4 in. threaded rods whose upper end was screwed into each of the square bars and the other end was bolted to the upper channel stringer. This support scheme, also shown in Fig. 3 allowed for local levelling of the glass surface to within ±0.005 in. of a plane surface. The lower channel stringers were welded to the upper flanges of two steel wide flange-beams running parallel along the channel basin. The beams were pivoted near the downstream end and were supported by a pair of jacks 21 ft from the downstream end, permitting the channel slope to be changed.

Rainfall was simulated by a series of 12 rainfall modules suspended from a frame above the channel from which capillary tubes protrude down. The details of a module are schematically shown in Fig. 4. The globe valve on each module was adjusted to maintain an equal flow rate from each of the 12 modules. The inflow to the modules was controled by solenoid valves and rainfall could be generated almost instantaneously and stopped within 3 seconds by this means.

The height of the modules above the channel bottom could be adjusted to a maximum of 13 ft by two ropes on each side of each module through pulleys attached to the top of the framework. For the capillary tubes used in this study the equivalent drop diameter varied from 2.92 to 3.26 mm or an average of 3.1 mm for an intensity range of 0.5-15 in./hr. The tube pattern (Fig. 4) used was based on the drop impact pattern study reported by Mutchler (18). Two drop patterns, a 1 in. and 2 in., spacing were used by Yoon (2) as shown in Fig. 4, to evaluate the effect of η in Eq. 25. A recirculating system provided water for both the rainfall modules and the head box as shown in Fig. 2. The head box provided a base flow so that a wide range of Reynolds numbers could be obtained. Separate centrifugal pumps supplied the head box and the rainfall modules via a manifold distribution tank. Flow was monitored by orifice meters calibrated gravimetrically in place. The maximum Reynolds number which could be obtained with the flow system was approximately 5,500.

Depth was measured using a micrometer point gauge which could be read to 0.001 in. With impinging raindrops, a visual micrometer reading of water surface position was not possible because of the irregular water surface caused by the raindrop impact. Therefore, an electrical resistance meter was connected between the point gauge and water. The gauge was lowered to the surface until the resistance meter began to oscillate, indicating contact with the crest of the waves. The gauge was then lowered until the meter reading dropped to a steady lower value, indicating that the point was just below the surface wave troughs. The true depths reading was taken as the

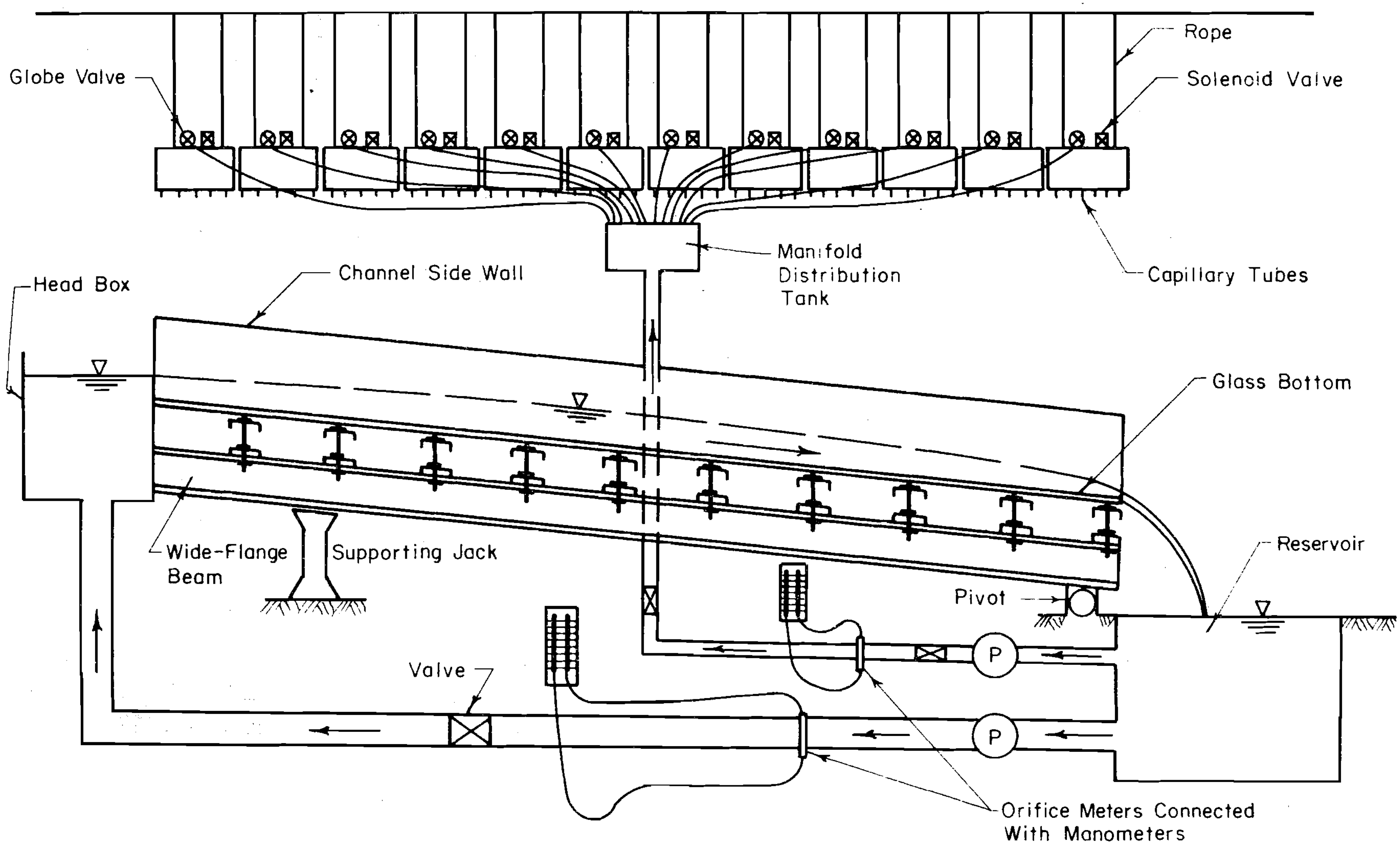

Fig. 2 **Schematic** of Apparatus

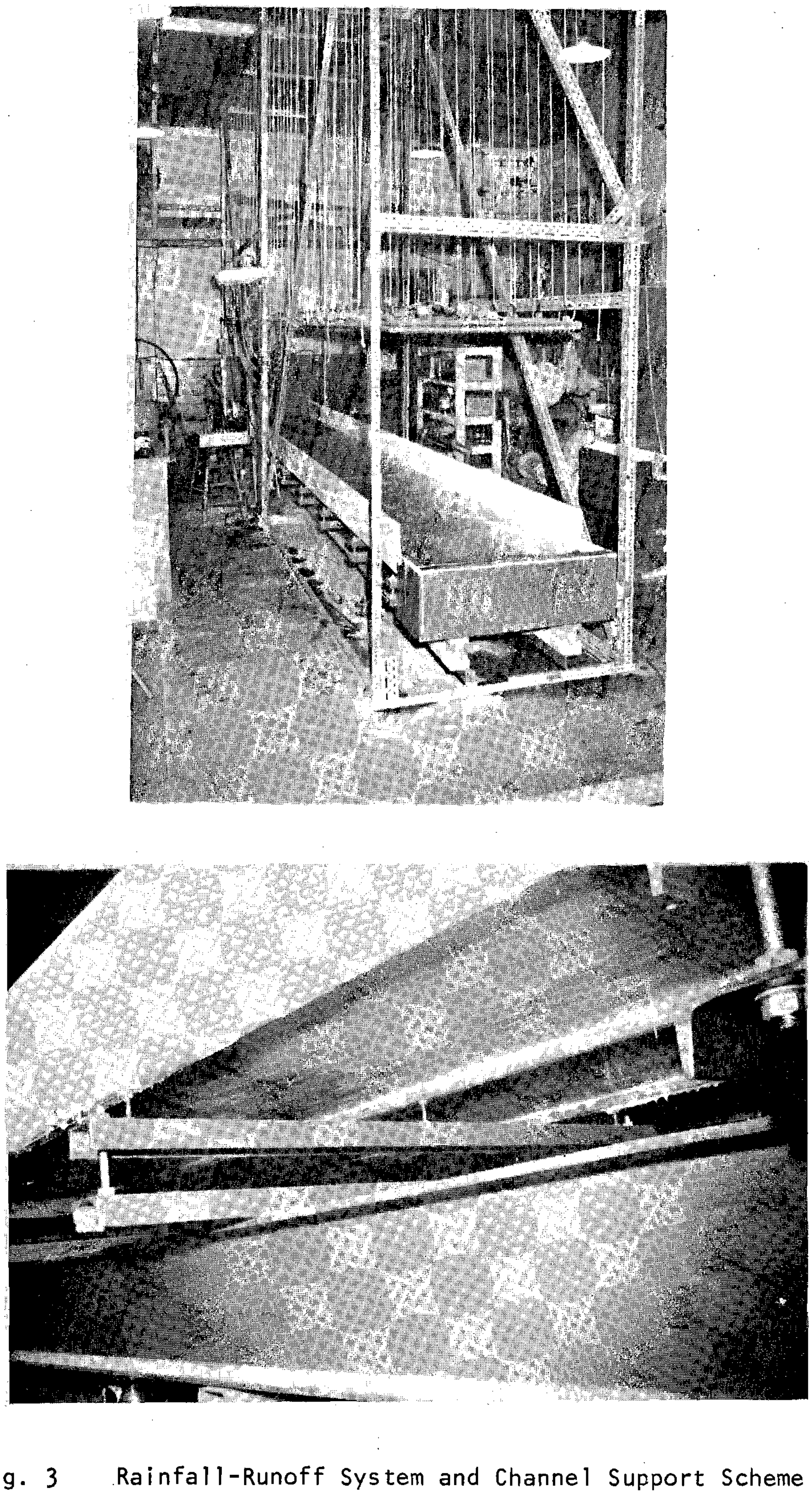

Fig. 3 Rainfall-Runoff System and Channel Support Scheme

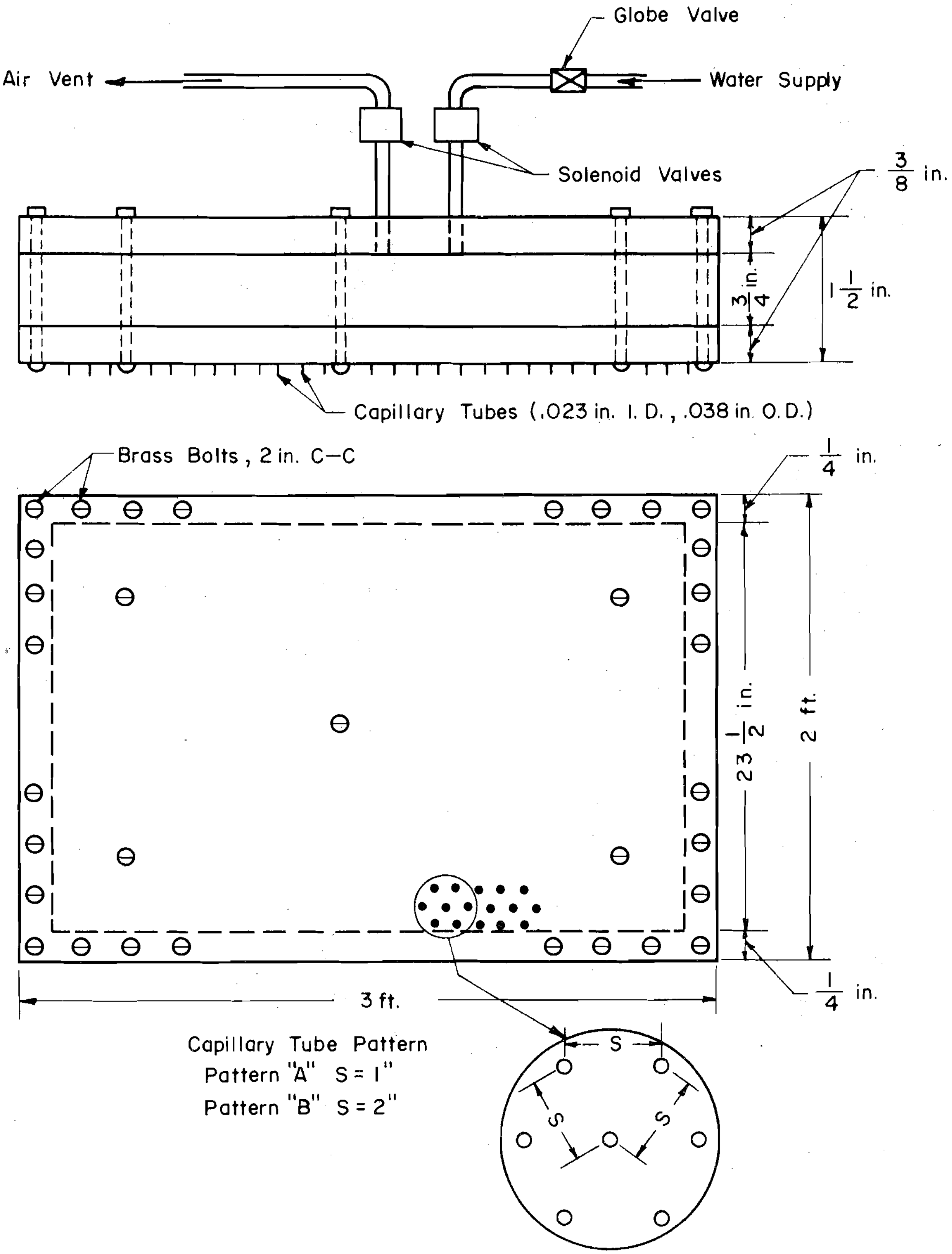

Fig. 4 Rainfall Module

average of the crest and trough gauge readings, and the resistance meter value at that average depth was used as a reading criterion throughout the tests. To be consistent on this criterion the zero reading of resistance meter was periodically checked.

3.2 - Mean Velocity and Turbulence Measurement

A Thermo-Systems Inc. Model 1010 constant temperature anemometer was used by Yoon (2) for measurements of velocity, turbulence and boundary shear stress along with a linearizer, RMS and DC voltmeters and chart and tape recorders. The details of the circuitry, calibration and operation of the equipment was described in detail by Yoon (2). TSI boundary layer hot film sensors (Model 1218-60W) and straight hot film sensors (Model 1210-60W) having a 0.006 in. diameter quartz coated platinum-film cylindrical sensor with a sensitive length of 0.080 in. were used for these measurements.

3.3 - Boundary Shear Stress Measurement

A TSI Model 1237-LW flat surface hot film sensor coupled with the anemometer was used by Yoon to obtain a semi-direct measurement of boundary shear. The probe was mounted flush with the glass surface and was calibrated in a rectangular conduit over the same Reynolds number range as was encountered in the measurements. Photographs of the surface probe, boundary layer probe, and instrument carriage are shown in Fig. 5.

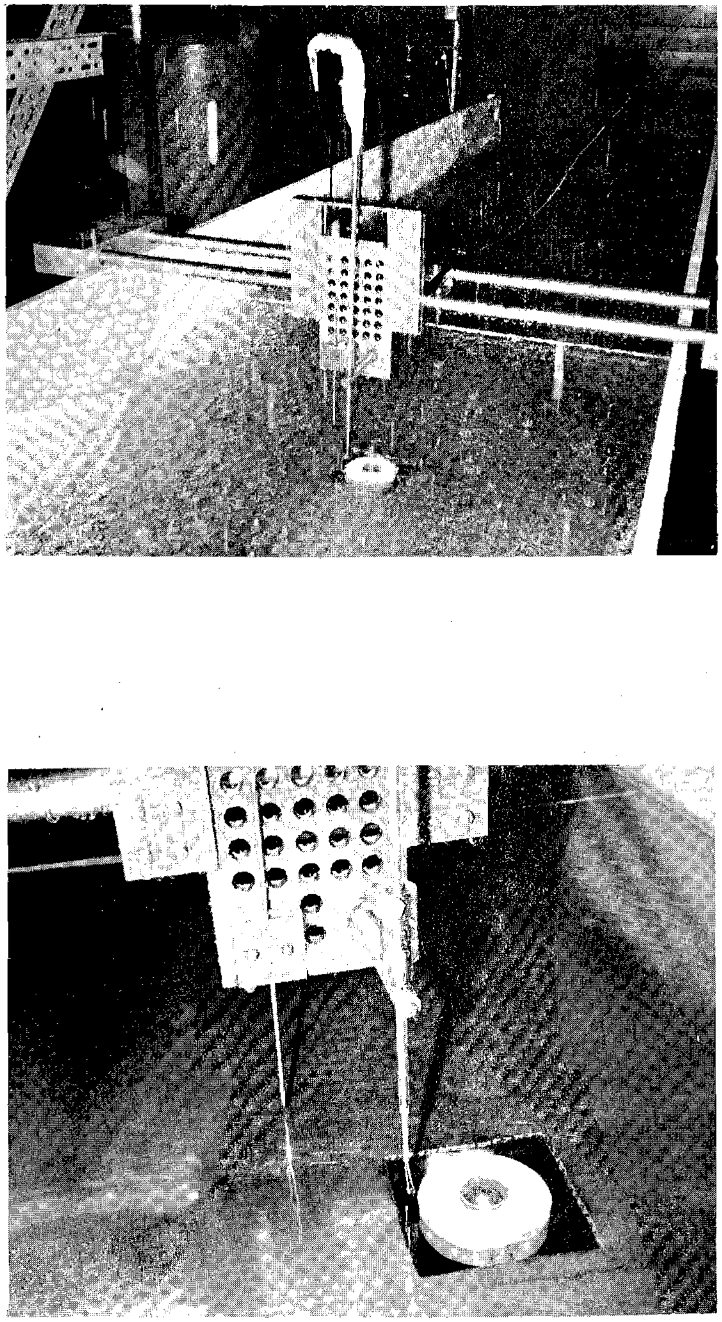

Fig. 5 Instrument Carriage and Probe

3.4 - Turbulent Energy Spectrum Measurement

In order to observe the effects of rainfall on the distribution of turbulence energy a Sangamo 3500 tape recorder was used to record the turbulence at three levels in the flow for various Reynolds numbers and rainfall intensities. The signal was analyzed using a General Radio Model 1564-A Sound and Vibration Analyzer together with the integrating portion of the mean product computer of a Hubbard Old Gold Model hot wire anemometer. The latter was used to obtain a valid average output reading from the analyzer at the various central frequencies. A band width of 16 percent of the central frequency was used, which corresponded to a rectangular response curve of unit height having the same area as that under the actual response curve. It was found that the analyzer was not capable of picking up the entire signal over all the frequencies since the area under the spectrum curve was in general lower than $\overline{u'^2}$. However this problem is not uncommon with this method of analysis and could only be overcome by using analog to digital conversion. This was not done because the results were judged sufficiently accurate to convey the information desired.

3.5 - Single Drop Impact Pressure

The experimental phase of the study by Wang (1) consisted of the measurement of the pressure-time relationship immediately beneath the impact point of a single drop as it struck a thin stagnant water layer. Various drop sizes, water layer depths and impact velocities were investigated. The pressure was measured by a Model 606A Kistler quartz pressure transducer in series with a Model 504 charge amplifier and a Model 548A8 filters for resonance attenuation. The signal was recorded on storage oscilloscope. The transducer was mounted flush with the bottom of a 2 ft square plexiglass tray which was oriented so that the drop struck directly over the center of the transducer. Drops were formed using a single capillary inserted through the bottom of a water container. Various drop sizes were produced by using tubes with different outside and inside diameters.

4. RESULTS

4.1 - Effect of Significant Parameters on Flow Resistance on a Smooth Surface

4.1.1 - Computation of Friction Factor

The boundary shear stress and hence the friction factor and friction slope can be computed from Eqs. 2.1 and 2.2 if all of the other terms in the resulting equation are known.

$$f = \frac{8\tau_{ox}}{\beta V^2} = \frac{8gS_f y_o}{V^2} = \frac{8gy_o}{V^2}\left[S_o - \frac{dy_o}{dx}\left(\cos\theta - \frac{\beta q^2}{gy_o^3}\right) + \frac{iU}{gy_o}\cos\psi - \frac{2\beta iq}{gy_o^2}\right] \quad (4.1)$$

Surface profiles for various slopes, rainfall intensities, values of U, and initial upstream Reynolds numbers were measured. These data are given in the Appendix. Eq. 4.1 was transformed into a difference equation using the following substitutions:

$$\frac{dy_o}{dx} = \frac{y_2 - y_1}{\Delta x} \qquad \Delta x = 2 \text{ ft}$$

$$y_o = \frac{y_1 + y_2}{2} \quad (4.2)$$

$$q = q_o + i\left(\frac{x_1 + x_2}{2}\right)$$

Smooth curves were drawn through the raw surface profile data and the smoothed profiles were used to compute f values at 1 ft intervals. The initial 4 ft of development length and the downstream portion of each profile which was judged to be affected by the free overfall were not included in the calculations. The results are presented in Figs. 6-11 in the conventional form of f vs N_R with intensity as a parameter at constant slope and drop spacing. This was found to be the best form in which to present the results. Referring to Eq. 2.5 it was found that the parameter $\rho i y_o/\mu$ and $U/\sqrt{g y_o}$ did not yield any significant correlation with f. Since the drop size was essentially constant the dimensionless $\rho i d/\mu$ is proportional to i if the variation of μ is neglected. Since the intensity was the most significant parameter it was used in dimensional form for practical purposes. The Froude number was not of primary importance and the roughness ε was constant.

4.1.2 - Effect of Rainfall Intensity and Slope

The most significant and obvious result is that for Reynolds numbers below approximately 2,000 the rainfall intensity increases the resistance to flow, with higher f values associated with higher intensities. Above this value, which corresponds to the usual transition range from laminar to turbulent flow as shown in Figs. 6, 7, 9, and 11 for $i = 0$, the effect of intensity decreases rapidly until it becomes insignificant. For Reynolds numbers below 1,000 the result can be described mathematically by a straight line parallel to the theoretical $f = 24/N_R$ for laminar flow, i.e.

$$f = \frac{C}{N_R} \tag{4.3}$$

where C is a function of slope and intensity. Values of C taken from the lines in Figs. 6-11 are shown as functions of rainfall intensity with slope as a parameter in Fig. 12.

4.1.3 - Effect of Impact Velocity

Tests were performed with the rainfall modules positioned 15 in., 2 ft and 13 ft above the channel producing impact velocities of approximately 8.8, 11.0 and 22.3 ft/sec (1). The tests by Yoon were performed with the modules at 3.875 ft above the channel for an impact velocity of 14.5 ft/sec. Examination of the order of magnitude of the term containing U in Eq. 4.1, as discussed in Sec. 4, indicates that it is of the order of 1 percent of S_f and thus no experimental effect was expected. This was verified in the analysis of the data and so the position of the modules was not significant.

4.1.4 - Effect of Momentum Coefficient

Velocity profile measurements by Yoon (2) indicated that the range of β with rainfall was 1.06 to 1.14. The correct values were used in Eq. 4.1 for his analysis. The rest of the data which were taken before Yoon's were analyzed using $\beta = 1.0$. This was justified by computing some typical f values using $\beta = 1.0$ and its maximum value of 1.2. The maximum effect was approximately a 5 percent change in f. Therefore, a constant value of $\beta = 1.0$ was used.

4.1.5 - Effect of Froude Number

The location of $N_F = 1.0$ is shown in Figs. 6-11. With the exception of one slope, $S_o = 0.03$, the flow was subcritical up to $N_R = 800$. In these cases no significant effect of N_F is noticeable. However, on $S_o = 0.03$ roll waves were present. Furthermore, as can be seen in Fig. 11, the transition region, which is generally characterized by a reduction in the effect

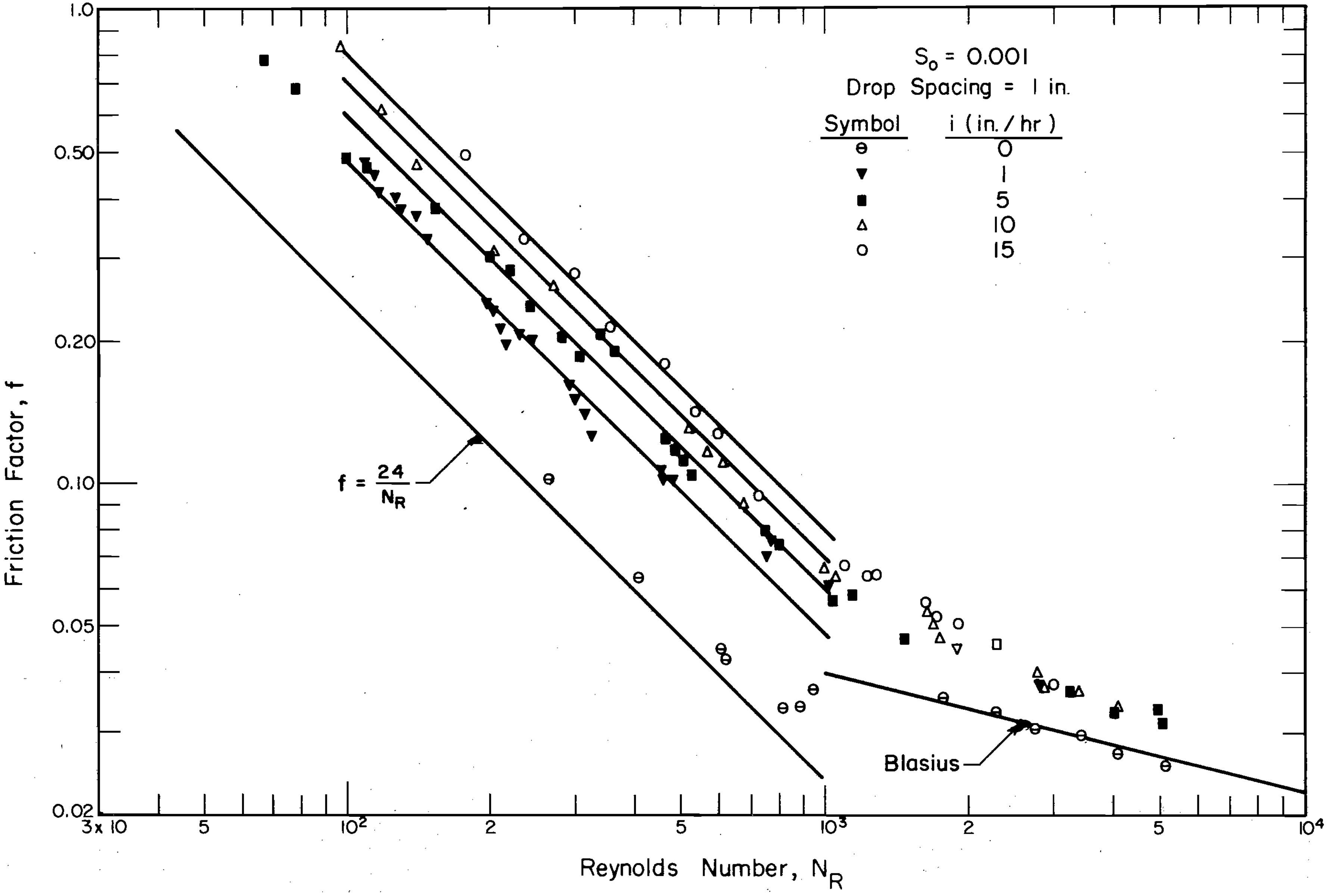

Fig. 6 Friction Factor vs. Reynolds Number for S_o = 0.001

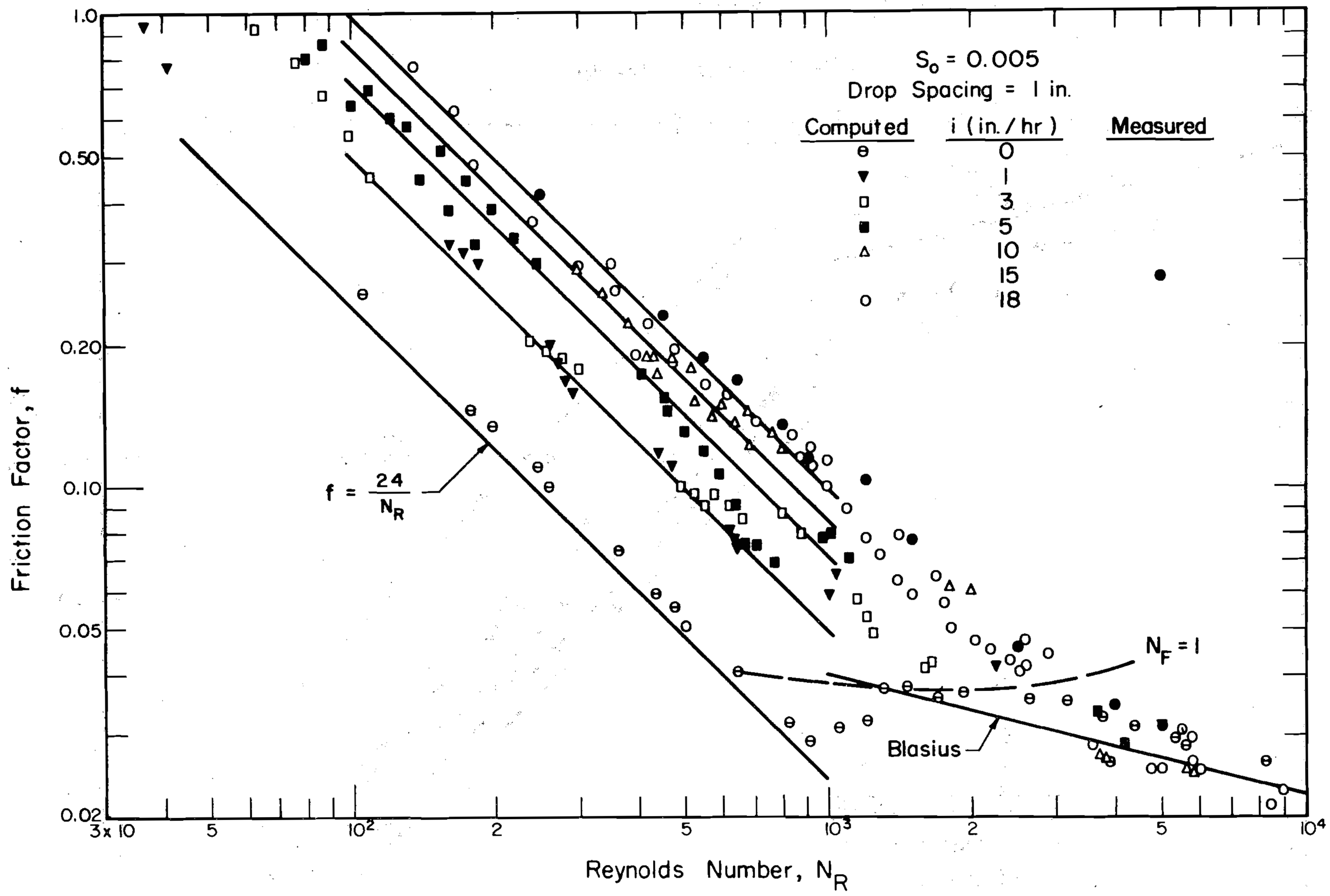

Fig. 7 Friction Factor vs. Reynolds Number for $S_o = 0.005$

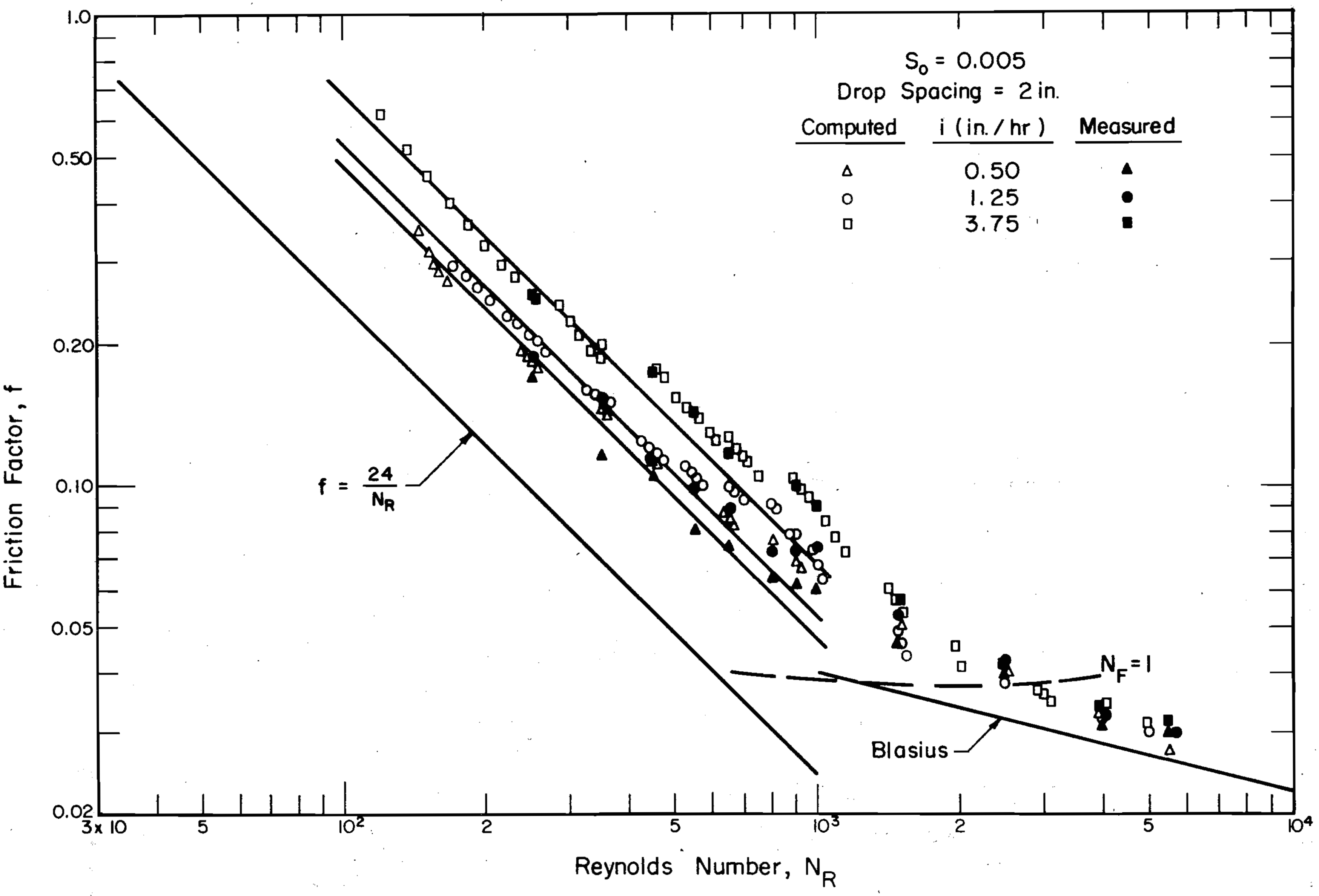

Fig. 8. Friction Factor vs. Reynolds Number for $S_o = 0.005$

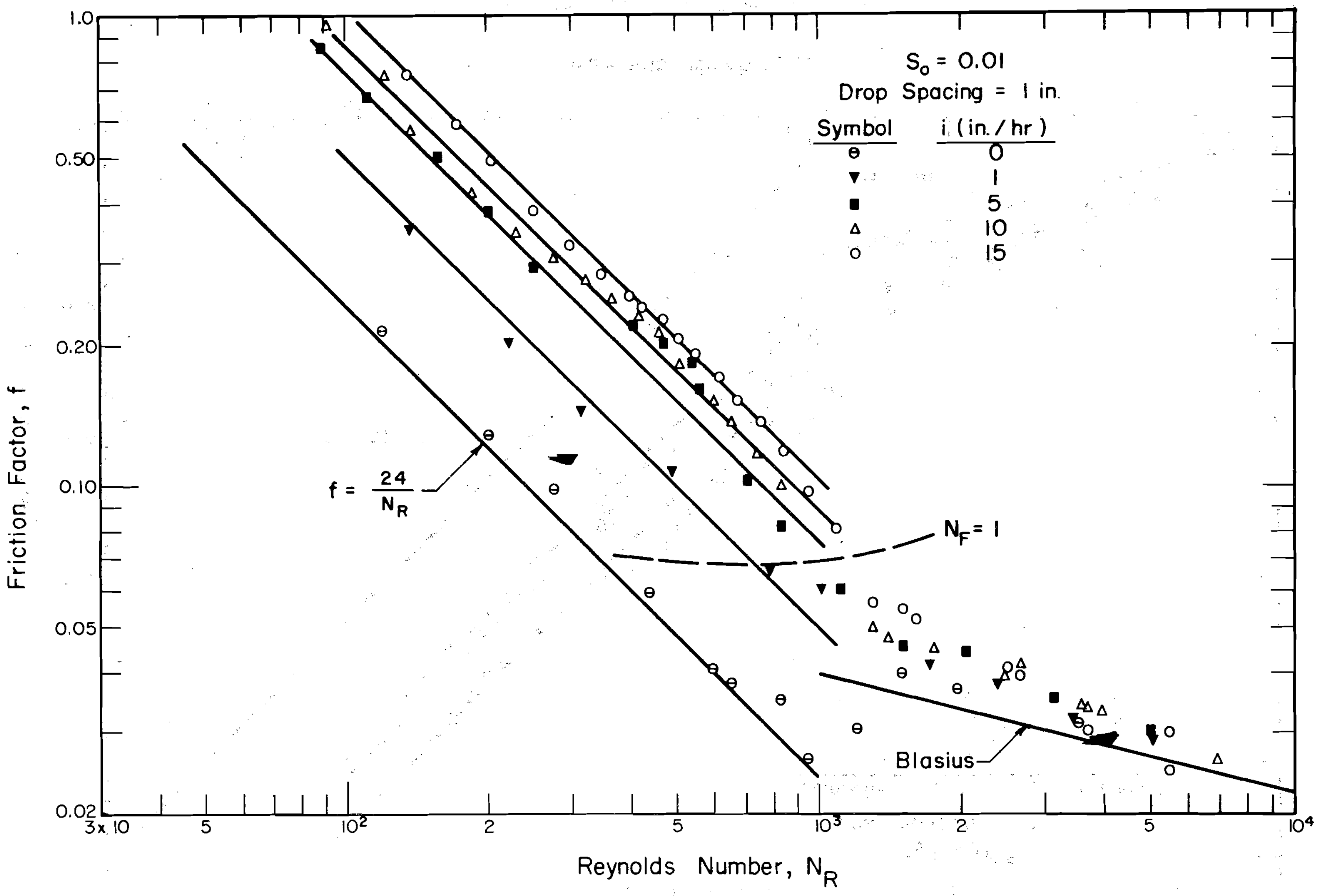

Fig. 9 Friction Factor vs. Reynolds Number for $S_o = 0.01$

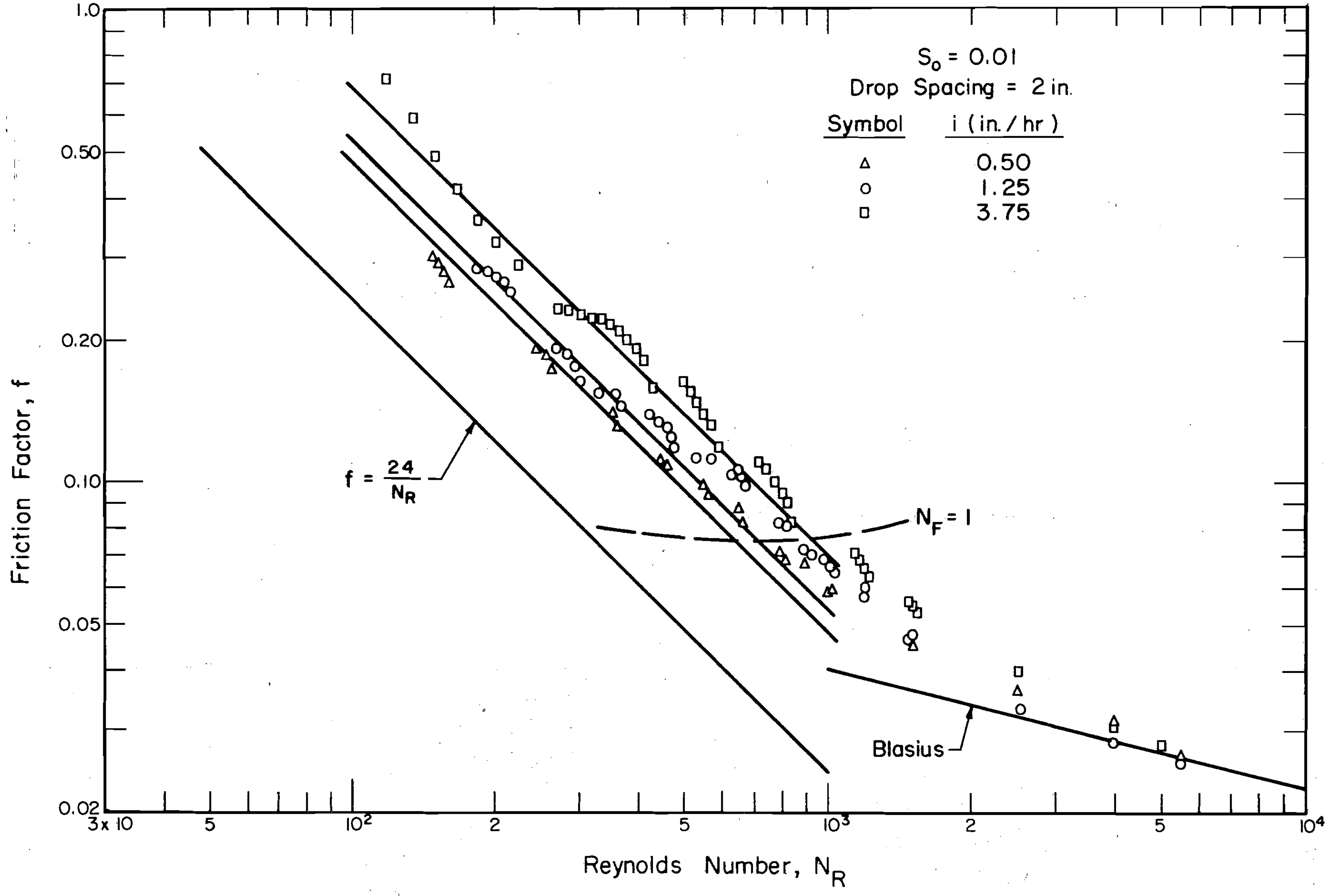

Fig. 10 Friction Factor vs. Reynolds Number for $S_o = 0.01$

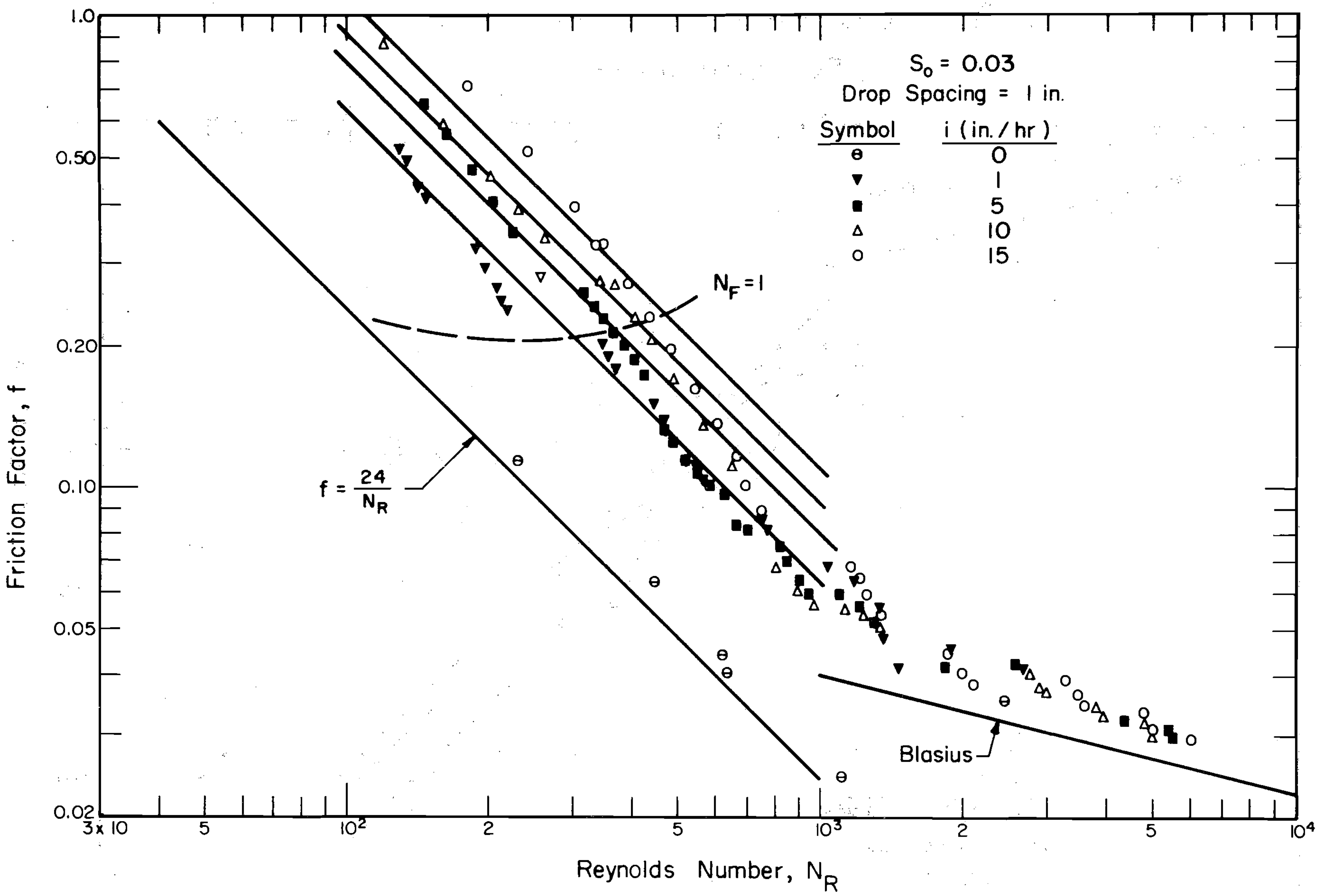

Fig. 11 Friction Factor vs. Reynolds Number for $S_o = 0.03$

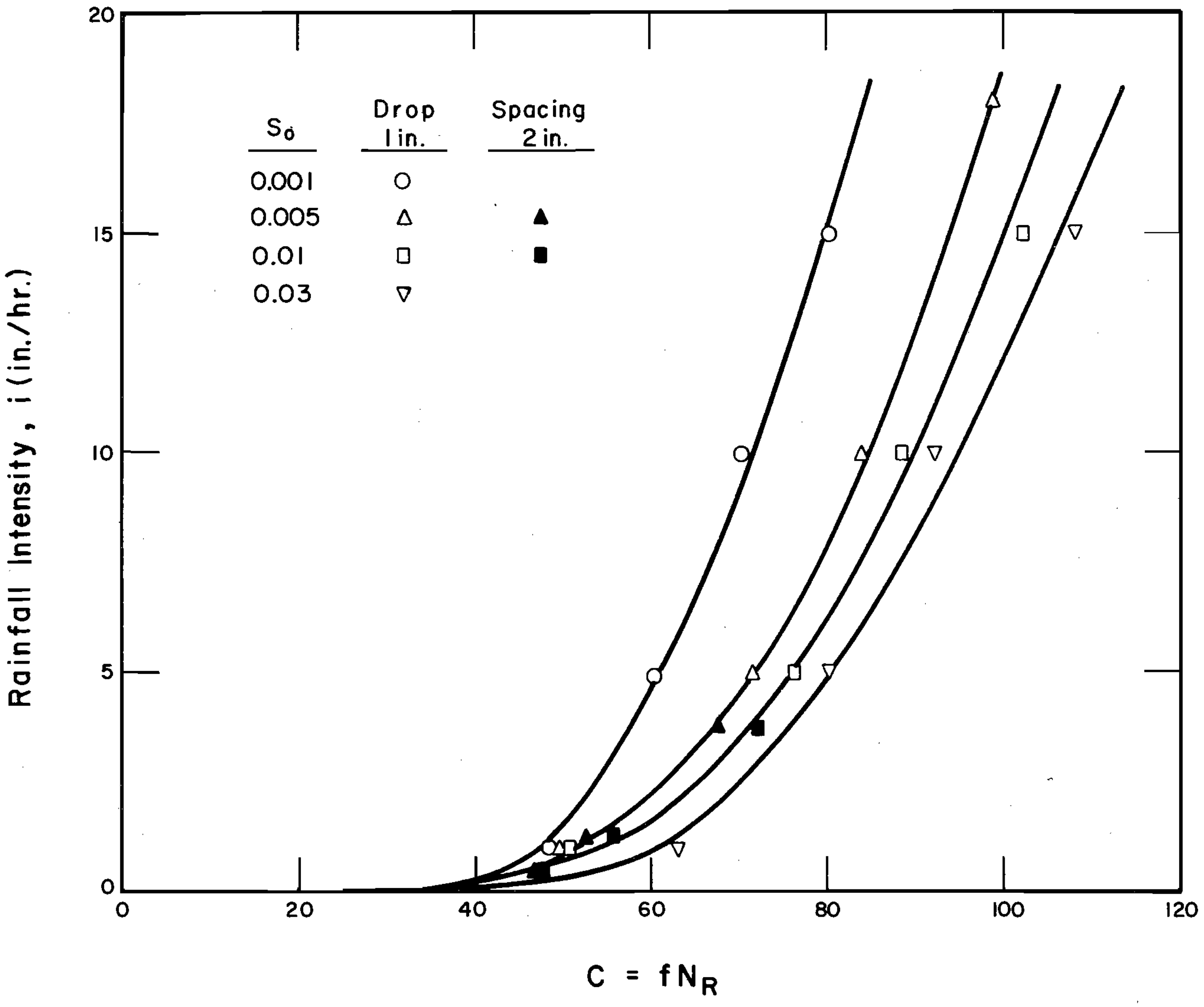

Fig. 12 Coefficient C vs. Rainfall Intensity

of intensity on f, occurs at a lower Reynolds number and just after critical flow was reached. Thus, the transition to supercritical flow may be initiated by or related to the transition region. For lower slopes the critical Reynolds numbers occur in the usual transition region of $N_R = 1{,}000 - 2{,}000$ so that this effect, if it exists, is not discernible. The presence of roll waves on $S_o = 0.03$ made the measurement of the surface profile using the point gauge more difficult and subject to additional error.

4.1.6 - Direct Measurement of Boundary Shear

Comparison of the measured and computed boundary shear stress values by Yoon (2) indicated that the hot film surface probe method produces accurate results which are not subject to the errors associated with the use of surface profile measurements and Eq. 4.1. Figures 7 and 8 include the results of f computed from Eq. 2.2 using direct measurements of τ_{ox}. Although not apparent here, comparison of τ_{ox} vs N_R curves determined by measurement and computation (2) indicate much smoother results from direct measurement. This might be expected by observing that the determination of f from τ_{ox} involves multiplication by y_o^2, i.e. $f = 8\,\tau_{ox}\,y_o^2/\rho q^2$. Thus, any percent error in y is doubled when computing f.

4.1.7 - Comparison of Terms in Spatially Varied Flow Equation

In order to compare the contribution to the friction slope, S_f, of the various terms in Eq. 4.1 it can be written as

$$S_f = S_o - S_1 - S_2 + S_3 \qquad (4.4)$$

where
$$S_1 = \frac{2\ iq}{gy_o^2}$$
$$S_2 = \frac{dy_o}{dx}\ (\cos\theta - \frac{q^2}{gy_o^3})$$
$$S_3 = \frac{iU}{gy_o} \cos\psi$$

The values of S_f and the percentage contribution of S_1, S_2, and S_3 as functions of N_R are shown as Figs. 13 and 14 for the maximum and minimum slopes tested and for various rainfall intensities. Actually a band should be used instead of a line to show the relationship, but the width of the band is not great and a line shows the variation more clearly. Of these terms the most significant is S_2 which varies considerably with both N_R and S_o. On the low slope the surface profile curvature is higher while on the high slope it is almost zero. Furthermore, S_2 can change sign but in doing so the largest absolute value at any Reynolds number is still associated with the largest rainfall intensity. The next most important term is S_1 which does not change significantly with slope at a constant intensity and Reynolds number, but its percentage contribution to S_f decreases with increasing slope. The term S_3 is always less than 2 percent of S_f and is not important, as verified experimentally by changing the value of U. It is interesting to note, however, that the impact velocity is very important if f were defined on the basis of the energy approach (23) rather than the momentum approach.

4.2 - Effect of Surface Roughness

Time did not permit tests to be performed using various rough surfaces. However, data taken by the Los Angeles District, Corps of Engineers (10)

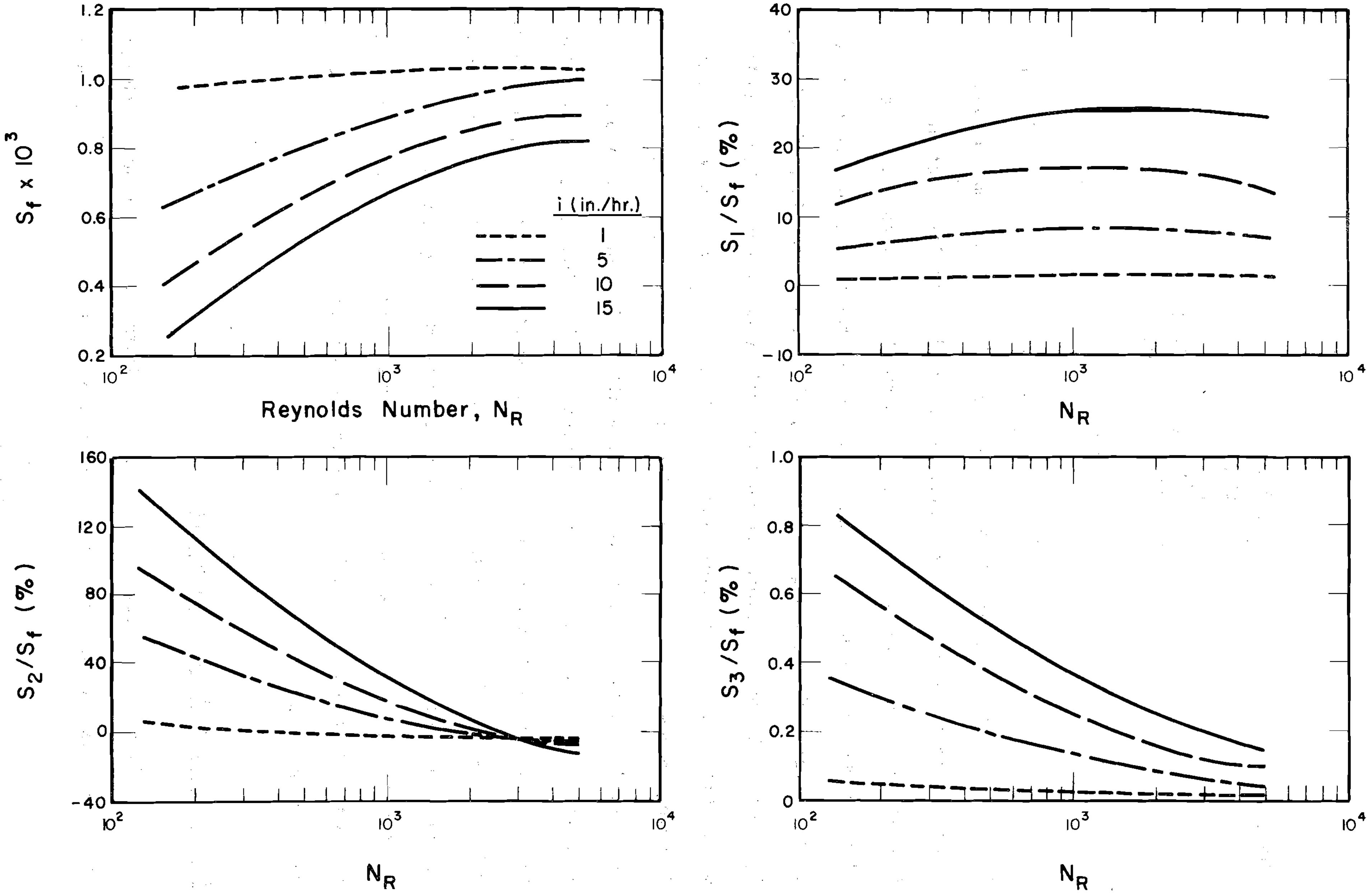

Fig. 13 Contribution to S_f vs. Reynolds Number for $S_o = 0.001$

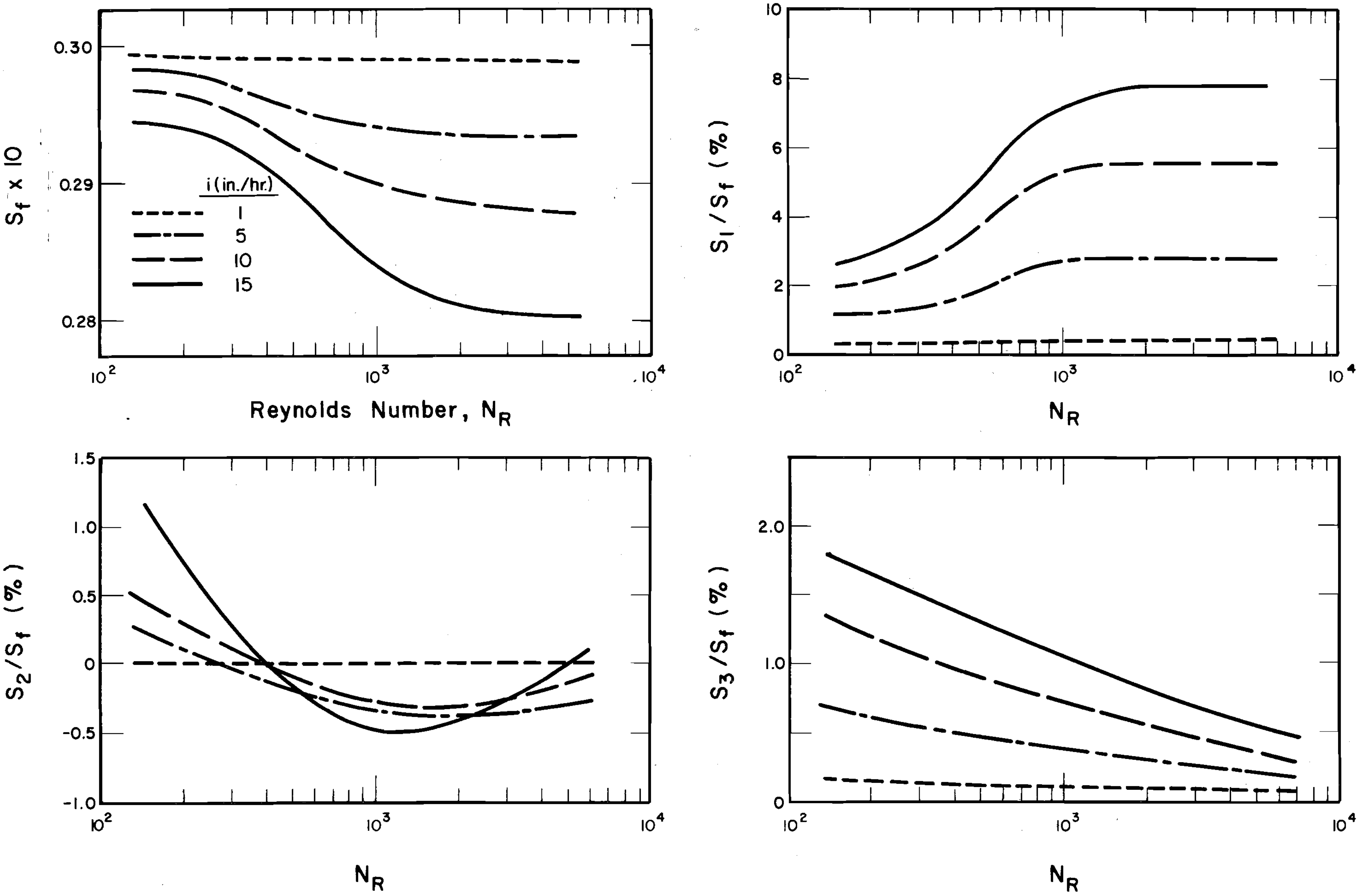

Fig. 14 Contribution to S_f vs. Reynolds Number for $S_o = 0.03$

were analyzed. In this study a concrete channel 500 ft long and 3 ft wide was used with rainfall produced by a series of spray nozzles suspended above. Depth was measured at 33.5 ft, 166.9 ft, and 333.5 ft from the downstream end using piezometers constructed from pipes installed in the concrete bed. Discharge was measured using weirs and a volumetric tank. Channel slopes of 0.005, 0.01 and 0.02 were used along with five types of rough surfaces: concrete, simulated turf, roughened simulated turf, excelsior turf and actual grass. Uniform steady spatially varied and unsteady spatially varied flow tests were performed.

The friction factor computations were made in the same manner as previously described, although the surface profile was defined by only three points and thereby created a possible significant source of error.

In order to isolate the effects on f of roughness from those of rainfall, uniform flow data from each surface were analyzed. Uniform flow friction factors were first computed. For the concrete and simulated turf data the results were then substituted into the Colebrook transition formula (19)

$$\frac{1}{\sqrt{f}} = -\,2.0 \log \left(\frac{k_s}{14.83y_o} + \frac{0.63}{N_R\sqrt{f}}\right) \qquad (4.5)$$

in which k_s = the equivalent sand grain roughness. The resulting average value of k_s for concrete was 0.0028 ft and 0.159 ft for the simulated turf. For the excelsior turf and grass the assumption was made that the flow was fully rough and the roughness computed from (19)

$$\frac{1}{\sqrt{f}} = 2.0 \log \left(12.62 \frac{y_o}{k_s}\right) \qquad (4.6)$$

The results indicated an average k_s value of 1.29 ft for the excelsior turf and 0.94 ft for the grass. These high k_s values (of the order of ten times the depth) indicate that for these extremely rough surfaces k_s loses any physical significance and is truly an equivalent roughness rather than a measure of the physical size of roughness elements.

The uniform data for all slopes and surfaces are shown in Fig. 15. The lines are plots of Eqs. 4.5 and 4.6 for indicated values of y_o/k_s. The results of f for the spatially varied flow computations are shown as solid points with the associated rainfall intensity values written nearby. The most obvious conclusion which can be made is that rainfall does not significantly effect the friction factor in the range of Reynolds numbers which were studied. It should be pointed out that the excelsior turf and grass restuls are in the fully rough range of flow and the data from the other surfaces is in the transition range. As can be seen in Figs. 6-11 this conclusion is in agreement with the smooth surface results, that is rainfall has a significant effect on f below the transition range. Close examination of the simulated turf data indicates that the rainfall has lowered the value of f. This is difficult to explain since it implies that the product $y_o^2 \tau_{ox}$ is lower, at a constant Reynolds number, for flow with rainfall than for uniform flow. This is not indicated by other data taken by the Corps or by Yoon. On the other hand if it is assumed that k_s is constant, then an increase in y_o will produce an increase in y_o/k_s which would be in agreement with the trend shown. Another explanation could lie in a change in the operation of the piezometers used to measure the depth due to the presence of rainfall, yielding erroneous depth measurements, or the estimates of

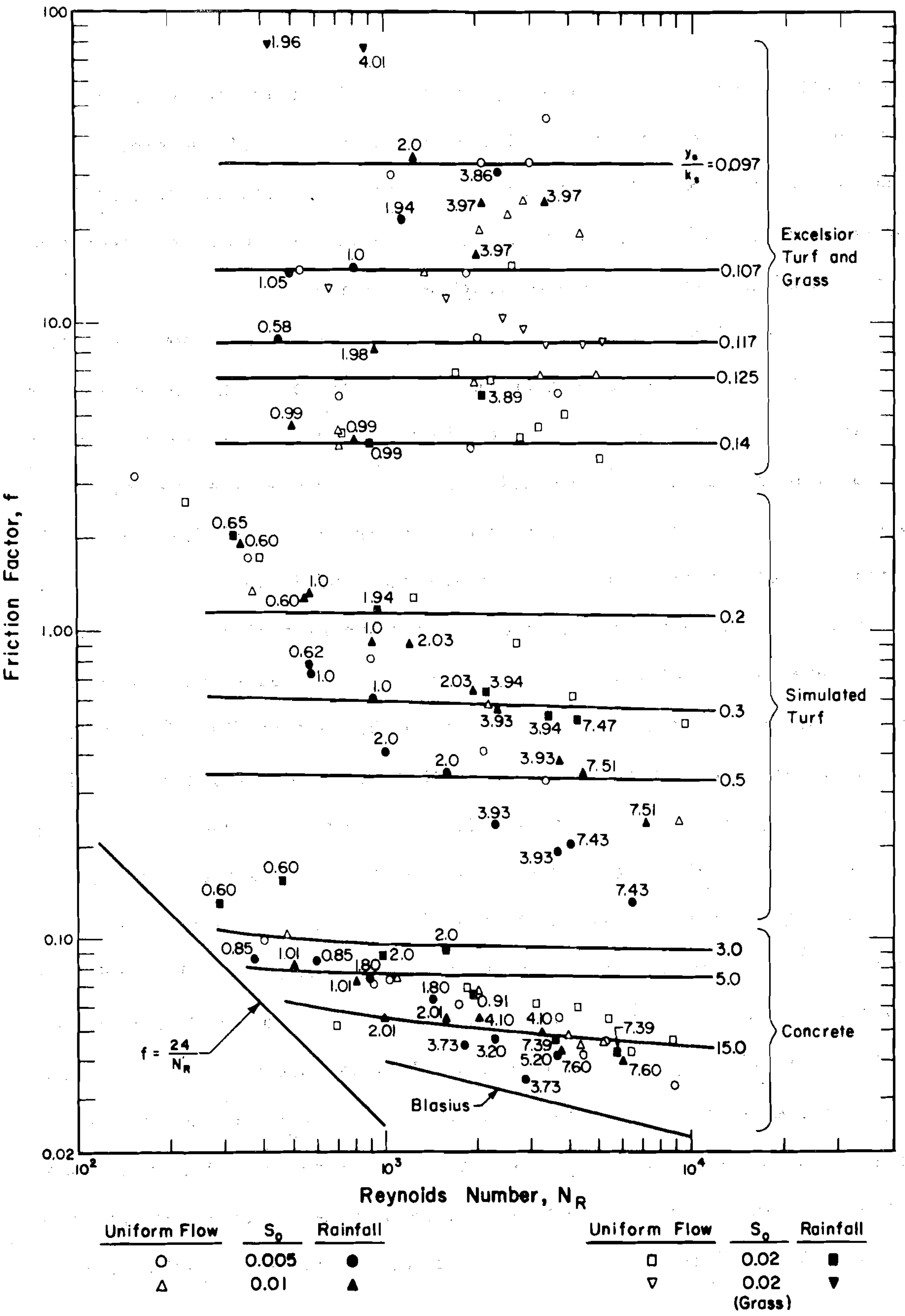

Fig. 15 Friction Factor vs. Reynolds Number for Rough Surfaces

dy_o/dx used in the computation of f could be in error since the surface profile was not well defined. In any case, the data does not support a clear effect of rainfall or the rough surfaces and it is felt that additional measurements are required.

4.3 - Velocity Profiles

Some typical velocity profiles obtained by Yoon (2) are shown in Figs. 16 and 17. The lines indicated the predicted profiles using Eqs. 2.7 and 2.9. Correlation of the lower part of the velocity profile with Eq. 2.7 indicated correlation coefficients ranging from 0.903 to 0.963. Values of the von Karman constant κ were found to be 0.190 and 0.212 for uniform flow without rainfall on slopes of 0.005 and 0.01 respectively. With rainfall κ ranged from 0.192 to 0.287, increasing with intensity.

Equation 2.9 was fitted to the upper portion of the profile using a least squares criterion to determine D with the κ values from the lower portion. It was found that the velocity gradient at the surface decreased with increasing rainfall intensity at a constant Reynolds number, increased with increasing Reynolds number at a constant intensity and was lower for the smaller slope and a given intensity and Reynolds number. The relative position of the point of maximum velocity at a given Reynolds number and slope decreased with increasing intensity, it increased with increasing Reynolds number at constant intensity and slope, and it decreased slightly with increasing slope at a constant intensity and Reynolds number. These results seem reasonable based on momentum considerations as discussed by Yoon.

The most significant effect of the rainfall is to cause a logarithmic type velocity profile with surface retardation at Reynolds numbers below 1,000 where the flow would normally be laminar. The logarithmic form of the lower part of the velocity profiles is indicative of the turbulence which is generated by the drops in the surface region and diffuses downward into the flow. The velocity retardation shown in the upper portion of the profiles indicates the local effects of drop impact. Reference is made to Yoon's work (2) for a detailed discussion of the profiles.

4.4 - Turbulence Measurements

4.4.1 - Turbulence Intensity Profiles

Typical absolute longitudinal turbulence intensity profiles for $i = 3.75$ in./hr as obtained by Yoon (2) are shown in Fig. 18. It is seen that the intensity decreases monotically from the surface. However, the relative intensity profiles shown in Fig. 19 indicate a minimum value in the central region and a sharp rise near the surface. This is in sharp contrast to the profile without rainfall as seen in the lower two graphs of Fig. 19. The effect of rainfall intensity for Reynolds numbers below 800 is significant throughout the profile, with higher relative turbulence intensity associated with higher rainfall intensity as might be expected. As the Reynolds number enters the transition region however, the turbulence generated from the boundary dominates the lower profile and rainfall intensity has little effect as seen in Fig. 19.

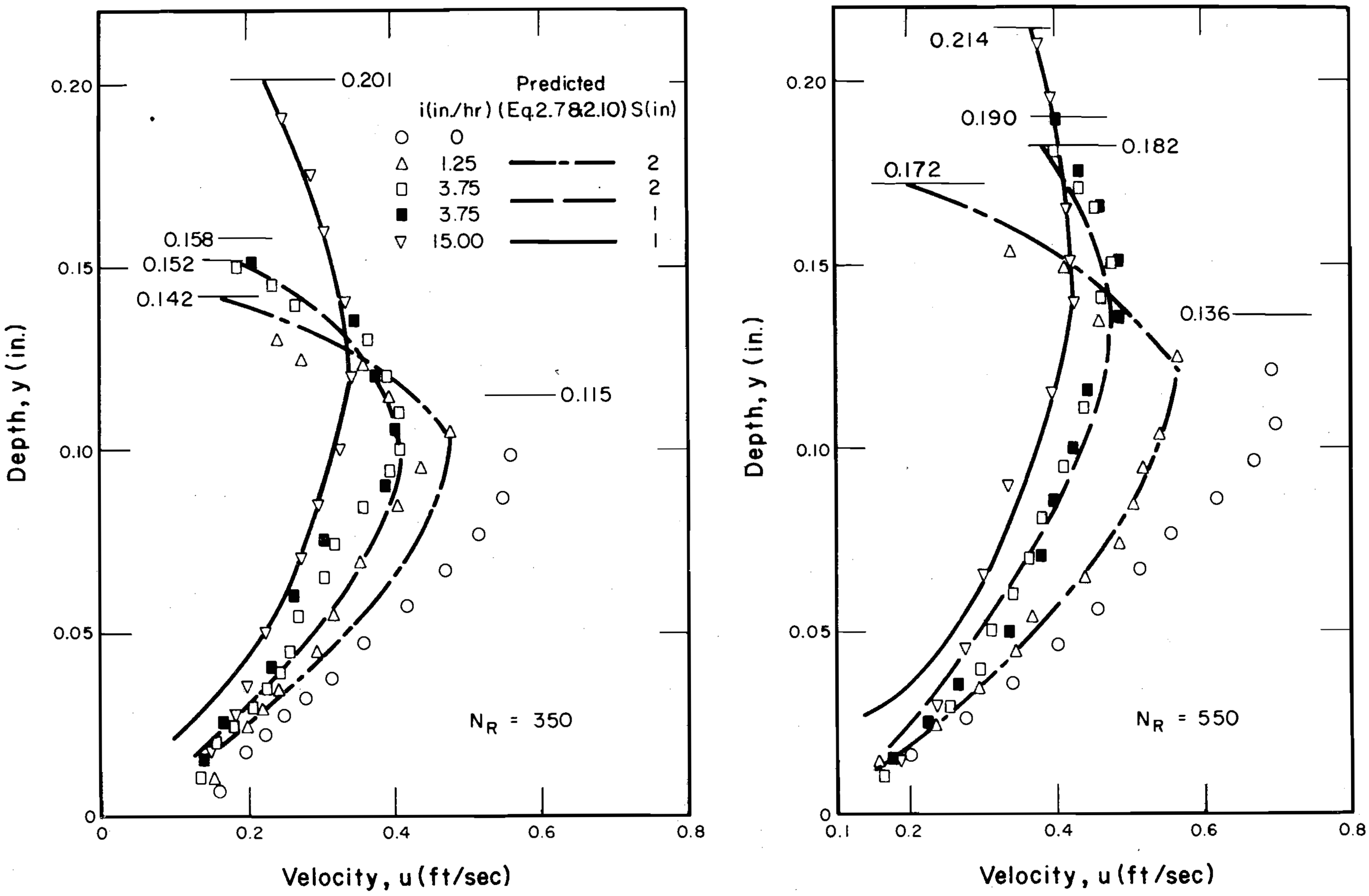

Fig. 16 Velocity Profiles for $S_o = 0.005$

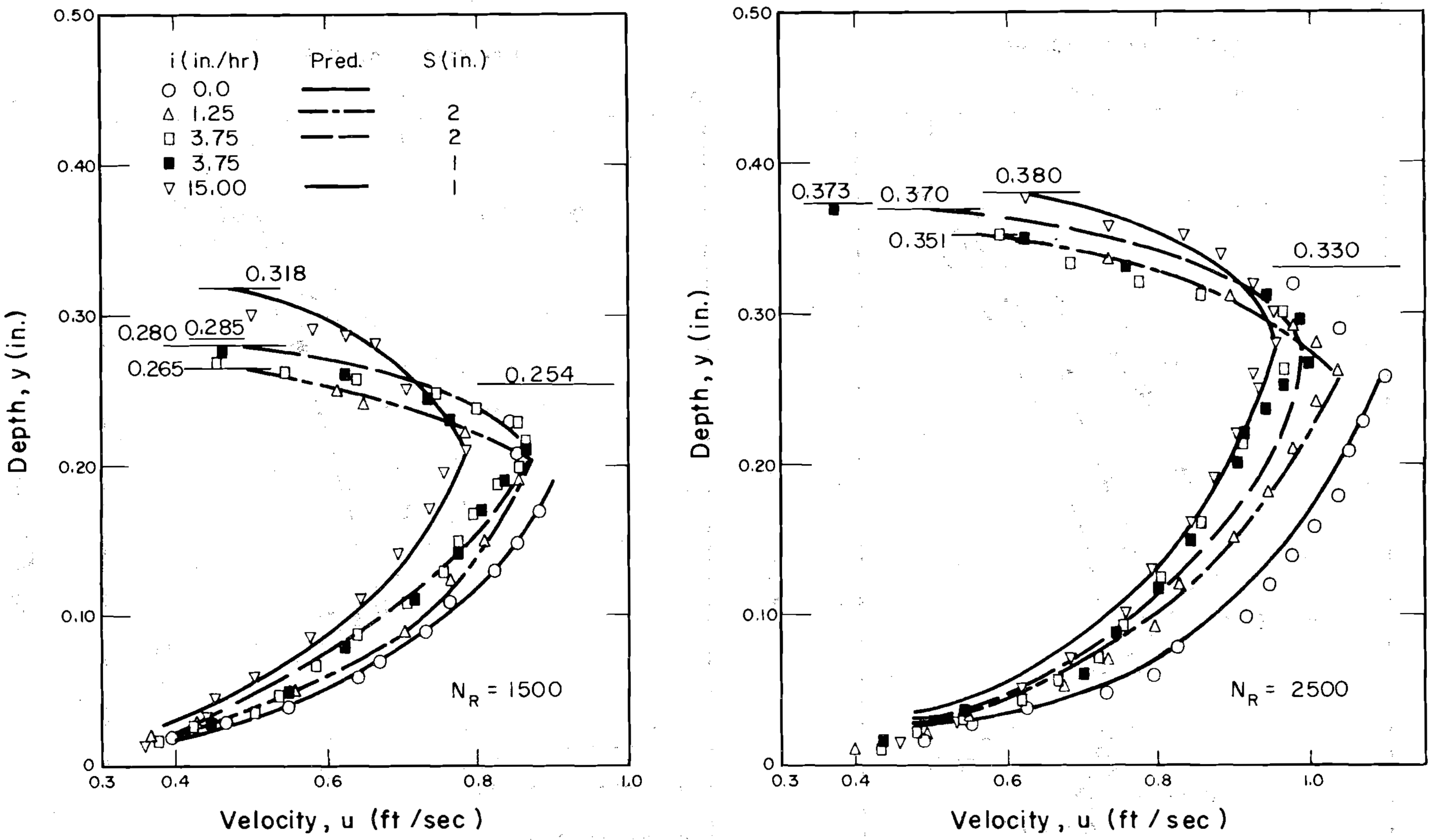

Fig. 17 Velocity Profiles for $S_o = 0.005$

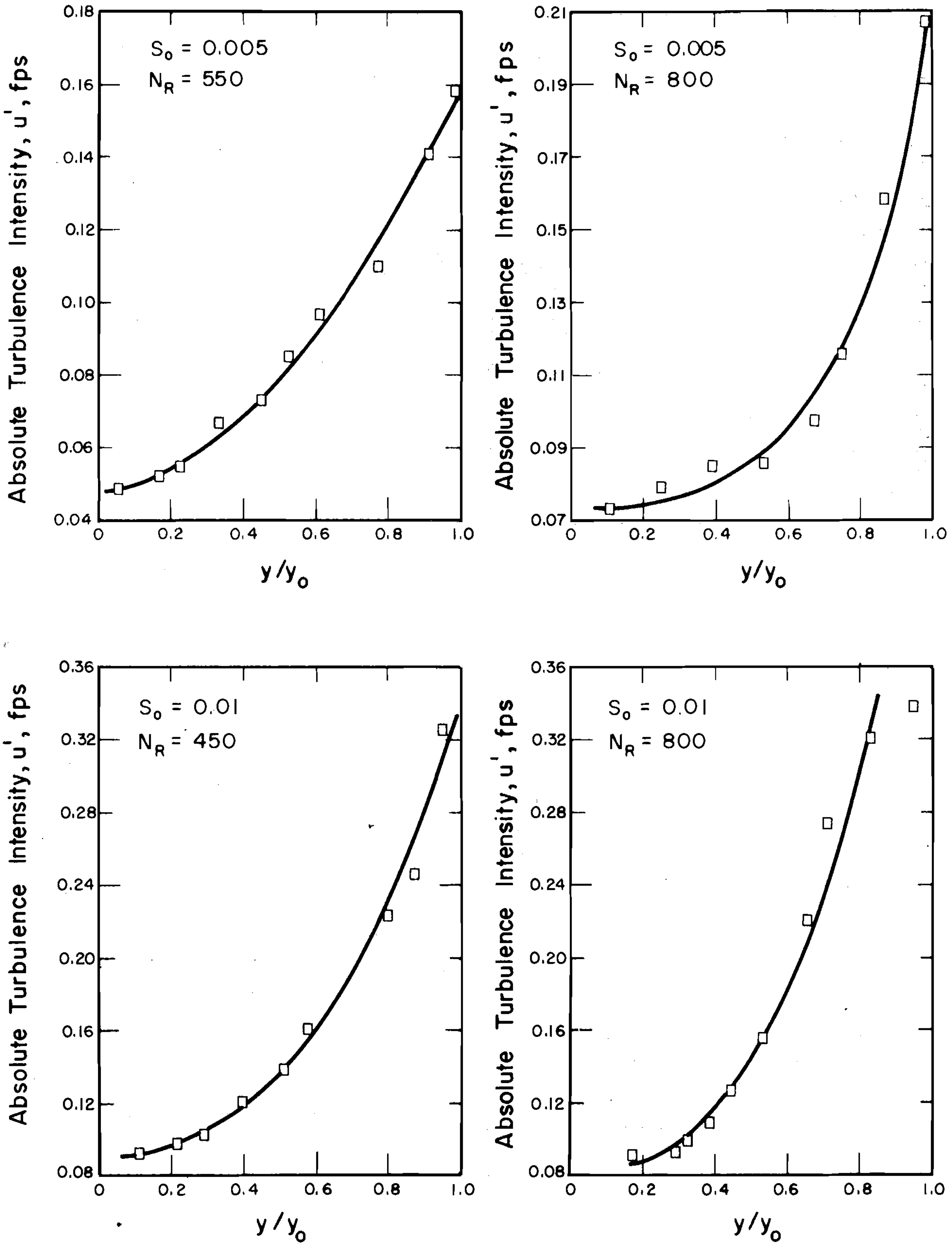

Fig. 18 Turbulence Intensity Profiles for i = 3.75 in./hr

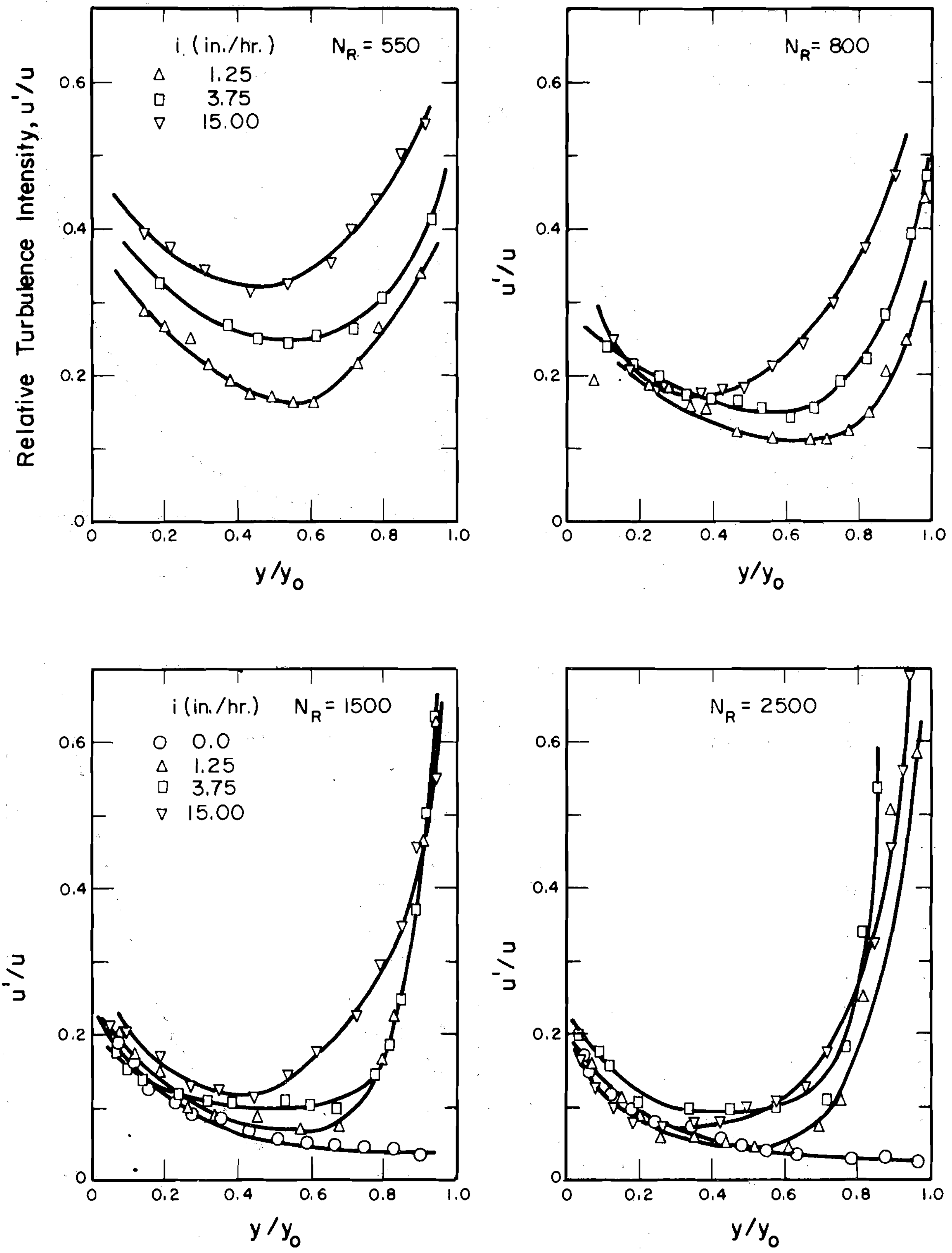

Fig. 19 Turbulence Intensity Profiles for $S_o = 0.005$

4.4.2 - Turbulent Energy Spectra

Energy spectra were obtained using the method described previously at three relative depths for the cases with and without rainfall at two different Reynolds numbers. In Fig. 20 the energy spectra for uniform flow of N_R = 4000 are shown. The total energy content is seen to increase with the decreasing relative depths, which could be expected in view of Eq. 2.15 and the turbulence intensity profile. The spectrum taken at y/y_o = 0.10 shows a somewhat larger energy content at the lower frequencies ($n < 20$ H_z) than the spectrum further away from the boundary at y/y_o = 0.95. This is in agreement with Raichlen's measurement (20).

In Figs. 21 and 22 the energy spectra for N_R = 4000, i = 3.75 and 15 in./hr are shown for different relative depths. In contrast to the uniform flow data, the total turbulent energy content at the same Reynolds number is much greater near the water surface than near the boundary. It is also greater near the boundary than near mid-depth possibly because the wall-generated turbulence intensity is higher at the boundary than at the mid-depth. This is well evidenced by the measured RMS velocity, u', shown in the figures. This shows, as do the turbulence intensity profiles, that much of the kinetic energy of the drops is transferred to turbulent energy near the surface. Another interesting finding is the effect of rainfall on the distribution of energy over the frequency range. It is shown that for both i = 3.75 and 15 in./hr the spectra at y/y_o = 0.95 show an increasing energy content at higher frequencies compared to the uniform flow case and to the case of y/y_o = 0.10 and 0.50 for both rainfall intensities. This agrees with the previous work done by Barfield (16). He reported that the time for which the autocorrelations becomes zero was markedly reduced by rainfall. Furthermore, he observed a substantial reduction in the time scale of turbulence due to the superimposed rainfall. Since the spectral density function is the Fourier transform of the autocorrelation function, the result of decreasing the time for which correlation approaches zero is the same as increasing the energy spectrum at the higher frequencies.

The energy spectra for N_R = 550, i = 3.75 and 15 in./hr are presented in Figs. 23 and 24. This flow would normally be laminar without rainfall and hence would have no turbulence energy if no rainfall were present. However, as shown in the figures considerable energy is present at this low Reynolds number due to the presence of rainfall. The total energy content of turbulence decreases as the boundary is approached, which agrees with the result of the absolute turbulence intensity profile previously shown in Fig. 18. The tendency toward an increasing energy content at higher frequencies as the free surface is approached is also apparent in the figures.

The energy spectra shown in Figs. 20-24 are replotted in Figs. 25-29 and compared to those obtained by Laufer (21) and Raichlen (20). The abscissa and ordinate have been normalized by multiplying by y_o/u and u/y_o, respectively.

It is seen in Fig. 25 that for uniform flow without rainfall the data indicate less energy at the higher frequencies than was observed by Laufer and Raichlen. This may be due to the significant difference in Reynolds numbers of the tests. Figures 26-29 all show clearly the shift of energy to higher frequencies, particularly near the surface, caused by rainfall.

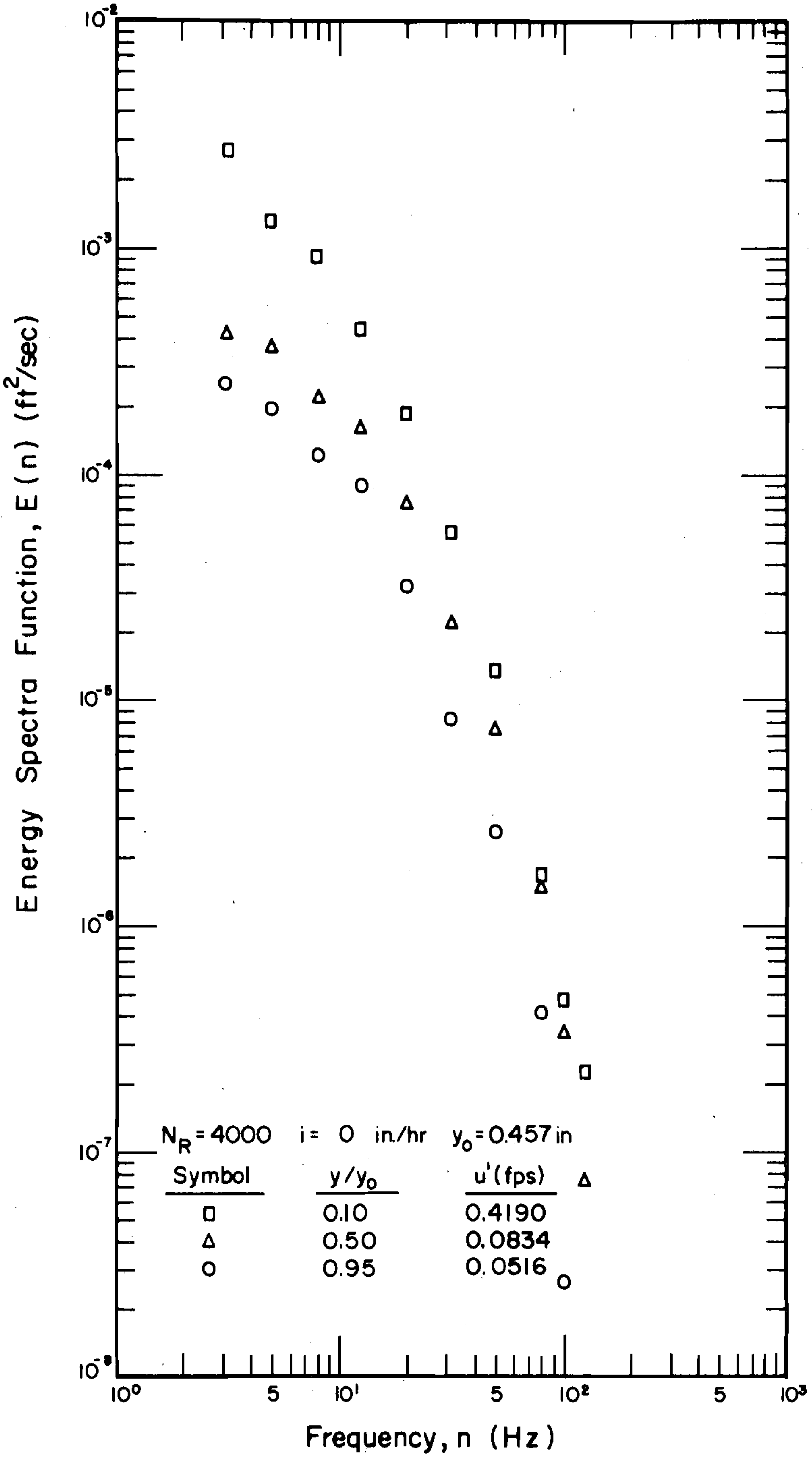

Fig. 20 Turbulent Energy Spectra for Uniform Flow at N_R = 4,000

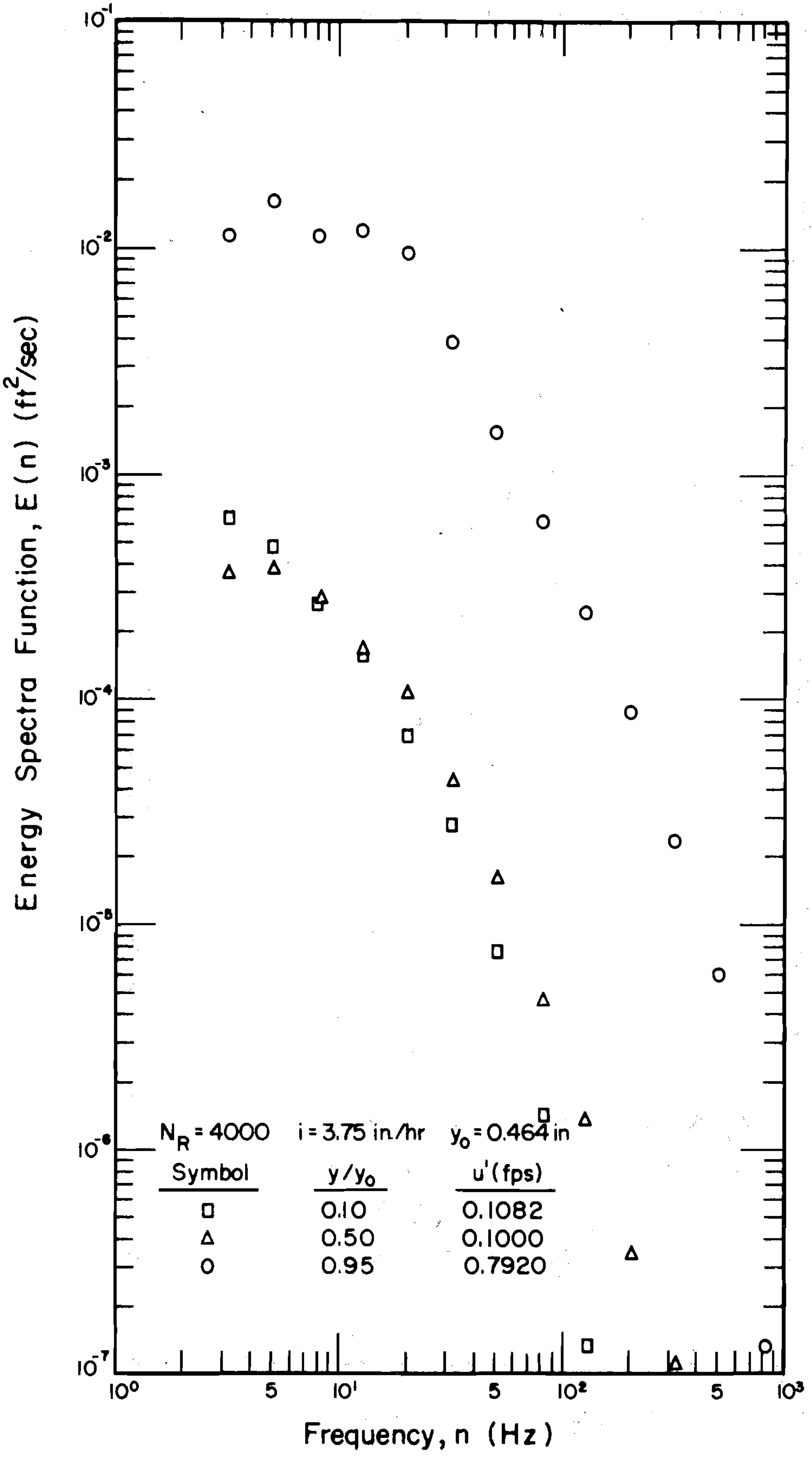

Fig. 21 Turbulent Energy Spectra for N_R = 4,000, i = 3.75 in./hr

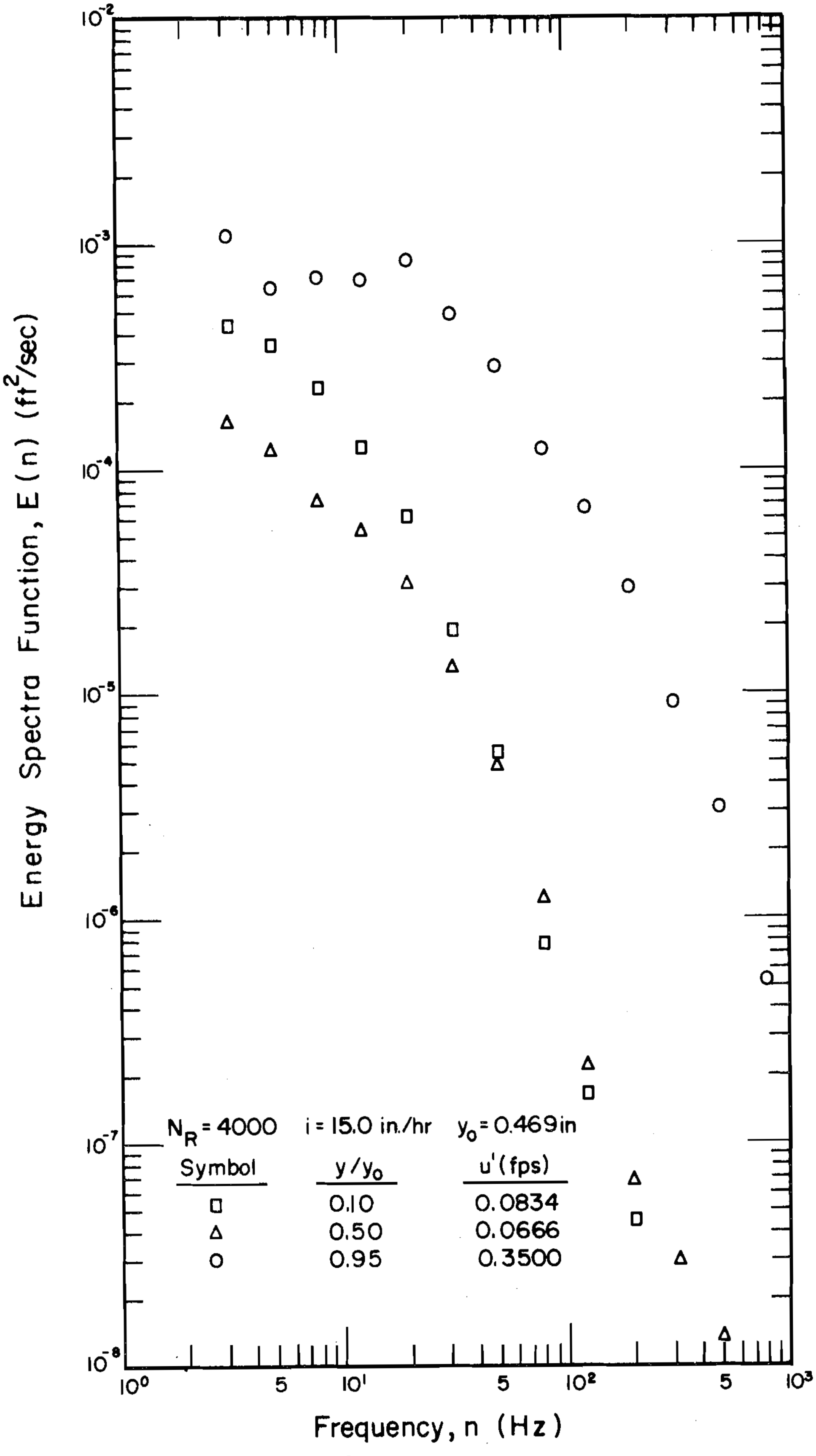

Fig. 22 Turbulent Energy Spectra for N_R = 4,000, i = 15 in./hr

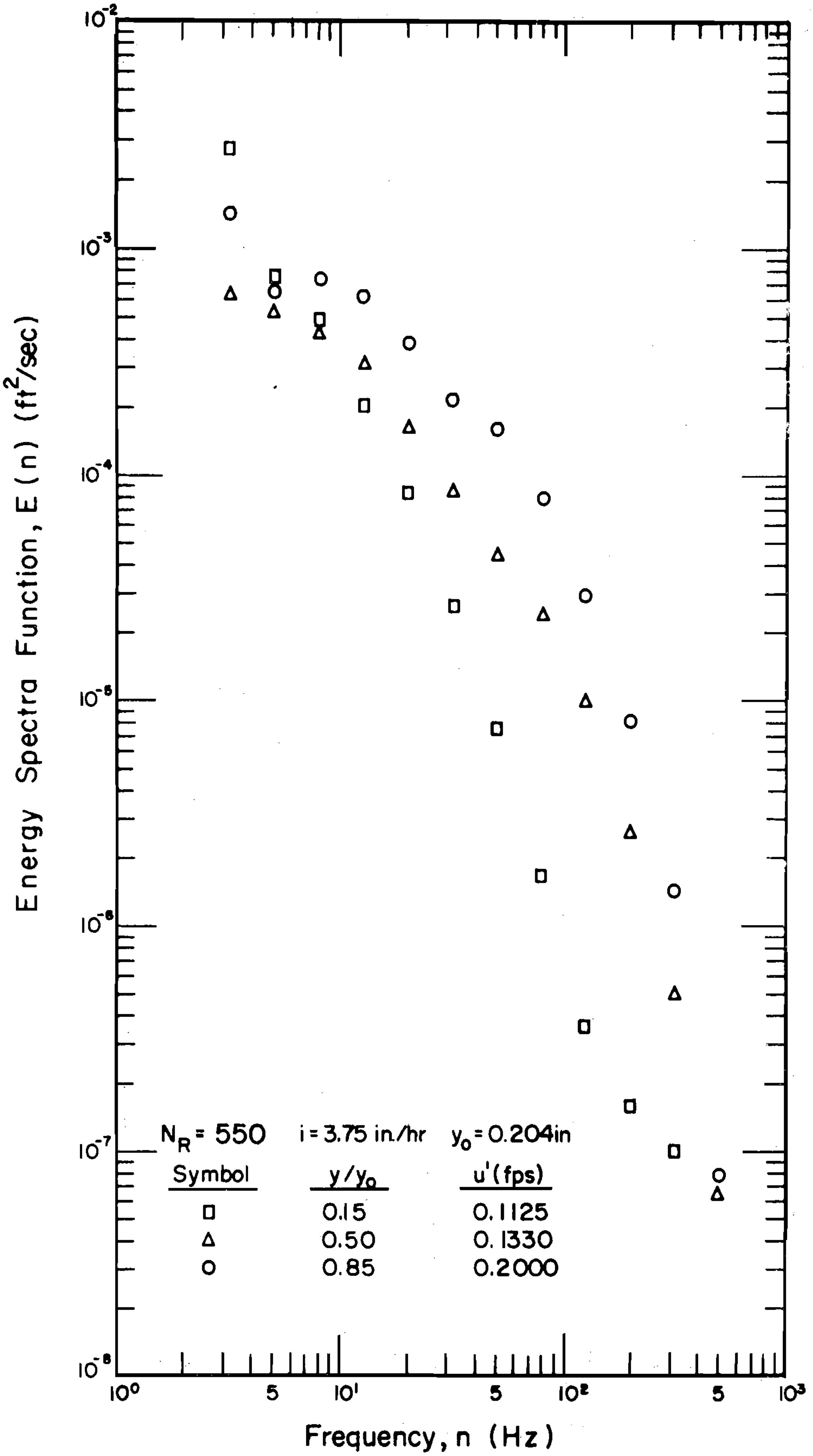

Fig. 23 Turbulent Energy Spectra for N_R = 550, i = 3.75 in./hr

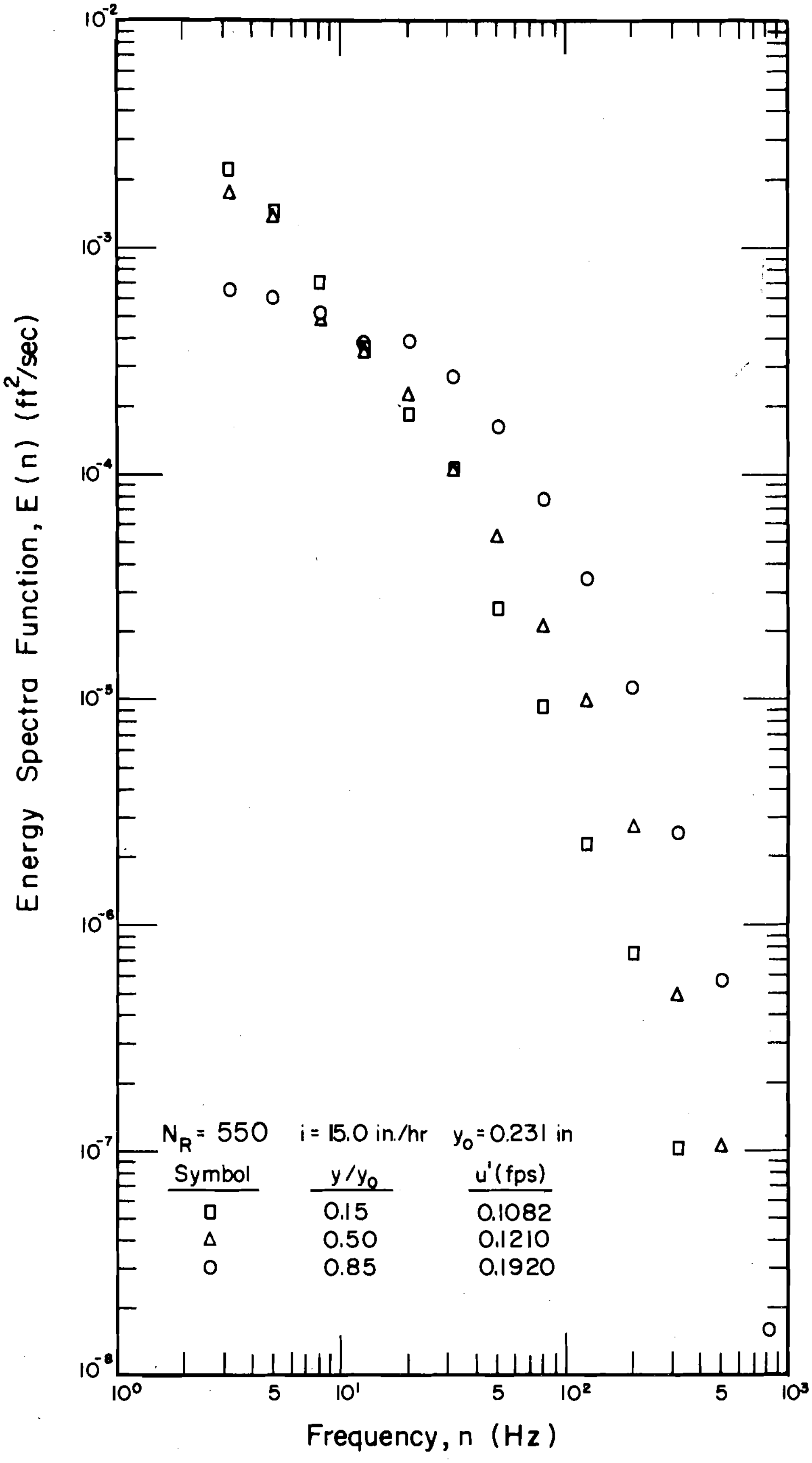

Fig. 24 Turbulent Energy Spectra for N_R = 550,
i = 15 in./hr

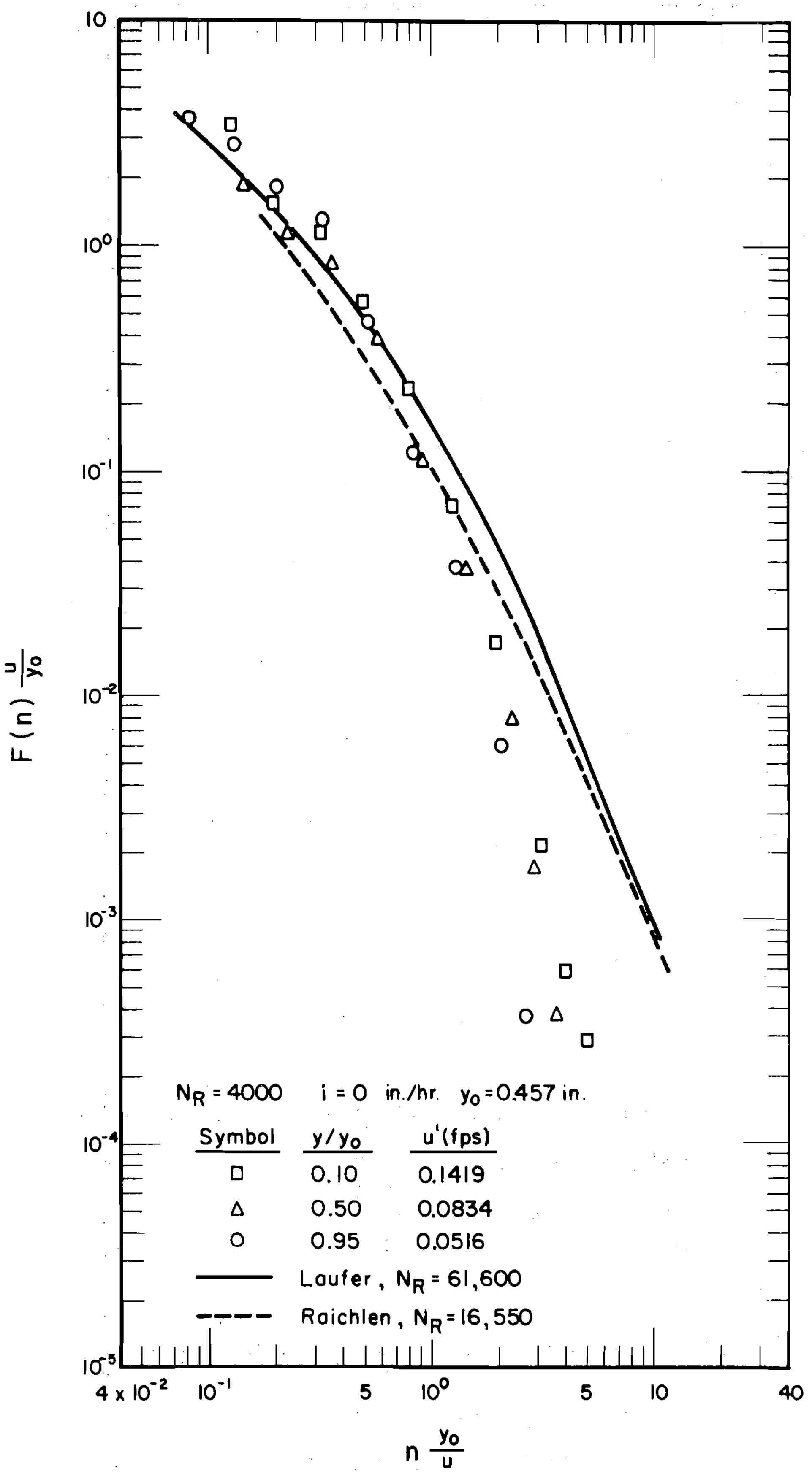

Fig. 25 Normalized Turbulent Energy Spectra for Uniform Flow at N_R = 4,000, i = 3.75 in./hr

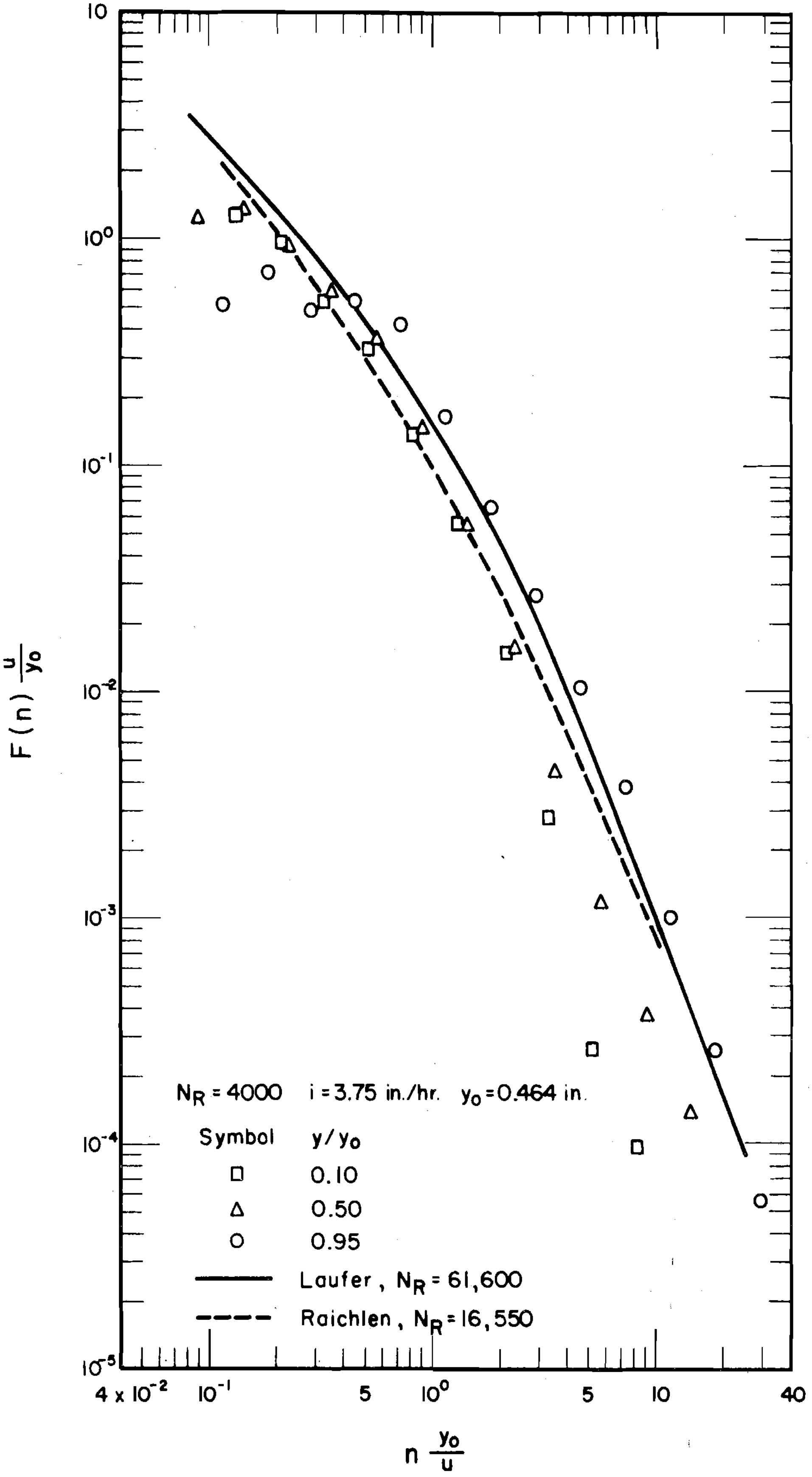

Fig. 26 – Normalized Turbulent Energy Spectra for $N_R = 4{,}000$, i = 3.75 in./hr

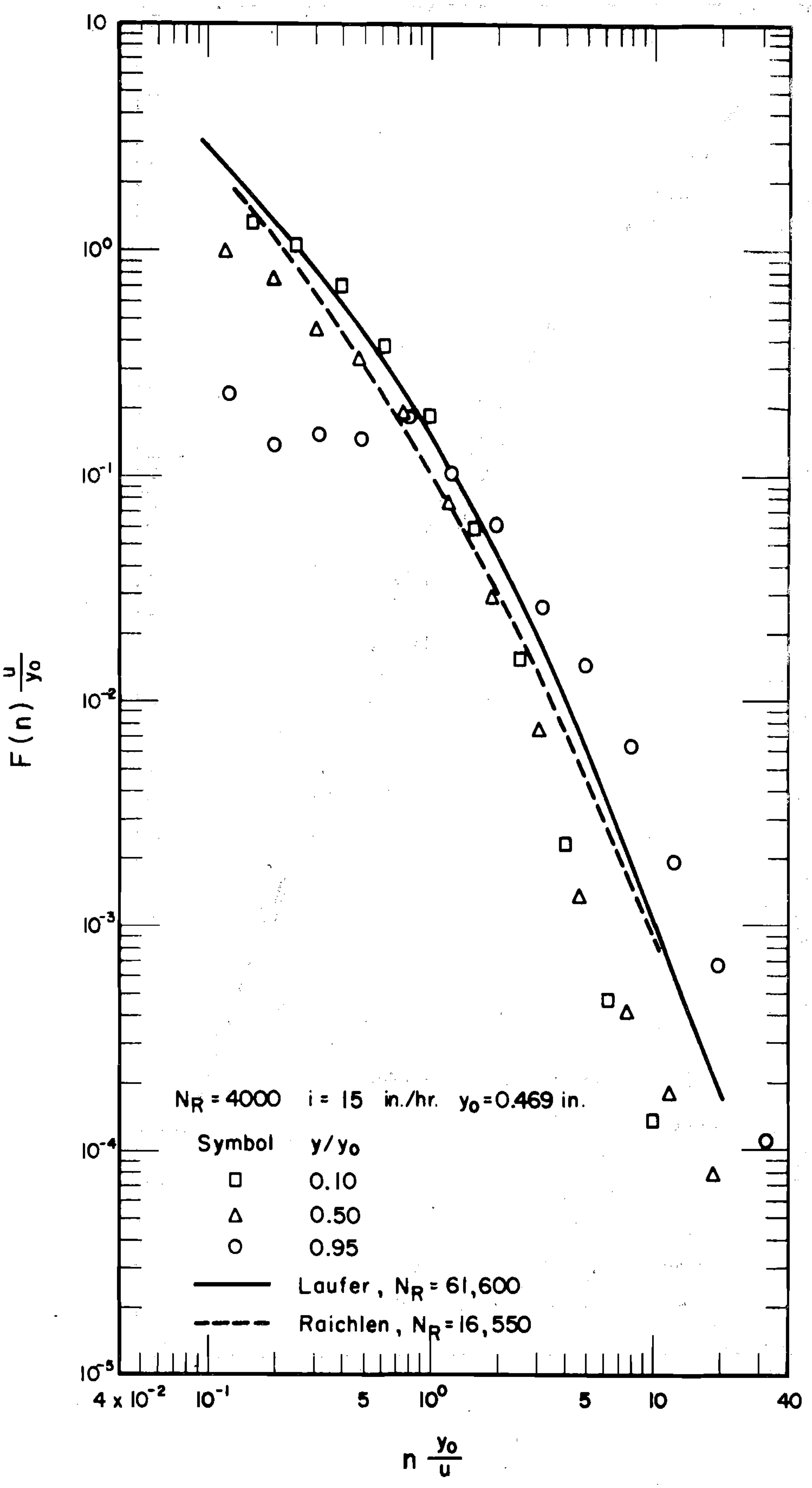

Fig. 27 Normalized Turbulent Energy Spectra for $N_R = 4{,}000$, i = 15 in./hr

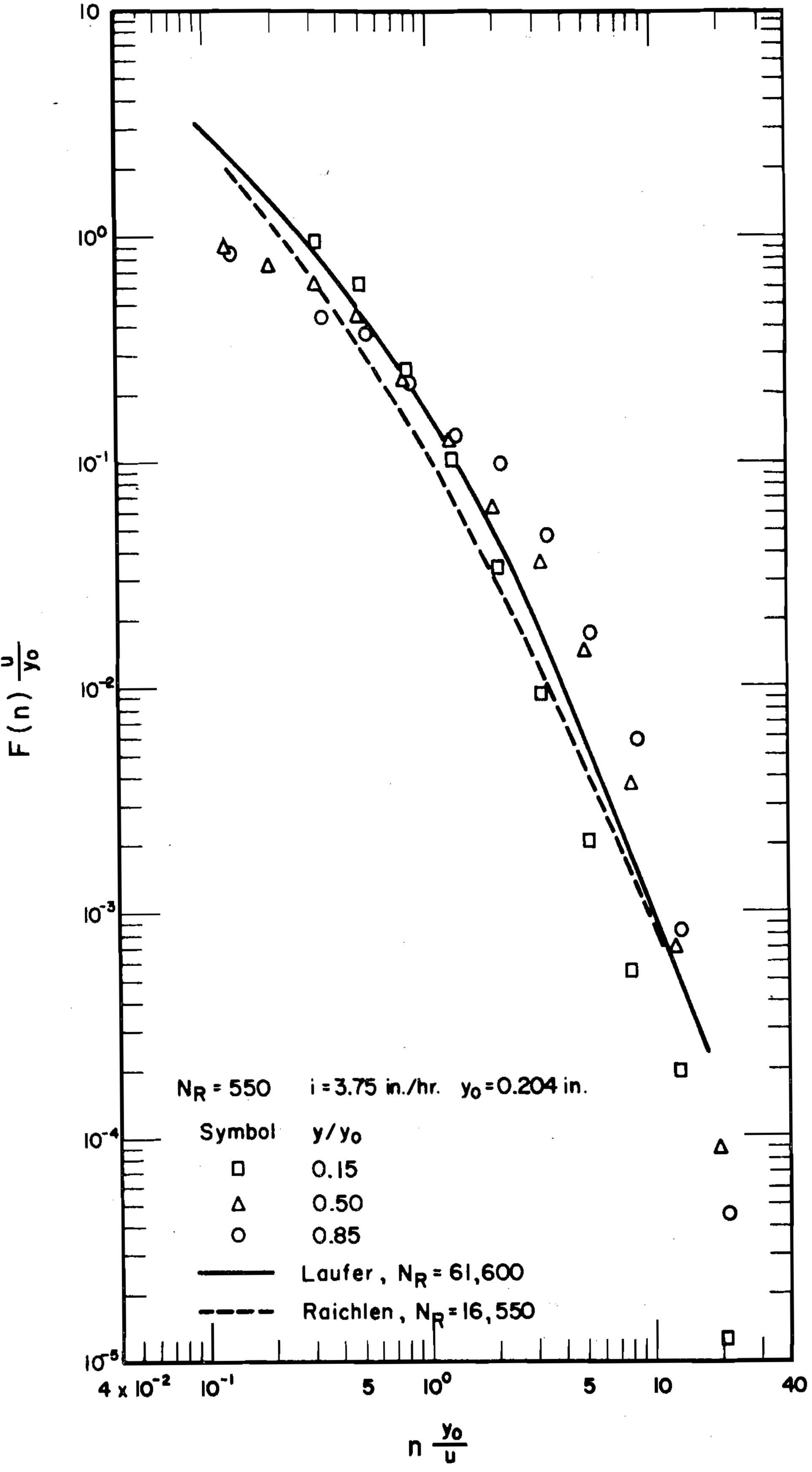

Fig. 28 Normalized Turbulent Energy Spectra for N_R = 550, i = 3.75 in./hr

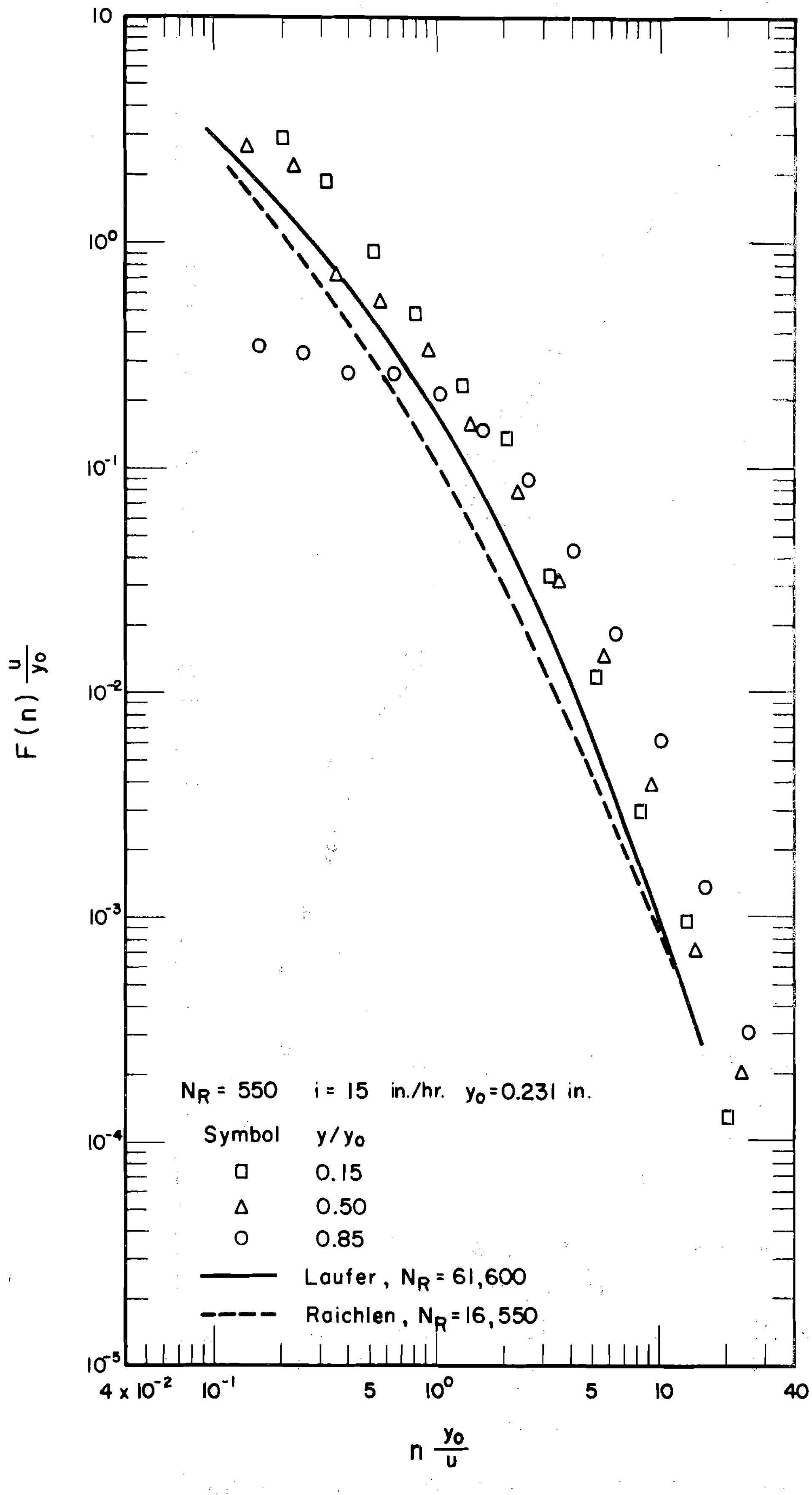

Fig. 29 Normalized Turbulent Energy Spectra for N_R = 550, i = 15 in./hr

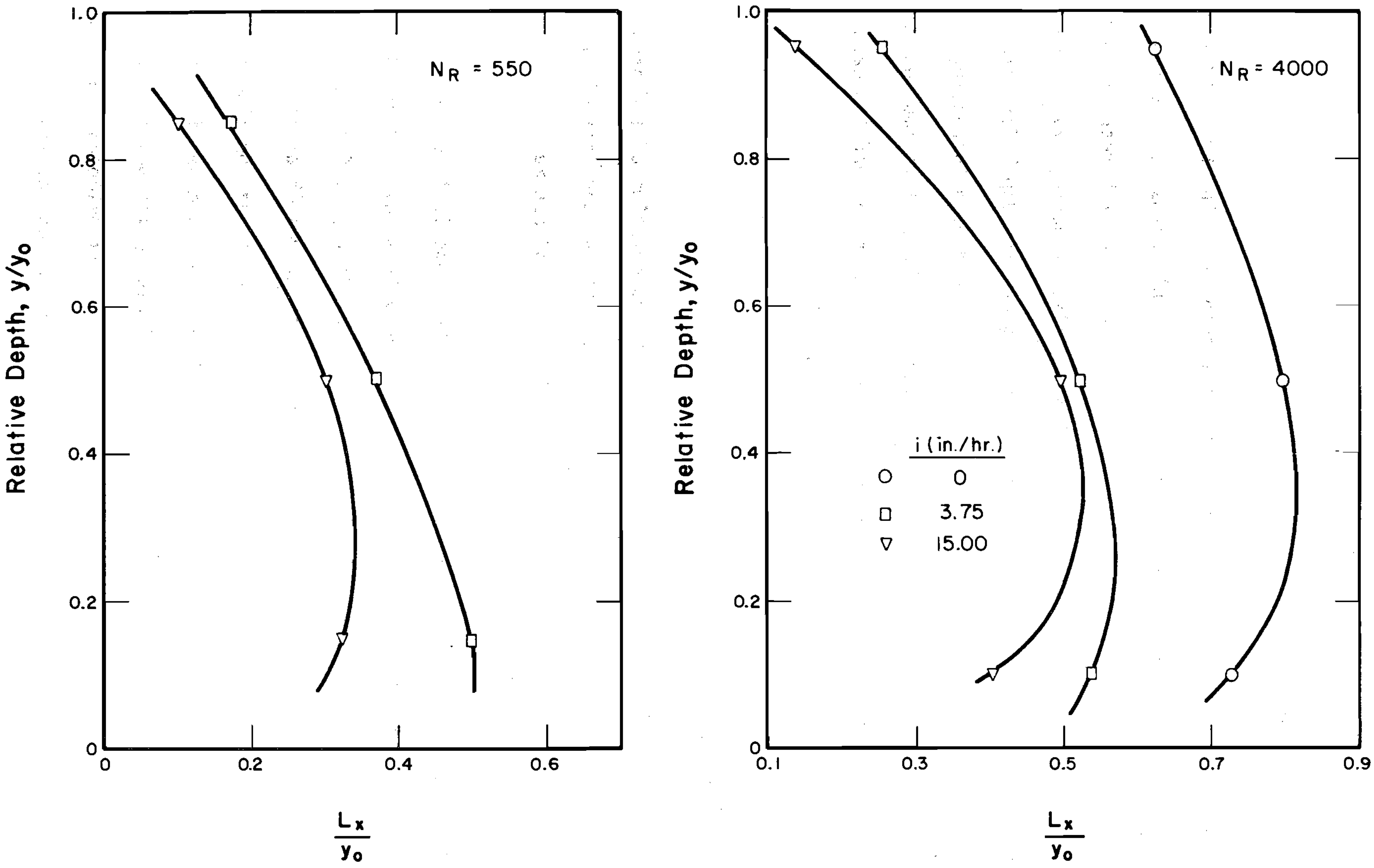

Fig. 30 Normalized Macroscale of Turbulence vs. Relative Depth

4.4.3 - Macroscale of Turbulence

The macroscale of turbulence were obtained using Eq. 2.18 with the estimation of n_{50} from the linear plot of F(n) versus n. The result is shown in Fig. 30. The macroscales were normalized with respect to the flow depth and are plotted as a function of relative depth, y/y_o. The rainfall clearly reduces the macroscale throughout the depth for both Reynolds numbers studied. The macroscale is reduced with increasing intensity at a given relative depth and Reynolds number. This implies that rainfall reduces the turbulence macroscale, or eddy size, and increases the energy spectrum at the higher frequencies.

4.5 - Single Drop Impact Study

The mathematical model permitted the computation of the pressure and velocity fields, free surface and shear stress as functions of time. Details of the results were presented by Wang (1) and are merely summarized here.

Figure 31 shows a typical plot of the dimensionless experimental and theoretical maximum impact pressure at the bottom which occurs directly under the drop impact point, and the water layer depth, h, for various values of drop impact velocity, V_o. Good agreement was obtained. Because the maximum pressure occurs very early in the process the non-linear terms in the equations have little effect and a dimensionless model for the maximum impact pressure at the bottom under the impact point was developed by plotting the data as shown in Fig. 32. A further dimensionless correlation of the radial pressure distribution along the bottom at the instant of maximum pressure is shown in Fig. 33.

Typical analytical results for the boundary shear stress at the bottom as functions of time and space are shown in Fig. 34. This shows that high local shears can develop. For example, using the water layer depth in Fig. 34 of 0.083 in., the boundary shear for uniform two-dimensional flow on a 1 percent slope is lower than the maximum shown by a factor of 1/42. This maximum is also approximately four times greater than the permissible tractive force for canals in noncohesive material with 1 mm particles as recommended by the Bureau of Reclamation. This would imply that the impact process would cause erosion.

Wang also presented examples of the vertical distribution of pressure, the velocity vector field and the configuration of the free surface. He showed that surface tension forces are significant throughout the impact process and that the region of influence of a drop is approximately one inch in diameter.

This work was limited because of the amount of computer time required but represents a first step in the deterministic approach to describing the effect of rainfall on sheet flow.

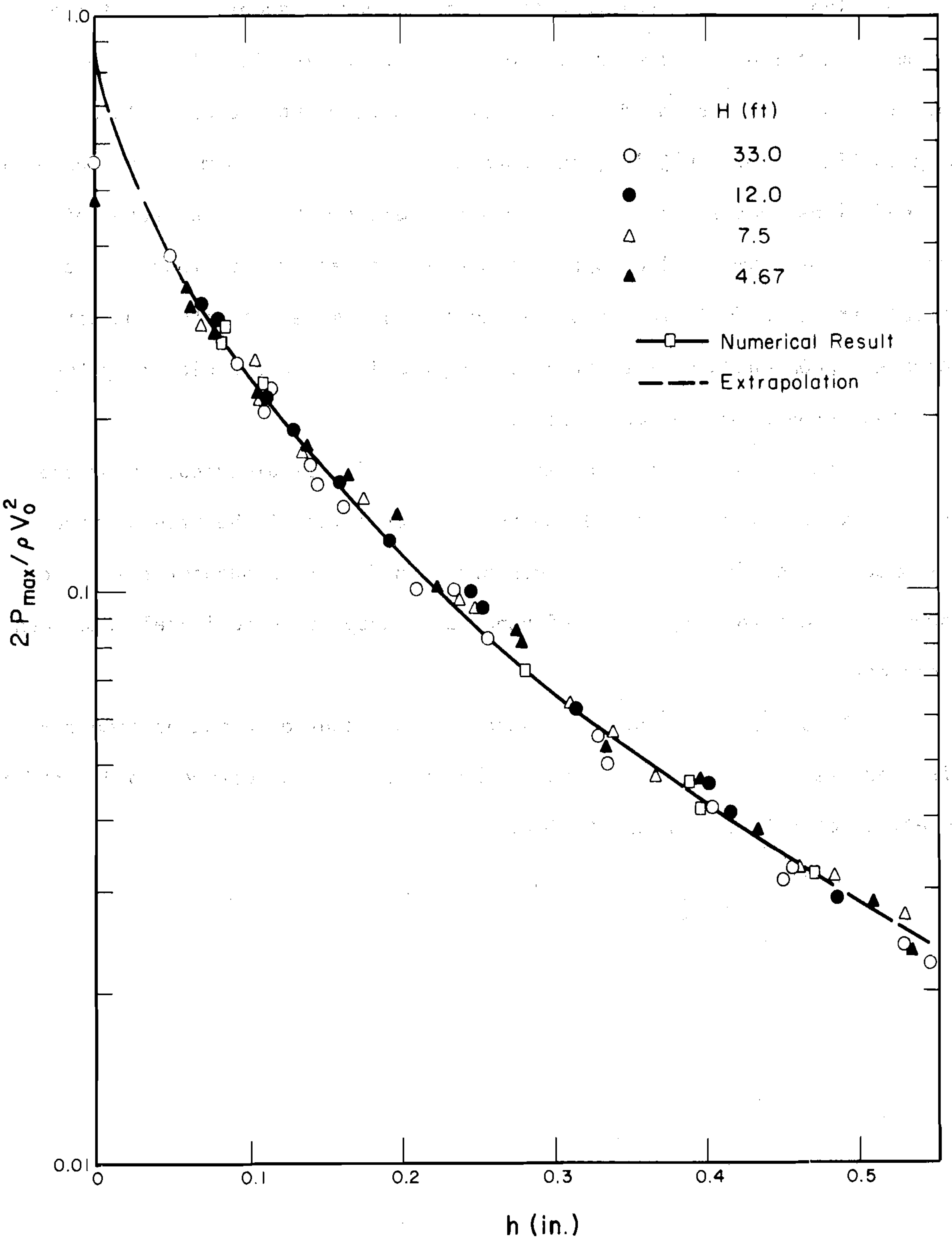

Fig. 31 Dimensionless Maximum Impact Presure vs. Depth for d = 3.12 mm

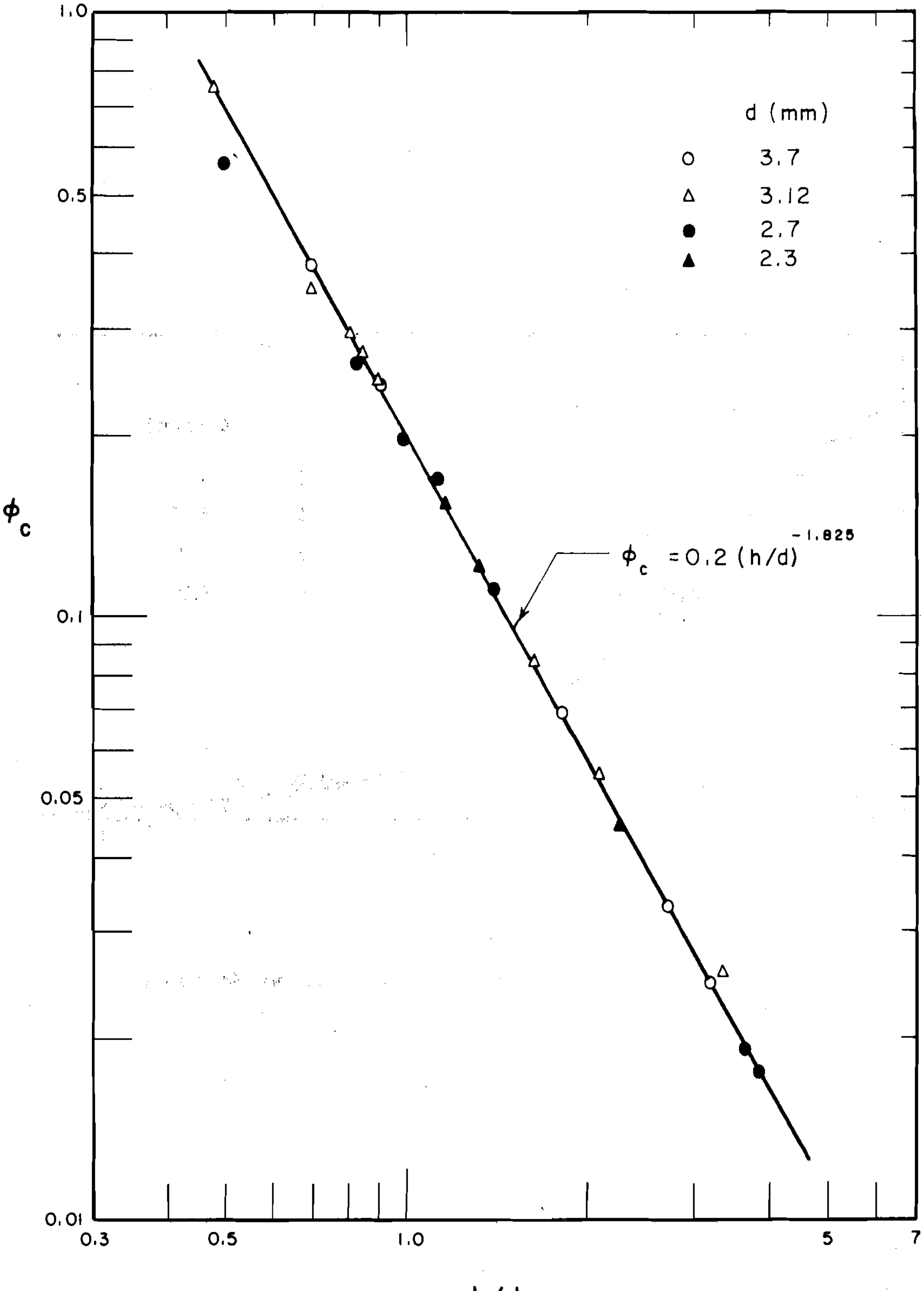

Fig. 32 Dimensionless Pressure vs. h/d

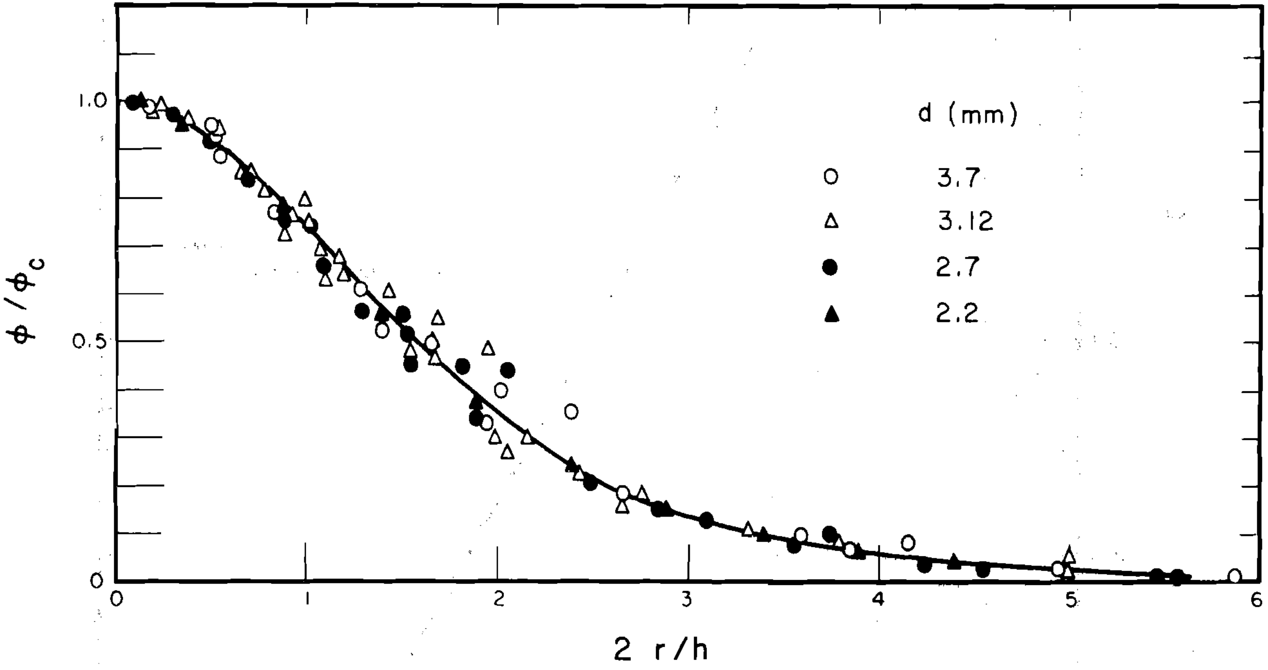

Fig. 33 Radial Variation in Pressure at Boundary

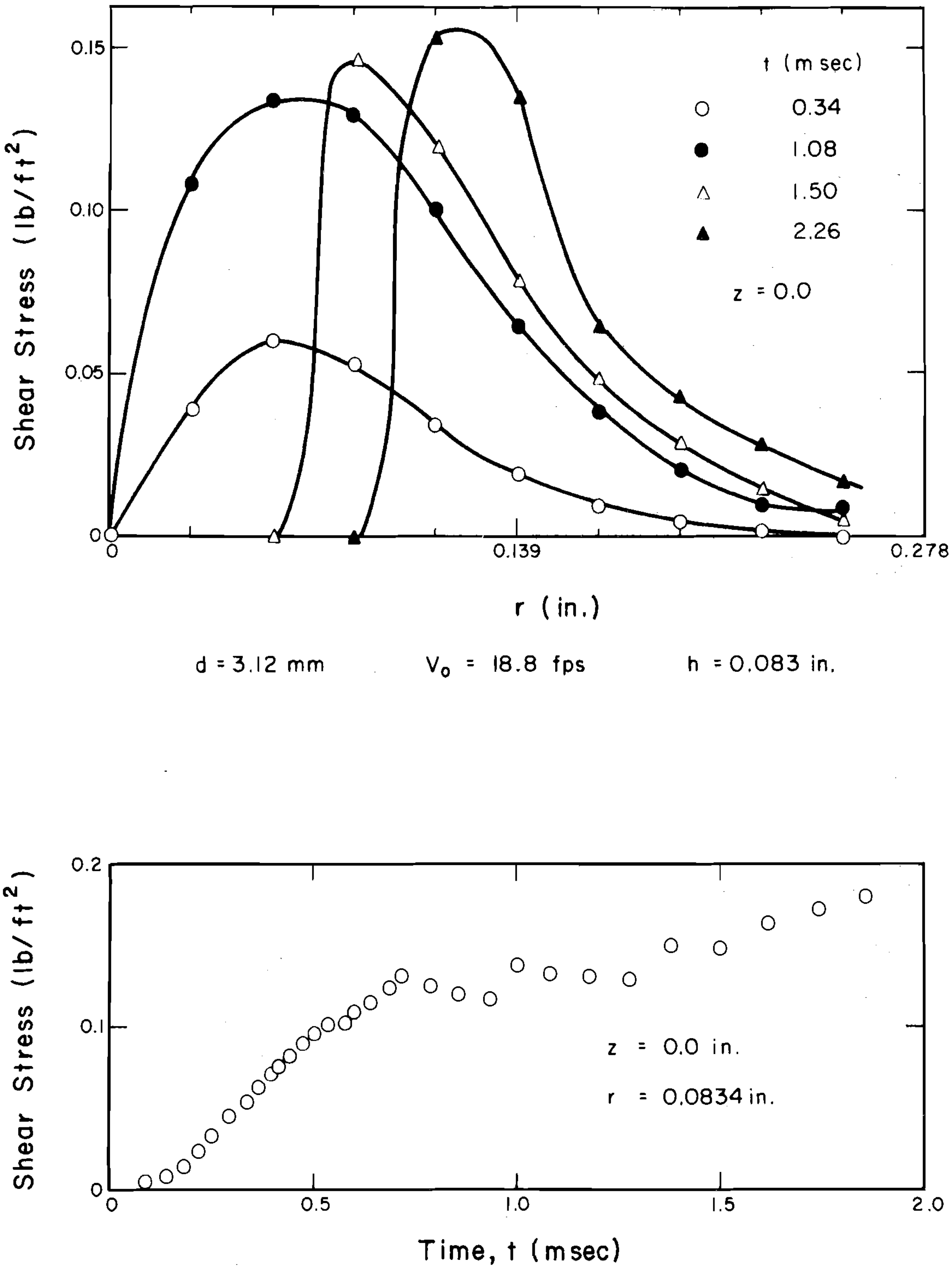

Fig. 34 Shear Stress Variation with r and t

5. CONCLUSIONS

The following conclusions are made based on the work reported here and by Wang (1) and Yoon (2).

Concerning flow resistance:

1. On a hydraulically smooth surface the presence of rainfall superimposed on sheet flow causes an increase in the fraction factor providing the Reynolds number is below the fully rough range. For Reynolds numbers below 1,000 Eq. 4.3 together with Fig. 12 can be used to describe the resistance as a function of surface slope and rainfall intensity.
2. The spacing of drops does not significantly effect resistance for the two spacings tested.
3. The impact velocity of the drops does not effect the friction factor within a physically realistic range.
4. The Froude number is not significant in regard to resistance on the subcritical range of flow.
5. Surface roughness appears to lower the transition Reynolds number and thus lowers the upper bound on the Reynolds number range in which rainfall may have a significant effect on resistance.

Concerning the mechanics of sheet flow with rainfall:

1. The local mean boundary shear stress computed from the spatially varied flow equation agrees well with measurements obtained using a flat surface hot-film sensor.

2. Rainfall reduces the mean velocity at a given Reynolds number (below 1,500) and hence increases the depth.
3. The velocity profile with rainfall is characterized by retardation near the free surface. A two part model can be used to describe the lower and upper regions of the profile.
4. The momentum coefficient decreases with increasing Reynolds number and rainfall intensity, reaching a value of 1.06 in the transition region.
5. The longitudinal relative turbulence intensity at a given relative depth increases substantially with increasing rainfall intensities for Reynolds numbers below 800. As the Reynolds number increases beyond this value the effect decreases. At a given rainfall intensity the relative turbulence intensity decreases with increasing Reynolds numbers except on the surface region where the rainfall intensity effect is dominant.
6. Turbulent energy spectra show that rainfall causes a shift of energy to higher frequencies than would be the case for uniform flow. This is more prominant near the free surface than near the boundary.

Concerning the mechanics of single drop impact:

1. The Synthetic-Cell-Fluid scheme introduced by Wang can be used to analyze this phenomenon.
2. Dimensionless impact pressure models for maximum pressure under the impact point and radially along the boundary as shown in Figs. 33 and 34 have been developed.

3. Significant local disturbance within a one inch diameter region occurs.
4. A Strong boundary shear force is generated during the impact process, initially directed radially outward from the impact point and then inward at later stages of the phenomenon. The magnitude of this force can be sufficient to cause soil erosion.
5. Surface tension cannot be neglected in any phase of the impact process.
6. The total energy dissipated through viscous action is small in the early phases of the impact process.

Time did not permit a detailed study of the effect of surface roughness. This is an obvious next step in a systematic study of this subject. Previous related studies concerning roughness have suffered from a lack of clear definition of depth or rather crude apparatus or laboratory procedures. Any future study must be careful to overcome these deficiencies if satisfactory results are to be obtained.

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APPENDIX

Surface Profile Data

S_o = 0.001
Drop spacing = 1 in.
U = 11.0 ft/sec

Note: X measured from upstream entrance
Y measured normal to channel bottom

i = 1.00 in./hr q_o = 0.0 cfs/ft T = 71.6°F		i = 1.00 in./hr q_o = 1.113×10^{-3} cfs/ft T = 66.9°F		i = 1.00 in./hr q_o = 2.040×10^{-3} cfs/ft T = 68.5°F		i = 1.00 in./hr q_o = 2.037×10^{-3} cfs/ft T = 67.6°F		i = 1.00 in./hr q_o = 3.030×10^{-3} cfs/ft T = 68.4°F	
X(ft)	Y(in.)	X(ft)	Y(in.)	X(ft)	Y(in.)	X(ft)	Y(in.)	X(ft)	Y(in.)
1	--	1	--	1	--	1	--	1	--
2	--	2	--	2	--	2	--	2	--
3	0.079	3	0.170	3	0.196	3	0.204	3	0.224
4	0.087	4	--	4	--	4	--	4	--
5	0.086	5	0.170	5	0.192	5	0.198	5	0.220
6	0.083	6	--	6	--	6	--	6	--
7	0.091	7	0.162	7	0.185	7	0.190	7	0.214
8	--	8	--	8	--	8	--	8	--
9	0.097	9	0.170	9	0.194	9	0.199	9	0.217
10	--	10	--	10	--	10	--	10	--
11	0.099	11	0.172	11	0.198	11	0.199	11	0.221
12	--	12	--	12	--	12	--	12	--
13	0.111	13	0.178	13	0.195	13	0.202	13	0.220
14	--	14	--	14	--	14	--	14	--
15	0.117	15	0.179	15	0.197	15	0.204	15	0.209
16	--	16	--	16	--	16	--	16	--
17	0.113	17	0.177	17	0.190	17	0.196	17	0.208
18	--	18	--	18	--	18	--	18	--
19	0.129	19	0.176	19	0.190	19	0.196	19	0.205
20	--	20	--	20	--	20	--	20	--
21	0.131	21	0.172	21	0.185	21	0.190	21	0.195
22	0.132	22	--	22	--	22	--	22	--
23	0.184	23	0.171	23	--	23	0.179	23	--
24	--	24	--	24	--	24	--	24	--

S_o = 0.001
Drop spacing = 1 in.
U = 11.0 ft/sec

Note: X measured from upstream entrance
Y measured normal to channel bottom

i = 1.00 in./hr $q_o = 0.457\times10^{-2}$ cfs/ft T = 67.6°F		i = 1.00 in./hr $q_o = 0.795\times10^{-2}$ cfs/ft T = 68.4°F		i = 1.00 in./hr $q_o = 1.070\times10^{-2}$ cfs/ft T = 69.7°F		i = 1.00 in./hr $q_o = 2.030\times10^{-2}$ cfs/ft T = 69.1°F		i = 1.01 in./hr $q_o = 3.080\times10^{-2}$ cfs/ft T = 68.7°F	
X(ft)	Y(in.)	X(ft)	Y(in.)	X(ft)	Y(in.)	X(ft)	Y(in.)	X(ft)	Y(in.)
1	--	1	--	1	--	1	--	1	--
2	--	2	--	2	--	2	--	2	--
3	0.254	3	0.320	3	0.369	3	0.498	3	0.614
4	--	4	--	4	--	4	--	4	--
5	0.252	5	0.317	5	0.364	5	0.497	5	0.614
6	--	6	--	6	--	6	--	6	--
7	0.244	7	0.307	7	0.351	7	0.496	7	0.613
8	--	8	--	8	--	8	--	8	--
9	0.250	9	0.314	9	0.360	9	0.494	9	0.610
10	--	10	--	10	--	10	--	10	--
11	0.253	11	0.316	11	0.364	11	0.493	11	0.607
12	--	12	--	12	--	12	--	12	--
13	0.253	13	0.316	13	0.360	13	0.490	13	0.600
14	--	14	--	14	--	14	--	14	--
15	0.253	15	0.316	15	0.357	15	0.483	15	0.589
16	--	16	--	16	--	16	--	16	--
17	0.239	17	0.314	17	0.341	17	0.472	17	0.569
18	--	18	--	18	--	18	--	18	--
19	0.245	19	0.297	19	0.332	19	0.457	19	0.546
20	--	20	--	20	--	20	---	20	--
21	0.225	21	0.276	21	0.316	21	0.435	21	0.518
22	--	22	0.259	22	0.296	22	--	22	--
23	0.197	23	0.244	23	0.277	23	--	23	--
24	--	24	--	24	--	24	--	24	--

$S_o = 0.001$
Drop spacing = 1 in.
$U = 8.8$ ft/sec

Note: X measured from upstream entrance
Y measured normal to channel bottom

$i = 4.95$ in./hr $q_o = 0.0$ cfs/ft $T = 67.6^\circ F$		$i = 4.91$ in./hr $q_o = 0.212 \times 10^{-2}$ cfs/ft $T = 63.8^\circ F$		$i = 4.87$ in./hr $q_o = 0.495 \times 10^{-2}$ cfs/ft $T = 63.1^\circ F$		$i = 4.99$ in./hr $q_o = 0.790 \times 10^{-2}$ cfs/ft $T = 63.3^\circ F$		$i = 4.91$ in./hr $q_o = 1.207 \times 10^{-2}$ cfs/ft $T = 62.5^\circ F$	
X(ft)	Y(in.)	X(ft)	Y(in.)	X(ft)	Y(in.)	X(ft)	Y(in.)	X(ft)	Y(in.)
1	0.147	1	--	1	--	1	--	1	--
2	--	2	0.250	2	0.313	2	0.359	2	0.422
3	0.153	3	0.245	3	0.308	3	0.355	3	0.410
4	0.165	4	0.245	4	0.305	4	0.353	4	0.413
5	0.163	5	0.248	5	0.302	5	0.353	5	0.411
6	0.173	6	0.251	6	0.309	6	0.356	6	0.416
7	0.170	7	0.245	7	0.303	7	0.352	7	0.411
8	0.174	8	0.244	8	0.299	8	0.348	8	0.406
9	0.185	9	0.260	9	0.316	9	0.360	9	0.418
10	--	10	0.266	10	0.319	10	0.366	10	0.422
11	0.198	11	0.263	11	0.320	11	0.364	11	--
12	--	12	--	12	--	12	--	12	0.416
13	0.201	13	0.270	13	0.320	13	0.364	13	0.424
14	--	14	--	14	--	14	--	14	0.431
15	0.209	15	0.268	15	0.319	15	0.367	15	0.417
16	--	16	--	16	--	16	--	16	--
17	0.202	17	0.257	17	0.309	17	0.350	17	0.401
18	--	18	--	18	--	18	--	18	--
19	0.204	19	0.251	19	0.300	19	0.340	19	0.391
20	--	20	--	20	--	20	--	20	--
21	0.198	21	0.239	21	0.278	21	0.319	21	0.369
22	--	22	--	22	--	22	--	22	--
23	0.181	23	0.206	23	0.242	23	0.278	23	0.333
24	--	24	--	24	--	24	--	24	--

S_o = 0.001

Drop spacing = 1 in.

U = 8.8 ft/sec

Note: X measured from upstream entrance

Y measured normal to channel bottom

i = 4.98 in./hr q_o = 1.674x10^{-2} cfs/ft T = 61.7°F		i = 4.95 in./hr q_o = 2.450x10^{-2} cfs/ft T = 67.1°F		i = 4.93 in./hr q_o = 3.500x10^{-2} cfs/ft T = 66.4°F		i = 4.57 in./hr q_o = 4.470x10^{-2} cfs/ft T = 64.9°F		i = 4.61 in./hr q_o = 5.730x10^{-2} cfs/ft T = 64.0°F	
X(ft)	Y(in.)	X(ft)	Y(in.)	X(ft)	Y(in.)	X(ft)	Y(in.)	X(ft)	Y(in.)
1	--	1	--	1	--	1	0.790	1	0.892
2	0.479	2	0.591	2	0.676	2	--	2	--
3	0.474	3	--	3	--	3	0.762	3	0.879
4	0.473	4	0.582	4	0.665	4	--	4	--
5	0.468	5	--	5	--	5	0.757	5	0.859
6	0.475	6	0.587	6	0.677	6	--	6	--
7	0.467	7	--	7	--	7	0.764	7	0.852
8	0.471	8	0.574	8	0.664	8	--	8	--
9	0.481	9	--	9	--	9	0.764	9	0.860
10	0.484	10	0.587	10	0.682	10	--	10	--
11	--	11	--	11	--	11	0.760	11	0.853
12	0.469	12	0.574	12	0.659	12	--	12	--
13	--	13	--	13	--	13	0.749	13	0.852
14	0.486	14	0.589	14	0.670	14	--	14	--
15	--	15	--	15	--	15	0.747	15	0.837
16	0.464	16	0.559	16	0.643	16	--	16	--
17	--	17	--	17	--	17	0.721	17	0.806
18	0.455	18	0.537	18	0.621	18	--	18	--
19	--	19	--	19	--	19	0.691	19	0.783
20	0.434	20	0.517	20	0.595	20	--	20	--
21	--	21	--	21	--	21	0.648	21	0.741
22	0.400	22	0.464	22	0.546	22	--	22	--
23	--	23	0.410	23	0.498	23	0.580	23	0.667
24	--	24	--	24	--	24	--	24	--

S_o = 0.001
Drop spacing = 1 in.
U = 8.8 ft/sec

Note: X measured from upstream entrance
Y measured normal to channel bottom

i = 10.44 in./hr q_o = 0.0 cfs/ft T = 65.7°F		i = 10.08 in./hr q_o = 0.500×10^{-2} cfs/ft T = 65.5°F		i = 10.04 in./hr q_o = 1.000×10^{-2} cfs/ft T = 64.9°F		i = 9.95 in.hr q_o = 1.700×10^{-2} cfs/ft T = 66.0°F		i = 9.95 in./hr q_o = 3.000×10^{-2} cfs/ft T = 66.2°F	
X(ft)	Y(in.)	X(ft)	Y(in.)	X(ft)	Y(in.)	X(ft)	Y(in.)	X(ft)	Y(in.)
1	--	1	--	1	--	1	--	1	--
2	0.231	2	0.353	2	0.438	2	0.530	2	0.671
3	0.232	3	0.352	3	0.431	3	0.526	3	0.669
4	0.242	4	0.350	4	0.432	4	0.524	4	0.668
5	0.245	5	0.350	5	0.426	5	0.520	5	0.667
6	0.258	6	0.363	6	0.436	6	0.527	6	0.668
7	0.253	7	0.354	7	0.428	7	0.516	7	0.659
8	0.258	8	0.350	8	0.426	8	0.515	8	0.658
9	0.272	9	0.363	9	0.445	9	0.526	9	0.666
10	0.278	10	0.368	10	0.444	10	0.533	10	0.666
11	0.278	11	0.372	11	0.444	11	0.532	11	0.661
12	--	12	--	12	--	12	--	12	--
13	0.288	13	0.373	13	0.444	13	0.533	13	0.659
14	--	14	--	14	--	14	--	14	--
15	0.288	15	0.368	15	0.441	15	0.526	15	0.640
16	--	16	--	16	--	16	--	16	--
17	0.280	17	0.361	17	0.426	17	0.510	17	0.618
18	--	18	--	18	--	18	--	18	0.617
19	0.274	19	0.348	19	0.413	19	0.495	19	0.615
20	--	20	--	20	--	20	--	20	--
21	0.261	21	0.325	21	0.391	21	0.461	21	0.554
22	--	22	--	22	--	22	--	22	--
23	0.218	23	0.285	23	0.348	23	0.398	23	0.493
24	--	24	--	24	--	24	--	24	--

S_o = 0.001
Drop spacing = 1 in.
U = 8.8 ft/sec

Note: X measured from upstream entrance
Y measured normal to channel bottom

i = 10.08 in./hr q_o = 3.670×10^{-2} cfs/ft T = 65.1°F		i = 10.12 in./hr q_o = 4.370×10^{-2} cfs/ft T = 64.6°F		i = 14.99 in./hr q_o = 0.0 cfs/ft T = 61.7°F		i = 14.99 in./hr q_o = 0.467×10^{-2} cfs/ft T = 65.3°F		i = 14.81 in./hr q_o = 1.052×10^{-2} cfs/ft T = 64.7°F	
X(ft)	Y(in.)	X(ft)	Y(in.)	X(ft)	Y(in.)	X(ft)	Y(in.)	X(ft)	Y(in.)
1	--	1	--	1	--	1	--	1	--
2	0.758	2	0.809	2	0.302	2	0.393	2	0.477
3	0.743	3	0.797	3	0.301	3	0.381	3	0.472
4	0.736	4	0.793	4	0.306	4	0.384	4	0.474
5	0.739	5	0.795	5	0.313	5	0.389	5	0.473
6	0.737	6	0.787	6	0.319	6	0.398	6	0.477
7	0.719	7	0.779	7	0.320	7	0.382	7	0.470
8	0.714	8	0.802	8	0.318	8	0.382	8	0.471
9	0.740	9	0.789	9	0.335	9	0.397	9	0.486
10	0.739	10	0.809	10	0.342	10	0.407	10	0.492
11	0.730	11	0.785	11	0.347	11	0.412	11	0.492
12	--	12	--	12	--	12	--	12	--
13	0.721	13	0.787	13	0.354	13	0.419	13	0.491
14	--	14	--	14	--	14	--	14	--
15	0.716	15	0.768	15	0.359	15	0.413	15	0.490
16	--	16	--	16	--	16	--	16	--
17	0.686	17	0.739	17	0.346	17	0.405	17	0.472
18	--	18	--	18	--	18	--	18	--
19	0.649	19	0.723	19	0.339	19	0.392	19	0.466
20	--	20	--	20	--	20	--	20	--
21	0.627	21	0.689	21	0.317	21	0.372	21	0.438
22	--	22	--	22	--	22	--	22	--
23	0.559	23	0.600	23	0.276	23	0.336	23	0.381
24	--	24	--	24	--	24	--	24	--

S_o = 0.001
Drop spacing = 1 in.
U = 8.8 ft/sec

Note: X measured from upstream entrance
Y measured normal to channel bottom

i = 14.99 in./hr q_o = 1.770×10^{-2} cfs/ft T = 63.1°F		i = 14.99 in./hr q_o = 3.230×10^{-2} cfs/ft T = 62.6°F		i = 15.30 in./hr q_o = 5.970×10^{-2} cfs/ft T = 63.5°F	
X(ft)	Y(in.)	X(ft)	Y(in.)	X(ft)	Y(in.)
1	--	1	--	1	--
2	0.581	2	0.747	2	0.987
3	0.571	3	0.736	3	0.993
4	0.575	4	0.737	4	0.948
5	0.574	5	0.733	5	0.949
6	0.581	6	0.742	6	0.970
7	0.572	7	0.730	7	0.931
8	0.570	8	0.725	8	0.958
9	0.586	9	0.727	9	0.957
10	0.588	10	0.737	10	0.940
11	0.588	11	0.741	11	0.965
12	--	12	--	12	--
13	0.585	13	0.724	13	0.932
14	--	14	--	14	--
15	0.581	15	0.718	15	0.920
16	--	16	--	16	--
17	0.564	17	0.703	17	0.902
18	--	18	--	18	--
19	0.546	19	0.668	19	0.892
20	--	20	--	20	--
21	0.514	21	0.629	21	0.856
22	--	22	--	22	--
23	0.435	23	0.554	23	0.718
24	--	24	--	24	--

S_o = 0.005
Drop spacing = 1 in.
U = 11.0 ft/sec

Note: X measured from upstream entrance
Y measured normal to channel bottom

i = 0.95 in./hr q_o = 0.0 cfs/ft T = 68.7°F		i = 0.95 in./hr q_o = 0.154×10^{-2} cfs/ft T = 68.5°F		i = 0.01 in./hr q_o = 0.267×10^{-2} cfs/ft T = 68.0°F		i = 1.00 in./hr q_o = 0.459×10^{-2} cfs/ft T = 68.2°F		i = 1.03 in./hr q_o = 0.657×10^{-2} cfs/ft T = 68.0°F	
X(ft)	Y(in.)	X(ft)	Y(in.)	X(ft)	Y(in.)	X(ft)	Y(in.)	X(ft)	Y(in.)
1	--	1	--	1	--	1	--	1	--
2	--	2	--	2	--	2	--	2	--
3	--	3	0.107	3	0.131	3	0.152	3	0.169
4	--	4	--	4	--	4	--	4	--
5	0.039	5	0.102	5	0.122	5	0.147	5	0.165
6	--	6	--	6	--	6	--	6	--
7	0.045	7	0.110	7	0.130	7	0.159	7	0.185
8	--	8	--	8	--	8	--	8	--
9	0.054	9	0.108	9	0.127	9	0.157	9	0.172
10	--	10	--	10	--	10	--	10	--
11	0.056	11	0.115	11	0.135	11	0.156	11	0.173
12	--	12	--	12	--	12	--	12	--
13	0.059	13	0.111	13	0.128	13	0.158	13	0.170
14	--	14	--	14	--	14	--	14	--
15	0.057	15	0.116	15	0.125	15	0.160	15	0.180
16	--	16	--	16	--	16	--	16	--
17	0.051	17	0.106	17	0.124	17	0.155	17	0.169
18	--	18	--	18	--	18	--	18	--
19	0.055	19	0.111	19	0.125	19	0.156	19	0.171
20	--	20	--	20	--	20	--	20	--
21	0.062	21	0.113	21	0.130	21	0.152	21	0.165
22	--	22	--	22	--	22	--	22	--
23	--	23	--	23	--	23	--	23	--
24	--	24	--	24	--	24	--	24	--

S_o = 0.005
Drop spacing = 1 in.
U = 11.0 ft/sec

Note: X measured from upstream entrance
Y measured normal to channel bottom

i = 1.01 in./hr $q_o = 1.083\times10^{-2}$ cfs/ft T = 67.8°F		i = 1.03 in./hr $q_o = 2.460\times10^{-2}$ cfs/ft T = 67.3°F		i = 1.01 in./hr $q_o = 5.460\times10^{-2}$ cfs/ft T = 67.1°F		i = 2.72 in./hr $q_o = 0.615\times10^{-2}$ cfs/ft T = 66.3°F		i = 2.72 in./hr $q_o = 0.856\times10^{-2}$ cfs/ft T = 66.7°F	
X(ft)	Y(in.)	X(ft)	Y(in.)	X(ft)	Y(in.)	X(ft)	Y(in.)	X(ft)	Y(in.)
1	--	1	--	1	--	1	--	1	--
2	--	2	--	2	--	2	--	2	0.210
3	0.210	3	0.332	3	0.522	3	0.173	3	--
4	--	4	--	4	--	4	--	4	0.211
5	0.201	5	0.311	5	0.500	5	0.173	5	--
6	--	6	--	6	--	6	--	6	0.213
7	0.223	7	0.326	7	0.502	7	0.179	7	--
8	--	8	--	8	--	8	--	8	0.198
9	0.208	9	0.305	9	0.480	9	0.170	9	--
10	--	10	--	10	--	10	--	10	0.216
11	0.243	11	0.360	11	0.509	11	0.189	11	--
12	--	12	--	12	--	12	--	12	0.212
13	0.204	13	0.309	13	0.486	13	0.173	13	--
14	--	14	--	14	--	14	--	14	0.224
15	0.239	15	0.348	15	0.510	15	0.194	15	--
16	--	16	--	16	--	16	--	16	0.222
17	0.221	17	0.322	17	0.495	17	0.185	17	--
18	--	18	--	18	--	18	--	18	0.217
19	0.215	19	0.328	19	0.505	19	0.188	19	--
20	--	20	--	20	--	20	--	20	0.214
21	0.221	21	0.335	21	0.503	21	0.189	21	--
22	--	22	--	22	--	22	--	22	0.214
23	--	23	0.330	23	--	23	0.184	23	--
24	--	24	--	24	--	24	--	24	--

S_o = 0.005
Drop spacing = 1 in.

Note: X measured from upstream entrance
Y measured normal to channel bottom

i = 2.68 in./hr U = 11.0 ft/sec q_o = 1.190x10^{-2} cfs/ft T = 68.9°F		i = 2.76 in./hr U = 11.0 ft/sec q_o = 1.73x10^{-2} cfs/ft T = 66.2°F		i = 4.93 in./hr U = 8.8 ft/sec q_o = 0.0 cfs/ft T = 64.0°F		i = 4.93 in./hr U = 8.8 ft/sec q_o = 4.060x10^{-2} cfs/ft T = 63.7°F		i = 4.91 in./hr U = 21.0 ft/sec q_o = 0.0 cfs/ft T = 70.8°F	
X(ft)	Y(in.)	X(ft)	Y(in.)	X(ft)	Y(in.)	X(ft)	Y(in.)	X(ft)	Y(in.)
1	--	1	0.251	1	--	1	--	1	0.067
2	0.228	2	--	2	--	2	--	2	0.074
3	--	3	0.262	3	0.087	3	0.434	3	0.083
4	0.225	4	--	4	0.089	4	0.435	4	0.091
5	--	5	0.251	5	0.091	5	0.429	5	0.080
6	0.232	6	--	6	0.093	6	0.429	6	0.100
7	--	7	0.275	7	0.093	7	0.441	7	0.093
8	0.214	8	--	8	0.096	8	0.432	8	0.094
9	--	9	0.239	9	0.105	9	0.408	9	0.107
10	0.227	10	--	10	0.111	10	0.421	10	0.110
11	--	11	0.288	11	0.117	11	0.448	11	0.116
12	0.233	12	--	12	0.107	12	0.457	12	0.111
13	--	13	0.241	13	0.112	13	0.424	13	0.116
14	0.254	14	--	14	0.121	14	0.431	14	0.127
15	--	15	0.294	15	0.124	15	0.461	15	0.131
16	0.241	16	0.275	16	0.130	16	0.458	16	0.124
17	--	17	0.277	17	0.123	17	0.451	17	0.125
18	0.230	18	--	18	0.121	18	0.441	18	0.129
19	--	19	0.268	19	0.125	19	0.439	19	0.131
20	0.230	20	--	20	0.127	20	0.440	20	0.130
21	--	21	0.272	21	0.129	21	0.433	21	0.135
22	0.224	22	--	22	0.122	22	0.428	22	0.136
23	0.219	23	0.255	23	--	23	--	23	--
24	--	24	--	24	--	24	--	24	--

S_o = 0.005
Drop spacing = 1 in.
U = 21.0 ft/sec

Note: X measured from upstream entrance
Y measured normal to channel bottom

i = 4.98 in./hr $q_o = 0.240 \times 10^{-2}$ cfs/ft T = 70.5°F		i = 4.99 in./hr $q_o = 0.405 \times 10^{-2}$ cfs/ft T = 71.0°F		i = 4.93 in./hr $q_o = 0.647 \times 10^{-2}$ cfs/ft T = 66.4°F		i = 4.91 in./hr $q_o = 0.937 \times 10^{-2}$ cfs/ft T = 70.0°F		i = 4.99 in./hr $q_o = 4.450 \times 10^{-2}$ cfs/ft T = 68.0°F	
X(ft)	Y(in.)	X(ft)	Y(in.)	X(ft)	Y(in.)	X(ft)	Y(in.)	X(ft)	Y(in.)
1	--	1	--	1	--	1	--	1	--
2	--	2	--	2	--	2	--	2	--
3	--	3	0.173	3	--	3	--	3	--
4	0.136	4	0.155	4	0.177	4	0.218	4	0.425
5	0.119	5	0.166	5	0.172	5	0.224	5	0.433
6	0.124	6	0.158	6	0.180	6	0.207	6	0.432
7	0.138	7	0.154	7	0.173	7	0.225	7	0.445
8	0.136	8	0.168	8	0.173	8	0.216	8	0.441
9	0.147	9	0.161	9	0.175	9	0.208	9	0.417
10	0.151	10	0.173	10	0.191	10	0.239	10	0.410
11	0.151	11	0.184	11	0.197	11	0.257	11	0.437
12	0.152	12	0.178	12	0.184	12	0.231	12	0.443
13	0.152	13	0.166	13	0.181	13	0.223	13	0.422
14	0.155	14	0.180	14	0.196	14	0.244	14	0.429
15	0.169	15	0.184	15	0.185	15	0.242	15	0.447
16	0.166	16	0.180	16	0.198	16	0.236	16	0.439
17	0.168	17	0.176	17	0.191	17	0.230	17	0.437
18	0.164	18	0.173	18	0.190	18	0.236	18	0.439
19	0.174	19	0.177	19	0.193	19	0.229	19	0.424
20	0.175	20	0.176	20	0.195	20	0.250	20	0.429
21	0.161	21	0.182	21	0.192	21	0.237	21	0.432
22	0.166	22	0.170	22	0.185	22	0.234	22	0.419
23	0.161	23	0.177	23	0.187	23	0.229	23	0.415
24	--	24	--	24	--	24	--	24	--

$S_o = 0.005$
Drop spacing = 1 in.

Note: X measured from upstream entrance
Y measured normal to channel bottom

i = 7.65 in./hr U = 8.8 ft/sec q_o = 0.0 cfs/ft T = 63.5°F		i = 11.65 in./hr U = 8.8 ft/sec q_o = 0.262x10^{-2} cfs/ft T = 59.5°F		i = 9.95 in./hr U = 21.0 ft/sec q_o = 0.262x10^{-2} cfs/ft T = 67.7°F		i = 9.95 in./hr U = 21.0 ft/sec q_o = 0.245x10^{-2} cfs/ft T = 66.7°F		i = 9.90 in./hr U = 21.0 ft/sec q_o = 0.373x10^{-2} cfs/ft T = 67.6°F	
X(ft)	Y(in.)	X(ft)	Y(in.)	X(ft)	Y(in.)	X(ft)	Y(in.)	X(ft)	Y(in.)
1	0.081	1	--	1.5	0.090	1.5	0.149	1.5	0.170
2	--	2	--	2.5	0.100	2.5	0.150	2.5	0.174
3	0.101	3	--	3.5	0.100	3.5	0.156	3.5	0.166
4	0.105	4	0.172	4.5	0.105	4.5	0.153	4.5	0.175
5	0.110	5	0.169	5.5	0.109	5.5	0.149	5.5	0.163
6	0.112	6	0.180	6.5	0.107	6.5	0.158	6.5	0.177
7	0.114	7	0.176	7.5	0.116	7.5	0.161	7.5	0.178
8	0.117	8	0.177	8.5	0.125	8.5	0.161	8.5	0.185
9	0.122	9	0.186	9.5	0.133	9.5	0.172	9.5	0.192
10	0.132	10	0.198	10.5	0.154	10.5	0.202	10.5	0.205
11	0.135	11	0.200	11.5	0.159	11.5	0.196	11.5	0.219
12	0.133	12	0.192	12.5	0.154	12.5	0.196	12.5	0.204
13	0.139	13	0.199	13.5	0.159	13.5	0.203	13.5	0.219
14	0.151	14	0.217	14.5	0.173	14.5	0.215	14.5	0.223
15	0.157	15	0.216	15.5	0.167	15.5	0.207	15.5	0.227
16	0.152	16	0.212	16.5	0.177	16.5	0.206	16.5	0.226
17	0.153	17	0.214	17.5	0.176	17.5	0.207	17.5	0.234
18	0.154	18	0.217	18.5	0.174	18.5	0.213	18.5	0.231
19	0.156	19	0.217	19.5	0.173	19.5	0.224	19.5	0.232
20	0.159	20	0.221	20.5	0.180	20.5	0.221	20.5	0.238
21	0.159	21	0.221	21.5	0.179	21.5	0.211	21.5	0.236
22	0.156	22	--	22.5	0.187	22.5	0.222	22.5	0.240
23	0.170	23	--	23.5	0.197	23.5	0.212	23.5	0.239
24	--	24	--	24.5	--	24.5	--	24.5	--

$S_o = 0.005$
Drop spacing = 1 in.

Note: X measured from upstream entrance
Y measured normal to channel bottom

i = 9.95 in./hr U = 21.0 ft/sec $q_o = 1.377 \times 10^{-2}$ cfs/ft $T = 65.9^{\circ}F$		i = 9.95 in./hr U = 21.0 ft/sec $q_o = 1.890 \times 10^{-2}$ cfs/ft $T = 66.5^{\circ}F$		i = 9.95 in./hr U = 21.0 ft/sec $q_o = 3.930 \times 10^{-2}$ cfs/ft $T = 65.4^{\circ}F$		i = 10.03 in./hr U = 21.0 ft/sec $q_o = 6.00 \times 10^{-2}$ cfs/ft $T = 67.3^{\circ}F$		i = 14.99 in./hr U = 8.8 ft/sec q_o = 0.0 cfs/ft $T = 64.4^{\circ}F$	
X(ft)	Y(in.)	X(ft)	Y(in.)	X(ft)	Y(in.)	X(ft)	Y(in.)	X(ft)	Y(in.)
1.5	0.294	1.5	0.327	1	--	1	0.493	1	--
2.5	0.267	2.5	0.316	2	--	2	0.505	2	0.114
3.5	0.274	3.5	0.327	3	--	3	0.509	3	--
4.5	0.269	4.5	0.335	4	0.404	4	0.491	4	0.129
5.5	0.281	5.5	0.311	5	0.397	5	0.490	5	--
6.5	0.268	6.5	0.331	6	0.394	6	0.513	6	0.138
7.5	0.286	7.5	0.328	7	0.394	7	0.523	7	--
8.5	0.268	8.5	0.265	8	0.415	8	0.517	8	0.141
9.5	0.293	9.5	0.339	9	0.413	9	0.486	9	--
10.5	0.315	10.5	0.350	10	0.410	10	0.482	10	0.168
11.5	0.318	11.5	0.370	11	0.416	11	0.532	11	--
12.5	0.295	12.5	0.325	12	0.403	12	0.563	12	0.176
13.5	0.302	13.5	0.349	13	0.362	13	0.508	13	--
14.5	0.302	14.5	0.373	14	0.411	14	0.513	14	0.195
15.5	0.313	15.5	0.354	15	0.451	15	0.560	15	--
16.5	0.301	16.5	0.359	16	0.446	16	0.541	16	0.200
17.5	0.307	17.5	0.357	17	0.408	17	0.525	17	--
18.5	0.319	18.5	0.360	18	0.428	18	0.541	18	0.206
19.5	0.321	19.5	0.354	19	0.418	19	0.520	19	--
20.5	0.317	20.5	0.352	20	0.419	20	0.537	20	0.212
21.5	0.296	21.5	0.310	21	0.410	21	0.514	21	--
22.5	0.300	22.5	0.301	22	0.393	22	0.538	22	0.207
23.5	0.267	23.5	0.343	23	0.418	23	0.509	23	--
24.5	--	24.5	--	24	--	24	--	24	--

$S_o = 0.005$
Drop spacing = 1 in.
$U = 8.8$ ft/sec

Note: X measured from upstream entrance
Y measured normal to channel bottom

$i = 15.44$ in./hr $q_o = 0.357 \times 10^{-2}$ cfs/ft $T = 63.0^oF$		$i = 14.99$ in./hr $q_o = 0.443 \times 10^{-2}$ cfs/ft $T = 66.4^oF$		$i = 15.01$ in./hr $q_o = 1.010 \times 10^{-2}$ cfs/ft $T = 64.6^oF$		$i = 14.99$ in./hr $q_o = 1.270 \times 10^{-2}$ cfs/ft $T = 65.1^oF$		$i = 14.99$ in./hr $q_o = 1.750 \times 10^{-2}$ cfs/ft $T = 65.9^oF$	
X(ft)	Y(in.)	X(ft)	Y(in.)	X(ft)	Y(in.)	X(ft)	Y(in.)	X(ft)	Y(in.)
1	--	1	--	1	--	1	--	1	--
2	--	2	0.196	2	0.267	2	--	2	--
3	0.197	3	--	3	--	3	0.284	3	0.308
4	0.201	4	0.205	4	0.274	4	--	4	--
5	0.200	5	--	5	--	5	0.279	5	0.299
6	0.211	6	0.211	6	0.262	6	--	6	--
7	0.209	7	--	7	--	7	0.288	7	0.314
8	0.206	8	0.208	8	0.253	8	--	8	--
9	0.218	9	0.223	9	0.250	9	0.275	9	0.291
10	0.239	10	0.231	10	--	10	--	10	--
11	0.243	11	--	11	0.299	11	--	11	0.346
12	0.243	12	0.234	12	--	12	0.289	12	--
13	0.237	13	--	13	0.271	13	0.282	13	0.302
14	0.258	14	0.254	14	--	14	0.312	14	--
15	0.264	15	0.262	15	0.306	15	0.312	15	0.342
16	0.263	16	0.260	16	--	16	--	16	--
17	0.265	17	--	17	0.292	17	0.305	17	0.346
18	0.265	18	0.264	18	--	18	0.300	18	--
19	0.273	19	--	19	0.292	19	0.305	19	0.332
20	0.277	20	0.266	20	--	20	--	20	--
21	0.270	21	--	21	0.294	21	0.311	21	0.339
22	0.262	22	0.264	22	--	22	--	22	0.313
23	0.274	23	--	23	0.296	23	0.300	23	0.315
24	--	24	--	24	--	24	--	24	--

S_o = 0.005
Drop spacing = 1 in.

Note: X measured from upstream entrance
Y measured normal to channel bottom

i = 21.96 in./hr U = 8.8 ft/sec q_o = 0.0 cfs/ft T = 55.3°F		i = 18.00 in./hr U = 21.0 ft/sec q_o = 0.0 cfs/ft T = 65.2°F		i = 18.00 in./hr U = 21.0 ft/sec q_o = 0.366×10^{-2} cfs/ft T = 65.3°F		i = 18.00 in./hr U = 21.0 ft/sec q_o = 1.117×10^{-2} cfs/ft T = 63.1°F		i = 18.00 in./hr U = 21.0 ft/sec q_o = 2.100×10^{-2} cfs/ft T = 63.6°F	
X(ft)	Y(in.)	X(ft)	Y(in.)	X(ft)	Y(in.)	X(ft)	Y(in.)	X(ft)	Y(in.)
1	--	1	0.106	1	0.199	1	0.277	1	0.330
2	--	2	0.108	2	0.198	2	0.277	2	0.340
3	0.168	3	0.113	3	0.199	3	0.276	3	0.339
4	0.156	4	0.134	4	0.203	4	0.281	4	0.345
5	0.157	5	0.136	5	0.205	5	0.271	5	0.325
6	0.171	6	0.155	6	0.221	6	0.295	6	0.358
7	0.175	7	0.140	7	0.214	7	0.292	7	0.370
8	0.173	8	0.146	8	0.211	8	0.284	8	0.327
9	0.187	9	0.164	9	0.222	9	0.300	9	0.340
10	0.215	10	0.177	10	0.245	10	0.320	10	0.383
11	0.225	11	0.191	11	0.269	11	0.328	11	0.352
12	0.216	12	0.194	12	0.245	12	0.320	12	0.359
13	0.223	13	0.201	13	0.263	13	0.311	13	0.352
14	0.245	14	0.217	14	0.261	14	0.327	14	0.380
15	0.254	15	0.211	15	0.277	15	0.328	15	0.389
16	0.255	16	0.218	16	0.278	16	0.338	16	0.373
17	0.257	17	0.223	17	0.279	17	0.332	17	0.361
18	0.263	18	0.223	18	0.284	18	0.333	18	0.380
19	0.273	19	0.225	19	0.279	19	0.338	19	0.380
20	0.279	20	0.218	20	0.275	20	0.336	20	0.394
21	0.281	21	0.226	21	0.270	21	0.326	21	0.358
22	0.279	22	0.232	22	0.276	22	0.325	22	0.315
23	--	23	0.233	23	0.272	23	0.322	23	0.311
24	--	24	--	24	--	24	--	24	--

S_o = 0.005
Drop spacing = 1 in.
U = 21.0 ft/sec

Note: X measured from upstream entrance
Y measured normal to channel bottom

i = 17.77 in./hr		i = 17.77 in./hr		i = 17.87 in./hr		i = 20.52 in./hr		i =	
q_o = 3.970x10^{-2} cfs/ft		q_o = 5.170x10^{-2} cfs/ft		q_o = 6.170x10^{-2} cfs/ft		q_o = 9.770x10^{-2} cfs/ft		q_o = cfs/ft	
T = 63.3°F		T = 63.5°F		T = 63.9°F		T = 62.7°F		T =	
X(ft)	Y(in.)	X(ft)	Y(in.)	X(ft)	Y(in.)	X(ft)	Y(in.)	X(ft)	Y(in.)
1	0.418	1	--	1	0.528	1	--	1	
2	0.420	2	0.468	2	0.525	2	--	2	
3	0.428	3	0.473	3	0.534	3	0.677	3	
4	0.409	4	0.483	4	0.511	4	0.658	4	
5	0.404	5	0.480	5	0.548	5	0.690	5	
6	0.432	6	0.492	6	0.534	6	0.706	6	
7	0.448	7	0.495	7	0.549	7	0.715	7	
8	0.430	8	0.483	8	0.554	8	0.711	8	
9	0.407	9	0.462	9	0.516	9	0.656	9	
10	0.422	10	0.461	10	0.132	10	0.691	10	
11	0.515	11	0.518	11	0.578	11	0.698	11	
12	0.439	12	0.525	12	0.569	12	0.723	12	
13	0.425	13	0.519	13	0.541	13	0.712	13	
14	0.428	14	0.490	14	0.543	14	0.713	14	
15	0.440	15	0.519	15	0.588	15	0.752	15	
16	0.450	16	0.508	16	0.595	16	0.741	16	
17	0.454	17	0.505	17	0.578	17	0.741	17	
18	0.460	18	0.530	18	0.575	18	0.734	18	
19	0.458	19	0.500	19	0.579	19	0.740	19	
20	0.443	20	0.519	20	0.567	20	0.744	20	
21	0.435	21	0.517	21	0.573	21	0.745	21	
22	0.423	22	0.496	22	0.555	22	0.716	22	
23	--	23	0.526	23	0.564	23	0.685	23	
24	--	24	--	24	--	24	--	24	

$S_o = 0.005$
Drop spacing = 2 in.
$U = 11.0$ ft/sec

Note: X measured from upstream entrance
Y measured normal to channel bottom

i = 0.50 in./hr $q_o = 0.148\text{x}10^{-2}$ cfs/ft T = 67.0°F		i = 0.50 in./hr $q_o = 0.252\text{x}10^{-2}$ cfs/ft T = 68.8°F		i = 0.50 in./hr $q_o = 0.371\text{x}10^{-2}$ cfs/ft T = 66.8°F		i = 0.50 in./hr $q_o = 0.459\text{x}10^{-2}$ cfs/ft T = 70.1°F		i = 0.50 in./hr $q_o = 0.562\text{x}10^{-2}$ cfs/ft T = 70.5°F	
X(ft)	Y(in.)	X(ft)	Y(in.)	X(ft)	Y(in.)	X(ft)	Y(in.)	X(ft)	Y(in.)
1	--	1	--	1	--	1	--	1	--
2	--	2	--	2	--	2	--	2	--
3	0.104	3	0.119	3	0.150	3	0.155	3	0.158
4	--	4	--	4	--	4	--	4	--
5	0.103	5	0.115	5	0.146	5	0.147	5	0.166
6	--	6	--	6	--	6	--	6	--
7	0.109	7	0.120	7	0.147	7	0.152	7	0.167
8	--	8	--	8	--	8	--	8	--
9	0.108	9	0.126	9	0.152	9	0.155	9	0.171
10	--	10	--	10	--	10	--	10	--
11	0.097	11	0.116	11	0.147	11	0.149	11	0.156
12	--	12	--	12	--	12	--	12	--
13	0.099	13	0.119	13	0.136	13	0.147	13	0.156
14	--	14	--	14	--	14	--	14	--
15	0.110	15	0.123	15	0.151	15	0.156	15	0.171
16	--	16	--	16	--	16	--	16	--
17	0.105	17	0.124	17	0.147	17	0.150	17	0.161
18	--	18	--	18	--	18	--	18	--
19	0.103	19	0.122	19	0.142	19	0.150	19	0.166
20	--	20	--	20	--	20	--	20	--
21	0.093	21	0.119	21	0.143	21	0.153	21	0.164
22	--	22	--	22	--	22	--	22	--
23	0.106	23	0.120	23	0.140	23	--	23	0.155
24	--	24	--	24	--	24	--	24	--

S_o = 0.005
Drop spacing = 2 in.
U = 11.0 ft/sec

Note: X measured from upstream entrance
Y measured normal to channel bottom

i = 0.50 in./hr $q_o = 0.676 \times 10^{-2}$ cfs/ft T = 69.5°F		i = 0.50 in./hr $q_o = 0.818 \times 10^{-2}$ cfs/ft T = 70.8°F		i = 0.50 in./hr $q_o = 0.942 \times 10^{-2}$ cfs/ft T = 69.9°F		i = 0.50 in./hr $q_o = 1.026 \times 10^{-2}$ cfs/ft T = 70.8°F		i = 0.50 in./hr $q_o = 1.610 \times 10^{-2}$ cfs/ft T = 68.3°F	
X(ft)	Y(in.)	X(ft)	Y(in.)	X(ft)	Y(in.)	X(ft)	Y(in.)	X(ft)	Y(in.)
1	--	1	--	1	--	1	--	1	--
2	--	2	--	2	--	2	--	2	--
3	0.181	3	0.201	3	0.204	3	0.218	3	0.261
4	--	4	--	4	--	4	--	4	--
5	0.174	5	0.182	5	0.189	5	0.206	5	0.244
6	--	6	--	6	--	6	--	6	--
7	0.181	7	0.202	7	0.209	7	0.217	7	0.267
8	--	8	--	8	--	8	--	8	--
9	0.183	9	0.203	9	0.206	9	0.219	9	0.250
10	--	10	--	10	--	10	--	10	--
11	0.174	11	0.196	11	0.201	11	0.218	11	0.260
12	--	12	--	12	--	12	--	12	--
13	0.172	13	0.185	13	0.191	13	0.207	13	0.244
14	--	14	--	14	--	14	--	14	--
15	0.179	15	0.209	15	0.224	15	0.226	15	0.273
16	--	16	--	16	--	16	--	16	--
17	0.175	17	0.196	17	0.208	17	0.217	17	0.258
18	--	18	--	18	--	18	--	18	--
19	0.176	19	0.193	19	0.199	19	0.209	19	0.254
20	--	20	--	20	--	20	--	20	--
21	0.181	21	0.200	21	0.207	21	0.214	21	0.270
22	--	22	--	22	--	22	--	22	--
23	0.175	23	0.187	23	0.197	23	0.209	23	0.253
24	--	24	--	24	--	24	--	24	--

$S_o = 0.005$
Drop spacing = 2 in.
U = 11.0 ft/sec

Note: X measured from upstream entrance
Y measured normal to channel bottom

i = 0.50 in./hr $q_o = 2.710\times10^{-2}$ cfs/ft T = 68.3°F		i = 0.50 in./hr $q_o = 4.290\times10^{-2}$ cfs/ft T = 68.8°F		i = 0.50 in./hr $q_o = 6.048\times10^{-2}$ cfs/ft T = 68.3°F		i = 1.25 in./hr $q_o = 0.173\times10^{-2}$ cfs/ft T = 68.6°F		i = 1.25 in./hr $q_o = 0.230\times10^{-2}$ cfs/ft T = 68.6°F	
X(ft)	Y(in.)	X(ft)	Y(in.)	X(ft)	Y(in.)	X(ft)	Y(in.)	X(ft)	Y(in.)
1	--	1	--	1	--	1	--	1	--
2	--	2	--	2	--	2	0.125	2	0.137
3	0.362	3	0.464	3	0.569	3	--	3	--
4	--	4	--	4	--	4	0.109	4	0.120
5	0.337	5	0.427	5	0.511	5	--	5	--
6	--	6	--	6	--	6	0.123	6	0.124
7	0.347	7	0.431	7	0.508	7	0.111	7	--
8	--	8	--	8	--	8	0.101	8	0.109
9	0.340	9	0.436	9	0.509	9	--	9	--
10	--	10	--	10	--	10	0.123	10	0.123
11	0.351	11	0.449	11	0.534	11	--	11	--
12	--	12	--	12	--	12	0.115	12	0.123
13	0.325	13	0.421	13	0.506	13	0.113	13	0.124
14	--	14	--	14	--	14	--	14	--
15	0.359	15	0.449	15	0.520	15	0.121	15	0.133
16	--	16	--	16	--	16	--	16	--
17	0.344	17	0.440	17	0.524	17	0.118	17	0.127
18	--	18	--	18	--	18	--	18	--
19	0.341	19	0.427	19	0.504	19	0.118	19	0.131
20	--	20	--	20	--	20	--	20	--
21	0.350	21	0.434	21	0.512	21	0.112	21	0.129
22	--	22	--	22	--	22	--	22	--
23	0.336	23	0.432	23	0.503	23	0.125	23	0.130
24	--	24	--	24	--	24	--	24	--

S_o = 0.005
Drop spacing = 2 in.
U = 11.0 ft/sec

Note: X measured from upstream entrance
Y measured normal to channel bottom

i = 1.25 in./hr q_o = 0.329×10^{-2} cfs/ft T = 69.9°F		i = 1.25 in./hr q_o = 0.435×10^{-2} cfs/ft T = 69.9°F		i = 1.25 in./hr q_o = 0.560×10^{-2} cfs/ft T = 67.6°F		i = 1.25 in./hr q_o = 0.701×10^{-2} cfs/ft T = 68.3°F		i = 1.25 in./hr q_o = 0.825×10^{-2} cfs/ft T = 68.3°F	
X(ft)	Y(in.)	X(ft)	Y(in.)	X(ft)	Y(in.)	X(ft)	Y(in.)	X(ft)	Y(in.)
1	--	1	--	1	--	1	--	1	--
2	0.155	2	0.171	2	0.185	2	0.209	2	0.226
3	--	3	--	3	--	3	--	3	--
4	0.134	4	0.151	4	0.170	4	0.187	4	0.200
5	--	5	--	5	--	5	--	5	--
6	0.138	6	0.149	6	0.170	6	0.192	6	0.210
7	--	7	--	7	--	7	--	7	--
8	0.126	8	0.138	8	0.153	8	0.181	8	0.199
9	--	9	--	9	--	9	--	9	--
10	0.147	10	0.165	10	0.177	10	0.202	10	0.224
11	--	11	--	11	--	11	--	11	--
12	0.142	12	0.154	12	0.171	12	0.194	12	0.209
13	0.143	13	0.152	13	0.169	13	0.189	13	--
14	--	14	--	14	--	14	--	14	0.215
15	0.146	15	0.161	15	0.177	15	0.203	15	0.218
16	--	16	--	16	--	16	--	16	--
17	0.147	17	0.155	17	0.175	17	0.195	17	0.215
18	--	18	--	18	--	18	--	18	--
19	0.140	19	0.156	19	0.169	19	0.190	19	0.212
20	--	20	--	20	--	20	--	20	--
21	0.146	21	0.158	21	0.175	21	0.194	21	0.211
22	--	22	--	22	--	22	--	22	--
23	0.147	23	0.155	23	0.176	23	0.191	23	0.209
24	--	24	--	24	--	24	--	24	--

S_o = 0.005
Drop spacing = 2 in.
U = 11.0 ft/sec

Note: X measured from upstream entrance
Y measured normal to channel bottom

i = 1.25 in./hr q_o = 0.927×10^{-2} cfs/ft T = 68.8°F		i = 1.25 in./hr q_o = 1.026×10^{-2} cfs/ft T = 69.4°F		i = 1.25 in./hr q_o = 1.590×10^{-2} cfs/ft T = 68.3°F		i = 1.25 in./hr q_o = 2.650×10^{-2} cfs/ft T = 69.0°F		i = 1.25 in./hr q_o = 4.230×10^{-2} cfs/ft T = 69.3°F	
X(ft)	Y(in.)	X(ft)	Y(in.)	X(ft)	Y(in.)	X(ft)	Y(in.)	X(ft)	Y(in.)
1	--	1	--	1	--	1	--	1	--
2	0.241	2	--	2	--	2	--	2	--
3	--	3	0.220	3	0.265	3	0.350	3	0.468
4	0.205	4	--	4	--	4	--	4	--
5	--	5	0.211	5	0.249	5	0.332	5	0.421
6	0.216	6	--	6	--	6	--	6	--
7	--	7	0.230	7	0.274	7	0.332	7	0.437
8	0.202	8	--	8	--	8	--	8	--
9	--	9	0.213	9	0.243	9	0.321	9	0.425
10	0.238	10	--	10	--	10	--	10	--
11	--	11	0.245	11	0.272	11	0.355	11	0.448
12	0.210	12	0.216	12	0.248	12	0.332	12	0.425
13	0.203	13	--	13	--	13	-	13	--
14	--	14	0.224	14	0.255	14	0.327	14	0.420
15	0.231	15	--	15	--	15	--	15	--
16	--	16	0.207	16	0.250	16	0.336	16	0.434
17	0.223	17	--	17	--	17	--	17	--
18	--	18	0.219	18	0.257	18	0.346	18	0.431
19	0.213	19	--	19	--	19	--	19	--
20	--	20	0.212	20	0.247	20	0.332	20	0.421
21	0.223	21	--	21	--	21	--	21	--
22	--	22	0.217	22	0.251	22	0.343	22	0.431
23	0.208	23	0.217	23	0.253	23	0.366	23	0.429
24	--	24	--	24	--	24	--	24	--

S_o = 0.005
Drop spacing = 2 in.
U = 11.0 ft/sec

Note: X measured from upstream entrance
Y measured normal to channel bottom

i = 3.74 in./hr q_o = 0.983×10^{-3} cfs/ft T = 66.3°F		i = 3.74 in./hr q_o = 0.260×10^{-2} cfs/ft T = 66.9°F		i = 3.74 in./hr q_o = 0.484×10^{-2} cfs/ft T = 67.2°F		i = 3.74 in./hr q_o = 0.638×10^{-2} cfs/ft T = 67.8°F		i = 3.74 in./hr q_o = 0.840×10^{-2} cfs/ft T = 69.0°F	
X(ft)	Y(in.)	X(ft)	Y(in.)	X(ft)	Y(in.)	X(ft)	Y(in.)	X(ft)	Y(in.)
1	--	1	--	1	--	1	--	1	--
2	--	2	--	2	0.198	2	--	2	--
3	0.112	3	0.142	3	--	3	0.205	3	0.233
4	--	4	--	4	0.183	4	--	4	--
5	0.116	5	0.147	5	--	5	0.204	5	0.220
6	--	6	--	6	0.182	6	--	6	--
7	0.119	7	0.153	7	--	7	0.204	7	0.235
8	--	8	--	8	0.170	8	--	8	--
9	0.124	9	0.165	9	--	9	0.218	9	0.240
10	--	10	--	10	0.193	10	--	10	--
11	0.123	11	0.149	11	--	11	0.204	11	0.229
12	--	12	--	12	0.189	12	--	12	--
13	0.126	13	0.150	13	0.193	13	0.211	13	0.243
14	--	14	--	14	--	14	--	14	--
15	0.133	15	0.156	15	0.199	15	0.216	15	0.244
16	--	16	--	16	--	16	--	16	--
17	0.131	17	0.158	17	0.198	17	0.214	17	0.244
18	--	18	--	18	--	18	--	18	--
19	0.137	19	0.159	19	0.192	19	0.215	19	0.240
20	--	20	--	20	--	20	--	20	--
21	0.144	21	0.167	21	0.202	21	0.220	21	0.245
22	--	22	--	22	--	22	--	22	--
23	0.139	23	0.161	23	0.197	23	0.213	23	0.233
24	--	24	--	24	--	24	--	24	--

S_o = 0.005
Drop spacing = 2 in.
U = 11.0 ft/sec

Note: X measured from upstream entrance
Y measured normal to channel bottom

i = 3.74 in./hr $q_o = 1.081 \times 10^{-2}$ cfs/ft T = 67.4°F		i = 3.74 in./hr $q_o = 1.539 \times 10^{-2}$ cfs/ft T = 67.2°F		i = 3.74 in./hr $q_o = 2.062 \times 10^{-2}$ cfs/ft T = 67.7°F		i = 3.74 in./hr $q_o = 3.136 \times 10^{-2}$ cfs/ft T = 68.1°F		i = 3.74 in./hr $q_o = 4.222 \times 10^{-2}$ cfs/ft T = 68.3°F	
X(ft)	Y(in.)	X(ft)	Y(in.)	X(ft)	Y(in.)	X(ft)	Y(in.)	X(ft)	Y(in.)
1	--	1	--	1	--	1	--	1	--
2	--	2	--	2	--	2	--	2	--
3	0.250	3	0.247	3	0.311	3	0.376	3	0.468
4	--	4	--	4	--	4	--	4	--
5	0.236	5	0.260	5	0.278	5	0.361	5	0.462
6	--	6	--	6	--	6	--	6	--
7	0.262	7	0.286	7	0.306	7	0.373	7	0.443
8	--	8	--	8	--	8	--	8	--
9	0.277	9	0.293	9	0.304	9	0.379	9	0.436
10	--	10	--	10	--	10	--	10	--
11	0.245	11	0.273	11	0.306	11	0.374	11	0.446
12	--	12	--	12	--	12	--	12	--
13	0.235	13	0.261	13	0.282	13	0.366	13	0.455
14	--	14	--	14	--	14	--	14	--
15	0.262	15	0.296	15	0.321	15	0.404	15	0.454
16	--	16	--	16	--	16	--	16	--
17	0.254	17	0.274	17	0.304	17	0.391	17	0.451
18	--	18	--	18	--	18	--	18	--
19	0.240	19	0.266	19	0.296	19	0.397	19	0.435
20	--	20	--	20	--	20	--	20	--
21	0.247	21	0.290	21	0.317	21	0.378	21	0.453
22	--	22	--	22	--	22	--	22	--
23	0.246	23	0.269	23	0.295	23	0.384	23	0.434
24	--	24	--	24	--	24	--	24	--

S_o = 0.01
Drop spacing = 1 in.
U = 11.0 ft/sec

Note: X measured from upstream entrance
Y measured normal to channel bottom

i = 0.99 in./hr q_o = 0.115×10^{-2} cfs/ft T = 70.7°F		i = 0.99 in./hr q_o = 0.204×10^{-2} cfs/ft T = 70.4°F		i = 1.00 in./hr q_o = 0.303×10^{-2} cfs/ft T = 70.0°F		i = 0.99 in./hr q_o = 0.480×10^{-2} cfs/ft T = 71.0°F		i = 0.99 in./hr q_o = 0.792×10^{-2} cfs/ft T = 71.4°F	
X(ft)	Y(in.)	X(ft)	Y(in.)	X(ft)	Y(in.)	X(ft)	Y(in.)	X(ft)	Y(in.)
1	--	1	--	1	--	1	--	1	--
2	--	2	--	2	--	2	--	2	--
3	0.080	3	0.095	3	0.104	3	0.129	3	0.149
4	--	4	--	4	--	4	--	4	--
5	0.076	5	0.089	5	0.098	5	0.115	5	0.144
6	--	6	--	6	--	6	--	6	--
7	0.080	7	0.090	7	0.103	7	0.126	7	0.144
8	--	8	--	8	--	8	--	8	--
9	0.076	9	0.085	9	0.098	9	0.119	9	0.142
10	--	10	--	10	--	10	--	10	--
11	0.079	11	0.089	11	0.103	11	0.121	11	0.141
12	--	12	--	12	--	12	--	12	--
13	0.078	13	0.090	13	0.102	13	0.123	13	0.138
14	--	14	--	14	--	14	--	14	--
15	0.086	15	0.093	15	0.105	15	0.126	15	0.146
16	--	16	--	16	--	16	--	16	--
17	0.071	17	0.088	17	0.103	17	0.124	17	0.147
18	--	18	--	18	--	18	--	18	--
19	0.075	19	0.094	19	0.102	19	0.120	19	0.148
20	--	20	--	20	--	20	--	20	--
21	0.083	21	0.094	21	0.103	21	0.124	21	0.142
22	--	22	--	22	--	22	--	22	--
23	--	23	--	23	--	23	0.129	23	0.143
24	--	24	--	24	--	24	--	24	--

S_o = 0.01
Drop spacing = 1 in.
U = 11.0 ft/sec

Note: X measured from upstream entrance
Y measured normal to channel bottom

i = 0.99 in./hr $q_o = 1.017\times10^{-2}$ cfs/ft T = 71.7°F		i = 0.97 in./hr $q_o = 1.790\times10^{-2}$ cfs/ft T = 69.8°F		i = 0.99 in./hr $q_o = 2.500\times10^{-2}$ cfs/ft T = 70.2°F		i = 0.99 in./hr $q_o = 3.600\times10^{-2}$ cfs/ft T = 70.5°F		i = 0.99 in./hr $q_o = 5.700\times10^{-2}$ cfs/ft T = 71.2°F	
X(ft)	Y(in.)	X(ft)	Y(in.)	X(ft)	Y(in.)	X(ft)	Y(in.)	X(ft)	Y(in.)
1	--	1	--	1	--	1	--	1	--
2	--	2	--	2	0.256	2	--	2	--
3	0.170	3	0.209	3	--	3	0.306	3	0.401
4	--	4	0.213	4	0.255	4	--	4	--
5	0.167	5	0.221	5	--	5	0.310	5	0.410
6	--	6	--	6	0.259	6	--	6	--
7	0.163	7	0.213	7	--	7	0.299	7	0.399
8	--	8	--	8	0.255	8	--	8	--
9	0.161	9	0.209	9	--	9	0.299	9	0.401
10	--	10	--	10	0.247	10	--	10	--
11	0.161	11	0.208	11	--	11	0.304	11	0.392
12	--	12	--	12	0.257	12	--	12	--
13	0.158	13	0.210	13	--	13	0.303	13	0.401
14	--	14	--	14	0.246	14	--	14	--
15	0.168	15	0.209	15	--	15	0.309	15	0.393
16	--	16	--	16	0.259	16	--	16	--
17	0.164	17	0.209	17	--	17	0.300	17	0.399
18	--	18	--	18	0.248	18	--	18	--
19	0.165	19	0.209	19	--	19	0.311	19	0.401
20	--	20	--	20	0.252	20	--	20	--
21	0.166	21	0.211	21	--	21	0.307	21	0.401
22	--	22	--	22	0.248	22	--	22	--
23	0.165	23	0.210	23	--	23	0.304	23	--
24	--	24	--	24	--	24	--	24	--

S_o = 0.01
Drop spacing = 1 in.
U = 11.0 ft/sec

Note: X measured from upstream entrance
Y measured normal to channel bottom

i = 4.95 in./hr q_o = 0.0 cfs/ft T = 72.0°F		i = 5.0 in./hr q_o = 0.347×10^{-2} cfs/ft T = 71.7°F		i = 4.90 in./hr q_o = 0.723×10^{-2} cfs/ft T = 71.6°F		i = 4.95 in./hr q_o = 1.010×10^{-2} cfs/ft T = 71.5°F		i = 4.95 in./hr q_o = 1.443×10^{-2} cfs/ft T = 70.8°F	
X(ft)	Y(in.)	X(ft)	Y(in.)	X(ft)	Y(in.)	X(ft)	Y(in.)	X(ft)	Y(in.)
1	--	1	--	1	--	1	--	1	--
2	--	2	--	2	--	2	--	2	--
3	0.065	3	0.141	3	0.156	3	0.173	3	0.198
4	--	4	--	4	--	4	--	4	--
5	0.071	5	0.136	5	0.160	5	0.172	5	0.193
6	--	6	--	6	--	6	--	6	--
7	0.074	7	0.139	7	0.157	7	0.172	7	0.194
8	--	8	--	8	--	8	--	8	--
9	0.083	9	0.140	9	0.150	9	0.169	9	0.191
10	--	10	--	10	--	10	--	10	--
11	0.088	11	0.148	11	0.161	11	0.179	11	0.197
12	--	12	--	12	--	12	--	12	--
13	0.092	13	0.147	13	0.155	13	0.176	13	0.198
14	--	14	--	14	--	14	--	14	--
15	0.099	15	0.155	15	0.165	15	0.177	15	0.202
16	--	16	--	16	--	16	--	16	--
17	0.109	17	0.159	17	0.164	17	0.171	17	0.195
18	--	18	--	18	--	18	--	18	--
19	0.099	19	0.155	19	0.161	19	0.177	19	0.204
20	--	20	--	20	--	20	--	20	--
21	0.105	21	0.151	21	0.162	21	0.185	21	0.213
22	--	22	--	22	--	22	--	22	--
23	--	23	--	23	--	23	--	23	--
24	--	24	--	24	--	24	--	24	--

S_o = 0.01
Drop spacing = 1 in.
U = 11.0 ft/sec

Note: X measured from upstream entrance
Y measured normal to channel bottom

i = 4.95 in./hr $q_o = 2.050 \times 10^{-2}$ cfs/ft T = 70.5°F		i = 4.95 in./hr $q_o = 3.120 \times 10^{-2}$ cfs/ft T = 71.9°F		i = 4.95 in./hr $q_o = 5.030 \times 10^{-2}$ cfs/ft T = 71.8°F		i = 10.08 in./hr q_o = 0.0 cfs/ft T = 72.5°F		i = 10.04 in./hr $q_o = 0.480 \times 10^{-2}$ cfs/ft T = 72.0°F	
X(ft)	Y(in.)	X(ft)	Y(in.)	X(ft)	Y(in.)	X(ft)	Y(in.)	X(ft)	Y(in.)
1	--	1	--	1	--	1	--	1	--
2	--	2	--	2	--	2	--	2	--
3	0.235	3	0.289	3	0.376	3	0.082	3	0.157
4	--	4	--	4	--	4	--	4	--
5	0.239	5	0.300	5	0.387	5	0.088	5	0.157
6	--	6	--	6	--	6	--	6	--
7	0.241	7	0.288	7	0.374	7	0.094	7	0.159
8	--	8	--	8	--	8	--	8	--
9	0.242	9	0.289	9	0.370	9	0.107	9	0.164
10	--	10	--	10	--	10	--	10	--
11	0.236	11	0.296	11	0.381	11	0.114	11	0.174
12	--	12	--	12	--	12	--	12	--
13	0.237	13	0.294	13	0.384	13	0.124	13	0.166
14	--	14	--	14	--	14	--	14	--
15	0.240	15	0.291	15	0.383	15	0.142	15	0.187
16	--	16	--	16	--	16	--	16	--
17	0.243	17	0.285	17	0.373	17	0.138	17	0.183
18	--	18	--	18	--	18	--	18	--
19	0.248	19	0.304	19	0.382	19	0.141	19	0.174
20	--	20	--	20	--	20	--	20	--
21	0.244	21	0.298	21	0.369	21	0.151	21	0.175
22	--	22	--	22	--	22	--	22	--
23	--	23	--	23	--	23	0.147	23	0.176
24	--	24	--	24	--	24	--	24	--

S_o = 0.01
Drop spacing = 1 in.
U = 11.0 ft/sec

Note: X measured from upstream entrance
Y measured normal to channel bottom

i = 10.04 in./hr q_o = 1.013×10^{-2} cfs/ft T = 72.0°F		i = 10.04 in./hr q_o = 1.430×10^{-2} cfs/ft T = 73.1°F		i = 10.06 in./hr q_o = 2.383×10^{-2} cfs/ft T = 73.0°F		i = 10.06 in./hr q_o = 3.530×10^{-2} cfs/ft T = 72.9°F		i = 10.03 in./hr q_o = 6.200×10^{-2} cfs/ft T = 73.3°F	
X(ft)	Y(in.)	X(ft)	Y(in.)	X(ft)	Y(in.)	X(ft)	Y(in.)	X(ft)	Y(in.)
1	--	1	--	1	--	1	--	1	--
2	--	2	--	2	--	2	--	2	--
3	0.174	3	0.200	3	0.257	3	0.316	3	0.441
4	--	4	--	4	--	4	--	4	--
5	0.180	5	0.205	5	0.256	5	0.321	5	0.447
6	--	6	--	6	--	6	--	6	--
7	0.187	7	0.200	7	0.250	7	0.319	7	0.442
8	--	8	--	8	--	8	--	8	--
9	0.169	9	0.203	9	0.254	9	0.312	9	0.452
10	--	10	--	10	--	10	--	10	--
11	0.183	11	0.203	11	0.262	11	0.324	11	0.439
12	--	12	--	12	--	12	--	12	--
13	0.184	13	0.216	13	0.272	13	0.330	13	0.441
14	--	14	--	14	--	14	--	14	--
15	0.189	15	0.228	15	0.269	15	0.325	15	0.436
16	--	16	--	16	--	16	--	16	--
17	0.182	17	0.225	17	0.273	17	0.331	17	0.426
18	--	18	--	18	--	18	--	18	--
19	0.189	19	0.221	19	0.283	19	0.339	19	0.452
20	--	20	--	20	--	20	--	20	--
21	0.202	21	0.237	21	0.282	21	0.333	21	0.434
22	--	22	--	22	--	22	--	22	--
23	0.196	23	0.230	23	0.284	23	-.340	23	0.433
24	--	24	--	24	--	24	--	24	--

S_o = 0.01
Drop spacing = 1 in.
U = 11.0 ft/sec

Note: X measured from upstream entrance
Y measured normal to channel bottom

i = 14.99 in./hr q_o = 0.0 cfs/ft T = 66.3°F		i = 14.99 in./hr $q_o = 0.501 \times 10^{-2}$ cfs/ft T = 66.0°F		i = 14.99 in./hr $q_o = 1.176 \times 10^{-2}$ cfs/ft T = 65.8°F		i = 14.99 in./hr $q_o = 2.273 \times 10^{-2}$ cfs/ft T = 66.5°F		i = 14.99 in./hr $q_o = 3.953 \times 10^{-2}$ cfs/ft T = 66.3°F	
X(ft)	Y(in.)	X(ft)	Y(in.)	X(ft)	Y(in.)	X(ft)	Y(in.)	X(ft)	Y(in.)
1	--	1	--	1	--	1	--	1	--
2	0.095	2	0.176	2	--	2	--	2	--
3	0.101	3	0.166	3	0.185	3	0.264	3	0.333
4	0.106	4	0.172	4	--	4	--	4	--
5	0.113	5	0.181	5	0.192	5	0.249	5	0.324
6	0.120	6	0.186	6	--	6	0.285	6	--
7	0.125	7	0.179	7	0.199	7	0.256	7	0.328
8	--	8	--	8	--	8	--	8	--
9	0.131	9	0.186	9	0.205	9	0.255	9	0.323
10	0.135	10	0.189	10	0.209	10	0.262	10	0.337
11	--	11	--	11	--	11	--	11	--
12	0.137	12	0.204	12	0.218	12	0.261	12	0.333
13	0.138	13	0.188	13	0.213	13	0.260	13	0.339
14	0.143	14	0.194	14	0.206	14	0.276	14	0.332
15	0.151	15	0.209	15	0.215	15	0.272	15	0.341
16	--	16	--	16	--	16	--	16	--
17	0.157	17	0.203	17	0.226	17	0.296	17	0.344
18	0.165	18	0.206	18	--	18	--	18	--
19	0.166	19	0.298	19	0.233	19	0.281	19	0.346
20	0.172	20	--	20	--	20	--	20	--
21	0.182	21	0.199	21	0.236	21	0.301	21	0.376
22	0.181	22	0.193	22	--	22	--	22	--
23	0.176	23	0.181	23	0.228	23	0.277	23	0.337
24	--	24	--	24	--	24	--	24	--

S_o = 0.01
Drop spacing = 1 in.
U = 11.0 ft/sec

Note: X measured from upstream entrance
Y measured normal to channel bottom

i = 14.99 in./hr
q_o = 5.609×10^{-2} cfs/ft
T = 66.5°F

X(ft)	Y(in.)
1	--
2	--
3	0.399
4	--
5	0.385
6	--
7	0.400
8	--
9	0.393
10	0.397
11	--
12	0.387
13	0.390
14	0.396
15	0.398
16	--
17	0.395
18	--
19	0.400
20	--
21	0.419
22	--
23	0.413
24	--

S_o = 0.01
Drop spacing = 2 in.
U = 11.0 ft/sec

Note: X measured from upstream entrance
Y measured normal to channel bottom

i = 0.5 in./hr $q_o = 0.156 \times 10^{-2}$ cfs/ft T = 64.0°F		i = 0.5 in./hr $q_o = 0.272 \times 10^{-2}$ cfs/ft T = 64.0°F		i = 0.5 in./hr $q_o = 0.380 \times 10^{-2}$ cfs/ft T = 65.0°F		i = 0.5 in./hr $q_o = 0.493 \times 10^{-2}$ cfs/ft T = 65.0°F		i = 0.5 in./hr $q_o = 0.599 \times 10^{-2}$ cfs/ft T = 66.0°F	
X(ft)	Y(in.)	X(ft)	Y(in.)	X(ft)	Y(in.)	X(ft)	Y(in.)	X(ft)	Y(in.)
1	--	1	--	1	--	1	--	1	--
2	--	2	--	2	--	2	--	2	--
3	0.074	3	0.099	3	0.112	3	0.119	3	0.130
4	--	4	--	4	--	4	--	4	--
5	0.086	5	0.099	5	0.113	5	0.122	5	0.135
6	--	6	--	6	--	6	--	6	--
7	0.079	7	0.103	7	0.119	7	0.128	7	0.142
8	--	8	--	8	--	8	--	8	--
9	0.079	9	0.100	9	0.113	9	0.130	9	0.133
10	--	10	--	10	--	10	--	10	--
11	0.084	11	0.103	11	0.113	11	0.122	11	0.134
12	--	12	--	12	--	12	--	12	--
13	0.079	13	0.101	13	0.112	13	0.119	13	0.135
14	--	14	--	14	--	14	--	14	--
15	0.086	15	0.102	15	0.119	15	0.126	15	0.138
16	--	16	--	16	--	16	--	16	--
17	0.082	17	0.103	17	0.115	17	0.123	17	0.130
18	--	18	--	18	--	18	--	18	--
19	0.086	19	0.104	19	0.118	19	0.127	19	0.135
20	--	20	--	20	--	20	--	20	--
21	0.082	21	0.099	21	0.110	21	0.123	21	0.137
22	--	22	--	22	--	22	--	22	--
23	0.077	23	0.094	23	0.102	23	0.120	23	0.131
24	--	24	--	24	--	24	--	24	--

$S_o = 0.01$
Drop spacing = 2 in.
$U = 11.0$ ft/sec

Note: X measured from upstream entrance
Y measured normal to channel bottom

$i = 0.5$ in./hr $q_o = 0.710\times10^{-2}$ cfs/ft $T = 66.0^{\circ}$F		$i = 0.5$ in./hr $q_o = 0.875\times10^{-2}$ cfs/ft $T = 66.3^{\circ}$F		$i = 0.5$ in./hr $q_o = 0.987\times10^{-2}$ cfs/ft $T = 66.2^{\circ}$F		$i = 0.5$ in./hr $q_o = 1.125\times10^{-2}$ cfs/ft $T = 64.5^{\circ}$F		$i = 0.5$ in./hr $q_o = 1.674\times10^{-2}$ cfs/ft $T = 65.5^{\circ}$F	
X(ft)	Y(in.)	X(ft)	Y(in.)	X(ft)	Y(in.)	X(ft)	Y(in.)	X(ft)	Y(in.)
1	--	1	--	1	--	1	--	1	--
2	--	2	--	2	--	2	--	2	--
3	0.141	3	0.152	3	0.161	3	0.165	3	0.203
4	--	4	--	4	--	4	--	4	--
5	0.148	5	0.154	5	0.164	5	0.171	5	0.202
6	--	6	--	6	--	6	--	6	--
7	0.149	7	0.162	7	0.167	7	0.174	7	0.207
8	--	8	--	8	--	8	--	8	--
9	0.136	9	0.152	9	0.160	9	0.168	9	0.201
10	--	10	--	10	--	10	--	10	--
11	0.146	11	0.158	11	0.165	11	0.174	11	0.199
12	--	12	--	12	--	12	--	12	--
13	0.142	13	0.150	13	0.157	13	0.163	13	0.196
14	--	14	--	14	--	14	--	14	--
15	0.151	15	0.162	15	0.165	15	0.174	15	0.206
16	--	16	--	16	--	16	--	16	--
17	0.143	17	0.155	17	0.163	17	0.174	17	0.201
18	--	18	--	18	--	18	--	18	--
19	0.144	19	0.161	19	0.166	19	0.177	19	0.211
20	--	20	--	20	--	20	--	20	--
21	0.140	21	0.154	21	0.165	21	0.172	21	0.201
22	--	22	--	22	--	22	--	22	--
23	0.137	23	0.147	23	0.155	23	--	23	--
24	--	24	--	24	--	24	--	24	--

S_o = 0.01
Drop spacing = 2 in.
U = 11.0 ft/sec

Note: X measured from upstream entrance
Y measured normal to channel bottom

i = 0.50 in./hr q_o = 2.762×10^{-2} cfs/ft T = 66.5°F		i = 0.50 in./hr q_o = 4.455×10^{-2} cfs/ft T = 66.1°F		i = 0.50 in./hr q_o = 6.096×10^{-2} cfs/ft T = 66.6°F		i = 1.25 in./hr q_o = 0.182×10^{-2} cfs/ft T = 65.8°F		i = 1.25 in./hr q_o = 0.275×10^{-2} cfs/ft T = 66.3°F	
X(ft)	Y(in.)	X(ft)	Y(in.)	X(ft)	Y(in.)	X(ft)	Y(in.)	X(ft)	Y(in.)
1	--	1	--	1	--	1	--	1	--
2	--	2	--	2	--	2	--	2	--
3	0.280	3	0.364	3	0.424	3	0.090	3	0.096
4	--	4	--	4	--	4	--	4	0.101
5	0.278	5	0.354	5	0.408	5	0.089	5	--
6	--	6	--	6	--	6	--	6	0.106
7	0.282	7	0.353	7	0.406	7	0.093	7	0.101
8	--	8	--	8	--	8	--	8	--
9	0.279	9	0.342	9	0.401	9	0.092	9	0.107
10	--	10	--	10	--	10	--	10	--
11	0.274	11	0.345	11	0.400	11	0.097	11	0.102
12	--	12	--	12	--	12	--	12	--
13	0.270	13	0.339	13	0.396	13	0.090	13	0.108
14	--	14	--	14	--	14	--	14	--
15	0.281	15	0.354	15	0.412	15	0.095	15	0.109
16	--	16	--	16	--	16	--	16	--
17	0.279	17	0.352	17	0.402	17	0.093	17	0.109
18	--	18	--	18	--	18	--	18	--
19	0.282	19	0.352	19	0.409	19	0.099	19	0.109
20	--	20	--	20	--	20	--	20	--
21	0.273	21	0.342	21	0.397	21	0.101	21	0.106
22	--	22	--	22	--	22	--	22	--
23	--	23	--	23	--	23	0.091	23	0.102
24	--	24	--	24	--	24	--	24	--

$S_o = 0.01$

Drop spacing = 2 in.

U = 11.0 ft/sec

Note: X measured from upstream entrance
Y measured normal to channel bottom

i = 1.25 in./hr $q_o = 0.344\times10^{-2}$ cfs/ft T = 67.0°F		i = 1.25 in./hr $q_o = 0.450\times10^{-2}$ cfs/ft T = 67.7°F		i = 1.25 in./hr $q_o = 0.563\times10^{-2}$ cfs/ft T = 67.2°F		i = 1.25 in./hr $q_o = 0.666\times10^{-2}$ cfs/ft T = 68.0°F		i = 1.25 in./hr $q_o = 0.827\times10^{-2}$ cfs/ft T = 68.1°F	
X(ft)	Y(in.)	X(ft)	Y(in.)	X(ft)	Y(in.)	X(ft)	Y(in.)	X(ft)	Y(in.)
1	--	1	--	1	--	1	--	1	--
2	--	2	--	2	--	2	--	2	--
3	0.114	3	--	3	0.135	3	0.142	3	0.156
4	--	4	0.121	4	--	4	--	4	--
5	0.112	5	0.131	5	0.137	5	0.148	5	0.155
6	--	6	--	6	--	6	--	6	--
7	0.112	7	0.128	7	0.141	7	0.152	7	0.159
8	--	8	--	8	--	8	--	8	--
9	0.109	9	0.122	9	0.143	9	0.146	9	0.156
10	--	10	--	10	--	10	--	10	--
11	0.113	11	0.129	11	0.144	11	0.152	11	0.163
12	--	12	--	12	--	12	--	12	--
13	0.112	13	0.123	13	0.136	13	0.145	13	0.157
14	0.114	14	0.129	14	--	14	--	14	--
15	0.117	15	0.130	15	0.144	15	0.152	15	0.164
16	--	16	--	16	--	16	--	16	--
17	0.119	17	0.125	17	0.138	17	0.144	17	0.157
18	--	18	--	18	--	18	--	18	--
19	0.119	19	0.134	19	0.150	19	0.154	19	0.164
20	--	20	--	20	--	20	--	20	--
21	0.114	21	0.131	21	0.146	21	0.150	21	0.164
22	--	22	--	22	--	22	--	22	--
23	0.109	23	0.126	23	--	23	--	23	--
24	--	24	--	24	--	24	--	24	--

S_o = 0.01
Drop spacing = 2 in.
U = 11.0 ft/sec

Note: X measured from upstream entrance
Y measured normal to channel bottom

i = 1.25 in./hr $q_o = 0.934 \times 10^{-2}$ cfs/ft T = 68.2°F		i = 1.25 in./hr $q_o = 1.040 \times 10^{-2}$ cfs/ft T = 68.4°F		i = 1.25 in./hr $q_o = 1.254 \times 10^{-2}$ cfs/ft T = 68.6°F		i = 1.25 in./hr $q_o = 1.569 \times 10^{-2}$ cfs/ft T = 69.0°F		i = 1.25 in./hr $q_o = 2.740 \times 10^{-2}$ cfs/ft T = 67.6°F	
X(ft)	Y(in.)	X(ft)	Y(in.)	X(ft)	Y(in.)	X(ft)	Y(in.)	X(ft)	Y(in.)
1	--	1	--	1	--	1	--	1	--
2	--	2	--	2	--	2	--	2	--
3	0.156	3	0.163	3	0.182	3	0.191	3	0.273
4	--	4	--	4	--	4	--	4	--
5	0.160	5	0.173	5	0.181	5	0.199	5	0.253
6	--	6	--	6	--	6	--	6	--
7	0.170	7	0.172	7	0.184	7	0.199	7	0.261
8	--	8	--	8	--	8	--	8	--
9	0.160	9	0.169	9	0.179	9	0.196	9	0.255
10	--	10	--	10	--	10	--	10	--
11	0.166	11	0.176	11	0.189	11	0.204	11	0.258
12	--	12	--	12	--	12	--	12	--
13	0.160	13	0.168	13	0.184	13	0.198	13	0.252
14	--	14	--	14	--	14	--	14	0.255
15	0.165	15	0.175	15	0.191	15	0.206	15	0.261
16	--	16	--	16	--	16	--	16	--
17	0.163	17	0.174	17	0.184	17	0.204	17	0.252
18	--	18	--	18	--	18	--	18	--
19	0.171	19	0.176	19	0.194	19	0.211	19	0.267
20	--	20	--	20	--	20	--	20	--
21	0.164	21	0.174	21	0.192	21	0.209	21	0.258
22	--	22	--	22	--	22	--	22	--
23	--	23	--	23	--	23	--	23	0.254
24	--	24	--	24	--	24	--	24	--

S_o = 0.01
Drop spacing = 2 in.
U = 11.0 ft/sec

Note: X measured from upstream entrance
Y measured normal to channel bottom

i = 1.25 in./hr q_o = 4.386×10^{-2} cfs/ft T = 66.8°F		i = 1.25 in./hr q_o = 6.138×10^{-2} cfs/ft T = 65.8°F		i = 3.74 in./hr q_o = 0.100×10^{-2} cfs/ft T = 65.2°F		i = 3.74 in./hr q_o = 0.268×10^{-2} cfs/ft T = 65.4°F		i = 3.74 in./hr q_o = 0.466×10^{-2} cfs/ft T = 68.8°F	
X(ft)	Y(in.)	X(ft)	Y(in.)	X(ft)	Y(in.)	X(ft)	Y(in.)	X(ft)	Y(in.)
1	--	1	--	1	--	1	--	1	--
2	--	2	--	2	--	2	--	2	--
3	0.361	3	0.425	3	0.095	3	0.111	3	0.143
4	--	4	--	4	--	4	--	4	--
5	0.347	5	0.417	5	0.095	5	0.115	5	0.149
6	--	6	--	6	--	6	--	6	--
7	0.349	7	0.402	7	0.099	7	0.119	7	0.145
8	--	8	--	8	--	8	--	8	--
9	0.339	9	0.398	9	0.099	9	0.124	9	0.147
10	--	10	--	10	--	10	--	10	--
11	0.331	11	0.402	11	0.106	11	0.130	11	0.156
12	--	12	--	12	--	12	--	12	--
13	0.325	13	0.391	13	0.102	13	0.125	13	0.148
14	0.334	14	0.408	14	--	14	--	14	--
15	0.332	15	0.413	15	0.101	15	0.128	15	0.146
16	--	16	--	16	--	16	--	16	--
17	0.332	17	0.403	17	0.105	17	0.129	17	0.149
18	--	18	--	18	--	18	--	18	--
19	0.332	19	0.407	19	0.106	19	0.137	19	0.158
20	--	20	--	20	--	20	--	20	--
21	0.323	21	0.389	21	0.106	21	0.139	21	0.163
22	--	22	--	22	--	22	--	22	--
23	0.330	23	0.401	23	0.106	23	0.137	23	--
24	--	24	--	24	--	24	--	24	--

S_o = 0.01
Drop spacing = 2 in.
U = 11.0 ft/sec

Note: X measured from upstream entrance
Y measured normal to channel bottom

i = 3.74 in./hr q_o = 4.266×10^{-2} cfs/ft T = 67.4°F		i = 3.74 in./hr q_o = 5.409×10^{-2} cfs/ft T = 66.8°F		i = q_o = cfs/ft T =		i = q_o = cfs/ft T =		i = q_o = cfs/ft T =	
X(ft)	Y(in.)	X(ft)	Y(in.)	X(ft)	Y(in.)	X(ft)	Y(in.)	X(ft)	Y(in.)
1	--	1	--	1		1		1	
2	--	2	--	2		2		2	
3	0.339	3	0.394	3		3		3	
4	--	4	--	4		4		4	
5	0.342	5	0.392	5		5		5	
6	--	6	--	6		6		6	
7	0.328	7	0.399	7		7		7	
8	--	8	--	8		8		8	
9	0.331	9	0.385	9		9		9	
10	--	10	--	10		10		10	
11	0.339	11	0.382	11		11		11	
12	--	12	--	12		12		12	
13	0.333	13	0.381	13		13		13	
14	--	14	--	14		14		14	
15	0.350	15	0.397	15		15		15	
16	--	16	--	16		16		16	
17	0.340	17	0.386	17		17		17	
18	--	18	--	18		18		18	
19	0.352	19	0.388	19		19		19	
20	--	20	--	20		20		20	
21	0.346	21	0.389	21		21		21	
22	--	22	--	22		22		22	
23	--	23	--	23		23		23	
24	--	24	--	24		24		24	

S_o = 0.03
Drop spacing = 1 in.
U = 11.0 ft/sec

Note: X measured from upstream entrance
Y measured normal to channel bottom

i = 1.00 in./hr $q_o = 0.600 \times 10^{-2}$ cfs/ft T = 65.0°F		i = 1.00 in./hr $q_o = 0.833 \times 10^{-2}$ cfs/ft T = 65.1°F		i = 1.00 in./hr $q_o = 1.127 \times 10^{-2}$ cfs/ft T = 65.2°F		i = 1.00 in./hr $q_o = 1.500 \times 10^{-2}$ cfs/ft T = 64.2°F		i = 1.00 in./hr $q_o = 2.130 \times 10^{-2}$ cfs/ft T = 64.5°F	
X(ft)	Y(in.)	X(ft)	Y(in.)	X(ft)	Y(in.)	X(ft)	Y(in.)	X(ft)	Y(in.)
1	--	1	--	1	--	1	--	1	--
2	--	2	--	2	--	2	--	2	--
3	0.101	3	0.115	3	0.136	3	0.150	3	0.165
4	--	4	--	4	--	4	--	4	--
5	0.098	5	0.108	5	0.129	5	0.145	5	0.168
6	--	6	--	6	--	6	--	6	--
7	0.106	7	0.122	7	0.135	7	0.143	7	0.173
8	--	8	--	8	--	8	--	8	--
9	0.104	9	0.117	9	0.125	9	0.144	9	0.166
10	--	10	--	10	--	10	--	10	--
11	0.097	11	0.110	11	0.132	11	0.144	11	0.171
12	0.100	12	0.115	12	0.137	12	0.147	12	0.168
13	--	13	--	13	--	13	--	13	--
14	0.101	14	0.115	14	0.134	14	0.142	14	0.173
15	0.101	15	0.114	15	0.130	15	0.146	15	0.171
16	--	16	--	16	--	16	--	16	--
17	0.094	17	0.115	17	0.131	17	0.140	17	0.172
18	--	18	--	18	--	18	--	18	--
19	0.102	19	0.115	19	0.135	19	0.146	19	0.174
20	--	20	--	20	--	20	--	20	--
21	--	21	--	21	--	21	--	21	--
22	--	22	--	22	--	22	--	22	--
23	--	23	--	23	--	23	--	23	--
24	--	24	--	24	--	24	--	24	--

S_o = 0.03
Drop spacing = 1 in.
U = 11.0 ft/sec

Note: X measured from upstream entrance
Y measured normal to channel bottom

i = 1.00 in./hr $q_o = 3.030 \times 10^{-2}$ cfs/ft T = 65.2°F		i = 1.00 in./hr $q_o = 4.330 \times 10^{-2}$ cfs/ft T = 65.4°F		i = 1.00 in./hr $q_o = 6.000 \times 10^{-2}$ cfs/ft T = 65.6°F		i = 5.00 in./hr q_o = 0.0 cfs/ft T = 64.6°F		i = 5.00 in./hr $q_o = 0.236 \times 10^{-2}$ cfs/ft T = 63.0°F	
X(ft)	Y(in.)	X(ft)	Y(in.)	X(ft)	Y(in.)	X(ft)	Y(in.)	X(ft)	Y(in.)
1	--	1	--	1	--	1	--	1	--
2	--	2	--	2	--	2	--	2	--
3	0.214	3	0.274	3	0.331	3	0.053	3	0.089
4	--	4	--	4	--	4	--	4	--
5	0.219	5	0.260	5	0.318	5	0.062	5	0.089
6	--	6	--	6	--	6	--	6	--
7	0.220	7	0.256	7	0.311	7	0.067	7	0.095
8	--	8	--	8	--	8	--	8	--
9	0.203	9	0.257	9	0.312	9	0.070	9	0.090
10	--	10	--	10	--	10	--	10	--
11	0.208	11	0.263	11	0.308	11	0.073	11	0.094
12	0.202	12	0.258	12	0.305	12	0.074	12	0.086
13	--	13	--	13	--	13	--	13	--
14	0.210	14	0.264	14	0.317	14	0.075	14	0.098
15	0.208	15	0.253	15	0.313	15	0.071	15	0.097
16	--	16	--	16	--	16	--	16	--
17	0.206	17	0.264	17	0.310	17	0.078	17	0.100
18	--	18	--	18	--	18	--	18	--
19	0.206	19	0.251	19	0.320	19	0.079	19	0.092
20	--	20	--	20	--	20	--	20	--
21	--	21	--	21	--	21	0.086	21	0.099
22	--	22	--	22	--	22	--	22	--
23	--	23	--	23	--	23	0.082	23	0.102
24	--	24	--	24	--	24	--	24	--

S_o = 0.03
Drop spacing = 1 in.
U = 11.0 ft/sec

Note: X measured from upstream entrance
Y measured normal to channel bottom

i = 5.00 in./hr q_o = 0.477×10^{-2} cfs/ft T = 62.3°F		i = 5.00 in./hr q_o = 0.579×10^{-2} cfs/ft T = 63.9°F		i = 5.00 in./hr q_o = 0.815×10^{-2} cfs/ft T = 65.2°F		i = 5.00 in./hr q_o = 1.120×10^{-2} cfs/ft T = 66.0°F		i = 5.00 in./hr q_o = 1.360×10^{-2} cfs/ft T = 62.2°F	
X(ft)	Y(in.)	X(ft)	Y(in.)	X(ft)	Y(in.)	X(ft)	Y(in.)	X(ft)	Y(in.)
1	--	1	--	1	--	1	--	1	--
2	--	2	--	2	--	2	--	2	--
3	0.099	3	0.103	3	0.125	3	0.128	3	0.134
4	--	4	0.--	4	--	4	--	4	--
5	0.094	5	0.103	5	0.115	5	0.129	5	0.134
6	--	6	--	6	--	6	--	6	--
7	0.102	7	0.105	7	0.121	7	0.132	7	0.137
8	--	8	--	8	--	8	--	8	--
9	0.092	9	0.101	9	0.120	9	0.124	9	0.130
10	--	10	--	10	--	10	--	10	--
11	0.098	11	0.101	11	0.114	11	0.129	11	0.132
12	0.096	12	0.101	12	0.117	12	0.128	12	0.138
13	--	13	--	13	--	13	--	13	--
14	0.101	14	0.101	14	0.115	14	0.131	14	0.138
15	0.096	15	0.102	15	0.113	15	0.126	15	0.138
16	--	16	--	16	--	16	--	16	--
17	0.099	17	0.102	17	0.109	17	0.129	17	0.145
18	--	18	--	18	--	18	--	18	--
19	0.102	19	0.106	19	0.116	19	0.134	19	0.143
20	--	20	--	20	--	20	--	20	--
21	0.102	21	0.107	21	0.115	21	0.144	21	0.152
22	--	22	--	22	--	22	--	22	--
23	0.106	23	0.108	23	0.115	23	0.138	23	0.142
24	--	24	--	24	--	24	--	24	--

S_o = 0.03
Drop spacing = 1 in.
U = 11.0 ft/sec

Note: X measured from upstream entrance
Y measured normal to channel bottom

i = 5.00 in./hr $q_o = 1.920 \times 10^{-2}$ cfs/ft T = 63.3°F		i = 5.00 in./hr $q_o = 2.700 \times 10^{-2}$ cfs/ft T = 64.2°F		i = 5.00 in./hr $q_o = 4.870 \times 10^{-2}$ cfs/ft T = 64.0°F		i = 5.00 in./hr $q_o = 6.120 \times 10^{-2}$ cfs/ft T = 64.0°F		i = 9.99 in./hr q_o = 0.0 cfs/ft T = 63.8°F	
X(ft)	Y(in.)	X(ft)	Y(in.)	X(ft)	Y(in.)	X(ft)	Y(in.)	X(ft)	**Y(in.)**
1	--	1	--	1	--	1	--	1	--
2	--	2	--	2	--	2	--	2	--
3	0.160	3	0.202	3	0.283	3	0.324	3	0.056
4	--	4	--	4	--	4	--	4	--
5	0.158	5	0.198	5	0.256	5	0.311	5	0.071
6	--	6	--	6	--	6	--	6	--
7	0.161	7	0.201	7	0.259	7	0.305	7	0.074
8	--	8	--	8	--	8	--	8	--
9	0.157	9	0.191	9	0.265	9	0.294	9	0.080
10	--	10	--	10	--	10	--	10	--
11	0.157	11	0.185	11	0.259	11	0.290	11	0.084
12	0.156	12	0.193	12	0.260	12	0.304	12	0.085
13	--	13	--	13	0.--	13	--	13	--
14	0.153	14	0.201	14	0.265	14	0.307	14	0.082
15	0.157	15	0.200	15	0.272	15	0.294	15	0.085
16	--	16	--	16	--	16	--	16	--
17	0.166	17	0.202	17	0.263	17	0.300	17	0.095
18	--	18	--	18	--	18	--	18	--
19	0.164	19	0.202	19	0.269	19	0.309	19	0.103
20	--	20	--	20	--	20	--	20	--
21	0.171	21	0.205	21	0.259	21	0.302	21	0.098
22	--	22	--	22	--	22	--	22	--
23	0.166	23	0.202	23	0.245	23	0.300	23	0.105
24	--	24	--	24	--	24	--	24	--

S_o = 0.03
Drop spacing = 1 in.
U = 11.0 ft/sec

Note: X measured from upstream entrance
Y measured normal to channel bottom

i = 9.99 in./hr $q_o = 0.240 \times 10^{-2}$ cfs/ft T = 63.6°F		i = 9.99 in./hr $q_o = 0.693 \times 10^{-2}$ cfs/ft T = 64.4°F		i = 9.99 in./hr $q_o = 1.120 \times 10^{-2}$ cfs/ft T = 61.7°F		i = 9.99 in./hr $q_o = 1.986 \times 10^{-2}$ cfs/ft T = 63.2°F		i = 9.99 in./hr $q_o = 3.148 \times 10^{-2}$ cfs/ft T = 63.0°F	
X(ft)	Y(in.)	X(ft)	Y(in.)	X(ft)	Y(in.)	X(ft)	Y(in.)	X(ft)	Y(in.)
1	--	1	--	1	--	1	--	1	--
2	--	2	--	2	--	2	--	2	--
3	0.093	3	0.113	3	0.134	3	0.197	3	0.211
4	--	4	--	4	--	4	--	4	--
5	0.102	5	0.116	5	0.135	5	0.189	5	0.210
6	--	6	--	6	--	6	--	6	--
7	0.106	7	0.115	7	0.143	7	0.199	7	0.219
8	--	8	--	8	--	8	--	8	--
9	0.098	9	0.110	9	0.130	9	0.192	9	0.210
10	--	10	--	10	--	10	--	10	--
11	0.106	11	0.106	11	0.134	11	0.197	11	0.220
12	0.107	12	0.111	12	0.131	12	0.179	12	0.215
13	0.095	13	--	13	--	13	--	13	--
14	--	14	0.108	14	0.134	14	0.189	14	0.211
15	0.108	15	0.117	15	0.139	15	0.191	15	0.216
16	--	16	--	16	--	16	--	16	--
17	0.110	17	0.116	17	0.148	17	0.193	17	0.214
18	--	18	--	18	--	18	--	18	--
19	0.113	19	0.119	19	0.142	19	0.202	19	0.226
20	--	20	--	20	--	20	--	20	--
21	0.117	21	0.110	21	0.150	21	0.222	21	0.233
22	--	22	--	22	--	22	--	22	--
23	0.109	23	0.116	23	0.145	23	0.207	23	0.238
24	--	24	--	24	--	24	--	24	--

$S_o = 0.03$
Drop spacing = 1 in.
$U = 11.0$ ft/sec

Note: X measured from upstream entrance
Y measured normal to channel bottom

$i = 9.99$ in./hr $q_o = 4.290 \times 10^{-2}$ cfs/ft $T = 63.5^{\circ}F$		$i = 9.99$ in./hr $q_o = 5.490 \times 10^{-2}$ cfs/ft $T = 63.6^{\circ}F$		$i = 14.99$ in./hr $q_o = 0.0$ cfs/ft $T = 63.7^{\circ}F$		$i = 14.99$ in./hr $q_o = 0.248 \times 10^{-2}$ cfs/ft $T = 63.2^{\circ}F$		$i = 14.99$ in./hr $q_o = 1.000 \times 10^{-2}$ cfs/ft $T = 63.2^{\circ}F$	
X(ft)	Y(in.)	X(ft)	Y(in.)	X(ft)	Y(in.)	X(ft)	Y(in.)	X(ft)	Y(in.)
1	--	1	--	1	--	1	--	1	--
2	--	2	--	2	--	2	--	2	--
3	0.266	3	0.296	3	0.070	3	0.100	3	0.135
4	--	4	--	4	--	4	--	4	--
5	0.251	5	0.295	5	0.085	5	0.107	5	0.147
6	--	6	--	6	--	6	--	6	--
7	0.250	7	0.286	7	0.094	7	0.116	7	0.142
8	--	8	--	8	--	8	--	8	--
9	0.252	9	0.281	9	0.096	9	0.101	9	0.143
10	--	10	--	10	--	10	--	10	--
11	0.245	11	0.277	11	0.092	11	0.111	11	0.142
12	0.244	12	0.292	12	0.105	12	0.110	12	0.146
13	--	13	--	13	--	13	--	13	--
14	0.255	14	0.282	14	0.112	14	0.109	14	0.141
15	0.251	15	0.283	15	0.109	15	0.111	15	0.142
16	--	16	--	16	--	16	--	16	--
17	0.249	17	0.284	17	0.116	17	0.113	17	0.152
18	--	18	--	18	--	18	--	18	--
19	0.266	19	0.298	19	0.113	19	0.121	19	0.154
20	--	20	--	20	--	20	--	20	--
21	0.278	21	0.312	21	0.111	21	0.121	21	0.170
22	--	22	--	22	--	22	--	22	--
23	0.262	23	0.291	23	0.117	23	0.133	23	0.153
24	--	24	--	24	--	24	--	24	--

S_o = 0.03
Drop spacing = 1 in.
U = 11.0 ft/sec

Note: X measured from upstream entrance
Y measured normal to channel bottom

i = 14.99 in./hr q_o = 1.840×10^{-2} cfs/ft T = 62.3°F		i = 14.99 in./hr q_o = 3.520×10^{-2} cfs/ft T = 64.0°F		i = 14.99 in./hr q_o = 5.243×10^{-2} cfs/ft T = 64.0°F	
X(ft)	Y(in.)	X(ft)	Y(in.)	X(ft)	Y(in.)
1	--	1	--	1	--
2	--	2	--	2	--
3	0.170	3	0.239	3	0.287
4	--	4	--	4	--
5	0.169	5	0.233	5	0.291
6	--	6	--	6	--
7	0.189	7	0.232	7	0.286
8	--	8	--	8	--
9	0.169	9	0.238	9	0.294
10	--	10	--	10	--
11	0.169	11	0.245	11	0.293
12	0.169	12	0.241	12	0.289
13	--	13	--	13	--
14	0.173	14	0.236	14	0.286
15	0.174	15	0.234	15	0.292
16	--	16	--	16	--
17	0.180	17	0.245	17	0.286
18	--	18	--	18	--
19	0.173	19	0.246	19	0.303
20	--	20	--	20	--
21	0.188	21	0.262	21	0.318
22	--	22	--	22	--
23	0.184	23	0.253	23	0.325
24	--	24	--	24	--