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Project Completion
Report No. 544

THE EFFECTS OF SILTATION ON EMBRYONIC MORTALITY OF TROUT

JOSEPH F. KOONCE
and
MITSUO TERAGUCHI

DEPARTMENT OF BIOLOGY
CASE WESTERN RESERVE UNIVERSITY
CLEVELAND, OHIO

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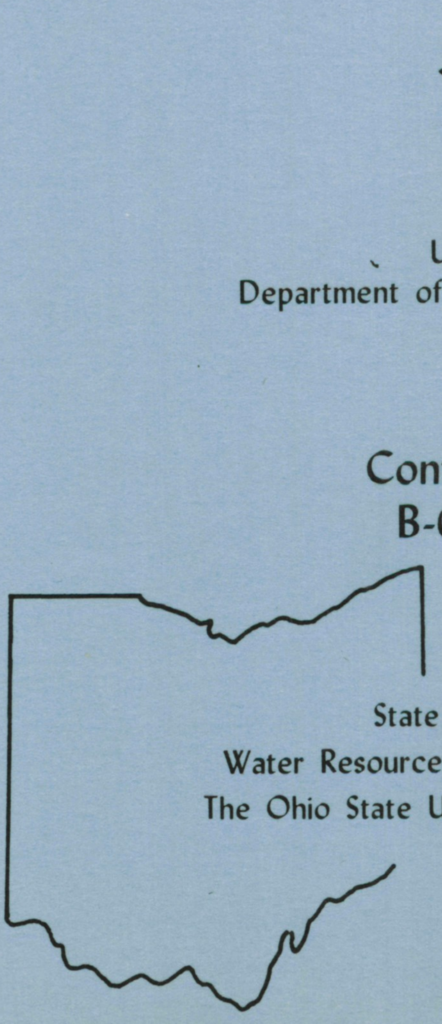

State of Ohio
Water Resources Center
The Ohio State University

THE EFFECTS OF SILTATION ON EMBRYONIC MORTALITY OF TROUT

Completion Report for Project No. B-071-OHIO
under the Matching Grant Program of the Office
of Water Research and Technology

by

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ABSTRACT

In this research project, we tested the hypothesis that siltation in streams eliminates natural reproduction by increasing mortality during embryonic development. We knew that several environmental factors (temperature, dissolved oxygen, and flow rates) affected embryonic development. These factors all change with siltation in streams, but the interaction of these factors with silt needed more experimentation. If we could determine the extent to which silt alone affected embryo mortality, we could design procedures to improve trout reproduction in silted streams. In the first 18 months of our project, we tried to define the critical period of susceptibility of trout embryos to siltation. Our findings were that siltation alone did not influence embryonic development. During the remaining six months of the project we explored the effects of siltation on spawning behavior and initiated a new project to determine the feasibility of selecting trout strains, which would be more tolerant to the marginal conditions in Northeastern Ohio.

INTRODUCTION

Siltation is a factor that has been implicated in reducing spawning success and reproduction of natural trout populations. Increased sediment load in streams is a consequence of alterations of the drainage basin of a stream and it frequently accompanies urbanization. As a consequence, many otherwise suitable trout streams may have been degraded by excessive siltation. This type of marginal stream is an important management problem. Restoring such streams is often well beyond reasonable costs. We believe that combined habitat improvement as well as judicious stocking programs could produce more reasonable cost/benefit ratios and thus be desirable alternative strategies. This study, therefore, was initiated to test some procedures to improve trout reproduction in marginal trout streams.

Siltation of streams has a series of interacting consequences. Peters (1962) reviewed evidence that siltation could produce a progressive downstream decrease in intragravel flow and dissolved oxygen concentration. These interacting factors clearly influence embryo mortality (Bianchi, 1963). By themselves, intragravel flow and dissolved oxygen concentration influence embryonic mortality (Coble, 1961; Silver _et al_., 1963; and Shumway _et al_., 1964). In addition, siltation may change the stream bed gravel composition and thereby influence emergence (Phillips _et al_., 1975; and Hausle and Coble, 1976). It is not clear, however, whether silt accumulation influences embryonic mortality directly. If such a direct effect of siltation were not observed, then habitat modification to enhance intragravel flow might significantly improve natural reproduction in marginal streams.

The objectivesof our study, therefore were twofold:

1. To test the hypothesis that substrate sedimentation is the major limit to trout reproduction in streams with marginal water quality because it inhibits embryonic development during the pregastrula stage.
2. To test a stream management scheme for marginal, sedimented streams that is primarily designed to promote useable trout populations by eliminating high mortality during embryonic stages.

PROCEDURE AND RESULTS

In the initial design of our research, we planned for work in three major phases. First we wanted to obtain some baseline data for a marginal trout stream in our area, and from these data we would select appropriate sites for habitat modification. In the second phase, we planned to study the effects of silt on trout egg development and to compare trout susceptibility to some apparently silt tolerant species, which spawn in the baseline stream. Finally, in phase three we planned to test a habitat modification that would minimize trout egg mortality due to siltation.

Our baseline studies focused on the upper reaches of Silver Creek in South Russell Township, Geauga County, Ohio. In this phase of the study, we had three objectives:

1. To determine the abundance of invertebrates (potential food for young and adult trout), temperature and current speed along a 0.3 mile stretch of the east branch below Frohrings Pond and along a 0.3 mile stretch of the west branch below Paw Paw Lake;
2. To assess the availability of suitable habitat for residential young and adult trout along these stretches; and
3. To find a suitable site for habitat modification.

The selection of the two stretches of the stream was motivated by their accessibility and numerous observations of trout in these stretches by others prior to our survey. In each stretch we set up 6 sampling stations at about 80 m intervals. These series of 6 sampling stations alternated between large gravel (<2.5 cm) and small gravel (<2.5 cm) beds. We sampled invertebrates with a modified Surber sampler from a 930 cm^2 area at each site. Samples were preserved in 10% formalin, and current speed, water temperature, and air temperature were obtained. From these data and other qualitative observations, we selected a site for the artificial spawning bed. The criteria for this selection were (i) easy access so that material to be used for the construction of this device could be transported to the site without a great deal of difficulty, (ii) suitable bank structure for anchoring the device, and (iii) a nearby site with good natural spawning bed, so that we can compare how well the device placed in a previously non-gravel area attracts the adult trout.

The results of this survey indicated that Silver Creek would serve as a good test stream. Summarizing the results by objective, we found for objective 1 the following:

1. Composition of inverts at the east branch was quite similar to that at the west branch (Table 1). In the dominant insect was chironomid larvae (40-50%) at both branches. The dominant non-insect was oligochaetes at both branches, and two branches differ only in that the caddisfly larvae are the 2nd dominant insect in the east branch and the 3rd dominant in the west branch (second ranking insect here is the beetle larvae).
2. Abundance trend along each stretch (Tables 2 & 3) showed chironomid, other dipteran and caddisfly larvae increase in abundance downstream at the east branch and decrease downstream at the west branch while oligochaetes increase in abundance downstream at the east branch and decrease downstream at the west branch. Thus we saw opposite trends for the 2 branches.
3. Ratio of abundance at small gravel sites to abundance at large gravel sites (Table 4) was the opposite for the two branches. In the east branch densities were higher at the small gravel habitat than at large gravel habitat just above all groups. The opposite trend occurred in the west branch.
4. There were no obvious trends in temperature along either stretch and average temperature was the same for both (Table 5).

5. On the average (Table 5) current speed on the east branch (46.9) is much higher than that in the west branch (35.5 cm/sec). This difference might account for difference in the value of above $(\frac{\text{small gravel}}{\text{large gravel}})$ ratio for the 2 branches. There was no obvious current-speed trend along either stretch.

In satisfying objective 2, we found:

1. Many riffles and small pools during the summer at these stretches (ideal for young trout).
2. Many large pools during the summer (suitable for young and adult trout), and, we suspect, they would be larger during periods of higher water (as in autumn and spring).
3. But only a few places with undercut banks and overhanging cover.

From these observations and the data above, we felt that Silver Creek could sustain a resident trout population. The lack of habitat cover however, could lower its productivity.

Finally, for objective 3, we found a suitable site for an artificial spawning bed upstream of the Music Street bridge. The site had good physical structure and a muddy bottom. A nearby natural spawning bed would allow us to compare both the effectiveness of an artificial spawning bed and its attractiveness relative to the natural bed.

In phase 2, we examined the effects of siltation on the embryonic development of trout in seven different experiments (Table 6). Experiments 1 and 2 were evaluations of different experimental systems. In experiment 1, we tested a flow-through system using simulated redds in laboratory stream channels. We found this system unworkable, and we then developed a recirculating system based on "hatchery" type jars for egg incubation. We built the recirculating system around a water management unit (Aquarium Systems, Inc. Model WM-500), which provided aeration, filtration, oxidation of ammonia, water circulation, buffering, and temperature control (Fig. 1). The incubation chambers and all plumbing and valves were PVC. The incubation chambers received water from the recycling system through a baffled chamber (Fig. 2). This chamber provided more even flow regulation into the bottom of the incubation chamber. Eggs in the incubation chamber were supported on a bed of washed quartz gravel, and screens were placed on the outlet during alevin emergence. We had two incubation systems for our experiments with seven incubation chambers each. Return flow to the management unit could be diverted to sewer drains thus making the system flow-through during silt applications. Water supply to these systems was from tap water, which we conditioned by filtration through activated carbon.

We obtained fertilized eggs from several sources (Table 6). Because of transport difficulties, we performed stripping and egg fertilization at the location of the adult trout, and we returned the fertilized eggs to our laboratory. In all cases, therefore, we initiated our experiments with water hardened eggs.

We designed our experimental protocol to determine if a critical period of silt effect could be identified. The design resulted in six siltation treatments (Table 7). Each siltation treatment involved addition of a silt slurry to an incubation chamber. After addition of the silt slurry, water flow through the chamber was stopped for 10 minutes then slowly returned to original flow rates. During this procedure, the system was in a flow-through mode until all fine day and silt particles were washed from the incuabtion chambers. The siltation procedures always left a heavy residue (0.04g drg wt. of silt/cm^2) of silt covering all eggs. Experiments 3 and 7 were treated in this manner.

In four of the experiments (experiments 2,4,5, and 6), we examined various procedural assumptions. In experiment 2, we replicated four of the incubation chambers to test the system and consistency of results. Because of differences in the performance of the two systems in experiment 3, we examined in experiment 4 the influence of flow rates on hatching success. Finally, in experiments 5 and 6, we tried various procedures to inhibit fungal growth in the incubation chambers.

The main difficulty we encountered in our experimental system was fungal growth on the eggs. The two incubation systems, however, did not show equal susceptibility. Attempts to control fungus growth with various fungicides or by running the experiments at different temperatures and flow rates were not successful. For example, in experiment 4, we found that variations in flow rate (300 to 2300 cm/hr) did affect mortality of eggs (Table 8), but we did observed significant effect of incubation system and we encountered very high post-hatching mortality. As we will show below, we were able to reduce the variability between incubation systems, but the closed system incubation method seemed very unstable. That we could obtain good hatch in the presence of fungal growth in our later experiments led us to believe that egg quality was a primary determinant of susceptibility to fungal infections. Variability in condition of females and sources of eggs, however, do not allow us to test this idea more rigorously.

Despite these procedural difficulties, we were successful in measuring the effect of siltation on egg development of Steelhead and Rainbow Trout. In neither case were we able to show a silt effect on mortality during development. Because of potential differences in the incubation systems, we ran our experiments in a randomized block design with the two blocks corresponding to the two incubation systems. From experiment 3 (Table 9), we were unable to show any affect of siltation. Analysis of variance indicated a significant block effect ($P < .001$), but no treatment effect ($P < .5$).

In experiment 7, we found no effect of silt treatment on Rainbow Trout eggs and less of a block effect (Table 10). Prior to this experiment we dismantled the entire hatchery apparatus and replaced the dolomite mixture in the filter of the water management unit for Block I. In this experiment, we also recorded numbers of abnormal alevins (Table 10) and alevin length after swim-up (Table 11). Analysis of variance also indicated no treatment effect on % hatch success ($P = .42$) nor on alevin length ($P = .26$). The block effect disappeared for % hatch ($P = .16$), but remained for alevin length ($P < .001$).

We interpreted these results to mean that the presence of silt alone did not affect embryonic development. Because the interactions of flow and oxygen have been well documented (Silver, et al., 1963), we next decided to focus on the sequence from spawning through water hardening of eggs. All of our experiments began with water hardened eggs, and we could not proceed to habitat modifications without some information about the effects of siltation on this portion of the reproductive cycle.

In experiment 8, therefore, we analyzed reproductive behavior of adults and spawning success in an artificial stream (Fig. 3). The stream had a continuous, potential velocity range of 0 to 2m/sec. The artificial bed consisted of 15 cm layer of washed gravel. At the upstream end of the apparatus, we placed a small barrier, which raised the water level. This additional hydraulic head created an intragravel flow pattern ending in an upwelling region near the center of the stream. Dye tracers revealed a fairly restricted upwelling region, and the rainbow trout we used always dug redds at this location. A spawning pair of adults when placed in this stream completed a normal spawning sequence, and we could recover live eggs from the redd after spawning. Following this experiment, we added a silt slurry to the artificial stream bed at a final density of 0.9 g/cm^2. Fine particulate material was flushed from the system leaving it with a slight residual turbidity. A spawning pair was then added to this system. Although spawning behavioral interactions between male and female occurred, and the female began redd excavation, we never obtained a successful spawning. Silt stirred from the stream bed as the female dug the redd appeared to interrupt the visual association of the spawning pair. Unfortunately we could not continue these experiments for different silt loads due to the lack of trout in spawning condition.

The lack of an observable effect of silt on egg development was unexpected. Without such a response, we could not carry out our planned comparison with other species. We also were left with no criteria for constructing the artificial spawning bed, and we thus abandoned the remainder of phase 2 and all of phase 3.

DISCUSSION

Siltation in trout streams can have a series of effects on trout reproduction. First, silt can alter physically the nature of the stream bed. Changes in the amount of sand and silt, for example, can directly affect the emergence of fry (Phillips *et al*., 1975; and Hausle and Coble, 1976). Siltation can also affect intra-gravel flow rates and oxygen concentration in the gravel (cf. Bianchi 1963). Flow rate and oxygen directly affect hatching success of trout embryos (Coble 1961; Silver *et al*., 1963; and Shumway *et al*., 1964). The overall effect of siltation is thus to lower natural reproduction in affected reaches (Bianchi 1963).

Our observations and experiments indicate that the effects of siltation on embryonic development are indirect. The presence of silt alone does not increase embryonic mortality. Therefore, it must affect physical properties of the gravel and result in changed flow rates and/or oxygen concentration. It may also, perhaps more importantly, reduce emergence. Habitat modification along the lines we originally proposed could not adequately address all of these problems.

Our preliminary evidence on the effects of siltation on spawning behavior indicated that simple intragravel flow augmentation may not produce positive results. To an unknown degree this disruption of the behavioral sequence in spawning could be an artifact of our artificial stream. During our surveys of Silver Creek for possible locations for a device with which to augment intragravel flow, for example, we learned from observations of land owners that redd excavations and spawning occurred in areas with gravel-silt mixtures. Nevertheless, streams like Silver Creek do not support self-maintaining populations of trout. Instead, trout seem to be maintained in these streams primarily by stocking. Initially, we suspected a fairly simple limitation imposed by siltation. Failing to find such a simple effect leaves a complex set of potential interacting problems including indirect effects of siltation on spawning beds, channelization, little bank vegetation or other cover, and bank erosion. Although we were not prepared for a full scale habitat improvement, it is clear from other studies (White and Bynildson, 1967) that physical modifications could substantially improve the quality of a stream like Silver Creek. These procedures, however, are very expensive, and during the remaining grant period, we focused our attention on a slightly different approach to this problem.

Given the economics involved with improving water quality, we wondered about the possibility of developing strains of trout that were more tolerant of marginal water quality conditions in this area. Combining water quality improvement with strain development would thus constitute a joint biological and physical-chemical recovery program that could potentially result in a desired level of restoration at lower costs than the physical-chemical approach by itself. Using the various trout strains that we had obtained in our embryonic studies, therefore, we began rearing and screening these strains for tolerance to combined low oxygen and high temperature stress. Subsequent to the formal completion of this project, we have in fact, found considerable variability in this kind of stress tolerance. We are now examining the heritability of this tolerance, but we now believe a combined biological and physical-chemical habitat improvement has substantial promise.

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Table 1. PERCENTAGE OF TOTAL ABUNDANCE FOR EAST AND WEST BRANCHES OF SILVER CREEK

	% of Total	
	East Branch	West Branch
Chironomid Larvae	45.1	40.4
Other Dipteran Larvae	8.2	2.7
Beetle Larvae	4.5	20.5
Caddisfly Larvae	25.2	8.9
Mayfly Larvae	0.3	0.8
Stonefly Larvae	0.3	0.2
Oligochaetes	14.9	18.1
Flatworms (Leeches?)	1.5	8.4

Table 2. Average Density (no. per 930 cm^2) at the Sampling Stations on the East Branch of Silver Creek

	STATIONS					
	E1	E2	E3	E4	E5	E6
Chironomid Larvae	27	16	24	205	76	116
Other Dipteran Larvae	1	4	6	21	5	44
Beetle Larvae	1.5	8	4	2.5	8	22
Caddisfly Larvae	35	7	17	92	64	41
Mayfly Larvae	<1	0	<1	1	<1	<1
Stonefly Larvae	0	0	<1	1.5	1	<1
Oligochaetes	8	6	5	30	50	54
Flatworms (Leeches?)	2.5	2.5	1	2	1.5	5

Very Rare; dragonfly larvae, bugs, roundworms and mites

E1, E3 and E5 - large gravel > 1" diam.

E2, E4 and E6 - small gravel < 1" diam.

E1 → E6 - downstream direction

Table 3. Average Density (no. per 930 cm^2) at the Sampling Stations on the West Branch of Silver Creek

	STATIONS					
	W1	W2	W3	W4	W5	W6
Chironomid Larvae	330	152	112	98	15	41
Other Dipteran Larvae	8	16	9	11	3	4
Beetle Larvae	84	75	131	41	15	34
Caddisfly Larvae	110	44	40	16	2.5	3.5
Mayfly Larvae	1	3.5	5.5	<1	<1	4.5
Stonefly Larvae	0	0	<1	2	0	1
Oligochaetes	67	73	156	26	9	5
Flatworms (Leeches?)	147	2.5	2.5	3.5	0	<1

Very Rare; dragonfly larvae, bugs, roundworms and mites

W1, W3 and W5 - large gravel > 1" diam.

W2, W4 and W6 - small gravel < 1" diam.

W1 → W6 - downstream direction

Table 4. Abundance at Small Gravel Sites/Abundance at Large Gravel Sites

	East Branch	West Branch
Chironomid Larvae	2.6	0.6
Other Dipteran Larvae	4.8	1.5
Beetle Larvae	2.3	0.6
Caddisfly Larvae	0.8	0.4
Mayfly Larvae	-	-
Stonefly Larvae	-	-
Oligochaetes	1.2	0.4
Flatworms (Leeches?)	1.9	0.4

Table 5

Average Temperature at the Sampling Stations on the East and West Branches of Silver Creek

E1	23.2	W1	24.1
E2	23.0	W2	23.2
E3	23.0	W3	23.0
E4	23.7	W4	23.4
E5	23.1	W5	23.0
E6	23.0	W6	22.5
Grand Mean	23.2		23.3

Average Depth (cm) and Current Speed (cm/sec) at the Sampling Stations on the East and West Branches of Silver Creek.

	Depth	Current Speed		Depth	Current Speed
E1	6.0	60.9	W1	10.5	3.4
E2	5.0	62.5	W2	6.0	45.0
E3	5.5	36.5	W3	7.0	38.2
E4	8.0	45.0	W4	5.0	50.0
E5	7.5	59.2	W5	6.0	22.0
E6	10	50.0	W6	7.5	31.0
Grand Mean	7.4	46.9		6.1	35.5

Table 6. Summary of experiments on the effects of siltation on the early phases of trout development.

Experiment		Egg Source	No. Eggs
1	11/10/76-12/6/76	Rainbow Trout Castalia Trout Farms (Castalia, Ohio)	600
2	2/18/77-3/31/77	Rainbow Trout Castalia Trout Farms (Castalia, Ohio)	1200
3	4/7/77-5/20/77	Steelhead Trout Michigan DNR Little Manistee Spawning Stock	30,000
4	6/9/77-7/4/77	Rainbow Trout Reynoldsdale Hatchery Pennsylvania Fish Commission	13,000
5	10/12/77-10/21/77	Rainbow Trout Castalia Trout Farms (Castalia, Ohio)	15,000
6	10/26/77-12/1/77	Rainbow Trout Castalia Trout Farms (Castalia, Ohio)	20,000
7	1/4/78-3/2/78	Rainbow Trout Castalia Trout Club (Castalia, Ohio)	10,000

Table 7. Protocol for silt treatments during embryonic development.

	Silt Application Period		
Treatment	1	2	3
1	-	-	-
2	+	+	+
3	+	-	-
4	+	+	-
5	-	+	-
6	-	+	+
7	-	-	+
Post-Fertilization Time Period (Days)	0-2	10-14	26-34

Table 8. Effect of flow rate on egg mortality for Rainbow Trout at 12°C. Data summarized for Block II only due to total mortality in Block I. Initial density was 800 eggs per jar and mortality is the percent of dead eggs at hatch.

	Mortality (%) Flow Rate (cm/hr)		
Replicate	300	1300	2300
1	27	28	26
2	28	29	27

Table 9. Effects of siltation at various periods during embryonic development of steelhead eggs. Data reported are normal alevins hatched from an initial 2,000 eggs for each treatment. Also included are the statistics from the analysis of variance using a randomized block design.

	Alevin Hatch out of 2,000 eggs	
Treatment	Block I	Block II
1	208	1371
2	277	1448
3	347	1450
4	214	1436
5	274	1420
6	440	1373
7	446	1425

ANOVA Results:

Item	Sum of Square	Degrees of Freedom	Mean Squares
Grand Total	1.49×10^7	14	
Grand Mean	1.05×10^7	1	
Treatments	3.03×10^4	6	5060
Blocks	4.27×10^6	1	4.27×10^6
Error	3.51×10^4	6	5840

F - (Treatment) = .87, P = .57

F - (Block) = 731, $P < .001$

Table 10. Effects of siltation at various periods during embryonic development of rainbow trout eggs. Data reported are initial densities, normal hatch, and abnormal hatch for various silt treatments in each block. Also included are the statistics from the analysis of variance using a randomized block design.

	Initial Density		Normal Hatch		Abnormal Hatch	
Treatment	B I	B II	B I	B II	B I	B II
1	701	615	504	464	14	19
2	710	598	531	433	15	11
3	717	740	544	568	10	14
4	677	774	510	614	20	14
5	677	747	485	590	15	14
6	710	712	517	510	16	24
7	667	748	498	586	26	25

ANOVA Results on corrected hatch (relative to 700 initial density)

Item	Sum of Squares	Degrees of Freedom	Mean Squares
Grand Total	3.863×10^6	14	
Grand Mean	3.859×10^6	1	
Treatments	1911	6	319
Blocks	686	1	686
Error	1617	6	270

F (Treatment) = 1.18 P = .42

F (Block) = 2.55 P = .16

Table 11. Effects of siltation on alevin length after hatch. Data reported are mean and standard deviation in cm of 50 alevins from each treatment for each block. Also included are the statistics from the analysis of variance using a randomized block design.

	Alevin Length (cm)			
	Block I		Block II	
Treatment	Mean	S.D.	Mean	S.D.
1	2.15	0.13	2.24	0.06
2	2.15	0.14	2.23	0.09
3	2.17	0.12	2.26	0.11
4	2.17	0.13	2.23	0.11
5	2.18	0.08	2.26	0.10
6	2.17	0.11	2.25	0.08
7	2.14	0.14	2.25	0.11

ANOVA Results:

Item	Sum of Squares	Degrees of Freedom	Mean Squares
Grand Total	67.98	14	
Grand Mean	67.95	1	
Treatments	1.53×10^{-3}	6	2.56×10^{-4}
Blocks	0.023	1	0.023
Error	3.8×10^{-4}	6	1.46×10^{-4}

F (Treatments) = 1.75   P = .26

F (Blocks) = 160   P < .001

Figure Legends

Figure 1. Schematic diagram of water distribution system for an experimental block.

Figure 2. Schematic diagram of hatchery jars used in siltation experiments.

Figure 3. Schematic diagram of articicial stream and device for creating upwelling through gravel bed of stream. Not shown is the attached water management unit, which regulates temperature of the circulating stream. The labels on the figure are as follows: A and B are the water exchange ports with the temperature regulation unit; C is an enclosed bed of dolomite gravel, which acts as a buffer and biological filter, F is a coarse mesh screen; I is the gravel bed; H is the barrier with which to augment intragravel flow; and G, D, and E are the controller, motor, and prop used to create the stream's current.

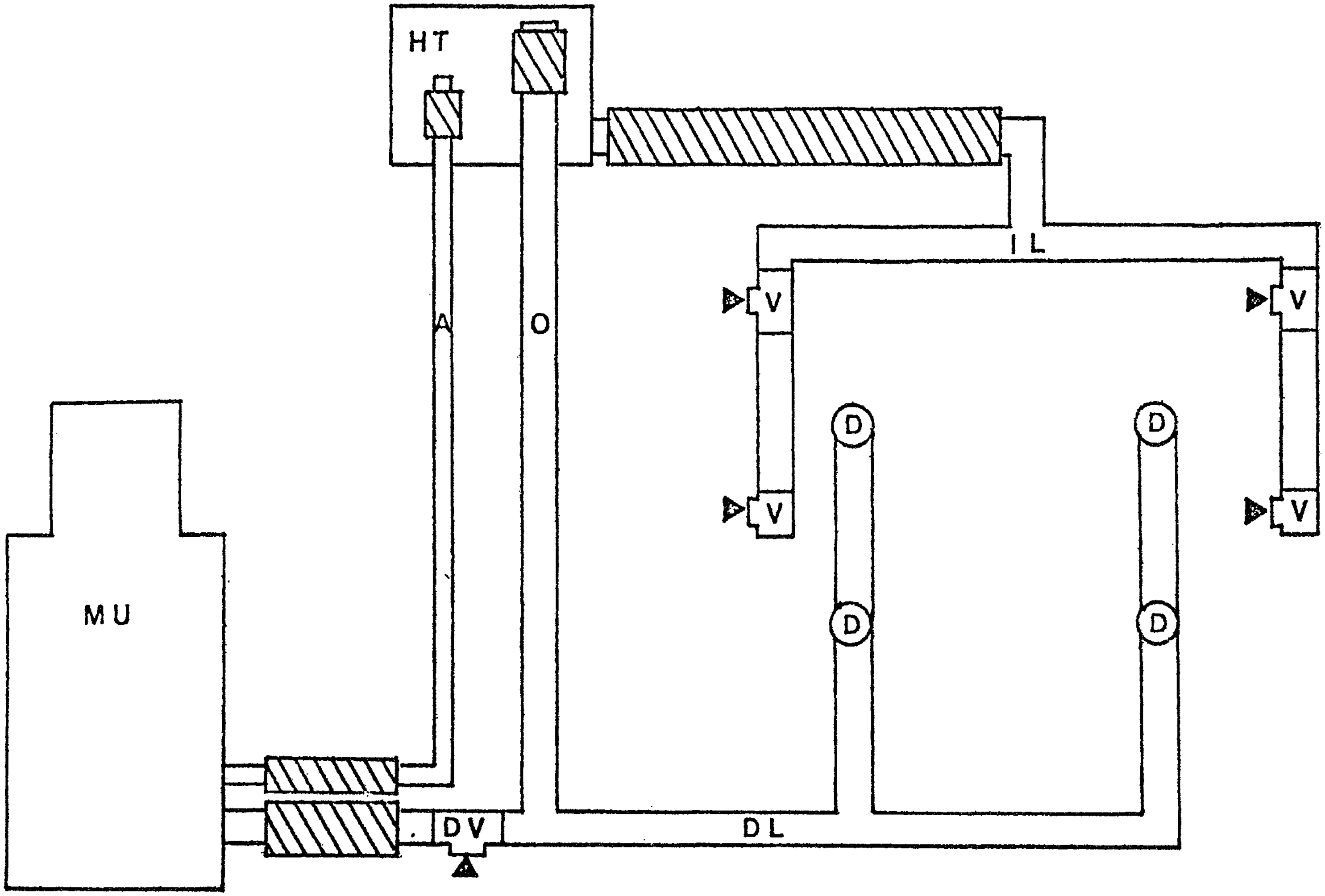

Fig 1

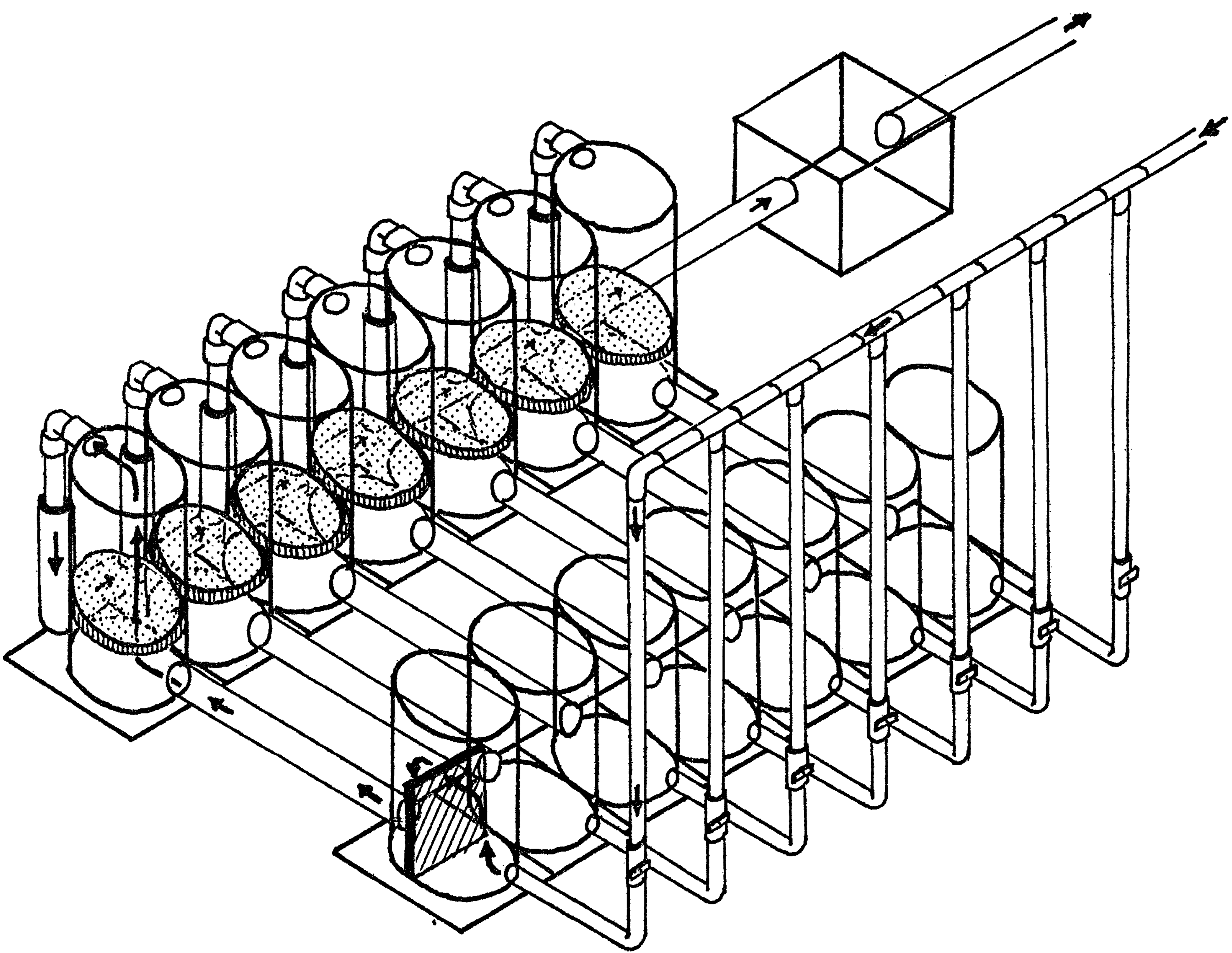

Fig 2

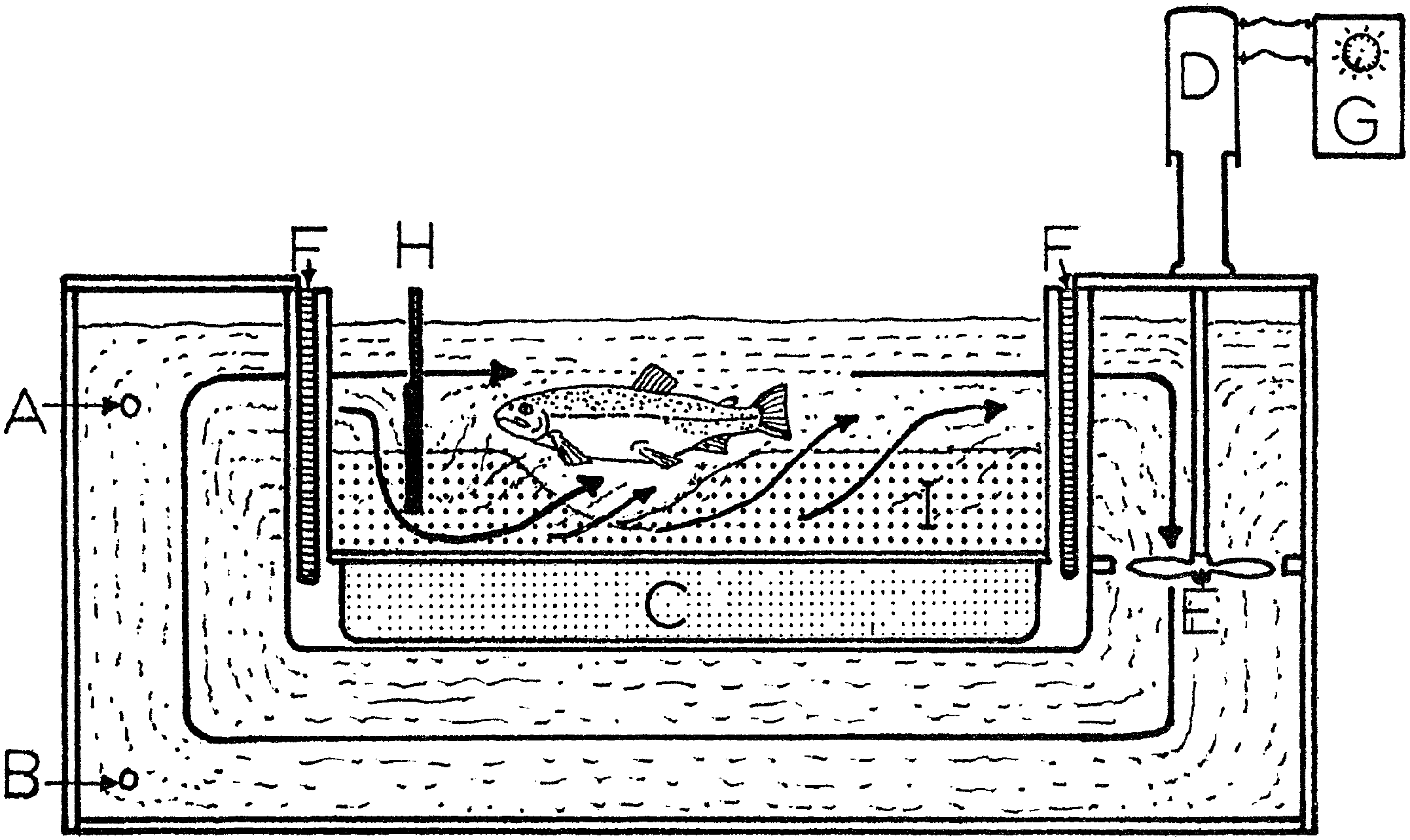

Fig. 3