To the Graduate Council:

I am submitting herewith a thesis written by Rita J. Schrader entitled "Vertical Transport Dynamics of Striped Bass Eggs." I recommend that it be accepted in partial fulfillment of the requirements for the degree of Master of Science, with a major in Wildlife and Fisheries Science.

J. Larry Wilson, Major Professor

We have read this thesis
and recommend its acceptance:

Accepted for the Council:

Vice Chancellor
Graduate Studies and Research

VERTICAL TRANSPORT DYNAMICS
OF STRIPED BASS EGGS

A Thesis
Presented for the
Master of Science
Degree
The University of Tennessee, Knoxville

Rita J. Schrader

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ABSTRACT

Eggs of the striped bass, *Morone saxatilis* (Walbaum), were obtained from the Eagle Bend Hatchery in Clinton, Tennessee. Terminal sinking velocities in static water were determined for live eggs of females from Norris and Chickamauga Reservoirs. A significant difference was indicated for egg terminal sinking velocity based on the lake origin of the female. It was not possible to determine the original strain of the females or whether hormone injections of females prior to spawning affected egg density. Terminal sinking velocity was found to be highly correlated with both egg diameter and the ratio of oil globule diameter to yolk diameter, but correlation was highest for the latter.

Terminal sinking velocities for stained eggs from Norris and Chickamauga females were also determined, and the vertical transport rates of these eggs were studied in laboratory flows. Experiments were conducted for six flow rates over smooth and rough substrates. Vertical transport rate was shown to be a function of egg density and the shear velocity of flow.

The relative number of eggs suspended under various flow conditions was determined and related to terminal egg sinking velocity and the shear velocity of flow. A method was developed by which the percentage of eggs suspended in natural stream flow may be estimated.

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CHAPTER I

INTRODUCTION

In 1954 it became known that striped bass, *Morone saxatilis* (Walbaum), could reproduce successfully in a freshwater impoundment. Reproduction was documented for a land-locked population of striped bass in Santee-Cooper Reservoir, South Carolina (Scruggs, 1955). Interest was quickly generated in the possibility of establishing inland striped bass fisheries elsewhere. Since the mid-1950's, striped bass have been stocked in selected reservoirs in Texas and Oklahoma and at least 50 reservoirs throughout the southeast (Bailey, 1974).

Although more than 30 inland fisheries have been established, only Santee-Cooper Reservoir and Kerr Reservoir, North Carolina-Virginia, are noted for their self-sustaining striped bass populations (Bailey, 1974). Natural reproduction has also been documented for Dardanelle Reservoir, Arkansas (Bailey, 1974), Keystone Reservoir, Oklahoma (Mensinger, 1970) and Kentucky, Barkley and Watts Bar Reservoirs, Tennessee (Hogue et al., 1977; Wallus, personal communication). Since 1966 approximately twelve million fry or fingerlings have been stocked in twelve reservoirs throughout the state of Tennessee (Tennessee Wildlife Resources Agency, 1976). Approximately 50 larvae have been taken in samples by the Tennessee Valley Authority, and almost all of these were found in Barkley Reservoir during one intensive survey in 1975 (Hogue et al., 1977; Wallus, personal communication). At present, the data is insufficient to establish whether natural reproduction in these Tennessee reservoirs is sufficient to produce self-sustaining populations. When the amount of striped bass stocking throughout the Southeast is considered, it must be concluded that habitats permitting successful reproduction are very limited.

Striped bass are known to prefer a spawning habitat characterized by moderate to swift currents (Albrecht, 1964; Tresselt, 1952; Raney, 1952; Talbot, 1966). The eggs are non-adhesive, pelagic and slightly denser than water (Mansueti, 1958). Mansueti (1958) inferred that suspension of eggs in the water column was necessary for hatching success. Later experiments by Albrecht (1964) showed that survival was much greater for suspended eggs than for eggs resting on a gravel substrate.

Bayless (1967) also studied the effects of egg suspension. He suggested that the excessive mortalities observed for sedimented eggs were most likely due to factors associated with water-quality in the immediate perimeters of sedimented eggs and with the type of substrate. Fine debris which settles on the chorion of sedimented eggs may interfere with respiration. Fungal infection may also result from direct contact with contaminated substrates. The work of both Albrecht and Bayless indicated that at least some degree of suspension was necessary for hatching success in natural streams. It is interesting to note that concentrations of suspended sediment at levels of 500 ppm or more have been shown to have no effect on hatching success of striped bass eggs in the laboratory. However, the egg development rate was slowed down at sediment levels as low as 50 ppm resulting in a delay of hatch (Morgan et al, 1973).

To date, no information has been published which fully characterizes flow regimes necessary to suspend striped bass eggs. Talbot (1966) reported one study that determined vertical water velocities necessary to suspend eggs. However, vertical velocities are not useful under normal flow conditions where the only measurable velocity is in the horizontal direction of flow.

Albrecht (1964) stated that a mean water surface velocity of approximately 0.3 meters per second was apparently necessary for striped bass egg suspension in the San Joaquin River, California. This estimate was based on the results of field sampling; there was a tendency for most eggs to be collected near the bottom when mean surface velocities were less than 0.3 meters per second. As is often the case in biological literature, channel dimensions necessary for a more accurate description of the flow were not given. In any case, flow in the San Joaquin River was stated to be under tidal influence. Flow patterns during flood tides are not characteristic of flow patterns observed in our inland streams (Vigander, personal communication).

Since at least some degree of suspension is necessary for hatching success in natural streams, information is needed concerning minimum flow regimes which will actively suspend striped bass eggs. The objectives of this study were: (1) to determine terminal sinking velocities in static water for live eggs taken from Norris Reservoir and Chickamauga Reservoir females, (2) to analyze variation in terminal sinking velocities (and, therefore, egg density) in terms of egg origin and various egg measurements, (3) to determine the vertical transport rate of eggs under various conditions of laboratory flow, (4) to determine the relative number of eggs which might be suspended by various flows, and (5) to develop a method by which the degree of egg suspension might be predicted for flows observed in natural streams.

Since eggs are passive entities subject entirely to stream flow, the problem of egg suspension is of an engineering nature. Literature from the field of hydraulic engineering was referred to extensively during the course of this study.

CHAPTER II

MATERIALS AND METHODS

Source of Eggs

Fertilized eggs of the striped bass, *Morone saxatilis*, were obtained from the Eagle Bend Hatchery operated by the Tennessee Wildlife Resources Agency in Clinton, Tennessee. Brood stock from which eggs were taken were adult females from an upland storage reservoir (Norris) and a mainstream reservoir (Chickamauga). They were collected during the 1978 and 1979 spawning seasons. The eggs were randomly drawn from spawning tanks by the use of a glass tube 20 mm in diameter with the tube being inserted the full depth of the tank so as to obtain a cross-section of egg densities for any given female. Eggs were placed in plastic bags filled with aerated water and transported in a styrofoam container.

Terminal Sinking Velocity Measurements

Live eggs were used to establish terminal sinking velocities in static water for eggs of five Norris and three Chickamauga females. Lake origin of the male and female broodfish, weight of each female, spawning date and temperature, age of the eggs, egg diameters, and water temperature of the test were noted for all tests in static water. A sample size of 60 eggs was used in the tests on eggs from Norris females. All of these females spawned in 1978. Chickamauga females were represented by sample sizes of 30, 50 and 58 eggs. One of these females spawned in 1978; the other two samples were obtained in 1979.

With one exception, all of the tests were made on fully water-hardened eggs. Tests were made on the eggs of one Norris female before and after the water-hardening process was complete. Eggs have been reported to be more dense prior to water-hardening (Talbot, 1966). According to Mansueti (1958), the water-hardening process is completed in 1-1.5 hours. During this time, water is absorbed by the egg until it reaches its greatest diameter.

Bottled distilled water was allowed to stand in a 4 liter graduated cylinder (10.5 cm in diameter) for approximately 45 minutes or more in order to insure against internal water movements. Bottled water was used in order to avoid problems which may be caused by minute air bubbles becoming attached to the eggs. Individual eggs were placed under the water surface in the center of the graduate with a soda straw.

In the course of their fall, eggs, like any object, will accelerate until some terminal velocity is reached. All eggs were allowed to reach this terminal velocity before a velocity measurement was recorded. The fall of each egg was timed through a distance of 61 mm. A few eggs showed damage in the form of dented chorions, oil globule separation, or yolk streams; however, eggs observed to be damaged were not included in tests.

Sinking velocities in static water were also determined for the eggs used in flume tests. Thirty-five stained eggs from each female were tested on 23 July at a water temperature of 25.5 C. These tests were conducted in the manner previously described with one exception; a 75.8 liter aquarium was used instead of a graduated cylinder.

A single classification analysis of variance (Sokal 1969) was used to compare the date for eggs from Norris Reservoir females to that for Chickamauga Reservoir females. The data for eggs were pooled according to reservoir origin of the female.

Egg Measurements

An effort was made to relate egg diameters, yolk diameters, and oil globule diameters to egg sinking velocities. An ocular micrometer was used for all measurements. Since the yolk mass was not perfectly spherical, it was measured across its widest part. All measurements were made with the vegetative pole in an uppermost position (oil globule atop the yolk mass). Thirty eggs from each of two Chickamauga females and 24 eggs from each of three Norris females were used in this study. Terminal sinking velocities were measured in the manner described previously. The mean and standard error of the mean were calculated for each variable.

Variation in the terminal sinking velocity of eggs was correlated with egg diameters and the ratio of oil diameter to yolk diameter. Data for eggs from females of both reservoirs were pooled for this analysis.

Staining of Eggs for Flume Tests

Live eggs were obtained from one Norris female on 11 May and one Chickamauga female on 18 May 1979. Since it was not possible to schedule flume tests for live eggs, the live eggs were transferred into quart jars and formalin was added to give a dilution of approximately 2% formalin. Prior study had shown preserved eggs to be more dense and, therefore, sink faster in static water than live eggs. However, the same preserved eggs will become less dense after a short period of time in fresh water. In order to avoid density changes during a flume test, the formalin solution was replaced with distilled water on 15 July--the evening before flume tests were to begin.

The distilled water was, in turn, replaced with a staining solution. This staining solution was prepared by adding one-eighth of a teaspoon of Brilliant Cresyl Blue (Color Index No. 51010, Eastman Kodak, dye content 50% by weight) to 1200 ml of distilled water. Each batch of eggs was held in this solution for 10 minutes. The staining solution was then diluted by successive transfers of water until the water was clear.

The quart jars containing the eggs were gently inverted in order to get all of the eggs into suspension. A soda straw was used to take samples of eggs throughout the depth of the jar. These samples were placed in small, sterile jars filled with distilled water. Each jar contained a sufficient number of eggs for any one test. By having separate samples of eggs for each test, undue agitation of all eggs throughout the testing procedure was avoided. It was also hoped that bacterial or fungal contamination of the eggs might be avoided in this way.

Laboratory Apparatus for Flume Tests

All flowing water tests were made at the Tennessee Valley Authority Water Engineering Laboratory in Norris, Tennessee. Eggs were inserted into a plexiglass test flume which was 11.9 meters long, 0.38 meters wide and 0.38 meters deep. Water was supplied from the laboratory reservoir and pumped into the flume at selected discharge rates; the subsequent flow rate for any one test was held constant. A net was provided in the flume outlet to prevent eggs from entering the reservoir and being recycled into the flume.

Three initial velocity profiles were made over a smooth bottom at a mean velocity approximating 0.43 m/second in order to determine whether uniform flows could be achieved within the length of the flume. Uniform flow is usually defined as flow for which the velocity stays the same over the length of the channel for any given depth (Chow, 1959). When water enters a channel, the velocity distribution will change for some distance along the channel. If channel dimensions and the roughness of the channel boundaries remain uniform, the velocity distribution will reach a definite pattern at some distance along the channel. Once this uniform flow is established, velocity profiles will be identical. The distance at which uniform flow is established increases as channel roughness or flow rate increases.

Velocity measurements were made at selected depths in the beginning, middle and end sections of the flume in order to provide velocity profiles for these sections. The velocity profiles indicated that uniform flow did not exist throughout the flume. However, flow in the latter half of the flume approached uniformity, and it was decided to make all observations on egg transport toward the end of the flume.

When water velocities are measured across a channel section, the mid-channel velocity is greater since the flow there is least retarded by the frictional effects of side boundaries. One aim of this study was to determine vertical transport rates of eggs released in open water; therefore, it was felt best to confine observations to those eggs transported in the midstream section of the flume. It is also true that in order to state changes in vertical position of the eggs over time (vertical transport rate), one must be able to establish the length of transport time. Eggs were assumed to be transported at a mean velocity equivalent to the mean velocity of flow measured in mid-channel.

It was then necessary, for two reasons, to make all egg observation in the center cross-section of the flume. In order to provide a guideline for confining observations to this section, a series of four tungsten lamps were hung over the study section. Strips of hardboard were placed over the top of the flume providing a single slit in the center. This allowed a beam of light approximately 13 cm wide to define the midstream section. Due to mixing processes in turbulent flow, eggs released tended to spread somewhat over distance. For this reason, it was found to be impractical to confine observations to a more narrow region.

Three criteria had to be met for a device to release eggs into the flow. Any device must be such that eggs are unlikely to be damaged and flow disturbances are minimized at the point of release. The device must also allow for observation of the eggs so that observably damaged eggs can be excluded from the test.

An L-shaped clear plastic tube 18 mm in diameter was fitted into a frame and clamped to the flume in a downstream direction. Some flow disturbance was created by the vertical arm of the tube; therefore, the horizontal arm was made 25 cm in length to minimize any disturbance at the point of release. This insertion device was placed 1.5 m upstream from the initial observation point. The submerged end of the tube was located approximately 25 cm from the flume bottom. A funnel was placed in the mouth of the tube above the water surface. The submerged end was closed with a rubber stopper to which a fine wire was attached so that it could be removed from the surface.

The vertical transport rate of eggs must be some function of the vertical fluctuations in the velocity of turbulent flow. It is accepted that the degree of turbulence is determined, in part, by the magnitude of the horizontal velocity and the roughness of the boundary over which the flow passes. In order to observe egg transport over a range of flow conditions, a decision was made to include flows over both smooth and rough substrates. The smooth substrate was the plexiglass bottom of the flume. Corrugated fiberglass panels were selected as a rough substrate. The height of the corrugations was 1.27 cm, and the surface of the material was slightly dimpled. The greatest width between the corrugations was 6.35 cm.

Sections of fiberglass were cut to fit the bottom of the flume so that the corrugations presented a surface normal to the flow. Iron bars (1.27 cm square) were attached to the fiberglass to keep it on the bottom during high flows.

In order to determine the vertical position of each egg at all observation stations, a series of colored, transparent strips of plastic were arranged vertically on each side of the flume. Each individual color strip was 3 cm wide, and the strips were arranged to give a color match-up at any given depth. The stained eggs were easily seen through the plastic. From an observer's point of view, it was much easier to line up matching color strips (thereby avoiding parallax problems in determining egg position) than it would be to try and associate similar lines from opposing sides of the flume.

Flume Tests

Flume tests were conducted during the period of 16-20 July 1979. Thirty-five stained eggs from each female were observed over smooth and rough substrates at six different water discharges. Changes in vertical position were noted for each individual egg in the study.

Four stations were selected from which to note the vertical position of each egg as it moved downstream. These stations were spaced at 1.22 m intervals and covered a total distance of 3.66 m. The egg insertion device was located approximately 1.5 m upstream from the first station in order to eliminate any flow disturbances created by the device.

Individual eggs were placed into the flow in the following manner. The closed insertion tube was filled with water, and a small number of eggs were gently poured into the tube. A slight leak in the stoppered end of the tube allowed the eggs to drop slowly with the water level in the tube. When the water levels inside and outside the tube were the same, the stopper was removed. A small amount of water was added to the tube in order to move the eggs to the end of the tube. The eggs tended to be spaced out along the horizontal arm of the tube; this allowed for observation of egg damage. In most cases, individual eggs were pulled into the flume by the action of the flow. At low flows, it was sometimes necessary to flush eggs into the flow by adding a little water to the insertion tube.

As an egg moved downstream, change in its vertical position was noted. At each observation station, a depth was recorded in terms of a color indicated by the depth guide described previously. A hand-held tape recorder was used for recording data. When the data were transcribed, the depth accorded to any color was taken as the mean depth for the 3 cm range given by the depth guide. As mentioned previously, those eggs which were observably damaged or those which moved outside the mid-stream section were not included in the data.

The phrase "vertical transport" will be used to denote changes in the vertical position of eggs in flowing water. Negative vertical transport rates indicate a downward or sinking movement for the eggs; a positive vertical transport indicates an upward movement. Mean vertical transport rates were based on the movements of 35 eggs over the length of the study section (3.66 m). As might be expected, vertical movements of the eggs were of an erratic and random nature--reflecting turbulent fluctuations in the flow. For this reason, it was felt that average movements over the entire study section were more meaningful than descriptions of individual egg movements.

Mean vertical transport velocites (V_f) were calculated for each flow-substrate combination.

It was necessary to relate vertical egg transport rates in the flume to some property of the flow. Since the vertical position of any given egg was presumably affected by its density and the vertical component of turbulent flow, a property which serves as an indicator of turbulence was needed.

Mean velocities taken alone are not indicators of the degree of turbulence present in flowing water. Shear velocity ($V*$) is a function of the shear stress resulting from adjacent layers of water having different velocities. It is proportional to the velocity gradient ($\frac{dv}{y}$) of the flow (for a derivation of shear velocity, see Chow, 1959). Velocity gradients vary with the roughness of the substrate and the mean velocity of flow--as does turbulence. Prandtl (1949) stated that shear velocity is of the same order of magnitude as the vertical and horizontal velocity fluctuations due to turbulence; it can, therefore, be taken as an indicator of turbulence.

It should be noted that shear velocity is operative only in the region of flow where a velocity gradient exists. A velocity gradient is found only in the boundary layer of flow. The upper limit of the boundary layer is defined as that point at which local velocity is 99% of the maximum velocity, and, in fully developed turbulent flow, it may extend virtually to the water surface (Chow, 1959).

Vertical egg transport was also studied in terms of percentage suspension for any given test. A net displacement of zero over the length of the study section was taken as a minimum condition for suspension.

Since percentage suspension must also be some function of egg density and turbulence, it was decided to relate percentage suspension to the ratio $\frac{V_s}{KV*}$, where K is von Karman's constant and equal to 0.4 for clear water. (Von Karman's constant is a constant of proportionality relating a measure of the length scale of turbulence to a given distance y from the channel boundary (Henderson, 1966). This ratio is a non-dimensional value which has been used previously in studies of sediment suspension (Vanoni, 1963; Chow, 1964; Henderson, 1966).

CHAPTER III

RESULTS

Terminal Sinking Velocities for Live Eggs

Terminal sinking velocities in static water (V_s) are given for individual eggs of five Norris females and three Chickamauga females in Tables 1 - 8. Mean terminal sinking velocities for eggs from Norris females (total mean of 0.40 cm/second) were always found to be greater than those for Chickamauga females (total mean of 0.25 cm/second). The results of the analysis of variance used to compare data for individual eggs on the basis of lake origin of the female are given in Table 9. Terminal sinking velocities of eggs from Norris females were strongly indicated to be significantly different from those of Watts Bar females at a .25 probability level. Significance was tested at this level in order to decrease the probability of a Type II error.

The terminal sinking velocities of eggs from Norris Female E (see Table 5) were also determined before the water-hardening process was complete. The data for these eggs are reported in Table 10. These eggs were smaller and more dense than water-hardened eggs from the same female. A mean terminal sinking velocity of 0.50 cm/second with a standard error (SE) of 0.003 was calculated for these eggs.

Relationship of Terminal Sinking Velocity to Egg Measurements

Measurements of egg, yolk and oil globule diameters and corresponding terminal egg sinking velocities for three Norris females and two Chickamauga females are given in Table 11. The mean value of each of these measurements is given for the eggs of each female in Table 12.

Table 1. Terminal Sinking Velocities (V_s) of Live Eggs from Norris Reservoir Female A

Weight of female: 6.8 kg
Date of spawning: 13 May 1978
Water temperature at spawning: 18.5 C
Lake origin of male broodfish: Norris Reservoir
Age of eggs for test: 6 hours
Water temperature of test: 21.5 C
Sample size: 60 eggs
Egg diameter: Mean, 3.04 mm   Range: 2.56 - 3.20 mm
Mean V_s: 0.36 cm/second   SE: 0.003

V_s (cm/second)	No. of Eggs
0.32	1
0.33	3
0.34	9
0.35	15
0.36	9
0.37	15
0.38	3
0.39	2
0.40	1
0.42	2

Table 2. Terminal Sinking Velocities (V_s) of Live Eggs from Norris Reservoir Female B

Weight of female: 4.5 kg
Date of spawning: 18 May 1978
Water temperature at spawning: 18.5 C
Lake origin of male broodfish: Norris Reservoir
Age of eggs for test: 13 hours
Water temperature of test: 21.0 C
Sample size: 60 eggs
Egg diameter: Mean, 2.70 mm Range: 240 - 2.88 mm
Mean V_s: 0.40 cm/second SE: 0.002

V_s (cm/second)	No. of Eggs
0.36	2
0.37	1
0.38	2
0.39	16
0.40	13
0.41	19
0.42	6
0.44	1

Table 3. Terminal Sinking Velocities (V_s) of Live Eggs from Norris Reservoir Female C

Weight of female: 4.8 kg
Date of spawning: 18 May 1978
Water temperature at spawning: 18.5 C
Lake origin of male broodfish: Norris Reservoir
Age of eggs for test: 30 hours
Water temperature of test: 22.0 C
Sample size: 60 eggs
Egg diameter: Mean, 2.66 mm Range: 2.40 - 2.72 mm
Mean V_s: 0.45 cm/second SE: 0.002

V_s (cm/second)	No. of Eggs
0.42	3
0.43	8
0.44	18
0.45	17
0.46	11
0.47	3

Table 4. Terminal Sinking Velocities (V_s) of Live Eggs from Norris Reservoir Female D

Weight of Female: 4.8 kg
Date of spawning: 18 May 1978
Water temperature of spawning: 18.5 C
Lake origin of male broodfish: Norris Reservoir
Age of eggs for test: 22 hours
Water temperature of test: 22.0 C
Sample size: 60 eggs
Egg diameter: Mean, 2.62 mm Range: 2.24 - 2.72 mm
Mean V_s: 0.38 cm/second SE: 0.002

V_s (cm/second)	No. of Eggs
0.36	9
0.37	13
0.38	15
0.39	17
0.40	2
0.41	3
0.42	1

Table 5. Terminal Sinking Velocities (V_s) of Live Eggs from Norris Reservoir Female E

Weight of female: 5.4 kg
Date of spawning: 19 May 1978
Water temperature of spawning: 18.5 C
Lake origin of male broodfish: Norris Reservoir
Age of eggs for test: 18 hours
Water temperature of test: 21.0 C
Sample size: 60 eggs
Egg diameter: Mean, 2.70 mm Range: 2.56 - 2.88 mm
Mean V_s: 0.43 cm/second SE: 0.002

V_s (cm/second)	No. of Eggs
0.40	1
0.41	6
0.42	15
0.43	18
0.44	13
0.45	7

Table 6. Terminal Sinking Velocities (V_s) of Live Eggs from Chickamauga Reservoir Female X

Weight of female: 7.3 kg
Date of spawning: 5 May 1978
Water temperature at spawning: 18.4 C
Lake origin of male broodfish: Chickamauga Reservoir
Age of eggs for test: 8 hours
Water temperature of test: 23.0 C
Sample size: 50 eggs
Egg diameter: Mean, 2.85 mm Range: 2.40 - 3.04 mm
Mean V_s: 0.20 cm/second SE: 0.002

V_s (cm/second)	No. of Eggs
0.18	3
0.19	11
0.20	21
0.21	3
0.22	7
0.23	1
0.24	2
0.26	2

Table 7. Terminal Sinking Velocities (V_s) of Live Eggs from Chickamauga Reservoir Female Y

Weight of female: 8.5 kg
Date of spawning: 15 May 1979
Water temperature at spawning: 20.0 C
Lake origin of male broodfish: Chickamauga Reservoir
Age of eggs for test: 12 hours
Water temperature of test: 25.0 C
Sample size: 58 eggs
Egg diameter: Mean, 2.85 mm Range: 1.92 - 3.04 mm
Mean V_s: 0.28 cm/second SE: 0.004

V_s (cm/second)	No. of Eggs
0.22	1
0.25	4
0.26	4
0.27	20
0.28	8
0.29	9
0.30	2
0.31	4
0.32	2
0.33	1
0.35	1
0.40	1
0.41	1

Table 8. Terminal Sinking Velocities (V_s) of Live Eggs from Chickamauga Reservoir Female Z

Weight of female: 10.9 kg
Date of spawning: 17 May 1979
Water temperature at spawning: 20.0 C
Lake origin of male broodfish: Chickamauga and Cherokee Reservoirs
Age of eggs for test: 17 hours
Water temperature of test: 24.0 C
Sample size: 30 eggs
Egg diameter: Mean, 2.78 mm Range: 2.64 - 2.92 mm
Mean V_s: 0.26 cm/second SE: 0.002

V_s (cm/second)	No. of Eggs
0.24	3
0.25	10
0.26	7
0.27	5
0.28	5

Table 9. Analysis of Variance Summary for the Effect of "Lake of Origin" on Terminal Sinking Velocities of Striped Bass Eggs from 5 Norris and 3 Chickamauga Reservoir Females

Source	S.S.	D.F.	M.S.	F
Lake of Origin	2.217	1	2.217	1582.56*
Error	0.611	436	0.001	
Total	2.828	437		

$*F_{.25} < 1.32$

Table 10. Terminal Sinking Velocities (V_s) of Eggs from Norris Reservoir Female E Prior to Water-Hardening

Age of eggs for test: 0.75 - 1.5 hours
Water temperature of test: 21.0 C.
Sample size: 27 eggs
Egg diameter: Mean, 2.46 mm   Range: 2.40 - 2.56 mm
Mean V_s: 0.50 cm/second   SE: 0.003

Vs (cm/second)	No. of Eggs
0.47	3
0.48	1
0.49	9
0.50	4
0.51	8
0.52	1
0.53	1

Table 11. Measurements of Egg, Yolk and Oil Globule Diameters and Terminal Sinking Velocities (V_s) for 3 Norris and 2 Chickamauga Females

Female	Egg (mm)	Yolk (mm)	Oil (mm)	V_s (cm/second)
Norris (B)	2.72	1.12	0.64	0.42
	2.88	1.12	0.64	0.39
	2.72	1.12	0.64	0.42
	2.72	1.12	0.64	0.41
	2.72	1.12	0.64	0.41
	2.72	1.12	0.64	0.41
	2.72	1.12	0.64	0.39
	2.72	1.12	0.64	0.39
	2.72	1.12	0.64	0.41
	2.72	1.12	0.64	0.40
	2.72	1.12	0.64	0.40
	2.72	1.12	0.64	0.37
	2.72	1.12	0.64	0.42
	2.88	1.12	0.64	0.36
	2.88	1.12	0.64	0.38
	2.88	1.12	0.64	0.38
	2.88	1.12	0.64	0.38
	2.56	1.12	0.64	0.39
	2.56	0.96	0.64	0.40
	2.56	1.12	0.48	0.42
	2.56	1.12	0.48	0.42
	2.40	0.96	0.48	0.42
	2.40	0.96	0.48	0.42
	2.40	0.96	0.48	0.42

Table 11 (Continued)

Female	Egg (mm)	Yolk (mm)	Oil (mm)	V_s (cm/second)
Norris (C)	2.56	1.12	0.48	0.46
	2.56	1.12	0.48	0.45
	2.56	1.12	0.48	0.46
	2.56	1.12	0.48	0.46
	2.56	1.12	0.48	0.46
	2.56	1.12	0.48	0.46
	2.56	1.12	0.48	0.46
	2.56	1.12	0.48	0.46
	2.56	1.12	0.48	0.47
	2.56	1.12	0.48	0.46
	2.72	1.28	0.64	0.44
	2.72	1.28	0.64	0.43
	2.72	1.28	0.64	0.42
	2.72	1.28	0.64	0.44
	2.72	1.28	0.64	0.44
	2.72	1.28	0.64	0.43
	2.72	1.28	0.64	0.44
	2.72	1.28	0.64	0.44
	2.72	1.28	0.64	0.44
	2.72	1.28	0.64	0.43
	2.72	1.28	0.64	0.43
	2.72	1.28	0.64	0.44
	2.72	1.28	0.64	0.43
	2.72	1.28	0.64	0.43

Table 11 (Continued)

Female	Egg (mm)	Yolk (mm)	Oil (mm)	V_s (cm/second)
Norris (E)	2.08	1.28	0.64	0.55
	2.56	1.20	0.64	0.45
	2.56	1.20	0.64	0.45
	2.56	1.20	0.64	0.44
	2.72	1.28	0.64	0.45
	2.72	1.20	0.64	0.42
	2.72	1.20	0.64	0.42
	2.72	1.20	0.64	0.44
	2.72	1.20	0.64	0.43
	2.72	1.20	0.64	0.41
	2.72	1.20	0.64	0.43
	2.72	1.20	0.64	0.44
	2.72	1.20	0.64	0.44
	2.72	1.20	0.64	0.43
	2.72	1.20	0.64	0.43
	2.72	1.20	0.64	0.43
	2.72	1.20	0.64	0.43
	2.72	1.20	0.64	0.42
	2.72	1.20	0.64	0.43
	2.72	1.20	0.64	0.43
	2.72	1.20	0.64	0.42
	2.72	1.20	0.64	0.42
	2.72	1.20	0.64	0.44
	2.72	1.20	0.64	0.42

Table 11 (Continued)

Female	Egg (mm)	Yolk (mm)	Oil (mm)	V_s (cm/second)
Chickamauga (Y)	2.88	1.12	0.8	0.27
	2.08	1.12	0.8	0.40
	2.88	1.28	0.8	0.26
	3.04	1.28	0.8	0.27
	2.72	1.12	0.8	0.29
	2.72	1.12	0.8	0.29
	3.04	1.28	0.8	0.27
	2.88	1.28	0.8	0.27
	2.88	1.12	0.8	0.26
	2.56	1.12	0.8	0.31
	3.04	1.28	0.8	0.27
	3.04	1.28	0.8	0.27
	2.88	1.12	0.8	0.28
	2.88	1.12	0.8	0.25
	3.04	1.28	0.8	0.28
	2.88	1.28	0.8	0.29
	2.40	1.12	0.8	0.31
	2.88	1.28	0.8	0.26
	2.72	1.12	0.8	0.28
	2.88	1.28	0.8	0.25
	3.04	1.12	0.8	0.28
	2.88	1.12	0.8	0.28
	2.88	1.12	0.8	0.28
	2.72	1.12	0.8	0.29
	3.04	1.12	0.8	0.22
	2.88	1.12	0.8	0.28
	2.72	1.12	0.80	0.27
	2.72	1.12	0.64	0.31
	2.40	1.12	0.64	0.35
	3.04	1.12	0.64	0.27

Table 11 (Continued)

Female	Egg (mm)	Yolk (mm)	Oil (mm)	V_s (cm/second)
Chickamauga (Z)	2.80	1.20	0.8	0.28
	2.80	1.20	0.8	0.28
	2.72	1.16	0.7	0.26
	2.84	1.20	0.8	0.26
	2.84	1.20	0.8	0.26
	2.68	1.20	0.8	0.25
	2.76	1.20	0.8	0.25
	2.84	1.20	0.8	0.24
	2.64	1.16	0.8	0.26
	2.80	1.20	0.8	0.27
	2.92	1.20	0.8	0.28
	2.72	1.16	0.8	0.25
	2.88	1.20	0.8	0.27
	2.72	1.16	0.8	0.25
	2.72	1.16	0.8	0.25
	2.68	1.20	0.8	0.25
	2.84	1.20	0.8	0.25
	2.84	1.20	0.8	0.25
	2.72	1.16	0.8	0.24
	2.72	1.16	0.8	0.24
	2.88	1.20	0.8	0.27
	2.92	1.20	0.8	0.27
	2.72	1.16	0.8	0.25
	2.84	1.20	0.8	0.27
	2.76	1.20	0.8	0.25
	2.68	1.16	0.7	0.26
	2.80	1.20	0.8	0.28
	2.80	1.20	0.8	0.26
	2.64	1.16	0.8	0.26
	2.80	1.20	0.8	0.28

Table 12. Mean Values of Egg, Yolk and Oil Diameters and Terminal Sinking Velocities (V_s) for 3 Norris and 2 Chickamauga Reservoir Females

Female	Sample Size	V_s cm/sec	Egg (mm)	SE	Yolk (mm)	SE	Oil (mm)	SE
Norris (B)	24	0.40	2.67	0.03	1.09	0.01	0.61	0.01
Norris (C)	24	0.45	2.65	0.16	1.21	0.02	0.57	0.02
Norris (E)	24	0.44	2.67	0.03	1.21	0.01	0.64	
Chickamauga (Y)	30	0.28	2.82	0.04	1.17	0.01	0.78	0.01
Chickamauga (Z)	30	0.26	2.78	0.01	1.19	0.01	0.79	0.01

When the data for all eggs were pooled, a partial correlation coefficient of 0.05 was calculated for terminal sinking velocity and egg diameter at a probability level of 0.0001. Terminal sinking velocity and the ratio of oil diameter to yolk diameter were more highly correlated with a partial correlation coefficient of 0.51 at a 0.0001 probability level.

Terminal Sinking Velocities for Eggs Used in Flume Tests

The sinking velocities for 35 stained eggs from each female represented in flume tests are given in Table 13. The mean terminal sinking velocity for the eggs of the Norris female was 0.36 cm/second with a range of 0.33 to 0.44 cm/second and a standard error (SE) of 0.004. Stained eggs from the Chickamauga female had a mean sinking velocity of 0.26 cm/second, a range of 0.23 to 0.31 cm/second and a standard error of 0.003. These terminal sinking velocities were in the same range as those determined for live eggs from females of corresponding reservoirs.

Table 13. Terminal Sinking Velocities (V_s) of Stained Eggs Used in Flume Experiments

Female	V_s (cm/second)	No. of Eggs	Mean V_s (cm/second)	SE
Norris	0.33	1	0.36	0.004
	0.34	4		
	0.35	9		
	0.36	10		
	0.38	5		
	0.39	5		
	0.44	1		
Chickamauga	0.23	1	0.26	0.003
	0.24	4		
	0.25	5		
	0.26	14		
	0.27	5		
	0.28	2		
	0.29	2		
	0.30	1		
	0.31	1		

Flume Tests

Study Flows

Velocity profiles were drawn for each discharge-substrate combination in order to characterize the flow. Before any one flume test was begun, velocity measurements were taken at selected depths in mid-channel. Since it is very difficult to mathematically fit a profile curve for flow which is not fully developed, the curves were drawn by hand. The area under each curve was determined by the planimeter method, and mean velocities for each test were calculated according to

$$\overline{V} = \frac{\text{Area under the curve}}{\text{Total depth}}$$

Mean velocities of 0.09, 0.16, 0.23, 0.30, 0.41, and 0.50 m/second were calculated for flows over the smooth substrate. Mean velocities of 0.10, 0.16, 0.29, 0.33, 0.45, and 0.52 m/second were calculated for flows over the rough substrate.

Theoretical velocity profiles for fully developed flow were calculated for comparison to curves based on empirical data. A standard method described by Chow (1959) was used for deriving the theoretical curves. Theoretical velocity profiles and profiles based on the empirical data for each flow-substrate combination are given in Figures A1-A12 in the Appendix. It was felt that the difference in the theoretical profiles and profiles based on measured velocities, particularly in the velocity distribution toward the bottom of the flume, was explained by the fact that a fully developed, uniform flow was not achieved in the flume.

Vertical Egg Transport in Flowing Water

Mean vertical transport velocities (V_f) were calculated for each flow-substrate combination. It must be remembered that the position of each egg was determined within a range of 3 cm; therefore, all values of individual egg position were subject to an error of ± 1.5 cm.

It was necessary to relate vertical egg transport rates in the flume to some property of the flow. Since the vertical position of any given egg was presumably affected by its density and the vertical component of turbulent flow, a property which serves as an indicator of turbulence was needed.

Mean velocities taken alone are not indicators of the degree of turbulence present in flowing water. Shear velocity (V*) is a function of the shear stress resulting from adjacent layers of water having different velocities. It is proportional to the velocity gradient ($\frac{dv}{y}$) of the flow (for a derivation of shear velocity, see Chow, 1959). Velocity gradients vary with the roughness of the substrate and the mean velocity of flow--as does turbulence. Prandtl (1949) stated that shear velocity is of the same order of magnitude as the vertical and horizontal velocity fluctuations due to turbulence; it can, therefore, be taken as an indicator of turbulence.

It should be noted that shear velocity is operative only in the region of flow where a velocity gradient exists. A velocity gradient is found only in the boundary layer of flow. The upper limit of the boundary layer is defined as that point at which local velocity is 99% of the maximum velocity, and, in fully developed turbulent flow, it may extend virtually to the water surface (Chow, 1959).

Values for mean velocity, shear velocity, mean vertical egg transport velocity and the ratio of mean vertical egg transport velocity to mean terminal sinking velocity for a given set of eggs are given in Table 14 for each test. Shear velocities were calculated using measured mean velocity and standard equations for fully developed flow (Chow, 1959).

Values for mean vertical transport rates were plotted against corresponding shear velocity values for each test (Figure 1). The curves for this graph were fitted by observation. They indicated that eggs for a given female or density tended to sink more slowly as shear velocity increased. In the final test at a shear velocity of 0.037 m/second, the

Table 14. Mean Flow Velocity ($\overline{V}$), Shear Velocity (V*), Mean Vertical Egg Transport Velocity ($\pm V_f$) and the Ratio of $-V_f$ to Terminal Sinking Velocity ($-V_s$) as Determined by Flume Experiments

		$\pm V_f$		V_f/V_s	
$\overline{V}$ (m/sec)	V* (m/sec)	Chickamauga	Norris	Chickamauga	Norris
0.09	0.005	-0.25	-0.37	0.96	1.03
0.10	0.007	-0.22	-0.30	0.85	0.83
0.16	0.007	-0.25	-0.34	0.96	0.94
0.23	0.010	-0.23	-0.38	0.88	1.06
0.16	0.011	-0.19	-0.26	0.73	0.72
0.30	0.013	-0.21	-0.32	0.81	0.89
0.41	0.017	-0.20	-0.29	0.77	0.81
0.29	0.021	-0.16	-0.31	0.62	0.86
0.50	0.021	-0.22	-0.26	0.85	0.72
0.33	0.023	-0.12	-0.21	0.46	0.58
0.45	0.032	-0.05	-0.09	0.19	0.25
0.52	0.037	+0.38	+0.25		

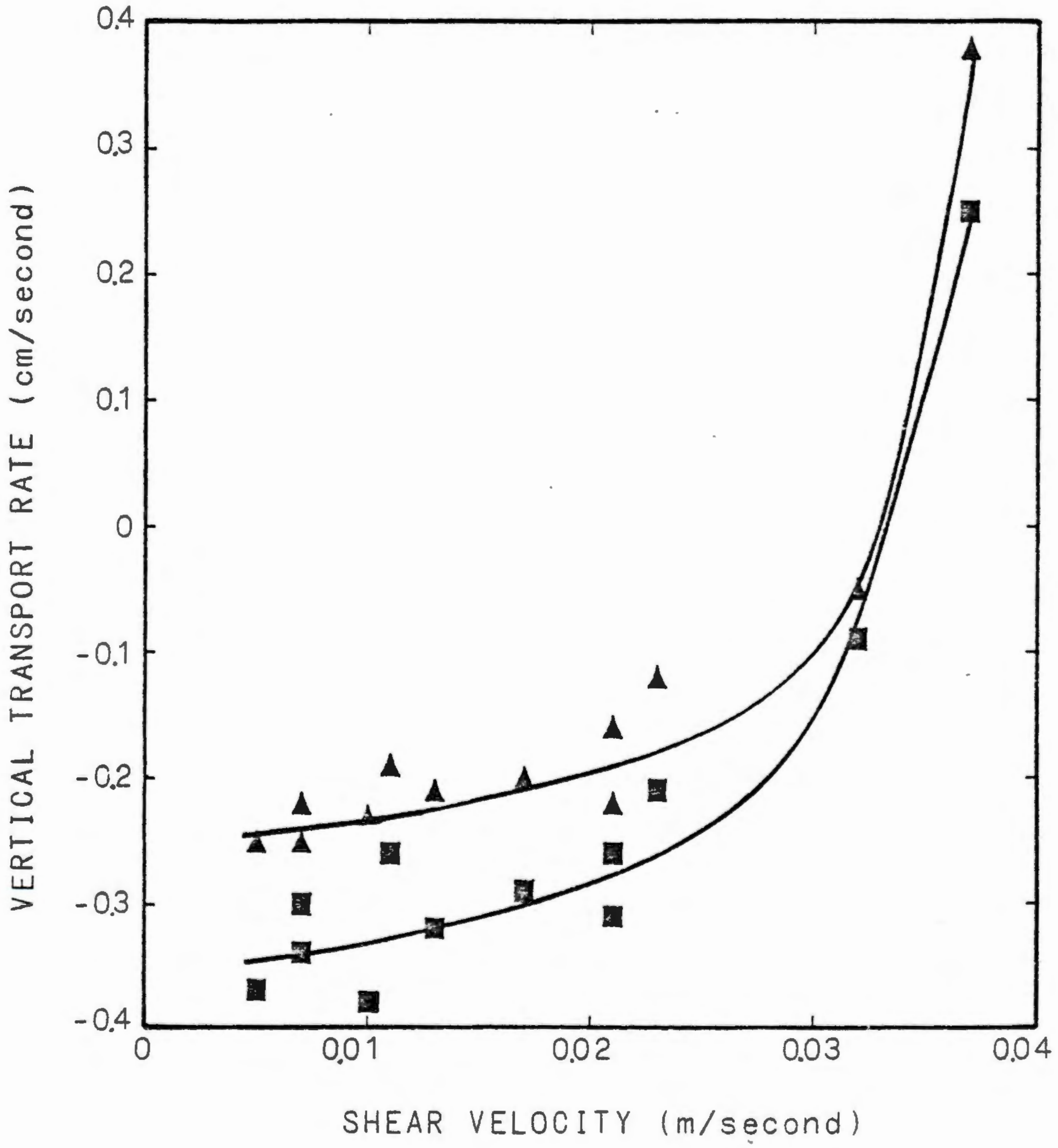

Figure 1. Vertical Transport Rate of Eggs in Flowing Water ($\pm V_f$) Graphed as a Function of the Shear Velocity of Flow

mean vertical transport was in an upward direction. The graph also substantiated that, for any given shear velocity, vertical transport is a function of egg density.

The ratio of mean vertical egg transport rate to mean terminal sinking velocity (V_f/V_s) was plotted as a function of shear velocity (V^*) in order to allow for the effects of egg density. Due to an error in measurement, the values for V_f of -0.37 and -0.38 cm/second were excluded from the data. These values indicated a mean sinking velocity in flowing water greater than that in static water. The values for V_f of +0.25 and +0.38 were also excluded since it is not possible to express a density dependence for positive and negative values of V_f in the same way.

A linear transformation was made for the data by plotting $(1.0 - \frac{V_f}{V_s})$ as a function of shear velocity on a log-log scale (Figure 2). The value 1.0 was the logical y-intercept on the graph of $y = \frac{V_f}{V_s}$ and $x = V^*$; $\frac{V_f}{V_s}$ must equal 1.0 when V^* is zero. This transformation gave the best linear fit for the model and resulted in a r^2 value of 0.67. A Model I regression was used in fitting a line to the data (Sokal, 1969).

Suspension of Eggs

Vertical egg transport was also studied in terms of percentage suspension for any given test. Percentage suspension was plotted as a function of $\frac{V_s}{KV^*}$ (Figure 3). A Model I regression (Sokal, 1969) was used in fitting a line to the data and resulted in an r^2 value of 0.85.

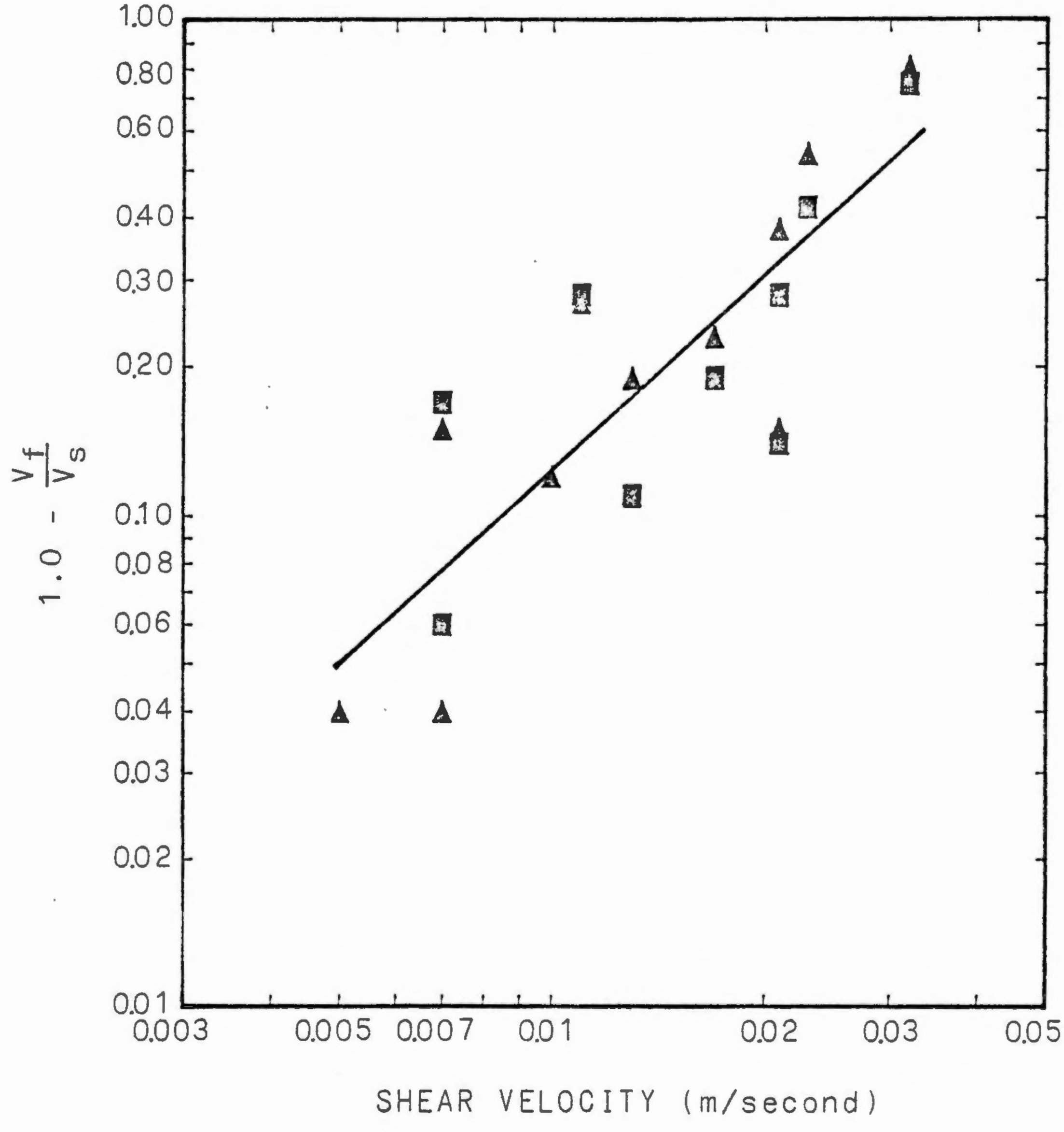

Figure 2. A Linear Transformation of V_f/V_s as a Function of Shear Velocity

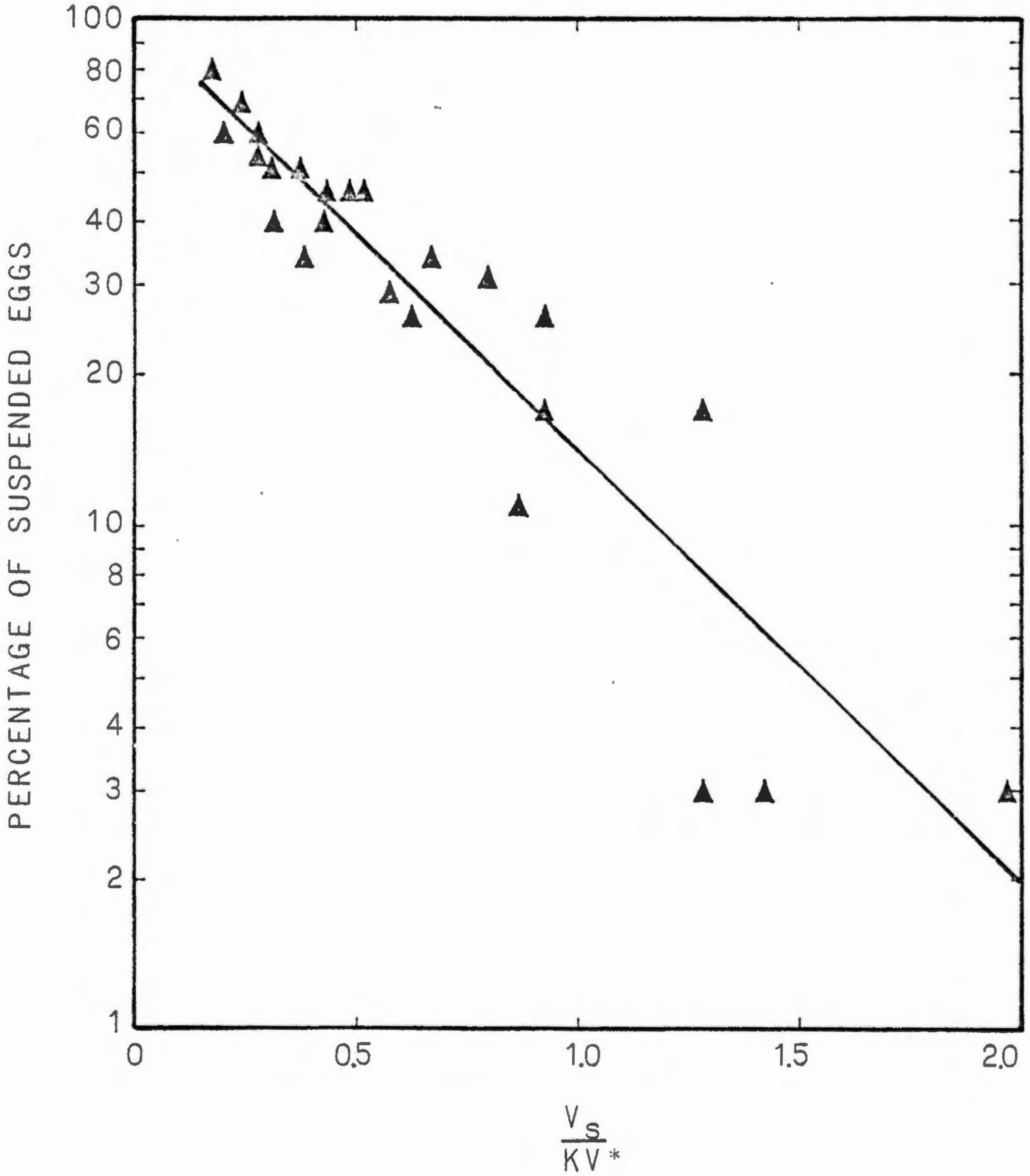

Figure 3. Percentage of Suspended Eggs Graphed as a Function of V_s/KV^*

CHAPTER IV

DISCUSSION

Terminal Sinking Velocities of Live Eggs

Statistical analysis strongly indicated that the terminal sinking velocities (and, therefore, densities) of eggs from Norris females were significantly different from those of Chickamauga females at a significance level of 75%. Possible causes for this difference were considered:

1. Condition factor and/or age of the female. Information for females was not sufficient to state condition factors. However, no fish was in notably poor condition. One Norris female weighed within one pound of a Chickamauga female taken in the same year; a significant difference was noted for those females despite the similarity in weight. The age of females was not determined; however, considering the weight range, it seemed unlikely that eggs of Norris females differed from those of Chickamauga females on the basis of female age. This is not to infer that differences would not exist for females in a wider range of size or age.

2. Male broodfish. No information was available on the size or age of male broodfish. All of the Norris females were mated with Norris males. Two of the Chickamauga females were mated with Chickamauga males; one of the 1979 females was mated with a Cherokee Reservoir and Chickamauga Reservoir male. Since all but one male was taken from the same reservoir as its mate, male contributions can neither be verified or ruled out.

3. Strain of fish. Due to past stocking procedures in the state of Tennessee, it was impossible to determine the original strain of the

striped bass used in this study. Striped bass of different strains in the size range studied are likely to be present in both lakes (Cottrel, personal communication).

It has been suggested that egg diameters, at least, do vary for females from widely different locations. Mansueti (1958) summarized data for egg diameters from North Carolina, California and Maryland females and stated that his data did not support such a thesis.

4. Age of eggs tested. Albrecht (1964) noted no differences among quarter stages of egg development in measurements of egg diameter and specific gravity. Eggs used in his study were taken from the San Joaquin and Sacramento Rivers.

5. Water temperature of the tests. Terminal egg sinking velocity tests were conducted in a range of 21 to 22 C for eggs from Norris females and 23 to 25 C for eggs from Chickamauga females. In order to determine whether differences in water temperature would be likely to significantly affect the results of the analysis of variance, specific gravities were calculated for the eggs from each female.

Specific gravity can be calculated for eggs when egg diameter, terminal sinking velocity and water temperature are known. The appropriate equation to be used for eggs with terminal sinking velocities and diameters similar to those of this study is

$$\text{specific gravity} = 0.75\ C_D + F^2 + 1.0$$

where C_D is a coefficient of drag and F is the Froude number for the egg. A further explanation of this equation is given by Chow (1964).

Specific gravities based on mean egg diameters and mean terminal sinking velocities at a given temperature are given in Table 15. It was concluded that the results of the analysis of variance were not

Table 15. Specific Gravity of Eggs from 5 Norris and 3 Chickamauga Females

Female	Specific Gravity	Mean Specific Gravity
Norris (A)	1.00134	1.00185
Norris (B)	1.00186	
Norris (C)	1.00223	
Norris (D)	1.00176	
Norris (E)	1.00204	
Chickamauga (X)	1.00066	1.00084
Chickamauga (Y)	1.00097	
Chickamauga (Z)	1.00090	

seriously affected by the temperature differences of the tests.

6. Effect of hormone injections on egg density. All of the females represented in this study were injected with chorionic gonadotropin at the hatchery. This hormone is commonly used in striped bass culture to induce ovulation in the female. There must be some question as to whether the use of this hormone affects egg density. All efforts toward obtaining eggs from non-injected females for this study were unsuccessful. With respect to the analysis of variance, any hormone effects would have to be masked in what appears to be an environmental or habitat effect.

Chickamauga females, on a given date, may be in a greater stage of progression toward spawning. If hormone injections result in somewhat premature ovulation, it is conceivable that eggs from Chickamauga females might be more fully developed and slightly larger in diameter than eggs from Norris females when the fish are captured and injected on or about the same date.

Any suggestions as to the effects of chorionic gonadotropin on egg density are purely speculative. No data was recorded concerning stage of egg development at capture. All females used in this study spawned 20 to 36 hours after injection. Albrecht (1964) reported a mean specific gravity of 1.00050 and a mean egg diameter of 3.7 mm for egg samples from the San Joaquin and Sacramento Rivers, California. The mean specific gravities of eggs from Norris and Chickamauga Reservoir used in this study were 1.00185 and 1.00084 respectively. The mean egg diameters for the two groups were 2.7 mm (Norris) and 2.8 mm (Chickamauga). It would appear that females in this area produce smaller and denser eggs than those of Albrecht's study, or else, hormone injections do result in the release of smaller and denser eggs than those naturally spawned.

Relationship of Terminal Sinking Velocity to Egg Measurements

Albrecht (1964) observed that larger eggs tended to be more buoyant and, therefore, more desirable providing that recruitment is correlated with egg survival. The results of this study indicated that terminal sinking velocity or buoyancy is more highly correlated with the ratio of oil to yolk diameter. Although egg diameter was highly correlated with terminal sinking velocity, it is felt that it would be a mistake to base differences in terminal sinking velocity on this one measurement.

Vertical Egg Transport in Flowing Water

When the mean terminal sinking velocity in static water is known for a group of eggs, one can predict the mean negative vertical transport rate for those eggs under conditions of known shear velocity (Figure 2, page 37). With extrapolation of the curve in Figure 2, a mean upward transport is indicated for an egg when a shear velocity approximating 0.05 m/second is exceeded. As egg density approaches that of water, the predicted differences in vertical transport rates at different shear velocities continually decrease to the point where the graph is of no practical use. It was felt, however, that Figure 2 could be used to predict mean vertical transport rates for most, if not all, striped bass eggs likely to be encountered.

Mean vertical transport rates, however, cannot be used to predict numbers of eggs which might be suspended at a given shear velocity. In terms of hatching success, it is more productive to approach the problem with a method based on the relative number of eggs expected to be suspended in a given flow.

Suspension of Eggs

Values for the percentage of eggs suspended at a given shear velocity were graphed in Figure 3 (page 38) as a function of $\frac{V_s}{KV^*}$. These data enable one to predict the percentage of eggs expected to be suspended under known conditions.

In this study, water temperatures were the same (25.5 C) for measurements of terminal sinking velocities in static water (V_s) and vertical transport velocities in the flume (V_f). If Figure 3 is used for predictive purposes, V_s should be measured at the same water temperature existing in the field.

The value of K, von Karman's constant, was taken as 0.4 for this study. The value of K, however, may change for certain field conditions. As mentioned previously, the value of this constant has been established as 0.4 for clear water; however, it has been given a value as low as 0.21 for suspended sediment concentrations of 15.8 grams/liter (Henderson, 1966).

The value of V* may be approximated for natural streams with a knowledge of mean velocity, stream width and depth, and substrate roughness (Chow, 1959).

If the velocity profiles of Figures A-1 to A-12 in the Appendix are referred to, it can be seen that the velocity gradients of theoretical profiles for fully developed flow were greater than those actually measured in the flume. The shear velocity values used in this study were derived from equations for fully developed flow. Since shear velocity increases with increasing velocity gradients, it was assumed that values used in this study were somewhat over-estimated. This means that the relationships given for vertical egg transport rates or percentage of suspension and shear velocity were conservative. Somewhat lower shear velocities might be expected to have the same effects observed in the laboratory flume.

It was not possible to determine distributions of eggs over depth under existing laboratory conditions. However, it was felt that the distribution of suspended eggs in a flow should follow the form of distribution equations developed for suspended sediment (Vanoni, 1963; Chow, 1964; Henderson, 1966).

Estimating Egg Suspension in Natural Streams

It should be stressed that shear velocity will change along the reach of a stream as channel parameters, substrate and mean water velocity change. Figure 4 illustrates how shear velocity varies with

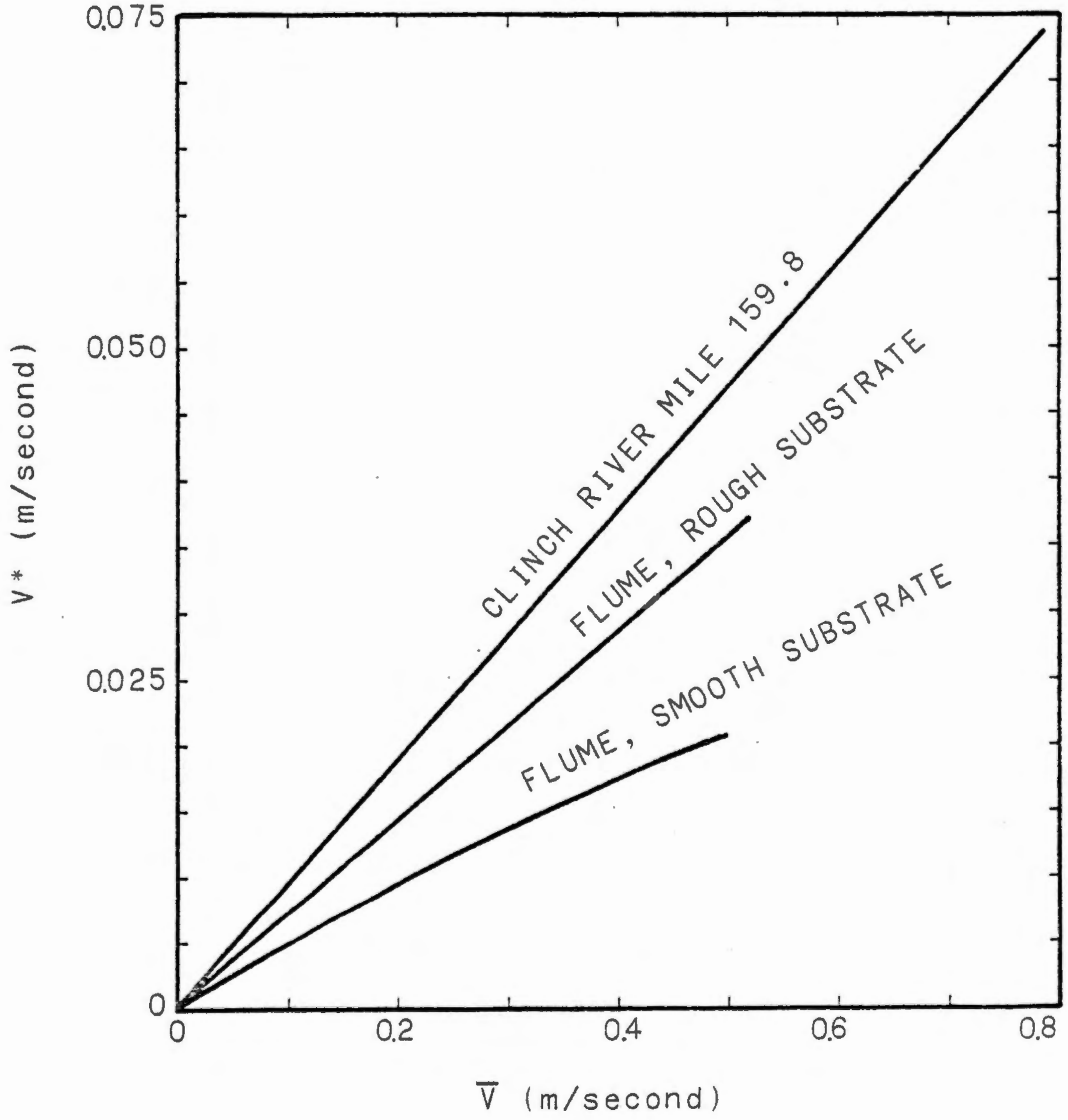

Figure 4. An Illustration of Variation in Shear Velocity with Substrate Roughness and Mean Velocity of Flow

mean velocity and roughness. Changes in shear velocity must be considered for any field application of this study.

Mature striped bass females have been captured in the Clinch River, a tributary of Norris Reservoir, in the vicinity of Clinch River Mile 151 (CRM 151). This section of the Clinch River was chosen to illustrate a method by which the results of this study could be used to predict the degree of egg suspension in natural streams.

Mean velocities for CRM 151, 140 and 129 were calculated from data provided by the United States Geological Survey office in Knoxville and Tennessee Valley Authority, Data Services Branch. Mean water velocities were based on minimum and maximum discharges for 15 April - 15 June in the years 1965 - 1975 and appropriate stream cross-sections. Corresponding shear velocities were calculated according to a standard equation based on Manning's coefficient of roughness (Chow, 1959; see Appendix B). A value of 0.035 was assumed for Manning's "n".

The mean terminal sinking velocity (V_s) of water-hardened Norris eggs was given a value of 0.40 cm/second--equivalent to the mean of all live eggs studied for Norris Reservoir females. V_s for eggs 0 to 1.5 hours old was assumed to be equal to the mean indicated by the one test completed for non-water-hardened eggs in this study. Eggs were assumed to move downstream at a mean velocity equal to that for the water. Actually, egg transport is expected to lag somewhat behind that of water. Time required for hatching was taken to be 48 hours at 18 C and 40 hours at 19 C (incubation periods are summarized by Doroshev, 1970 and Bayless, 1972).

Data pertinent to a field study are summarized in Table 16. It seems unlikely, based on the information in Table 16 (including assumed

Table 16. An Example of Data Necessary for Estimating Egg Suspension in Natural Streams

V_s (cm/sec)	Stream Section	$\overline{V}$ (m/second) Min.	$\overline{V}$ (m/second) Max.	Transport Time (hours) Min. $\overline{V}$	Transport Time (hours) Max. $\overline{V}$	$\frac{V_s}{KV^*}$ Min. $\overline{V}$	$\frac{V_s}{KV^*}$ Max $\overline{V}$	Predicted Suspension Min. $\overline{V}$	Predicted Suspension Max. $\overline{V}$	Water Temp. (C)	Time Remaining to Hatching (hours) Min. $\overline{V}$	Time Remaining to Hatching (hours) Max. $\overline{V}$
0.50	CRM 151-150	0.21	0.29	2.0	1.5	0.69	0.43	21-29%	38-44%	18 19	46 38	46.5 38.5
	CRM 150-140	0.14	0.20	32.0	22.0	0.91	0.50	13-20%	35-40%	18 19	14 6	24.5 16.5
0.40	CRM 140-129	0.05	0.08	45.0	28.0	3.33	1.43	0	0-11%	18 19	0 0	0 0

values for terminal egg sinking velocity), that hatching success in the Clinch River would be sufficient to establish a natural population of striped bass. It has been suggested, however, that striped bass eggs are transported downstream at, perhaps, 80% of the mean water velocity (Neal, 1969). If an 80% lag in transport time is assumed, it would be estimated that 35 to 40% of eggs released at CRM 151 would remain suspended in the given low flows and hatch at temperatures of 18 to 19 C before reaching CRM 140.

Periods of low water velocity on this section of the river are associated with high water discharges; backwater effects from Norris Reservoir extend to approximately CRM 151 during periods of maximum reservoir pool level. Based on this study, it would appear that low flow rates in this section of the river are less detrimental to predicted hatching success than are the more rapid flows which carry the eggs into the reservoir before hatching can occur.

Comparison of Field Observations and Laboratory Results

The lowest reported flow rate (during spawning) for a stream in which striped bass are known to maintain self-sustaining populations is 0.15 m/second in the Congaree and Wateree Rivers of the Santee-Cooper Reservoir system (May and Fuller, 1962). This mean velocity was given for sections near the mouth of each river.

Appropriate stream cross-sections were not available; however, some comparison can be made with the results of this study.

1. If the stream cross-sections were the same as would be observed for Clinch River Mile 159.8 and substrate roughness was similar, the shear velocity would have been approximately 0.015 m/second

(Figure 4, page 45). The results of this study (Figure 3, page 38) indicated that 37-42% of eggs with a V_s of 0.40 cm/second would be suspended. If the channel bottom of either river was smoother than that at CRM 159.8, the shear velocity would be less and suspension would be predicted for fewer eggs. However, no information is available for a cross-section at CRM 159.8 with a mean velocity of 0.15 m/second. The lowest recorded mean velocity was approximately 0.25 m/second with a cross-sectional area of 917 ft.^{2} (240 ft. wide x 3.8 ft. deep). The channel bottom at this cross-section is irregular.

2. If the stream cross-section was larger or smoother than that CRM 159.8, shear velocity would be less than 0.015 m/second and suspension would be predicted for a smaller number of eggs.

3. If the stream cross-section was smaller than that for CRM 159.8, shear velocity would be greater and suspension would be predicted for a larger percentage of eggs.

4. If striped bass eggs of Santee-Cooper females are less dense than those of this study, the relative numbers of suspended eggs would be greater under any of the above conditions.

When the conditions stated above are considered, it would seem that the results of this study may indicate a greater shear velocity than is necessary to suspend a given number of eggs. As previously stated, it was felt that the values of shear velocity for flume tests were overestimated. This leads to a conservative estimate of the relative number of eggs suspended at a stated shear velocity.

It is also true that eggs will saltate (bounce along the bottom) at a lower shear velocity than is necessary for suspension. Saltation might be sufficient for egg survival, particularly in the later stages of egg development. However, the possibility of eggs being mechanically damaged or trapped in small pockets of the substrate during the saltation process must be considered.

CHAPTER V

SUMMARY

Some degree of suspension has been shown to be necessary for successful hatching of striped bass eggs. This study was undertaken in order to determine flow requirements necessary for suspension. In order to determine whether or not suspension is possible in a given stream, some information about the eggs and the stream itself must be known.

The results indicated by this study are as follows:

1. Differences in the terminal sinking velocity or density of striped bass eggs appeared to be associated with some environmental factor. However, the effects of chorionic gonadotropin injections could have conceivably caused or contributed to the differences observed for eggs of females from different reservoirs.

2. The terminal sinking velocity of striped bass eggs was more highly correlated with the ratio of oil diameter to yolk diameter (partial correlation coefficient of 0.51 at a 0.0001 probability level) than it was to egg diameter (partial correlation coefficient of 0.05 at a 0.0001 probability level).

3. The vertical transport of striped bass eggs may be considered a function of egg density and shear velocity. Mean vertical transport rate in a downward direction may be determined if the terminal sinking velocity of eggs in static water and the shear velocity of the stream is known.

4. The relative number of striped bass eggs which will be suspended may be approximated for known shear velocities when the mean

terminal sinking velocity for eggs is known.

The distribution of suspended eggs over depth may well follow the equations set forth for suspended sediment distributions in hydraulics engineering literature. Additional research is needed in this area.

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LITERATURE CITED

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APPENDIXES

APPENDIX A

VELOCITY PROFILES FOR LABORATORY TESTS

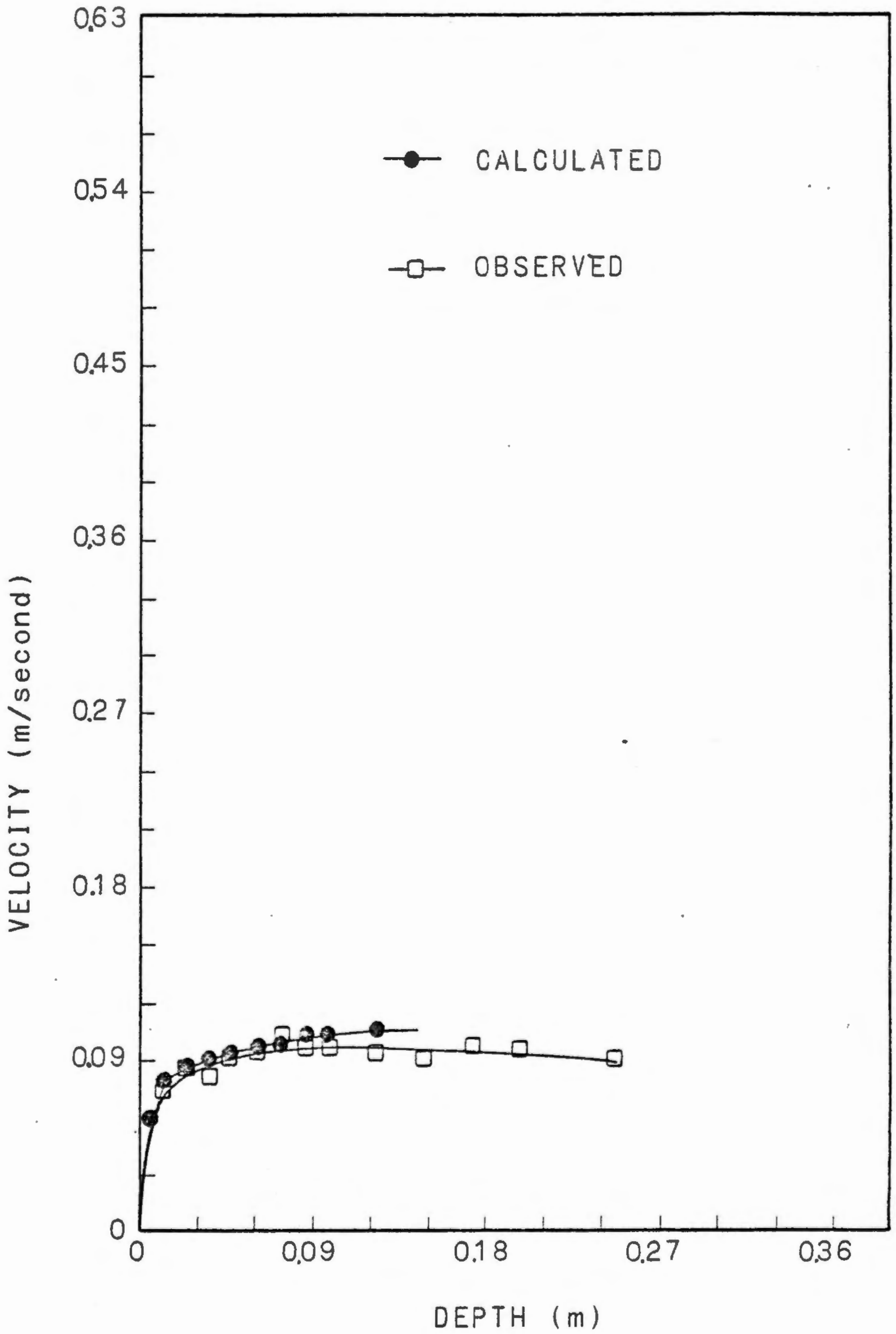

Figure A-1. Calculated and Observed Velocity Profiles for a Laboratory Flow of 0.09 M/Second Over a Smooth Substrate

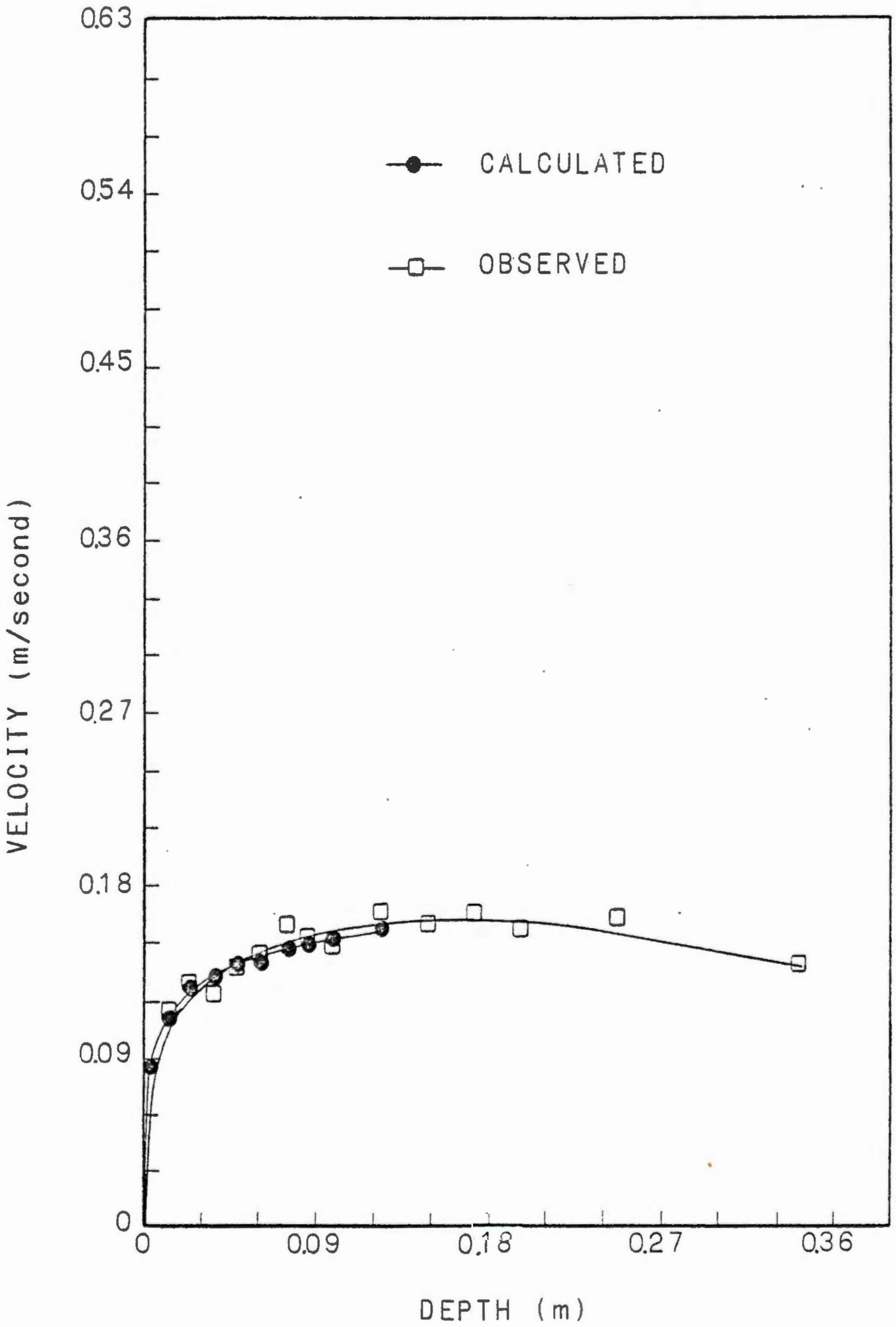

Figure A-2. Calculated and Observed Velocity Profiles for a Laboratory Flow of 0.16 M/Second Over a Smooth Substrate

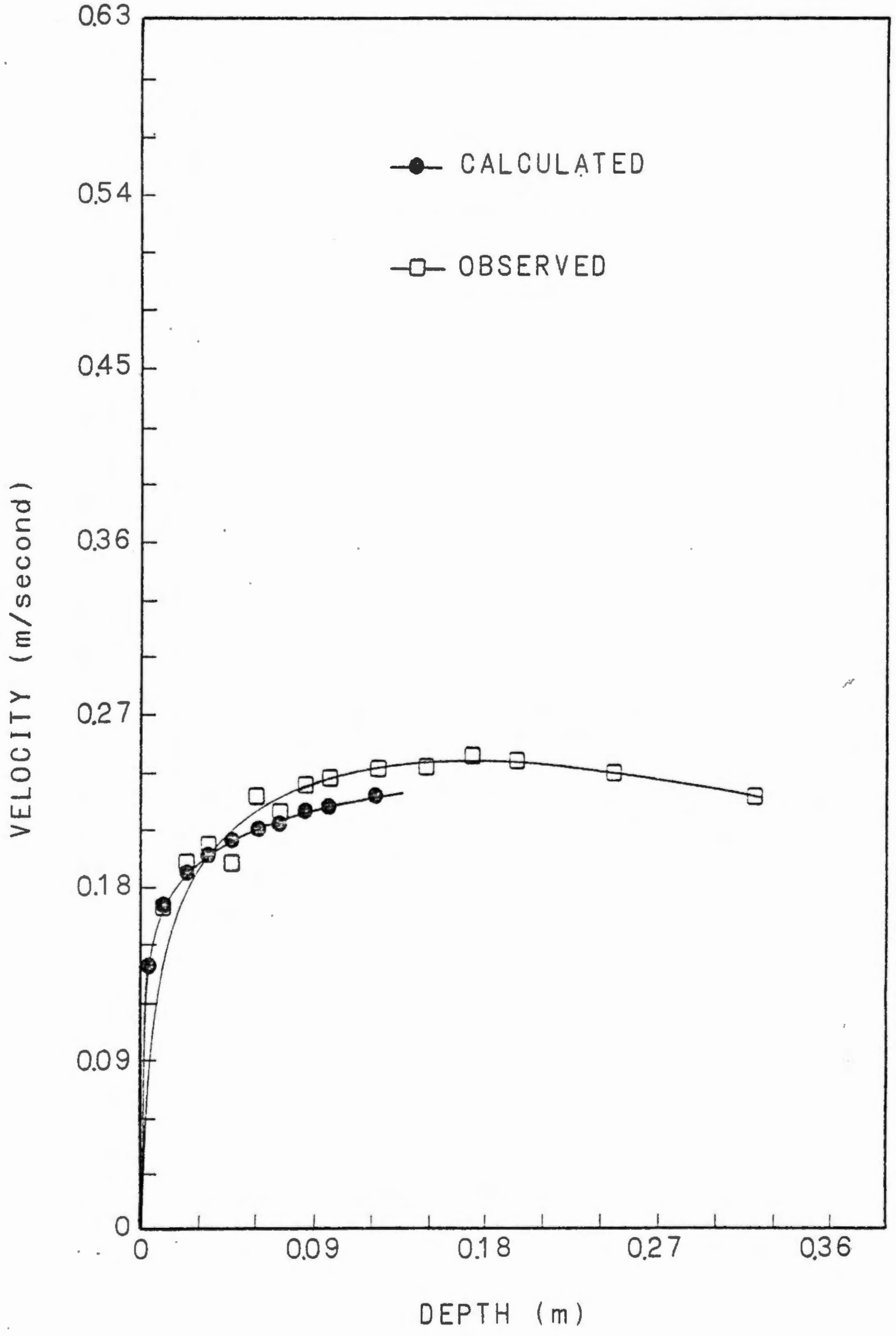

Figure A-3. Calculated and Observed Velocity Profiles for a Laboratory Flow of 0.23 M/Second Over a Smooth Substrate

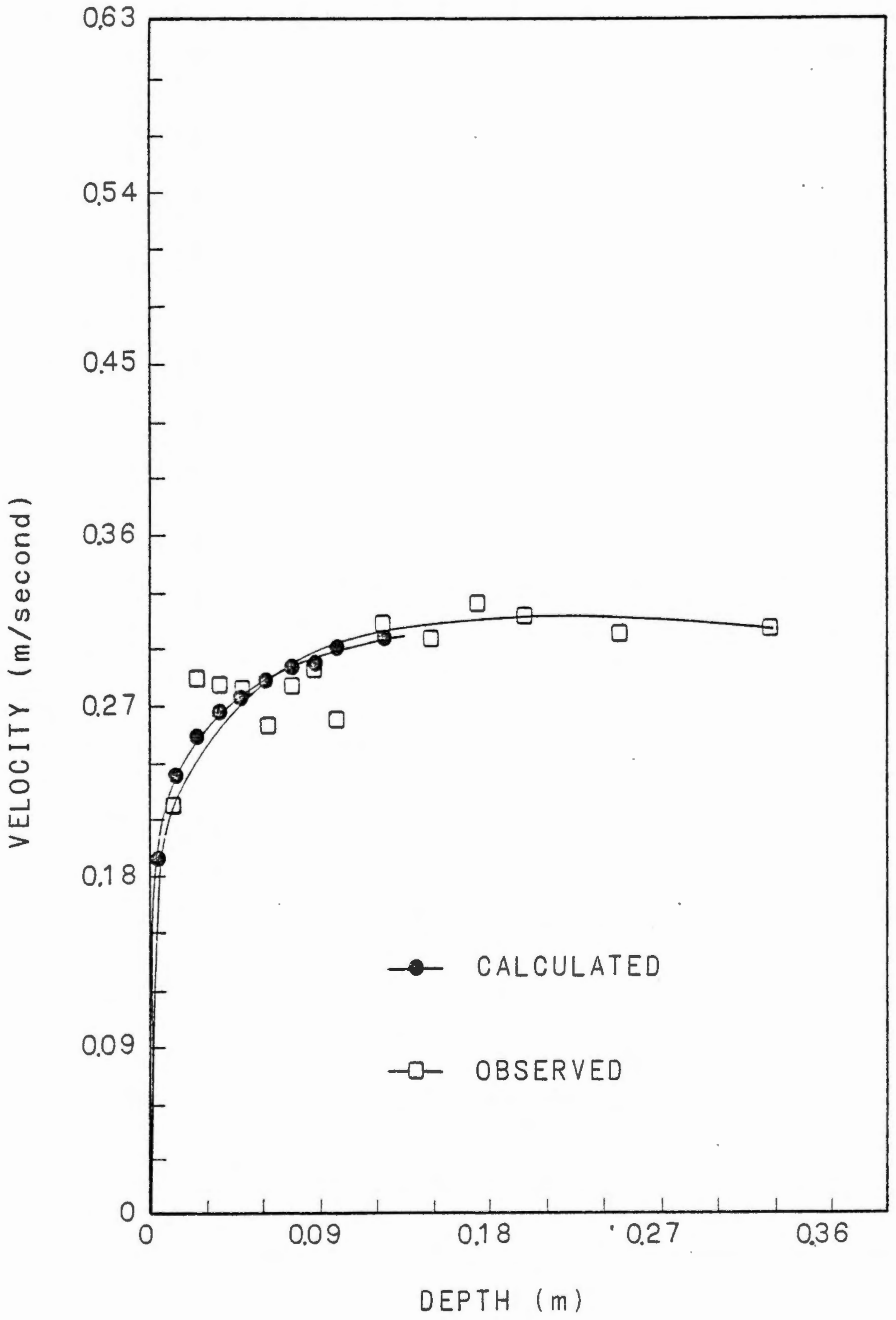

Figure A-4. Calculated and Observed Velocity Profiles for a Laboratory Flow of 0.30 M/Second Over a Smooth Substrate

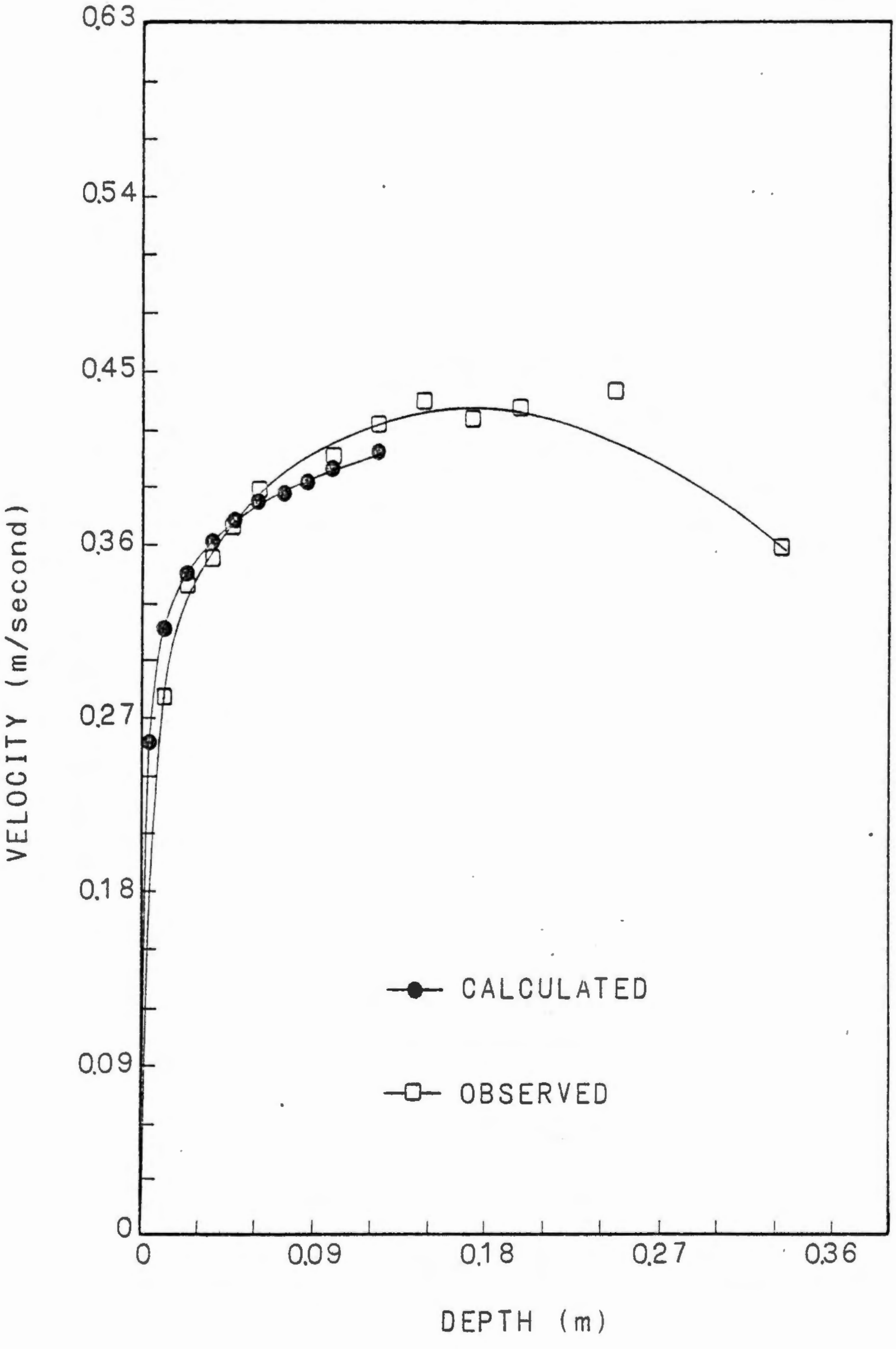

Figure A-5. Calculated and Observed Velocity Profiles for a Laboratory Flow of 0.41 M/Second Over a Smooth Substrate

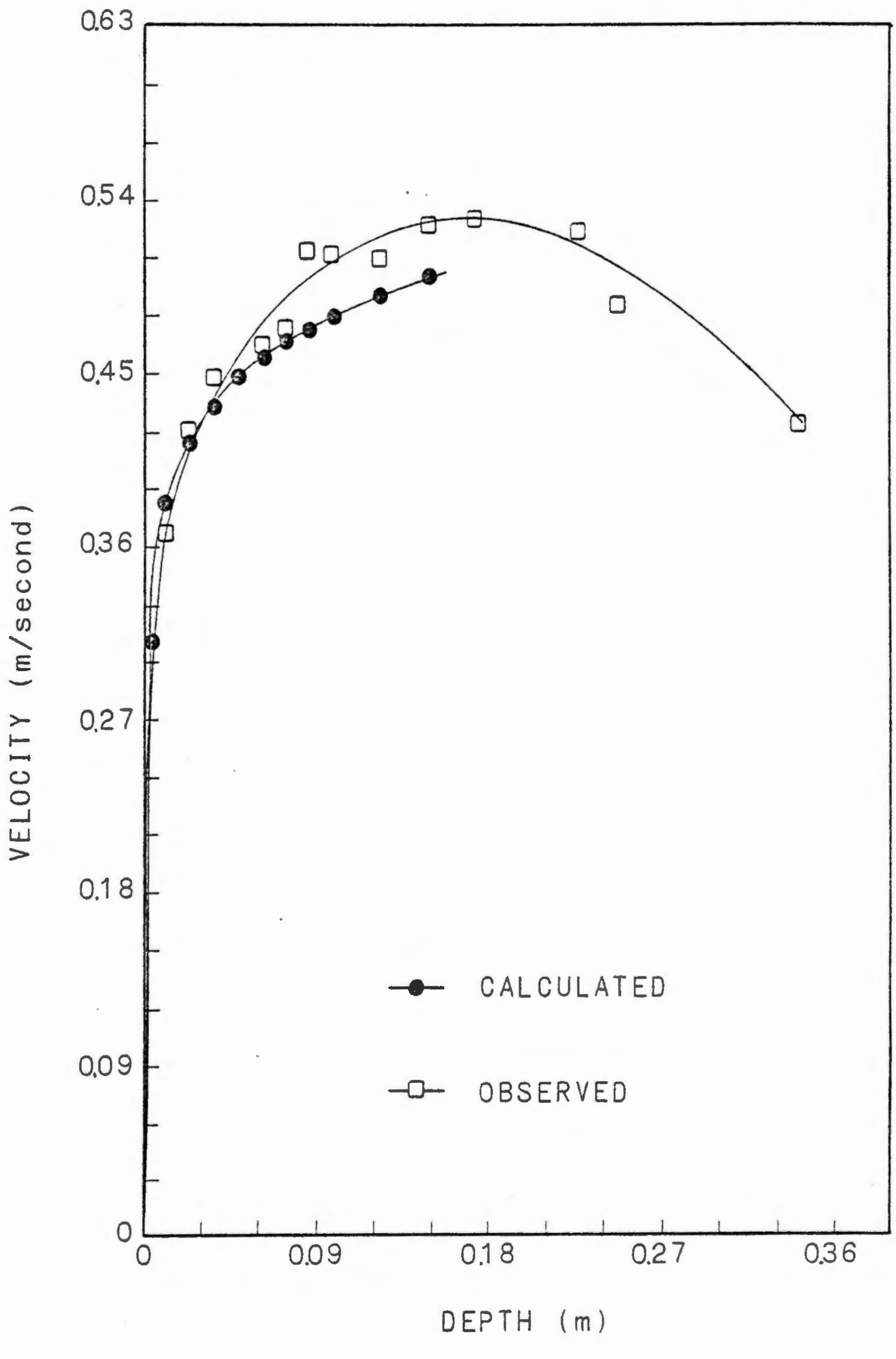

Figure A-6. Calculated and Observed Velocity Profiles for a Laboratory Flow of 0.50 M/Second Over a Smooth Substrate

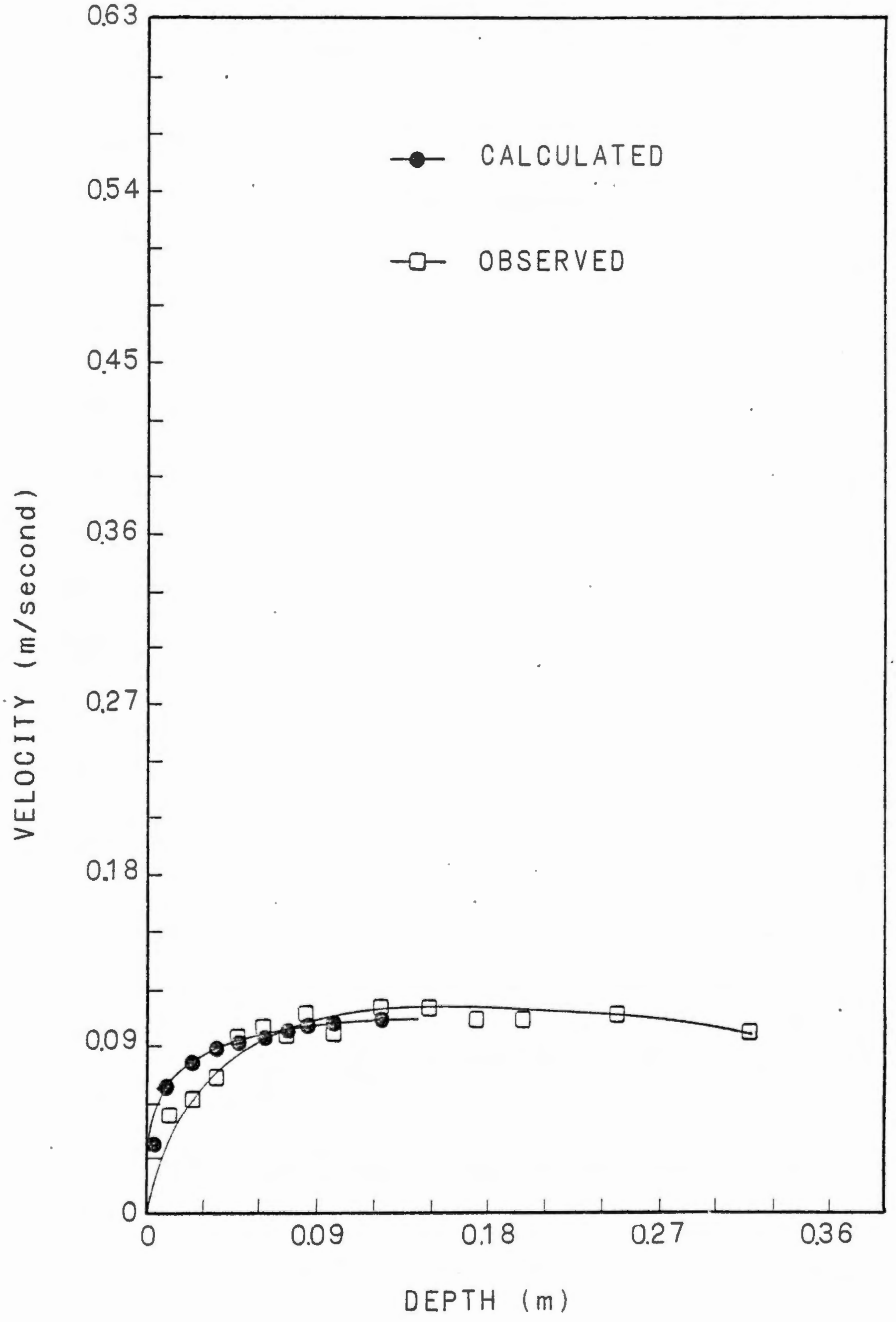

Figure A-7. Calculated and Observed Velocity Profiles for a Laboratory Flow of 0.10 M/Second Over a Rough Substrate

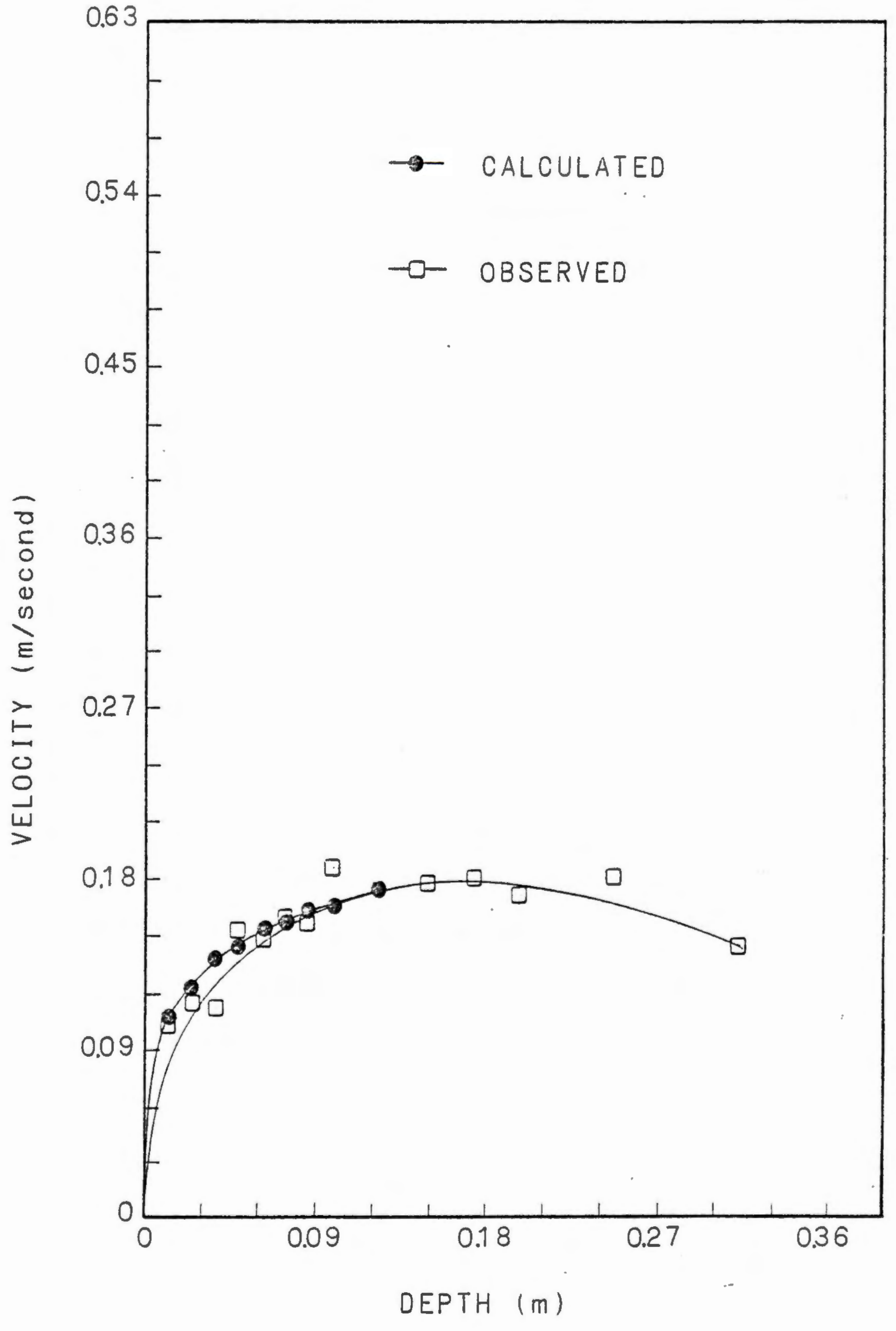

Figure A-8. Calculated and Observed Velocity Profiles for a Laboratory Flow of 0.16 M/Second Over a Rough Substrate

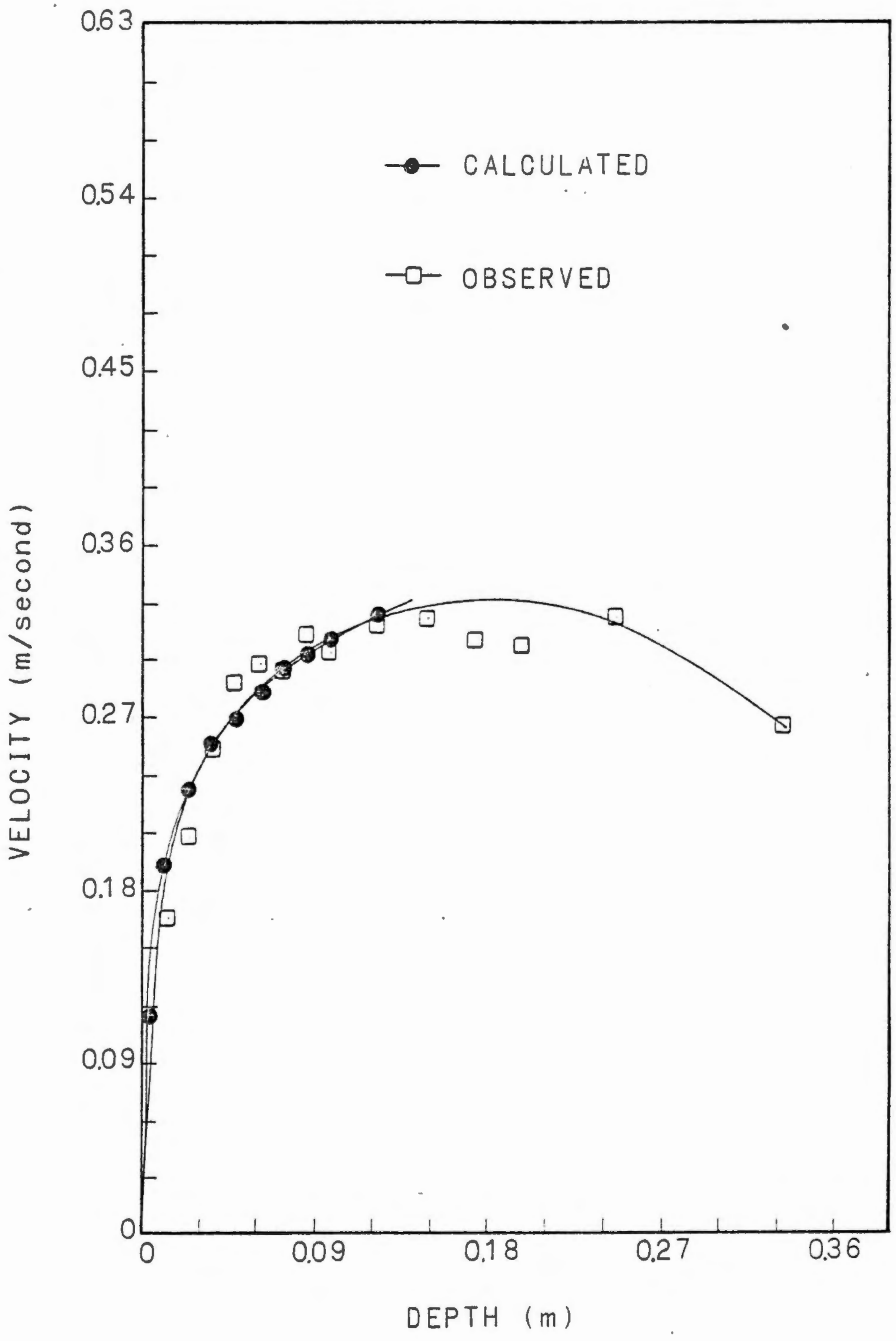

Figure A-9. Calculated and Observed Velocity Profiles for a Laboratory Flow of 0.29 M/Second Over a Rough Substrate

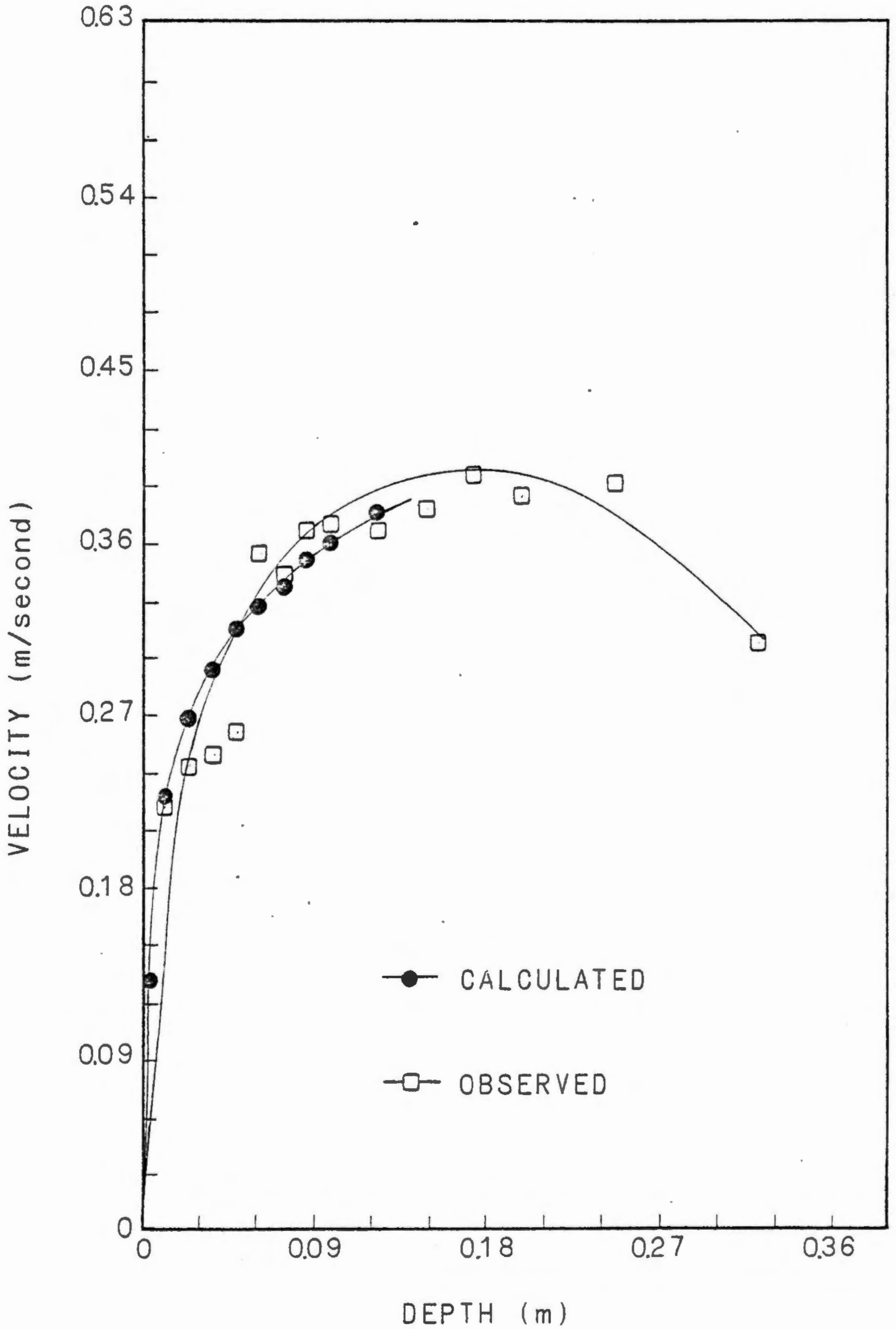

Figure A-10. Calculated and Observed Velocity Profiles for a Laboratory Flow of 0.33 M/Second Over a Rough Substrate

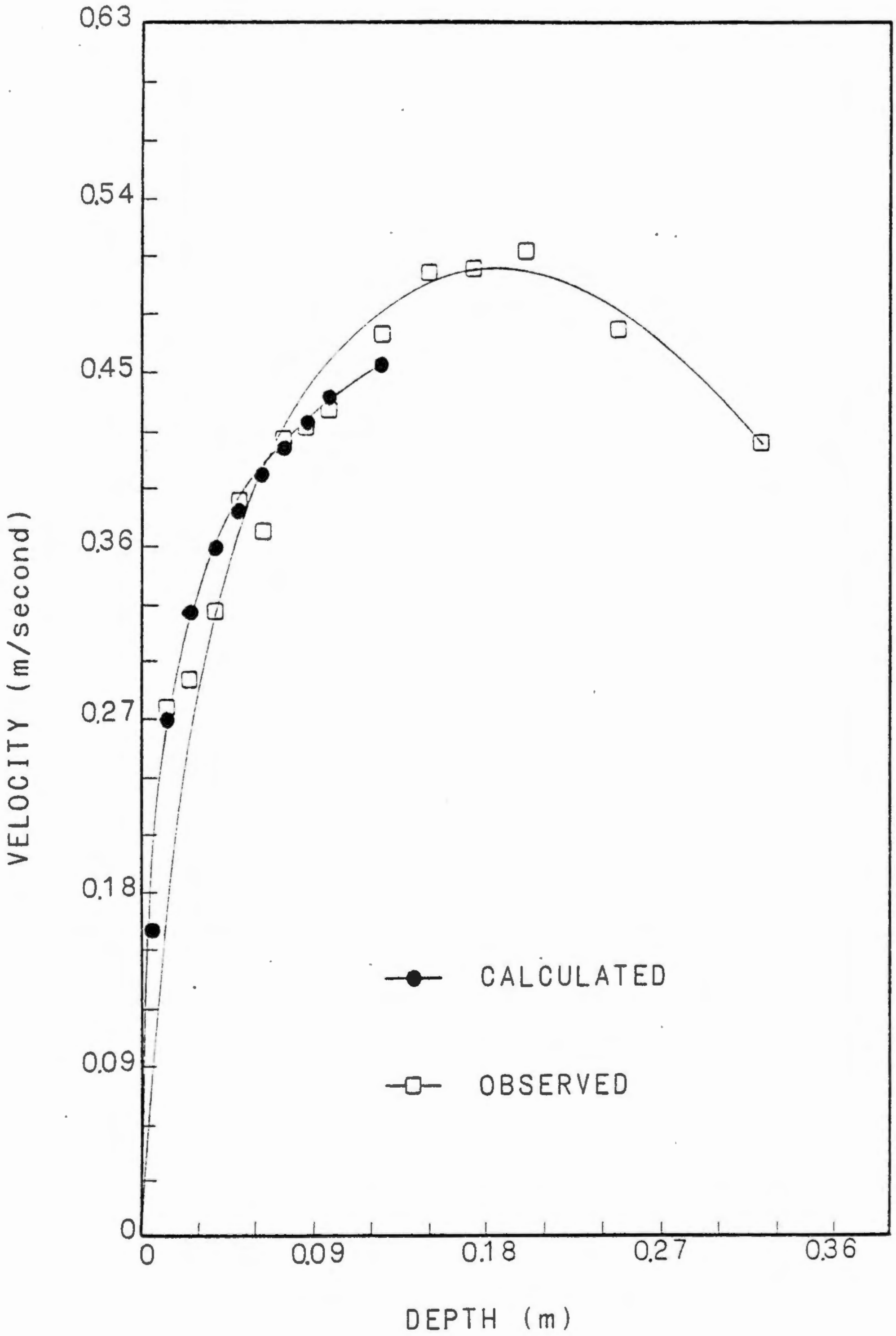

Figure A-11. Calculated and Observed Velocity Profiles for a Laboratory Flow of 0.45 M/Second Over a Rough Substrate

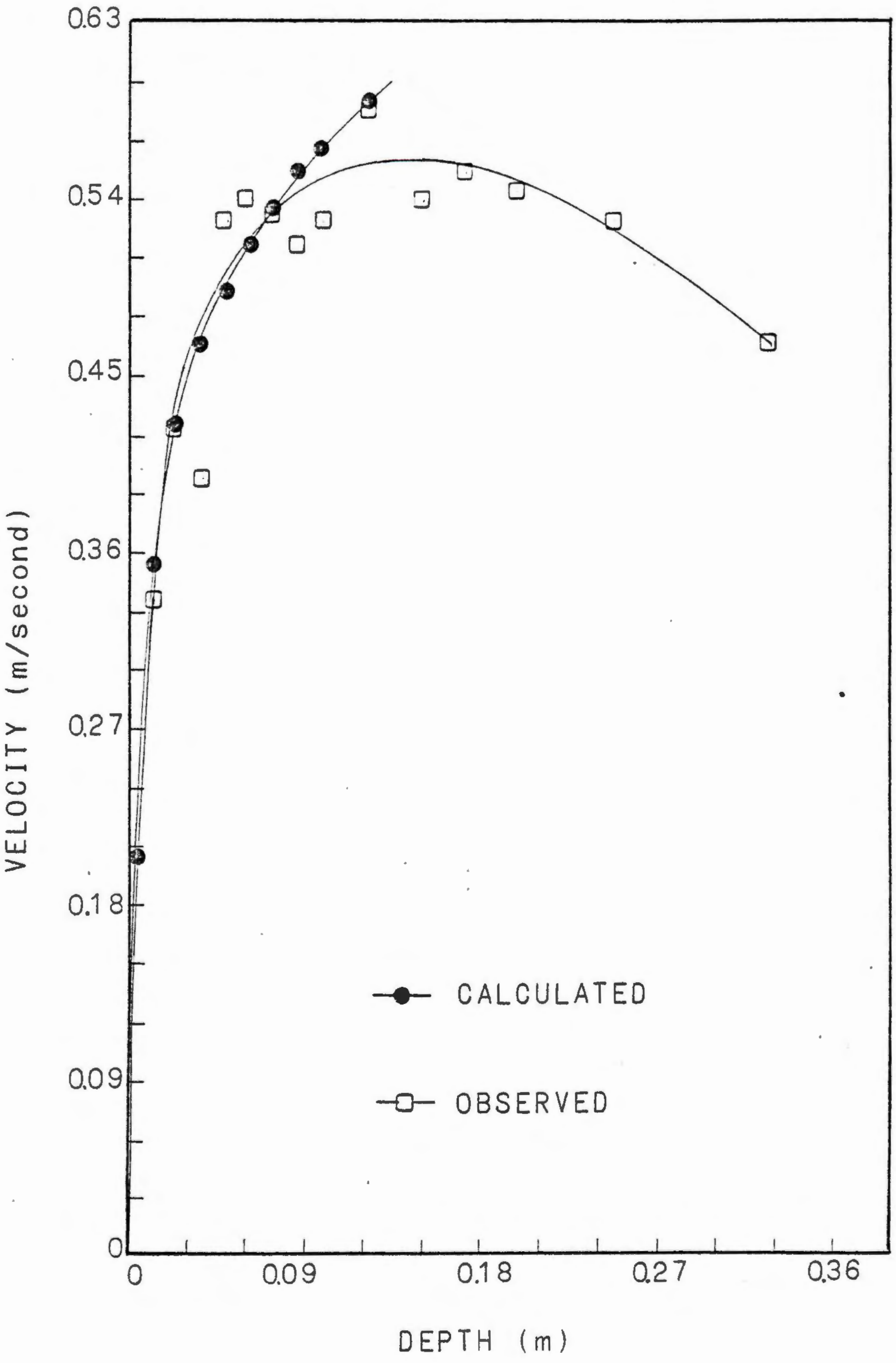

Figure A-12. Calculated and Observed Velocity Profiles for a Laboratory Flow of 0.52 M/Second Over a Rough Substrate

APPENDIX B

MATHEMATICAL APPENDIX

Equations for Calculating Shear Velocity

When the mean velocity of flow is known, shear velocity may be calculated for natural streams by using either of the following equations (Chow, 1959):

$$1. \quad V^* = \frac{\overline{V}}{C + 5.75 \log \frac{R}{k}}$$

where V* is shear velocity and $\overline{V}$ is mean velocity. R is the hydraulic radius of the steam and

$$R = \frac{WD}{W + 2D}$$

where W is width and D is depth. Substrate roughness is represented by k-- the height of approximately 65% of the roughness elements. C is a constant based on the Froude number of the flow. The average value of C for a range of flows may be taken as 6.25. Average values of C for various Froude numbers are given on page 206 of Chow (1959). The Froude number of flow depends on the mean velocity and depth of the flow; it is calculated as

$$F = \frac{\overline{V}}{gD}$$

where g is acceleration of gravity.

$$2. \quad V^* = \frac{\overline{V}}{\frac{1.49}{n} \cdot R^{1/6} \cdot \frac{1}{g}}$$

where V*, $\overline{V}$, R and g represent the same properties as given for Equation 1. Channel roughness is represented by "n"--Manning's coefficient of roughness. Values for Manning's n are approximated for various stream conditions by Chow (1959). The above equation is derived from two equations stated by Chow (1959):

$$\frac{\overline{V}}{V*} = \frac{C}{g} \text{ and } C = \frac{1.49\ R^{1/6}}{n}$$

VITA

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