ABSTRACT

HYDRAULICS OF SPATIAL PIPE FLOW

by Wan Wang Hu

The tile main of a soil profile drainage system should have sufficient capacity, yet not be oversized. The adequacy of its design is indicated in part by the position of the water surface profile in the conduit. In general, the pipe size increases with increased discharge. The position of the water surface depends on the several factors of discharge, tile diameter, tile roughness and slope. Discharge depends largely on precipitation and hydraulic conductivity of soil. The purpose of efficient design is twofold: First, to maintain a free water surface in the main tile so that pressurized flow will not result. Second, to avoid the uneconomical use of large size diameter pipes for small discharge.

The discharge carried by the tile main generally increases as the distance downstream from the inlet end of the main increases. The flow inside of the main increases by a constant quantity ΔQ from each lateral. The flow manifests a complex non-uniform profile. On steep slopes or with large inflows, supercritical flow and waves at lateral junctions may develop.

Past studies on variable discharge systems considered only water surface profiles within rectangular cross sections. This dissertation explores procedures for calculating the water surface profile in circular cross sections as influenced by channel slope and increased discharge.

General equations for calculating flow depths are derived from the momentum theory. Experimental observations on water depths at junctions of laterals as well as flow in the main have been carefully undertaken. A scale model was used to examine the validity of the theoretical analysis. In all instances, close agreement was observed between theory and experiment. The effects of surge waves was investigated analytically and experimentally. Only theoretical work has been done on the unsteady flow condition.

Recommendations, based on the results of theoretical and experimental evidences, are made for the selection of main tile sizes under twenty four different field conditions.

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HYDRAULICS OF SPATIAL PIPE FLOW

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W. W. Hu

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I

INTRODUCTION

In the field of Drainage Engineering, the Yarnell-Woodward formula $V = 138R^{2/3} S^{1/2}$ which was developed from extensive flow studies in full sized tile mains has been accepted for tile main design for over 35 years. Since the entire flow in this study entered the main at its upper end, recognition was not given to the disturbence of the flow by the injection of ΔQ's from tile laterals as would occur in a complete farm field drainage system. A study was initiated in the Agricultural Engineering Department at Michigan State University in 1960 with the following objectives:

1. To compute the water surface profiles in the main from derived theoretical equations with various combinations of flow, slope and tile diameter.
2. To select the most economical tile size combinations based on the theoretically derived profiles.
3. To verify the theoretical analysis by experiments on models.
4. To investigate the supercritical and subcritical flow and waves at lateral junctions in the main.

II

REVIEW OF LITERATURES

This dissertation is concerned with "spatial flow" in a closed conduit. A constant increment of discharge ΔQ is added to this conduit at constant sixty-six foot intervals of distance. Negligible research has been reported on problems of spatial flow in closed circular conduits.

Yarnell and Woodward (1920) worked intensively on the flow in drain tile. Full scale models were used for experimental investigations, but the theoretical analysis was based on the assumptions of uniform flow. These investigators checked the Chezy's uniform flow formula, tested the roughness coefficient of Kutter's uniform flow formula, and found that the velocity of flow is proportional to the square root of conduit slope and the two-thirds power of the mean hydraulic radius. They also disproved the belief that the velocity of flow in a pipe flowing one-half full was the same with the one flowing full as given by Chezy's formula.

For non-uniform and unsteady flow, Beij (1934) discovered that whereas the point of critical depth was located at the outlet of a gently sloping channel, this point moved upstream for increasing channel slopes. Keulegan (1944) derived an equation of motion for a rectangular channel with a continuously increasing flow. Surface profiles were calculated on the assumption that the rate of change of discharge with respect to the travel distance was a positive constant. Conservation of momentum was used to analyze the flow. Iwagaki (1954) derived the general equation of motion for the unsteady flow subject to spatial variation of discharge in open channels. An exact analytical solution of spatial flow is not available to date. All approaches to the problem depend on a number of simplifying assumptions.

For the study of waves, classical theories concerning the simpler problem of periodic waves contained much of the informations required. Bousinesq, Rayliegh, Stokes, and Korteweg had contributed to these theories and concluded that "the curvature of wave is assumed to increase linearly from the channel bed to the curved flow surface." Horton (1938) analyzed quantitatively the channel waves chiefly subjected to momentum control. Scott (1944) observed surge waves for several miles. Scott also conducted a series of experiments in a small laboratory flume on solitary wave and reported the detailed behavior of it. A study of open channel junctions was reported by Saint Anthony Fall Hydraulic Laboratory of University of Minnesota (1950), in which an intensive investigation of junction waves was observed. It was found that the backwater effects caused by junction inflows increased the water depth in upstream parts of the channel. Sandover (1957), experimenting in a model channel one meter deep and six hundred meters long, succeeded in measuring with reasonable accuracy some of the salient features, such as wave heights and lengths of undular surge wave trains.

Despite all developments, a satisfactory general solution of the wave problem has not been obtained. Practical hydraulicians, therefore, have come to regard the various conditions of waves as a number of isolated cases, each requiring its own emperical treatment.

III

DESIGN OF EXPERIMENT

When the land topography is gentle, a field that is independent might have a size of forty acres with dimensions of 1320 feet by 1320 feet. Three principal types of lateral subdrainage layouts in common use are the Random, Herringbone and Gridiron systems. The Gridiron system is economical since it can be designed for complete profile drainage of the field and few junctions of laterals to main are involved. It is especially advantageous in fields which have relatively uniform land slopes. It has the field layout shown in Fig. 1 in partial form for a forty-acre field.

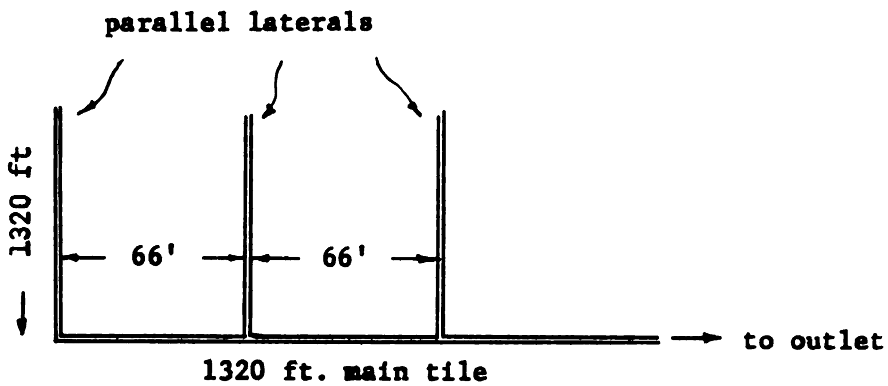


Figure 1. Gridiron Type Tile Drainage System

In Fig. 1, each of the twenty parallel underground laterals, spaced at sixty-six feet intervals, serves to collect the gravitational water from a two-acre area. A tile main collects the lateral discharges and carries it to the outlet. Since a discharge increment ΔQ is added at intervals of sixty-six feet, the flow inside the tile main can not be uniform. Theoretically, all of the laterals would discharge the same increment ΔQ into the main. On steep slopes or with large inflows, supercritical flow and surge waves may develop in the main. The position of the water surface profile developed in the main should be known and used as a guide in selecting proper sizes for the tile main.

Most investigations of spatial flow have been conducted in rectangular channel sections. An experimental investigation was essential for the determination of qualitative information for a circular channel section. The experimental study was developed to investigate 1) transitional flow from subcritical to supercritical and 2) surge waves at lateral junctions. The experimental study verified the theoretical derivation in this dissertation.

3.1 Design Data

The several variables that must be considered in analyzing the water surface profile are briefly described below:

1. Roughness: The Manning's roughness "n" was considered a constant of 0.011 for smooth clay or concrete tile.
2. Size of Tile: Lateral tiles were four inches diameter. Prototype main tiles used were four, five, six, eight and ten inches diameter.

3. Drainage Coefficient: The drainage coefficient C is the the depth of water in inches to be removed from the drainage area in twenty four hours. Correlating the drainage coefficient with rainfall is difficult since the distribution of rainfall during the crop growing season and the rainfall intensity must be considered along with evaporation and hydraulic conductivity of soils. Selection of the drainage coefficient is primarily based on experience and judgement. The rate of drainage selected should result in minimum crop damage. This research used three-, five-, seven-, and ten-eighths of an inch as the drainage coefficients of laterals, each serving a two-acre area in Fig. 1 were calculated from the equation $\Delta Q = 0.042CA$ * and tabulated below:

Drainage Coefficient C	Corresponding Discharge per Area of Two Acres ΔQ
3/8 inches	0.0315 cfs
5/8 inches	0.0525 cfs
7/8 inches	0.0735 cfs
10/8 inches	0.1050 cfs

* See reference: U. S. Soil Conservation Service (1953) "Farm Planners' Handbook"

4. Slope of Tile: Topography is the major factor influencing the slopes of tile lines. In this study, the slopes of laterals were assumed to be small, less than a fall of 1 ft per 1000 ft, so that high velocity or supercritical flow would not occur. Seven slopes of main tiles were studies to cover most field conditions. They were: 0.0005, 0.0010, 0.0025, 0.005, 0.010, 0.025 and 0.05 feet per foot of main.

3.2 Equipment

Sketches and photographs of the equipment used are shown in Figs. 2--8. The following paragraphs describe briefly the various components of the equipment and how they were used. Fig. 2 shows the general layout of the experimental set-up.

1. The main tank dimensions were 2.5 ft by 1.5 ft by 1.5 ft (see Fig.3). A gravel screen was used to tranquilize the inflowing water. The side walls were made of transparent plastic sheets.
2. Two lateral tanks supplied the lateral inflow. Each tank had 1) dimensions of 1.5 ft cubic and 2) transparent side walls and gravel screens. All junctions and edges are tightly sealed with rubber gaskets and glue to prevent leakage.
3. The main conduit shown in Fig. 2a was made of lucite pipe sections of the following sizes:

   2.5 inches inside diameter, 4 feet long;

   3 inches inside diameter, 4.5 feet long;

   4 inches inside diameter, 4.5 feet long.

The main conduit was laid on an adjustable slope for experiments on slope variation.

4. The two lateral lucite pipes shown in Fig. 2a had the following dimensions:

   2 inches inside diameter, 3 feet long;

   3 inches inside diameter, 3 feet long.

   Both lateral pipes were tightly connected to the main pipe. The Manning's roughness "n" for all lucite pipes were tested. It was a constant value of 0.009.

5. All pipe junctions were smoothly constructed to provide a straight bottom line. The junctions of pipes and tanks were sealed with soft rubber so that they could be tilted without leakage.

6. An adjustable hardwood bed slope was used to support the main pipe as shown in Fig. 5. It could be adjusted to a maximum slope of 0.05 ft per ft. To increase the slope, the lateral tanks were elevated by inserting blocks under the tank bottom. The lateral flow velocities were always low.

7. The main tank water was supplied by pump and controlled by valves. Lateral tanks were supplied by hoses connected to water faucets.

8. A white paper covered blackboard was installed vertically on the left side of the main, opposite the lateral tanks as shown in Fig. 6. The blackboard was set strictly parallel to the main pipe. A flood light was set at the right side of the main so that the light could project the flow profile on the white paper. A precise point gage was set to slide on the top edge of the board to measure the depth of profile projections. The point gage could be

moved to any horizontal position and could be read to one-hundredth of an inch.

9. The rate of flow was controlled by the valve openings. These were pretested by direct measurements and found to be accurate and reliable.

10. For shallow flow depths, dye (Potassium Permanganate, $KMnO_4$) was injected into the flow to color the water.

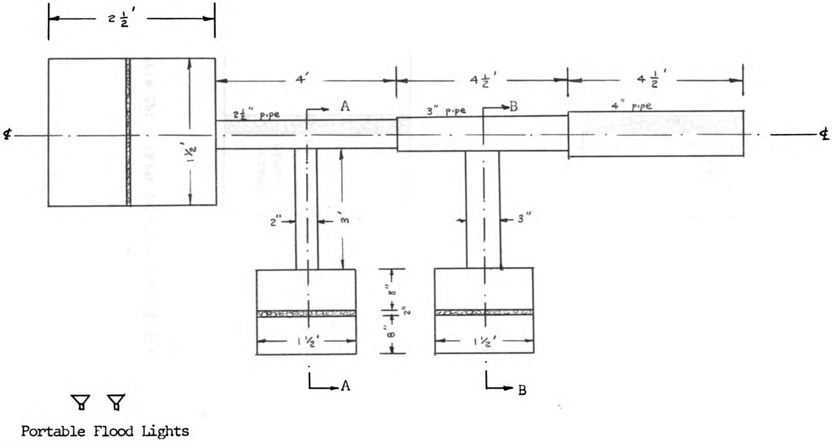
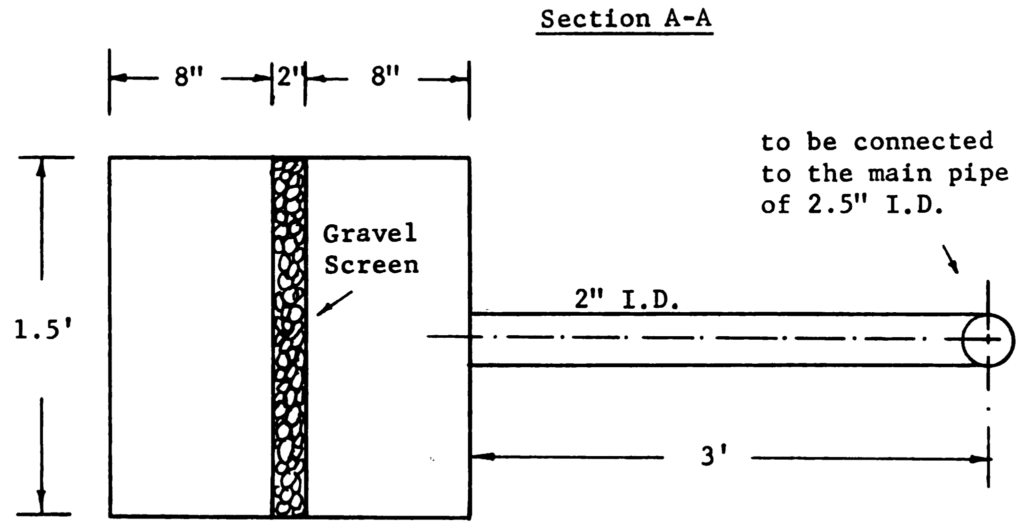


Figure 2a: Layout of Main and Lateral Tile System for Laboratory Study (not to scale)



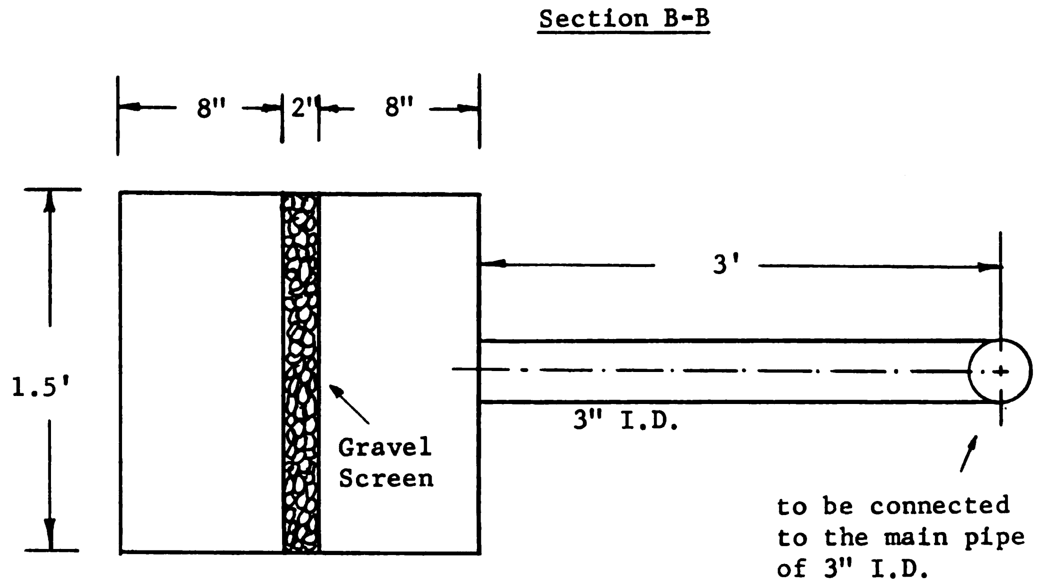


Figure 2b: Cross Sections A-A and B-B in Fig. 2a

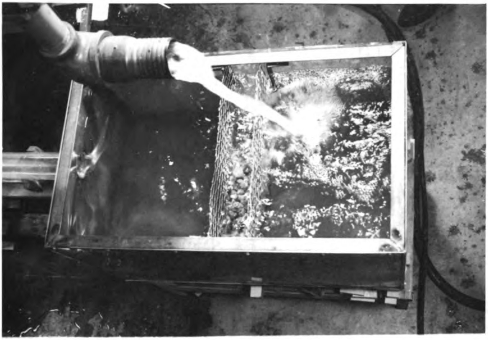


Figure 3: Head Tank in Operation

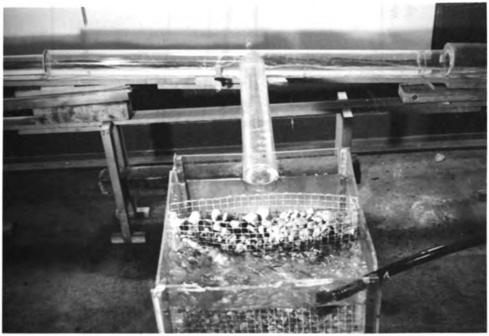


Figure 4: Side Tank in Operation

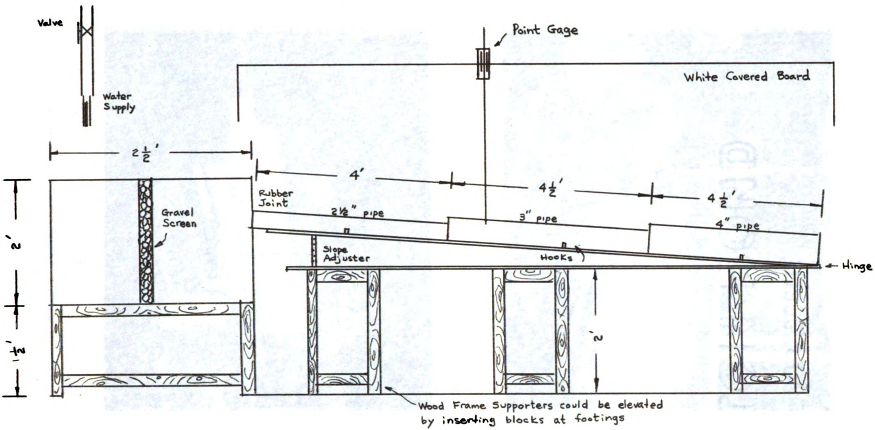
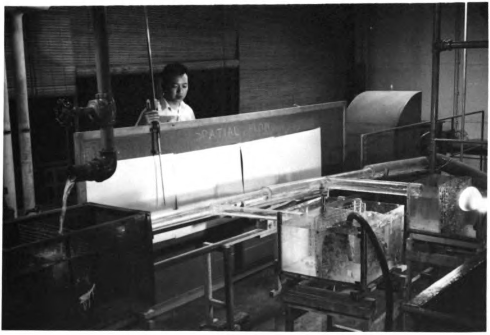


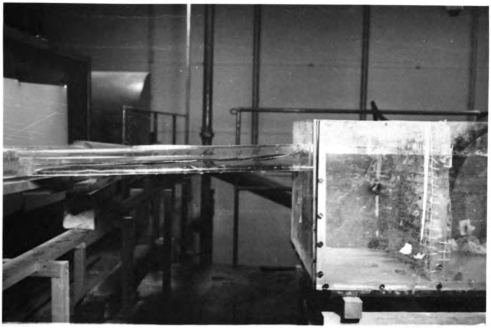
Figure 5: Elevation of Equipment (not to scale)

(a)

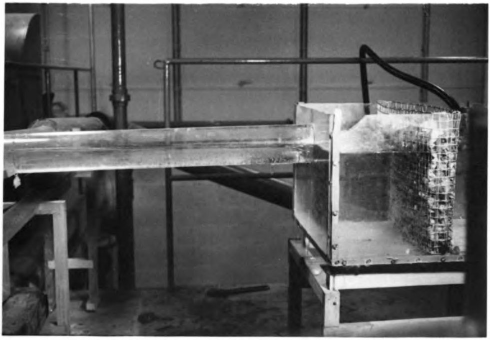


(b)

Figure 6: Equipment during Operation



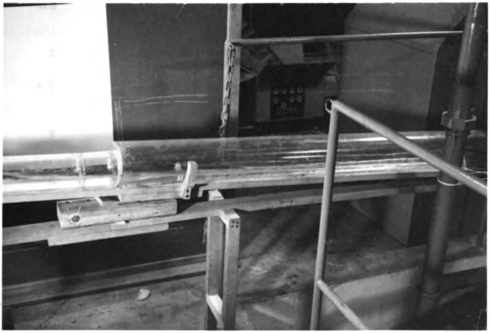
(a) $\Delta Q = 0.0735$ cfs



(b) $\Delta Q = 0.1050$ cfs

Figure 7: Lateral Inflows

(a)



(b)

Figure 8: Main Channel Flow at Maximum Condition
$\Delta Q = 0.1050$ cfs $S = 0.05$ $Q = 2.100$ cfs

3.3 Similitude

The problem under consideration was analyzed in two parts. Part one was the flow profile with a channel section of constant size and discharge. Part two was the flow depths just upstream and downstream from a junction where the lateral discharge produced a wave. In this section, Buckingham's π- method was used to analyze the parameters.

1. The analysis for channel sections of constant size and discharge

The following list of parameters was considered to be significant in the dimensional analysis of the problem under consideration:

Symbol	Entity	MLT Dimension
Δd	difference of flow depths of two flow sections	L
S	slope of the conduit	L^{0}
ΔL	distance between the two flow sections	L
V	average velocity of the two flow sections	LT^{-1}
D	average hydraulic depths of two flow sections	L
ρ	density of water	ML^{-3}
μ	dynamic viscosity of water	$ML^{-1} T^{-1}$
γ	unit weight of water	$ML^{-2} T^{-2}$

The difference of two flow depths, Δd, could then be expressed as a function of all other variables in this form:

$$\Delta d = \phi_1 (S, \Delta L, V, D, \rho, \mu, \gamma) \qquad \text{-------} \quad (3.3.1)$$

All these seven variables may be completely described by the three fundamental dimensions of MLT system. Hence there are 7 - 3 = 4 dimensionless π - terms:

$$\Delta d = \phi_1 (\pi_1 , \pi_2 , \pi_3 , \pi_4) \qquad \text{------------ (3.3.2)}$$

By choosing ρ, V and D as the repeating primary variables and assigning a negative unit exponent for each non-repeating variable, the four π - terms are formed as follows:

$$\pi_1 = \rho^{a_1} V^{b_1} D^{c_1} \gamma^{-1}$$

$$\pi_2 = \rho^{a_2} V^{b_2} D^{c_2} \mu^{-1}$$

$$\pi_3 = \rho^{a_3} V^{b_3} D^{c_3} S^{-1} \qquad \text{------------- (3.3.3)}$$

$$\pi_4 = \rho^{a_4} V^{b_4} D^{c_4} \Delta L^{-1}$$

Substituting the MLT dimensions, one obtains:

$$\pi_1 = M^0 L^0 T^0 = (ML^{-3})^{a_1} (LT^{-1})^{b_1} (L)^{c_1} (ML^{-2} T^{-2})^{-1} \qquad \text{-------- (3.3.4)}$$

By equating corresponding values of exponents on both sides of Eq. (3.3.4), one obtains the values of a_1 , b_1 , and c_1 to be: $a_1 = 1$, $b_1 = 2$ and $c_1 = -1$. This calculation shows that

$$\pi_1 = \rho V^2 / D\gamma = \text{Froude Number } N_F \qquad \text{------------- (3.3.5a)}$$

Following the same process, the other three π terms are found:

$$\pi_2 = VD\rho/\mu = \text{Reynolds Number } N_R$$

$$\pi_3 = S^{-1} \qquad \text{------------- (3.3.5b)}$$

$$\pi_4 = D/\Delta L$$

Therefore, the difference of two flow depths Δd can be expressed as

$$\Delta d = \phi_1 (N_F , N_R , D/\Delta L, S^{-1}) \qquad \text{------------- (3.3.6)}$$

Eq. (3.3.6) shows Δd as a function of Reynolds Number, Froude Number, slope and the depth-length ratio.

2. Flow wave at the junction

The variable, lateral inflow ΔQ, was added to the conditions existing under case 1. There would be eight variables and five dimensionless π terms. ΔQ has the dimension L^3T^{-1}. Proceeding as in case 1, one found:

$$\Delta d = \phi_2 (N_F , N_R , S^{-1} , D/\Delta L, VD^2/\Delta Q) \quad \text{-----------} \quad (3.3.7)$$

The fifth π term could be analyzed further. Since the continuity holds $Q = VA = N\Delta Q$, where N is the number of laterals, it follows that

$$\frac{VD^2}{\Delta Q} = \frac{NVD^2}{N\Delta Q} = \frac{NVD^2}{VA} = \frac{ND^2}{A} = \frac{ND}{T} \quad \text{-----------} \quad (3.3.8)$$

Substituting Eq. (3.3.8) into Eq. (3.3.7), Δd becomes a function of Reynolds Number, Froude Number, slope, the depth-length ratio and the depth-width ratio.

Geometric similarity could have been easily achieved in the design of the experiment, but the attainment of dynamic similarity required the simultaneous equalities of two dimensionless parameters N_F and N_R. For the experiment, it was difficult to construct precise equipment required to match the two dynamic similarities. However, the discharge of the main and the laterals of this problem were usually small and the author used the following procedures to overcome the difficulty:

(1) For investigation of open-channel flow as in case 1, Manning's formula was used for similarity. Thus by equating Manning's

velocities for model and prototype, one obtains the following equation:

$$\frac{Q_m}{Q_p} = \frac{A_m\ V_m}{A_p\ V_p} = \frac{D_m^2\ D_m^{2/3}\ n_m}{D_p^2\ D_p^{2/3}\ n_p} = 0.818\left(\frac{D_m}{D_p}\right)^{8/3} \qquad \text{------------ (3.3.9)}$$

(2) For investigation of wave motion and profile as in case 2. Froude Number was used for similarity. By equating Froude Number for model and prototype, one obtains the following equation:

$$\frac{Q_m}{Q_p} = \frac{A_m\ V_m}{A_p\ V_p} = \frac{D_m^2\ D_m^{1/2}}{D_p^2\ D_p^{1/2}} = \left(\frac{D_m}{D_p}\right)^{5/2} \qquad \text{------------ (3.3.10)}$$

If it was assumed that the discharge in the model was directly proportional to the discharge in the prototype, i.e., $Q_m = K\ Q_p$, then one could compute the values of K by Eqs. (3.3.9) and (3.3.10). These values are shown in Table 1.

Table 1: Values of K for Various Model and Prototype sizes as Computed from Eqs (3.3.9) and (3.3.10)

Equations	Model Diameter \ Prototype Diameter	4"	5"	6"	8"	10"
(3.3.9)	2.5"	0.223	0.128	0.079	0.037	0.021
(3.3.10)		0.309	0.177	0.112	0.054	0.031
(3.3.9)	3"	0.379	0.210	0.128	0.061	0.033
(3.3.10)		0.488	0.279	0.177	0.086	0.049
(3.3.9)	4"	0.818	0.452	0.278	0.128	0.071
(3.3.10)		1.000	0.573	0.363	0.177	0.101

Remarks: Eq. (3.3.9) is for the use of flow investigation;
Eq.(3.3.10) is for the use of wave investigation.

IV

METHODOLOGY AND DERIVATION OF EQUATIONS

4.1 Notation

Symbol	Definition	Unit
d	flow depth	ft
D	hydraulic depth	ft
A	cross sectional flow area	ft^2
T	free surface width of flow	ft
S	slope of channel	ft/ft
R	hydraulic radius	ft
θ	angle of channel inclination	--
L	length of channel	ft
ΔL	distance between two flow sections	ft
Q	discharge in main conduit	cfs
ΔQ	lateral discharge or increment of discharge	cfs
V	velocity of flow	fps
q	discharge per unit surface area	cfs/ft^2
m	ratio of D/R	--
x	distance along channel measured from the initial inlet end of the conduit	ft
E	specific energy	ft

f	coefficient of resistance	--
ϵ	infinitisimal increment of distance	ft
μ	dynamic viscosity	$lb\text{-}sec/ft^2$
ν	kinematic viscosity	ft^2/sec
γ	unit weight of water	lbs/ft^3
ρ	density of water	$lb\text{-}sec^2/ft^4$
n	Manning's roughness of channel	--
N	numbers of laterals	--
τ	frictional force	lb
τ_0	shear stress	psf
N_F	Froude Number	--
F_n	Froude Number at n-th section	--
N_R	Reynolds Number	--
r	radius of pipe	ft
C	wave celerity	fps
h	wave height	ft
F_p	pressure force	lb
F_m	momentum force	lb
W	weight of water body	lb
P	wetted perimeter	ft

4.2 Analysis

1. The free body diagram showing flow in main

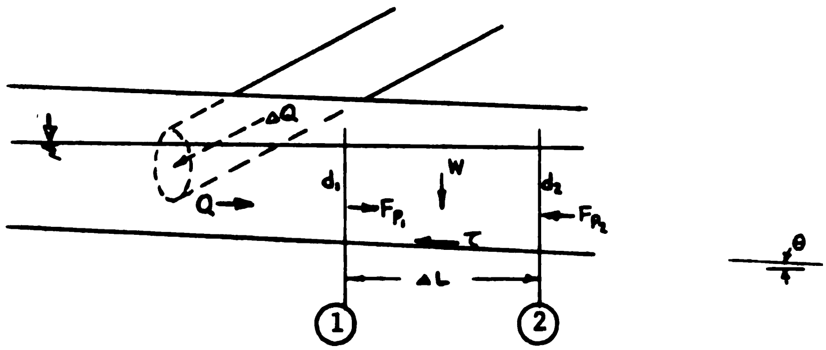


Figure 9: Flow in Main

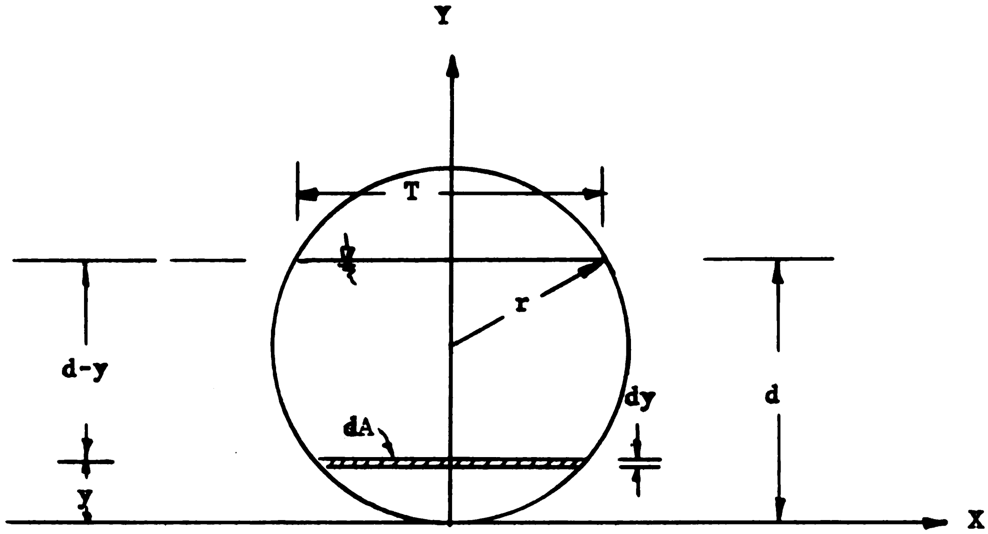
Forces, including pressure, gravitation, friction and momentum are involved and control the flow profile in the main tile. Momentum theory was used for analysis. The general momentum equation is:

$$F_{p_1} - F_{p_2} + W \sin\theta - \tau = F_m \qquad \text{--------------} \quad (4.2.1)$$

where F_p is the pressure force, W is the weight of the water body between sections (1) and (2) in Fig. 9, τ is the frictional force and F_m the momentum force.

2. Pressure force F_p

For the flow cross section shown in Fig. 10:



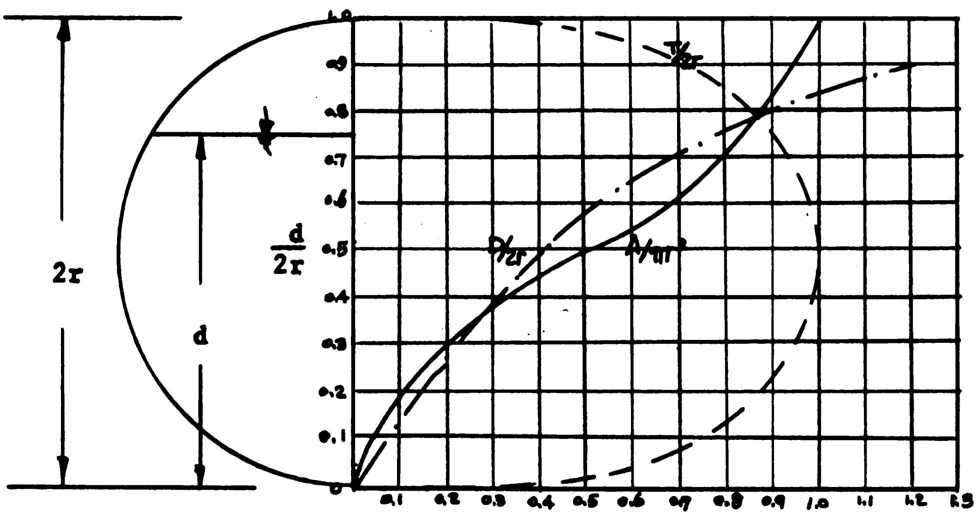


Figure 10: Geometrical Elements of A Flow Cross Section

the equation of circle is

$$x = \pm\sqrt{2ry - y^2} \qquad \text{-------------------} \quad (4.2.2)$$

The pressure force is defined as the product of the flow area A, the unit weight of water γ and the height of the centroid of A, thus,

$$F_p = \gamma\int_{y=0}^{y=d}(d-y)\,dA = \gamma\,(d-r)A + \frac{2}{3}\gamma\,(2rd-d^2)^{3/2} \qquad \text{--------} \quad (4.2.3)$$

where

$$A = \int_0^d 2x\,dy = \left[(d-r)\sqrt{2rd-d^2} - r^2\sin^{-1}\frac{(d-r)}{r} + \frac{1}{2}\pi r^2\right]$$

$$= \phi(d) \qquad \text{-------------------} \quad (4.2.4)$$

3. <u>Component of gravitational force W sinθ</u>

The gravitational force is equal to the unit weight of water times the volume of the water body and its component along the direction of flow is W sinθ:

$$W\sin\theta = \gamma\,\Delta L\,A\sin\theta$$

$$= \gamma\,\Delta L\sin\theta\left[(d-r)\sqrt{2rd-d^2} - r^2\sin^{-1}\frac{(d-r)}{r} + \frac{1}{2}\pi r^2\right]$$

$$\text{-------------------} \quad (4.2.5)$$

where ΔL is the distance between two neighboring cross sections. The depth d is the average depth of the water body. Since ΔL and $(d_1 - d_2)$ were taken small, d could be assumed equal to the end depth. Thus d for the cross sections N and N+1 was taken equal to d_{N+1}.

4. Frictional force τ

Based on the assumption that ΔL was small and the flow was uniform within the two cross sections, the Chezy's formula shows that

$$\tau_o = \gamma R S_e \quad \text{and} \quad S_e = \frac{V^2}{C^2 R} = \frac{Q^2}{C^2 A^2 R} \qquad \text{----------} \ (4.2.6)$$

where τ_o is the shear stress, R is the hydraulic radius, S_e is the slope of the energy line and C is the Chezy's constant. Frictional force τ equals the shear stress multiplied by the rubbing surface area:

$$\tau = \tau_o \Delta L\ P = \gamma R \frac{Q^2}{C^2 A^2 R} \Delta L\ P \qquad \text{----------} \ (4.2.7)$$

where P is the wetted perimeter. Since R = A/P and $C^2 = 8g/f$ where f is the resistance coefficient in Chezy's formula and g is the gravitational acceleration, then

$$\tau = \frac{\gamma \Delta L\ Q^2}{C^2 AR} = \frac{\gamma f\ Q^2 \Delta L}{8gAR} \qquad \text{----------} \ (4.2.8)$$

Substituting Manning's roughness n for f, one obtains

$$\frac{f}{8g} = \frac{n^2}{(1.486)^2 R^{1/3}} = \frac{(0.011)^2}{(1.486)^2 R^{1/3}} = \frac{0.0000548}{R^{1/3}} \qquad \text{-------} \ (4.2.9)$$

and

$$\tau = \frac{0.0000548\ Q^2 \Delta L}{AR^{4/3}} \qquad \text{----------} \ (4.2.10)$$

where n was assumed to have a constant value of 0.011 for smooth clay pipes.

5. Momentum force F_m

The momentum force is equal to the product of the mass and the change in flow velocities. Thus,

$$F_m = \rho Q(V_2 - V_1) = \rho\left(\frac{Q^2}{A_2} - \frac{Q^2}{A_1}\right) \qquad \text{------------} \quad (4.2.11)$$

where A can be computed from Eq. (4.2.4).

6. General equations

A. For calculating the two section depths in a conduit with a given constant discharge, Eq. (4.2.1) was applied. After substituting all values of forces and simplifying, this equation reduced to the following form:

$$\frac{Q^2}{gA_2} + (d_2 - r)A_2 + \frac{2}{3}(2rd_2 - d_2^2)^{3/2} - \Delta L \sin\theta \, A_2$$
$$+ \frac{0.0000548 \, Q^2 \, \Delta L}{A_2 R_2^{4/3}} = \frac{Q^2}{gA_1} + (d_1 - r)A_1 + \frac{2}{3}(2rd_1 - d_1^2)^{3/2}$$

------------- (4.2.12)

With one of the two depths known, the second depth could be calculated from Eq. (4.2.12). The controlling depth is the critical depth, and computation of the profile should begin at the critical section. Computation of critical depth is in the following section.

B. For calculation of the two adjacent depths just upstream and downstream at the lateral junction, Eq. (4.2.12) needs modification. At each junction where lateral discharge ΔQ flowed into the main as shown in Fig. 11, ΔL was only four inches and hence negligible.

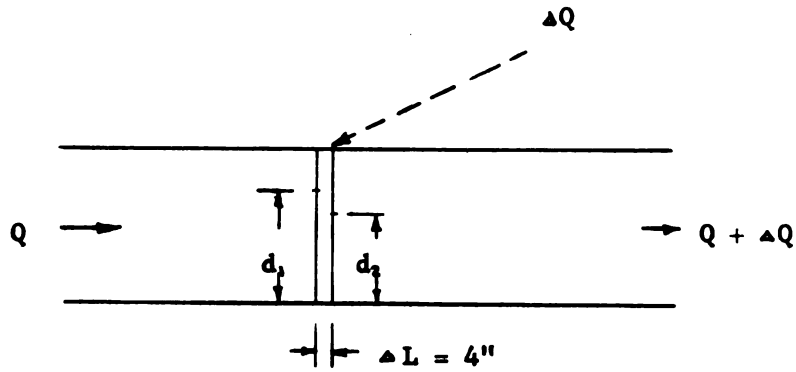


Figure 11: Flow at Junction

When the discharge was varied from Q to Q+ΔQ and ΔL neglected, Eq. (4.2.12) became:

$$\frac{Q^2}{gA_1} + (d_1 - r)A_1 + \frac{2}{3}(2rd_1 - d_1^2)^{3/2}$$

$$= \frac{(Q+\Delta Q)^2}{gA_2} + (d_2 - r)A_2 + \frac{2}{3}(2rd_2 - d_2^2)^{3/2} \quad \text{----} \quad (4.2.13)$$

4.3. Determination of Critical Depth

The critical depth is defined as the flow depth at which the flow energy assumes its least value. This depth can be computed from the given flow condition. In an open channel of subcritical slope with a spatial discharge, the critical depth occurs at the channel outlet. Critical depth moves upstream as the slope increases. Since critical depth is controlling, computation of the water surface profile requires that the magnitude and position of the critical depth be determined.

1. <u>The criterion for critical depth</u>

Since flow is down grade toward the outlet end of the tile main, its upper end could be considered closed and the lower end open. Continuity equation shows that

$$VA = N\Delta Q \quad \text{or} \quad VD = qx \qquad \text{---------} \quad (4.3.1)$$

where V is the average velocity of flow in tile, N is the number of laterals which carry each a discharge ΔQ into the main, D is the hydraulic depth which equals to A/T, T is the flow width of free surface (Fig. 10), x is the distance of the flow section from the inlet end of the main (Fig. 12) and q is the discharge per unit surface area or equals to Q/Tx.

The flow is tranquil for small values of x or N and critical depth occurs at the outlet section.

If the flow increases so that supercritical flow is realized at the open end of the channel, a critical flow section results at a distance x_c from the inlet end. This critical section must possess a Froude Number of unity.

As shown in Fig. 12, let x_1 and x_2 be the positions of upstream and downstream neighboring sections, each section is an infinitisimal distance ϵ from the critical section. Section ① is then subcritical and section ② is supercritical. The inequalities are then $F_1 < 1$ and $F_2 > 1$, F_n being the Froude Number of n-th section.

Between the two sections, the water surface exhibits either discontinuous or continuous conditions at the critical section. The discontinuous condition is a negative hydraulic jump which is known to be impossible. The continuous case is then the only physically valid condition which yields a finite value of dd/dx.

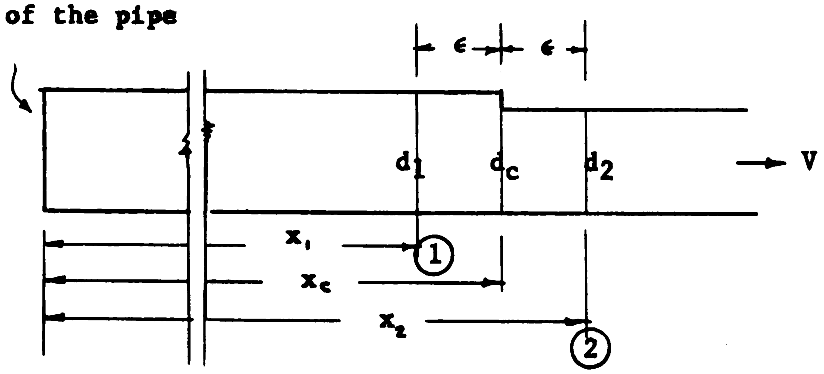


Figure 12: Neighboring Sections Upstream and Downstream of a Critical Section.

2. Equations for dd/dx with a finite value

Keulegan (1944) derived an equation of motion for rectangular channel from the theory of conservation of energy:

$$V \frac{dV}{dx} = g(S - \frac{dd}{dx}) - \frac{f_1 V^2}{2 R} - q \frac{V}{d} \qquad \text{----------------- (4.3.2)}$$

where f_1 is Blasius coefficient of resistance defined by

$$\tau = \rho f_1 \frac{V^2}{2} \qquad \text{---------} \quad (4.3.3)$$

For a circular conduit, the flow depth d may be replaced by its equivalence in term of the hydraulic depth D. For the friction term, it suffices to multiply f_1 by the ratio $m = D/R$ for the transformation from a rectangular channel to circular conduit. Eq. (4.3.2) is then:

$$V\frac{dV}{dx} = g(S - \frac{dD}{dx}) - \frac{mf_1V^2}{2D} - q\frac{V}{D} \qquad \text{----------} \quad (4.3.4)$$

The original derivation assumed uniform velocity at cross sections. For accuracy, the term VdV/dx should be multiplied by the energy correction factor α which is near unity, to account for non-uniform velocity distribution. An approximation was introduced by assuming α to be equal to unity.

It was found from the continuity equation (4.3.1) that

$$VD = qx \qquad \text{and} \qquad V\frac{dD}{dx} + D\frac{dV}{dx} = q \qquad \text{-----------} \quad (4.3.5)$$

Let Eq. (4.3.5) be multiplied by V/D, to obtain

$$V\frac{dV}{dx} = q\frac{V}{D} - \frac{V^2dD}{Ddx} \qquad \text{-----------} \quad (4.3.6)$$

Eq. (4.3.6) can be substituted into Eq. (4.3.4), which then becomes:

$$q\frac{V}{D} - \frac{dD}{dx}\frac{V^2}{D} = g(S - \frac{dD}{dx}) - \frac{mf_1V^2}{2D} - q\frac{V}{D} \qquad \text{-----------} \quad (4.3.7)$$

and

$$\frac{dD}{dx} = \frac{-2qV - \frac{mf_1V^2}{2} + gDS}{gD - V^2} \qquad \text{-----------} \quad (4.3.8)$$

At the critical section, the value of gD approaches V since its Froude Number must equal to unity. This means that the numerator on the right side of Eq. (4.3.8) must approach zero to give dD/dx a finite value.

Accordingly,

$$gDS - \frac{mf_1 V^2}{2} - 2qV = 0 \qquad \text{----------} \quad (4.3.9)$$

replacing gD by V^2, one obtains

$$S - \frac{mf_1}{2} = \frac{2q}{V} \qquad \text{----------} \quad (4.3.10)$$

Since $V^2 = gD$ and $VD = qx$, it follows that

$$V^3 = qgx \quad \text{and} \quad V = (qgx)^{1/3} \qquad \text{----------} \quad (4.3.11)$$

Eliminating V in Eq. (4.3.10), one obtains

$$x = \frac{8q^2}{(S - mf_1/2)^3 g} \qquad \text{----------} \quad (4.3.12)$$

This criterion has led to the location of the critical depth. Since the free outlet end of the pipe was lower than the inlet end, S was considered positive. When S was greater than the value of $mf_1/2$, x had a positive value, and if S was decreased, but still maintained larger than $mf_1/2$, the critical depth moved towards the free end of the conduit.

To obtain the maximum slope for which the critical depth was at the free end of conduit, f_1 was denoted as the resistance coefficient at the end of conduit. Since there were twenty laterals, the total discharge was 20(ΔQ). The value of x = L was 1320 ft. Eq. (4.3.12) then led to the following:

$$S = mf_1/2 + (8q^2/gL)^{1/3} \qquad \text{----------} \quad (4.3.13)$$

From the condition $gD = V^2 = (Q/A)^2$ and the fact that D = A/T where T was the width of the free water surface, it has followed that for the critical condition:

$$Q^2/g = A_c^3 / T_c \qquad \text{-----------} \qquad (4.3.14)$$

from geometry,

$$T = 2\sqrt{d(2r - d)} \qquad \text{-----------} \qquad (4.3.15)$$

The largest diameter of the outlet end pipe for this research was 10 inches and the maximum discharge was 20(ΔQ) = 20(0.1050) cfs. It was assumed that the viscosity ν of water at 70°F is a constant value of 1.05×10^{-5} ft²/sec. Substituting these values into Eq. (4.3.14), one obtains

$$A_c^3 / T_c = 0.137$$

When Eqs. (4.2.4) and (4.3.15) were used, the value of the critical depth d_c was found by trial to be 6.42 inches. The corresponding data for the critical section were:

critical area $A_c = 0.3699$ ft²

critical wetted perimeter $P_c = 1.55$ ft

critical hydraulic depth $D_c = 0.2389$ ft

critical velocity $V_c = 5.68$ fps

By Blassiu's law of resistance, it was concluded that

$$f_1 = 0.056(VR/\nu)^{-1/4} = 0.00296$$

also, $mf_1/2 = Df_1/2R = Af_1/2TR = 0.00286$,

furthermore, by Eq. (4.3.1)

$$q = \frac{VD}{x} = \frac{VA}{TL} = \frac{5.68 \times 0.3699}{\frac{9.61}{12} \times 1320} = 0.001987$$

Therefore, by Eq. (4.3.13), the value of the critical slope for the extreme condition of this problem was

$$S_c = \frac{mf_1}{2} + \left(\frac{8q^2}{gL}\right)^{1/3} = 0.003765$$

This value of S_c was a demarcation between subcritical flow and supercritical flow. Flatter slopes resulted in a critical depth at the free outlet of the channel and its critical section moved upstream when the slope was greater than 0.003765.

3. Computation

A. For slopes flatter than 0.003765, the critical depths were calculated from Eq. (4.3.14) by trial. It was observed that the critical section for those conditions occured at the outlet end.

B. For slopes steeper than 0.003765, the critical depths could be calculated by the following procedures:

a. Estimate the approximate size of pipe to be used in certain intervals of lateral inflows. A discharge $N\Delta Q$ and the corresponding hydraulic elements were roughly obtained.

b. Where the flow was turbulent, the coefficient of resistance f_1 from Moody's diagram was found with the hydraulic elements given by step a..

c. The position of critical depth was found from Eq.(4.3.12).

d. A careful experiment was run to simulate the prototype at critical section. The model flow depth was measured.

e. By the technique of similitude which was stated in previous section "DESIGN OF EXPERIMENT", the model critical depth was converted to the prototype critical depth.

Values of critical depths and their positions are listed in Table 2 for several values of discharge, slope and pipe diameter.

Table 2. **Values of Critical Depths d_c and Positions x_c for Various Slopes, Discharges and Diameters**

Slope S	Lateral Discharge ΔQ cfs	x_c (ft)		d_c in	2r in
		From Outlet	From Inlet		
0.0005	0.0315 0.0525 0.0735 0.1050	0	1320	4.62 5.27 5.77 6.42	10 10 10 10
0.0010	0.0315 0.0525 0.0735 0.1050	0	1320	4.62 5.27 5.77 6.42	10 10 10 10
0.0025	0.0315 0.0525 0.0735 0.1050	0	1320	4.62 5.27 5.77 6.42	10 10 10 10
0.0050	0.0315 0.0525 0.0735 0.1050	282.75 240.00 168.30 100.00	1037.25 1080.00 1151.70 1220.00	4.10 4.40 4.48 4.50	8 8 8 8
0.0100	0.0315 0.0525 0.0735	370.00 316.00 160.00	950.00 1004.00 1160.00	3.86 4.04 4.21	6 6 8
0.0250	0.0315 0.0525 0.0735	543.50 483.80 360.00	776.50 836.20 960.00	2.74 2.60 2.97	5 5 6
0.0500	0.0315 0.0525	680.75 291.35	639.25 1028.65	2.41 4.27	4 5

V

UNSTEADY FLOW CONDITION

5.1 General Consideration

The purpose of this section was to analyze mathematically the velocity-depth relationship and the variation of water surface profile under the unsteady flow condition. The experimental investigation for this phase usually required a very large scale model.

Since there was an increment of lateral discharge into the main at a sixty-six foot interval, general analysis for non-uniform lateral inflows was difficult. However, an assumption that the lateral inflows were uniform and continuous permitted a simplication in the analysis and led to adequate results. With this assumption, a lateral inflow of $\Delta Q = 0.1050$ cfs occurring every sixty six feet was considered as $q = 0.1050/66 = 0.0016$ cfs per foot of main.

For laminar flow, the Reynolds Number $N_R = VD/\nu$ must be less than 2000. By this criteria, a four-inch diameter main tile must possess a velocity of less than 0.06 fps for laminar flow at 70° F. When the diameter was larger, the velocity for laminar flow was still less. Since the velocities in drain tiles were usually greater than 0.06 fps, laminar flow was seldom experienced and only turbulent flow has been considered herein.

5.2 Theoretical Derivation

Steady flow motion was expressed by Eq. (4.3.4) which is repeated here for ready reference:

$$V \frac{dV}{dx} = g(S - \frac{dD}{dx}) - \frac{mf_1 V^2}{2D} - q \frac{V}{D} \qquad \text{---------} \; (4.3.4)$$

The equation of motion for unsteady flow has the same form except that the term dV/dt should be added to the left side of Eq.(4.3.4). The equation then becomes:

$$V \frac{dV}{dx} + \frac{dV}{dt} = g(S - \frac{dD}{dx}) - \frac{mf_1 V^2}{2D} - q \frac{V}{D} \qquad \text{---------} \; (5.2.1)$$

The friction term, $mf_1 V^2/2D$ may be expressed in terms of τ_o , ρ , R, n and g as follows:

$$\frac{mf_1 V^2}{2D} = \frac{\tau_o}{\rho R} = \frac{n^2 g V^2}{2.24 \, R^{4/3}} = 0.00174 V^2/R^{4/3} \qquad \text{---------} \; (5.2.2)$$

where the value 0.011 was used for n. Thus,

$$V \frac{dV}{dx} + \frac{dV}{dt} + g \frac{dD}{dx} = gS - 0.00174 \frac{V^2}{R^{4/3}} - q \frac{V}{D} \qquad \text{---------} \; (5.2.3)$$

When the slope is steep, flow is nearly uniform and the left side of Eq. (5.2.3) could be assumed to be zero. Therefore,

$$gS = 0.00174 \frac{V^2}{R^{4/3}} - q \frac{V}{D} \qquad \text{---------} \; (5.2.4)$$

and

$$V = \frac{dx}{dt} = \frac{R^{4/3}}{0.00348} \left[\frac{q}{D} + \sqrt{(\frac{q}{D})^2 + 0.224 \frac{S}{R^{4/3}}} \right] \qquad \text{---------} \; (5.2.5)$$

Eq. (5.2.5) shows the velocity-depth and also the x-t relationships.

5.3 Presentation of Data

As a numerical example, the following conditions were assumed:

diameter of pipe $2r = 8$ inches

total length of pipe $x = 66$ feet

Manning's roughness $n = 0.011$

slope of pipe $S = 0.050$, 0.025 and 0.010

lateral discharge $\Delta Q = 0.1050$ and 0.0735 cfs.

For a given hydraulic depth D, Eqs. (4.2.4) and (4.3.15) led to the value of flow depth d which in turn could be used to compute the value of hydraulic radius R*. Eq. (4.3.1) yielded the value of q. With these data, Eq. (5.2.5) could be used to calculate the velocity V.

Fig. 13 shows the relationship between velocity and hydraulic depth for various values of lateral discharges ΔQ and slopes S. It was observed that for a given hydraulic depth D, the flatter the slope S, and the larger the ΔQ, the slower was the velocity V. Eq. (5.2.5) also expresses the relationship between the pipe length x and the time of flow t. Using the same conditions given above, the "characteristic" curve C, which defines the boundary between steady and unsteady regions could be established. This curve is shown in Fig. 14.

* Appendix Table 4 shows the relationships between d, A and R for various diameters of pipes ranging from four-inch to ten-inch.

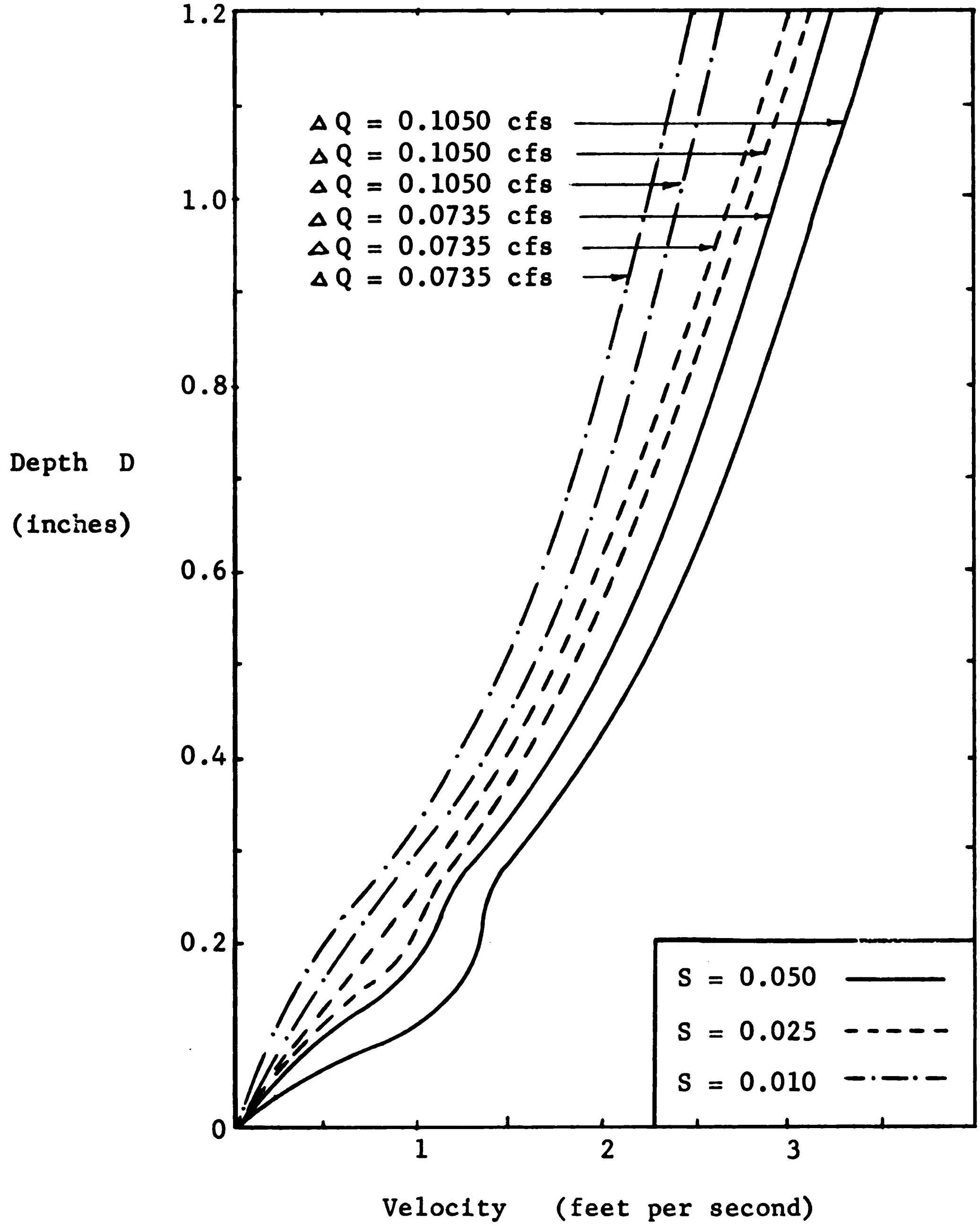


Figure 13: Velocity, Depth, Slope and Rate of Lateral Inflow Relationship Curves for Pipe Diameter of 8 Inches

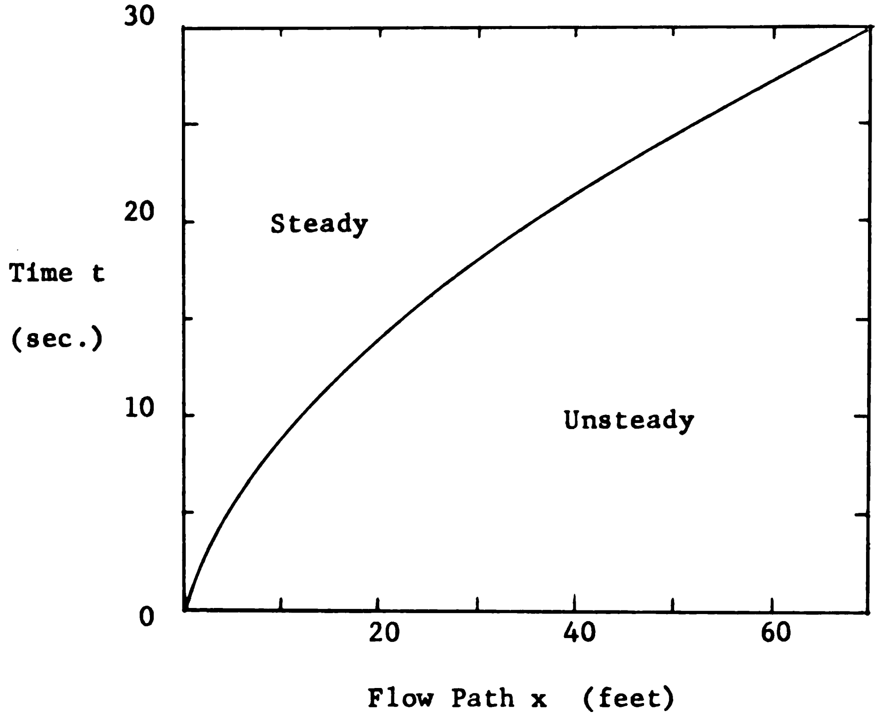


Figure 14: Characteristic Curve for $\Delta Q = 0.1050$ cfs

VI

SURGE WAVES

6.1 General Consideration

Fig. 15 shows schematically the wave conditions existing at the junction of a lateral and the main. In order to analyze this surge wave, it was necessary to make several assumptions as follows:

1. Conservation of energy existed.
2. Kinetic energy correction factor α was equal to unity.
3. The frictional force for this small distance, between upstream and downstream of the lateral, which equals to the lateral diameter four inches, could be neglected.

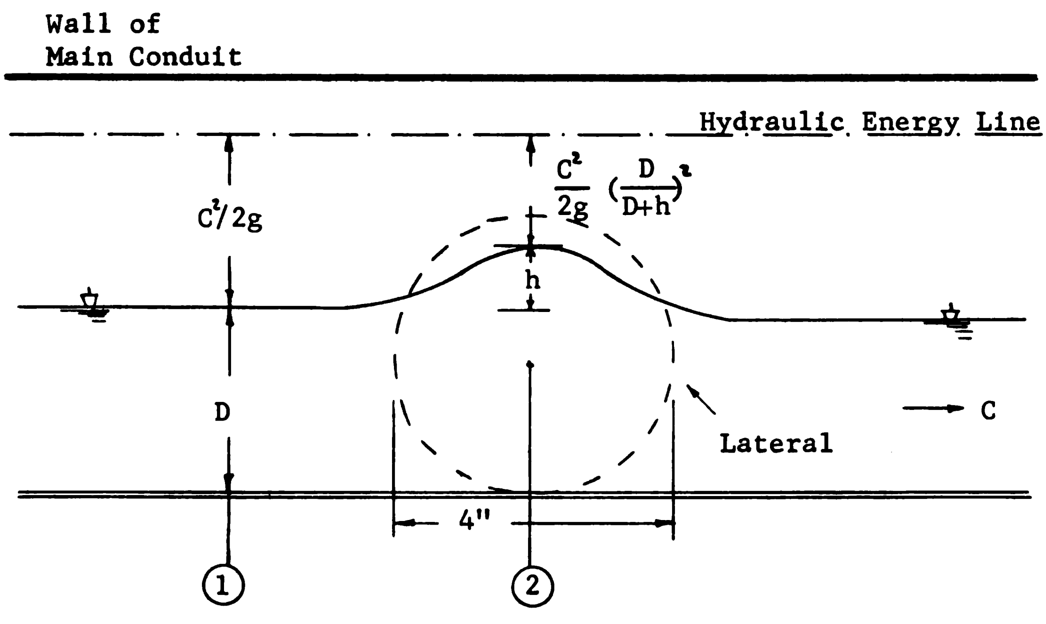


Figure 15: Surge Wave at Junction of A Lateral and Main

Based on the above assumptions, the equation defining the surge wave was:

$$D + \frac{C^2}{2g} = D + h + \frac{C^2}{2g}\left(\frac{D}{D + h}\right)^2 \qquad \text{------------ (6.1.1)}$$

where h was the wave height above the normal flow depth. The wave celerity C was found from Eq. (6.1.1):

$$C = \sqrt{\frac{2g(D + h)^2}{2D + h}} \qquad \text{------------ (6.1.2)}$$

Experiments showed that the surge height h was generally small compared to the flow hydraulic depth D except for the largest lateral discharge $\Delta Q = 0.1050$ cfs, which was not usual in practical field situations. Thus it was possible to neglect h in computation in order to simplify the analysis.

As shown in Figs.16a and 16b, a surge, when arriving at a conduit junction, splits into several surges entering the connecting conduit. Since there was no surge at conduit II and III before

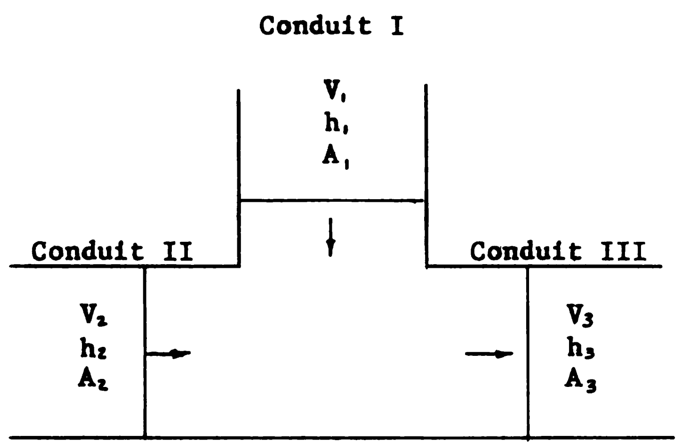


Figure 16a: Condition before Merging of Lateral Inflow

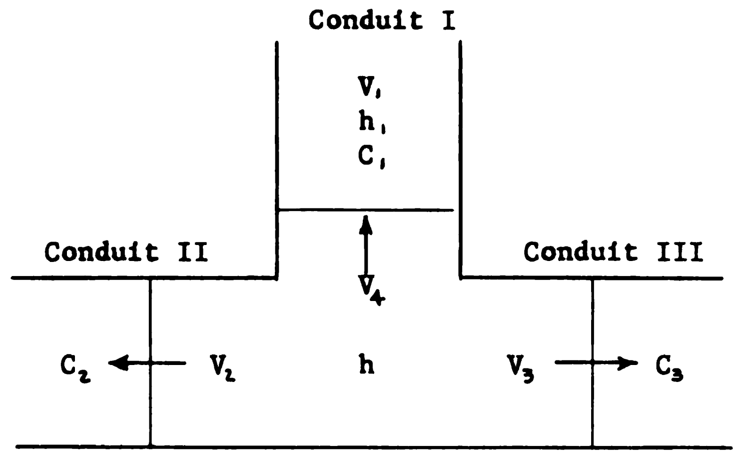


Figure 16b: Condition after Merging of Lateral Inflow

merging (see Fig. 16a), the wave height $h_2 = h_3 = 0$, and the velocity difference $V_3 - V_2$ in the conduit before merging was zero. When the lateral inflow reached the junction, its flow height was reduced because the flow area was expanded. A surge of height h then traveled through conduits II and III with celerities C_2 and C_3 respectively (see Fig. 16b). In the meantime, a reflected wave traveled along conduit I at a celerity equal to C_1 as shown in Fig. 16b.

From the above condition and Eqs. (6.1.1) and (6.1.2), it could be shown that

$$h_1 - h = C_1(V_4 - V_1)/g$$

$$h_1 = C_1 V_1/g \quad \text{for conduit I}$$

$$h = C_2 V_2/g \quad \text{for conduit II} \qquad \text{---------} \ (6.1.3)$$

$$h = C_3 V_3/g \quad \text{for conduit III}$$

The continuity requires that

$$A_1 V_4 = A_2 V_2 + A_3 V_3 \qquad \text{---------} \ (6.1.4)$$

Solving Eqs. (6.1.3) and (6.1.4) simultaneously for h, one obtains:

$$h = \frac{2\ h_1 A_1}{\left(\frac{A_1}{C_1} + \frac{A_2}{C_2} + \frac{A_3}{C_3}\right) C_1} \qquad \text{----------} \ (6.1.5)$$

where all C values were $\sqrt{gD}$.

To examine the validity of the various assumptions made in analyzing the surge wave, a number of experiments with various conditions were performed. Typical experimental set-ups are shown in Fig. 17.

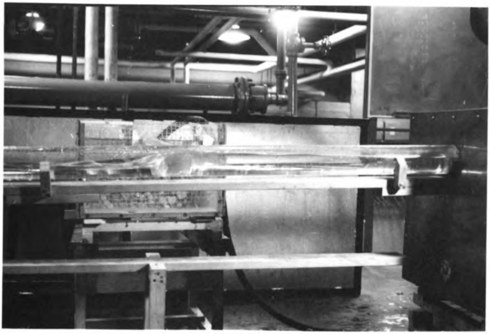
6.2 Presentation of Surge Wave Data

The results of theoretical calculations and those of experimental investigations of the surge waves are summarized in the curves of Fig. 18. The flow conditions are indicated below each curve. Both theoretical and experimental curves were superimposed for comparison. The term "horizontal distance across lateral" means a horizontal measurement of the diameter of the lateral by considering that the upper edge of junction of the lateral to the main as zero inch.

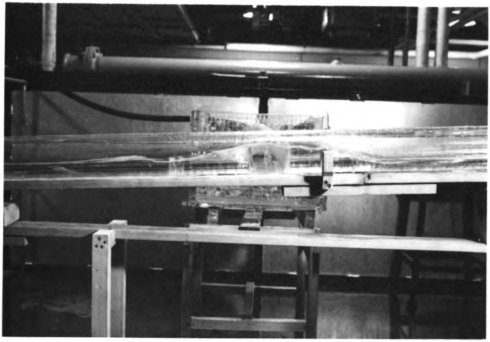
Examination of the various curves shown in Fig. 18 led to the following conclusions:

1. The theoretical analysis were generally in good agreement with experimental observations.
2. When the flow slope became steeper and the flow rate larger, the theoretical and experimental data showed a greater deviation.

3. Since the deviations between theory and experiments were generally small, the proposed theoretical analysis could be used for predicting the wave profiles.

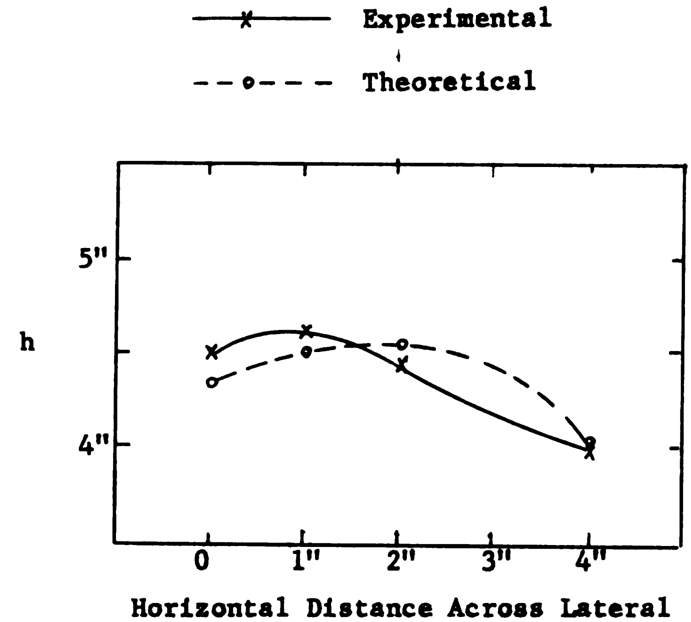


(a) Q = 2.100 cfs

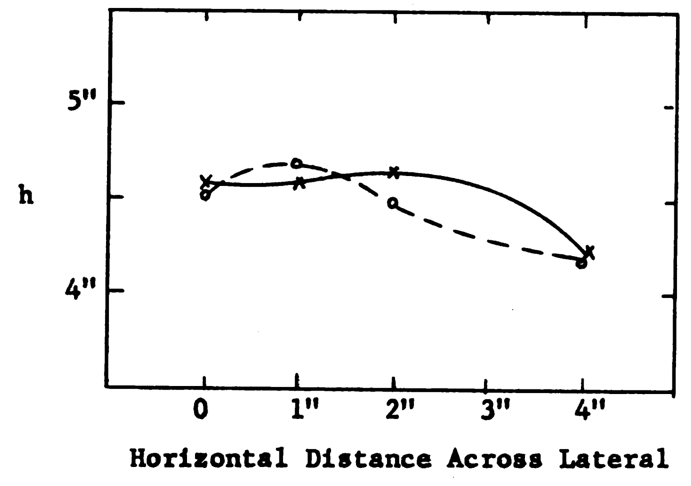


(b) Q = 1.050 cfs

Figure 17: Junction Wave at Maximum Condition
ΔQ = 0.1050 cfs S = 0.05

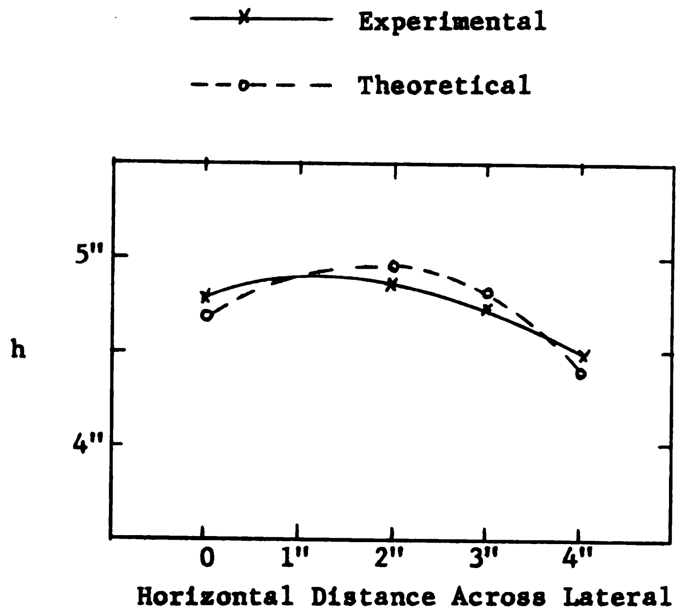


(a) 396' from outlet, 8" pipe, S = 0.005, ΔQ = 0.0315 cfs
Q_1 = 0.4410 cfs, Q_2 = 0.4725 cfs

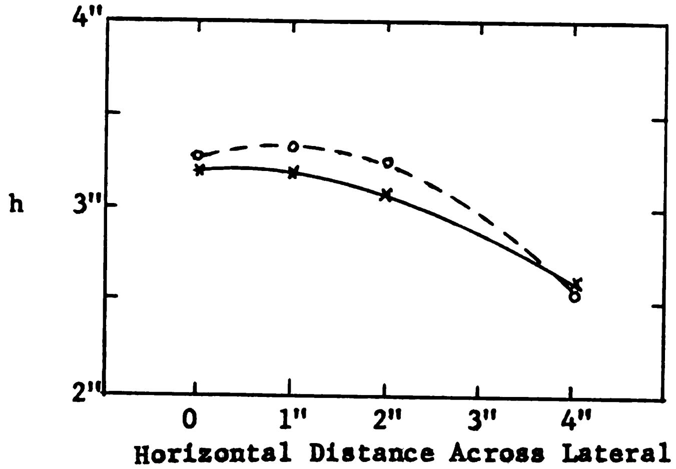


(b) 594' from outlet, 6" pipe, S = 0.005, ΔQ = 0.0315 cfs
Q_1 = 0.3465 cfs, Q_2 = 0.3780 cfs

Figure 18: Junction Waves under Various Conditions

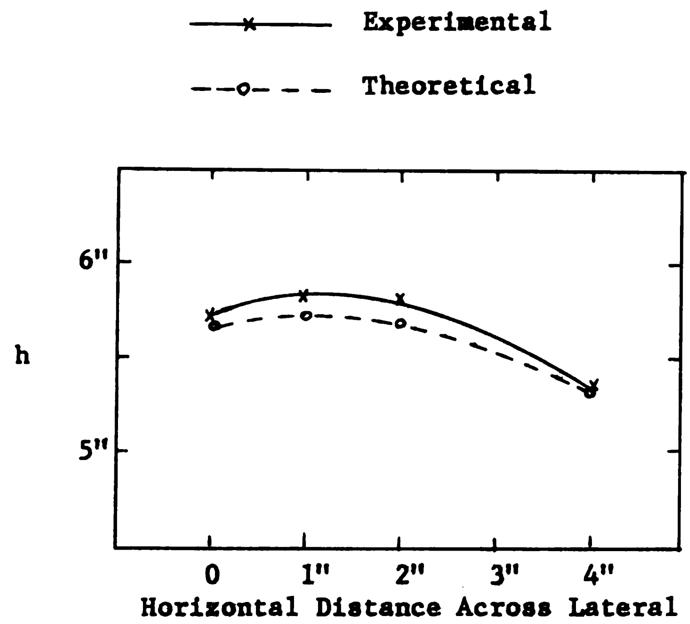


(c) 264' from outlet, 8" pipe, S = 0.005, ΔQ = 0.0525 cfs
Q_1 = 0.8400 cfs, Q_2 = 0.8925 cfs

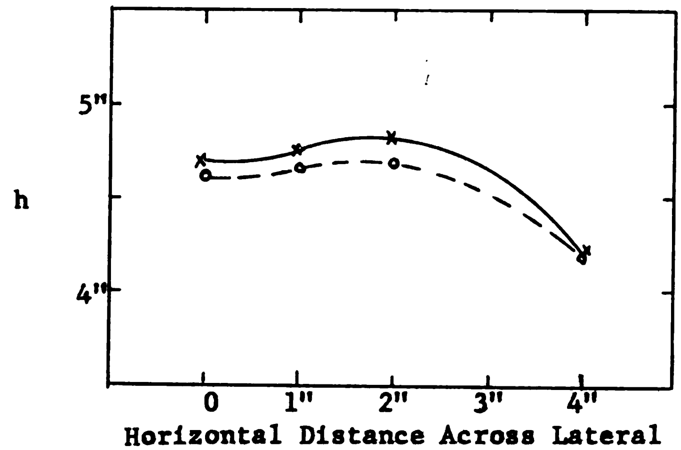


(d) 1188' from outlet, 5" pipe, S = 0.005, ΔQ = 0.0525 cfs
Q_1 = 0.1050 cfs, Q_2 = 0.1575 cfs

Figure 18: (continued)

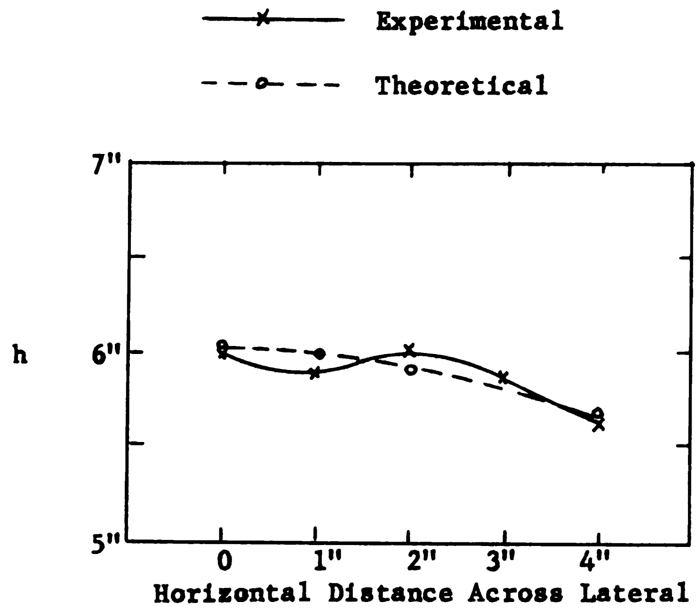


(e) 462' from outlet, 8" pipe, S = 0.005, ΔQ = 0.0735 cfs
Q_1 = 0.9555 cfs, Q_2 = 1.0290 cfs

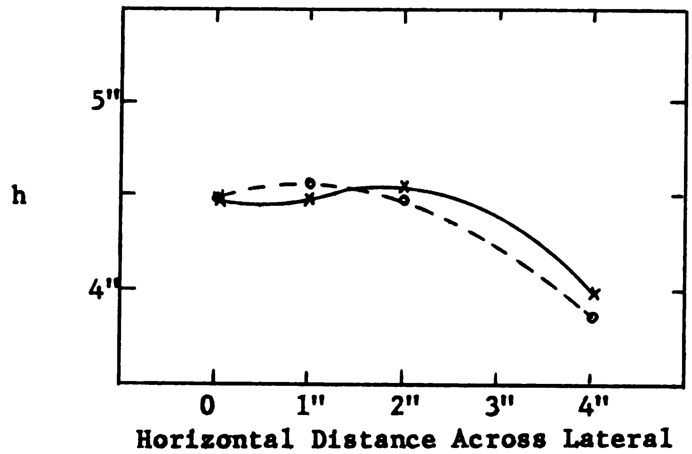


(f) 726' from outlet, 6" pipe, S = 0.005, ΔQ = 0.0735 cfs
Q_1 = 0.6615 cfs, Q_2 = 0.7350 cfs

Figure 18: (continued)

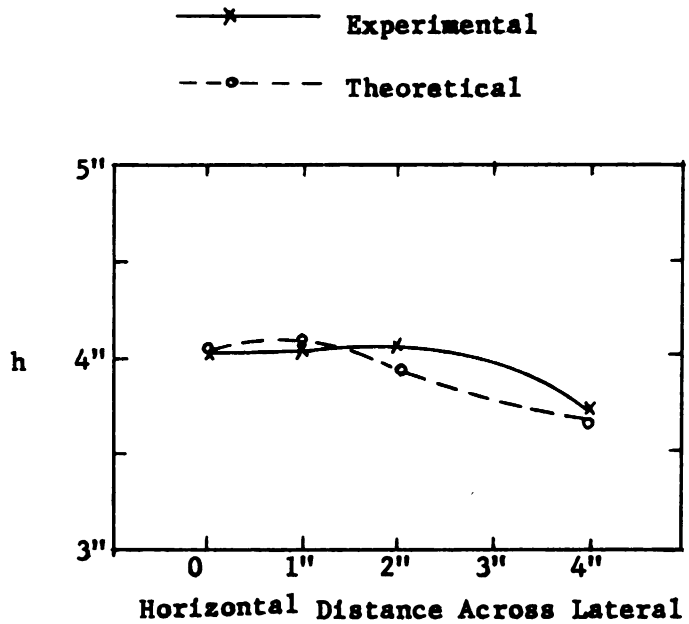


(g) 528' from outlet, 8" pipe, S = 0.005, ΔQ = 0.1050 cfs
Q_1 = 1.2600 cfs, Q_2 = 1.3650 cfs

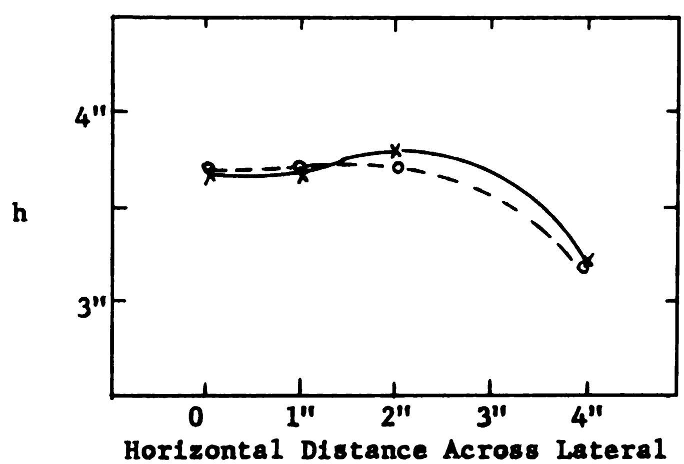


(h) 1122' from outlet, 6" pipe, S = 0.005, ΔQ = 0.1050 cfs
Q_1 = 0.3150 cfs, Q_2 = 0.4200 cfs

Figure 18: (continued)

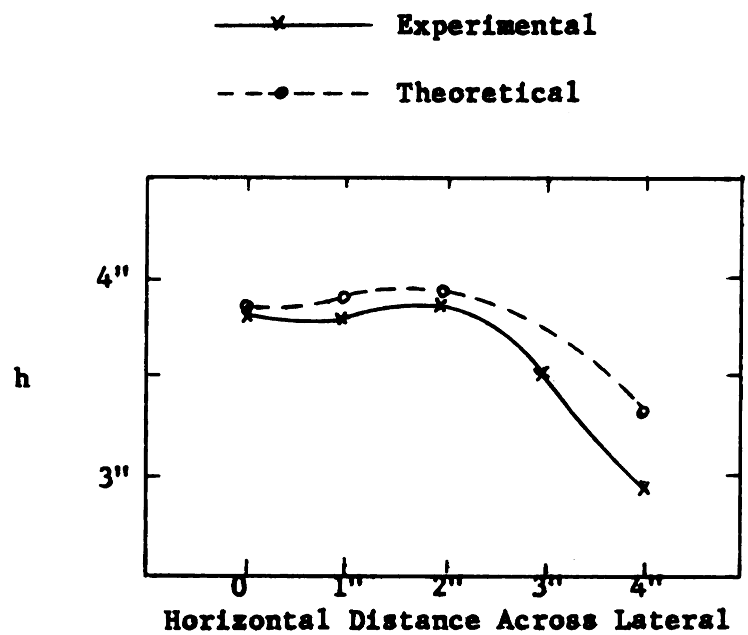


(i) 462' from outlet, 6" pipe, S = 0.010, ΔQ = 0.0315 cfs
Q_1 = 0.4095 cfs, Q_2 = 0.4410 cfs

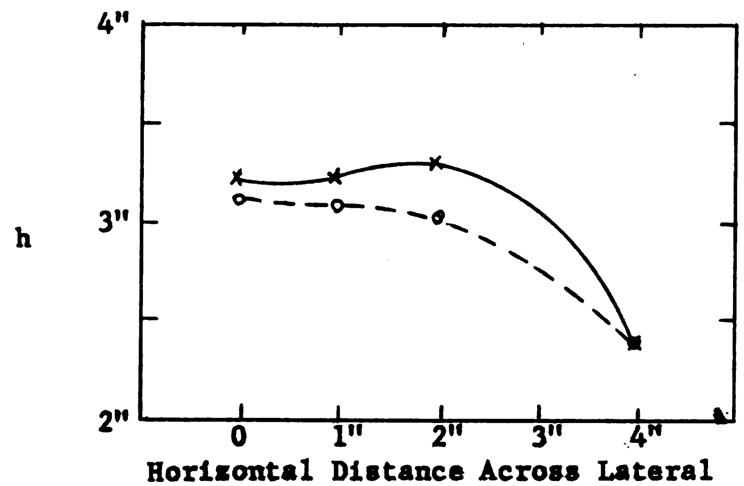


(j) 792' from outlet, 5" pipe, S = 0.010, ΔQ = 0.0315 cfs
Q_1 = 0.4095 cfs, Q_2 = 0.4410 cfs

Figure 18: (continued)

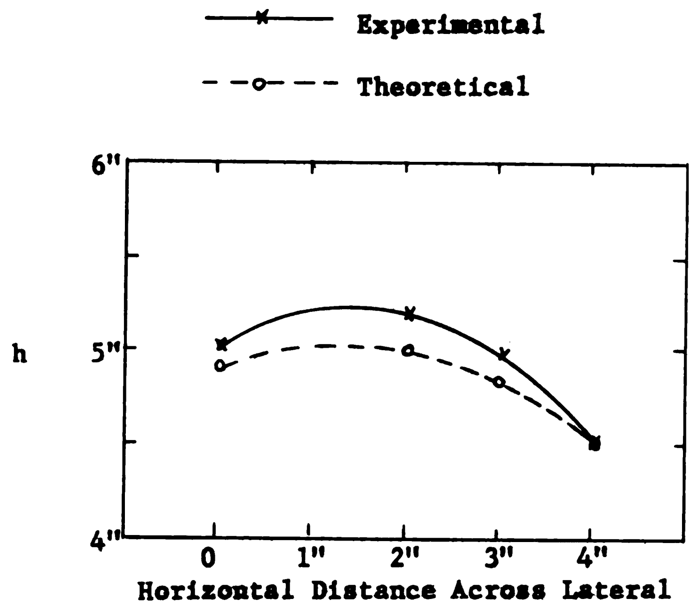


(k) 660' from outlet, 6" pipe, S = 0.010, ΔQ = 0.0525 cfs
Q_1 = 0.5250 cfs, Q_2 = 0.5775 cfs

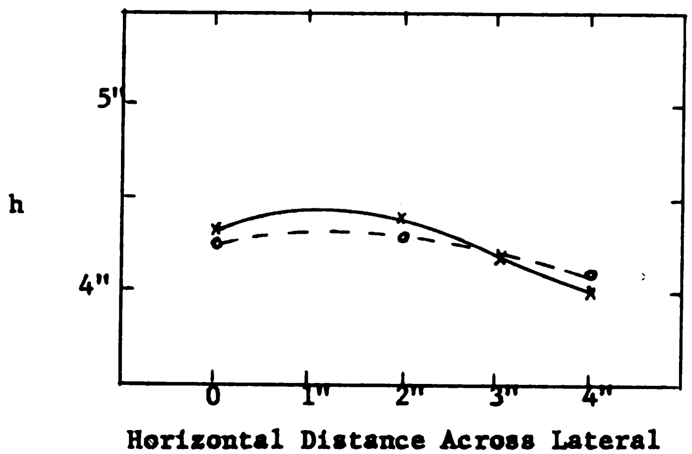


(l) 1188' from outlet, 4" pipe, S = 0.010, ΔQ = 0.0525 cfs
Q_1 = 0.1050 cfs, Q_2 = 0.1575 cfs

Figure 18: (continued)

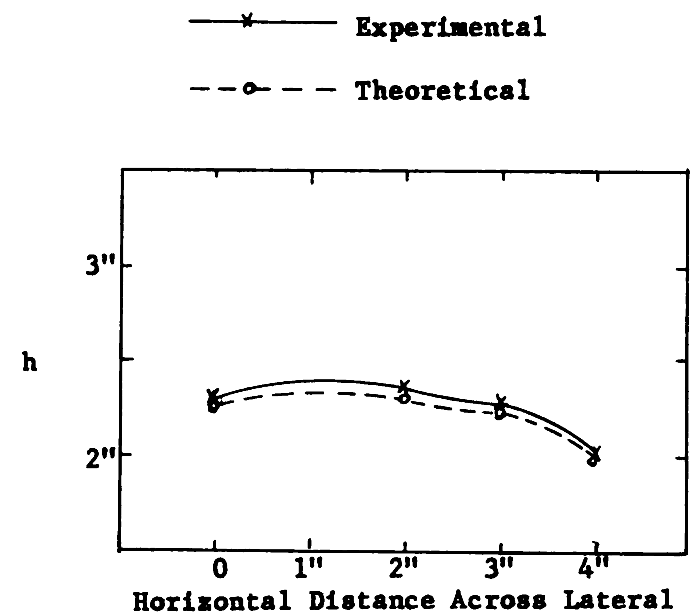


(m) 462' from outlet, 8" pipe, S = 0.010, ΔQ = 0.0735 cfs
Q_1 = 0.9555 cfs, Q_2 = 1.0290 cfs

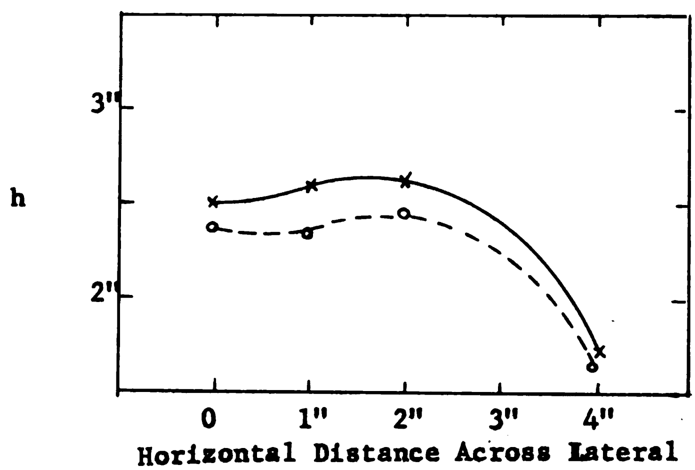


(n) 726' from outlet, 6" pipe, S = 0.010, ΔQ = 0.0735 cfs
Q_1 = 0.6615 cfs, Q_2 = 0.7350 cfs

Figure 18: (continued)

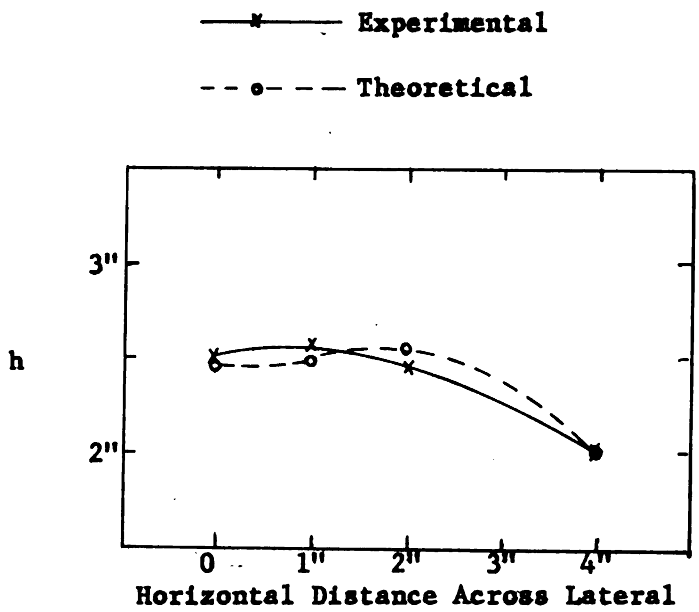


(o) 462' from outlet, 5" pipe, S = 0.025, ΔQ = 0.0315 cfs
Q_1 = 0.4095 cfs, Q_2 = 0.4410 cfs

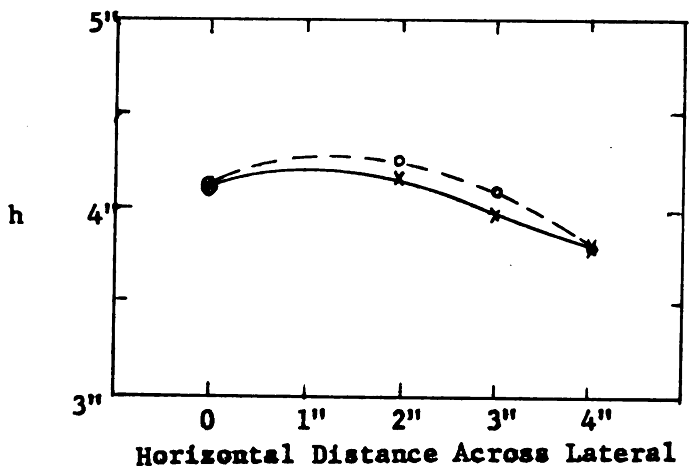


(p) 1122' from outlet, 4" pipe, S = 0.025, ΔQ = 0.0315 cfs
Q_1 = 0.0935 cfs, Q_2 = 0.1260 cfs

Figure 18: (continued)

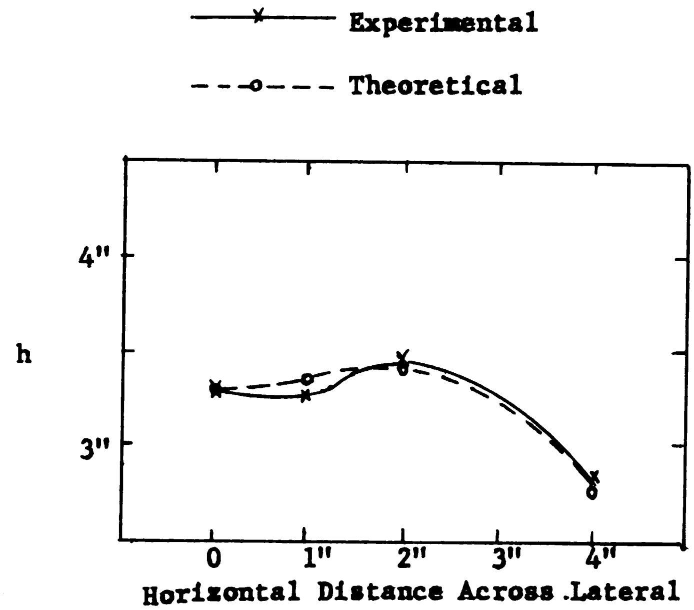


(q) 330' from outlet, 6" pipe, S = 0.025, ΔQ = 0.0525 cfs
Q_1 = 0.7875 cfs, Q_2 = 0.8400 cfs

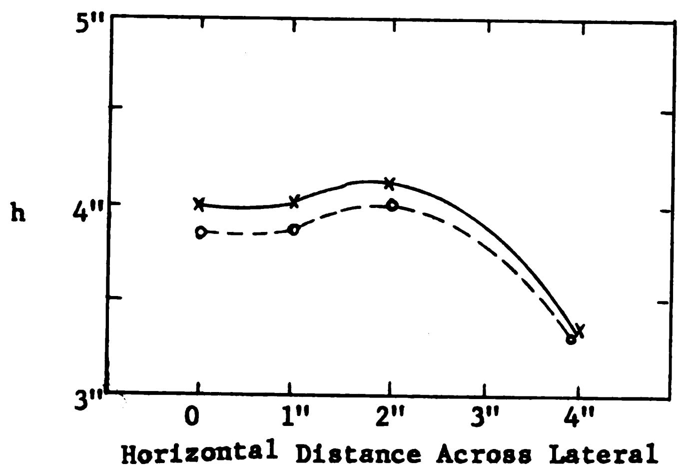


(r) 660' from outlet, 5" pipe, S = 0.025, ΔQ = 0.0525 cfs
Q_1 = 0.5250 cfs, Q_2 = 0.5775 cfs

Figure 18: (continued)

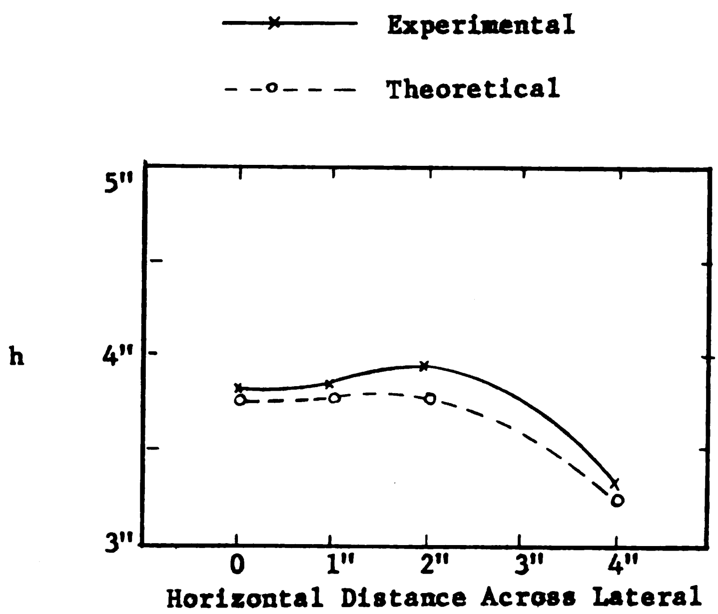


(s) 528' from outlet, 6" pipe, S = 0.025, ΔQ = 0.0735 cfs
Q_1 = 0.8820 cfs, Q_2 = 0.9555 cfs

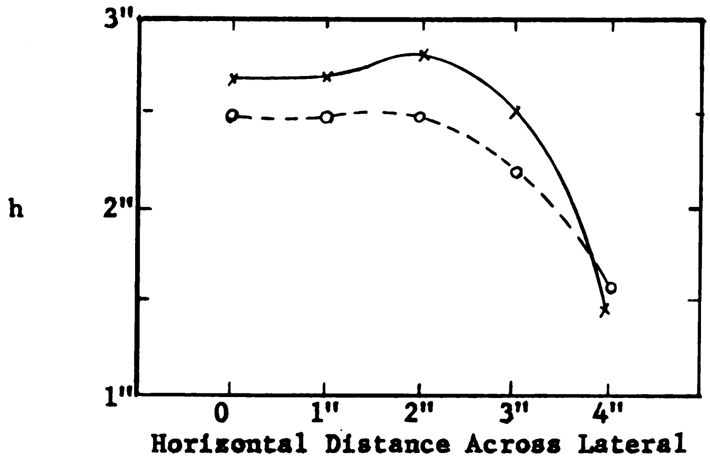


(t) 924' from outlet, 5" pipe, S = 0.025, ΔQ = 0.0735 cfs
Q_1 = 0.4410 cfs, Q_2 = 0.5415 cfs

Figure 18: (continued)

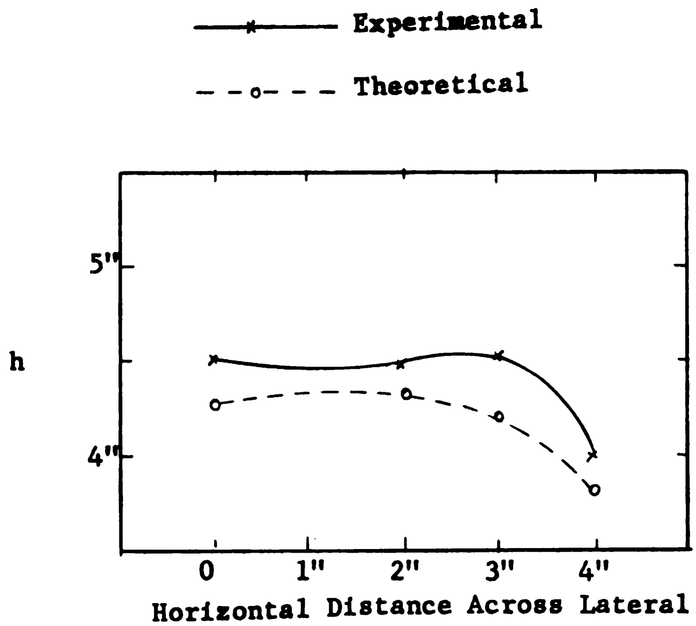


(u) 396' from outlet, 5" pipe, S = 0.05, ΔQ = 0.0315 cfs
Q_1 = 0.4410 cfs, Q_2 = 0.4725 cfs

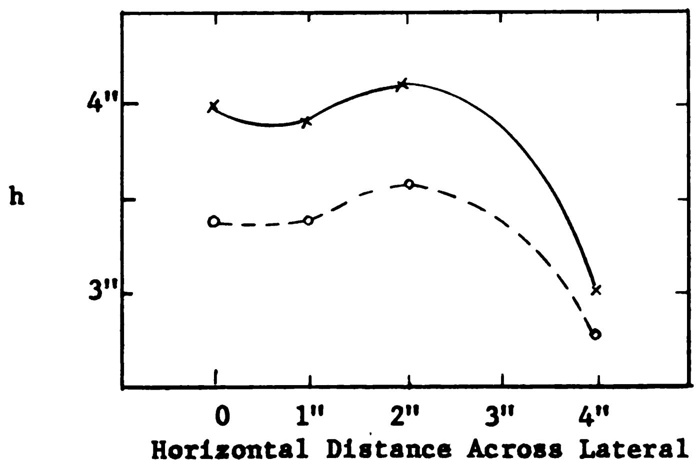


(v) 1122' from outlet, 4" pipe, S = 0.05, ΔQ = 0.0315 cfs
Q_1 = 0.0945 cfs, Q_2 = 0.1260 cfs

Figure 18: (continued)



(w) 462' from outlet, 5" pipe, S = 0.05, ΔQ = 0.0525 cfs
Q_1 = 0.6825 cfs, Q_2 = 0.7350 cfs



(x) 660' from outlet, 5" pipe, S = 0.05, ΔQ = 0.0525 cfs
Q_1 = 0.5250 cfs, Q_2 = 0.5775 cfs

Figure 18: (continued)

VII

PRESENTATION OF PROFILE DATA

Table 3 summarizes the most economical combinations of the main tile sizes under various conditions for an overall length of drain of 1320 feet. The several conditions investigated included the slope which varied from 0.0005 to 0.05 ft/ft, lateral discharge varying from 0.0315 cfs to 0.1050 cfs, and pipe diameter ranging from four to ten inches.

A complete set of profile data, comparing theory and experiment are given in Appendix in Table 5.1 to 5.24.

Table 3: **Combination of Pipe Length and Sizes under Various Conditions of Flow for an Overall Length of Drainage of 1320 Feet**

Slope S	Lateral Discharge ΔQ cfs	Length of Pipes in Feet — Diameter in Inches 10"	8"	6"	5"	4"
0.0005	0.0315	745	575	0	0	0
	0.0525	810	510	0	0	0
	0.0735	960	360	0	0	0
	0.1050	1170	150	0	0	0
0.0010	0.0315	370	650	200	100	0
	0.0525	440	640	240	0	0
	0.0735	700	520	100	0	0
	0.1050	960	360	0	0	0
0.0025	0.0315	100	530	270	200	220
	0.0525	230	460	460	170	0
	0.0735	360	460	500	0	0
	0.1050	490	530	300	0	0
0.0050	0.0315	0	420	340	260	300
	0.0525	0	560	330	430	0
	0.0735	0	690	270	360	0
	0.1050	0	820	500	0	0
0.0100	0.0315	0	150	470	330	370
	0.0525	0	300	350	340	230
	0.0735	0	560	390	370	0
0.0250	0.0315	0	0	300	400	620
	0.0525	0	0	430	420	470
	0.0735	0	0	560	460	300
0.0500	0.0315	0	0	0	630	690
	0.0525	0	0	0	830	490

VIII

CONCLUSIONS

1. The flow profile under a given condition may be adequately predicted from Eqs. (4.2.12) and (4.2.13).
2. For constant pipe size and lateral discharge, the critical depth moves upstream in the main as the slope increases.
3. For constant slope and constant pipe size, the critical depth moves upstream as the discharge in the main increases.
4. A change of pipe size influences the position of critical depth only slightly.
5. The roughness or the coefficient of friction of the pipe exerts a major influence on the flow profile as seen in Eqs. (4.2.12) and (4.2.13).
6. As a result of momentum conservation, the upstream depth at a junction inflow would always be greater than the downstream depth.
7. For slopes or discharges other than the twenty-four profiles presented, an approximate design of pipe size combinations could be accomplished by interpolation. Accurate design should include all steps and considerations of this dissertation.
8. The twenty-four water surface profiles should prove a valuable tool for the design of drainage main tiles with lateral inflows. It should stimulate further experimental research in a large model.

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APPENDIX

Table 4: Relationships between d, A, R and 2r for Various Pipe Diameters.

4.1 for 10" Pipe
4.2 for 8" Pipe
4.3 for 6" Pipe
4.4 for 5" Pipe
4.5 for 4" Pipe

This table is calculated from Eqs. (4.2.3) and (4.2.4).

Table 4.1: Relationships between d, A, R and 2r for a 10" Pipe.

d inch feet	A $(ft)^2$	$R^{4/3}$ $(ft)^{4/3}$	$(d-r)A + \frac{2}{3}(2rd-d^2)^{3/2}$ $(ft)^3$
4.500 0.375	0.238055	0.19425	0.0375357
4.60 0.3833	0.244931	0.19716	0.0396184
4.70 0.3916	0.251875	0.20000	0.0417414
4.80 0.4000	0.258819	0.20283	0.0438555
4.90 0.4083	0.265763	0.20558	0.0459952
5.00 0.4167	0.272707	0.20833	0.0482291
5.10 0.4250	0.279653	0.21092	0.0505403
5.20 0.4333	0.286597	0.21342	0.0529458
5.30 0.4416	0.293542	0.21592	0.0553768
5.40 0.4500	0.300486	0.21833	0.0577987
5.50 0.4583	0.307361	0.22075	0.0602614
5.60 0.4666	0.314306	0.22300	0.0629077
5.70 0.4750	0.321181	0.22525	0.0656108
5.80 0.4833	0.327986	0.22733	0.0682343
5.90 0.4916	0.334861	0.22942	0.0710587
6.00 0.5000	0.341666	0.23133	0.0738108
6.10 0.5083	0.348472	0.23308	0.0766659
6.20 0.5167	0.355308	0.23483	0.0797058
6.30 0.5250	0.361944	0.23658	0.0825987
6.40 0.5333	0.368611	0.23833	0.0856466
6.50 0.5416	0.375277	0.24008	0.0887766

Table 4.1: (continued)

d inch feet	A (ft)	$R^{4/3}$ $(ft)^{4/3}$	$(d-r)A + \frac{2}{3}(2rd-d^2)^{3/2}$ $(ft)^3$
6.60 0.5500	0.381875	0.24158	0.0918882
6.70 0.5583	0.388472	0.24308	0.0951576
6.80 0.5666	0.394931	0.24413	0.0984926
6.90 0.5750	0.401388	0.24583	0.1016604
7.00 0.5833	0.407777	0.24683	0.1050000
7.10 0.5916	0.414166	0.24775	0.1086259
7.20 0.6000	0.420416	0.24866	0.1154766
7.30 0.6083	0.426597	0.24958	0.1191293
7.40 0.6166	0.432708	0.25050	0.1197840
7.50 0.6250	0.438750	0.25142	0.1227458

Table 4.2: Relationships between d, A, R and 2r for an 8" Pipe.

d inch feet	A $(ft)^2$	$R^{4/3}$ $(ft)^{4/3}$	$(d-r)A + \frac{2}{3}(2rd-d^2)^{3/2}$ $(ft)^3$
3.28 0.2733	0.13476	0.0767	0.0153821
3.36 0.2800	0.13911	0.0783	0.0163412
3.44 0.2867	0.14351	0.0800	0.0172682
3.52 0.2933	0.14791	0.0818	0.0182198
3.60 0.3000	0.15236	0.0835	0.0192313
3.68 0.3067	0.15676	0.0855	0.0202733
3.76 0.3133	0.16120	0.0869	0.0213503
3.84 0.3200	0.16564	0.0885	0.0224213
3.92 0.3267	0.17009	0.0901	0.0235230
4.00 0.3333	0.17453	0.0917	0.0246914
4.08 0.3400	0.17897	0.0932	0.0258499
4.16 0.3467	0.18342	0.0948	0.0270754
4.24 0.3533	0.18787	0.0962	0.0283317
4.32 0.3600	0.19231	0.0977	0.0295817
4.40 0.3667	0.19671	0.0991	0.0308670
4.48 0.3733	0.20115	0.1004	0.0321822
4.56 0.3800	0.20556	0.1018	0.0335580
4.64 0.3867	0.20991	0.1030	0.0349510
4.72 0.3933	0.21431	0.1043	0.0363263
4.80 0.4000	0.21867	0.1056	0.0378005
4.88 0.4067	0.22303	0.1065	0.0392275

Table 4.2: (continued)

d inch feet	A $(ft)^2$	$R^{4/3}$ $(ft)^{4/3}$	$(d-r)A + \frac{2}{3}(2rd-d^2)^{3/2}$ $(ft)^3$
4.96 0.4133	0.22730	0.1076	0.0407813
5.04 0.4200	0.23164	0.1087	0.0423148
5.12 0.4267	0.23591	0.1097	0.0438618
5.20 0.4333	0.24018	0.1108	0.0454518
5.28 0.4400	0.24440	0.1117	0.0470331
5.36 0.4467	0.24862	0.1127	0.0487154
5.44 0.4533	0.25275	0.1139	0.0503961
5.52 0.4600	0.25689	0.1144	0.0521040
5.60 0.4667	0.26098	0.1150	0.0538172
5.68 0.4733	0.26507	0.1156	0.0555755
5.76 0.4800	0.26907	0.1161	0.0573370
5.84 0.4867	0.27302	0.1167	0.0591477
5.92 0.4933	0.27693	0.1173	0.0609739
6.00 0.5000	0.28080	0.1178	0.0628333
6.08 0.5067	0.28462	0.1183	0.0647277
6.16 0.5133	0.28840	0.1186	0.0666300
6.24 0.5200	0.29213	0.1189	0.0685715
6.32 0.5267	0.29578	0.1190	0.0705327
6.40 0.5333	0.29938	0.1191	0.0725195
6.48 0.5400	0.30289	0.1193	0.0745261
6.56 0.5467	0.30635	0.1192	0.0765656

Table 4.2: (continued)

d inch feet	A $(ft)^2$	$R^{4/3}$ $(ft)^{4/3}$	$(d-r)A + \frac{2}{3}(2rd-d^2)^{3/2}$ $(ft)^3$
6.64 0.5533	0.30973	0.1191	0.0786133
6.72 0.5600	0.31302	0.1190	0.0806875
6.80 0.5667	0.31622	0.1187	0.0827661
6.88 0.5733	0.31937	0.1183	0.0849015
6.96 0.5800	0.32240	0.1178	0.0870399
7.04 0.5867	0.32533	0.1174	0.0891835
7.12 0.5933	0.32817	0.1167	0.0913722
7.20 0.6000	0.33089	0.1159	0.0935684
7.28 0.6067	0.33351	0.1150	0.0957894
7.36 0.6133	0.33600	0.1140	0.0980217
7.44 0.6200	0.33831	0.1129	0.1002630
7.52 0.6267	0.34052	0.1116	0.1025277
7.60 0.6333	0.34253	0.1099	0.1048025
7.68 0.6400	0.34440	0.1082	0.1071005
7.76 0.6467	0.34600	0.1060	0.1093936
7.84 0.6533	0.34747	0.1034	0.1117011
7.92 0.6600	0.34849	0.0999	0.1140343
8.00 0.6667	0.34906	0.0917	0.1163533

Table 4.3: Relationships between d, A, R and 2r for a 6" Pipe.

d inch feet	A $(ft)^2$	$R^{4/3}$ $(ft)^{4/3}$	$(d-r)A + \frac{2}{3}(2rd-d^2)^{3/2}$ $(ft)^3$
3.06 0.255	0.10068	0.0635	0.0109117
3.12 0.260	0.10312	0.0645	0.0114270
3.18 0.265	0.10567	0.0656	0.0119351
3.24 0.270	0.10817	0.0665	0.0124782
3.30 0.275	0.11065	0.0675	0.0130252
3.36 0.280	0.11315	0.0684	0.0135770
3.42 0.285	0.11563	0.0694	0.0141575
3.48 0.290	0.11808	0.0702	0.0147413
3.54 0.295	0.12055	0.0711	0.0153427
3.60 0.300	0.12300	0.0719	0.0159420
3.66 0.305	0.12545	0.0726	0.0165645
3.72 0.310	0.12788	0.0733	0.0172087
3.78 0.315	0.13030	0.0740	0.0178518
3.84 0.320	0.13270	0.0748	0.0185050
3.90 0.325	0.13510	0.0755	0.0191756
3.96 0.330	0.13748	0.0762	0.0198622
4.02 0.335	0.14000	0.0768	0.0205762
4.08 0.340	0.14218	0.0774	0.0212554
4.14 0.345	0.14450	0.0779	0.0220054
4.20 0.350	0.14680	0.0784	0.0227073
4.26 0.355	0.14910	0.0787	0.0234333

Table 4.3: (continued)

d inch feet	A $(ft)^2$	$R^{4/3}$ $(ft)^{4/3}$	$(d-r)A + \frac{2}{3}(2rd-d^2)^{3/2}$ $(ft)^3$
4.32 0.360	0.15135	0.0791	0.0241883
4.38 0.365	0.15358	0.0795	0.0249593
4.44 0.370	0.15578	0.0799	0.0257210
4.50 0.375	0.15795	0.0803	0.0265032
4.56 0.380	0.16010	0.0806	0.0272973
4.62 0.385	0.16223	0.0808	0.0281084
4.68 0.390	0.16433	0.0810	0.0289325
4.74 0.395	0.16638	0.0811	0.0297573
4.80 0.400	0.16840	0.0812	0.0305933
4.86 0.405	0.17034	0.0813	0.0314355
4.92 0.410	0.17233	0.0812	0.0322962
4.98 0.415	0.17423	0.0811	0.0331609
5.04 0.420	0.17608	0.0810	0.0340366
5.10 0.425	0.17788	0.0808	0.0349253
5.16 0.430	0.17965	0.0806	0.0358196
5.22 0.435	0.18135	0.0803	0.0367168
5.28 0.440	0.18300	0.0799	0.0375905
5.34 0.445	0.18460	0.0795	0.0385448
5.40 0.450	0.18613	0.0790	0.0394760
5.46 0.455	0.18760	0.0784	0.0404133
5.52 0.460	0.18900	0.0777	0.0413534

Table 4.3: (continued)

d inch feet	A $(ft)^2$	$R^{4/3}$ $(ft)^{4/3}$	$(d-r)A + \frac{2}{3}(2rd-d^2)^{3/2}$ (ft)
5.58 0.465	0.19030	0.0770	0.0422988
5.64 0.470	0.19155	0.0760	0.0432563
5.70 0.475	0.19263	0.0749	0.0442151
5.76 0.480	0.19373	0.0737	0.0451858
5.82 0.485	0.19463	0.0723	0.0461519
5.88 0.490	0.19540	0.0705	0.0471246
5.94 0.495	0.19603	0.0681	0.0481092
6.00 0.500	0.19635	0.0625	0.0490880

Table 4.4: Relationships between d, A, R and 2r for a 5" Pipe.

d inch feet	A $(ft)^2$	$R^{4/3}$ $(ft)^{4/3}$	$(d-r)A + \frac{2}{3}(2rd-d^2)^{3/2}$ $(ft)^3$
2.25 0.1875	0.0595125	0.0446	0.0046919
2.30 0.1916	0.0612328	0.0455	0.0049523
2.35 0.1958	0.0629687	0.0464	0.0052177
2.40 0.2000	0.0647049	0.0473	0.0054819
2.45 0.2041	0.0664410	0.0482	0.0057494
2.50 0.2083	0.0681771	0.0490	0.0060286
2.55 0.2125	0.0699132	0.0498	0.0063175
2.60 0.2167	0.0716493	0.0506	0.0066182
2.65 0.2208	0.0733854	0.0514	0.0069221
2.70 0.2250	0.0751215	0.0522	0.0072248
2.75 0.2291	0.0768403	0.0529	0.0075327
2.80 0.2333	0.0785764	0.0537	0.0078635
2.85 0.2375	0.0802951	0.0544	0.0082014
2.90 0.2416	0.0819965	0.0551	0.0085293
2.95 0.2458	0.0837152	0.0558	0.0088823
3.00 0.3000	0.0854167	0.0564	0.0092264
3.05 0.2541	0.0871181	0.0569	0.0095831
3.10 0.2583	0.0888021	0.0575	0.0099632
3.15 0.2625	0.0904861	0.0581	0.0103248
3.20 0.2667	0.0921528	0.0586	0.0107058
3.25 0.2708	0.0938194	0.0592	0.0110971

Table 4.4: (continued)

d inch feet	A $(ft)^2$	$R^{4/3}$ $(ft)^{4/3}$	$(d-r)A + \frac{2}{3}(2rd-d^2)^{3/2}$ $(ft)^3$
3.30 0.2750	0.0954687	0.0597	0.0114860
3.35 0.2791	0.0971181	0.0602	0.0118997
3.40 0.2833	0.0987326	0.0607	0.0122991
3.45 0.2875	0.1003472	0.0611	0.0127076
3.50 0.2916	0.1019444	0.0614	0.0131250
3.55 0.2958	0.1035417	0.0617	0.0135657
3.60 0.3000	0.1051042	0.0620	0.0139973
3.65 0.3041	0.1066492	0.0624	0.0144346
3.70 0.3083	0.1081771	0.0627	0.0148912
3.75 0.3125	0.1096875	0.0630	0.0153432
3.80 0.3167	0.1111806	0.0632	0.0153432
3.85 0.3208	0.1126562	0.0634	0.0162670
3.90 0.3250	0.1141146	0.0635	0.0167452
3.95 0.3291	0.1155382	0.0636	0.0172148
4.00 0.3333	0.1169444	0.0637	0.0177044
4.05 0.3375	0.1183160	0.0637	0.0181869
4.10 0.3417	0.1196701	0.0637	0.0186893
4.15 0.3458	0.1209896	0.0636	0.0191919
4.20 0.3500	0.1222743	0.0635	0.0196974
4.25 0.3541	0.1235234	0.0634	0.0196974
4.30 0.3583	0.1247569	0.0632	0.0207293

Table 4.4: (continued)

d inch feet	A $(ft)^2$	$R^{4/3}$ $(ft)^{4/3}$	$(d-r)A + \frac{2}{3}(2rd-d^2)^{3/2}$ $(ft)^3$
4.35 0.3625	0.1259375	0.0630	0.0212411
4.40 0.3667	0.1270833	0.0627	0.0217746
4.45 0.3708	0.1281944	0.0624	0.0223086
4.50 0.3750	0.1292535	0.0619	0.0228443
4.55 0.3791	0.1302778	0.0614	0.0233857
4.60 0.3833	0.1312500	0.0609	0.0239314
4.65 0.3875	0.1321528	0.0603	0.0244786
4.70 0.3916	0.1330208	0.0597	0.0250459
4.75 0.3958	0.1338021	0.0587	0.0255871
4.80 0.4000	0.1345312	0.0578	0.0261480
4.85 0.4041	0.1351562	0.0567	0.0267076
4.90 0.4083	0.1356944	0.0553	0.0272748
4.95 0.4125	0.1361285	0.0534	0.0278404
5.00 0.4167	0.1363542	0.0490	0.0284071

Table 4.5: Relationships between d, A, R and 2r for a 4" Pipe.

d inch feet	A $(ft)^2$	$R^{4/3}$ $(ft)^{4/3}$	$(d-r)A + \frac{2}{3}(2rd-d^2)^{3/2}$ $(ft)^3$
1.04 0.0867	0.018033	0.0187	0.00064053
1.08 0.0900	0.019011	0.0195	0.00070302
1.12 0.0933	0.020000	0.0203	0.00076774
1.16 0.0967	0.021000	0.0212	0.00083821
1.20 0.1000	0.022022	0.0219	0.00090954
1.24 0.1033	0.023044	0.0227	0.00098622
1.28 0.1067	0.024077	0.0235	0.00106360
1.32 0.1100	0.025111	0.0243	0.00114446
1.36 0.1133	0.026166	0.0251	0.00122498
1.40 0.1167	0.027222	0.0259	0.00131813
1.44 0.1200	0.028288	0.0266	0.00141036
1.48 0.1233	0.029355	0.0274	0.00150574
1.52 0.1267	0.030433	0.0281	0.00160704
1.56 0.1300	0.031511	0.0289	0.00170381
1.60 0.1333	0.032599	0.0296	0.00180879
1.64 0.1367	0.033688	0.0304	0.00192282
1.68 0.1400	0.034777	0.0311	0.00204276
1.72 0.1433	0.035877	0.0317	0.00215853
1.76 0.1467	0.036977	0.0325	0.00227751
1.80 0.1500	0.038088	0.0331	0.00240392
1.84 0.1533	0.039188	0.0339	0.00253425

Table 4.5: (continued)

d inch feet	A $(ft)^2$	$R^{4/3}$ $(ft)^{4/3}$	$(d-r)A + \frac{2}{3}(2rd-d^2)^{3/2}$ $(ft)^3$
1.88 0.1567	0.040300	0.0345	0.0026688
1.92 0.1600	0.041411	0.0351	0.0028027
1.96 0.1633	0.042533	0.0358	0.0029404
2.00 0.1667	0.043633	0.0364	0.0030864
2.04 0.1700	0.044744	0.0370	0.0032313
2.08 0.1733	0.045855	0.0376	0.0033844
2.12 0.1767	0.046966	0.0382	0.0035414
2.16 0.1800	0.048077	0.0388	0.0036977
2.20 0.1833	0.049177	0.0393	0.0038585
2.24 0.1867	0.050288	0.0398	0.0040228
2.28 0.1900	0.051388	0.0404	0.0041948
2.32 0.1933	0.052477	0.0409	0.0043689
2.36 0.1967	0.053577	0.0414	0.0045408
2.40 0.2000	0.054666	0.0419	0.0047176
2.44 0.2033	0.055755	0.0423	0.0049034
2.48 0.2067	0.056833	0.0427	0.0050977
2.52 0.2100	0.057911	0.0431	0.0052893
2.56 0.2133	0.058977	0.0435	0.0054827
2.60 0.2167	0.060044	0.0440	0.0056815
2.64 0.2200	0.061100	0.0443	0.0058791
2.68 0.2233	0.062155	0.0447	0.0060894

Table 4.5: (continued)

d inch feet	A $(ft)^2$	$R^{4/3}$ $(ft)^{4/3}$	$(d-r)A + \frac{2}{3}(2rd-d^2)^{3/2}$ $(ft)^3$
2.72 0.2267	0.063188	0.0452	0.0062995
2.76 0.2300	0.064222	0.0454	0.0065130
2.80 0.2333	0.065244	0.0456	0.0067272
2.84 0.2367	0.066266	0.0459	0.0069469
2.88 0.2400	0.067266	0.0461	0.0071671
2.92 0.2433	0.068255	0.0463	0.0073935
2.96 0.2467	0.069233	0.0466	0.0076217
3.00 0.2500	0.070200	0.0467	0.0078542
3.04 0.2533	0.071155	0.0469	0.0080910
3.08 0.2567	0.072100	0.0471	0.0083288
3.12 0.2600	0.073033	0.0472	0.0085714
3.16 0.2633	0.073944	0.0472	0.0087502
3.20 0.2667	0.074844	0.0473	0.0090649
3.24 0.2700	0.075722	0.0473	0.0093158
3.28 0.2733	0.076588	0.0473	0.0095707
3.32 0.2767	0.077433	0.0473	0.0098267
3.36 0.2800	0.078255	0.0472	0.0100859
3.40 0.2833	0.079055	0.0471	0.0103458
3.44 0.2867	0.079844	0.0469	0.0106127
3.48 0.2900	0.080600	0.0467	0.0108800
3.52 0.2933	0.081333	0.0466	0.0111479

Table 4.5: (continued)

d inch feet	A $(ft)^2$	$R^{4/3}$ $(ft)^{4/3}$	$(d-r)A + \frac{2}{3}(2rd-d^2)^{3/2}$ $(ft)^3$
3.56 0.2967	0.082044	0.0463	0.0114215
3.60 0.3000	0.082722	0.0460	0.0116961
3.64 0.3033	0.083377	0.0456	0.0119737
3.68 0.3067	0.084000	0.0452	0.0122527
3.72 0.3100	0.084577	0.0448	0.0125329
3.76 0.3133	0.085133	0.0443	0.0128160
3.80 0.3167	0.085633	0.0436	0.0131003
3.84 0.3200	0.086100	0.0429	0.0133876
3.88 0.3233	0.086500	0.0420	0.0136742
3.92 0.3267	0.086844	0.0410	0.0139626
3.96 0.3300	0.087122	0.0396	0.0142543
4.00 0.3333	0.087266	0.0364	0.0145442

Table 5. Theoretical and Experimental Profile Data for Various Conditions.

5. 1	$\Delta Q = 0.0315$ cfs	$n = 0.011$	$S = 0.0005$
5. 2	$\Delta Q = 0.0525$ cfs	$n = 0.011$	$S = 0.0005$
5. 3	$\Delta Q = 0.0735$ cfs	$n = 0.011$	$S = 0.0005$
5. 4	$\Delta Q = 0.1050$ cfs	$n = 0.011$	$S = 0.0005$
5. 5	$\Delta Q = 0.0315$ cfs	$n = 0.011$	$S = 0.0010$
5. 6	$\Delta Q = 0.0525$ cfs	$n = 0.011$	$S = 0.0010$
5. 7	$\Delta Q = 0.0735$ cfs	$n = 0.011$	$S = 0.0010$
5. 8	$\Delta Q = 0.1050$ cfs	$n = 0.011$	$S = 0.0010$
5. 9	$\Delta Q = 0.0315$ cfs	$n = 0.011$	$S = 0.0025$
5.10	$\Delta Q = 0.0525$ cfs	$n = 0.011$	$S = 0.0025$
5.11	$\Delta Q = 0.0735$ cfs	$n = 0.011$	$S = 0.0025$
5.12	$\Delta Q = 0.1050$ cfs	$n = 0.011$	$S = 0.0025$
5.13	$\Delta Q = 0.0315$ cfs	$n = 0.011$	$S = 0.0050$
5.14	$\Delta Q = 0.0525$ cfs	$n = 0.011$	$S = 0.0050$
5.15	$\Delta Q = 0.0735$ cfs	$n = 0.011$	$S = 0.0050$
5.16	$\Delta Q = 0.1050$ cfs	$n = 0.011$	$S = 0.0050$
5.17	$\Delta Q = 0.0315$ cfs	$n = 0.011$	$S = 0.0100$
5.18	$\Delta Q = 0.0525$ cfs	$n = 0.011$	$S = 0.0100$
5.19	$\Delta Q = 0.0735$ cfs	$n = 0.011$	$S = 0.0100$
5.20	$\Delta Q = 0.0315$ cfs	$n = 0.011$	$S = 0.0250$
5.21	$\Delta Q = 0.0525$ cfs	$n = 0.011$	$S = 0.0250$
5.22	$\Delta Q = 0.0735$ cfs	$n = 0.011$	$S = 0.0250$
5.23	$\Delta Q = 0.0315$ cfs	$n = 0.011$	$S = 0.0500$
5.24	$\Delta Q = 0.0525$ cfs	$n = 0.011$	$S = 0.0500$

This table is an extensive set of theoretical profile data for various conditions as computed from Eqs. (4.2.12) and (4.2.13). Spot checks were made experimentally in an effort to evaluate the validity of the theoretical computations. These experimental values are also included and indicate that, in general, there was good agreement between theory and experiment.

Table 5.1: Theoretical and Experimental Profile Data for the Condition:

ΔQ = 0.0315 cfs n = 0.011 S = 0.0005

Distance from Outlet (ft)	Calculated Depth (in)	Experimental Depth (in)	Discharge (cfs)	Diameter (in)
0.00	4.620		0.6300	10
2.55	4.800		0.6300	10
6.00	5.000		0.6300	10
10.15	5.200		0.6300	10
14.82	5.400		0.6300	10
26.34	5.600		0.6300	10
36.00	5.800		0.6300	10
50.00	6.000		0.6300	10
66.00	6.170	6.2	0.6300	10
66.00	6.320	6.5	0.5985	10
76.75	6.400		0.5985	10
110.00	6.600		0.5985	10
132.00	6.700	6.7	0.5985	10
132.00	6.810	6.9	0.5670	10
160.00	6.900		0.5670	10
198.00	7.000		0.5670	10
198.00	7.090		0.5355	10
210.95	7.100		0.5355	10
236.45	7.130		0.5355	10
264.00	7.150	7.2	0.5355	10
264.00	7.230	7.3	0.5040	10
286.00	7.220		0.5040	10
308.00	7.220		0.5040	10
330.00	7.220		0.5040	10
330.00	7.290		0.4725	10
374.04	7.250		0.4725	10
396.00	7.230		0.4725	10
396.00	7.290		0.4410	10
424.25	7.250		0.4410	10
442.00	7.230		0.4410	10
450.52	7.210		0.4410	10
462.00	7.190	7.2	0.4410	10
462.00	7.250	7.3	0.4095	10
478.12	7.210		0.4095	10
506.00	7.150		0.4095	10
528.00	7.110		0.4095	10
528.00	7.180		0.3780	10
554.00	7.100		0.3780	10
568.95	7.040		0.3780	10
594.00	6.980		0.3780	10
594.00	7.010		0.3465	10
614.00	6.990		0.3465	10

Table 5.1: (continued)

Distance from Outlet (ft)	Calculated Depth (in)	Experimental Depth (in)	Discharge (cfs)	Diameter (in)
628.00	6.950		0.3465	10
634.90	6.930		0.3465	10
654.95	6.870		0.3465	10
660.00	6.860		0.3465	10
660.00	6.910		0.3150	10
676.00	6.850		0.3150	10
690.00	6.800		0.3150	10
726.00	6.720	6.8	0.3150	10
726.00	6.770	6.9	0.2835	10
744.58	6.690	6.7	0.2835	10
744.58	7.210	7.3	0.2835	10
770.00	7.160	7.3	0.2835	8
792.00	7.120	7.3	0.2835	8
792.00	7.180	7.5	0.2520	8
814.00	7.120		0.2520	8
828.00	7.080		0.2520	8
842.94	7.040		0.2520	8
858.00	7.000		0.2520	8
858.00	7.055		0.2205	8
872.15	7.000		0.2205	8
884.15	6.960		0.2205	8
894.82	6.920		0.2205	8
908.16	6.880		0.2205	8
920.00	6.840		0.2205	8
924.00	6.830		0.2205	8
924.00	6.880		0.1890	8
935.35	6.830		0.1890	8
942.72	6.800		0.1890	8
952.95	6.760		0.1890	8
962.00	6.720		0.1890	8
972.12	6.680		0.1890	8
982.94	6.640		0.1890	8
990.00	6.610	6.6	0.1890	8
990.00	6.650	6.7	0.1575	8
1000.55	6.600		0.1575	8
1010.00	6.560		0.1575	8
1018.38	6.520		0.1575	8
1026.82	6.480		0.1575	8
1036.00	6.440		0.1575	8
1044.00	6.400		0.1575	8
1056.00	6.350		0.1575	8
1056.00	6.390		0.1260	8
1070.00	6.320		0.1260	8

Table 5.1: (continued)

Distance from Outlet (ft)	Calculated Depth (in)	Experimental Depth (in)	Discharge (cfs)	Diameter (in)
1084.15	6.240		0.1260	8
1100.15	6.160		0.1260	8
1116.74	6.080		0.1260	8
1122.00	6.060	6.0	0.1260	8
1122.00	6.090	6.1	0.0945	8
1138.55	6.000		0.0945	8
1154.00	5.920		0.0945	8
1168.50	5.840		0.0945	8
1184.00	5.760		0.0945	8
1188.00	5.740		0.0945	8
1188.00	5.770		0.0630	8
1216.00	5.600		0.0630	8
1230.35	5.520		0.0630	8
1244.84	5.440		0.0630	8
1254.00	5.390	5.5	0.0630	8
1254.00	5.410	5.6	0.0315	8
1262.00	5.360		0.0315	8
1276.00	5.280		0.0315	8
1288.58	5.200		0.0315	8
1302.95	5.120		0.0315	8
1316.24	5.040		0.0315	8
1320.00	5.020		0.0315	8

Table 5.2: Theoretical and Experimental Profile Data for the condition:
$\Delta Q = 0.0525$ cfs $n = 0.011$ $S = 0.0005$

Distance from Outlet (ft)	Calculated Depth (in)	Experimental Depth (in)	Discharge (cfs)	Diameter (in)
0.00	5.270	5.3	1.0500	10
2.60	5.425		1.0500	10
8.00	5.690		1.0500	10
11.20	5.760		1.0500	10
15.20	5.920		1.0500	10
18.60	6.000		1.0500	10
40.00	6.300		1.0500	10
66.00	6.635	6.6	1.0500	10
66.00	6.790	6.8	0.9975	10
76.00	6.865		0.9975	10
104.00	7.000		0.9975	10
132.00	7.150		0.9975	10
132.00	7.265		0.9450	10
162.00	7.310		0.9450	10
198.00	7.380	7.4	0.9450	10
198.00	7.480	7.5	0.8925	10
234.00	7.515		0.8925	10
264.00	7.560		0.8925	10
264.00	7.630		0.8400	10
298.00	7.670		0.8400	10
330.00	7.710		0.8400	10
330.00	7.800		0.7875	10
360.00	7.795		0.7875	10
396.00	7.790	7.8	0.7875	10
396.00	7.880	7.9	0.7350	10
428.00	7.875		0.7350	10
462.00	7.865		0.7350	10
462.00	7.900		0.6825	10
490.00	7.875		0.6825	10
528.00	7.840	7.9	0.6825	10
528.00	7.880	7.9	0.6300	10
560.00	7.825		0.6300	10
594.00	7.775		0.6300	10
594.00	7.850		0.5775	10
628.00	7.730		0.5775	10
660.00	7.700		0.5775	10
660.00	7.800		0.5250	10
692.00	7.700		0.5250	10
726.00	7.610	7.6	0.5250	10
726.00	7.670	7.7	0.4725	10
758.00	7.625		0.4725	10
792.00	7.590		0.4725	10
792.00	7.670		0.4200	10

Table 5.2: (continued)

Distance from Outlet (ft)	Calculated Depth (in)	Experimental Depth (in)	Discharge (cfs)	Diameter (in)
810.00	7.600		0.4200	10
810.00	7.900		0.4200	8
830.00	7.780		0.4200	8
858.00	7.610		0.4200	8
858.00	7.660		0.3675	8
890.00	7.530		0.3675	8
924.00	7.400	7.4	0.3675	8
924.00	7.490	7.5	0.3150	8
960.00	7.300		0.3150	8
990.00	7.130		0.3150	8
990.00	7.200		0.2625	8
1022.00	7.050		0.2625	8
1056.00	6.900		0.2625	8
1056.00	6.925		0.2100	8
1090.00	6.750		0.2100	8
1122.00	6.580	6.6	0.2100	8
1122.00	6.590	6.6	0.1575	8
1150.00	6.450		0.1575	8
1188.00	6.255		0.1575	8
1188.00	6.325		0.1050	8
1220.00	6.120		0.1050	8
1254.00	5.900		0.1050	8
1254.00	5.960		0.0525	8
1293.00	5.690		0.0525	8
1320.00	5.500		0.0525	8

Table 5.3: Theoretical and Experimental Profile Data for the condition: $\Delta Q = 0.0735$ cfs $n = 0.011$ $S = 0.0005$

Distance from Outlet (ft)	Calculated Depth (in)	Experimental Depth (in)	Discharge (cfs)	Diameter (in)
0.00	5.770	5.8	1.4700	10
3.85	5.820		1.4700	10
8.20	6.190		1.4700	10
14.00	6.350		1.4700	10
26.10	6.510		1.4700	10
36.00	6.140		1.4700	10
66.00	6.940	7.0	1.4700	10
66.00	7.190	7.2	1.3965	10
100.00	7.390		1.3965	10
132.00	7.580		1.3965	10
132.00	7.790		1.3230	10
162.00	7.920		1.3230	10
198.00	8.080		1.3230	10
198.00	8.210		1.2495	10
230.00	8.270		1.2495	10
264.00	8.300		1.2495	10
264.00	8.420		1.1760	10
298.00	8.450		1.1760	10
330.00	8.500	8.5	1.1760	10
330.00	8.590	8.6	1.1025	10
360.00	8.580		1.1025	10
396.00	8.570		1.1025	10
396.00	8.660		1.0290	10
428.00	8.620		1.0290	10
462.00	8.580		1.0290	10
462.00	8.650		0.9555	10
490.00	8.610		0.9555	10
528.00	8.570		0.9555	10
528.00	8.650		0.8820	10
560.00	8.550		0.8820	10
594.00	8.470		0.8820	10
594.00	8.530		0.8085	10
628.00	8.440		0.8085	10
660.00	8.370	8.4	0.8085	10
660.00	8.470	8.6	0.7350	10
692.00	8.370		0.7350	10
726.00	8.275		0.7350	10
726.00	8.360		0.6615	10
758.00	8.250		0.6615	10
792.00	8.140	8.1	0.6615	10
792.00	8.230	8.3	0.5880	10
820.00	8.130		0.5880	10

Table 5.3: (continued)

Distance from Outlet (ft)	Calculated Depth (in)	Experimental Depth (ft)	Discharge (cfs)	Diameter (in)
858.00	8.000		0.5880	10
858.00	8.120		0.5145	10
890.00	7.970		0.5145	10
924.00	7.790	7.8	0.5145	10
924.00	7.840	7.8	0.4410	10
960.00	7.600	7.6	0.4410	10
960.00	7.890	7.9	0.4410	8
990.00	7.530		0.4410	8
990.00	7.560		0.3675	8
1022.00	7.405		0.3675	8
1056.00	7.230		0.3675	8
1056.00	7.290		0.2940	8
1090.00	7.140		0.2940	8
1122.00	7.000		0.2940	8
1122.00	7.080		0.2205	8
1156.00	7.990		0.2205	8
1188.00	6.880	6.9	0.2205	8
1188.00	7.000	7.0	0.1470	8
1220.00	6.860		0.1470	8
1254.00	6.700		0.1470	8
1254.00	6.800		0.0735	8
1288.00	6.470		0.0735	8
1320.00	6.170		0.0735	8

Table 5.4: Theoretical and Experimental Profile Data for the Condition:
ΔQ = 0.1050 cfs n = 0.011 S = 0.0005

Distance from Outlet (ft)	Calculated Depth (in)	Experimental Depth (in)	Discharge (cfs)	Diameter (in)
0.00	6.420	6.4	2.1000	10
4.00	6.600		2.1000	10
6.30	6.700		2.1000	10
9.80	6.800		2.1000	10
13.00	6.900		2.1000	10
22.00	7.200		2.1000	10
42.00	7.330		2.1000	10
53.90	7.410		2.1000	10
66.00	7.500	7.5	2.1000	10
66.00	7.770	7.7	1.9950	10
100.00	7.880		1.9950	10
132.00	8.000		1.9950	10
132.00	8.250		1.8900	10
162.00	8.340		1.8900	10
198.00	8.490		1.8900	10
198.00	8.750		1.7850	10
230.00	8.820		1.7850	10
264.00	8.900		1.7850	10
264.00	9.140		1.6800	10
298.00	9.180		1.6800	10
330.00	9.190		1.6800	10
330.00	9.400		1.5750	10
360.00	9.400		1.5750	10
396.00	9.430	9.2	1.5750	10
396.00	9.570	9.6	1.4700	10
428.00	9.600		1.4700	10
462.00	9.610		1.4700	10
462.00	9.700		1.3650	10
490.00	9.700		1.3650	10
528.00	9.690		1.3650	10
528.00	9.800		1.2600	10
560.00	9.740		1.2600	10
594.00	9.660	9.7	1.2600	10
594.00	9.870	9.9	1.1550	10
628.00	9.670		1.1550	10
660.00	9.570		1.1550	10
660.00	9.630		1.0500	10
692.00	9.520		1.0500	10
726.00	9.420		1.0500	10
726.00	9.510		0.9450	10
758.00	9.400		0.9450	10
792.00	9.290	9.3	0.9450	10
792.00	9.350	9.5	0.8400	10

Table 5.4: (continued)

Distance from Outlet (ft)	Calculated Depth (in)	Experimental Depth (in)	Discharge (cfs)	Diameter (in)
820.00	9.240		0.8400	10
858.00	9.080		0.8400	10
858.00	9.170		0.7350	10
890.00	9.000		0.7350	10
924.00	8.820	8.8	0.7350	10
924.00	8.880	9.0	0.6300	10
960.00	8.650		0.6300	10
990.00	8.450		0.6300	10
990.00	8.525		0.5250	10
1022.00	8.350		0.5250	10
1056.00	8.175		0.5250	10
1056.00	8.245		0.4200	10
1090.00	8.040		0.4200	10
1122.00	7.840		0.4200	10
1122.00	7.940		0.3150	10
1146.00	7.750		0.3150	10
1170.00	7.570	7.6	0.3150	10
1170.00	7.930	8.1	0.3150	8
1188.00	8.840		0.3150	8
1188.00	7.890		0.2100	8
1220.00	7.710		0.2100	8
1254.00	7.520		0.2100	8
1254.00	7.590		0.1050	8
1288.00	7.180		0.1050	8
1320.00	6.800		0.1050	8

Table 5.5: Theoretical and Experimental Profile Data for the Condition: ΔQ = 0.0315 cfs n = 0.011 S = 0.001

Distance from Outlet (ft)	Calculated Depth (in)	Experimental Depth (in)	Discharge (cfs)	Diameter (in)
0.00	4.620	4.6	0.6300	10
3.00	4.800		0.6300	10
5.30	4.900		0.6300	10
7.50	5.000		0.6300	10
11.72	5.100		0.6300	10
14.95	5.200		0.6300	10
20.28	5.400		0.6300	10
40.15	5.600		0.6300	10
62.50	5.800		0.6300	10
66.00	5.820	5.8	0.6300	10
66.00	5.990	6.1	0.5985	10
83.00	6.040		0.5985	10
110.85	6.100		0.5985	10
132.00	6.140		0.5985	10
132.00	6.250		0.5670	10
181.15	6.230		0.5670	10
198.00	6.220		0.5670	10
198.00	6.330		0.5355	10
214.25	6.300		0.5355	10
222.00	6.280		0.5355	10
238.74	6.240		0.5355	10
256.84	6.200		0.5355	10
264.00	6.190	6.2	0.5355	10
264.00	6.305	6.4	0.5040	10
288.12	6.230		0.5040	10
296.00	6.200		0.5040	10
330.00	6.100		0.5040	10
330.00	6.200		0.4725	10
354.50	6.100		0.4725	10
370.00	6.060		0.4725	10
370.00	6.390		0.4725	8
396.00	6.440	6.5	0.4725	8
396.00	6.570	6.6	0.4410	8
424.55	6.550		0.4410	8
457.25	6.530		0.4410	8
462.00	6.528		0.4410	8
462.00	6.645		0.4095	8
474.25	6.600		0.4095	8
486.85	6.560		0.4095	8
504.94	6.520		0.4095	8
528.00	6.470	6.5	0.4095	8
528.00	6.580	6.6	0.3780	8

Table 5.5: (continued)

Distance from Outlet (ft)	Calculated Depth (in)	Experimental Depth (in)	Discharge (cfs)	Diameter (in)
533.90	6.560		0.3780	8
548.00	6.500		0.3780	8
564.25	6.440		0.3780	8
584.00	6.380		0.3780	8
594.00	6.350	6.4	0.3780	8
594.00	6.440	6.5	0.3465	8
602.05	6.400		0.3465	8
618.42	6.320		0.3465	8
636.00	6.240		0.3465	8
654.82	6.160		0.3465	8
660.00	6.140		0.3465	8
660.00	6.240		0.3150	8
672.00	6.160		0.3150	8
686.00	6.080		0.3150	8
700.45	6.000		0.3150	8
715.50	5.920		0.3150	8
726.75	5.860	5.9	0.3150	8
726.75	5.960	6.1	0.2835	8
732.00	5.920		0.2835	8
747.15	5.840		0.2835	8
765.14	5.760		0.2835	8
770.00	5.680		0.2835	8
783.00	5.600		0.2835	8
792.00	5.550		0.2835	8
792.00	5.650		0.2520	8
798.55	5.600		0.2520	8
810.80	5.520		0.2520	8
822.82	5.440		0.2520	8
834.00	5.360		0.2520	8
846.48	5.280		0.2520	8
858.00	5.210	5.2	0.2520	8
858.00	5.310	5.3	0.2205	8
872.14	5.200		0.2205	8
882.35	5.120		0.2205	8
894.00	5.040		0.2205	8
904.55	4.960		0.2205	8
918.00	4.880		0.2205	8
924.00	4.840		0.2205	8
924.00	4.940		0.1890	8
932.75	4.880		0.1890	8
940.55	4.800		0.1890	8
952.00	4.720		0.1890	8
962.05	4.640		0.1890	8

Table 5.5: (continued)

Distance from Outlet (ft)	Calculated Depth (in)	Experimental Depth (in)	Discharge (cfs)	Diameter (in)
973.82	4.560		0.1890	8
984.85	4.480		0.1890	8
990.00	4.450	4.4	0.1890	8
990.00	4.560	4.7	0.1575	8
998.92	4.480		0.1575	8
1008.02	4.400		0.1575	8
1020.00	4.310	4.4	0.1575	8
1020.00	4.670	4.7	0.1575	6
1030.00	4.620		0.1575	6
1042.35	4.560		0.1575	6
1056.00	4.500		0.1575	6
1056.00	4.640		0.1260	6
1066.12	4.560		0.1260	6
1074.20	4.500		0.1260	6
1082.00	4.440		0.1260	6
1100.00	4.320		0.1260	6
1118.10	4.200		0.1260	6
1122.00	4.180	4.2	0.1260	6
1122.00	4.310	4.4	0.0945	6
1133.28	4.200		0.0945	6
1146.48	4.080		0.0945	6
1160.55	3.960		0.0945	6
1176.50	3.840		0.0945	6
1188.00	3.750		0.0945	6
1188.00	3.860		0.0630	6
1196.30	3.780		0.0630	6
1208.75	3.660		0.0630	6
1220.00	3.550	3.7	0.0630	6
1220.00	3.750	3.9	0.0630	5
1230.00	3.650		0.0630	5
1242.15	3.550		0.0630	5
1254.00	3.450		0.0630	5
1254.00	3.560		0.0315	5
1264.00	3.450		0.0315	5
1272.18	3.350		0.0315	5
1290.46	3.150		0.0315	5
1310.00	2.950		0.0315	5
1320.00	2.850		0.0315	5

Table 5.6: Theoretical and Experimental Profile Data for the Condition:
ΔQ = 0.0525 cfs n = 0.011 S = 0.001

Distance from Outlet (ft)	Calculated Depth (in)	Experimental Depth (in)	Discharge (cfs)	Diameter (in)
0.00	5.270	5.3	1.0500	10
4.00	5.400		1.0500	10
8.00	5.540		1.0500	10
13.00	5.650		1.0500	10
20.00	5.770		1.0500	10
40.00	6.000		1.0500	10
60.00	6.170		1.0500	10
66.00	6.220	6.0	0.9975	10
66.00	6.485	6.5	0.9975	10
100.00	6.500		0.9975	10
132.00	6.600		0.9975	10
132.00	6.770		0.9975	10
164.00	6.810		0.9975	10
198.00	6.860		0.9975	10
198.00	6.950		0.8925	10
230.00	6.930		0.8925	10
264.00	6.925	7.0	0.8925	10
264.00	7.040	7.1	0.8400	10
296.00	6.980		0.8400	10
330.00	6.900		0.8400	10
330.00	7.020		0.7875	10
362.00	6.985		0.7875	10
396.00	6.930		0.7875	10
396.00	7.070		0.7350	10
420.00	7.000		0.7350	10
440.00	6.925	7.0	0.7350	10
440.00	7.300	7.5	0.7350	8
462.00	7.300		0.7350	8
462.00	7.380		0.6825	8
496.00	7.370		0.6825	8
528.00	7.370		0.6825	8
528.00	7.440		0.6300	8
560.00	7.325		0.6300	8
594.00	7.200	7.2	0.6300	8
594.00	7.280	7.3	0.5775	8
628.00	7.150		0.5775	8
660.00	7.050		0.5775	8
660.00	7.100		0.5250	8
692.00	6.980		0.5250	8
726.00	6.830		0.5250	8
726.00	6.860		0.4725	8

Table 5.6: (continued)

Distance from Outlet (ft)	Calculated Depth (in)	Experimental Depth (in)	Discharge (cfs)	Diameter (in)
760.00	6.650		0.4725	8
792.00	6.470		0.4725	8
792.00	6.540		0.4200	8
822.00	6.300		0.4200	8
858.00	6.020	6.0	0.4200	8
858.00	6.120	6.2	0.3675	8
890.00	5.920		0.3675	8
924.00	5.710		0.3675	8
924.00	5.800		0.3150	8
960.00	5.570		0.3150	8
990.00	5.365		0.3150	8
990.00	5.465		0.2625	8
1022.00	5.220		0.2625	8
1056.00	5.000		0.2625	8
1056.00	5.100		0.2100	8
1080.00	4.980	5.0	0.2100	8
1080.00	5.410	5.5	0.2100	6
1100.00	5.275		0.2100	6
1122.00	5.120		0.2100	6
1122.00	5.210		0.1575	6
1154.00	4.960		0.1575	6
1188.00	4.700		0.1575	6
1188.00	4.800		0.1050	6
1220.00	4.550		0.1050	6
1236.00	4.410		0.1050	6
1254.00	4.275		0.1050	6
1254.00	4.365		0.0525	6
1284.00	4.040		0.0525	6
1320.00	3.170		0.0525	6

Table 5.7: Theoretical and Experimental Profile Data for the Condition: $\Delta Q = 0.0735$ cfs $n = 0.011$ $S = 0.001$

Distance from Outlet (ft)	Calculated Depth (in)	Experimental Depth (in)	Discharge (cfs)	Diameter (in)
0.00	5.770	5.8	1.4700	10
5.80	5.820		1.4700	10
14.45	6.060		1.4700	10
18.00	6.130		1.4700	10
24.00	6.210		1.4700	10
33.00	6.290		1.4700	10
40.00	6.330		1.4700	10
50.00	6.400		1.4700	10
66.00	6.500	6.5	1.4700	10
66.00	6.690	6.7	1.3965	10
100.00	6.790		1.3965	10
132.00	6.890		1.3965	10
132.00	7.080		1.3230	10
164.00	7.130		1.3230	10
198.00	7.200		1.3230	10
198.00	7.330		1.2495	10
230.00	7.350		1.2495	10
264.00	7.390		1.2495	10
264.00	7.470		1.1760	10
296.00	7.460		1.1760	10
330.00	7.470	7.5	1.1760	10
330.00	7.570	7.6	1.1025	10
362.00	7.560		1.1025	10
396.00	7.565		1.1025	10
396.00	7.635		1.0290	10
430.00	7.600		1.0290	10
462.00	7.600		1.0290	10
462.00	7.700		0.9555	10
496.00	7.650		0.9555	10
528.00	7.610		0.9555	10
528.00	7.700		0.8820	10
560.00	7.620		0.8820	10
594.00	7.545	7.6	0.8820	10
594.00	7.610	7.7	0.8085	10
628.00	7.500		0.8085	10
660.00	7.400		0.8085	10
660.00	7.510		0.8085	10
700.00	7.300	7.3	0.7350	10
700.00	7.600	7.8	0.7350	8
726.00	7.660		0.7350	8
726.00	7.730		0.6615	8

Table 5.7: (continued)

Distance from Outlet (ft)	Calculated Depth (in)	Experimental Depth (in)	Discharge (cfs)	Diameter (in)
760.00	7.630		0.6615	8
792.00	7.520		0.6615	8
792.00	7.600		0.5880	8
822.00	7.410		0.5880	8
858.00	7.200		0.5880	8
858.00	7.300		0.5145	8
890.00	7.020	7.1	0.5145	8
924.00	6.725	6.5	0.5145	8
924.00	6.776		0.4410	8
960.00	6.380		0.4410	8
990.00	6.050		0.4410	8
990.00	6.110		0.3675	8
1022.00	5.920		0.3675	8
1056.00	5.700		0.3675	8
1056.00	5.800		0.2940	8
1080.00	5.610		0.2940	8
1100.00	5.470		0.2940	8
1122.00	5.300		0.2940	8
1122.00	5.335		0.2205	8
1154.00	5.100		0.2205	8
1188.00	4.825		0.2205	8
1188.00	4.910		0.1470	8
1220.00	4.760	4.8	0.1470	8
1220.00	5.060	5.1	0.1470	6
1236.00	4.970		0.1470	6
1254.00	4.860		0.1470	6
1254.00	4.960		0.0735	6
1284.00	4.680		0.0735	6
1320.00	4.335		0.0735	6

Table 5.8: Theoretical and Experimental Profile Data for the Condition:
ΔQ = 0.1050 cfs   n = 0.011   S = 0.001

Distance from Outlet (ft)	Calculated Depth (in)	Experimental Depth (in)	Discharge (cfs)	Diameter (in)
0.00	6.420		2.1000	10
4.00	6.460		2.1000	10
9.00	6.530		2.1000	10
14.50	6.590		2.1000	10
27.00	6.710		2.1000	10
40.00	6.800		2.1000	10
50.00	6.830		2.1000	10
66.00	6.900	7.0	2.1000	10
66.00	7.020	7.2	1.9950	10
100.00	7.100		1.9950	10
132.00	7.160		1.9950	10
132.00	7.290		1.8900	10
164.00	7.370		1.8900	10
198.00	7.440		1.8900	10
198.00	7.560		1.7850	10
230.00	7.600		1.7850	10
264.00	7.630	7.6	1.7850	10
264.00	7.700	7.7	1.6800	10
296.00	7.730		1.6800	10
330.00	7.770		1.6800	10
330.00	7.850		1.5750	10
362.00	7.830		1.5750	10
396.00	7.835		1.5750	10
396.00	7.921		1.4700	10
430.00	7.770		1.4700	10
462.00	7.850		1.4700	10
462.00	7.830		1.3650	10
496.00	7.900		1.3650	10
528.00	7.865	7.8	1.3650	10
528.00	7.840	7.8	1.2600	10
560.00	7.920		1.2600	10
594.00	7.900		1.2600	10
594.00	7.860		1.1550	10
628.00	7.950		1.1550	10
660.00	7.900		1.1550	10
660.00	7.850		1.0500	10
692.00	7.950		1.0500	10
726.00	7.900	7.9	1.0500	10
726.00	7.920	7.9	0.9450	10
760.00	7.850		0.9450	10
792.00	7.780		0.9450	10
792.00	7.870		0.8400	10

Table 5.8: (continued)

Distance from Outlet (ft)	Calculated Depth (in)	Experimental Depth (in)	Discharge (cfs)	Diameter (in)
822.00	7.740		0.8400	10
858.00	7.590		0.8400	10
858.00	7.700		0.7350	10
-890.00	7.490		0.7350	10
924.00	7.225	7.2	0.7350	10
924.00	7.335	7.4	0.6300	10
960.00	6.960	7.0	0.6300	10
960.00	7.410	7.5	0.6300	8
990.00	7.400		0.6300	8
990.00	7.525		0.5250	8
1022.00	7.370		0.5250	8
1056.00	7.190	7.2	0.5250	8
1056.00	7.250	7.3	0.4200	8
1086.00	6.920		0.4200	8
1100.00	6.650		0.4200	8
1122.00	6.360		0.4200	8
1122.00	6.435		0.3150	8
1154.00	6.044		0.3150	8
1188.00	5.600	5.6	0.3150	8
1188.00	5.725	5.8	0.2100	8
1220.00	5.470		0.2100	8
1236.00	5.340		0.2100	8
1254.00	5.210		0.2100	8
1254.00	5.265		0.1050	8
1284.00	4.950		0.1050	8
1320.00	4.550		0.1050	8

Table 5.9: Theoretical and Experimental Profile Data for the Condition:
ΔQ = 0.0315 cfs n = 0.011 S = 0.025

Distance from Outlet (ft)	Calculated Depth (in)	Experimental Depth (in)	Discharge (cfs)	Diameter (in)
0.00	4.620		0.6300	10
5.00	4.700		0.6300	10
11.00	4.760		0.6300	10
13.50	4.800		0.6300	10
23.50	4.850		0.6300	10
29.50	4.900		0.6300	10
66.00	4.950	5.0	0.6300	10
66.00	5.280	5.3	0.5985	10
72.00	5.200		0.5985	10
92.00	5.000		0.5985	10
100.00	4.940	5.0	0.5985	10
100.00	4.740	4.6	0.5985	8
101.00	4.800		0.5985	8
102.00	4.880		0.5985	8
107.50	5.040		0.5985	8
116.50	5.200		0.5985	8
132.00	5.360		0.5985	8
132.00	5.695		0.5670	8
149.50	5.600		0.5670	8
170.20	5.520		0.5670	8
198.00	5.450	5.5	0.5670	8
198.00	5.735	5.8	0.5355	8
203.50	5.680		0.5355	8
212.50	5.600		0.5355	8
233.50	5.440		0.5355	8
264.00	5.290		0.5355	8
264.00	5.570		0.5040	8
276.00	5.440		0.5040	8
294.50	5.280		0.5040	8
300.00	5.240		0.5040	8
330.00	5.120		0.5040	8
330.00	5.410		0.4725	8
340.50	5.280		0.4725	8
357.50	5.120		0.4725	8
376.00	4.960		0.4725	8
396.00	4.880	5.0	0.4725	8
396.00	5.180	5.2	0.4410	8
407.00	5.040		0.4410	8
422.50	4.880		0.4410	8
443.50	4.720		0.4410	8
462.00	4.640		0.4410	8
462.00	4.960		0.4095	8

Table 5.9: (continued)

Distance from Outlet (ft)	Calculated Depth (in)	Experimental Depth (in)	Discharge (cfs)	Diameter (in)
474.50	4.800		0.4095	8
489.00	4.640		0.4095	8
499.00	4.560		0.4095	8
528.00	4.410	4.4	0.4095	8
528.00	4.750	4.8	0.3780	8
541.13	4.560		0.3780	8
556.22	4.400		0.3780	8
580.78	4.240		0.3780	8
594.00	4.190		0.3780	8
594.00	4.550		0.3465	8
603.72	4.400		0.3465	8
616.33	4.240		0.3465	8
630.00	4.110	4.0	0.3465	8
630.00	3.840	3.7	0.3465	6
632.03	4.080		0.3465	6
635.54	4.200		0.3465	6
638.94	4.320		0.3465	6
644.85	4.440		0.3465	6
651.75	4.560		0.3465	6
660.00	4.650		0.3465	6
660.00	4.030		0.3150	6
670.38	4.980		0.3150	6
685.74	4.920		0.3150	6
703.35	4.860		0.3150	6
726.00	4.800	4.8	0.3150	6
726.00	5.090	5.1	0.2835	6
731.25	5.040		0.2835	6
736.67	4.980		0.2835	6
748.84	4.860		0.2835	6
762.59	4.740		0.2835	6
778.86	4.620		0.2835	6
792.00	4.500		0.2835	6
792.00	4.830		0.2520	6
798.38	4.740		0.2520	6
806.47	4.620		0.2520	6
816.67	4.500		0.2520	6
827.64	4.380		0.2520	6
840.36	4.260		0.2520	6
858.00	4.130	4.1	0.2520	6
858.00	4.455	4.5	0.2205	6
866.44	4.320		0.2205	6
874.53	4.200		0.2205	6

Table 5.9: (continued)

Distance from Outlet (ft)	Calculated Depth (in)	Experimental Depth (in)	Discharge (cfs)	Diameter (in)
885.25	4.040		0.2205	6
900.00	3.840	4.0	0.2205	6
900.00	3.880	4.0	0.2205	5
909.33	4.000		0.2205	5
924.00	4.100		0.2205	5
924.00	4.495		0.1890	5
948.87	4.300		0.1890	5
980.49	4.100		0.1890	5
990.00	4.050	4.1	0.1890	5
990.00	4.370	4.4	0.1575	5
1001.03	4.200		0.1575	5
1015.70	4.000		0.1575	5
1031.65	3.800		0.1575	5
1050.56	3.600		0.1575	5
1056.00	3.550		0.1575	5
1056.00	3.890		0.1260	5
1066.00	3.700		0.1260	5
1077.35	3.500		0.1260	5
1090.00	3.300		0.1260	5
1100.00	3.150	3.2	0.1260	5
1100.00	3.260	3.5	0.1260	4
1110.00	3.360		0.1260	4
1122.00	3.440		0.0945	4
1122.00	3.860		0.0945	4
1130.76	3.760		0.0945	4
1142.45	3.600		0.0945	4
1162.77	3.360		0.0945	4
1188.00	3.120	3.1	0.0945	4
1188.00	3.470	3.5	0.0630	4
1200.00	3.200		0.0630	4
1210.00	2.960		0.0630	4
1222.31	2.720		0.0630	4
1238.00	2.480		0.0630	4
1254.00	2.280		0.0630	4
1254.00	2.680		0.0315	4
1266.00	2.360		0.0315	4
1278.91	2.040		0.0315	4
1292.89	1.720		0.0315	4
1320.00	1.400		0.0315	4

Table 5.10: Theoretical and Experimental Profile Data for the Condition:
$\Delta Q = 0.0525$ cfs $n = 0.011$ $S = 0.0025$

Distance from Outlet (ft)	Calculated Depth (in)	Experimental Depth (in)	Discharge (cfs)	Diameter (in)
0.00	5.270		1.0500	10
7.50	5.335		1.0500	10
18.80	5.430		1.0500	10
26.00	5.480		1.0500	10
30.20	5.500		1.0500	10
66.00	5.500		1.0500	10
66.00	5.880		0.9975	10
100.00	5.880		0.9975	10
132.00	5.880	6.0	0.9975	10
132.00	6.210	6.3	0.9450	10
150.00	6.075		0.9450	10
160.00	6.000		0.9450	10
180.00	5.940		0.9450	10
200.00	5.880		0.9450	10
200.00	6.320		0.8925	8
214.00	6.100	6.0	0.8925	8
230.00	5.950	6.0	0.8925	8
234.00	5.800		0.8925	8
246.00	5.920		0.8925	8
264.00	5.980		0.8925	8
264.00	6.390		0.8400	8
270.00	6.320		0.8400	8
298.00	6.120		0.8400	8
313.00	6.069		0.8400	8
330.00	5.990	6.0	0.8400	8
330.00	6.350	6.4	0.7875	8
334.00	6.290		0.7875	8
364.00	5.920		0.7875	8
379.00	5.780		0.7875	8
396.00	5.650		0.7875	8
396.00	5.950		0.7350	8
412.00	5.680		0.7350	8
432.00	5.400		0.7350	8
462.00	5.230		0.7350	8
462.00	5.590		0.6825	8
480.00	5.265		0.6825	8
500.00	5.080		0.6825	8
528.00	4.910	5.0	0.6825	8
528.00	5.290	5.3	0.6300	8
541.00	5.140		0.6300	8
560.00	4.945		0.6300	8
580.00	4.780		0.6300	8

Table 5.10: (continued)

Distance from Outlet (ft)	Calculated Depth (in)	Experimental Depth (in)	Discharge (cfs)	Diameter (in)
594.00	4.690		0.6300	8
594.00	5.150		0.5775	8
610.00	4.980		0.5775	8
634.00	4.820		0.5775	8
660.00	4.680		0.5775	8
660.00	5.230		0.5250	8
670.00	5.060		0.5250	8
690.00	4.865	5.0	0.5250	8
690.00	4.550	4.5	0.5250	6
694.00	4.780		0.5250	6
698.00	4.875		0.5250	6
710.00	5.020		0.5250	6
726.00	5.090	5.1	0.5250	6
726.00	5.490	5.5	0.4725	6
750.00	5.350		0.4725	6
772.00	5.290		0.4725	6
792.00	5.290		0.4725	6
792.00	5.685		0.4200	6
817.00	5.350		0.4200	6
840.00	5.250		0.4200	6
858.00	5.210		0.4200	6
858.00	5.575		0.3675	6
879.00	5.165		0.3675	6
882.00	5.135		0.3675	6
900.00	5.000		0.3675	6
924.00	4.920	5.0	0.3675	6
924.00	5.375	5.4	0.3150	6
950.00	5.000		0.3150	6
971.00	4.820		0.3150	6
990.00	4.750		0.3150	6
990.00	5.200		0.2625	6
1022.50	4.650		0.2625	6
1036.00	4.450		0.2625	6
1056.00	4.245		0.2625	6
1056.00	4.620		0.2100	6
1079.00	4.080		0.2100	6
1102.00	3.800		0.2100	6
1122.00	3.690	3.8	0.2100	6
1122.00	4.090	4.2	0.1575	6
1150.00	3.590		0.1575	6
1150.00	3.250		0.1575	5
1151.00	3.380		0.1575	5

Table 5.10: (continued)

Distance from Outlet (ft)	Calculated Depth (in)	Experimental Depth (in)	Discharge (cfs)	Diameter (in)
1155.00	3.540		0.1575	5
1162.00	3.690		0.1575	5
1170.00	3.750		0.1575	5
1188.00	3.800		0.1575	5
1188.00	4.150		0.1050	5
1210.00	3.610		0.1050	5
1232.00	3.400		0.1050	5
1254.00	3.250		0.1050	5
1254.00	3.610		0.0525	5
1280.00	2.835		0.0525	5
1300.00	2.500		0.0525	5
1320.00	2.100		0.0525	5

Table 5.11: Theoretical and Experimental Profile Data for the Condition:
▲Q = 0.0735 cfs n = 0.011 S = 0.0025

Distance from Outlet (ft)	Calculated Depth (in)	Experimental Depth (in)	Discharge (cfs)	Diameter (in)
0.00	5.770	5.8	1.4700	10
6.00	5.850		1.4700	10
16.00	5.940		1.4700	10
26.00	5.947		1.4700	10
44.00	6.035		1.4700	10
50.50	6.040	6.0	1.4700	10
66.00	6.040	6.0	1.4700	10
66.00	6.350	6.4	1.3965	10
100.00	6.400		1.3965	10
132.00	6.470		1.3965	10
132.00	6.800		1.3230	10
166.00	6.800		1.3230	10
198.00	7.165		1.3230	10
198.00	6.900		1.2495	10
218.00	6.790		1.2495	10
240.00	6.720		1.2495	10
264.00	6.730		1.2495	10
264.00	7.100		1.1760	10
287.00	6.650		1.1760	10
308.00	6.460		1.1760	10
330.00	6.350	6.4	1.1760	10
330.00	6.700	6.7	1.1025	10
360.00	6.140	6.1	1.1025	10
360.00	5.850	6.0	1.1025	8
365.00	6.180		1.1025	8
374.00	6.335		1.1025	8
384.00	6.400		1.1025	8
396.00	6.400		1.1025	8
396.00	6.700		1.0290	8
420.00	6.260		1.0290	8
440.00	6.090		1.0290	8
462.00	5.990	6.1	1.0290	8
462.00	6.400	6.3	0.9555	8
486.00	6.045		0.9555	8
508.00	5.870		0.9555	8
528.00	5.775		0.9555	8
528.00	6.230		0.8820	8
546.00	5.930		0.8820	8
570.00	5.725		0.8820	8
594.00	5.570		0.8820	8
594.00	6.045		0.8085	8
612.00	5.700		0.8085	8
636.00	5.500		0.8085	8
660.00	5.420		0.8085	8
660.00	5.900		0.7350	8

Table 5.11: (continued)

Distance from Outlet (ft)	Calculated Depth (in)	Experimental Depth (in)	Discharge (cfs)	Diameter (in)
682.00	5.600		0.7350	8
708.00	5.390		0.7350	8
726.00	5.315		0.7350	8
726.00	5.745		0.6615	8
743.00	5.350		0.6615	8
770.00	5.140		0.6615	8
792.00	5.065	5.1	0.6615	8
792.00	5.470	5.5	0.5880	8
820.00	5.050	5.1	0.5880	8
820.00	4.735	4.5	0.5880	6
822.00	4.950		0.5880	6
826.00	5.090		0.5880	6
836.00	5.200		0.5880	6
858.00	5.340		0.5880	6
858.00	5.820		0.5145	6
882.00	5.480		0.5145	6
902.00	5.320		0.5145	6
924.00	5.200	5.2	0.5145	6
924.00	5.620	5.6	0.4410	6
939.00	5.435		0.4410	6
964.00	5.200		0.4410	6
990.00	5.050		0.4410	6
990.00	5.445		0.3675	6
1008.00	5.100		0.3675	6
1032.00	4.900		0.3675	6
1056.00	4.815		0.3675	6
1056.00	5.280		0.2940	6
1073.00	5.000		0.2940	6
1096.00	4.750		0.2940	6
1122.00	4.600	4.6	0.2940	6
1122.00	4.970	5.0	0.2205	6
1130.00	4.745		0.2205	6
1145.00	4.400		0.2205	6
1170.00	4.090		0.2205	6
1188.00	3.920		0.2205	6
1188.00	4.350		0.1470	6
1211.00	3.770		0.1470	6
1234.00	3.500		0.1470	6
1254.00	3.310		0.1470	6
1254.00	3.800		0.0735	6
1276.00	3.200		0.0735	6
1298.00	2.645		0.0735	6
1320.00	2.245		0.0735	6

Table 5.12: Theoretical and Experimental Profile Data for the Condition:
ΔQ = 0.1050 cfs n= 0.011 S = 0.0025

Distance from Outlet (ft)	Calculated Depth (in)	Experimental Depth (in)	Discharge (cfs)	Diameter (in)
0.00	6.420		2.1000	10
6.00	6.530		2.1000	10
10.00	6.580		2.1000	10
18.00	6.610		2.1000	10
28.00	6.060		2.1000	10
40.00	6.700		2.1000	10
66.00	6.740	6.5	2.1000	10
66.00	7.110	7.2	1.9950	10
100.00	7.145		1.9950	10
132.00	7.170		1.9950	10
132.00	7.500		1.8900	10
166.00	7.500		1.8900	10
198.00	7.500		1.8900	10
198.00	7.750		1.7850	10
220.00	7.380		1.7850	10
240.00	7.170		1.7850	10
250.00	7.090		1.7850	10
264.00	6.990	7.0	1.7850	10
264.00	7.470	7.5	1.6800	10
285.00	7.070		1.6800	10
306.00	6.800		1.6800	10
315.00	6.740		1.6800	10
330.00	6.640		1.6800	10
330.00	7.150		1.5750	10
352.00	6.700		1.5750	10
370.00	6.490		1.5750	10
375.00	6.420		1.5750	10
385.00	6.350		1.5750	10
396.00	6.290	6.3	1.5750	10
396.00	6.830	7.0	1.4700	10
422.00	6.400		1.4700	10
436.00	6.255		1.4700	10
447.00	6.150		1.4700	10
462.00	6.080		1.4700	10
462.00	6.690		1.3650	10
464.80	6.500		1.3650	10
468.00	6.370		1.3650	10
490.00	6.060	6.0	1.3650	10
490.00	5.720	5.5	1.3650	8
493.80	5.900		1.3650	8
498.00	5.950		1.3650	8
512.00	6.080		1.3650	8
528.00	6.130		1.3650	8
528.00	6.550		1.2600	8
560.00	6.550		1.2600	8

Table 5.12: (continued)

Distance from Outlet (ft)	Calculated Depth (in)	Experimental Depth (in)	Discharge (cfs)	Diameter (in)
594.00	6.700		1.2600	8
594.00	7.050		1.1550	8
610.00	6.720		1.1550	8
640.00	6.390		1.1550	8
660.00	6.200	6.0	1.1550	8
660.00	6.675	6.8	1.0500	8
684.00	6.250		1.0500	8
710.00	5.970		1.0500	8
726.00	5.860		1.0500	8
726.00	6.350		0.9450	8
748.00	6.000		0.9450	8
776.00	5.700		0.9450	8
792.00	5.600		0.9450	8
792.00	6.150		0.8400	8
815.00	5.820		0.8400	8
838.00	5.600		0.8400	8
858.00	5.500	5.5	0.8400	8
858.00	6.110	6.1	0.7350	8
890.00	5.660		0.7350	8
903.00	5.500		0.7350	8
924.00	5.300		0.7350	8
924.00	5.800		0.6300	8
940.00	5.545		0.6300	8
964.00	5.200		0.6300	8
990.00	5.000		0.6300	8
990.00	5.600		0.5250	8
1005.00	5.400		0.5250	8
1020.00	5.210	5.5	0.5250	8
1020.00	4.875	5.0	0.5250	6
1023.00	5.150		0.5250	6
1030.00	5.300		0.5250	6
1056.00	5.500		0.5250	6
1056.00	5.810		0.4200	6
1098.00	5.220		0.4200	6
1122.00	4.960		0.4200	6
1122.00	5.500		0.3150	6
1170.00	4.590		0.3150	6
1188.00	4.380	4.4	0.3150	6
1188.00	4.810	5.0	0.2100	6
1232.00	3.990		0.2100	6
1254.00	3.700		0.2100	6
1254.00	4.260		0.1050	6
1302.00	3.000		0.1050	6
1320.00	2.730		0.1050	6

Table 5.13: Theoretical and Experimental Profile Data for the Condition:
ΔQ = 0.0315 cfs n = 0.011 S = 0.005

Distance from Outlet (ft)	Calculated Depth (in)	Experimental Depth (in)	Discharge (cfs)	Diameter (in)
0.00	2.140	2.0	0.6300	8
6.00	2.240		0.6300	8
18.50	2.320		0.6300	8
38.25	2.400		0.6300	8
66.00	2.470	2.5	0.6300	8
66.00	2.750	3.0	0.5985	8
72.00	2.800		0.5985	8
84.00	2.880		0.5985	8
108.25	2.960		0.5985	8
132.00	3.010		0.5985	8
132.00	3.340		0.5670	8
153.95	3.420		0.5670	8
180.50	3.500		0.5670	8
198.00	3.530	3.5	0.5670	8
198.00	3.910	4.0	0.5335	8
228.45	3.880		0.5335	8
265.00	3.850		0.5335	8
265.00	4.090		0.5040	8
282.75	4.100		0.5040	8
330.00	4.120		0.5040	8
330.00	4.420		0.4725	8
336.34	4.320		0.4725	8
348.00	4.240		0.4725	8
359.15	4.160		0.4725	8
378.72	4.080		0.4725	8
396.00	4.010	4.0	0.4725	8
396.00	4.340	4.5	0.4410	8
408.86	4.120		0.4410	8
420.00	4.040	4.0	0.4410	8
420.00	3.170	3.5	0.4410	6
422.00	3.760		0.4410	6
424.30	3.840		0.4410	6
428.00	3.920		0.4410	6
436.00	4.080		0.4410	6
446.14	4.240		0.4410	6
462.00	4.360	4.4	0.4410	6
462.00	4.730	4.7	0.4095	6
472.00	4.640		0.4095	6
486.00	4.560		0.4095	6
506.85	4.480		0.4095	6
528.00	4.390		0.4095	6
528.00	4.880		0.3780	6
538.00	4.720		0.3780	6
546.00	4.640		0.3780	6

Table 5.13: (continued)

Distance from Outlet (ft)	Calculated Depth (in)	Experimental Depth (in)	Discharge (cfs)	Diameter (in)
554.00	4.560		0.3780	6
562.50	4.480		0.3780	6
575.55	4.320		0.3780	6
594.00	4.180	4.2	0.3780	6
594.00	4.530	4.6	0.3465	6
600.00	4.480		0.3465	6
606.45	4.320		0.3465	6
624.40	4.160		0.3465	6
640.82	4.000		0.3465	6
660.00	3.900		0.3465	6
660.00	4.340		0.3150	6
664.75	4.240		0.3150	6
678.00	4.080		0.3150	6
696.00	3.920		0.3150	6
718.00	3.760		0.3150	6
726.00	3.710		0.3150	6
726.00	4.080		0.2835	6
732.45	3.920		0.2835	6
742.52	3.780		0.2835	6
760.00	3.560	3.6	0.2835	6
760.00	3.360	3.4	0.2835	5
774.00	3.540		0.2835	5
792.00	3.630		0.2835	5
792.00	4.110		0.2520	5
804.90	4.000		0.2520	5
828.00	3.840		0.2520	5
858.00	3.790		0.2520	5
858.00	4.210		0.2205	5
868.00	4.080		0.2205	5
884.00	3.900		0.2205	5
900.75	3.780		0.2205	5
924.00	3.680	3.7	0.2205	5
924.00	4.020	4.0	0.1890	5
930.15	3.900		0.1890	5
944.00	3.720		0.1890	5
958.80	3.540		0.1890	5
976.25	3.360		0.1890	5
990.00	3.270		0.1890	5
990.00	3.680		0.1575	5
1004.00	3.410		0.1575	5
1120.00	3.190	3.0	0.1575	5
1120.00	3.250	3.2	0.1575	4
1034.00	3.360		0.1575	4

Table 5.13: (continued)

Distance from Outlet (ft)	Calculated Depth (in)	Experimental Depth (in)	Discharge (cfs)	Diameter (in)
1056.00	3.370		0.1575	4
1056.00	3.790		0.1260	4
1072.62	3.580		0.1260	4
1098.00	3.300		0.1260	4
1122.00	3.020	3.0	0.1260	4
1122.00	3.460	3.5	0.0945	4
1136.00	3.240		0.0945	4
1154.10	2.960		0.0945	4
1170.15	2.780		0.0945	4
1188.00	2.620	2.6	0.0945	4
1188.00	3.140	3.3	0.0630	4
1204.00	2.800		0.0630	4
1223.40	2.480		0.0630	4
1254.00	2.080		0.0630	4
1254.00	2.520		0.0315	4
1264.95	2.320		0.0315	4
1282.38	1.880		0.0315	4
1300.58	1.480		0.0315	4
1320.00	1.200		0.0315	4

Table 5.14: Theoretical and Experimental Profile Data for the Condition: ΔQ = 0.0525 cfs n = 0.011 S = 0.005

Distance from Outlet (ft)	Calculated Depth (in)	Experimental Depth (in)	Discharge (cfs)	Diameter (in)
0.00	2.800		1.0500	8
4.15	2.870		1.0500	8
14.00	2.990		1.0500	8
44.20	3.140		1.0500	8
66.00	3.200	3.2	1.0500	8
66.00	3.580	3.6	0.9975	8
88.00	3.640		0.9975	8
112.70	3.710		0.9975	8
132.00	3.740		0.9975	8
132.00	4.130		0.9450	8
164.00	4.130		0.9450	8
198.00	4.130		0.9450	8
198.00	4.430		0.8925	8
220.00	4.410		0.8925	8
240.00	4.400		0.8925	8
264.00	4.390	4.5	0.8925	8
264.00	4.680	4.8	0.8400	8
296.05	4.640		0.8400	8
330.00	4.600		0.8400	8
330.00	4.680		0.7875	8
359.80	4.840		0.7875	8
396.00	4.800		0.7875	8
396.00	5.120		0.7350	8
409.80	5.000		0.7350	8
436.00	4.840		0.7350	8
462.00	4.710		0.7350	8
462.00	5.070		0.6825	8
475.90	4.860		0.6825	8
493.90	4.670		0.6825	8
514.00	4.510		0.6825	8
528.00	4.460	4.5	0.6825	8
528.00	4.850	4.8	0.6300	8
534.30	4.660		0.6300	8
547.00	4.500		0.6300	8
560.00	4.380		0.6300	8
560.00	4.050		0.6300	6
563.10	4.090		0.6300	6
571.55	4.200		0.6300	6
583.25	4.290		0.6300	6
594.00	4.340		0.6300	6
594.00	4.650		0.5775	6
601.00	4.500		0.5775	6
640.00	4.080		0.5775	6

Table 5.14: (continued)

Distance from Outlet (ft)	Calculated Depth (in)	Experimental Depth (in)	Discharge (cfs)	Diameter (in)
660.00	3.970	4.0	0.5775	6
660.00	4.450	4.5	0.5250	6
668.00	4.350		0.5250	6
680.00	4.240		0.5250	6
706.00	3.990		0.5250	6
726.00	3.830		0.5250	6
726.00	4.290		0.4725	6
750.00	4.050		0.4725	6
770.00	3.860		0.4725	6
792.00	3.730	4.0	0.4725	6
792.00	4.060	4.5	0.4200	6
815.85	3.820		0.4200	6
840.00	3.630		0.4200	6
858.00	3.500		0.4200	6
858.00	3.760		0.3675	6
867.90	3.580		0.3675	6
878.00	3.460		0.3675	6
890.00	3.360	3.4	0.3675	6
890.00	3.110	3.1	0.3675	5
900.00	3.260		0.3675	5
912.60	3.400		0.3675	5
924.00	3.470		0.3675	5
924.00	3.800		0.3150	5
946.40	3.550		0.3150	5
970.00	3.370		0.3150	5
990.00	3.260	3.3	0.3150	5
990.00	3.730	3.7	0.2650	5
1016.00	3.400		0.2650	5
1039.00	3.190		0.2650	5
1056.00	3.110		0.2650	5
1056.00	3.570		0.2100	5
1088.00	3.230		0.2100	5
1122.00	2.860		0.2100	5
1122.00	3.360		0.1575	5
1155.00	2.890		0.1575	5
1188.00	2.560	2.6	0.1575	5
1188.00	3.240	3.2	0.1050	5
1219.85	2.770		0.1050	5
1254.00	2.280		0.1050	5
1254.00	2.940		0.0525	5
1280.00	2.260		0.0525	5
1302.00	1.740		0.0525	5
1320.00	1.440		0.0525	5

Table 5.15: Theoretical and Experimental Profile Data for the Condition:
ΔQ = 0.0735 cfs n = 0.011 S = 0.005

Distance from Outlet (ft)	Calculated Depth (in)	Experimental Depth (in)	Discharge (cfs)	Diameter (in)
0.00	3.290		1.4700	8
4.45	3.380		1.4700	8
18.20	3.550		1.4700	8
22.60	3.740		1.4700	8
66.00	3.810	4.0	1.4700	8
66.00	4.180	4.5	1.3965	8
100.00	4.190		1.3965	8
132.00	4.200		1.3965	8
132.00	4.460		1.3230	8
168.20	4.480		1.3230	8
198.00	4.500		1.3230	8
198.00	4.700		1.2495	8
230.00	4.750		1.2495	8
264.00	4.740	4.7	1.2495	8
264.00	5.030	5.0	1.1760	8
294.00	5.000		1.1760	8
330.00	4.970		1.1760	8
330.00	5.310		1.1025	8
360.00	5.280		1.1025	8
396.00	5.260		1.1025	8
396.00	5.580		1.0290	8
430.00	5.430		1.0290	8
462.00	5.300	5.3	1.0290	8
462.00	5.650	5.7	0.9555	8
473.10	5.500		0.9555	8
500.00	5.230		0.9555	8
528.00	4.990		0.9555	8
528.00	5.300		0.8820	8
542.80	5.000		0.8820	8
571.35	4.620		0.8820	8
594.00	4.420		0.8820	8
594.00	4.970		0.8085	8
608.40	4.670		0.8085	8
628.00	4.390		0.8085	8
640.00	4.270		0.8085	8
660.00	4.050	4.0	0.8085	8
660.00	4.570	4.7	0.7350	8
666.60	4.350		0.7350	8
676.00	4.170		0.7350	8
690.00	4.030		0.7350	8
690.00	3.640		0.7350	6
694.10	3.800		0.7350	6
700.00	3.930		0.7350	6

Table 5.15: (continued)

Distance from Outlet (ft)	Calculated Depth (in)	Experimental Depth (in)	Discharge (cfs)	Diameter (in)
715.55	4.110		0.7350	6
726.00	4.170	4.2	0.7350	6
726.00	4.600	4.7	0.6615	6
760.00	4.210		0.6615	6
792.00	3.860		0.6615	6
792.00	4.400		0.5880	6
816.25	3.900		0.5880	6
838.00	3.570		0.5880	6
858.00	3.420		0.5880	6
858.00	4.040		0.5145	6
876.00	3.710		0.5145	6
898.30	3.410		0.5145	6
924.00	3.170		0.5145	6
924.00	3.680		0.4410	6
931.90	3.380		0.4410	6
944.00	3.190		0.4410	6
960.00	3.060	3.0	0.4410	6
960.00	2.750	2.8	0.4410	5
968.30	2.950		0.4410	5
978.75	3.040		0.4410	5
990.00	3.120		0.4410	5
990.00	3.600		0.3675	5
1020.00	3.450		0.3675	5
1056.00	3.280		0.3675	5
1056.00	3.720		0.2940	5
1088.00	3.330		0.2940	5
1122.00	3.110		0.2940	5
1122.00	3.670		0.2205	5
1156.14	3.300		0.2205	5
1188.00	2.960	3.0	0.2205	5
1188.00	3.530	3.7	0.1470	5
1220.00	2.920		0.1470	5
1254.00	2.370		0.1470	5
1254.00	3.140		0.0735	5
1280.00	2.530		0.0735	5
1302.85	1.980		0.0735	5
1320.00	1.660		0.0735	5

Table 5.16: Theoretical and Experimental Profile Data for the Condition:
ΔQ = 0.1050 cfs n = 0.011 S = 0.005

Distance from Outlet (ft)	Calculated Depth (in)	Experimental Depth (in)	Discharge (cfs)	Diameter (in)
0.00	3.630		2.1000	8
7.00	3.800		2.1000	8
20.00	3.960		2.1000	8
40.15	4.120		2.1000	8
66.00	4.220	4.0	2.1000	8
66.00	4.430	4.5	1.9950	8
100.00	4.500		1.9950	8
132.00	4.550		1.9950	8
132.00	4.720		1.8900	8
166.50	4.780		1.8900	8
198.00	4.820		1.8900	8
198.00	5.010		1.7850	8
230.00	5.060		1.7850	8
264.00	5.100	5.0	1.7850	8
264.00	5.360	5.5	1.6800	8
300.00	5.430		1.6800	8
330.00	5.380		1.6800	8
330.00	5.690		1.5750	8
368.00	5.740		1.5750	8
396.00	5.700		1.5750	8
396.00	6.010		1.4700	8
430.00	5.970		1.4700	8
462.00	5.780		1.4700	8
462.00	6.150		1.3650	8
490.00	6.000		1.3650	8
528.00	5.600	5.6	1.3650	8
528.00	6.010	6.0	1.2600	8
548.20	5.920		1.2600	8
571.50	5.740		1.2600	8
594.00	5.470		1.2600	8
594.00	6.000		1.1550	8
611.85	5.540		1.1550	8
637.90	5.140		1.1550	8
660.00	4.880	5.0	1.1550	8
660.00	5.450	5.5	1.0500	8
711.35	4.840		1.0500	8
726.00	4.780		1.0500	8
726.00	5.180		0.9450	8
755.00	4.800		0.9450	8
776.00	4.580		0.9450	8
792.00	4.450	4.5	0.9450	8
792.00	4.840	5.0	0.8400	8

Table 5.16: (continued)

Distance from Outlet (ft)	Calculated Depth (in)	Experimental Depth (in)	Discharge (cfs)	Diameter (in)
820.00	4.920	5.0	0.8400	8
820.00	4.530	4.5	0.8400	6
824.45	4.680		0.8400	6
830.35	4.780		0.8400	6
846.00	4.910		0.8400	6
858.00	4.940		0.8400	6
858.00	5.270		0.7350	6
885.80	5.080		0.7350	6
911.00	4.840		0.7350	6
924.00	4.680	4.7	0.7350	6
924.00	5.150	5.2	0.6300	6
947.20	4.710		0.6300	6
972.00	4.460		0.6300	6
990.00	4.340		0.6300	6
990.00	4.780		0.5250	6
1016.60	4.470		0.5250	6
1040.00	4.240		0.5250	6
1056.00	4.180		0.5250	6
1056.00	4.560		0.4200	6
1090.00	4.180		0.4200	6
1122.00	3.840	4.0	0.4200	6
1122.00	4.480	4.5	0.3150	6
1156.00	3.940		0.3150	6
1188.00	3.580		0.3150	6
1188.00	4.040		0.2100	6
1220.00	3.480		0.2100	6
1254.00	2.860		0.2100	6
1254.00	3.480		0.1050	6
1280.00	2.760		0.1050	6
1303.45	2.120		0.1050	6
1320.00	1.780		0.1050	6

Table 5.17: Theoretical and Experimental Profile Data for the Condition:
ΔQ = 0.0315 cfs n = 0.011 S = 0.010

Distance from Outlet (ft)	Calculated Depth (in)	Experimental Depth (in)	Discharge (cfs)	Diameter (in)
0.00	2.230		0.6300	8
22.00	2.420		0.6300	8
46.25	2.530		0.6300	8
66.00	2.610	3.0	0.6300	8
66.00	2.940	3.5	0.5985	8
90.24	3.060		0.5985	8
132.00	3.110		0.5985	8
132.00	3.500		0.5670	8
136.82	3.390		0.5670	8
150.00	3.230	3.3	0.5670	6
150.00	2.880	2.9	0.5670	6
178.80	3.070		0.5670	6
200.00	3.130		0.5670	6
200.00	3.410		0.5355	6
230.00	3.410		0.5355	6
264.00	3.420	3.5	0.5355	6
264.00	3.720	3.7	0.5040	6
330.00	3.640		0.5040	6
330.00	3.820		0.4725	6
370.00	3.860		0.4725	6
396.00	3.910		0.4725	6
396.00	4.180		0.4410	6
405.00	4.050		0.4410	6
421.73	3.930		0.4410	6
462.00	3.670	3.7	0.4410	6
462.00	4.020	4.0	0.4095	6
472.20	3.900		0.4095	6
510.00	3.660		0.4095	6
528.00	3.560		0.4095	6
528.00	4.080		0.3780	6
536.74	3.960		0.3780	6
550.70	3.780		0.3780	6
570.00	3.540		0.3780	6
594.00	3.340		0.3780	6
594.00	3.820		0.3465	6
604.34	3.600		0.3465	6
620.00	3.430	3.4	0.3465	6
620.00	3.090	3.1	0.3465	5
628.65	3.390		0.3465	5
640.30	3.480		0.3465	5
660.00	3.570		0.3465	5
660.00	4.030		0.3150	5
668.10	3.900		0.3150	5
685.00	3.750		0.3150	5

Table 5.17: (continued)

Distance from Outlet (ft)	Calculated Depth (in)	Experimental Depth (in)	Discharge (cfs)	Diameter (in)
726.00	3.500		0.3150	5
726.00	4.080		0.2835	5
736.00	3.800		0.2835	5
760.00	3.550		0.2835	5
792.00	3.210	3.2	0.2835	5
792.00	3.700	3.7	0.2520	5
800.00	3.600		0.2520	5
836.00	3.200		0.2520	5
858.00	2.960		0.2520	5
858.00	3.520		0.2205	5
866.00	3.400		0.2205	5
904.00	3.050		0.2205	5
924.00	2.830		0.2205	5
924.00	3.340		0.1890	5
932.00	3.180		0.1890	5
950.00	2.890	3.0	0.1890	5
950.00	3.080	3.2	0.1890	4
965.00	3.180		0.1890	4
976.50	3.240		0.1890	4
990.00	3.290		0.1890	4
990.00	3.720		0.1575	4
1000.00	3.560		0.1575	4
1016.00	3.400		0.1575	4
1038.00	3.200		0.1575	4
1056.00	3.020	3.0	0.1575	4
1056.00	3.500	3.5	0.1260	4
1066.00	3.300		0.1260	4
1084.00	3.080		0.1260	4
1100.00	2.880		0.1260	4
1122.00	2.540		0.1260	4
1122.00	3.030		0.0945	4
1130.24	2.880		0.0945	4
1160.45	2.400		0.0945	4
1188.00	2.120	2.1	0.0945	4
1188.00	2.630	2.6	0.0630	4
1212.20	2.220		0.0630	4
1236.30	1.960		0.0630	4
1254.00	1.810		0.0630	4
1254.00	2.370		0.0315	4
1284.30	2.720		0.0315	4
1304.00	1.400		0.0315	4
1320.00	1.040		0.0315	4

Table 5.18: Theoretical and Experimental Profile Data for the Condition: Q = 0.0525 cfs n = 0.011 S = 0.010

Distance from Outlet (ft)	Calculated Depth (in)	Experimental Depth (in)	Discharge (cfs)	Diameter (in)
0.00	2.500		1.0500	8
10.80	2.760		1.0500	8
21.85	2.940		1.0500	8
66.00	3.060	3.0	1.0500	8
66.00	3.350	3.5	0.9975	8
81.45	3.470		0.9975	8
99.55	3.540		0.9975	8
110.80	3.590		0.9975	8
132.00	3.610		0.9450	8
132.00	3.900		0.9450	8
141.15	3.850		0.9450	8
170.00	3.850		0.9450	8
198.00	3.820		0.9450	8
198.00	4.170		0.8925	8
230.00	4.140		0.8925	8
264.00	4.100		0.8925	8
264.00	4.400		0.8400	8
300.00	4.250	4.2	0.8400	8
300.00	3.950	4.0	0.8400	6
316.00	4.040		0.8400	6
330.00	4.040		0.8400	6
330.00	4.430		0.7875	6
362.00	4.470		0.7875	6
396.00	4.300		0.7875	6
396.00	4.750		0.7350	6
417.10	4.490		0.7350	6
440.00	4.270		0.7350	6
462.00	4.140	4.2	0.7350	6
462.00	4.560	4.6	0.6825	6
468.70	4.480		0.6825	6
488.00	4.180		0.6825	6
511.20	4.020		0.6825	6
528.00	3.920	4.0	0.6825	6
528.00	4.430	4.5	0.6300	6
560.00	4.000		0.6300	6
594.00	3.740		0.6300	6
594.00	4.190		0.5775	6
621.25	3.890		0.5775	6
640.00	3.510		0.5775	6
660.00	3.310	2.9	0.5775	6
660.00	3.810	3.8	0.5250	6
683.85	3.500		0.5250	6
708.75	3.180		0.5250	6

Table 5.18: (continued)

Distance from Outlet (ft)	Calculated Depth (in)	Experimental Depth (in)	Discharge (cfs)	Diameter (in)
726.00	3.050		0.5250	6
726.00	3.520		0.4725	6
750.00	3.450	3.5	0.4725	6
750.00	2.890	3.0	0.4725	5
754.15	2.900		0.4725	5
763.00	3.150		0.4725	5
775.00	3.260		0.4725	5
792.00	3.320		0.4725	5
792.00	3.870		0.4200	5
824.00	3.630		0.4200	5
858.00	3.380		0.4200	5
858.00	3.770		0.3675	5
886.00	3.500		0.3675	5
924.00	3.140	3.2	0.3675	5
924.00	3.580	3.6	0.3150	5
956.00	3.350		0.3150	5
990.00	3.100		0.3150	5
990.00	3.620		0.2625	5
1014.00	3.100		0.2625	5
1038.00	2.750		0.2625	5
1056.00	2.640		0.2625	5
1056.00	3.190		0.2100	5
1070.00	2.910		0.2100	5
1090.00	2.550	2.6	0.2100	5
1090.00	2.700	2.7	0.2100	4
1102.00	2.840		0.2100	4
1122.00	2.960		0.2100	4
1122.00	3.400		0.1575	4
1144.70	2.910		0.1575	4
1166.00	2.600		0.1575	4
1188.00	2.380	2.4	0.1575	4
1188.00	3.080	3.2	0.1050	4
1212.00	2.640		0.1050	4
1238.00	2.250		0.1050	4
1254.00	2.090		0.1050	4
1254.00	3.100		0.0525	4
1278.00	2.240		0.0525	4
1299.00	1.800		0.0525	4
1320.00	1.400		0.0525	4

Table 5.19: Theoretical and Experimental Profile Data for the Condition: ΔQ = 0.0735 cfs n = 0.011 S = 0.010

Distance from Outlet (ft)	Calculated Depth (in)	Experimental Depth (in)	Discharge (cfs)	Diameter (in)
0.00	2.720	3.0	1.4700	8
12.90	2.900		1.4700	8
18.85	2.970		1.4700	8
30.00	3.100		1.4700	8
39.35	3.190		1.4700	8
66.00	3.420	3.5	1.4700	8
66.00	3.460	3.7	1.3965	8
99.45	3.880		1.3965	8
117.35	3.980		1.3965	8
132.00	4.000		1.3965	8
132.00	4.210		1.3230	8
160.00	4.210		1.3230	8
198.00	4.220	4.0	1.3230	8
198.00	4.580	4.6	1.2495	8
230.00	4.550		1.2495	8
264.00	4.520		1.2495	8
264.00	4.900		1.1760	8
297.00	4.840		1.1760	8
330.00	4.650		1.1760	8
330.00	4.980		1.1025	8
364.00	4.870		1.1025	8
396.00	4.690		1.1025	8
396.00	5.080		1.0290	8
427.00	4.800		1.0290	8
462.00	4.490	4.5	1.0290	8
462.00	4.920	5.0	0.9555	8
494.55	4.600		0.9555	8
528.00	4.280		0.9555	8
528.00	4.700		0.8820	8
536.45	4.660		0.8820	8
548.20	4.500		0.8820	8
560.00	4.500	4.5	0.8820	8
560.00	4.080	4.0	0.8820	6
564.00	4.230		0.8820	6
568.50	4.320		0.8820	6
580.50	4.400		0.8820	6
594.00	4.430		0.8820	6
594.00	4.700		0.8085	6
620.45	4.600		0.8085	6
660.00	4.470	4.5	0.8085	6
660.00	4.810	5.0	0.7350	6
677.45	4.500		0.7350	6

Table 5.19: (continued)

Distance from Outlet (ft)	Calculated Depth (in)	Experimental Depth (in)	Discharge (cfs)	Diameter (in)
702.00	4.090		0.7350	6
726.00	3.820	4.0	0.7350	6
726.00	4.230	4.3	0.6615	6
741.15	4.090		0.6615	6
768.35	3.840		0.6615	6
792.00	3.660		0.6615	6
792.00	4.140		0.5880	6
824.00	3.860		0.5880	6
858.00	3.580		0.5880	6
858.00	4.120		0.5145	6
893.95	3.600		0.5145	6
924.00	3.200	3.2	0.5145	6
924.00	3.680	3.7	0.4410	6
950.00	3.340	3.3	0.4410	6
950.00	3.600	3.8	0.4410	5
958.00	3.640		0.4410	5
990.00	3.750		0.4410	5
990.00	4.120		0.3675	5
1023.00	3.800		0.3675	5
1056.00	3.480		0.3675	5
1056.00	3.950	4.0	0.2940	5
1078.00	3.660		0.2940	5
1095.15	3.450		0.2940	5
1122.00	3.290		0.2940	5
1122.00	3.780		0.2205	5
1140.00	3.390		0.2205	5
1168.00	2.910		0.2205	5
1188.00	2.690		0.2205	5
1188.00	3.220		0.1470	5
1220.00	2.800		0.1470	5
1254.00	2.370		0.1470	5
1254.00	3.100		0.0735	5
1273.00	2.650		0.0735	5
1297.10	2.100		0.0735	5
1320.00	1.650		0.0735	5

Table 5.20: Theoretical and Experimental Profile Data for the Condition:
ΔQ = 0.0315 cfs n = 0.011 S = 0.025

Distance from Outlet (ft)	Calculated Depth (in)	Experimental Depth (in)	Discharge (cfs)	Diameter (in)
0.00	0.530		0.6300	6
18.20	0.720		0.6300	6
38.20	0.840		0.6300	6
52.00	0.960		0.6300	6
66.00	1.000	1.0	0.6300	6
66.00	1.250	1.4	0.5985	6
132.00	1.280		0.5985	6
132.00	1.560		0.5670	6
164.45	1.500		0.5670	6
198.00	1.470		0.5670	6
198.00	1.720		0.5355	6
215.55	1.600		0.5355	6
245.75	1.520		0.5355	6
264.00	1.460	1.5	0.5355	6
264.00	1.730	1.7	0.5040	6
276.80	1.520		0.5040	6
300.00	1.270		0.5040	6
300.00	1.020		0.5040	5
308.35	1.130		0.5040	5
318.90	1.220		0.5040	5
330.00	1.300		0.5040	5
330.00	1.530		0.4725	5
340.00	1.580		0.4725	5
367.74	1.630		0.4725	5
396.00	1.590		0.4725	5
396.00	1.970		0.4410	5
462.00	1.990	2.0	0.4410	5
462.00	2.250	2.3	0.4095	5
490.48	2.300		0.4095	5
528.00	2.430		0.4095	5
528.00	2.610		0.3780	5
558.00	2.840		0.3780	5
594.00	3.120		0.3780	5
594.00	3.440		0.3465	5
610.60	3.300		0.3465	5
645.15	3.040		0.3465	5
660.00	2.970	3.0	0.3465	5
660.00	3.390	3.4	0.3150	5
686.05	2.980		0.3150	5
700.00	2.820		0.3150	5
726.00	2.870	3.0	0.3150	4
726.00	3.320	3.5	0.2835	4

Table 5.20: (continued)

Distance from Outlet (ft)	Calculated Depth (in)	Experimental Depth (in)	Discharge (cfs)	Diameter (in)
740.00	3.140		0.2835	4
757.75	2.980		0.2835	4
774.72	2.880		0.2835	4
792.00	2.730		0.2835	4
792.00	3.290		0.2520	4
804.00	3.120		0.2520	4
823.40	2.880		0.2520	4
840.58	2.720		0.2520	4
858.00	2.570	2.6	0.2520	4
858.00	3.150	3.2	0.2205	4
865.94	3.040		0.2205	4
878.00	2.880		0.2205	4
892.00	2.760		0.2205	4
908.24	2.600		0.2205	4
924.00	2.420		0.2205	4
924.00	3.020		0.1890	4
934.92	2.880		0.1890	4
942.74	2.720		0.1890	4
970.00	2.500		0.1890	4
990.00	2.120	2.1	0.1890	4
990.00	2.690	2.7	0.1575	4
1097.50	2.600		0.1575	4
1012.20	2.400		0.1575	4
1030.68	2.200		0.1575	4
1056.00	1.990		0.1575	4
1056.00	2.670		0.1260	4
1070.00	2.400		0.1260	4
1097.00	2.000		0.1260	4
1122.00	1.660	1.7	0.1260	4
1122.00	2.340	2.5	0.0935	4
1135.32	2.120		0.0935	4
1158.00	1.800		0.0935	4
1188.00	1.430		0.0935	4
1188.00	2.280		0.0630	4
1198.55	1.920		0.0630	4
1210.00	1.800		0.0630	4
1234.00	1.380		0.0630	4
1254.00	1.190		0.0630	4
1254.00	2.190		0.0315	4
1262.80	1.820		0.0315	4
1276.52	1.600		0.0315	4
1284.00	1.320		0.0315	4
1320.00	0.850		0.0315	4

Table 5.21: Theoretical and Experimental Profile Data for the Condition:
ΔQ = 0.0525 cfs n = 0.011 S = 0.025

Distance from Outlet (ft)	Calculated Depth (in)	Experimental Depth (in)	Discharge (cfs)	Diameter (in)
0.00	0.800		1.0500	6
18.00	1.090		1.0500	6
34.00	1.250		1.0500	6
52.00	1.400		1.0500	6
66.00	1.470	1.5	1.0500	6
66.00	1.650	1.7	0.9975	6
100.00	1.680		0.9975	6
132.00	1.710		0.9975	6
132.00	1.900		0.9450	6
162.00	1.870		0.9450	6
198.00	1.830		0.9450	6
198.00	2.040		0.8925	6
222.00	2.000		0.8925	6
246.00	1.950		0.8925	6
264.00	1.800		0.8925	6
264.00	2.260		0.8400	6
280.00	2.130		0.8400	6
299.10	2.040		0.8400	6
320.00	2.000		0.8400	6
330.00	2.000	2.0	0.8400	6
330.00	2.470	2.5	0.7875	6
360.00	2.270		0.7875	6
373.85	2.120		0.7875	6
396.00	2.040		0.7875	6
396.00	2.580		0.7350	6
410.00	2.430		0.7350	6
420.00	2.340		0.7350	6
430.00	2.300	2.3	0.7350	6
430.00	1.940	2.0	0.7350	5
436.00	2.040		0.7350	5
450.00	2.180		0.7350	5
462.00	2.210		0.7350	5
462.00	2.460		0.6825	5
469.25	2.530		0.6825	5
483.80	2.600		0.6825	5
506.15	2.660		0.6825	5
528.00	2.690	2.7	0.6825	5
528.00	3.070	3.1	0.6300	5
549.90	3.180		0.6300	5
572.00	3.260		0.6300	5
594.00	3.300	3.5	0.6300	5
594.00	3.650	3.7	0.5775	5

Table 5.21: (continued)

Distance from Outlet (ft)	Calculated Depth (in)	Experimental Depth (in)	Discharge (cfs)	Diameter (in)
624.00	3.230		0.5775	5
660.00	3.810	3.8	0.5775	5
660.00	4.100	4.1	0.5250	5
682.41	3.900		0.5250	5
726.00	3.740		0.5250	5
726.00	3.660		0.4725	5
747.50	4.010		0.4725	5
770.00	3.600		0.4725	5
792.00	3.520		0.4725	5
792.00	3.850		0.4200	5
801.50	3.670		0.4200	5
814.00	3.500		0.4200	5
830.00	3.410	3.5	0.4200	5
830.00	3.150	3.2	0.4200	4
836.35	3.280		0.4200	4
858.00	3.370		0.4200	4
858.00	3.780		0.3675	4
880.00	3.520		0.3675	4
904.00	3.350		0.3675	4
924.00	3.240		0.3675	4
924.00	3.550		0.3150	4
956.00	3.100		0.3150	4
975.00	2.830		0.3150	4
990.00	2.620	2.6	0.3150	4
990.00	3.100	3.5	0.2625	4
1018.00	2.780		0.2625	4
1056.00	2.400		0.2625	4
1056.00	2.990		0.2100	4
1086.00	2.560		0.2100	4
1122.00	2.080		0.2100	4
1122.00	2.740		0.1575	4
1155.00	2.300		0.1575	4
1188.00	1.860		0.1575	4
1188.00	2.540		0.1050	4
1198.00	2.280		0.1050	4
1226.00	1.900		0.1050	4
1254.00	1.520	1.5	0.1050	4
1254.00	2.470	2.5	0.0525	4
1282.00	1.800		0.0525	4
1310.75	1.150		0.0525	4
1320.00	0.980		0.0525	4

Table 5.22: Theoretical and Experimental Profile Data for the Condition:
ΔQ = 0.0735 cfs n = 0.011 S = 0.025

Distance from Outlet (ft)	Calculated Depth (in)	Experimental Depth (in)	Discharge (cfs)	Diameter (in)
0.00	1.110		1.4700	6
16.00	1.390		1.4700	6
29.10	1.540		1.4700	6
36.80	1.630		1.4700	6
66.00	1.870	2.0	1.4700	6
66.00	2.060	2.0	1.3965	6
100.00	2.090		1.3965	6
132.00	2.100		1.3965	6
132.00	2.320		1.3230	6
162.05	2.340		1.3230	6
198.00	2.550		1.3230	6
198.00	2.580		1.2495	6
229.95	2.550		1.2495	6
264.00	2.540		1.2495	6
264.00	2.820		1.1760	6
280.00	2.800		1.1760	6
301.90	2.780		1.1760	6
330.00	2.760	2.8	1.1760	6
330.00	3.030	3.0	1.1025	6
360.00	2.970		1.1025	6
396.00	2.900		1.1025	6
396.00	3.250		1.0290	6
415.85	2.990		1.0290	6
438.00	2.830		1.0290	6
462.00	2.750		1.0290	6
462.00	3.170		0.9555	6
484.25	2.930		0.9555	6
506.00	2.790		0.9555	6
528.00	2.730	2.8	0.9555	6
528.00	3.300	3.3	0.8820	6
537.15	3.110		0.8820	6
549.35	2.950		0.8820	6
560.00	2.890	2.9	0.8820	6
560.00	2.630	2.6	0.8820	5
563.50	2.800		0.8820	5
570.00	2.970		0.8820	5
580.00	3.150		0.8820	5
594.00	3.200		0.8820	5
594.00	3.500		0.8085	5
624.00	3.490		0.8085	5
660.00	3.460	3.5	0.8085	5
660.00	3.680	4.0	0.7350	5
692.00	3.670		0.7350	5

Table 5.22: (continued)

Distance from Outlet (ft)	Calculated Depth (in)	Experimental Depth (in)	Discharge (cfs)	Diameter (in)
726.00	3.660		0.7350	5
726.00	3.890		0.6615	5
737.10	3.920		0.6615	5
770.00	3.970		0.6616	5
792.00	3.970		0.6615	5
792.00	4.380		0.5880	5
830.75	3.850		0.5880	5
858.00	3.170		0.5880	5
858.00	4.200		0.5145	5
871.90	3.970		0.5145	5
890.55	3.660		0.5145	5
924.00	3.300	3.3	0.5145	5
924.00	3.850	4.0	0.4410	5
960.00	2.960		0.4410	5
990.00	2.760		0.4410	5
990.00	3.470		0.3675	5
1000.00	3.280		0.3675	5
1010.00	3.140		0.3675	5
1020.00	3.070		0.3675	5
1020.00	2.770		0.3675	4
1023.00	2.890		0.3675	4
1030.00	2.980		0.3675	4
1043.70	3.080		0.3675	4
1056.00	3.130		0.3675	4
1056.00	3.410		0.2940	4
1088.00	3.340		0.2940	4
1122.00	3.260		0.2940	4
1122.00	3.680		0.2205	4
1141.40	3.330		0.2205	4
1165.00	2.970		0.2205	4
1188.00	2.690		0.2205	4
1188.00	3.120		0.1470	4
1220.00	2.410		0.1470	4
1254.00	1.710		0.1470	4
1254.00	2.970		0.0735	4
1270.00	2.460		0.0735	4
1294.55	1.730		0.0735	4
1320.00	1.110		0.0735	4

Table 5.23: Theoretical and Experimental Profile Data for the Condition:
ΔQ = 0.0315 cfs   n = 0.011   S = 0.05

Distance from Outlet (ft)	Calculated Depth (in)	Experimental Depth (in)	Discharge (cfs)	Diameter (in)
0.00	2.040		0.6300	5
10.10	2.150		0.6300	5
26.15	2.320		0.6300	5
44.40	2.450		0.6300	5
66.00	2.590	3.0	0.6300	5
66.00	2.900	3.5	0.5985	5
89.21	3.010		0.5985	5
110.05	3.090		0.5985	5
132.00	3.110		0.5985	5
132.00	3.470		0.5670	5
160.00	3.490		0.5670	5
198.00	3.410		0.5670	5
198.00	3.780		0.5355	5
211.75	3.690		0.5355	5
225.70	3.620		0.5355	5
242.35	3.600		0.5355	5
264.00	3.550	3.5	0.5355	5
264.00	3.590	3.5	0.5040	5
276.25	3.800		0.5040	5
286.50	3.700		0.5040	5
297.50	3.600		0.5040	5
312.80	3.500		0.5040	5
330.00	3.460		0.5040	5
330.00	3.920		0.4725	5
338.10	3.800		0.4725	5
353.30	3.600		0.4725	5
372.15	3.400		0.4725	5
396.00	3.250	3.3	0.4725	5
396.00	3.740	3.8	0.4410	5
406.15	3.600		0.4410	5
420.15	3.400		0.4410	5
438.54	3.200		0.4410	5
462.00	3.030		0.4410	5
462.00	3.530		0.4095	5
472.90	3.300		0.4095	5
485.55	3.100		0.4095	5
496.40	2.900		0.4095	5
518.00	2.700		0.4095	5
528.00	2.620		0.4095	5
528.00	3.190		0.3780	5
537.24	3.000		0.3780	5
550.25	2.800		0.3780	5
563.35	2.700		0.3780	5

Table 5.23: (continued)

Distance from Outlet (ft)	Calculated Depth (in)	Experimental Depth (in)	Discharge (cfs)	Diameter (in)
577.10	2.600		0.3780	5
594.00	2.450		0.3780	5
594.00	2.930		0.3465	5
603.30	2.700		0.3465	5
614.20	2.500		0.3465	5
630.00	2.310	2.0	0.3465	5
630.00	1.840	1.5	0.3465	4
646.65	2.000		0.3465	4
660.00	2.060		0.3465	4
660.00	2.300		0.3150	4
680.75	2.410		0.3150	4
692.45	2.460		0.3150	4
708.00	2.500		0.3150	4
726.00	2.610		0.3150	4
726.00	3.080		0.2835	4
734.00	3.000		0.2835	4
754.75	2.800		0.2835	4
780.00	2.600		0.2835	4
792.00	2.520		0.2835	4
792.00	3.120		0.2520	4
798.35	3.000		0.2520	4
810.00	2.800		0.2520	4
828.00	2.600		0.2520	4
858.00	2.260		0.2520	4
858.00	3.050		0.2205	4
868.00	2.800		0.2205	4
882.24	2.600		0.2205	4
898.80	2.400		0.2205	4
924.00	2.080		0.2205	4
924.00	2.870		0.1890	4
930.60	2.720		0.1890	4
939.35	2.600		0.1890	4
952.00	2.400		0.1890	4
970.00	2.200		0.1890	4
990.00	1.910		0.1890	4
990.00	2.720		0.1575	4
1000.00	2.500		0.1575	4
1012.55	2.260		0.1575	4
1026.50	2.080		0.1575	4
1040.70	1.920		0.1575	4
1056.00	1.710		0.1575	4
1056.00	2.600		0.1260	4
1066.00	2.400		0.1260	4
1076.00	2.200		0.1260	4

Table 5.23: (continued)

Distance from Outlet (ft)	Calculated Depth (in)	Experimental Depth (in)	Discharge (cfs)	Diameter (in)
1090.00	2.000		0.1260	4
1105.00	1.800		0.1260	4
1122.00	1.580	1.5	0.1260	4
1122.00	2.520	2.7	0.0945	4
1130.25	2.320		0.0945	4
1138.20	2.200		0.0945	4
1148.45	2.000		0.0945	4
1160.75	1.800		0.0945	4
1172.70	1.600		0.0945	4
1188.00	1.380		0.0945	4
1188.00	2.450		0.0630	4
1202.25	2.000		0.0630	4
1222.50	1.600		0.0630	4
1236.00	1.400		0.0630	4
1254.00	1.200		0.0630	4
1254.00	2.320		0.0315	4
1265.30	2.000		0.0315	4
1278.65	1.600		0.0315	4
1296.60	1.200		0.0315	4
1320.00	0.800		0.0315	4

Table 5.24: Theoretical and Experimental Profile Data for the Condition:
ΔQ = 0.0525 cfs   n = 0.011   S = 0.05

Distance from Outlet (ft)	Calculated Depth (in)	Experimental Depth (in)	Discharge (cfs)	Diameter (in)
0.00	2.330		1.0500	5
10.00	2.460		1.0500	5
18.00	2.560		1.0500	5
29.00	2.700		1.0500	5
44.80	2.870		1.0500	5
66.00	3.000	3.5	1.0500	5
66.00	3.320	4.0	0.9975	5
86.00	3.380		0.9975	5
103.45	3.430		0.9975	5
132.00	3.460		0.9975	5
132.00	3.750		0.9450	5
138.00	3.800		0.9450	5
170.00	3.850		0.9450	5
198.00	3.900		0.9450	5
198.00	4.140		0.8925	5
230.00	4.100		0.8925	5
264.00	4.060		0.8925	5
264.00	4.320		0.8400	5
291.35	4.270		0.8400	5
330.00	4.200	4.0	0.8400	5
330.00	4.670	4.7	0.7875	5
337.40	4.560		0.7875	5
351.00	4.400		0.7875	5
364.00	4.330		0.7875	5
377.40	4.240		0.7875	5
396.00	4.190		0.7875	5
396.00	4.590		0.7350	5
407.35	4.410		0.7350	5
424.45	4.140		0.7350	5
444.00	3.920		0.7350	5
462.00	3.790	4.0	0.7350	5
462.00	4.260	4.5	0.6825	5
471.10	4.110		0.6825	5
492.00	4.870		0.6825	5
514.90	4.640		0.6825	5
528.00	3.560		0.6825	5
528.00	4.110		0.6300	5
642.00	3.800		0.6300	5
559.00	3.500		0.6300	5
577.50	3.220		0.6300	5
594.00	3.080		0.6300	5
594.00	3.750		0.5775	5
619.00	3.240		0.5775	5
641.95	2.940		0.5775	5

Table 5.24: (continued)

Distance from Outlet (ft)	Calculated Depth (in)	Experimental Depth (in)	Discharge (cfs)	Diameter (in)
660.00	2.780	3.0	0.5775	5
660.00	3.400	4.0	0.5250	5
666.40	3.240		0.5250	5
684.00	2.940		0.5250	5
706.00	2.690		0.5250	5
726.00	2.590		0.5250	5
726.00	3.160		0.4725	5
735.25	2.680		0.4725	5
776.00	2.210		0.4725	5
792.00	2.800		0.4725	5
792.00	2.630		0.4200	5
803.65	2.300		0.4200	5
812.00	2.160		0.4200	5
830.00	2.100		0.4200	5
830.00	1.470		0.4200	4
834.00	1.570		0.4200	4
840.50	1.650		0.4200	4
849.60	1.730		0.4200	4
858.00	1.750		0.4200	4
858.00	2.040		0.3675	4
866.00	2.160		0.3675	4
884.00	2.280		0.3675	4
903.30	2.350		0.3675	4
924.00	2.350		0.3675	4
924.00	2.650		0.3150	4
950.00	2.650		0.3150	4
990.00	2.660		0.3150	4
990.00	3.400		0.2625	4
1010.00	2.900		0.2625	4
1032.00	2.420		0.2625	4
1056.00	2.040		0.2625	4
1056.00	2.960		0.2100	4
1090.00	2.400		0.2100	4
1122.00	1.910		0.2100	4
1122.00	3.010		0.1575	4
1150.00	2.440		0.1575	4
1188.00	1.650		0.1575	4
1188.00	2.950		0.1050	4
1207.00	2.480		0.1050	4
1254.00	1.560		0.1050	4
1254.00	3.010		0.0525	4
1280.00	2.030		0.0525	4
1320.00	1.100		0.0525	4