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SWIMMING PERFORMANCE OF ARCTIC GRAYLING
(*Thymallus arcticus*)

A proposal
to the
U. S. FISH AND WILDLIFE SERVICE

by
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Swimming performance of Arctic Grayling (*Thymallus arcticus*)

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General Objectives:

1. To establish design criteria for culverts which will insure the maintenance of fish populations in streams traversed by the proposed oil pipe-line and associated highway in Alaska.
2. To determine maximum water velocities which would allow arctic grayling to pass through culverts and other facilities which might obstruct the upstream passage of fish.
3. To determine the most efficient construction, installation and modifications of fish and water passage facilities (mainly culverts) which would permit the upstream migration of various size-classes of fish at various temperature regimes.

Introduction:

Fish speeds both sustained and for short lengths of time have been determined for a few varieties and sizes of fish by previous investigators. The ability of fish to pass through a culvert is essentially a function of water velocity, distance or time, length of fish, temperature and species. Trout, for example, can swim rapidly for short intervals of up to 20 seconds at 14° C but are limited to relatively low levels of performance for sustained lengths of time (Figure 1 after Bainbridge, 1960).

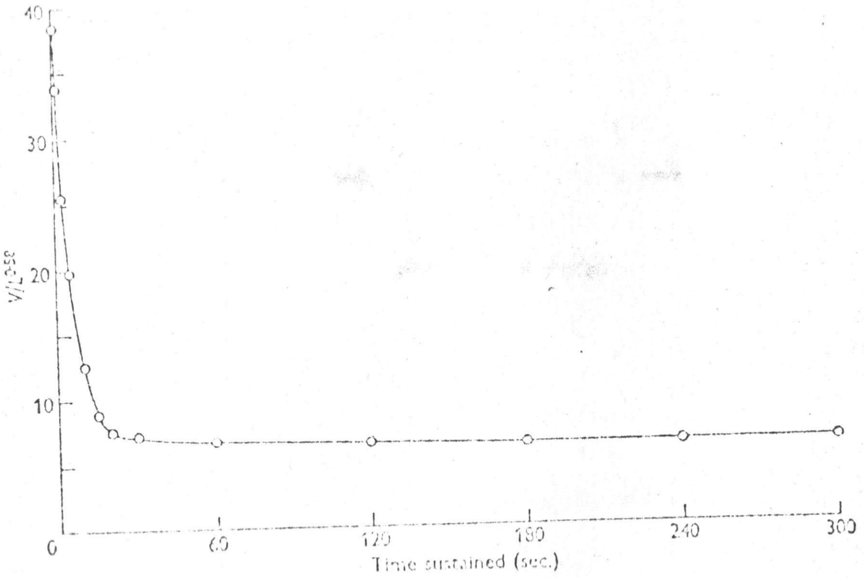

Fig. **1.** Mean values for the relationship between speed and the length of time it can be sustained for periods of swimming from 0·5 sec. to 5 min. for eight trout (*Salmo irideus*) that had previously been exercised for 12 months by swimming continuously at 25 cm./sec. Speed is expressed in terms of body lengths raised to the power of 0·58.

Speed is apparently a function of fish length raised to some power. Once the value of the exponent is determined empirically from experimental data (such as the 0.58 for trout in Bainbridge's figures) the speed of any size-class of fish can be interpolated and extrapolated within limits.

For streamlined fish, length is of greater significance than species as a factor governing swimming performance especially with regard to smaller fish (Kerr, 1953) and maximum short duration performance of larger fish (Haley, 1966).

Brett, Hollands and Alderdice (1958) (Figure 2) demonstrate that cruising speed of coho salmon increases with fish size and temperature up to a point. The cruising speed of coho is much slower at 5° C than 10° C and higher. Cruising speed has been defined by the above authors as that rate which a fish can maintain for a period of one hour under strong stimulus without gross variation in performance.

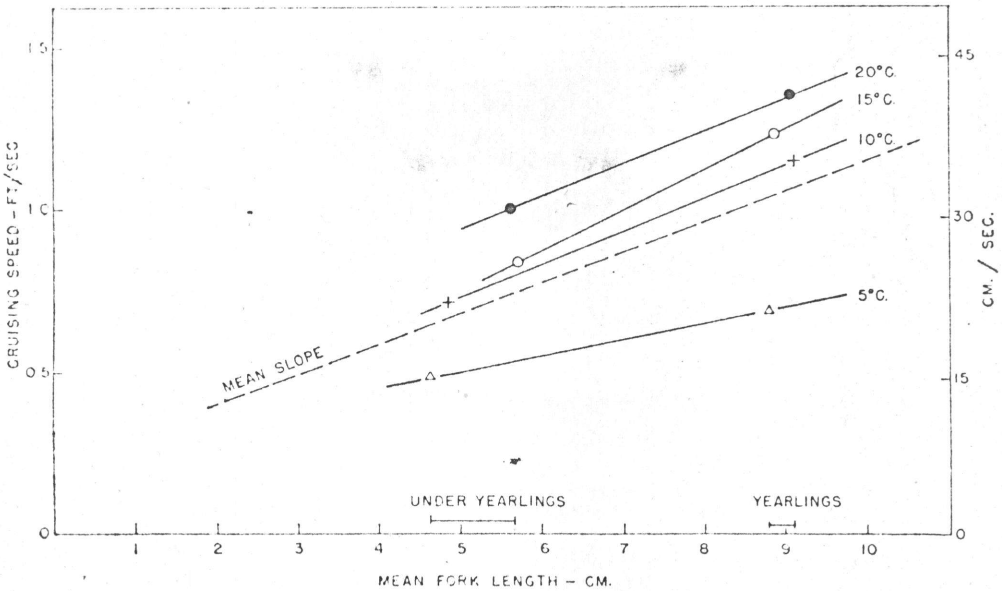

FIG. 2. Mean cruising speed for underyearling and yearling coho salmon, for four levels of acclimation. In general, from the mean slope, for every increase in length of 1 cm. the cruising speed increased by about 0.09 ft. per sec. (3 cm./sec.).

We infer from Brett et al., that the maximum cruising speed of different sized fish of the same species occurs at identical temperatures even though the absolute speeds of different size-classes are markedly different (Figure 3).

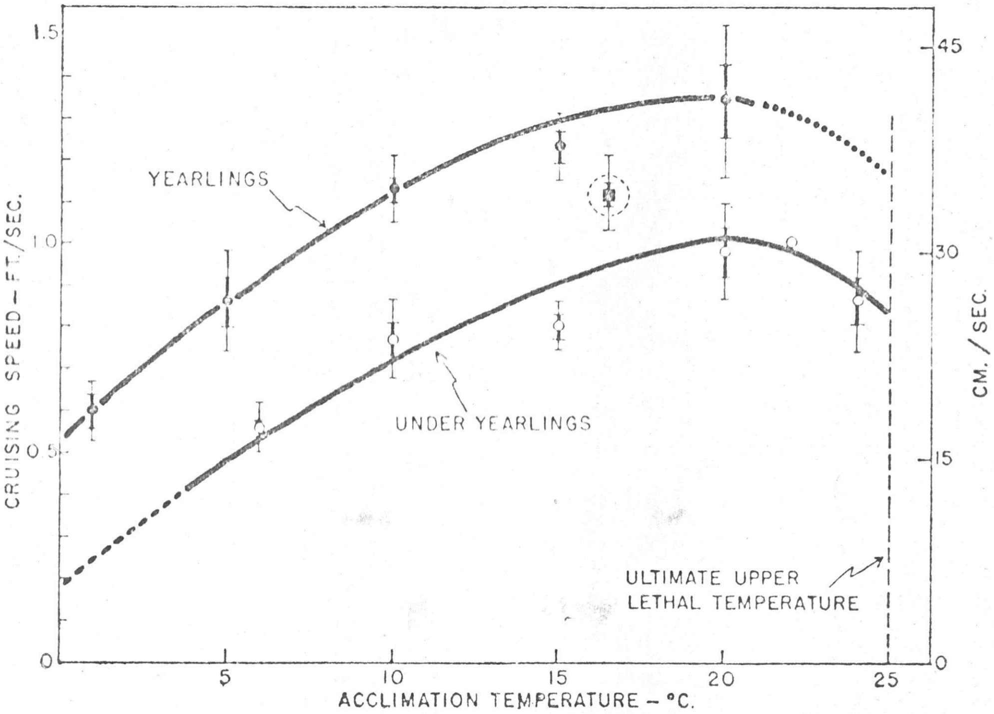

FIG. 3. Variation in cruising speed for temperature acclimated underyearling and yearling coho, adjusted in each age group to common mean lengths of 5.4 cm. and 8.9 cm. respectively. The circled point between two curves is for *exercised* underyearling coho acclimated to 16.5°C. (see text). Standard deviation and standard error are indicated for each sample.

The optimum cruising speed among species could vary significantly (Figure 4). We would guess that the optimum cruising speed for grayling, a cold-water adapted species, is at a considerably lower temperature than that of sockeye salmon. This variable will be examined in this study.

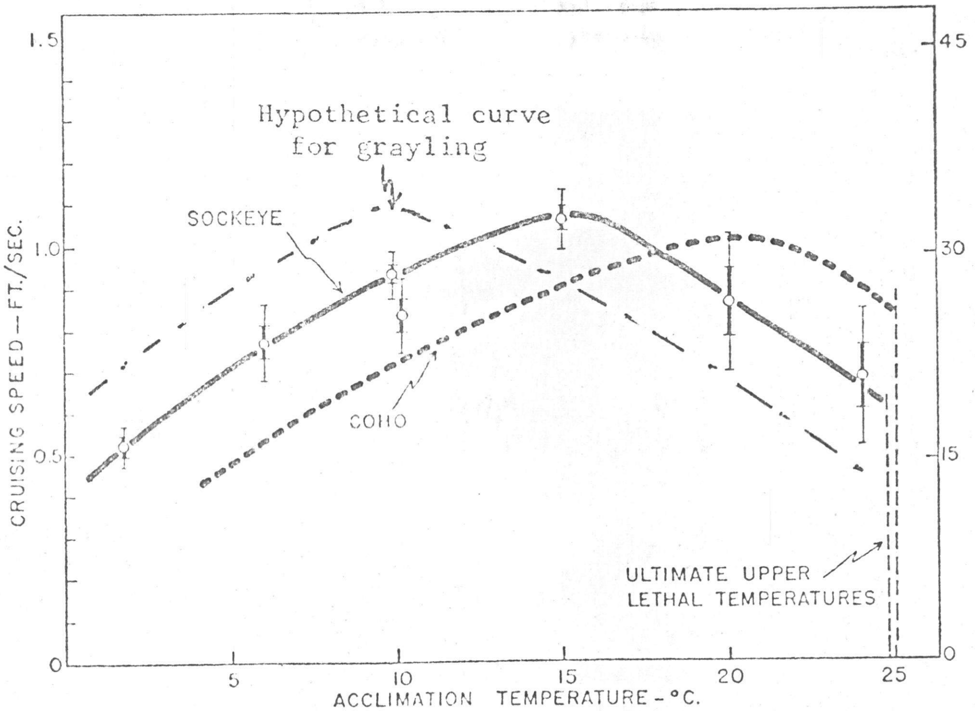

FIG. 4. Variation in cruising speed for temperature acclimated underyearling sockeye and coho, adjusted in each case to common mean lengths of 6.9 cm. and 5.4 cm. respectively. The samples were cultured under similar conditions and are of comparable age, 4 to 6 months from hatching. (The curve for coho is the lower curve of Figure 3.)

The scope of activity is the difference in the rate of oxygen intake of resting fish and fish swimming at a maximum steady speed (Figure 5 after Graham, 1949). The scope of activity varies with temperature; the maximum scope occurring near the preferred temperature of a species. Moreover the maximum scope of activity is directly related to maximum cruising speed of fish (Figure 6 after Graham, 1949). The general concepts of scope of activity developed by various investigations are relevant to fish passage through culverts and the implications of such concepts must be considered.

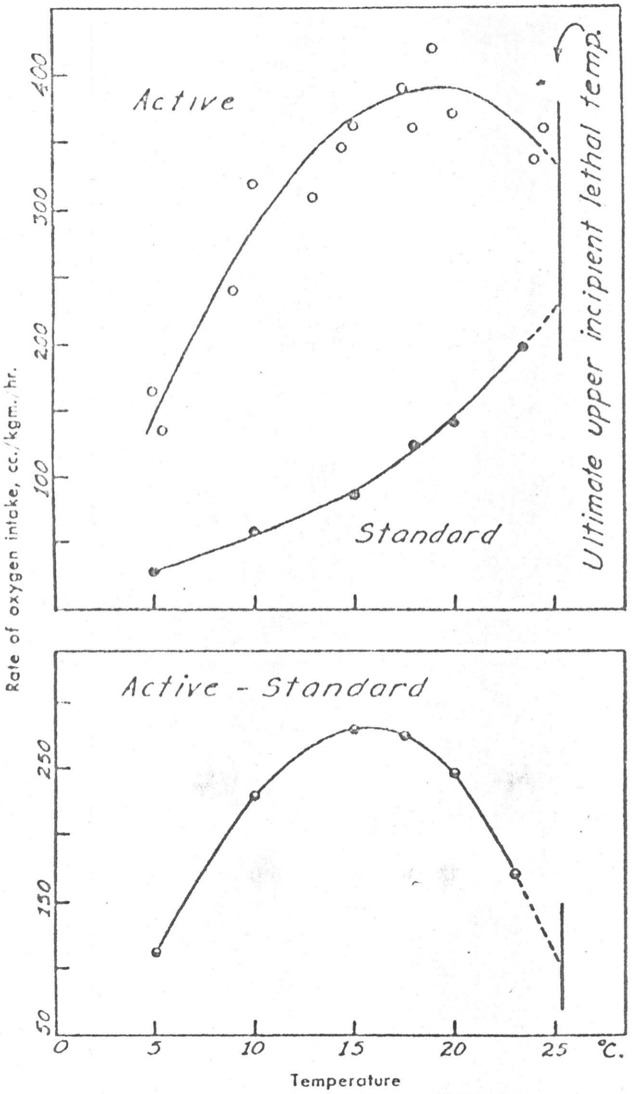

FIG. 5. *Relation of oxygen uptake to temperature in acclimated speckled trout.*
Active: Oxygen uptake of trout swimming at a maximum steady speed.
Standard: Oxygen uptake of resting trout at the lowest point in the diurnal cycle.
Active – Standard: The difference between the active and standard levels of oxygen uptake at the various acclimation temperatures.

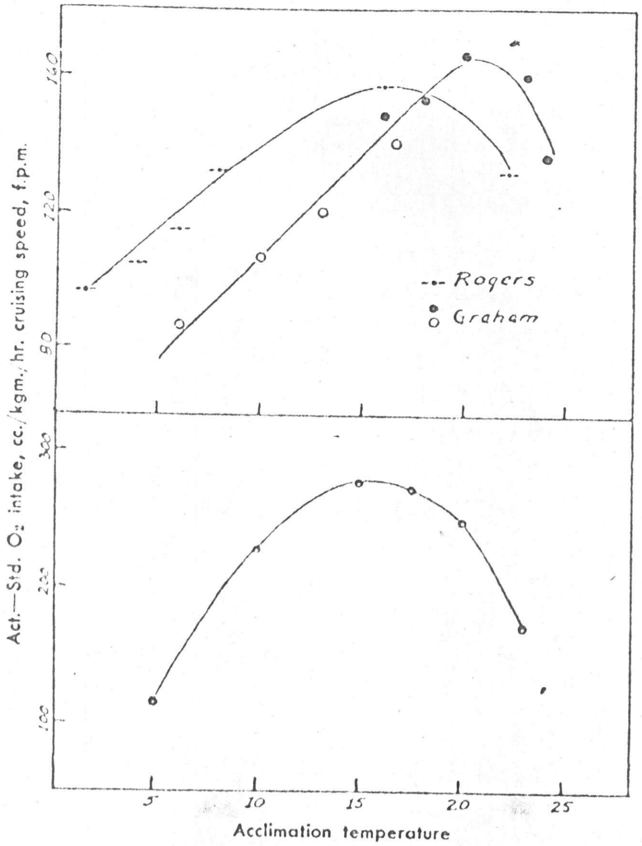

FIG. 6. *A comparison of the maximum speed at which speckled trout can swim steadily at various temperatures, and the difference between the active and standard levels of oxygen intake.*

We use figure 7 to hypothetically suggest what could happen to grayling in a culvert if fish passage were marginal. A flow through a culvert of 0.5 ft/sec on a fish with a performance and temperature curve as indicated by the solid line could limit the passage of that fish to temperatures between 13 and 17° C (dotted line). Moreover, the margin of success is reduced to a point where a slight increase in flow could completely block the ascent of the hypothetical fish even at temperatures between 13 and 17° C.

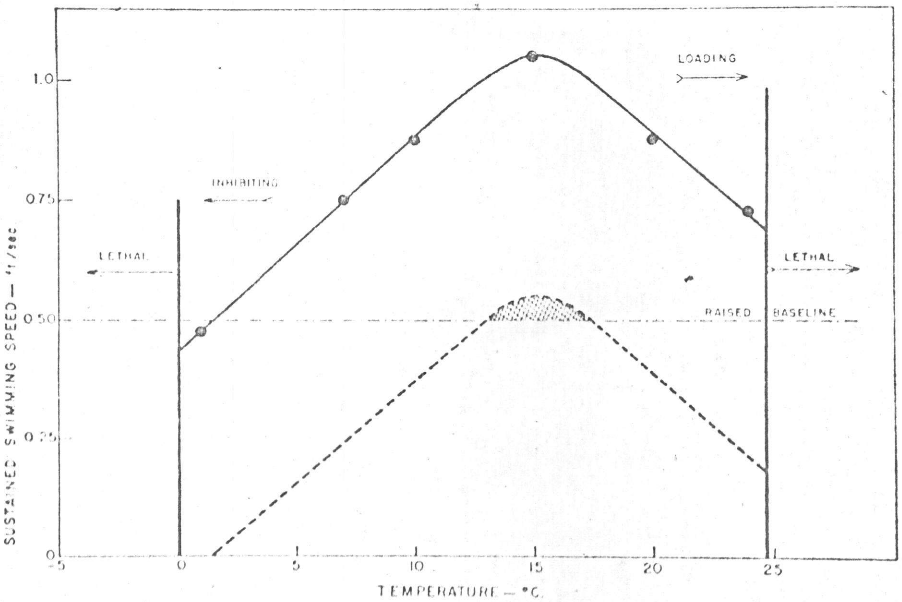

FIG. 7. Relation between performance and temperature for acclimated young sockeye. The dotted curve represents the remaining energy (capacity to swim) when stemming a current of 0.5 ft. per sec. (15 cm./sec.). The raised base-line has been elevated by an amount equal to the energy demand of swimming at 0.5 ft. per sec. and represents an assumed increment from imposed multiple stress. Only in the cross-hatched area could young salmon meet this situation. (From: Brett, 1958).

As we see the biological problem of upstream passage of grayling through culverts, four variables are involved: the size of the fish, the temperature of the water, the velocity of water within a culvert and the distance through the culvert that the fish have to surmount. With specific reference to spawning runs of grayling in central Alaska, the most significant variable is water velocity. The culvert lengths will be dictated by the width of the proposed highway, the height of fill and the skew angle of the stream. The velocity of flow in the culverts will vary almost directly with the slope of the invert of the culvert. The average water temperature during the spawning run will be relatively constant within limits and while mature grayling will vary somewhat in size, data from the smaller mature fish could be used to develop minimum design specifications for fish passage.

With this in mind, we believe that first priority should be given to the construction of a culvert facility on the bank of or in a stream having a known grayling spawning run. This *in situ* facility would provide unrefutable and exact data on maximum water velocities through which mature grayling should be able to pass. Interpretations from such data would provide design specifications for similar culverts.

As a second priority we would investigate the effect of size on the swimming performance of grayling. Tests would be performed in a circular trough placed on or near a stream bank and would include both immature and mature fish. The general procedures would be modifications of those suggested by Bainbridge and Brown (1958), Brett *et al*. (1958) and MacLeod (1967). Of primary importance is the potential of our relating the swimming speed of grayling to that of other species tested under somewhat similar experimental conditions.

As a third priority we recommend that temperature be investigated as a variable influencing swimming performance. Temperature tests would be conducted in four circular troughs constructed in separate controlled bioassay laboratories at the University of Idaho in Moscow. For these tests smaller grayling would be shipped live by air and held in Idaho until tests in Alaska were completed. We believe that we can ship live grayling to Idaho because we have successfully obtained live salmonids by commercial airplane from the Eagle Creek Hatchery near Portland, Oregon and squawfish from California by methods developed by Shelton (1965).

We state some of the biological advantages and disadvantages of culvert and circular trough tests:

Advantages of an inclined plane culvert for testing fish performance:

1. Depending on site location fish would not be handled prior to testing or if they were handled a recovery period would be allowed in a holding pool from which they could proceed into the culvert without further handling.
2. The use of a test culvert takes advantage of the innate upstream migratory responses of the fish and does not depend on physical stimulation to elicit a swimming response.
3. A culvert placed in a stream would be the typical, man-made obstacle that migrating grayling would encounter and have to surmount. Fish could be expected to perform equally well in highway culverts under the same conditions as in the test culvert.
4. The precise water velocity and distance in a culvert that a given percentage of grayling would successfully surmount would be obtained within temperature limits.

Disadvantages of using an inclined plane culvert:

1. Only mature fish with a migratory instinct can be tested. Smaller size-classes cannot be tested.
2. Water temperature cannot be controlled. At best the performance of grayling could only be determined within natural narrow temperature limits.

Advantages of using a circular trough:

1. The swimming speed of immature grayling can be measured.
2. The effect of temperature on the swimming performance of grayling can be determined.

Disadvantages of using a circular trough:

1. The fish must be handled prior to performance.
2. The fish are placed in an unnatural situation not representative of the culverts through which they might have to pass.

3. The fish have to respond to visual cues which probably would not elicit peak swimming responses. Thus it will be necessary to standardize performance in the circular trough with that in an inclined culvert.

Although we have rated the biological experiments in this proposal according to priority, we must stress that priorities 2 and 3 are extremely important to extrapolate data for all fish passage situations. Thus, we recommend that you consider proceeding with all three suggested attacks on the fish passage problem.

Job No. 1

Title: Swimming Performance of Grayling in Culverts

Objective:

To determine the swimming speed of mature grayling during their spawning run in an inclined plane culvert or channel in which flows and velocities of water are regulated.

Procedures:

A culvert about 2 feet or larger in diameter and of suitable length of a type intended for use on the Alaskan pipe-line highway would be used as a test facility (Figure 8). The pipe with adequate longitudinal support would be place on jacks so that its invert could be adjusted to alter the velocity of water flow.

The culvert would be located in a stream having a known grayling spawning run. A stream would be selected that could be dammed to provide a head of water to the culvert or a stream with sufficient gradient would be selected to allow water to be flumed to the culvert from a short distance upstream.

The general design of the installation would be a modification of a design by Slatick (1970) for use with Pacific salmon. A holding facility for grayling would be placed at the outflow end of the culvert. This would provide a pool area from which grayling could voluntarily enter the culvert and be counted.

A weir would be designed to guide grayling into the holding pen directly from the stream with no handling of fish.

A pool and trap would be placed at the upper end of the culvert

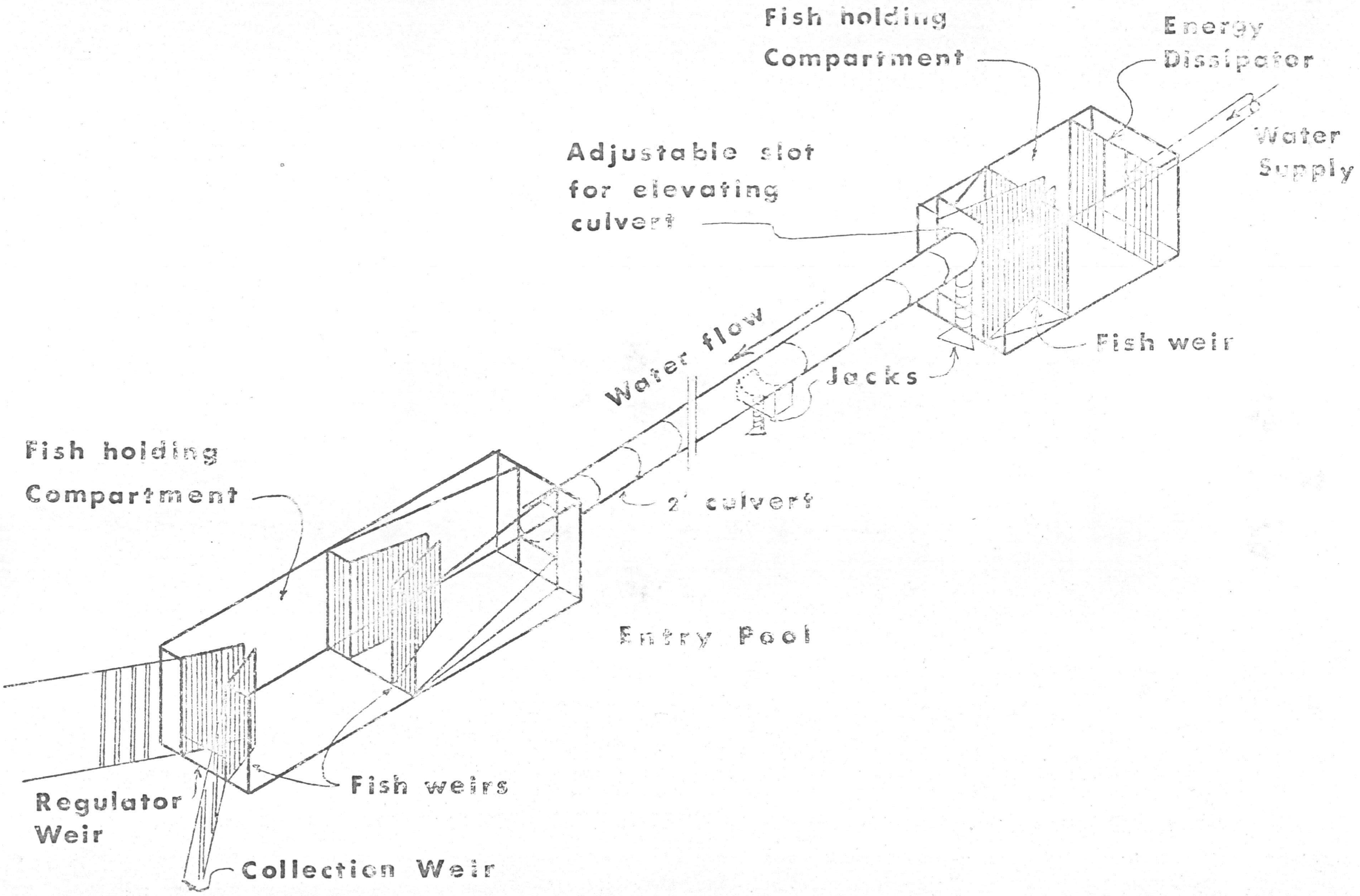

Figure 8. An inclined culvert and accessory fish holding facilities designed to test *in situ* the ability of spawning runs of grayling to swim upstream through highway culverts. Water velocities are regulated by changing the slope of the culvert with jacks.

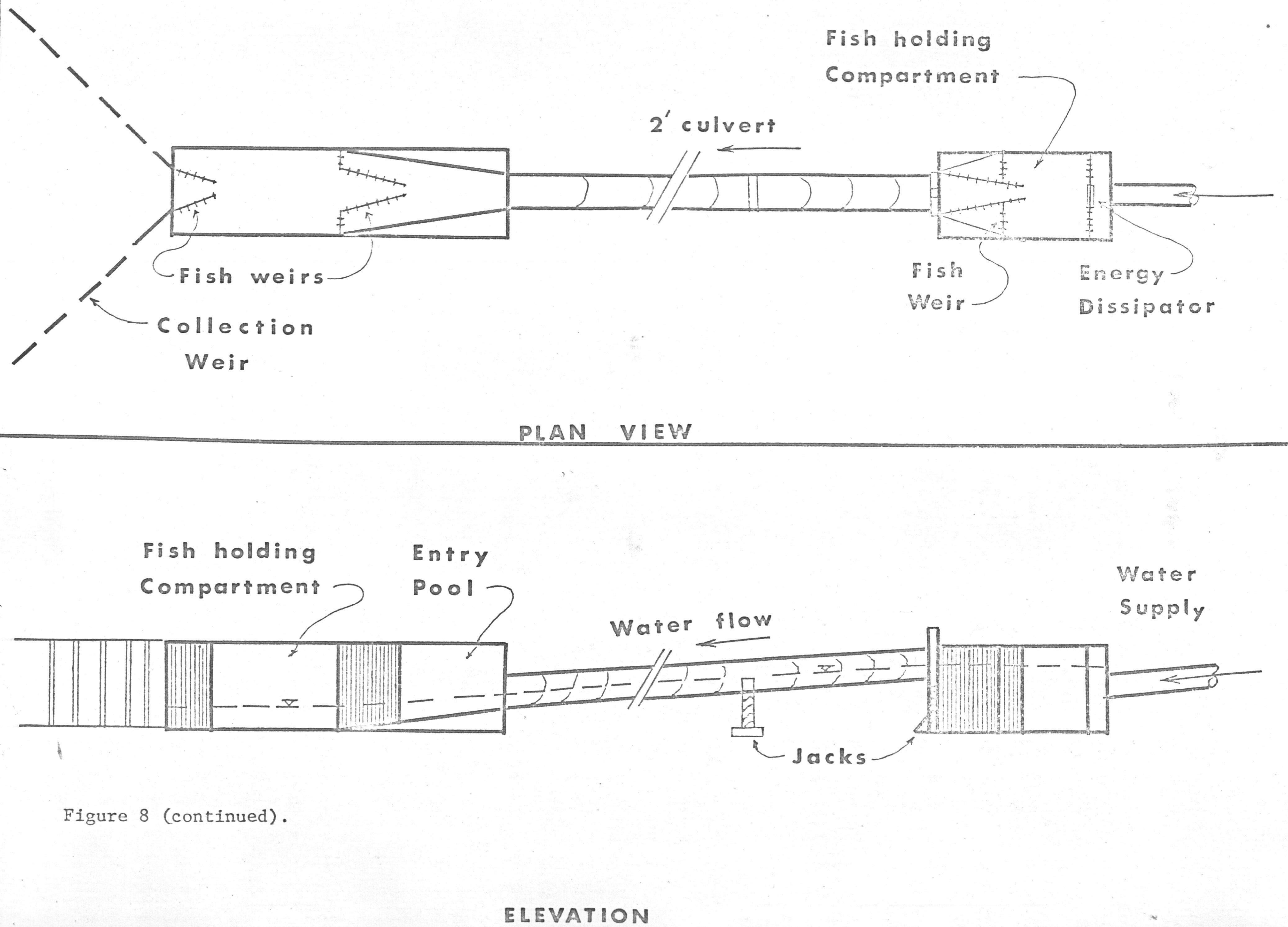

Figure 8 (continued).

for counting, measuring and sexing fish. The grayling would be marked before being released so that repeat fish could be recognized if any inadvertantly entered the experimental facility a second time.

A flume or pipe would be used to direct water from the stream into the pool at the head of the culvert. The culvert invert would be set to a specified slope to obtain the desired flow velocity. This procedure would be repeated for several different slope settings.

Depending on the length of time of the spawning run and the availability of fish we would determine water velocities that would pass 0, 50, and 100 per cent of the grayling.

Intermediate values between zero and 100 per cent would be calculated empirically using standard bioassay methods of analysis; i.e., velocity would be analogous to dose and fish-passage to survival. A graph or table could be developed by such methods of analysis that would indicate the expected percentage of fish that would be able to pass upstream through a water culvert for any given water velocity.

Job No. 2.

Title: Swimming Speeds of Grayling of Different Size-classes in Circular Channels.

Objectives:

To determine the cruising speed of various size-classes of grayling in circular channels at prevailing stream temperatures

Procedure:

The effect of temperature and size on swimming speeds of grayling would be best measured by techniques (or a modification thereof) described by Bainbridge and Brown (1958), Brett _et al_ (1958) or MacLeod (1967). The apparatus varies. Brett _et al_ used an annular rotating wheel-like trough (40 inches in diameter) similar to that conceived by Fry and Hart (1948) for measuring the swimming speeds of sockeye up to 15 cm in length. Bainbridge and Brown used a somewhat similar rotating wheel (78 inches in diameter) for measuring the swimming speeds of trout up to 30 cm in length. MacLeod developed an open-topped oval channel in which a current was created with two paddle wheels. He provided a water velocity which was slightly greater than the maximum swimming speed of the fish. This caused the fish to move backwards, the maximum swimming speed being calculated from the current velocity, circumference of the channel, and the number of laps lost during a specific time period.

For large grayling we are proposing a circular channel 11 feet in diameter (Figure 9). Water velocities would be controlled by jets of water from one or more water pump(s). We would use MacLeod's procedure for calculating the swimming speed of fish.

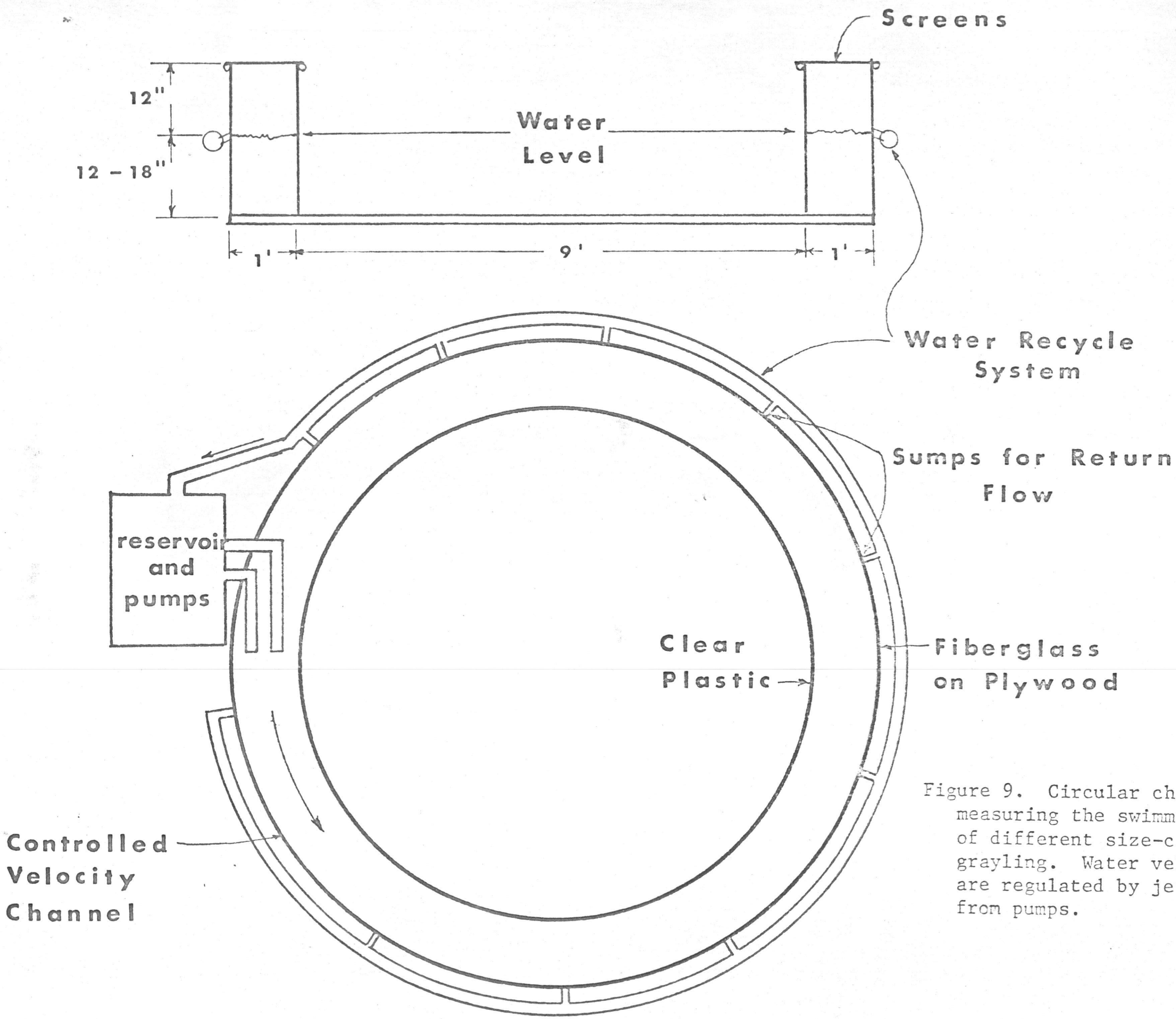

Figure 9. Circular channel for measuring the swimming speeds of different size-classes of grayling. Water velocities are regulated by jets of water from pumps.

We would test the swimming ability of mature grayling in the circular channel during their spawning migration. This would enable us to compare the performance of fish in the circular channel with that of fish in the culvert as the physiological state of the fish and the quality and the temperature of the test water would be identical. From the data obtained we would calculate a conversion factor for the swimming speeds of grayling subjected to the two different facilities. In this way we would compare the efficiency of one facility with that of the other in terms of fish performance.

Later, we could compare in the circular channel the swimming performance of large immature grayling with that found for mature fish of the same length during the spawning run and calculate a second conversion factor. If water temperatures were essentially the same, this second factor would give us a measure of the effect of migratory instinct and physiology on the swimming ability of mature versus immature grayling.

Immature grayling of various size classes would be tested in the circular channel after the spawning migration was completed. We would use the two conversion factors mentioned above and the swimming speed of immature fish ascertained in the circular channel to predict the swimming performance that immature grayling might be expected to exhibit in a culvert. This is necessary because we believe that fish responding to their innate migratory instinct will perform better than ones stimulated to swim by visual cues.

Prevailing water temperatures would be used for these tests, but heating units could also be used to modify water temperatures within limits.

Job No. 3.

Title: Swimming Speeds of Grayling in Circular Channels at Different Water Temperatures.

Objective:

To determine the cruising speed of arctic grayling in circular channels with a range of water temperatures.

Procedure:

If fish were available, follow-up temperature controlled tests on fish performance would be made in our temperature controlled bioassay laboratories on the Idaho campus.

Live grayling would be shipped by air to Idaho where they would be fed and held until tested.

We propose placing circular channels similar to that used in the field in Job No. 2 in constant temperature rooms. Water temperature would be held at 0, 5, 10, 15 and 20 degrees Centigrade. Tests on swimming performance would also be made at intervening temperatures if such temperatures were deemed critical to the interpretation of results.

The general tests procedures would be the same as described under Job No. 2.

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