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FISH AND BOAT PASS CHANNEL HYDRAULIC MODEL STUDIES AND FISH ASCENDING TESTS

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FISH AND BOAT PASS CHANNEL HYDRAULIC MODEL STUDIES AND FISH ASCENDING TESTS

by

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Synopsis

The hydraulics of five fish and boat pass channel designs referred to as PWRI Model 1, 2, 3, 4 and 5 are studied experimentally and analytically. The nature of the flow is described and extensive velocity measurements are presented. Velocity profiles in the centerline and at sections away from the centerline display almost similar characteristics in all the models. Feasibility study is conducted for Ayu (*Plecoglossus altivelis*) and Yoshinobori fish (*Rhinogobius* sp.) migration. Tests for this purpose are conducted in a 0.90-m wide and 15.33-m long channel fitted with baffles (Model 5). The performances of Ayu also known as sweet fish and Yoshinobori in the test channel are also assessed. Ayu and Yoshinobori readily entered and ascended the 15-m long fish and boat pass channel that was positioned at a slope of 10%. Hydraulic characteristics and fish migratory observations indicated that the models could be used to pass such weak swimmers as Ayu and Yoshinobori fish over small barriers

Key words: hydraulics, fishways, fish and boat pass, fish passage, ayu, yoshinobori, migration, fluid friction coefficient

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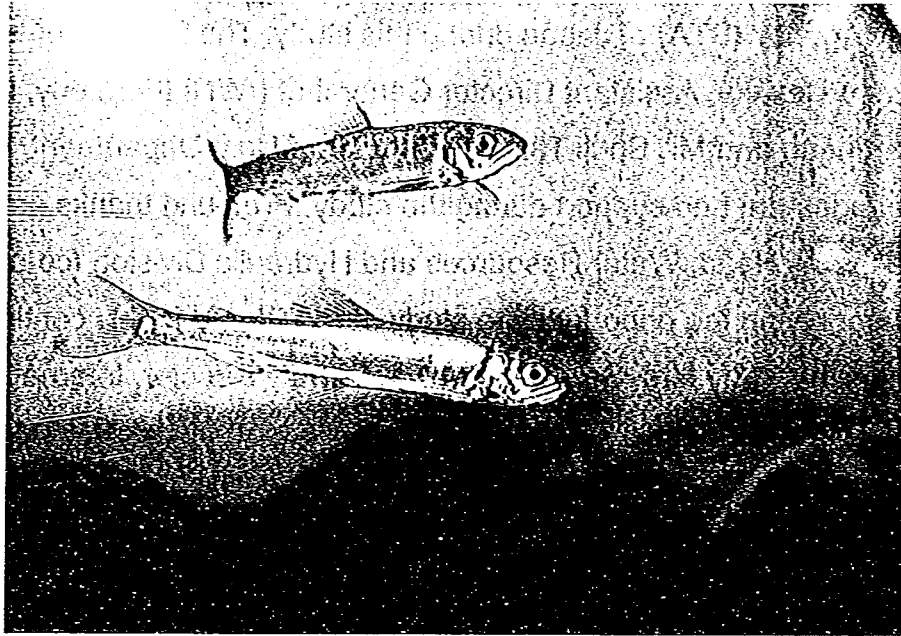
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Ayu (*Plecoglossus altivelis*)



Yoshinobori (*Rhinogobius* sp.,)

1. INTRODUCTION

Fishways contribute to the sustainable development of water resources projects by providing the means to maintain the fish migration routes. Fishways provide a path that allows upstream migrating fish to continue past the obstructions and complete the life cycle requirements, which include movements between reproductive, feeding and refuge habitat. Fishways also contribute to making streams more passable for other aquatic organisms. Obstructions may be natural (e.g. waterfall), or man-made (e.g. dams and weirs etc.,). While in most cases fishways are built for adult spawners, in some cases migrating juveniles are the target species. Ayu (*Plecoglossus altivelis*), Yoshinobori (*Rhinogobius sp.*), Carp (*Cyprinus carpio*) Trout, Salmon etc., are some of the important migratory fish in Japan.

Biological and hydraulic criteria for designing fishways vary with species and sizes of fish. In fishway channels, fish transport relies on water velocities not exceeding the swimming abilities of the migrating species. Swimming ability varies with species, size, as well as water temperature and other environmental parameters. Water velocities depend on fishway type, channel slope and water depth. Attracting fish to fishway entrance is also critical for the successful design of fishway.

Fishways usually consist of a sloping channel partitioned by weirs or baffles with openings for fish to swim through. Fishways can broadly be classified into three groups: the pool and weir type, Denil and the vertical slot fishways (Clay, 1961). In addition, there are special fishways for eels and other facilities to help fish overcome obstructions, like fish locks, fish lifts and trucking of fish. The different physical and hydraulic characteristics of each fishway type may make them suitable for some fish species and not suitable for others.

The pool and weir fishway consists of a sloping (or stepped) rectangular channel partitioned into pools by weirs. Water flows over the weirs or through orifices placed at the bottom of weirs or both over the weirs and through the orifices. Fish are attracted to move from pool to pool by the surface flow over the

baffles or by the jet flow out of the orifices. Pool and weir fishways are the oldest fishways and majority of the fishways built in Japan is belonging to this category.

Like a pool and weir fishway, a vertical slot fishway consists of a sloping rectangular channel, which is partitioned into pools. Water flows down the channel from pool to pool through the slots oriented vertically. A water jet formed at each slot and energy dissipation by jet mixing occurs in each pool. Fish can swim through the slot at any depth they prefer. The main advantage of the vertical slot fishway is the ability to handle the large variations in water levels. Named after its inventor, the Denil fishway is essentially a sloping straight rectangular channel provided to with closely spaced baffles on the bottom and sides. These baffles are arranged at regular and relatively short intervals along the length to keep proper depth and to bring about proper flow pattern for fish. Denil and subsequent researchers due to the complexity in original design later developed simpler versions (Denil 1909,1937, McLeod and Nemenyi, 1941, White and Nemenyi, 1942, Zimmer, 1962). Of the many different types of the Denil fishways developed, the two commonly adopted types are the so called simple (plain or standard) Denil and the Steeppass fishways. Bottom baffle fishway developed for streams in France by Larinier (1991) also come under Denil type fishway are now built in streams in Japan and elsewhere. Rajaratnam and Katopodis (1984,1990) presented comprehensive hydraulic characteristics of a simple Denil and Steeppass fishways. Flow pattern in the Denil fishways is very complex and fish may seek and find the most favorable areas to negotiate the fishway. The Denil fish passes are relatively selective and are really only adapted to running water species that posses sufficient capacities in terms of swimming speed and endurance.

Taking the advantages of Denil fishways, Pohjamo (1995) developed a combined fishway for ascending of small pleasure boats and fish. Gurram and Pohjamo (1997, 1999) presented the model and field test results of this type of channel built at Evijarvi in Finland. They observed that at places where space is a constraint, a single channel with baffle arrangements would serve both fish migration and boat traffic instead of building two separate channels. Following the success of this channel, we planned to develop a similarly hypothesized fishway

suitable for a weak swimmer like Ayu and concurrently permit small power driven pleasure boats through the fishway. Hence an experimental program was conducted at Public Works Research Institute during 1998-99 to test the hydraulic performance of baffles on the model and to develop the efficient designs. We also wanted to test the feasibility of fish and boat pass channel for the upstream migration of two small and most popular migratory fish (Ayu and Yoshinobori). The results of this work are presented in this report.

2. EXPERIMENTAL MATERIALS AND METHODS

Five fish and boat pass channel designs were studied at the Water Resources and Hydraulic Division of Public Works Research Institute (PWRI). For convenience these designs were referred to as PWRI Model 1, 2, 3, 4 and 5. PWRI Model 1, 2, 3 and 4 were built to a scale of 1:5. Model 5 was built for the purpose of ascending tests of Ayu and Yoshinobori and therefore is an extension of Model 2 with enlarged dimensions to length and width of the channel. The details of baffle dimensions used in PWRI Model 1, 2, 3 and 4 are shown in Fig.1 and 2. Model 1 is almost similar to the fish and boat pass channel developed at Evijarvi (Pohjamo 95, Gurram and Pohjamo 97 and 99) except for the changes at the inlet of the channel. The herringbone type bottom baffle introduced at the inlet of the Evijarvi model was eliminated in Model 1. Model 2 was identical to Model 1 except for the trapezoidal groove provided at the bottom of the baffle. Model 2 and Model 3 baffle shapes are identical except for the roughness elements between the baffles. Two pairs of cylindrical roughness elements with 5-cm diameter were placed on either side of centerline between the baffles. In Model 4, the dimensions and shape of the baffle differ from that of Model 2, however, the same spacing was maintained between the baffles as in Model 1, 2 and 3. The spacing between the baffles were kept at 10 cm in all the four models. Model 5 dimensions are shown in Fig.3. The channel width and length of Model 5 was 1.5 and 6.4 times the width and length for other four models. The spacing between the baffles also increased to 18 cm. In all the models baffles were fixed at 45° to bed of the channel. Experiments were performed on slopes of 4% and 5% for Model 1-4 and for Model 5 the selected slope was 10%. The values of tested discharges for Model 1 to 4 were 20 L/s, 30 L/s and 40 L/s. For Model 5

these were 50 L/s, 75 L/s and 100 L/s. The discharges were measured with inductive discharge measurement devices located in the supply conduits to the flume. A gate at the downstream controls the flow in the channel. The velocity readings were obtained using a mini current meter. The current meter was connected to a computer from which maximum, minimum and average values for each reading (30 seconds duration) were obtained. The velocity was measured in a grid pattern as shown in Fig.4 starting at the bottom of the channel and moving towards the surface. The measurement grid shown in Fig.4a corresponds to Model 2. Similar grid pattern was used for Model 1, 3 and 4. Model 5 measurement grid is shown in Fig. 4b. Velocity observations were made at a section where the flow is fully developed and was free from affects of entrance and exit conditions. However, for Model 1 and 2 these were made also made at other sections. For water surface profiles, a point gauge was used to measure the water depths. The experiments for Model 1 to 4 were conducted in the arrangement as shown in the Fig.5 and the arrangement for the Model 5 is given in Fig.6.

2.1.METHODS FOR ASCENDING EXPERIMENTS

The upstream migration test was performed to study whether or not the flow conditions available in the fishway will permit 'the fish that want to migrate upstream' actually do so. Ayu were chosen as the principle fish for this study as it is a typical Japanese migratory fish and its swimming ability is relatively low in comparison with other migratory species like salmon and trout. Therefore, Ayu fish imposes restrictions on the channel design than other species. Further, it is easy to obtain the Ayu specimens for testing purposes. Separate test was also carried out using popular benthic Yoshinobori fish. Wada (1990), Kashiwai and Nonaka (1998) and Kashiwai et al. (1999) have performed many upstream migration experiments of Ayu fish. The results of Wada (1990) indicated that the Ayu tend to migrate at every four hour cyclic period. However, Kashiwai and Nonaka (1998) and Kashiwai et al. (1999) have found through their studies at Public Works Research Institute (PWRI) that the change in lighting conditions is one among the several other factors that is significant in Ayu fish migration. They observed that peak rate of migration was during sunset and sunrise with highest

migration rates registered at sunrise. Both of these studies recommended for further experiments to clarify migration time periods. The tests in the present study were carried out on the basis that the peak migration takes place during sunrise and sunset. Therefore, the test fish were released into downstream pool at 3:00 p.m. and the fish were prevented to enter into fishway immediately with a fine wire screen. Instead they were allowed to swim in the pool for about an hour to calm down. Then the fine wire screen was opened at about 4:00 p.m. to start the test. The flow of water was stopped on the following day at about 9:00 a.m. thus concluding the experiment. All the test fish that were migrated upstream and that remained in the downstream pool were collected and counted after the test was completed. Fish stayed in the middle of the channel were also collected. The body weights and lengths of all the test fish were also recorded. The Ayu used for the test were nursery-bred fish.

Upstream migration tests in this study were conducted by generating backwater in the channel up to a location of 5 m from the downstream end so that the flow impact on the downstream pool is as small as possible. Therefore, fish had to negotiate an effective length of 10 m to pass through a channel with 1/10 gradient as shown in Fig.6. About 100 fish were used in each test so as to have meaningful migration rates. The Ayu used for the tests were nursery-bred fish.

As in the case of Ayu, migration characteristics of Yoshinobori are also not known clearly. The tested Yoshinobori fish were caught in the local river just before the test day. Assuming that Yoshinobori move very slowly, the water flow was stopped at 9:00 a.m. on the third day.

Temperature of the flowing water in the channel was noted and a temperature in the range of 20.5-22.0 °C was maintained through out the testing period with the help of cooling system. Separate experiment was conducted for video graphic observations of fish movement for the case in which most number of fish have ascended. For this, separate video cameras were set at the side and at the bottom of the channel. A portion (1.0x0.90 m) of the channel wooden bottom was replaced with acrylic plate of same size to record the fish movement from the

bottom. Enough light was illuminated so that the camera was able to catch the fish movements. All the tests were performed in the time of a year when Ayu and Yoshinobori fish normally migrate upstream in the rivers.

3. EXPERIMENTAL RESULTS AND DISCUSSION

The flow in the models tested consisted of two interacting parts: main stream in the central portion of the channel and a series of systematic lateral streams each one corresponding to a side pocket created by the baffles. Observations revealed that the nature of the flow was less turbulent than in the standard Denil fishway. Extensive mixing of flow was evident between the main stream and the lateral streams. Water was guided to the side pockets by the baffles, where circulation pattern was visible. Subsequently was redirected to strike and counteract the main stream. The main stream was characterized by the systematic surface undulations. Considerable air entrainment was also noted throughout the flow. The intense interaction between the main and later streams appeared to provide the mechanism for transferring mass and momentum and producing considerable energy loss and turbulence. The nature of the flow in the fish and boat pass channel is shown in photographs in Appendix A for different models. Closer examination revealed similarities in flow conditions in all the models.

3.1. FLOW DEVELOPMENT

The longitudinal water surface profiles of Fig.7 through Fig.11 provide the flow development in the fish and boat pass channel model 1 to 5. These profiles were measured in the central part of the channel at each baffle location. Uniform flow conditions were quickly established in the channel and the profiles were almost parallel to the bed of the channel with a short distance of flow development region at the inlet. Within the short distance inside the channel the water depth decreases slightly till a depth was reached. Thereafter, the flow depth gradually rises to a level, which was maintained for almost entire length of the fish and boat pass channel. At the downstream end of the channel, water depth decreased due to the influence of free over fall arrangement. The fully developed flow region was

characterized by longitudinal water surface profiles in the central plane of the fishway, which were approximately parallel to the bed of the channel (Fig. 7 through 11). Free over fall of the model testing would not correspond to the actual field setting. In the field, the water outlet (or fish entrance) would be influenced by the elevation of tailwater. Normally, there would not be a significant drop in water level between the water outlet and the tailwater. The fully developed region is expected to represent the field conditions reasonably well. Observations indicated that the shape of the baffles aided the flow to be moderately turbulent. This may help the surface swimming fish as well as the boats ascending the channel.

3.2. VELOCITY PROFILES

The nature of velocity field in each model channel was studied by measuring the magnitude of velocity u (time averaged) and its distribution in the direction of flow. This velocity was measured at a baffle section in the region of fully developed flow. However, for Model 1 and 2, velocities were measured at several baffle locations along the central normal. The experimental data are included in Appendix B.

The variation of u with water depth y is shown in Fig. 12 through 23 for two slopes tested with Model 1 and 2. In these plots the vertical axis corresponds to water depth and the horizontal axis corresponds to the time averaged velocity readings made at a distance of 6.6 cm (A), 14.4 cm (B), 22.2 cm (C) and 30 cm (center, D) as shown in Fig. 4a from the side wall over the baffle No. 1, 5, 10, 17 and 21. In most of the experiments, the velocity profiles exhibit similar characteristics at the five baffle sections. They all display the same identical geometrical shape. The maximum velocity u_m occurs somewhere below the free surface and minimum velocity near the bottom of the channel. These velocity profiles vary little from baffle to baffle for the same slope and discharge. When moving transversely from center plane, the magnitude of velocities appears to be decreasing towards the sidewalls.

For Model 3 and 4 velocity measurements were made only at baffle no.11 located in the region of fully developed flow. These velocity profiles are given in Fig.24 and 25. The profiles exhibit similar characteristics as in Model 1 and 2. The introduction of two pairs of cylindrical roughness elements in Model 3 in between the baffles on either side of the centerline has no definite marked effect on the velocity profiles. The increase in resistance made flow velocities to increase and decrease without a standard pattern. For example, in case of the experiments with discharge of 40 l/s, the velocities at the center of the baffle were high in Model 3 as compared to the Model 2 for both the slopes tested. However, in case of the channel with slope of 4%, Model 3 has displayed low velocities for the case with 30 l/s. The effect of roughness on flow with channel of 5% slope is to reduce the flow at the surface, but increases the velocities at the bottom in the center of the channel. For the cases tested with 20l/s, the surface velocities at the center of the channel were reduced in Model 3 due to the presence of roughness elements but at the bottom these velocities were increased. Similar type of increase and decrease in flow velocities were observed at places away from the center of the channel too. Model 4 in general showed a trend of decrease in velocities at the center of the channel as compared to all other models.

The dimensionless local velocity (u/u_m) plotted against the dimensionless local depths (Y/y) in Fig.26 through 29 for the centerline velocity profiles (at D section, Fig.4) at the fully developed section further characterize the flow in fish and boat pass channel. Here u_m is the maximum value of u occurring at or near the water surface and Y is the local depth. For the range of the experiments carried out in this study, the dimensionless local velocities for all the discharges gradually increase from the bottom to the surface reaching a maximum near the surface.

3.3. VELOCITY CONTOURS

Velocity contours were drawn from the time averaged velocity measurements made in the grid pattern over the baffle. These contours shown in Fig.30 for Model 1, Fig.31 for Model 2, Fig.32 for Model 3, and Fig. 33 for Model 4 provide

comprehensive view of the velocity field on the five models tested. A mean water surface level is marked and the velocities are specified in cm/s for contour intervals of 10 cm/s.

The shape and distribution of the contours confirm some of the observations which have been made earlier. For Model 1 fish and boat pass channel (Fig.30), high velocities exist at the surface layers of the flow above the centerline of the channel. The velocities gradually reduced reaching a minimum at the bottom. Also the velocities diminished with distance from the centerline. Sharp turns in the contours represent the influence of the baffle sidewalls. In the Model 2 fish and boat pass channel, the contours in the clear opening of the channel, when compared to those of the Model 1 fish and boat pass channel display similar characteristics for the velocity field. Consistent with previous observations, high velocities are exhibited close to the water surface, however, the location of high velocity zone moved away from the centerline. The velocities were considerably reduced at the bottom and at the sides. The isotachs are more closely spaced for lower discharges than for higher discharges indicating a more gradual change in velocities at higher discharges. In a similar way to the Model 1, velocities in Model 2 are reduced with distance from the centerline. The velocity contours of Model 3 fish and boat pass channel (Fig.32) exhibit characteristics similar to those for Model 2. In Model 4, the spacing between the contours is generally higher than in the previous three models. Also, the high velocity zone appears to be shifting gradually away from the centerline with increase of discharges. This zone for the case with 40 l/s is located almost close to the sidewalls.

3.4. VELOCITY FIELD IN MODEL 5 FISH AND BOAT PASS CHANNEL

In the Model 5 study, the size (width and depth) of the channel was kept smaller than the prototype fish and boat pass channel of Model 2. Slope of the channel was however increased to 10% with an aim to obtain prototype velocity distribution using small amount of discharges. Though it is entirely not possible to reproduce the similar flow conditions as in the prototype fish and boat pass channel of Model 2 with this test method, however, considering that the

experiments using Model 5 were mainly designed for the testing of migration of Ayu and Yoshinobori, the scaling effects were thought to be not so prominent.

In PWRI Model 5, the velocity profiles (Fig.34) have a clear pattern with an increase in velocities from sides to the center and from bottom to the surface with the maximum velocity occurring close to the water surface near the central zone. When moving transversely from the center of the channel, the magnitudes of velocities are gradually increased up to a certain distance, thereafter, decrease at the sides for discharges up to 100 l/s. The dimensionless local velocity (u/u_m) plotted against the dimensionless local depths (Y/y) in Fig.35 for the centerline velocity profiles (at E section) further characterize the flow in Model 5. For the range of the experiments carried out in this study for Model 5, the dimensionless local velocities for all the discharges fall on one common curve and the velocities gradually increase from the bottom to the surface reaching a maximum near the surface.

The contours (Fig.36) inside the groove at the bottom of the baffle indicate a more gradual change and velocities were always less than 1 m/s. Small fish like Yoshinobori and Ayu are expected to utilize such small range of velocities inside the groove for passing through the channel. Maximum velocity region is noted near the water surface at a distance of 15 cm from the center. The structure of the velocity profiles indicates that a wide range of velocities are present in the channels so that small fish and fish with a poor swimming ability can also ascend the channels.

3.5. HYDRAULIC ANALYSIS

3.5.1. Flow Equations for Fish and Boat Pass Channel

Consider uniform flow in fish and boat pass channel with a depth of y for a discharge of Q and a slope of S . Following the procedure used for Denil fishways (Rajaratnam and Katopodis, 1984), we write

$$by\gamma S = (b + 2y)\tau \quad (1)$$

$$\tau = c_f \frac{\rho V^2}{2} \quad (2)$$

where τ is average shear stress between the mainstream and recirculating water on the bottom and sides, C_f is a coefficient of fluid friction, ρ is mass density of the water, γ is weight per unit volume of water and V is mean velocity in the fish and boat pass channel. Simplifying Eq.1 and 2, the coefficient of friction (C_f) between the main stream and the recirculating water on the sides and bottom in fishway channel is given by;

$$C_f = \frac{2gSy}{V^2 \left(1 + \frac{2y}{b}\right)} \quad (3)$$

Values of C_f were calculated for all the Models and are given in Table 1. From Table 1 it is evident that Model 4 exhibited the highest fluid friction coefficient (C_f) than Model 3, 2 and 1. Fig.37 show the correlation of C_f with y/b . In general, C_f decreases continuously as y/b increases. However, for Model 1, opposite is observed. C_f as large as 7.8 is seen in Model 4 and the lowest C_f of 0.5 is noted in Model 5. Depth averaged velocities (U) at the center of the channel are also given in the Table.

For flow rate, we used the following equation derived from Eq.1, 2 and 3

$$Q^* = \frac{Q}{\sqrt{gSb^2}} = f(y/b) \quad (4)$$

Where Q^* is the dimensionless discharge and f denotes some function. Eq.4 was evaluated using the experimental of all the models and are given in Fig. 38. The results are well described by the following equations.

$$\text{For Model 1 } Q^* = 0.4583(y/b)^{0.9195} \quad (5)$$

$$\text{For Model 2 } Q^* = 1.072(y/b)^{1.6283} \quad (6)$$

$$\text{For Model 3 } Q^* = 2.8313(y/b)^{2.359} \quad (7)$$

$$\text{For Model 4 } Q^* = 0.583(y/b)^{1.567} \quad (8)$$

$$\text{For Model 5 } Q^* = 64.668(y/b)^{3.7096} \quad (9)$$

These curves in Fig. 38 may be useful in the design of fish and boat bass channel.

3.5.2. Analysis for Model 5

An analysis was carried out in the present study to comprehend the amount of energy dissipation and flow resistance by way of roughness factors in Model 5 fish and boat pass channel. For studying different flow parameters, a comparison of Model 5 channel with a corresponding rectangular channel is made. Consider a rectangular channel of width b , with bed slope S carrying a discharge of Q . Let V_o and y_o be the mean velocity and depth. Assuming steady, uniform flow conditions in the channel, the Manning's equation is written as

$$V_o = \frac{1}{n_o} R_o^{\frac{2}{3}} \sqrt{S} \quad (10)$$

in which n_o is Manning roughness coefficient and R_o is the hydraulic radius. For Model 5 channel, let y be the depth and V the mean velocity (Q/by). Assuming a value of $n_o = 0.013$ as the channel is built of wood, the V_o and y_o values for rectangular channel were calculated and given in Table 2 along with calculated values of V and measured values of y . Comparison of V_o and V values reveals that the velocities in the Model 5 channel are about one-seventh to one-fifth of the velocities in the plane rectangular channel built of same material. The Froude numbers (F) shown in Table 2 were estimated from the depth averaged velocities (U) in the central plane of the Model 5 channel for the cases for which detailed velocity measurement were made. The Froude numbers are approaching to unity as the discharges are increasing. Comparative Froude numbers (F_o) in the rectangle channel was also given in the table.

Water velocity decreases as energy dissipation increases. Decreases in water velocities assist the migrating fish to go up the channel. Therefore, an appreciation of the magnitude of the energy dissipation in the Model 5 channel helps to testify the efficiency of the channel. Let E and E_o be the specific energies in the Model 5 channel and plane rectangular channel. The following relationships are written assuming uniform flow in both channels:

$$E = y + \frac{V^2}{2g}, E_o = y_o + \frac{V_o^2}{2g} \quad (11)$$

$$\varepsilon = \frac{E_o - E}{E_o} = 1 - \frac{E}{E_o} \quad (12)$$

Using (12), energy dissipation was estimated and is given in Table 2. Compared to an equivalent rectangular flume, Model 5 channel dissipated 57.4-72.1% of the flow energy.

Similar comparison for the roughness factors of Model 5 channel and equivalent rectangular flume built of the same material yield the following expression;

$$\frac{n_o}{n} = \left(\frac{y_o}{y} \right) \left(\frac{R_o}{R} \right)^{\frac{2}{3}} \quad (13)$$

Here n and R are Manning roughness coefficient and hydraulic radius for Model 5 channel and n_o , R_o are of the corresponding rectangular channel. Table 2 includes the values of n_o/n estimated from the flow measurements using (13). Roughness factors are high in Model 5 and about 12-23 times the roughness expected in the plain rectangular flume.

3.6. RESULTS OF ASCENDING TESTS FOR AYU AND YOSHINOBORI

The distribution of passed and not passed Ayu and Yoshinobori through the fish and boat pass channel (Model 5) in different discharges is given in Fig.39. In

all the cases tested, almost all the fish ascended the channel. The migration rate defined as number of passed fish to the total number of released fish is seen to be decreasing with increase of discharge. Yoshinobori, which are commonly smaller than the Ayu used the channel efficiently since 73% of the released Yoshinobori reached the upstream pool.

Fig.40 present the relationship of fish length with the number of passed and not passed Ayu fish. An examination of the distribution in these figures reveal no special trend in relation to body length as fish of all size passed through the channel and the number of passed fish are higher in all the body length classes. In other words, the fish that desired to migrate upstream did so regardless of their size. In Fig.41, the results of Yoshinobori fish tests are given. All the least sized fish passed through the channel. Therefore, in the studied range, both Ayu and Yoshinobori migration test showed that the desire or the motivation of the fish for migration under the available flow conditions is more important than the actual strength of the fish. About 42% of the successfully ascended Yoshinobori fish went up the channel on the first day itself. On the second day, more than half the total number of ascended fish passed the channel. Only about 6% have gone up on the third day. Therefore, the migration test results of Yoshinobori suggests that the after certain period of time, fish appear to show lack of interest to migrate upstream. All the data of experiments on ascending are given in Appendix B.

A separate test for finding the migration route of the fish using video camera set at the bottom of the channel provided the image of fish routes. The routes shown in Fig.42 were drawn by looking at the captured video. The filled in circles in the figure indicate the places where the fish were seen taking rest for more than 2 minutes before moving. Almost 90% of the fish were found in the upstream pool before the video recording was stopped. Only a fraction of the migrating fish was seen in the video. This may be mainly due to the insufficient lighting conditions and partly due to the speed at which the Ayu fish travel with in the frame of video camera. However, fish that were captured gave fairly good idea of their route while going up the channel. Many fish used (Fig.42) the trapezoidal groove provided at the bottom of the channel and the space between

the baffles for taking rest before continuing further upstream. The photographs of both successfully and unsuccessfully ascended fish are given in Appendix A. The photographs of fish (Photo No.6-9) waiting to go upstream, resting between the baffles and successfully ascended are given in Appendix A.

4. CONCLUSIONS

The hydraulic characteristics of the fish and boat pass channel were examined using model testing. Tests reveal that wide range of velocities were possible across the baffle width so that migratory fish have an option to go upstream from different locations depending their swimming capabilities.

The velocity profiles in all the models tested have been found display maximum velocities to be located at the surface for all the discharges and slopes.

Since majority of the migratory fishes of Japanese rivers have capability to ascend against the maximum velocities in the fishways in the range of 1.0 m/s to 2.0 m/s, the fish and boat pass channel is hoped to serve many of these species.

An analysis for fluid friction coefficient C_f between the main stream and recirculating flow on the sides and bottom reveal larger than the known for traditional open channel flow. The C_f values for Model 4 found to be higher than that of other models.

Migration tests indicated that Ayu and Yoshinobori entered and passed through the channel. Fish migration routes confirmed that the trapezoidal groove provided at the bottom of the baffle was helpful to the fish swimming at the bottom of the channel.

Ayu fish readily entered and passed through 15.3-m long test channel placed at 1-on-10 slope with no apparent difficulty. Ayu fish used the sides and bottom of the channel while passing the channel. Ayu fish did best (85% to 96% successes) in all the discharges tested.

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6. NOTATION

b	fish and boat pass channel width
C_f	coefficient of fluid friction
E	specific energy in fish and boat pass channel (Model 5)
E_o	specific energy in the c equivalent rectangular channel (Model 5)
F	Froude number for fish and boat pass channel (Model 5)
F_o	Froude number for an equivalent rectangular channel (Model 5)
g	acceleration due to gravity
n	Manning's roughness for fish and boat pass channel (Model 5)
n_o	Manning's roughness for an equivalent rectangular channel (Model 5)
R	hydraulic radius for fish and boat pass channel (Model 5)
R_o	hydraulic radius for an equivalent rectangular channel (Model 5)
S	bed slope for fish and boat pass channel
U	depth averaged velocities at the center of the channel
u	longitudinal velocity (time averaged)
u_m	maximum value of u
V	average velocity in fish and boat pass channel
Y	normal distance
y	depth of flow
y_o	depth of flow for an equivalent rectangular channel
γ	specific weight of water
ε	energy dissipation in fish and boat pass channel $(E-E_o)/E_o$ (Model 5)
ρ	mass density of water
τ	boundary shear stress

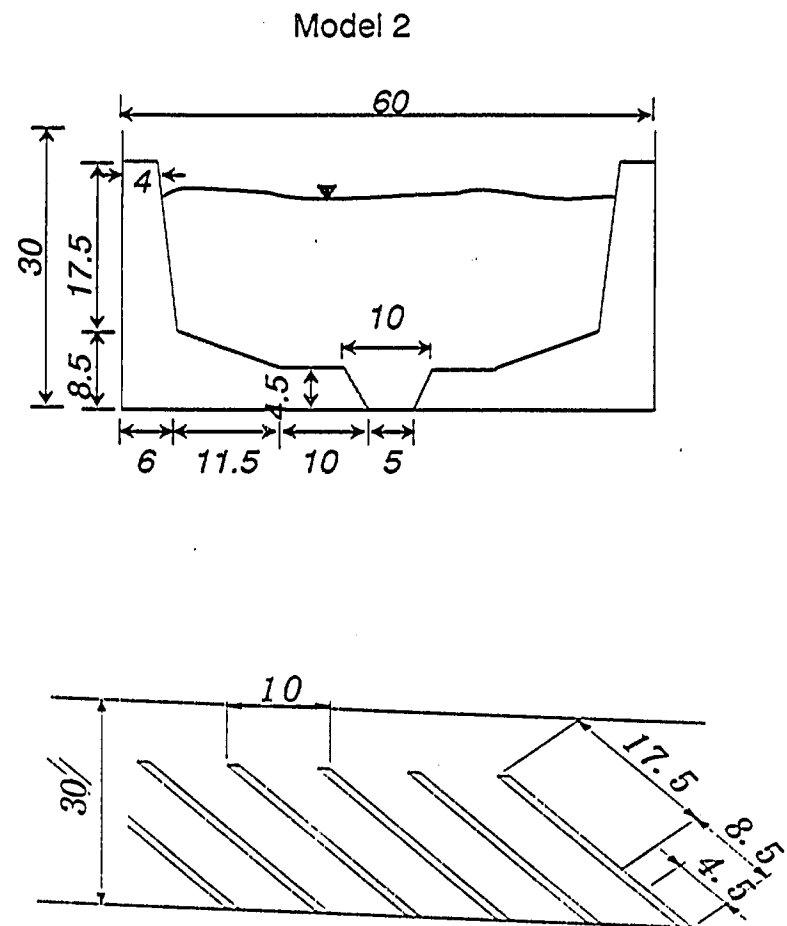
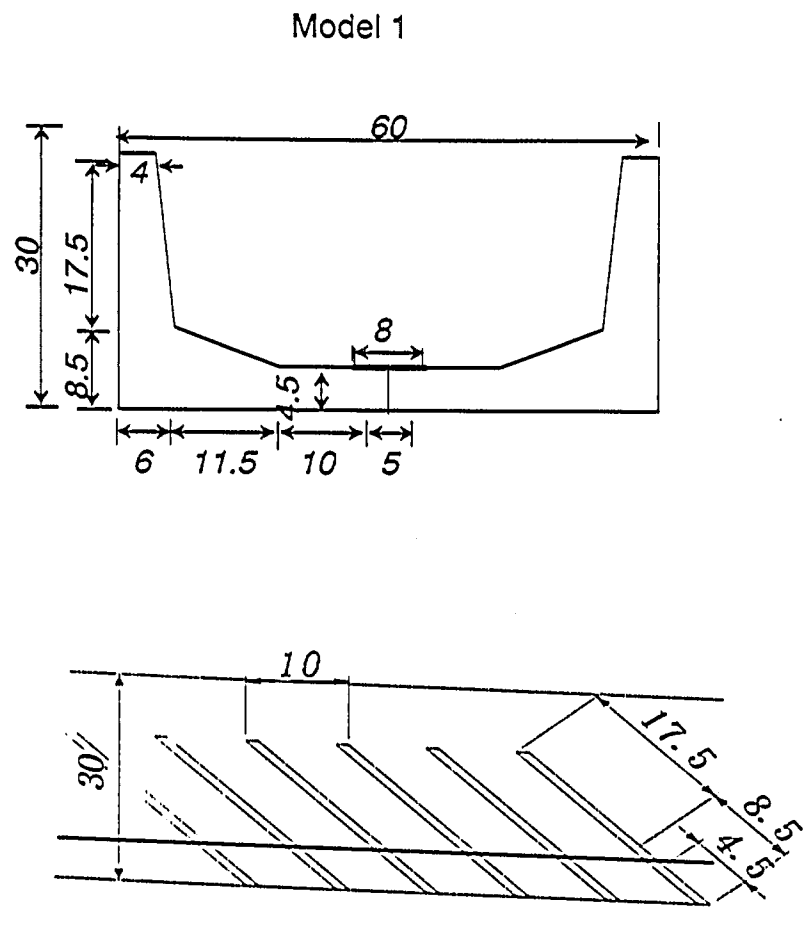
Table 1. Experimental Observations and Calculated Parameters

Design Type	Slope (S)	Q (l/s)	y (cm)	V cm/s	U cm/s	y/b	C _i
Model 1	1/25	20	14.8	30.03	114.30	0.247	2.42
		30	9.8	34.01	98.37	0.163	1.36
		40	6.3	35.27	77.09	0.105	0.87
	1/20	20	12.5	35.56	96.68	0.208	1.52
		30	9.1	36.63	121.68	0.152	1.11
		40	6.6	33.67	89.43	0.110	1.00
Model 2	1/25	20	15.9	27.95	40.36	0.265	2.95
		30	12.6	26.46	60.06	0.210	2.76
		40	10.17	21.85	72.00	0.170	3.41
	1/20	20	15	29.63	55.23	0.250	2.51
		30	12	27.78	70.82	0.200	2.41
		40	10	22.22	76.19	0.167	3.25
Model 3	1/25	20	15.7	28.31	52.60	0.262	2.85
		30	13.5	24.69	56.60	0.225	3.34
		40	11.9	18.67	71.60	0.198	5.29
	1/20	20	15.5	28.67	86.00	0.258	2.75
		30	13	25.64	60.50	0.217	3.01
		40	11.4	19.49	52.80	0.190	4.70
Model 4	1/25	20	21.4	20.77	19.50	0.357	6.60
		30	18.3	18.21	33.18	0.305	7.69
		40	13.7	16.22	41.20	0.228	7.83
	1/20	20	20.8	21.37	48.50	0.347	6.11
		30	17.5	19.05	44.00	0.292	6.81
		40	13.4	16.58	23.14	0.223	7.37
Model 5	1/10	50	13.6	40.85	97.00	0.151	1.23
		75	15	55.56	110.00	0.167	0.72
		100	16.4	67.751	125.00	0.182	0.51

Table 2. Model 5 in Compariosn with a Corresponding Rectangular Channel

Q (l/s)	y (cm)	V (m/s)	U/V	y_o (cm)	V_o (m/s)	V/V_o	F	F_o	ε	n_o/n	n
39.5	13.10	0.335		1.80	2.438	0.137		5.80	0.574	0.042	0.308
50.0*	13.60	0.408	2.375	2.00	2.778	0.147	0.840	6.27	0.650	0.047	0.274
59.7	14.10	0.470		2.34	2.879	0.163		6.06	0.658	0.057	0.230
69.8	14.90	0.520		2.55	3.045	0.171		6.09	0.673	0.061	0.212
75.0*	15.00	0.556	1.980	2.68	3.115	0.178	0.907	6.08	0.682	0.066	0.197
80.95	15.40	0.584		2.80	3.211	0.182		6.13	0.690	0.068	0.191
91.5	15.90	0.639		3.00	3.382	0.189		6.23	0.707	0.073	0.178
100.0*	16.40	0.678	1.845	3.17	3.505	0.193	0.985	6.29	0.715	0.076	0.171
110.8	17.00	0.724		3.39	3.628	0.200		6.29	0.721	0.080	0.162

* Detailed velocity measurements were made to these discharges only. For all other cases, only depth was measured.



Units: cm

Fig.1 Baffle Details of Model 1 and 2

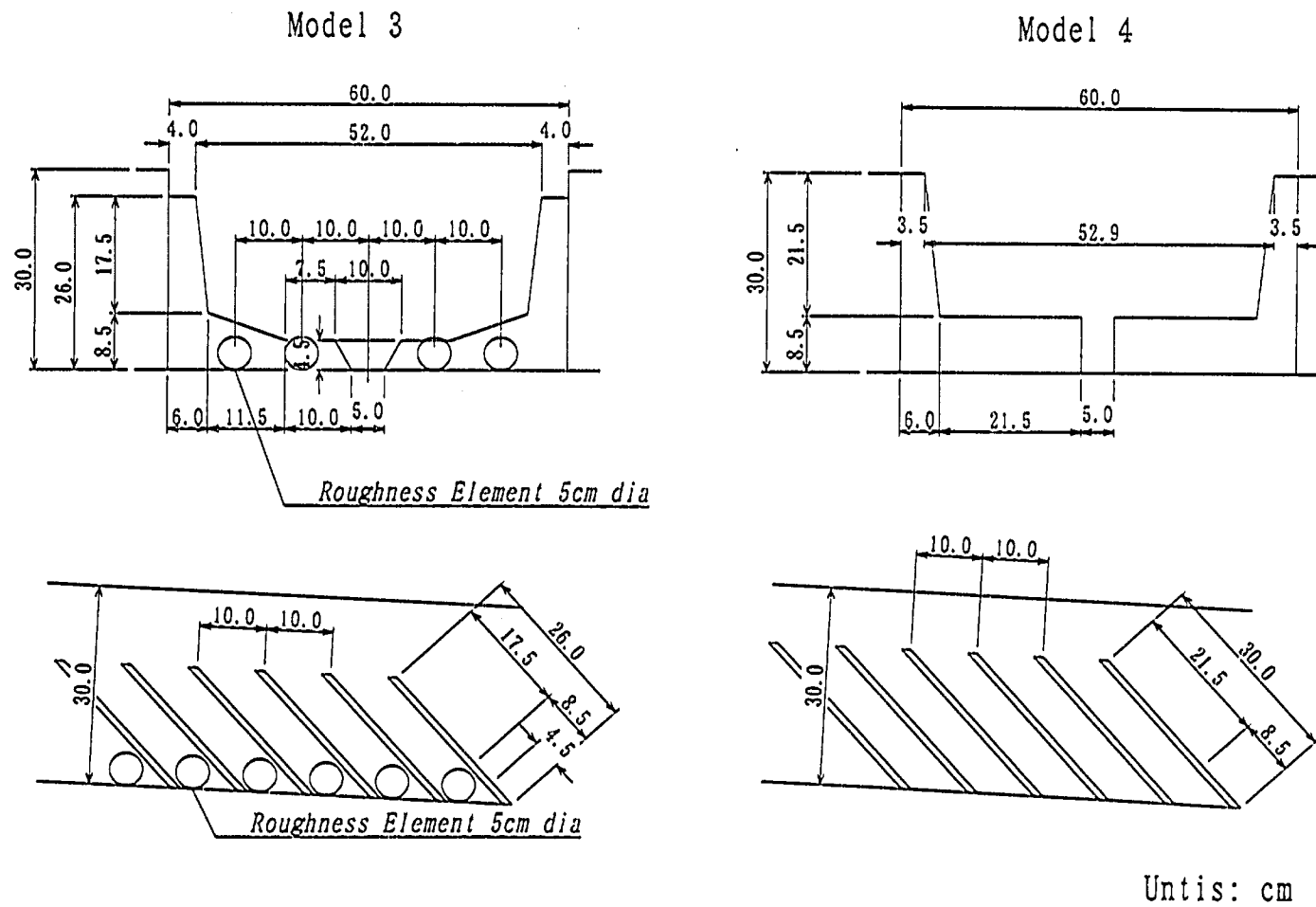
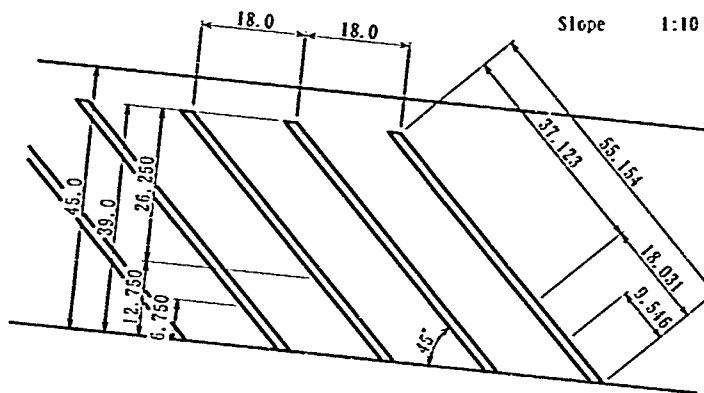
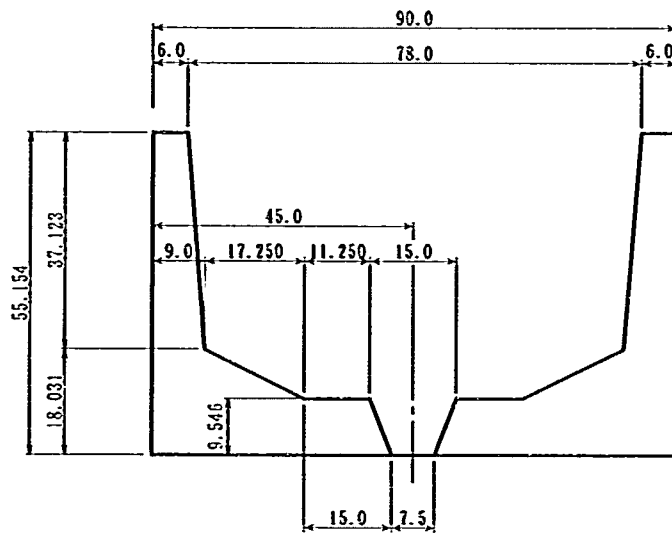
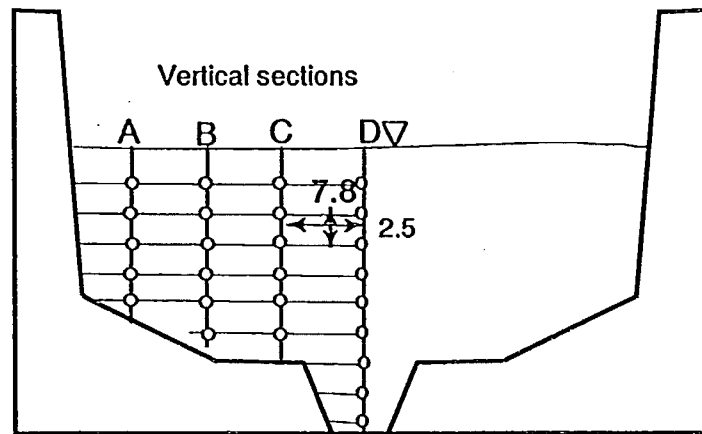


Fig.2 Baffle Details of Model 3 and 4



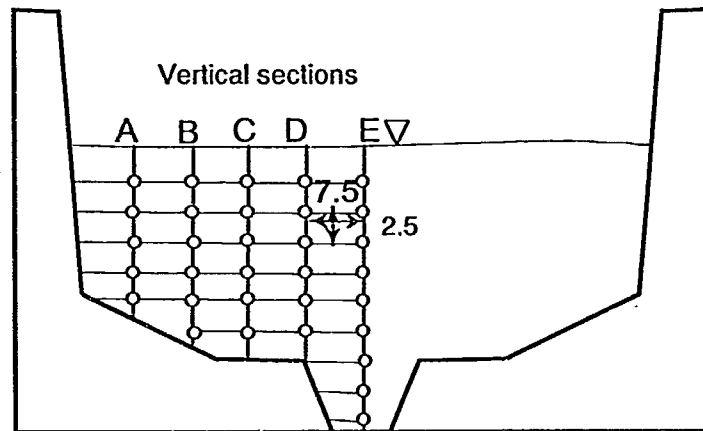
(Unit : cm)

Fig.3 Baffle Details of Model 5



a)

Units:cm, figure not to the scale



b)

Units:cm, figure not to the scale

Fig. 4 Velocity Measurements Grid for Model 2 (a) and 5 (b)

Fig.5 Experimental Setup for Model 3. Note similar setup was used for Model1,2 and 4

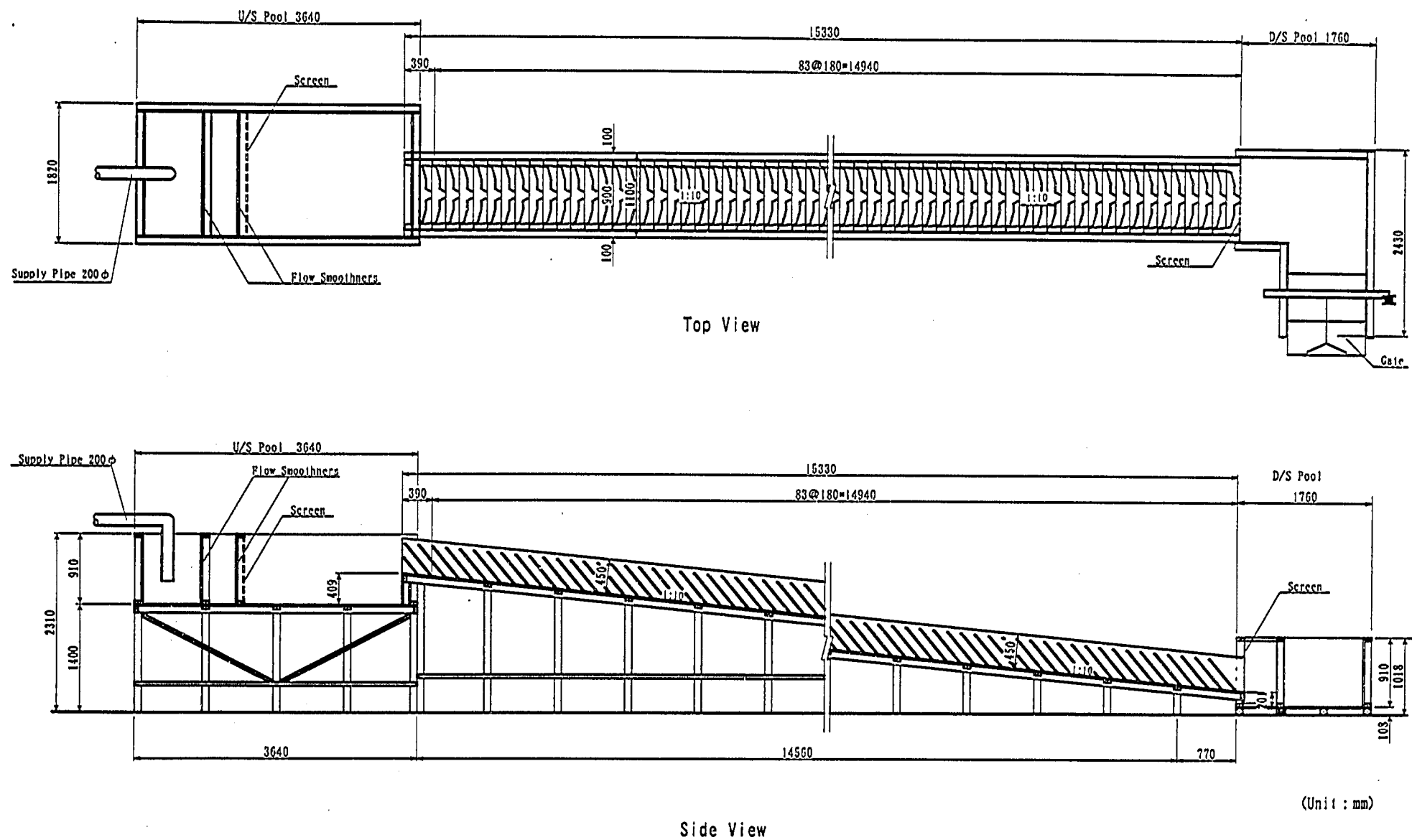
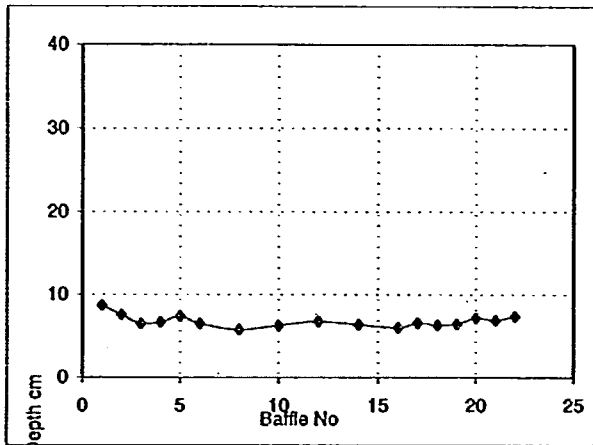
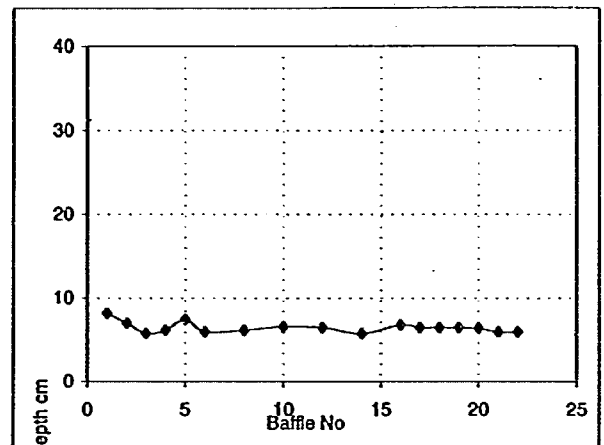


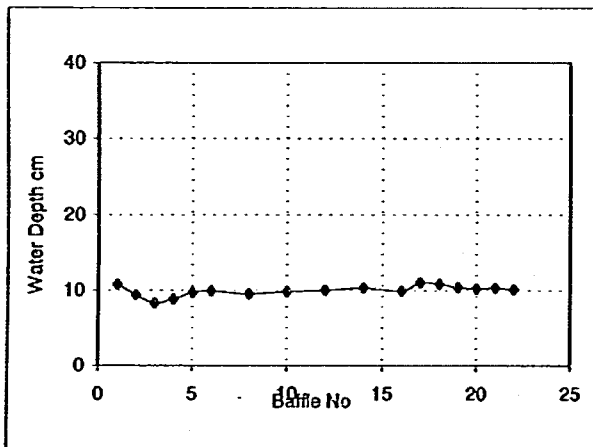
Fig.6 Experimental setup for Model 5



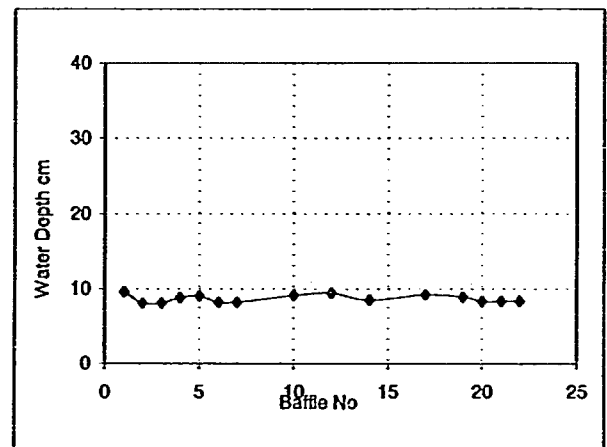
Discharge:20 l/s



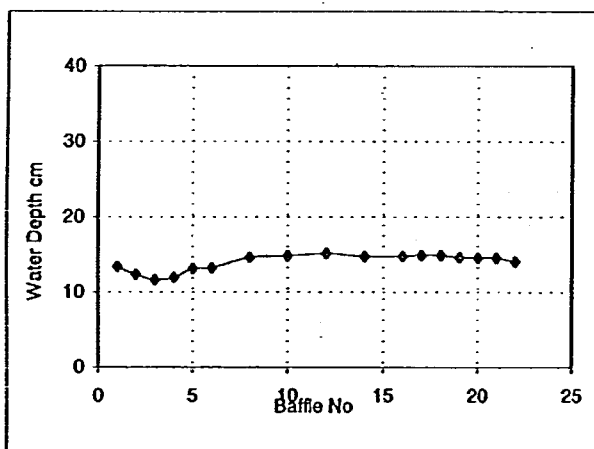
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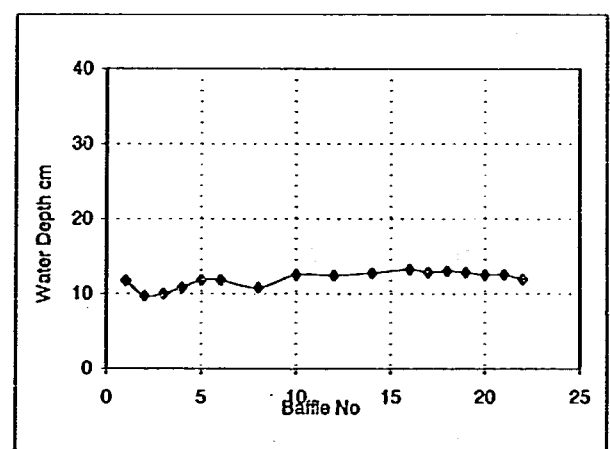
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Discharge:30 l/s



Discharge:40 l/s

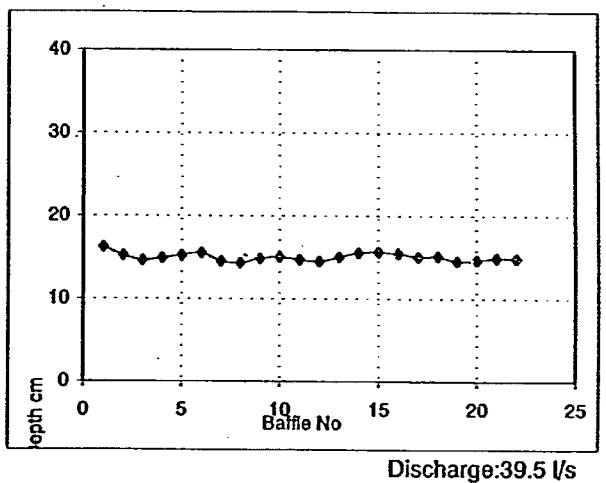
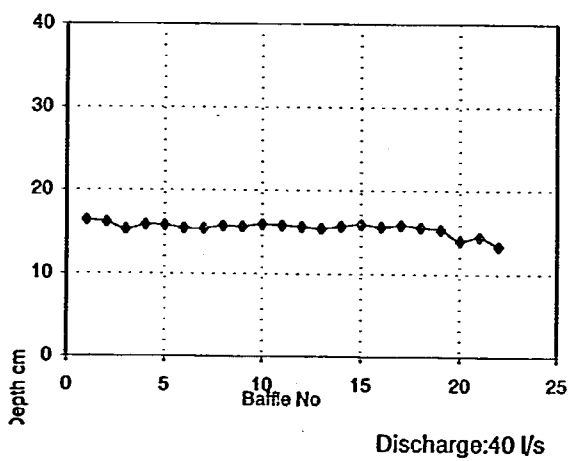
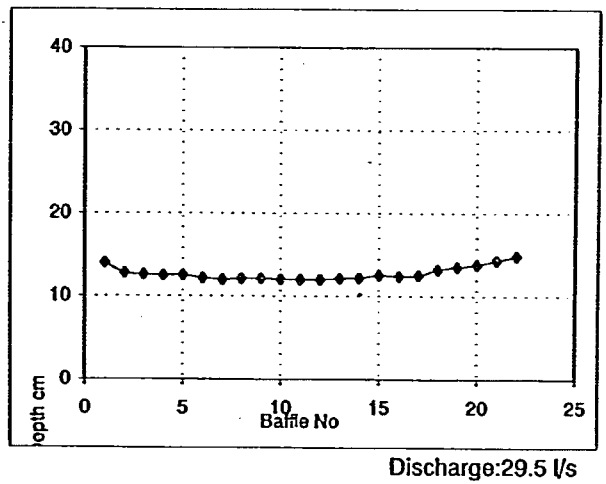
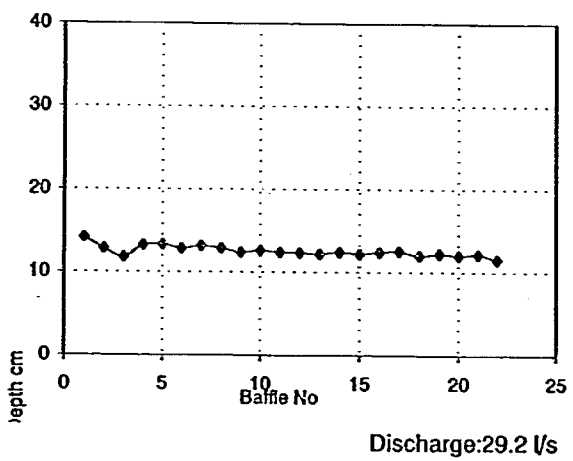
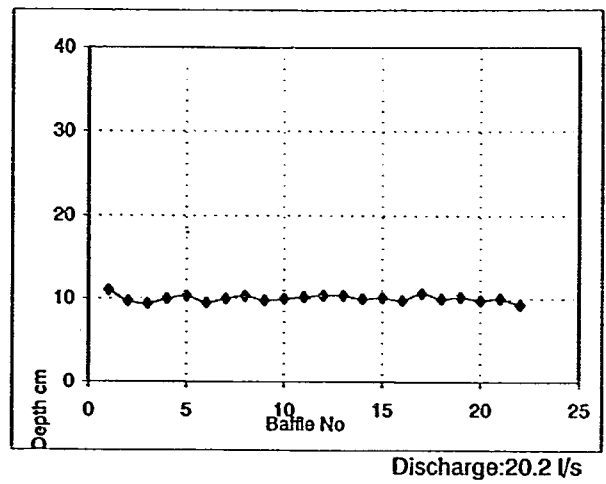
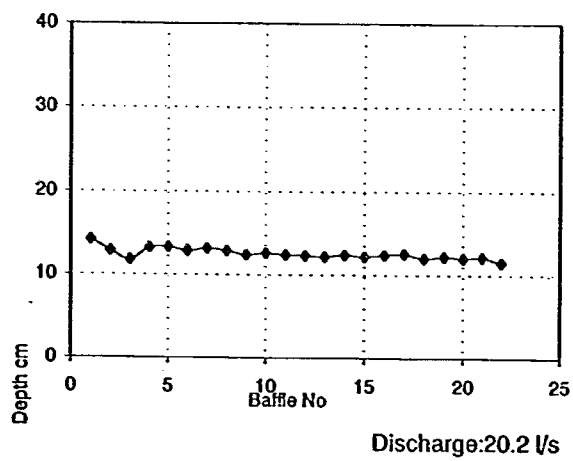


Discharge:40 l/s

Slope:1/25

Slope:1/20

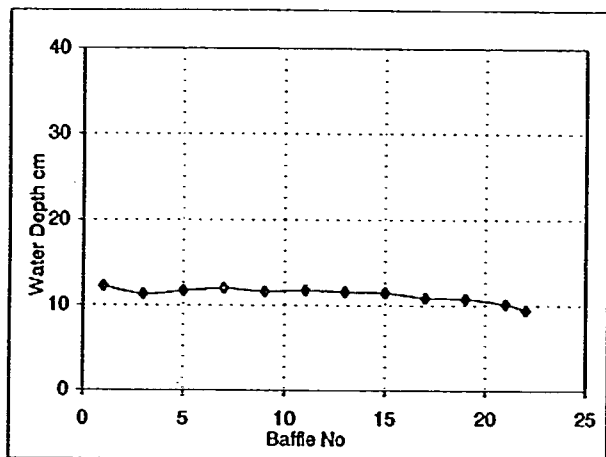
Fig.7 Water Surface Profiles in Model 1



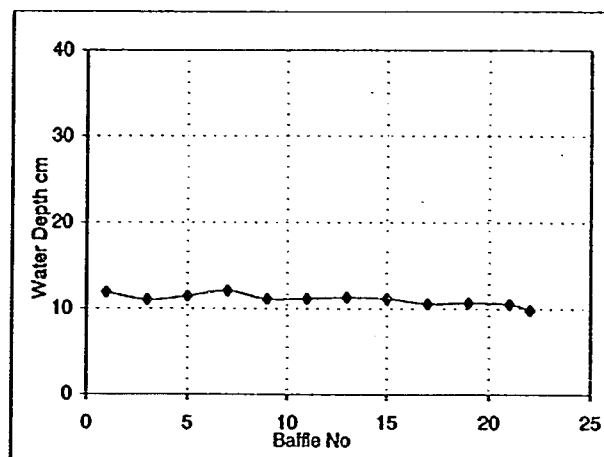
Slope: 1/25

Slope: 1/20

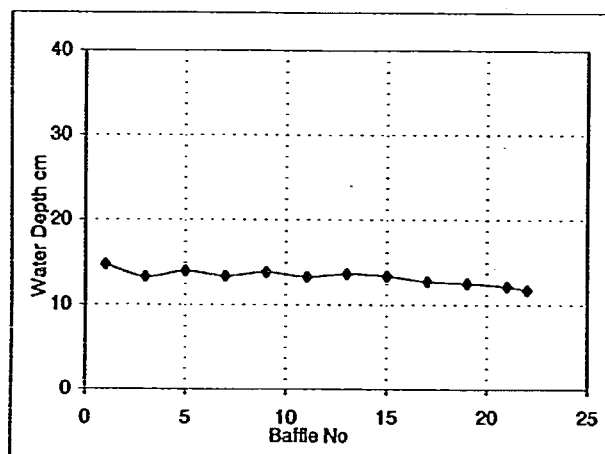
Fig.8 Water Surface Profiles in Model 2



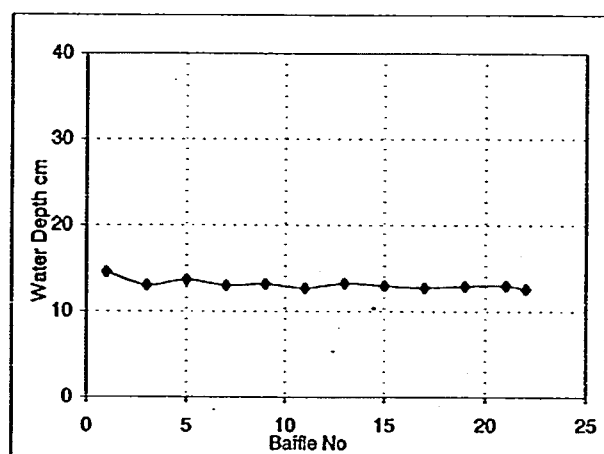
Discharge: 20.6 l/s



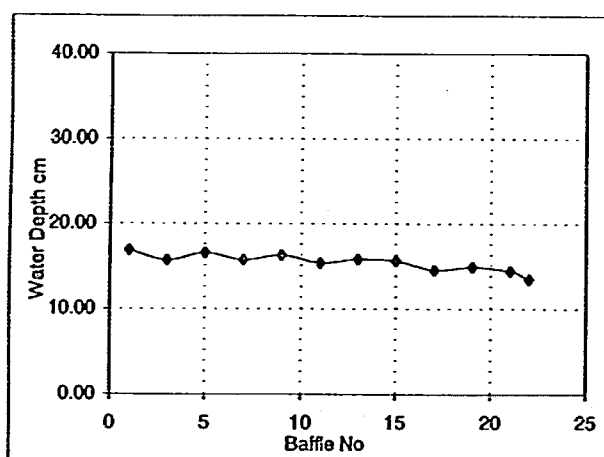
Discharge: 20.8 l/s



Discharge: 29.5 l/s

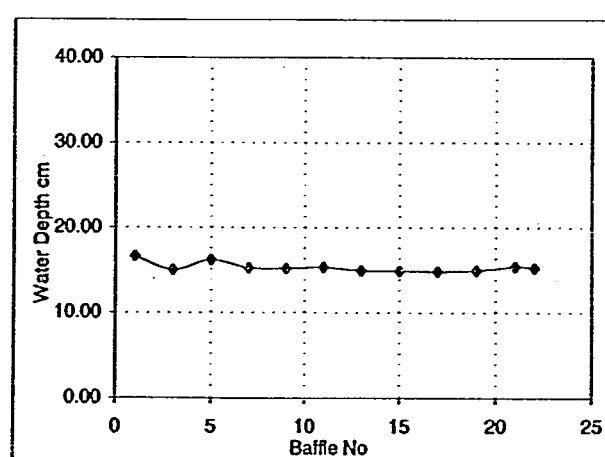


Discharge: 31 l/s



Discharge: 40.1 l/s

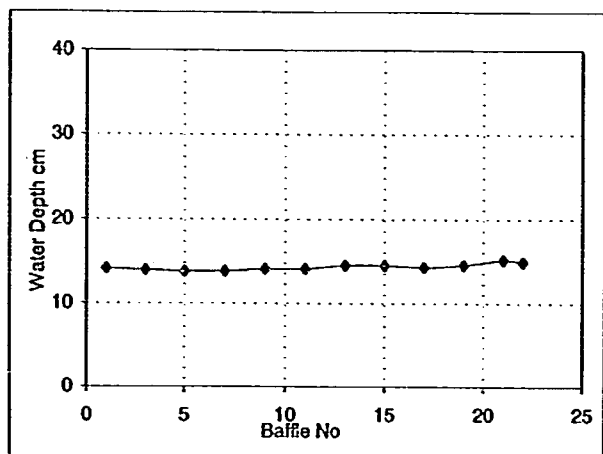
Slope: 1/25



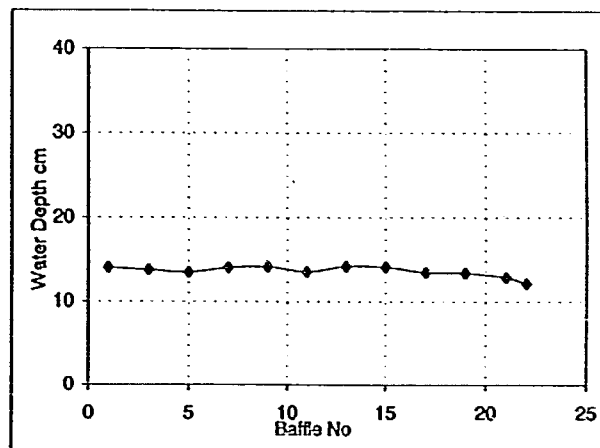
Discharge: 39.6 l/s

Slope: 1/20

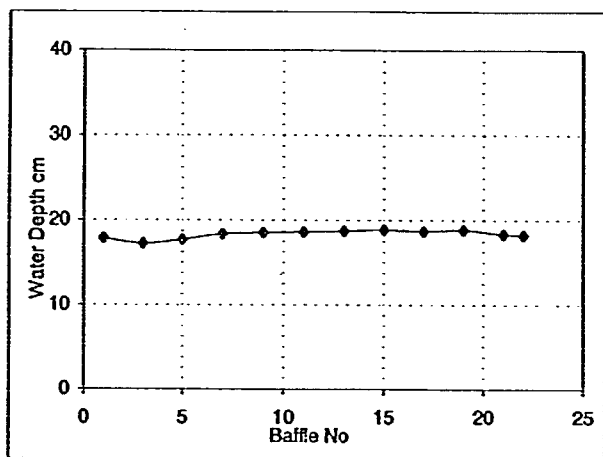
Fig.9 Water Surface Profiles in Model 3



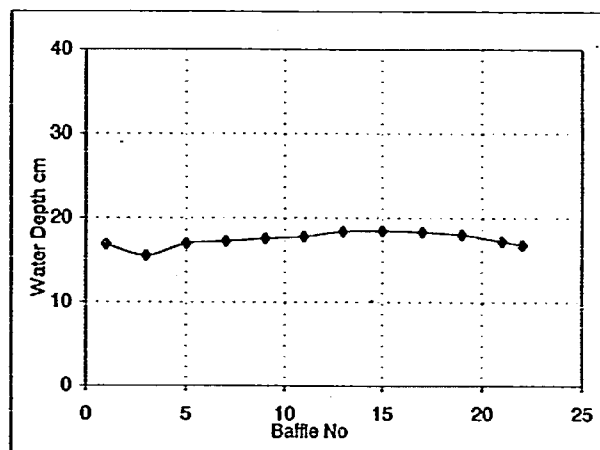
Discharge: 20.6 l/s



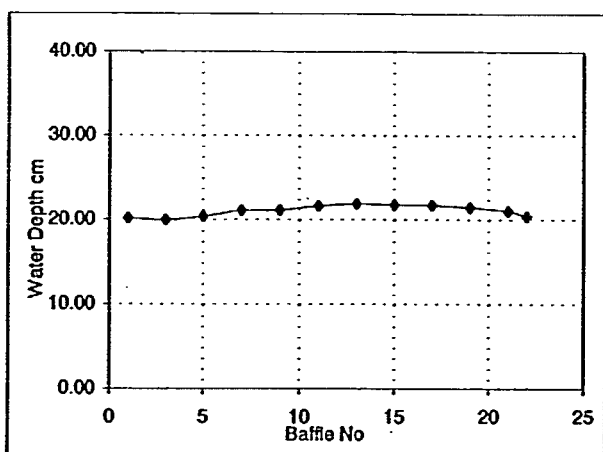
Discharge: 20.7 l/s



Discharge: 31 l/s

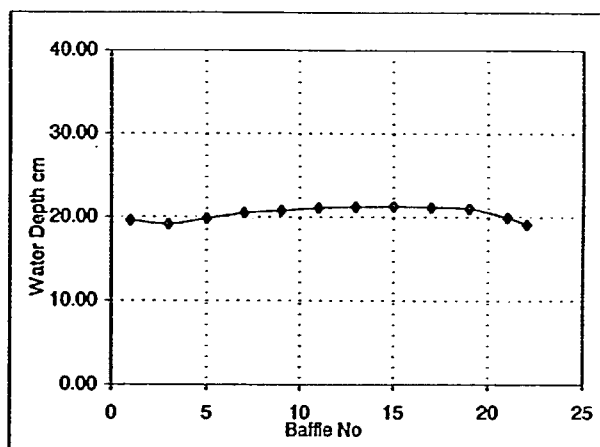


Discharge: 30.3 l/s



Discharge: 40.6 l/s

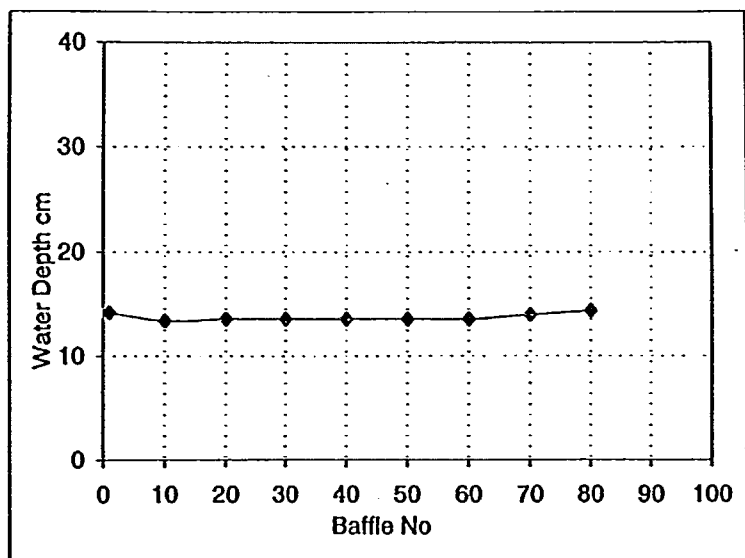
Slope: 1/25



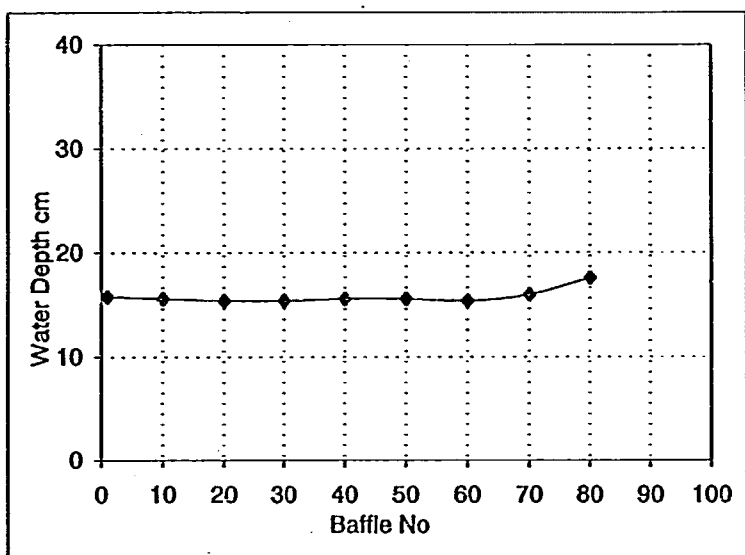
Discharge: 40.6 l/s

Slope: 1/20

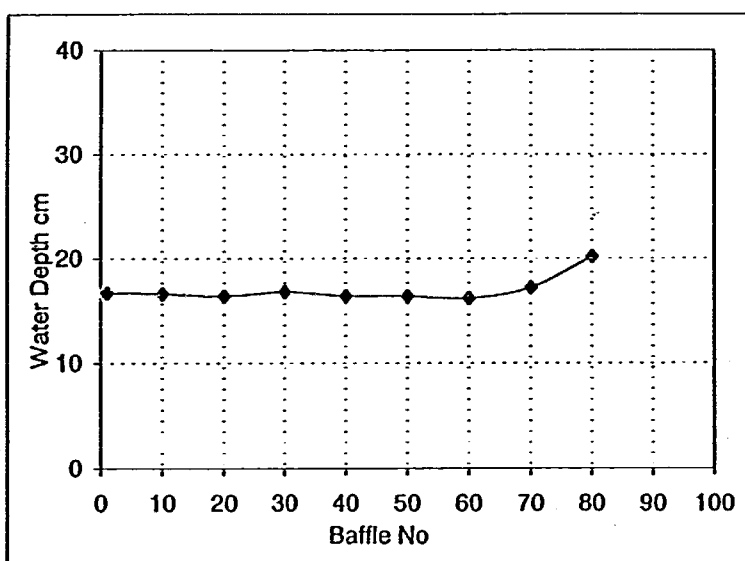
Fig.10 Water Surface Profiles in Model 4



Discharge:50 l/s



Discharge:75 l/s



Discharge:100 l/s

Fig.11 Water Surface Profiles in Model 5

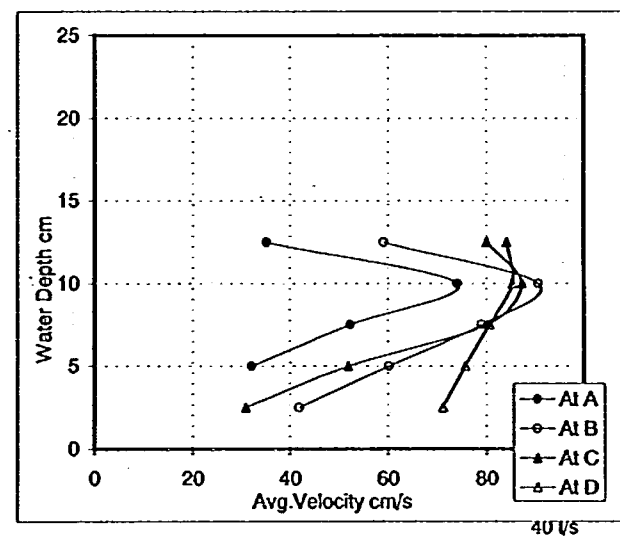
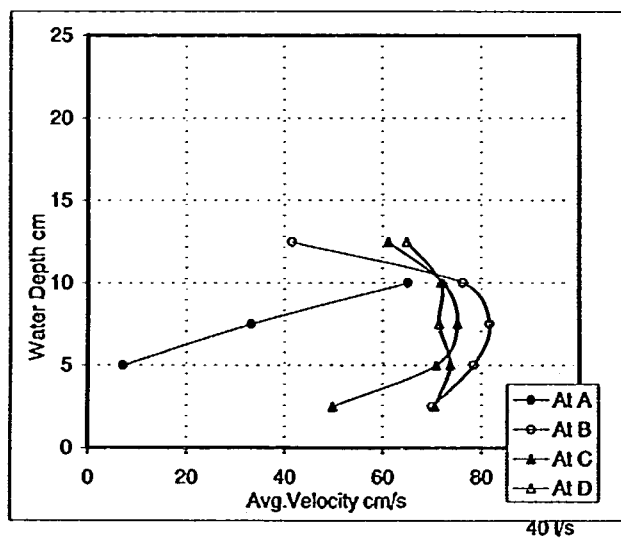
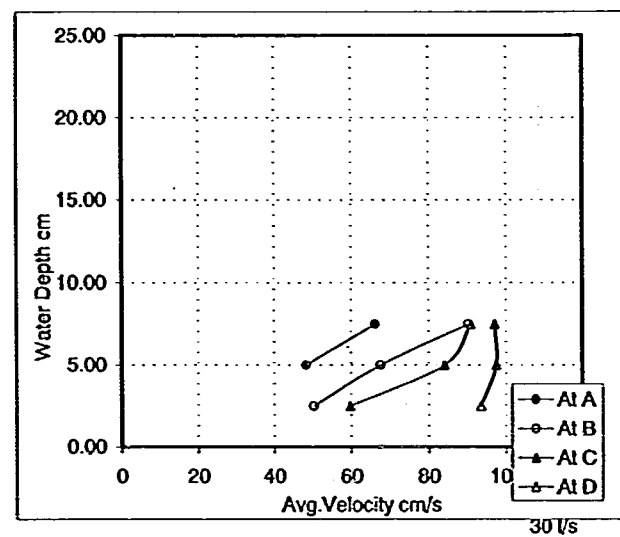
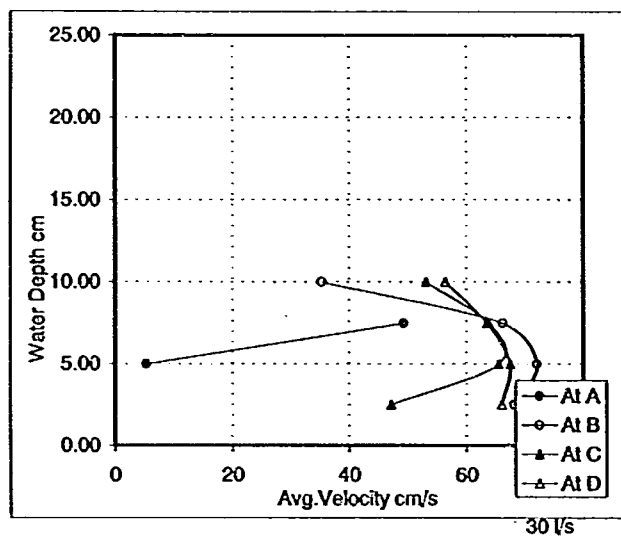
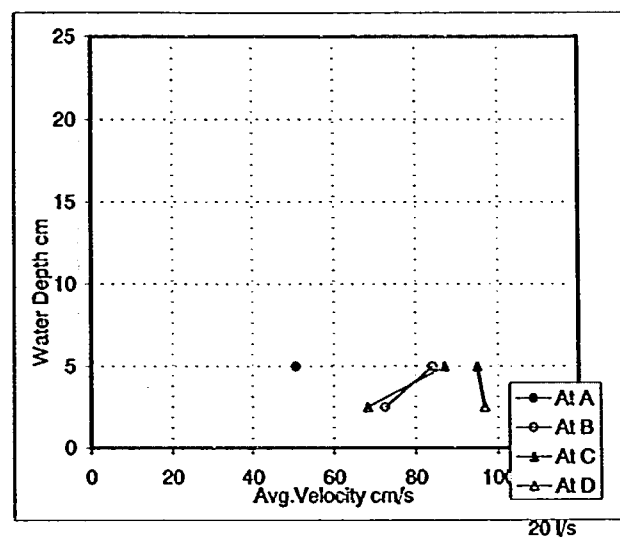
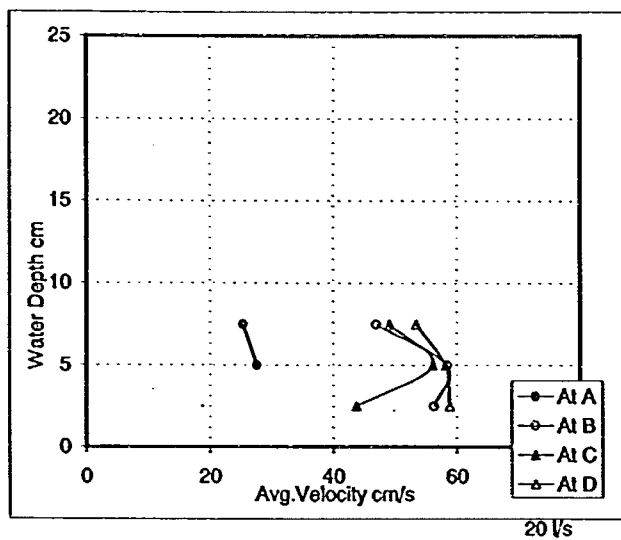


Fig.12 Velocity Profiles Over Baffle 1 and 5 (Model 1, Slope :1/25)

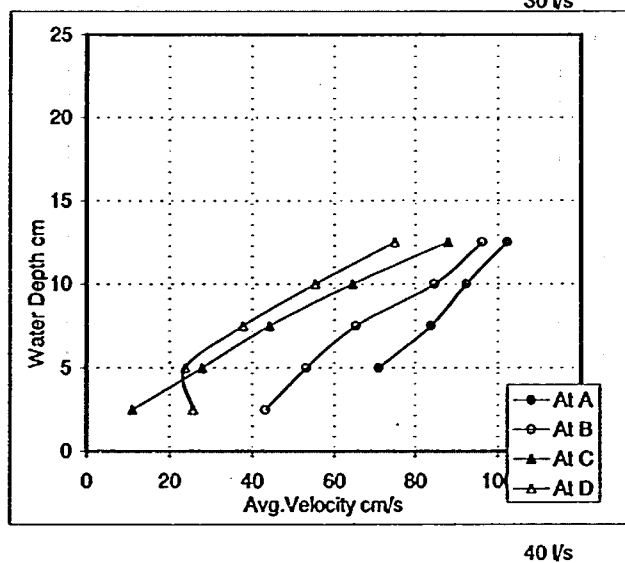
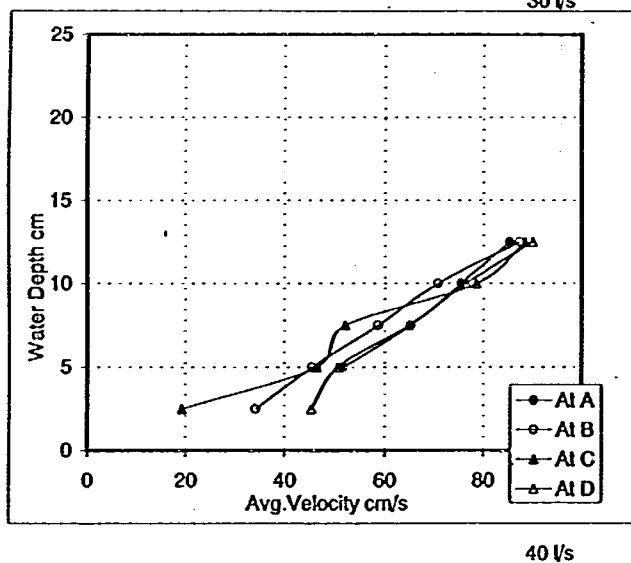
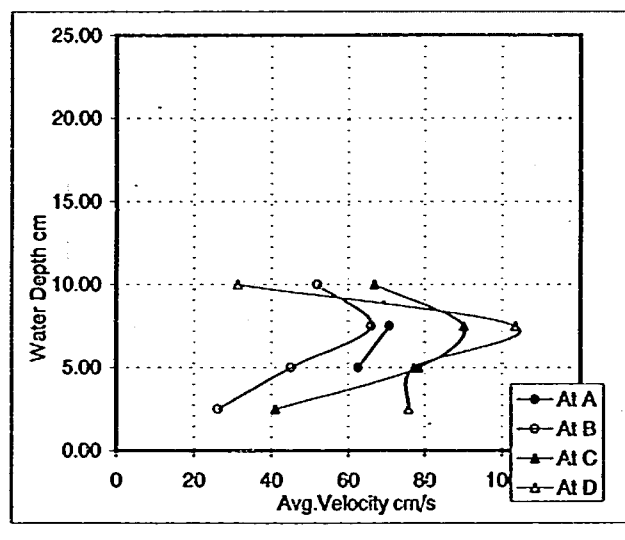
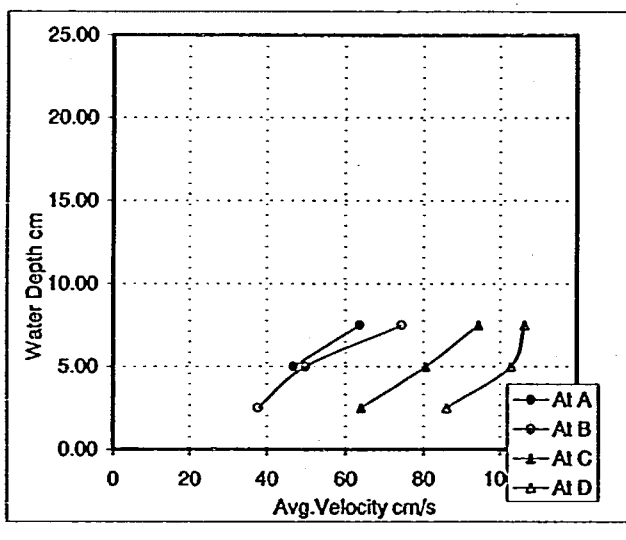
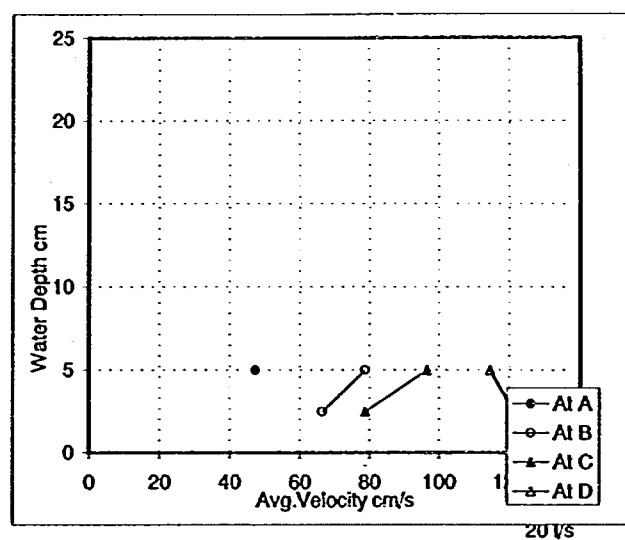
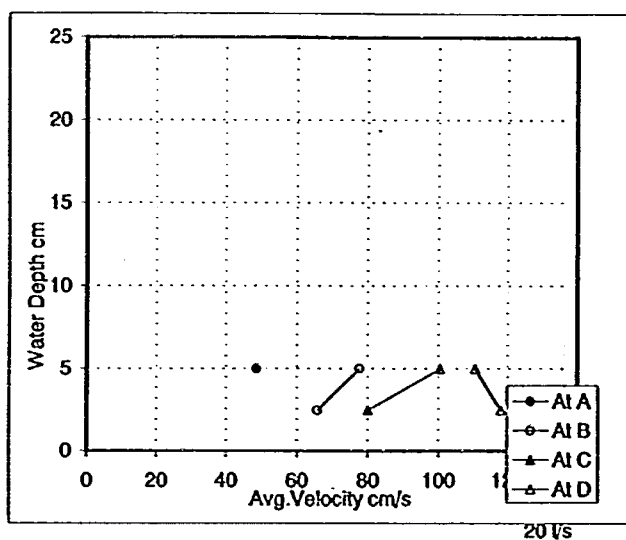


Fig.13 Velocity Profiles Over Baffle 10 and 17 (Model 1, Slope :1/25)

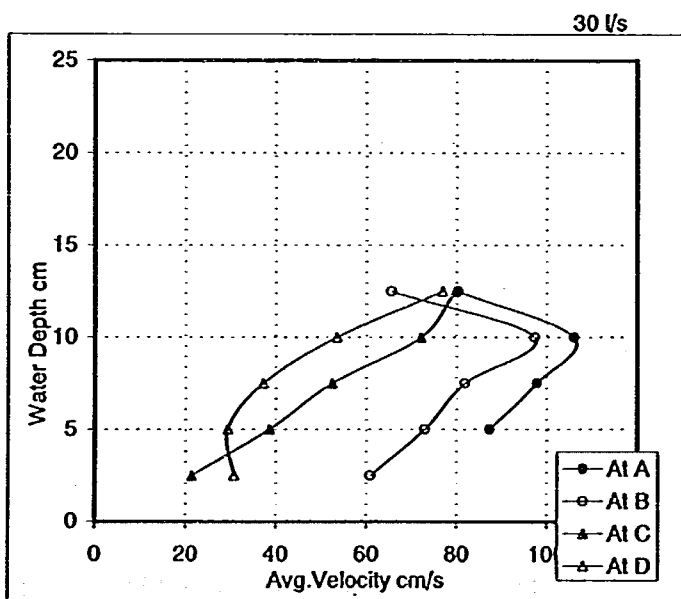
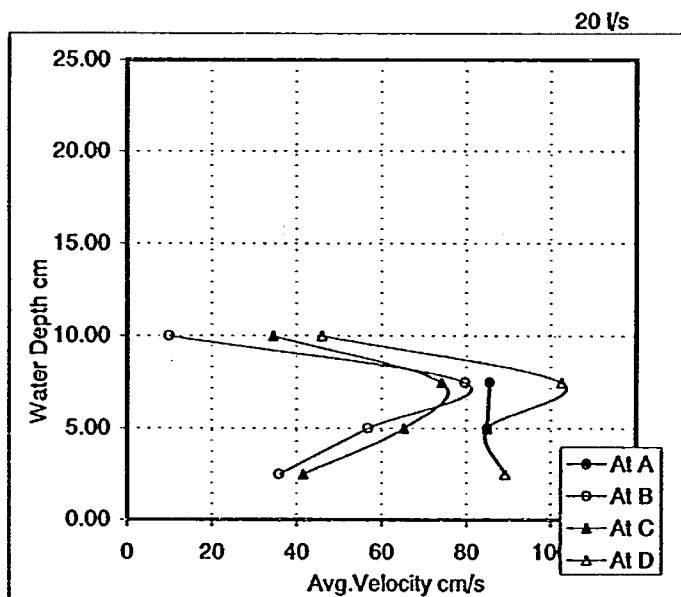
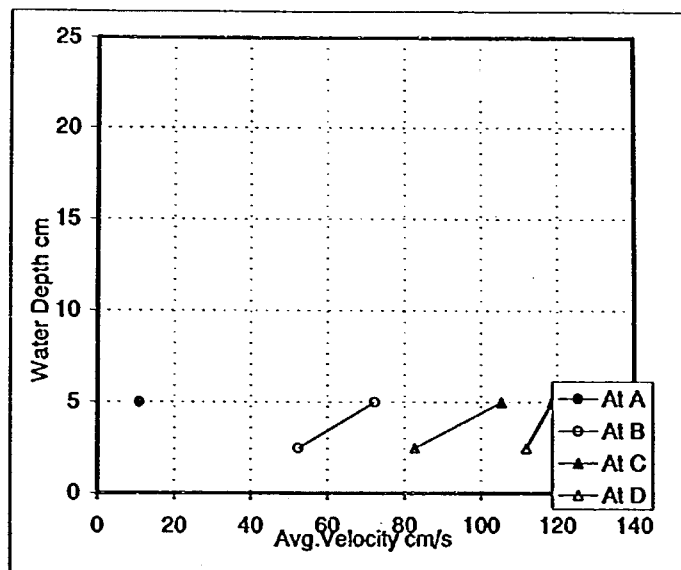


Fig.14 Velocity Profiles Over Baffle 21 (Model 1, Slope :1/25)

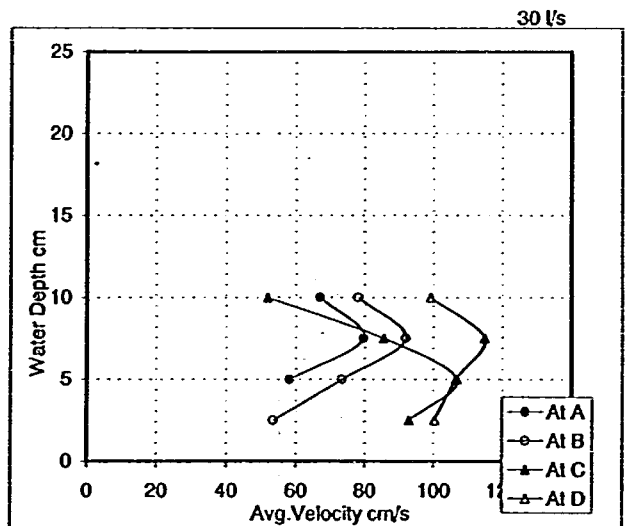
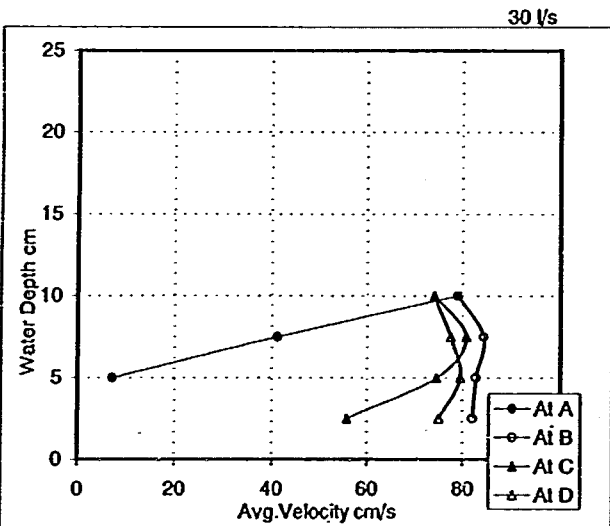
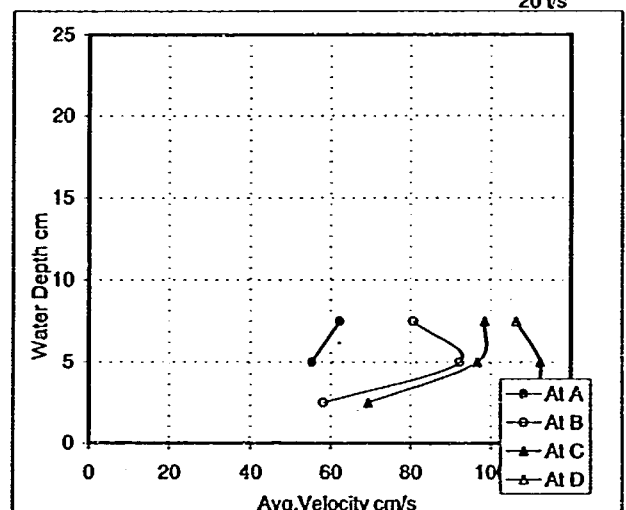
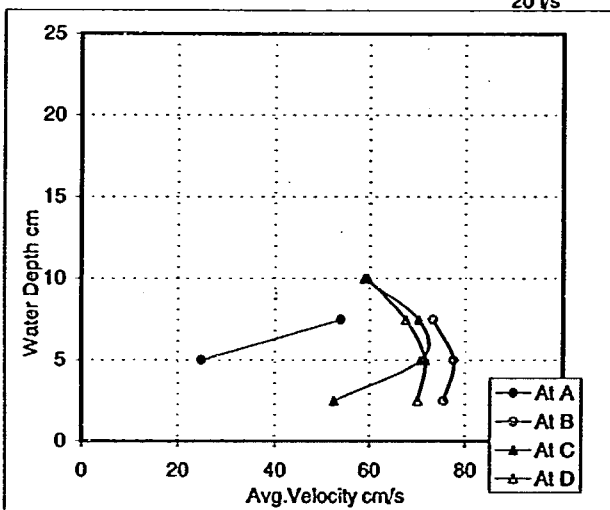
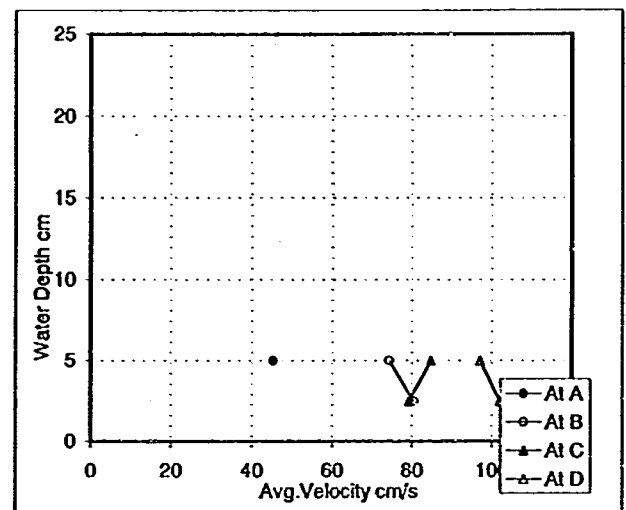
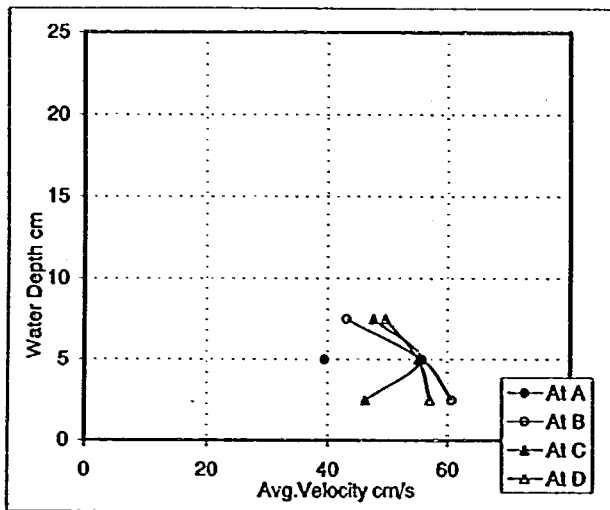
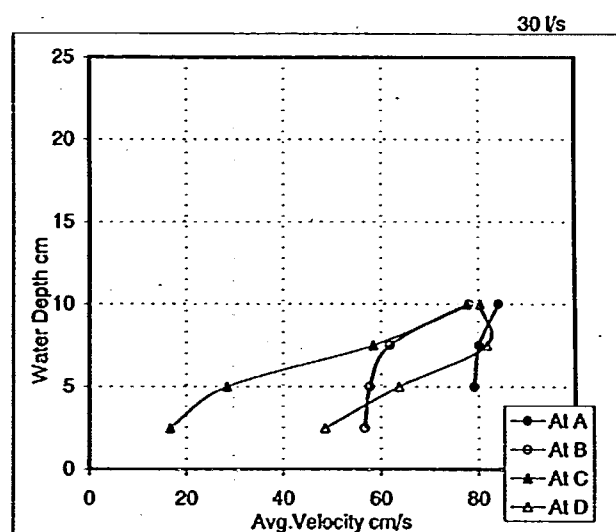
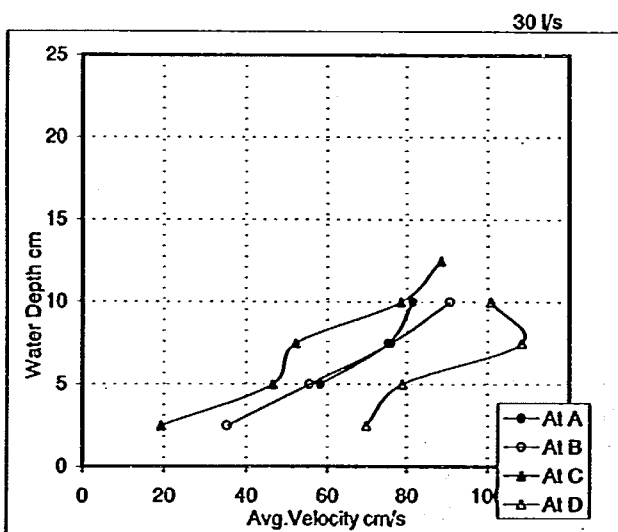
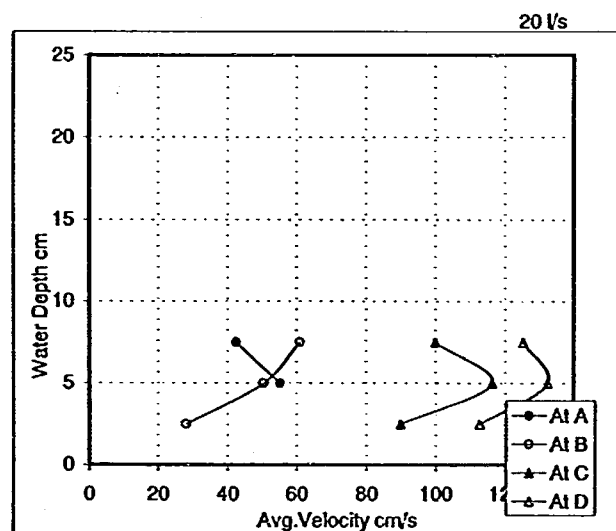
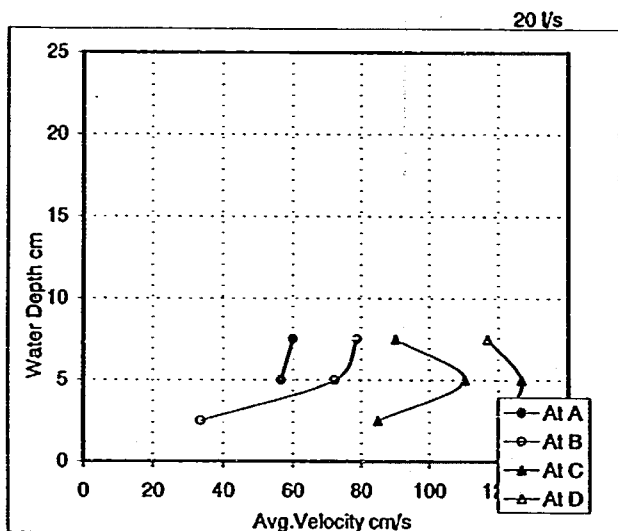
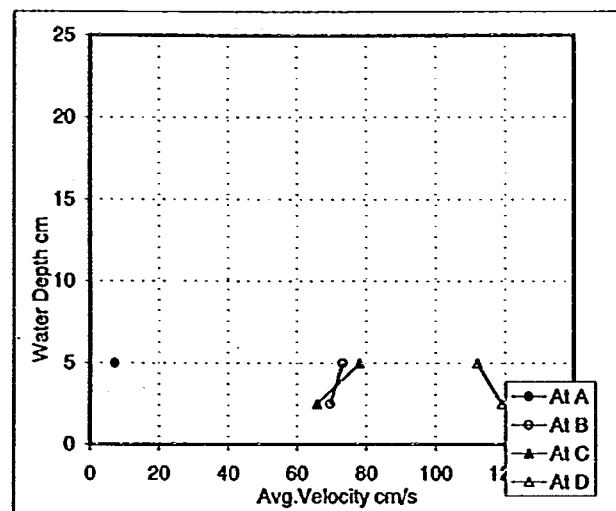
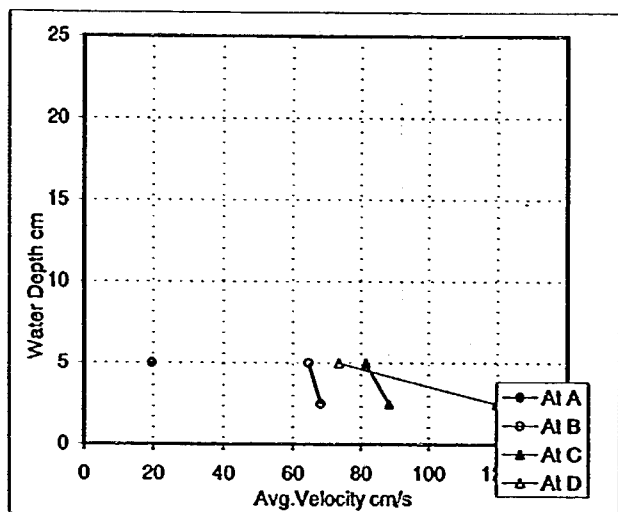


Fig.15 Velocity Profiles Over Baffle 1 and 5 (Model 1, Slope :1/20)



40 l/s

40 l/s

Fig.16 Velocity Profiles Over Baffle 10 and 17 (Model 1, Slope :1/20)

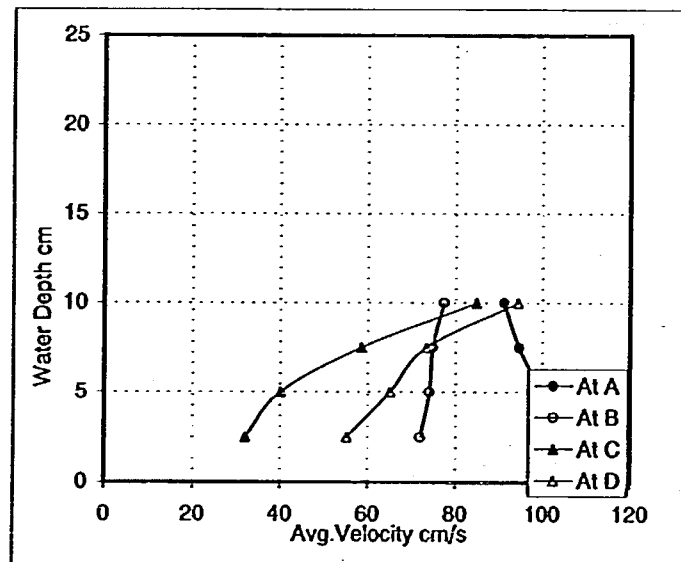
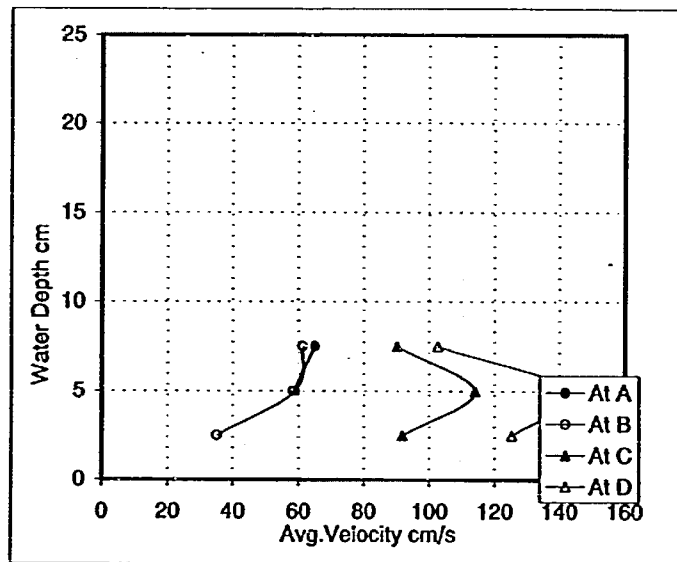
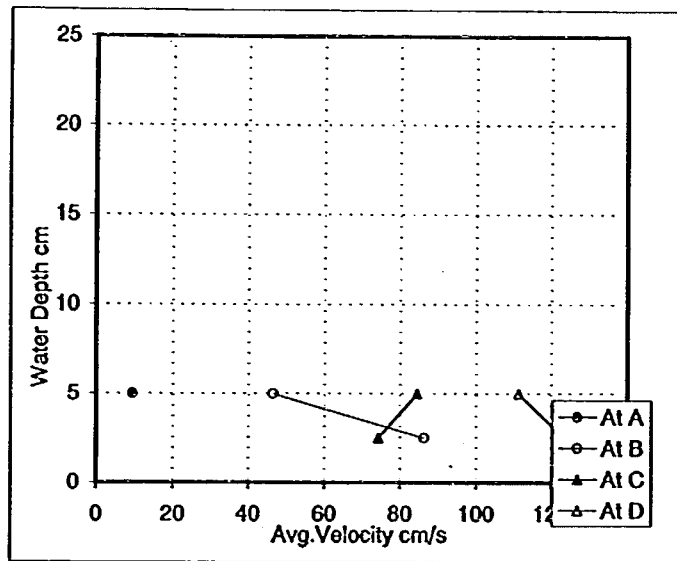


Fig. 17 Velocity Profiles Over Baffle 21 (Model 1, Slope :1/20)

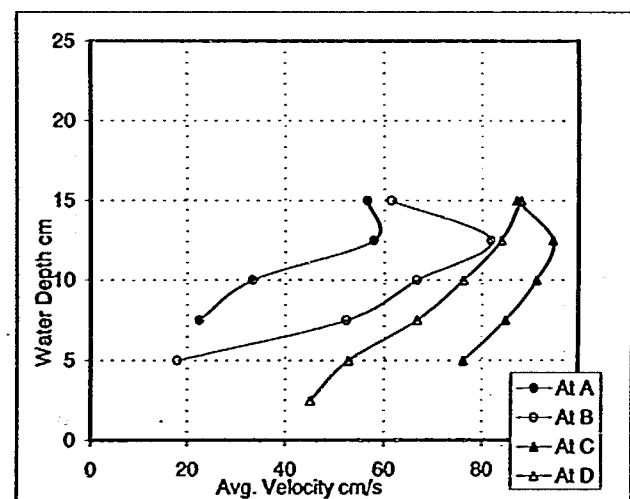
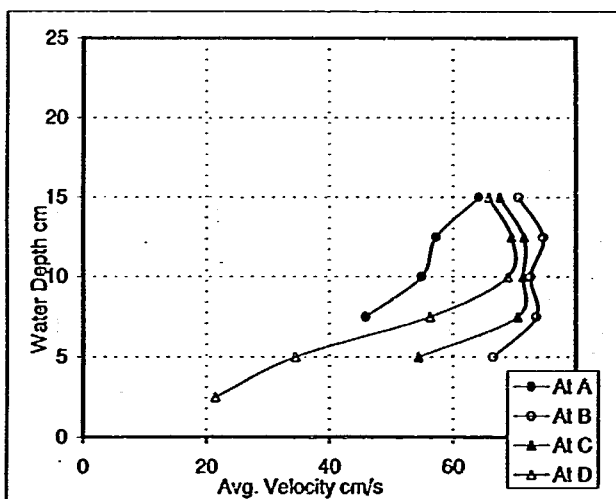
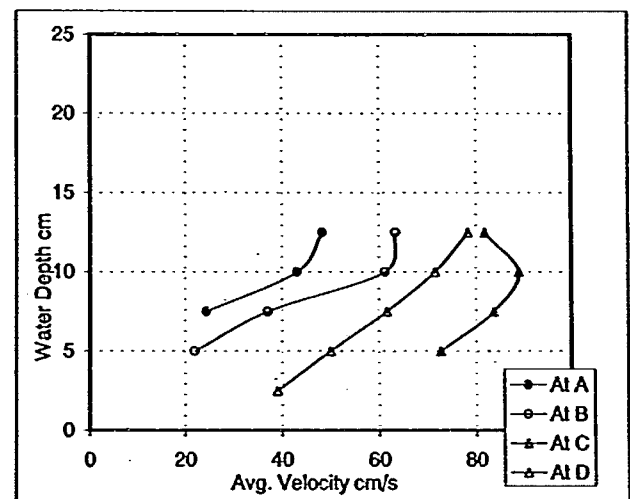
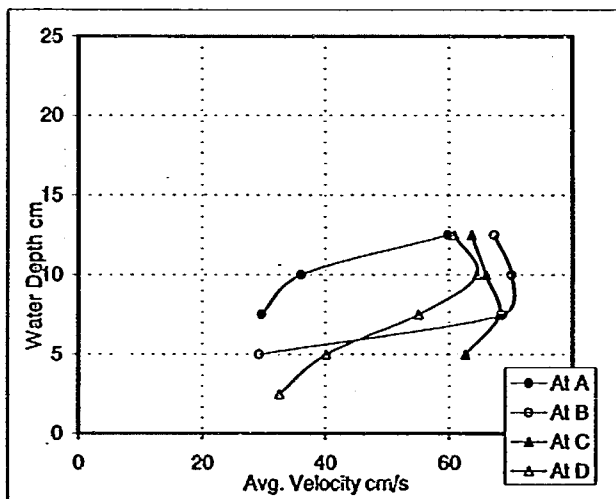
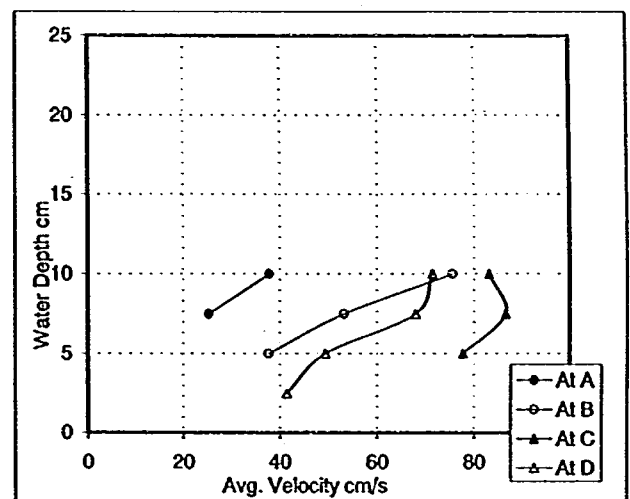
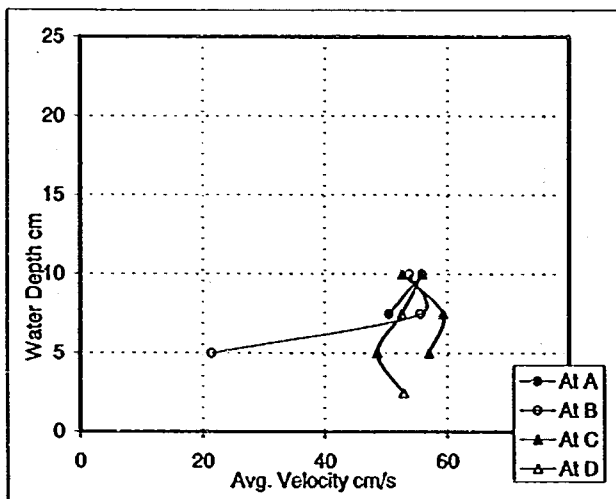
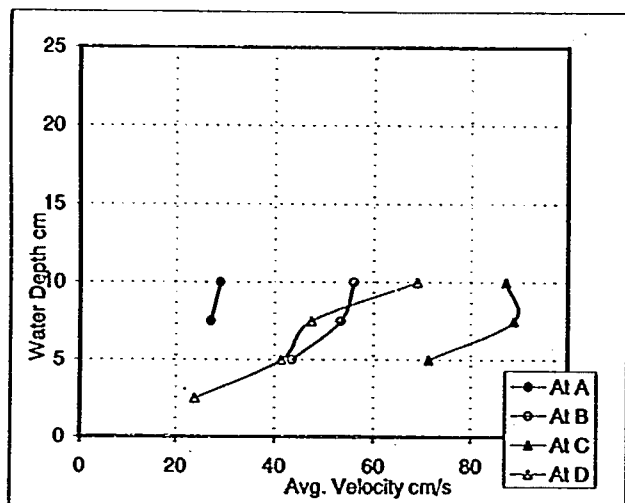
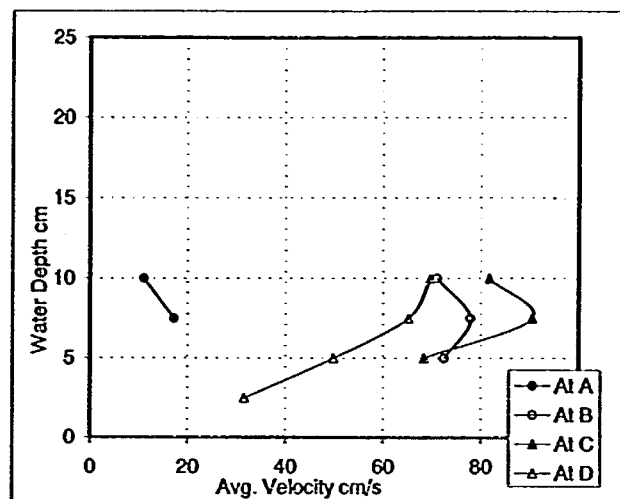


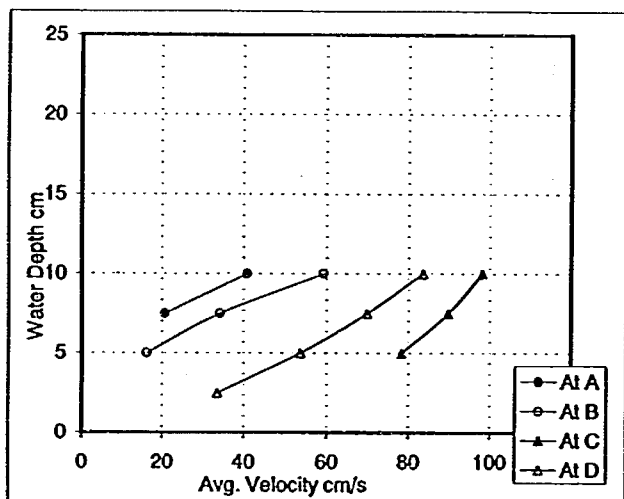
Fig.18 Velocity Profiles Over Baffle 1 and 5 (Model 2, Slope :1/25)



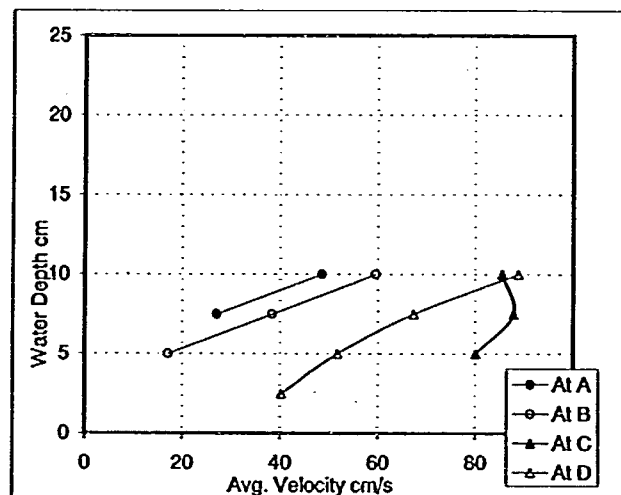
20 l/s



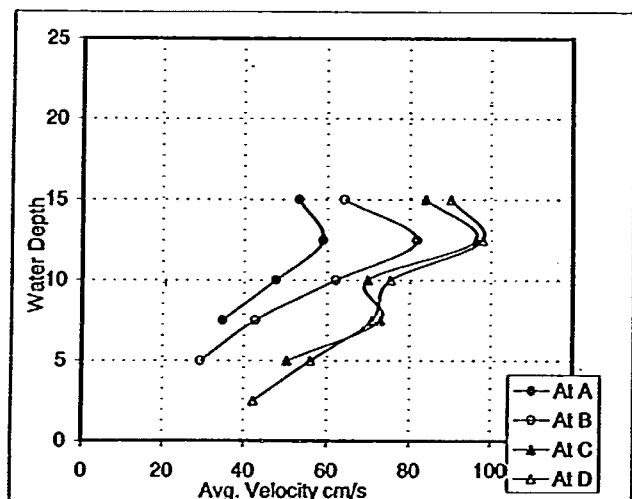
20 l/s



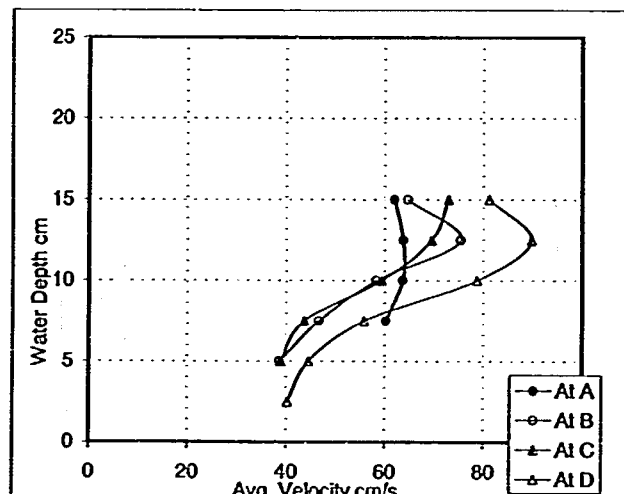
30 l/s



30 l/s

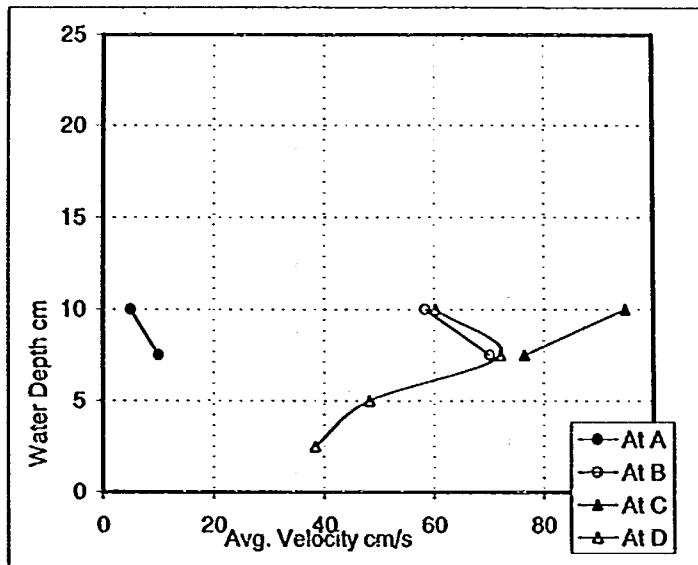


40 l/s

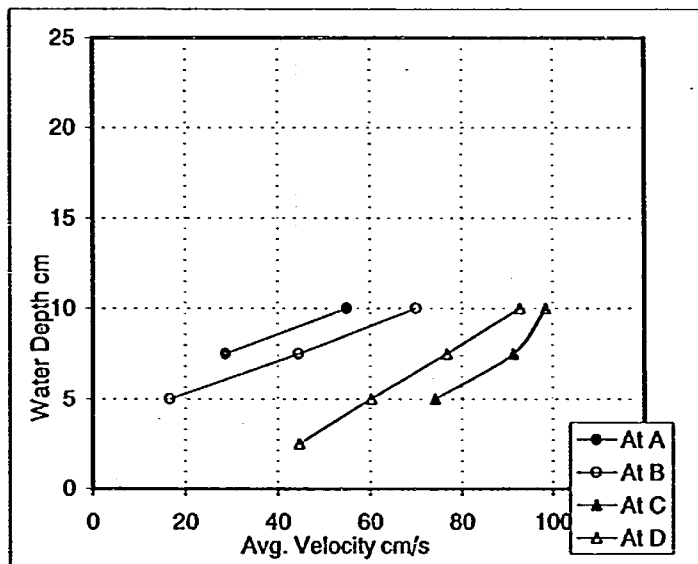


40 l/s

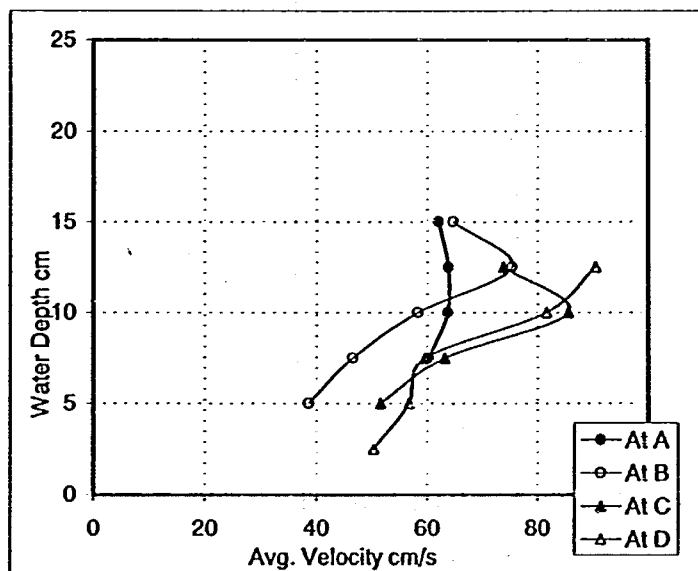
Fig.19 Velocity Profiles Over Baffle 10 and 17 (Model 2, Slope :1/25)



20 l/s

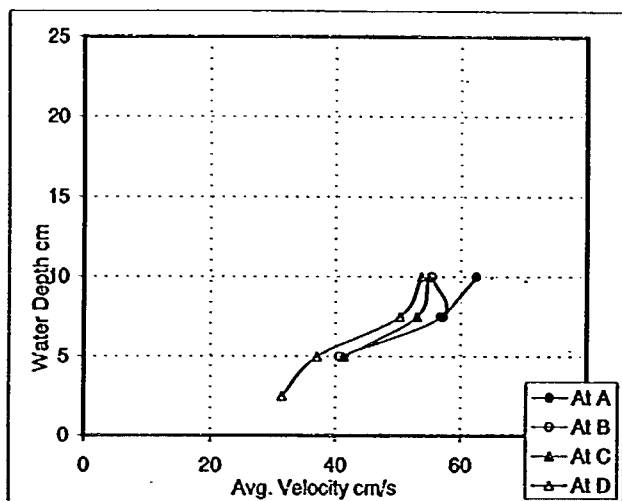


30 l/s

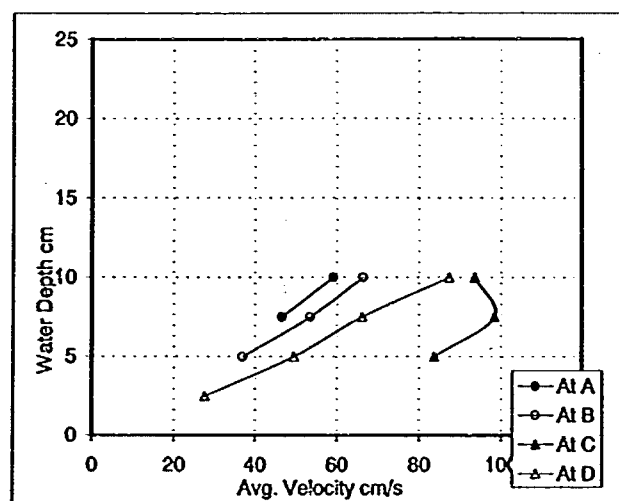


40 l/s

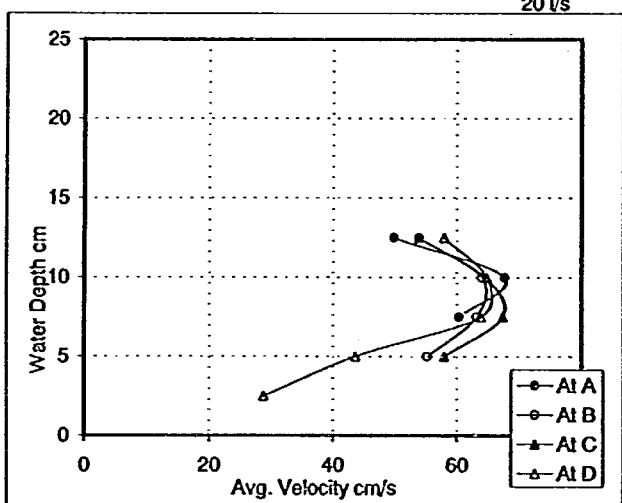
Fig.20 Velocity Profiles Over Baffle 21 (Model 2, Slope :1/25)



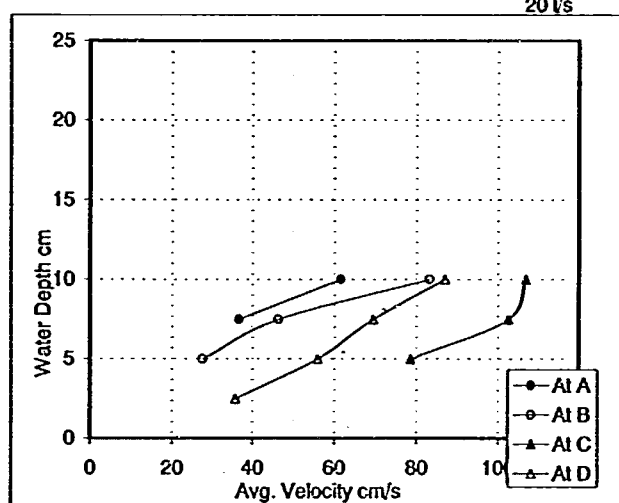
20 l/s



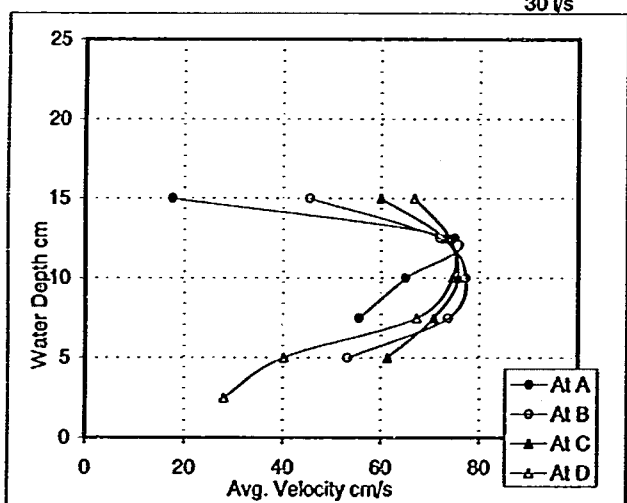
20 l/s



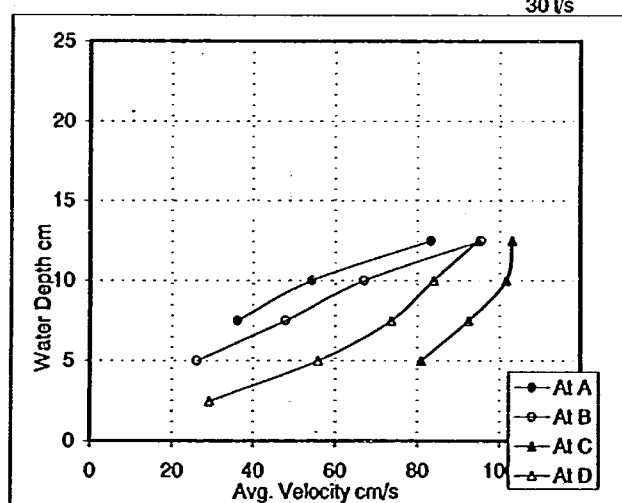
30 l/s



30 l/s

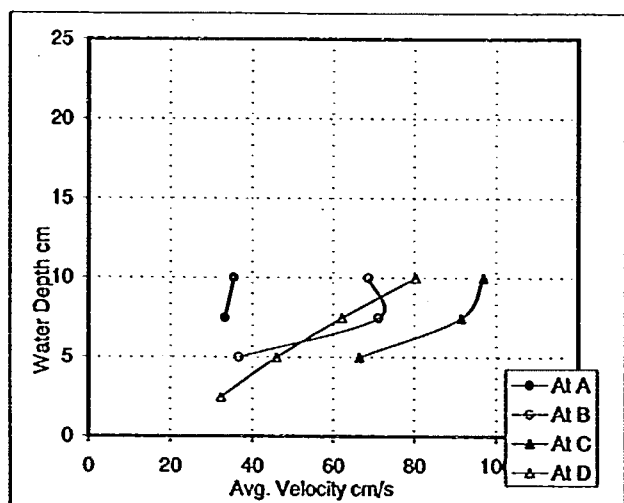


40 l/s

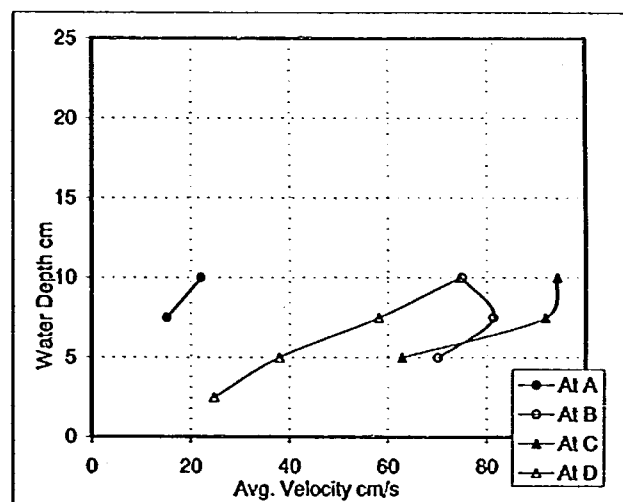


40 l/s

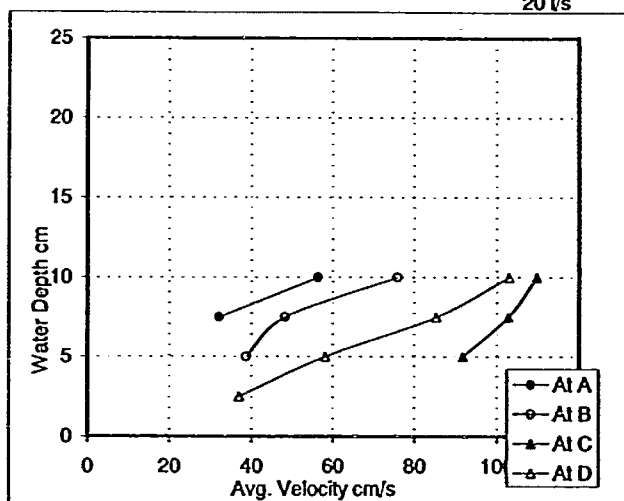
Fig.21 Velocity Profiles Over Baffle 1 and 5 (Model 2, Slope :1/20)



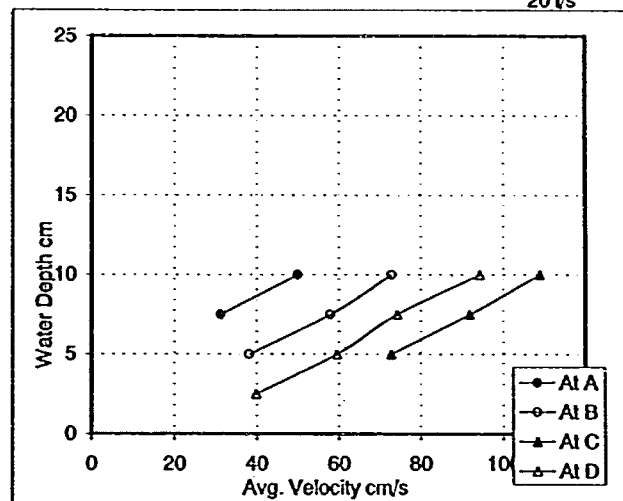
20 l/s



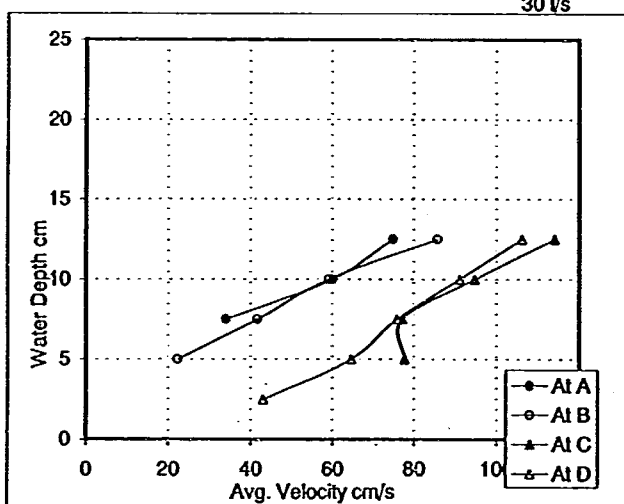
20 l/s



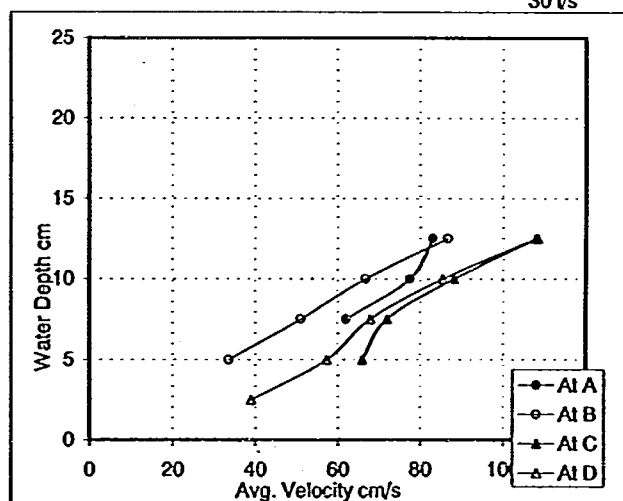
30 l/s



30 l/s

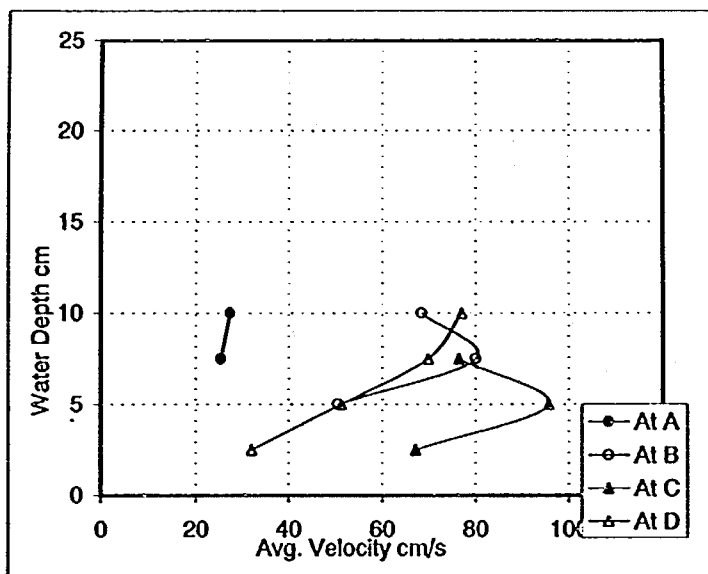


40 l/s

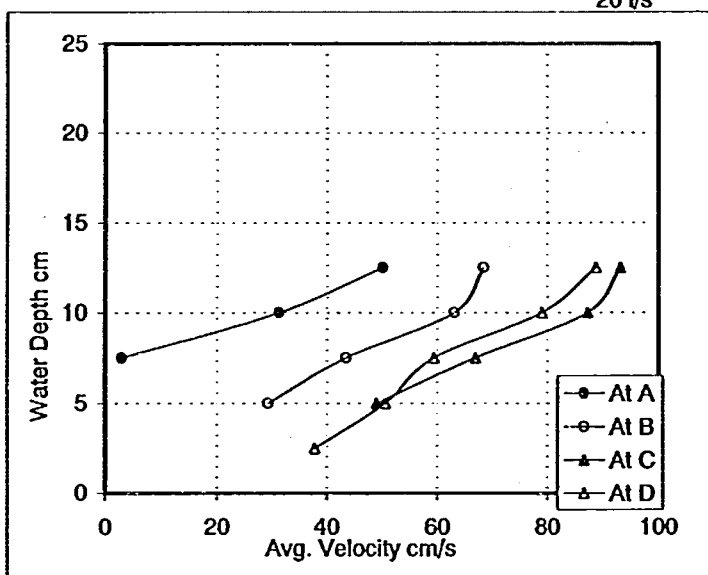


40 l/s

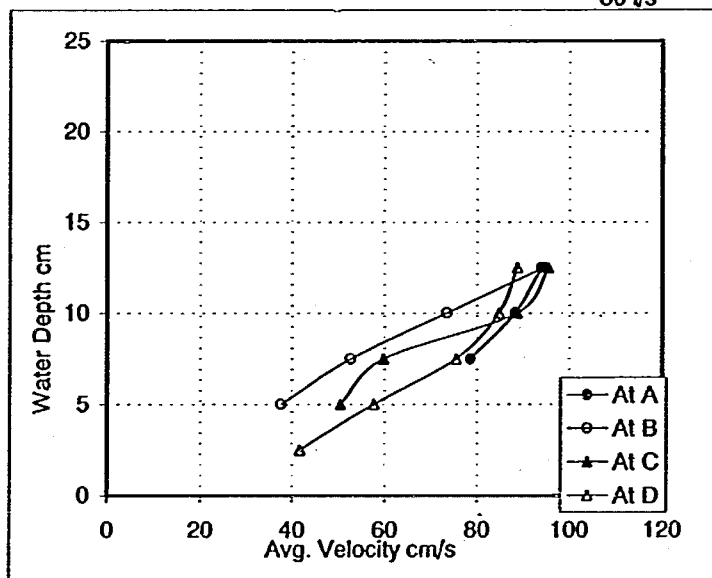
Fig.22 Velocity Profiles Over Baffle 10 and 17 (Model 2, Slope :1/20)



20 l/s



30 l/s

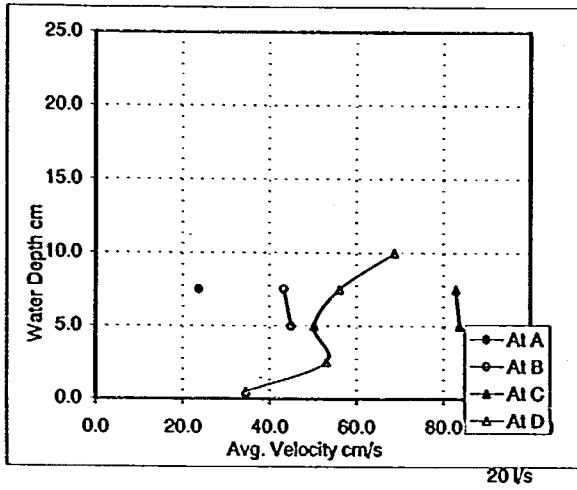


40 l/s

Velocity Profiles Over Baffle 21 Model 2 (Slope :1/20)

Fig.23 Velocity Profiles Over Baffle 21 (Model 2,Slope :1/20)

Slope:1/25



Slope 1/20

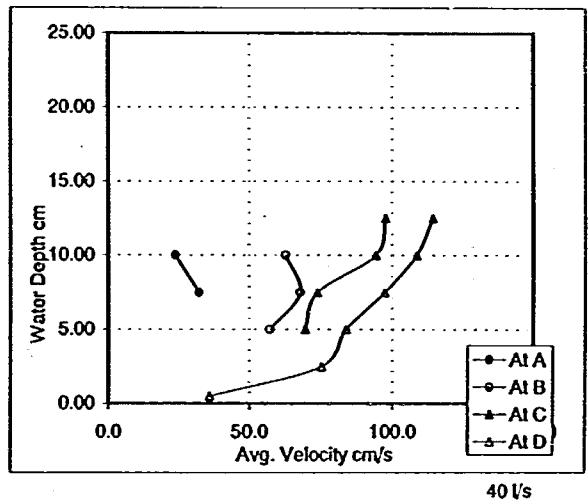
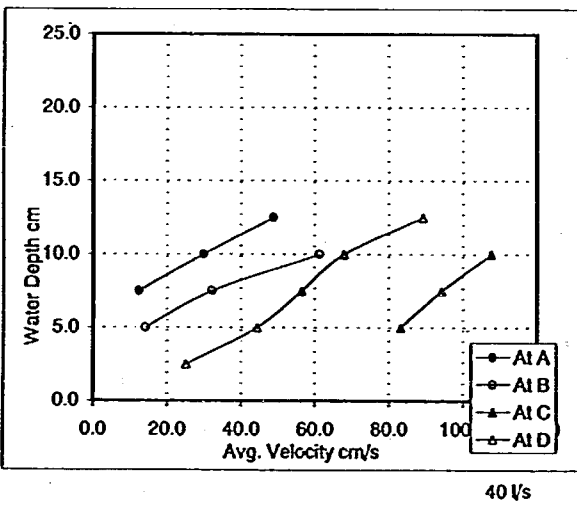
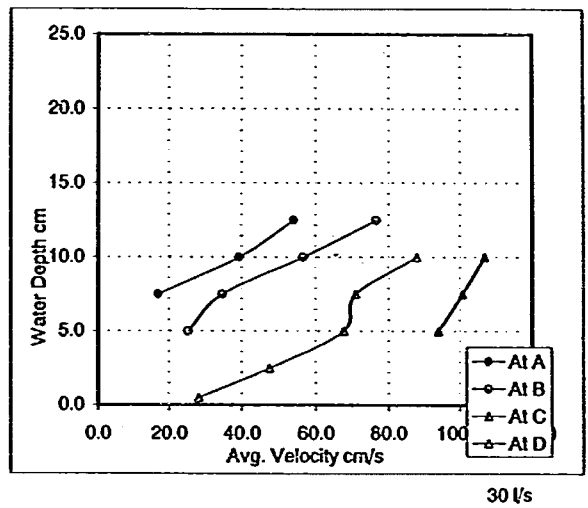
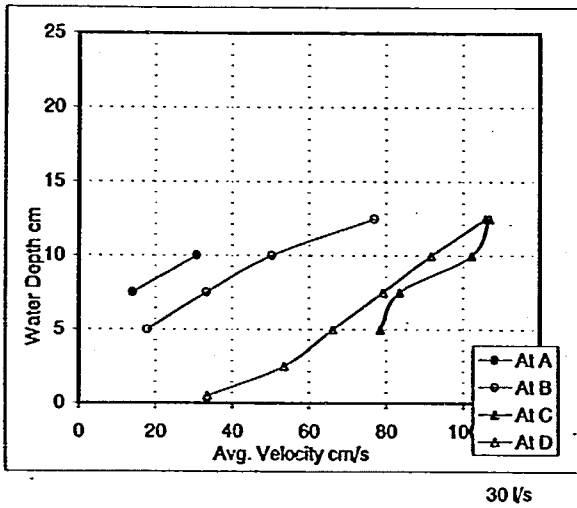
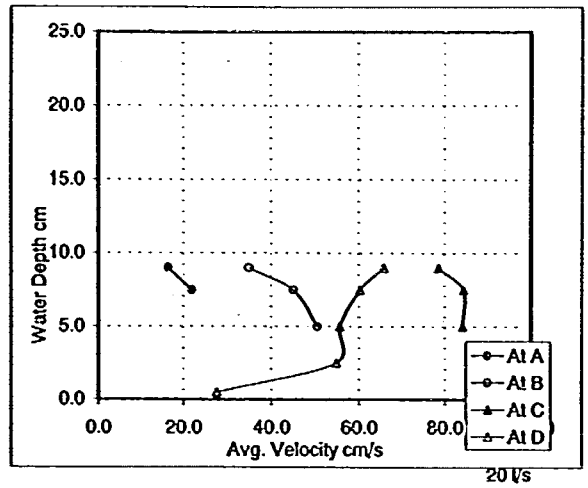


Fig.24 Velocity Profiles in Model 3

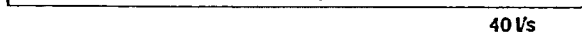
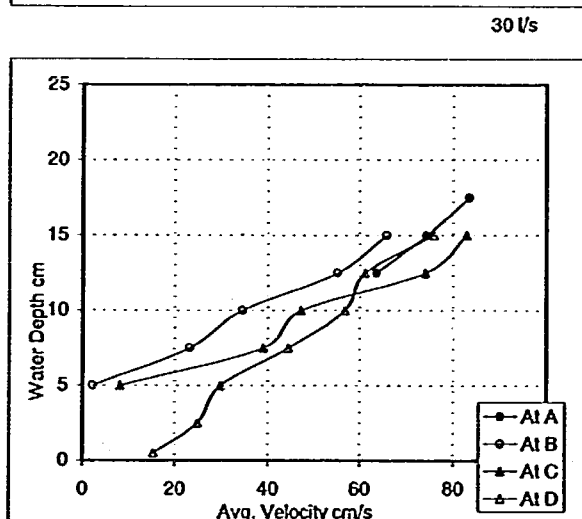
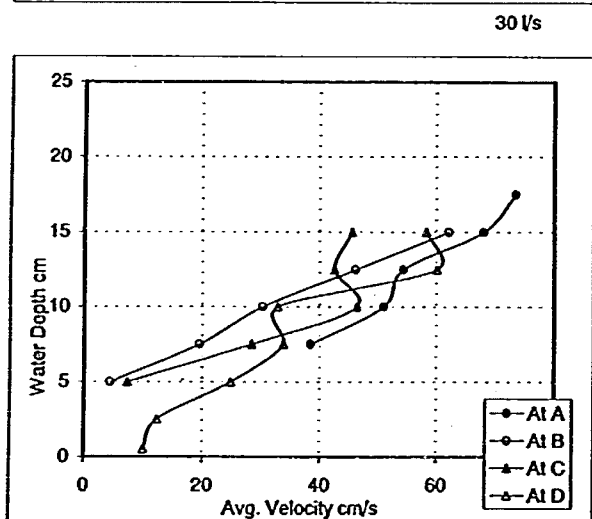
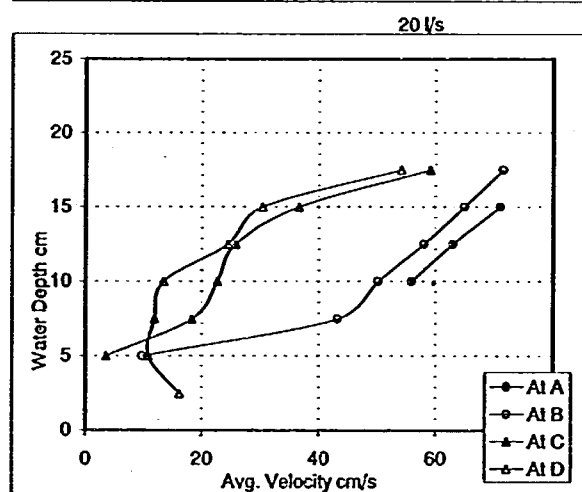
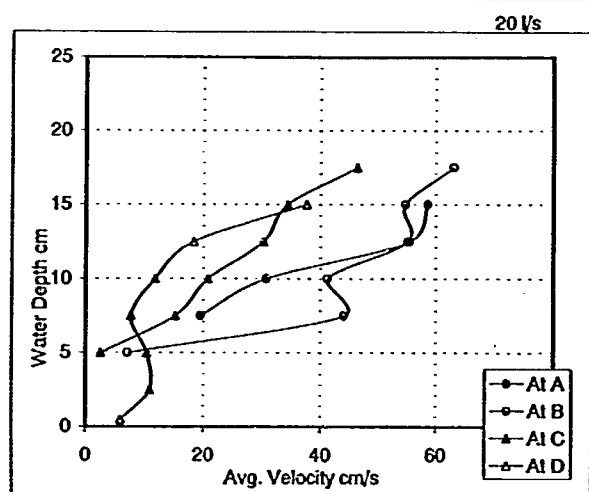
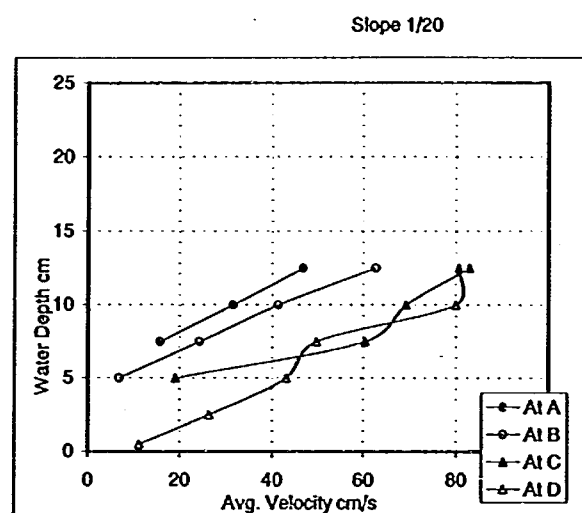
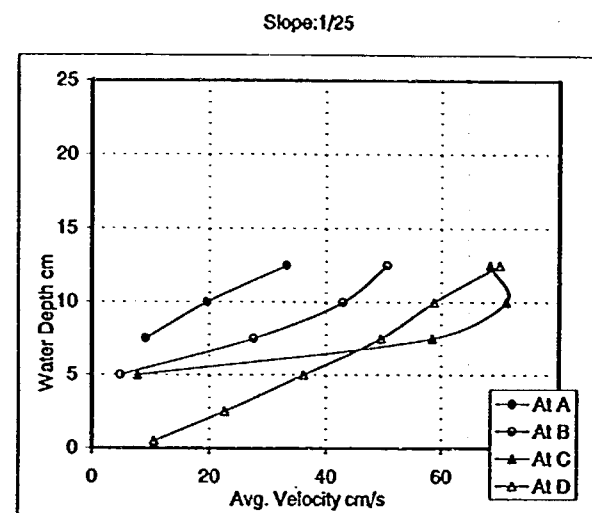
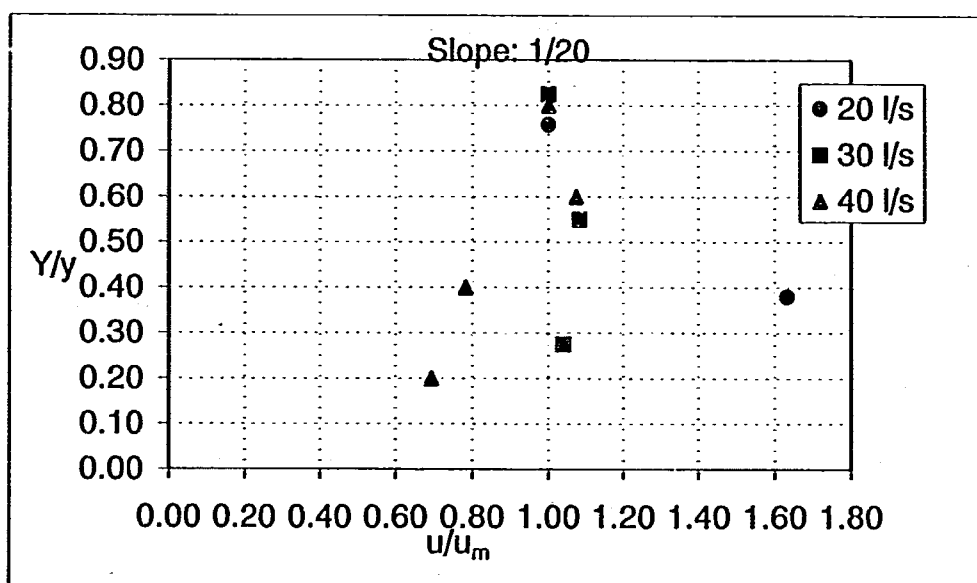
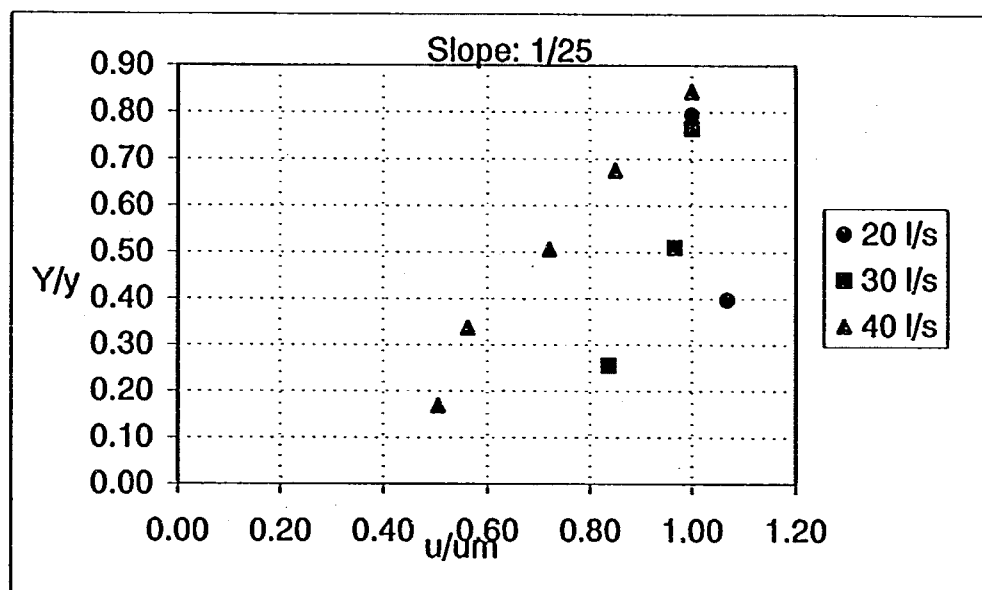


Fig.25 Velocity Profiles in Model 4



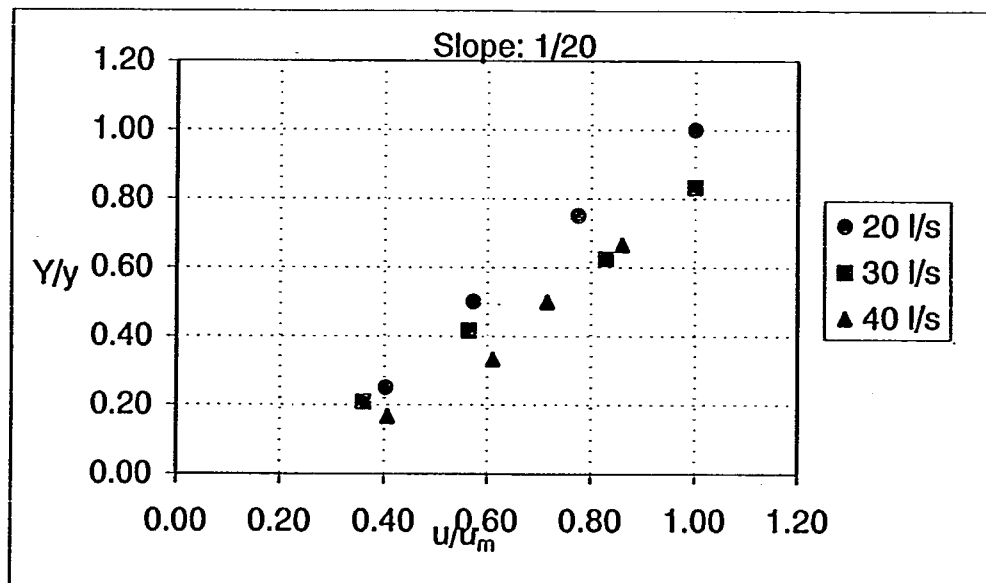
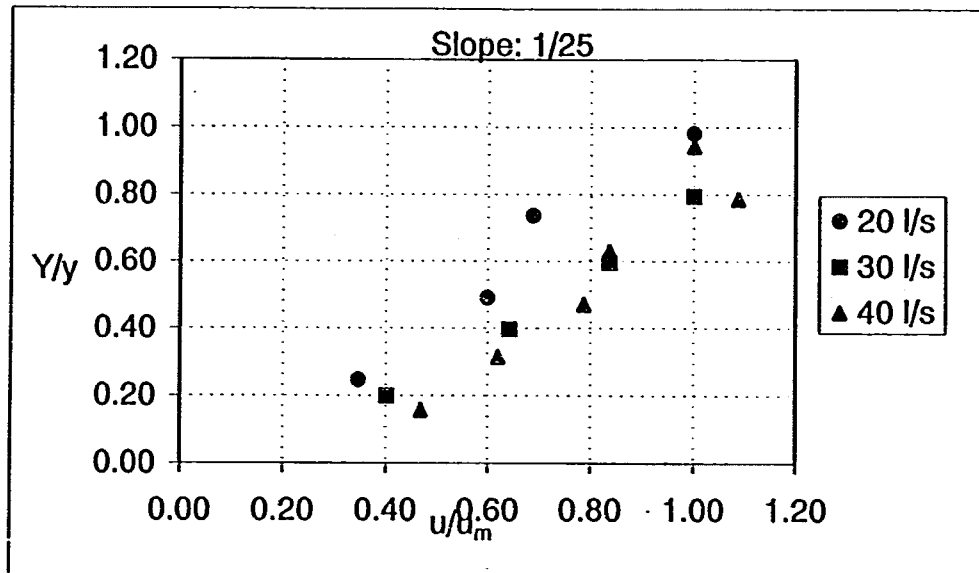


Fig.27 Normalized velocity Distribution for Model 2

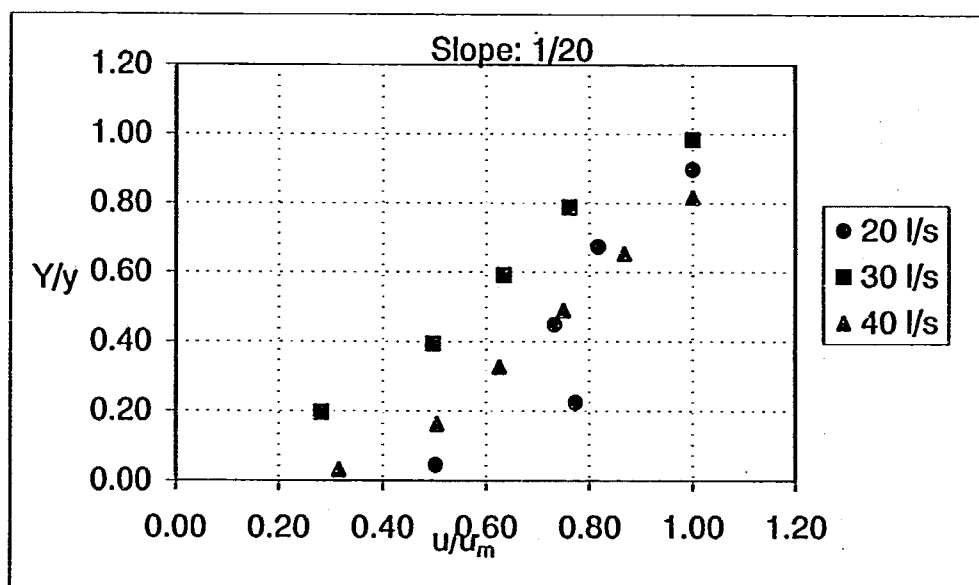
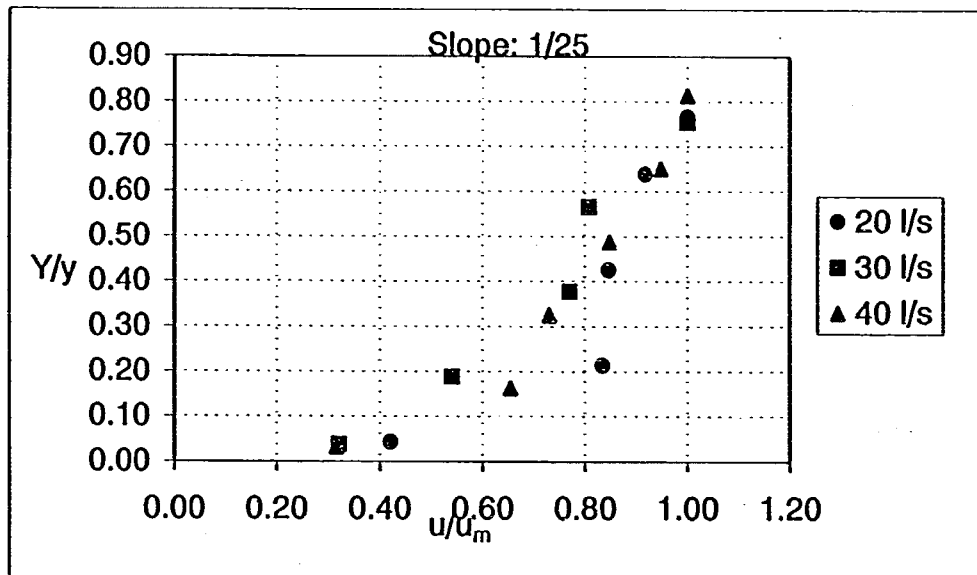


Fig.28 Normalized velocity distribution for Model 3

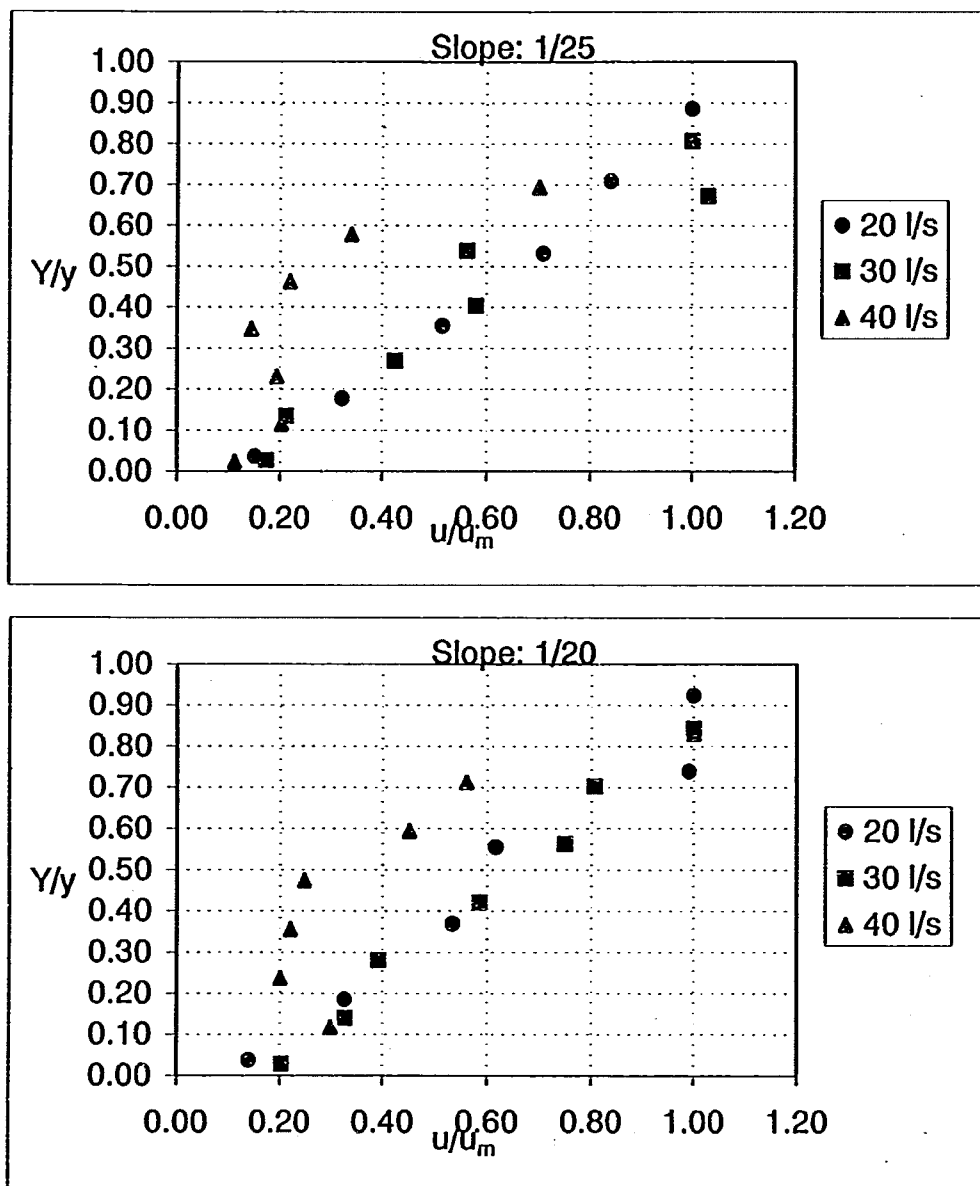


Fig.29 Normalized velocity distribution for Model 4

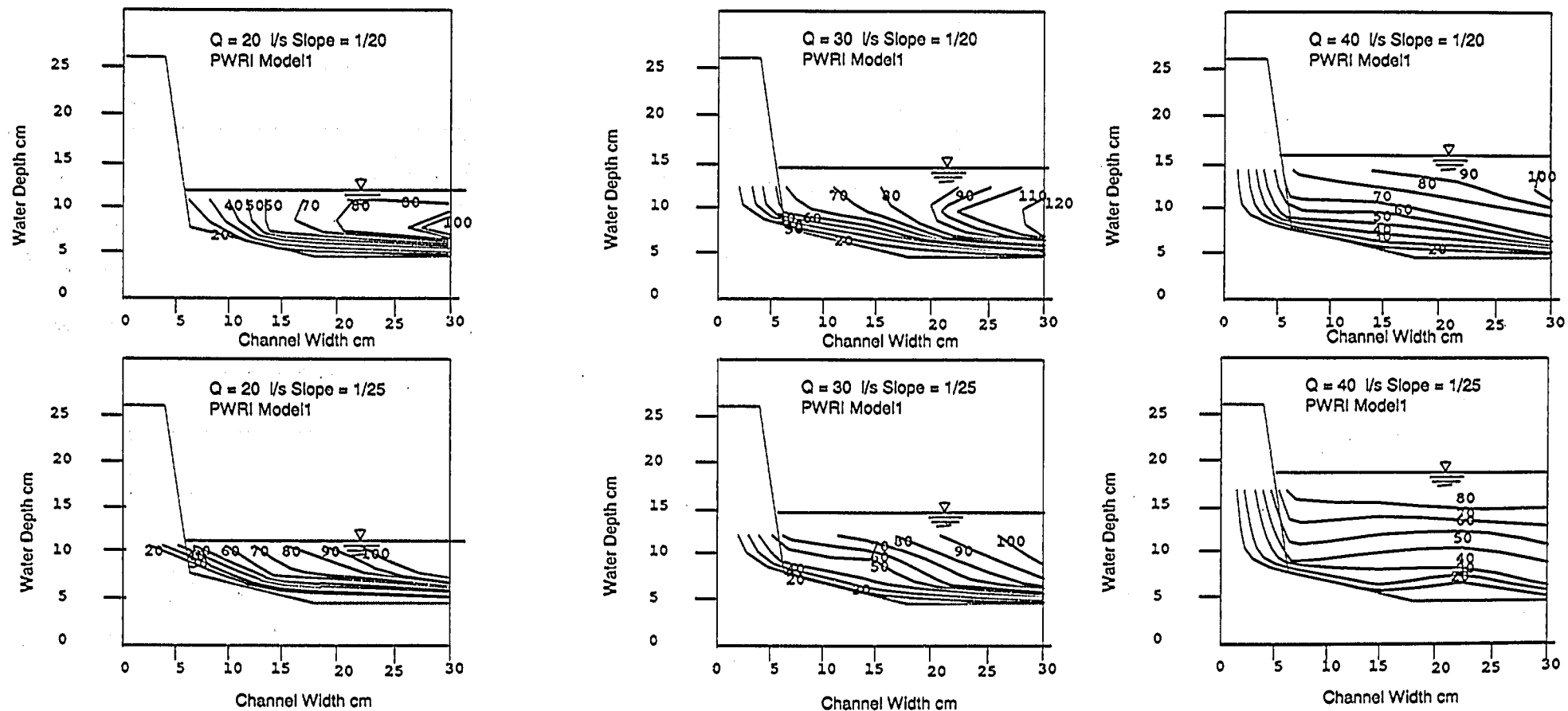


Fig.30 Velocity contours over Baffle No.10 in Model 1

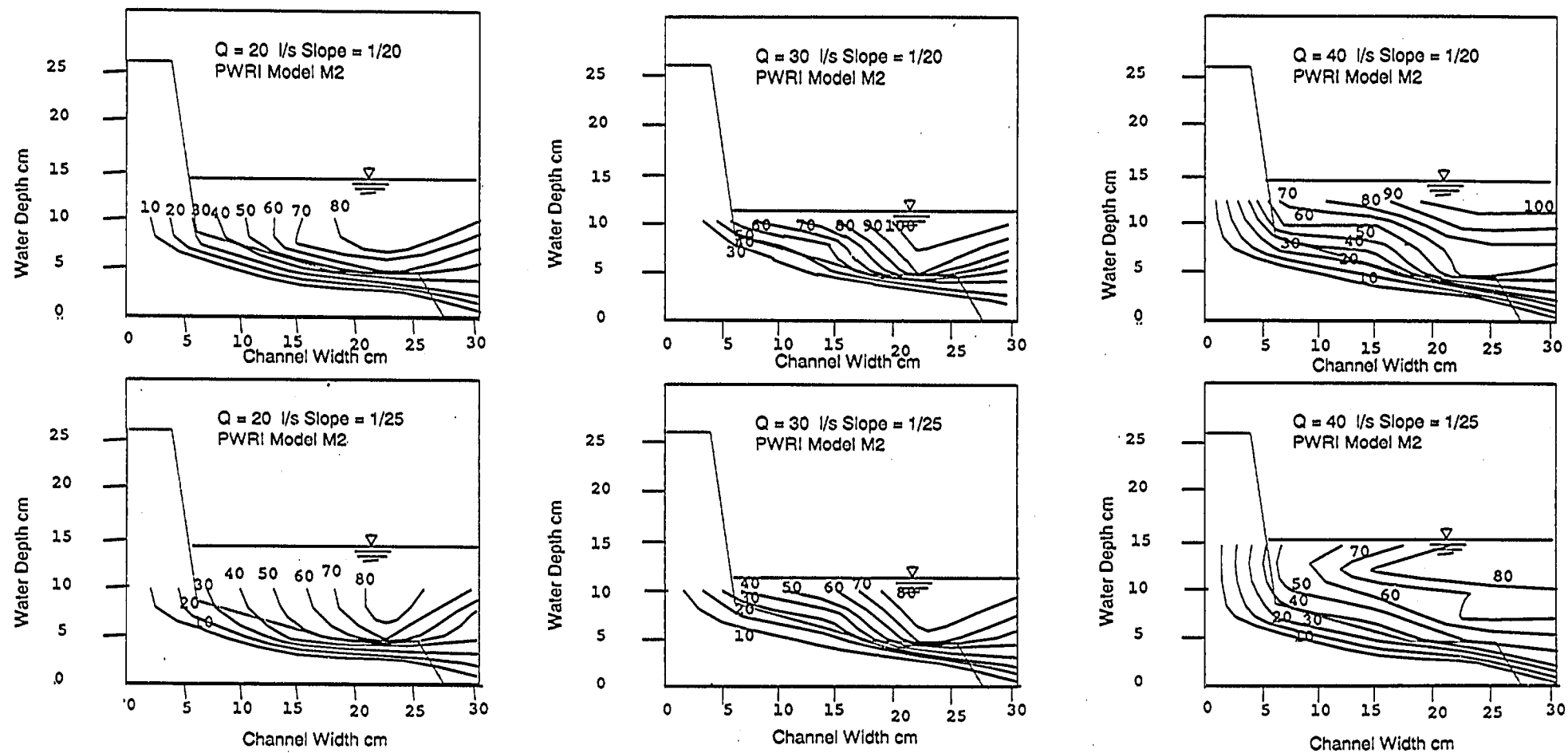


Fig.31 Velocity contours over Baffle No.10 in Model 2

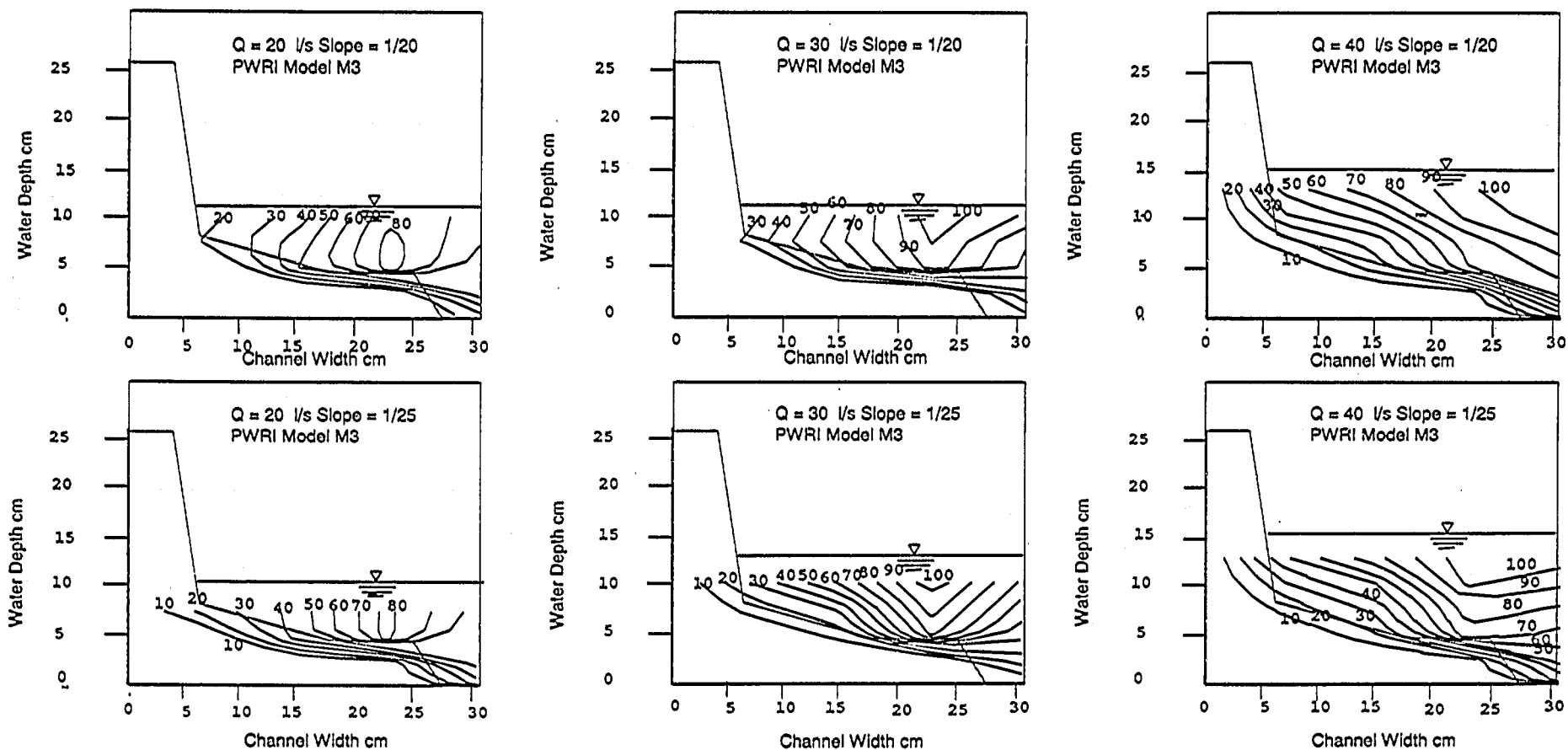


Fig.32 Velocity contours over Baffle No.11 in Model 3

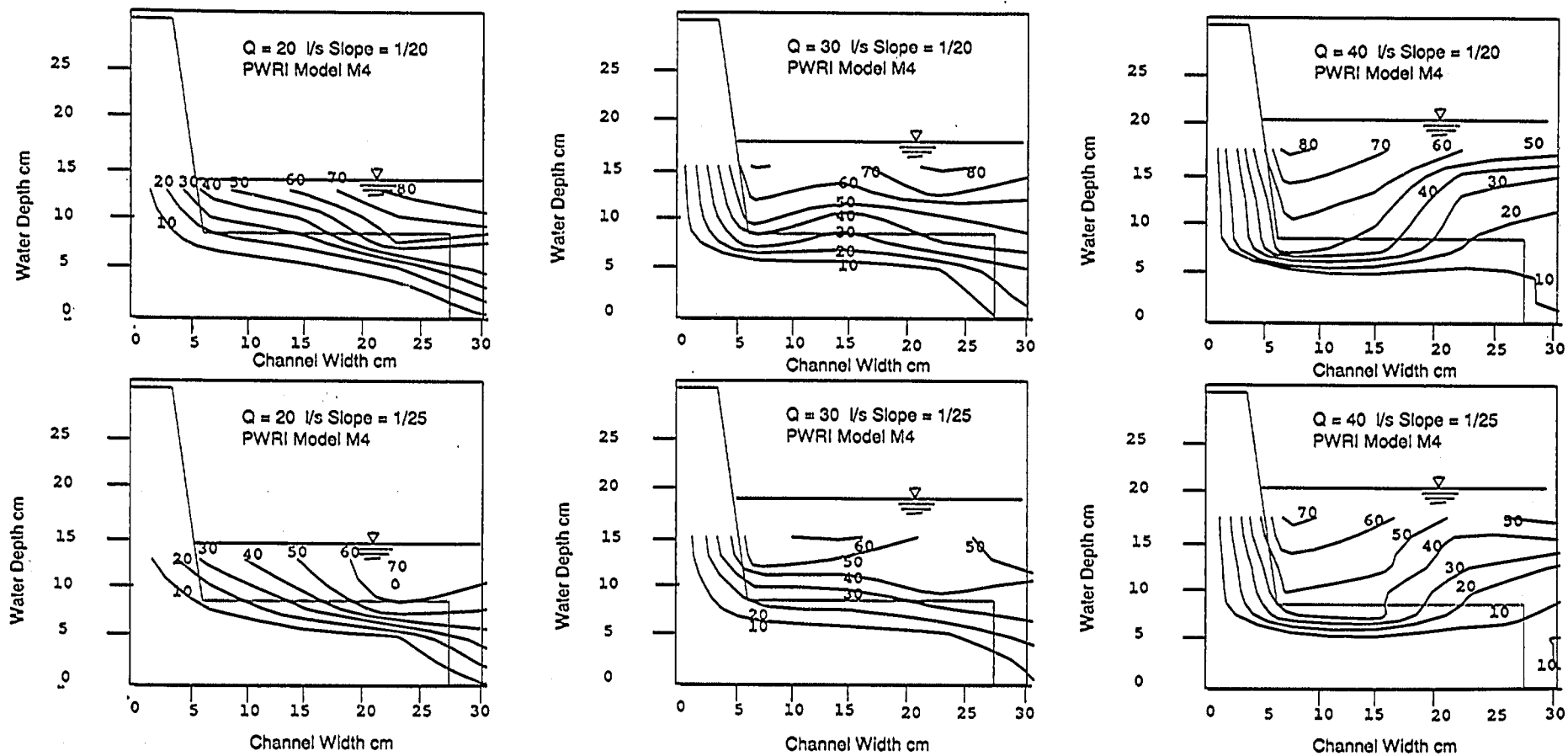


Fig.33 Velocity contours over Baffle No.11 in Model 4

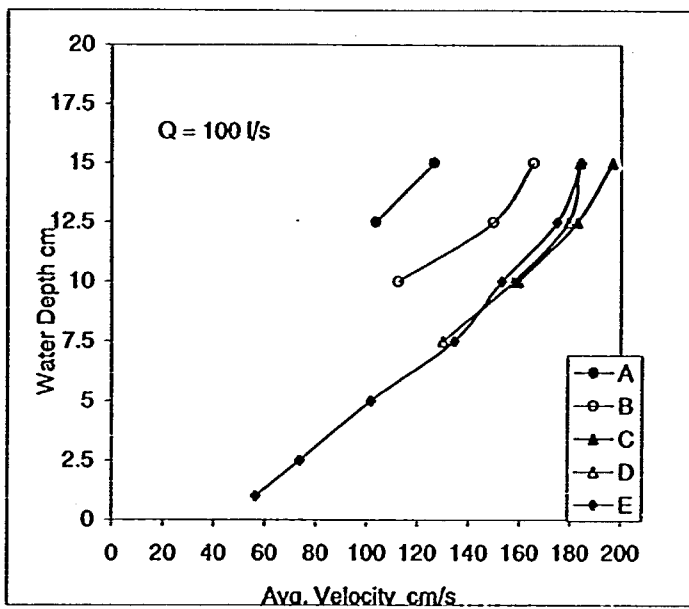
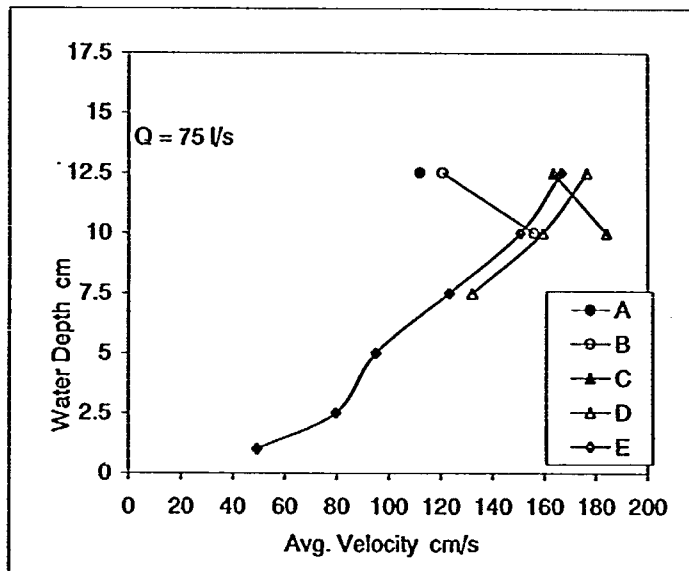
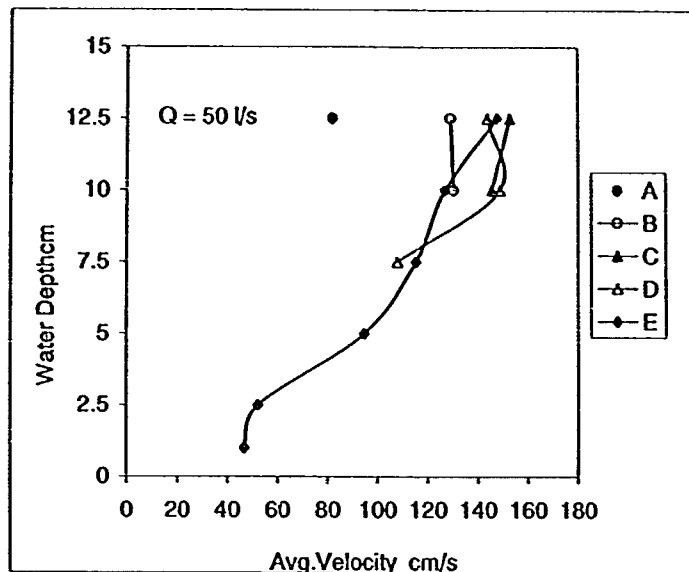


Fig.34 Velocity Profiles in Model 5 (Slope:1/10) in the region of fully developed flow

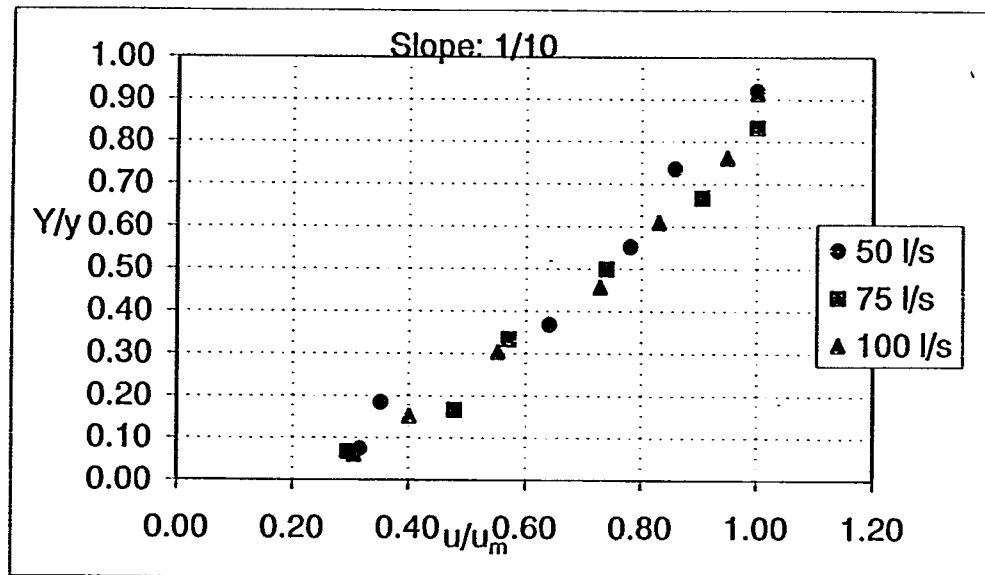


Fig.35 Normalized velocity Distribution for Model 5

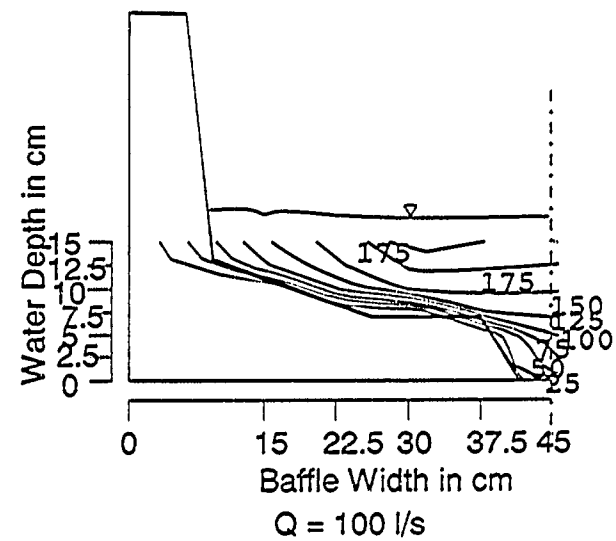
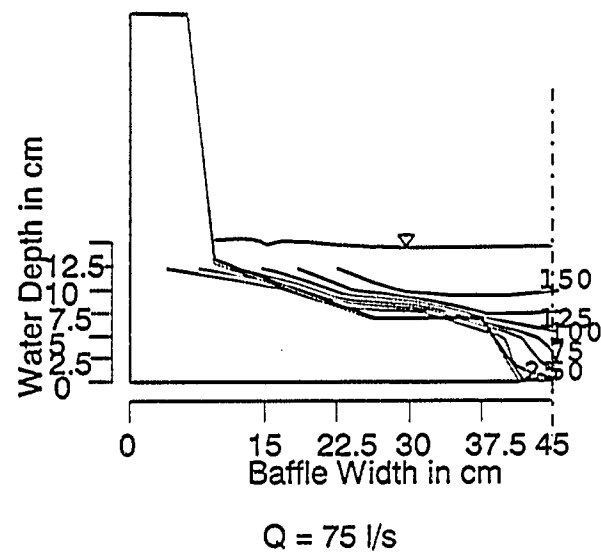
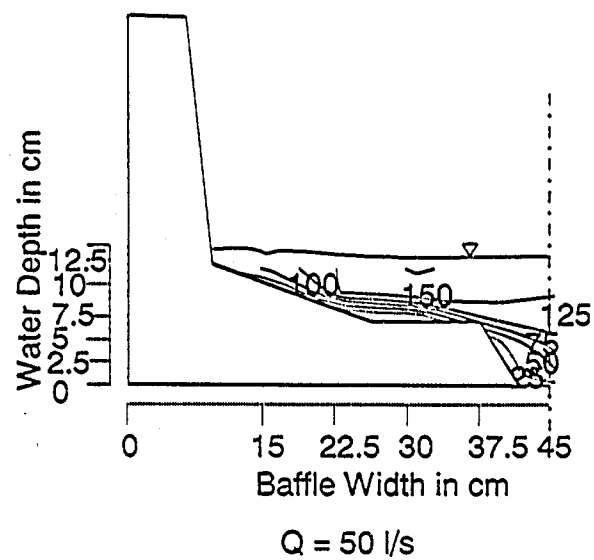


Fig.36 Velocity contours in Model 5

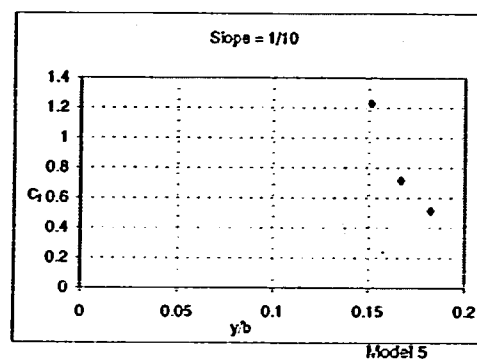
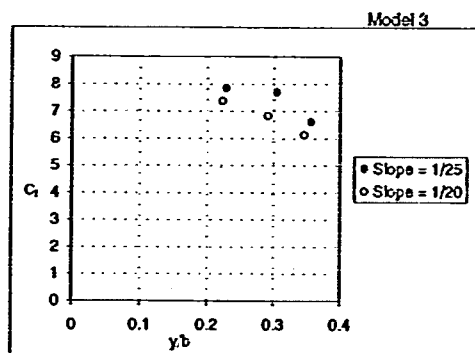
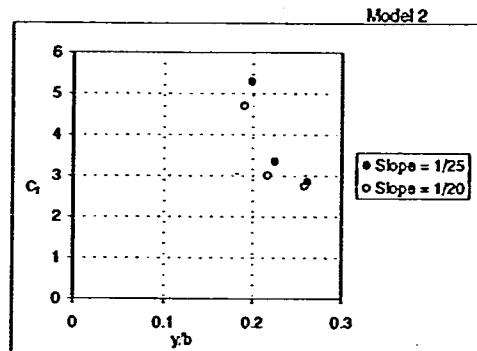
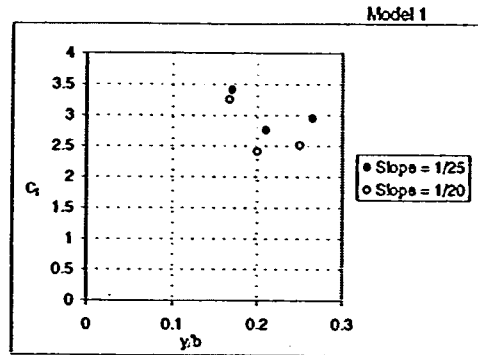
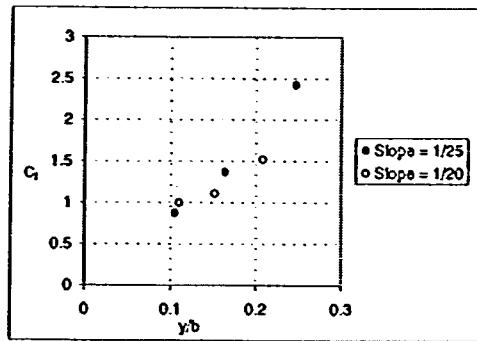


Fig.37 Variation of C_l with y/b

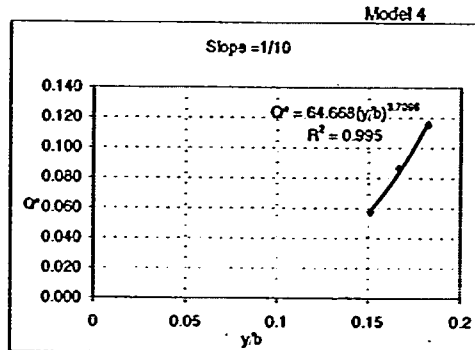
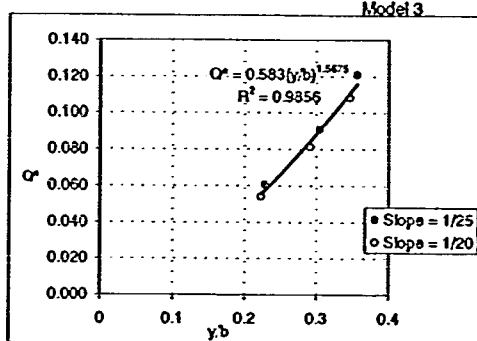
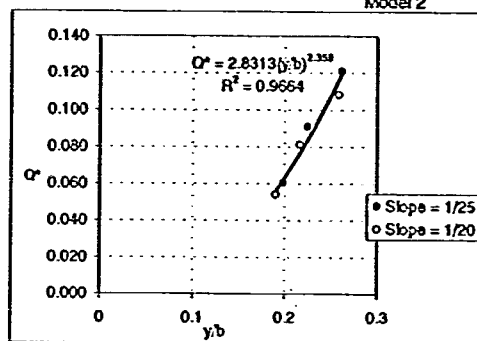
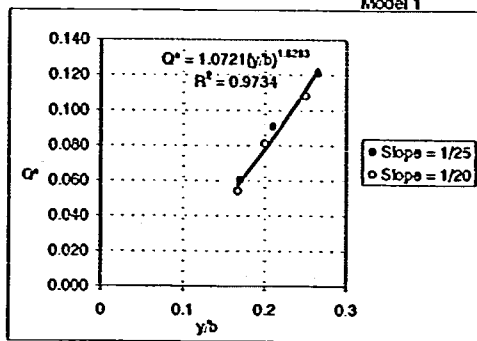
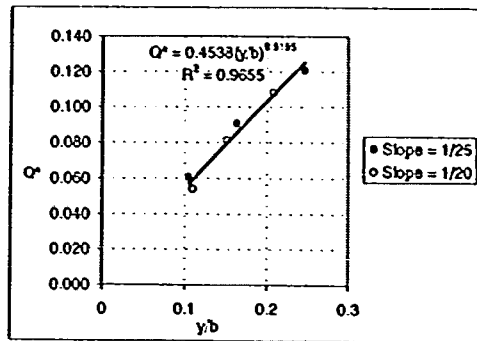


Fig.38 Variation of Q^* with y/b

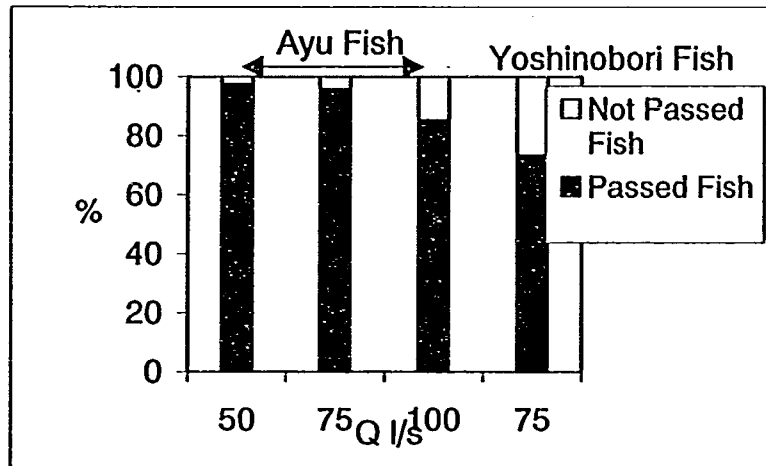


Fig.39 Distribution of fish with respect to discharges

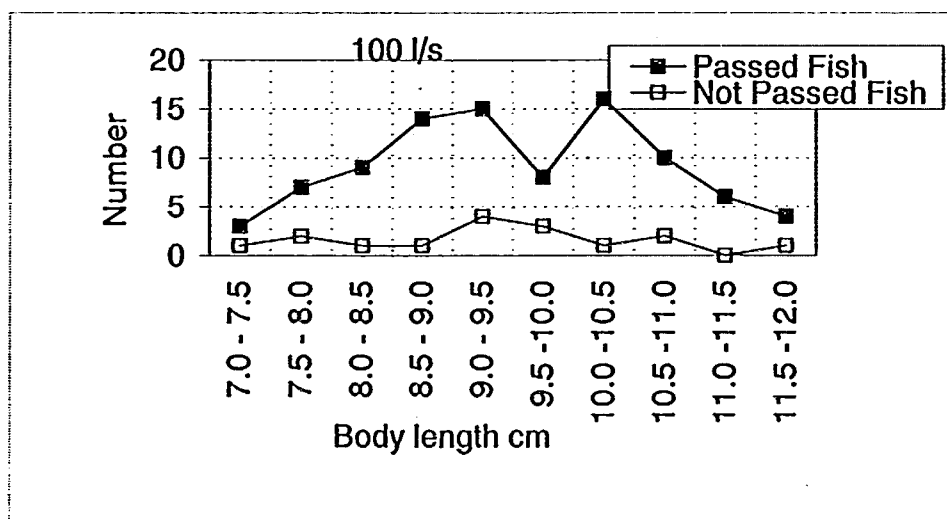
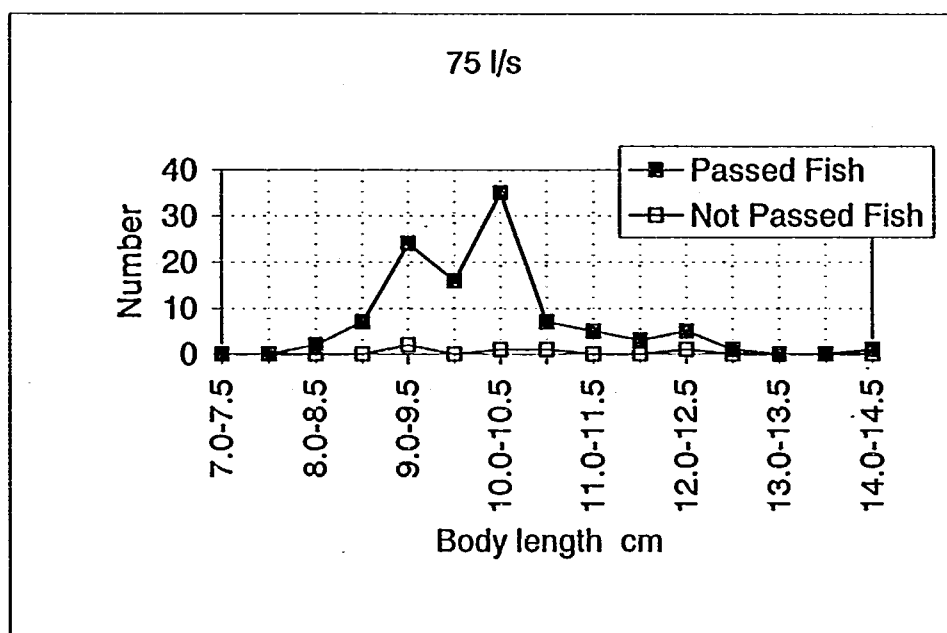
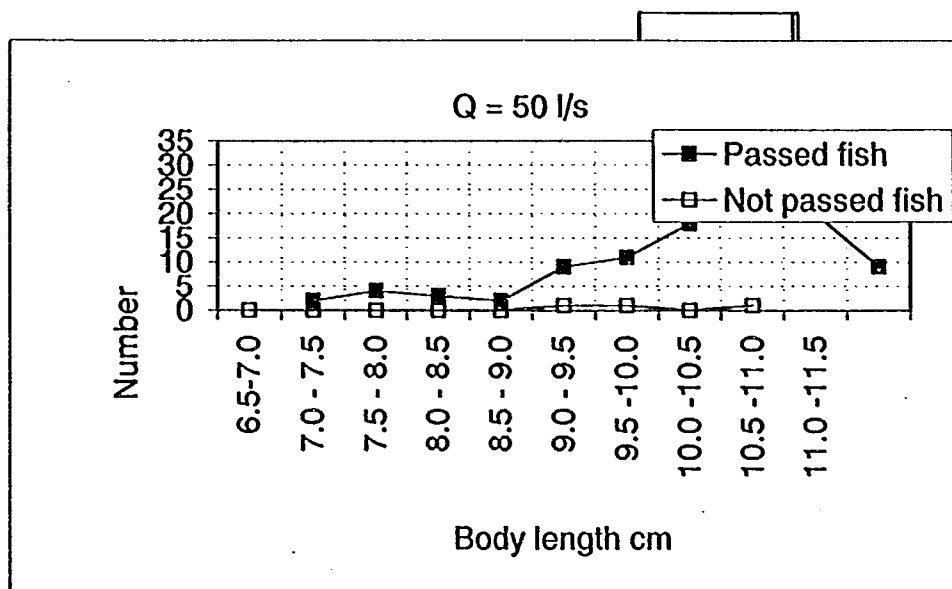


Fig.40 Distribution of Ayu fish with respect to the body length

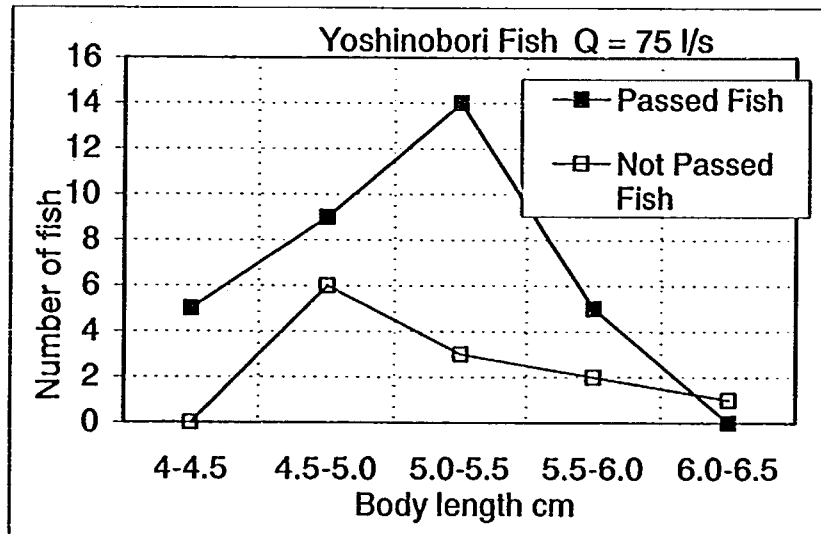


Fig.41 Distribution of Yoshonobori fish with respect to body lengths

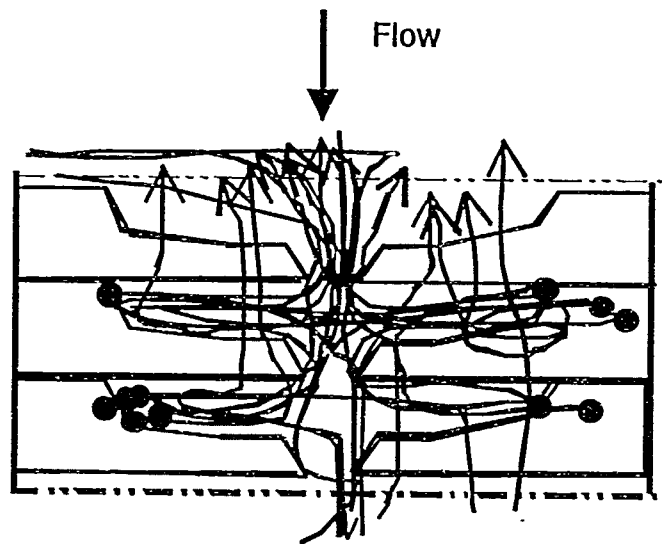


Fig.42 Ascending routes of fish inside the channel

APPENDIX A Photographs

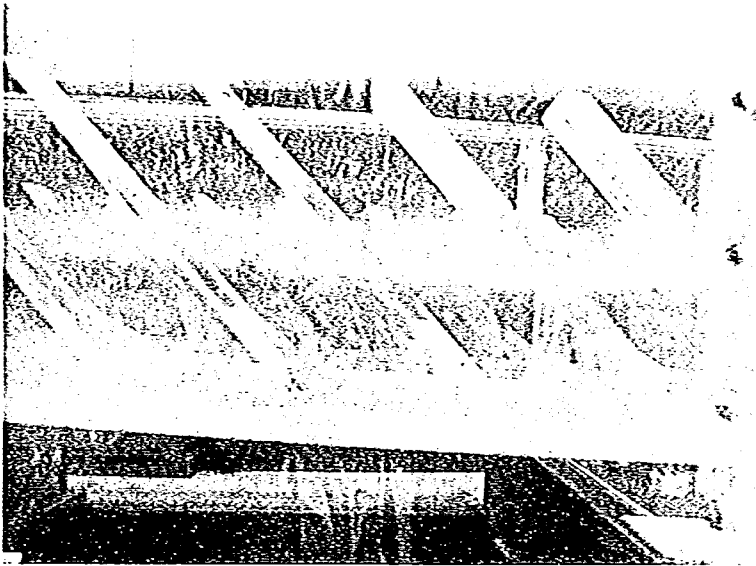


Photo 1 Flow in Model 1

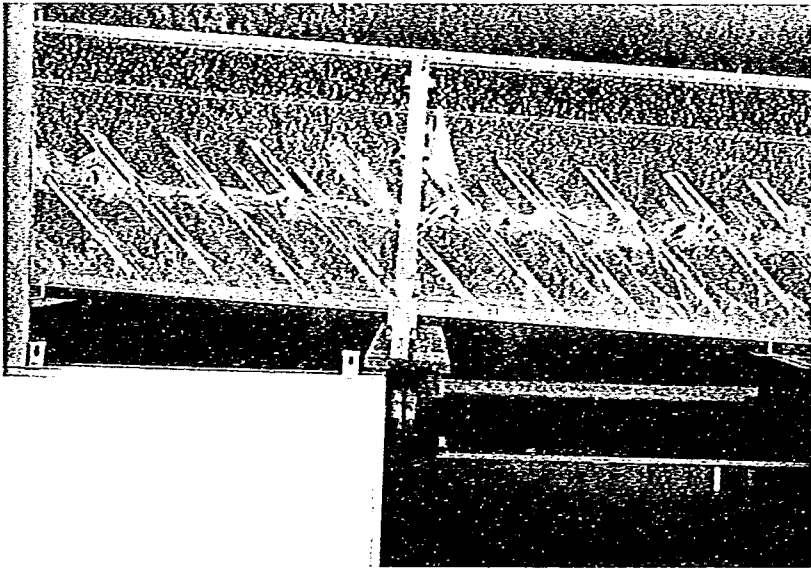
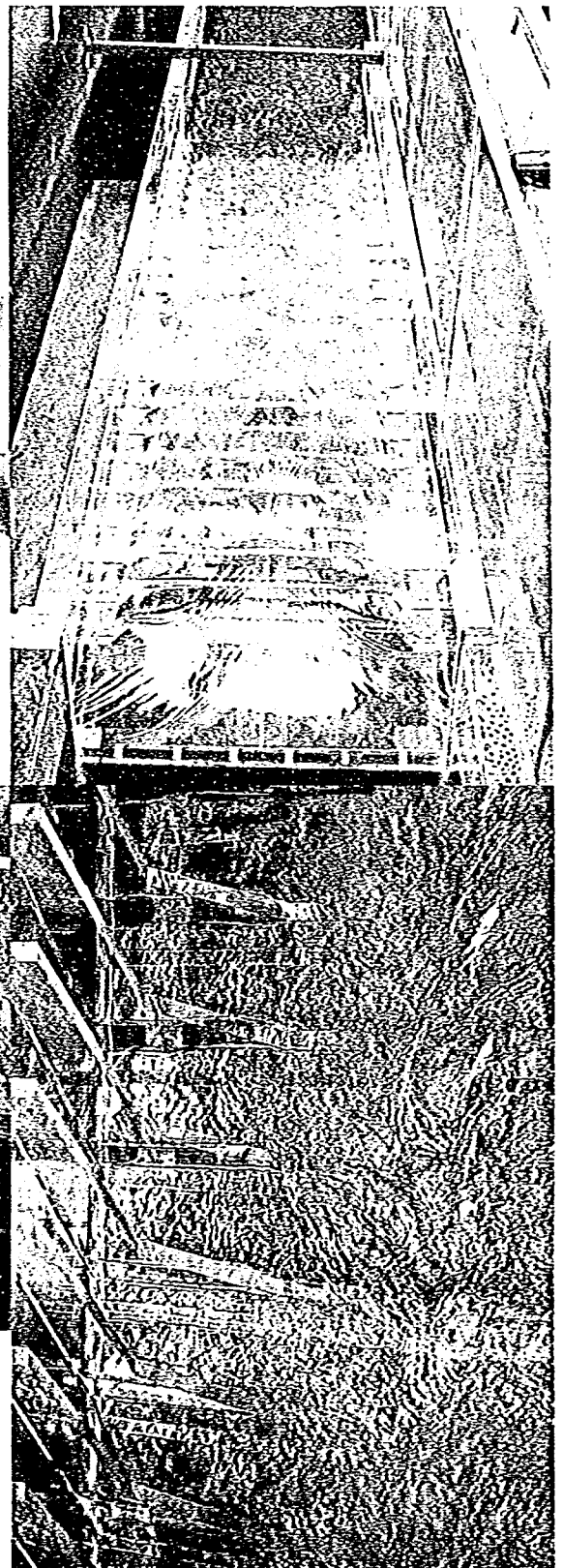


Photo 2 Flow in Model 2



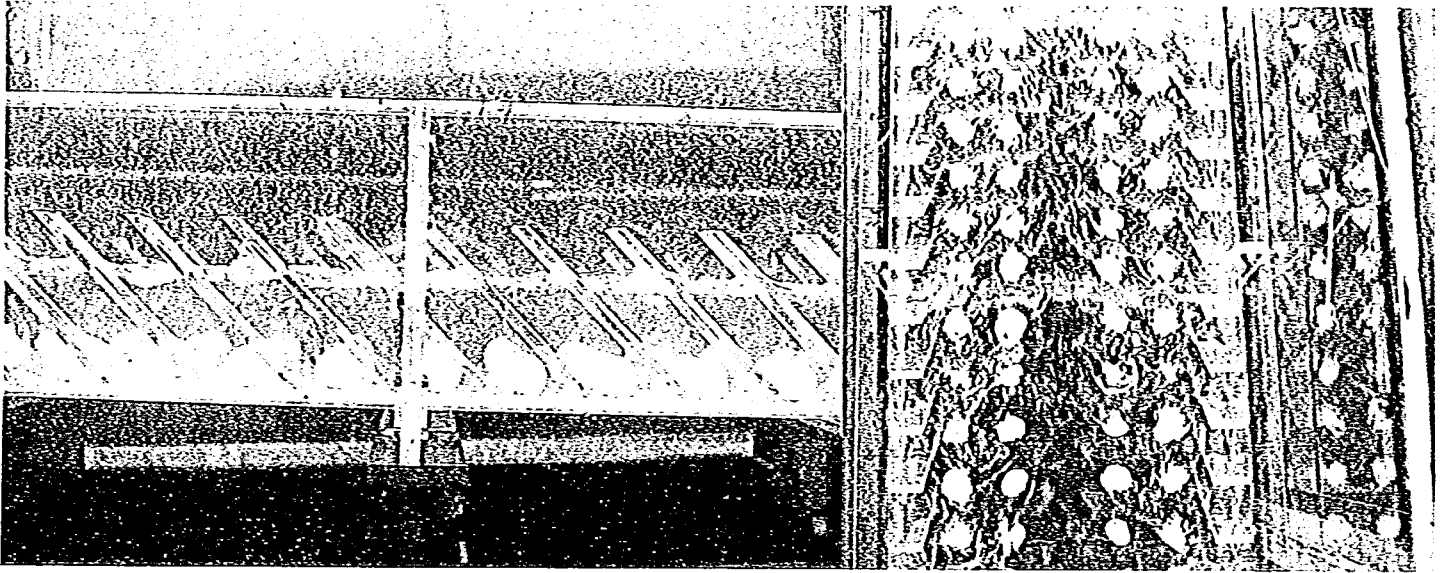


Photo 3 Flow in Model 3

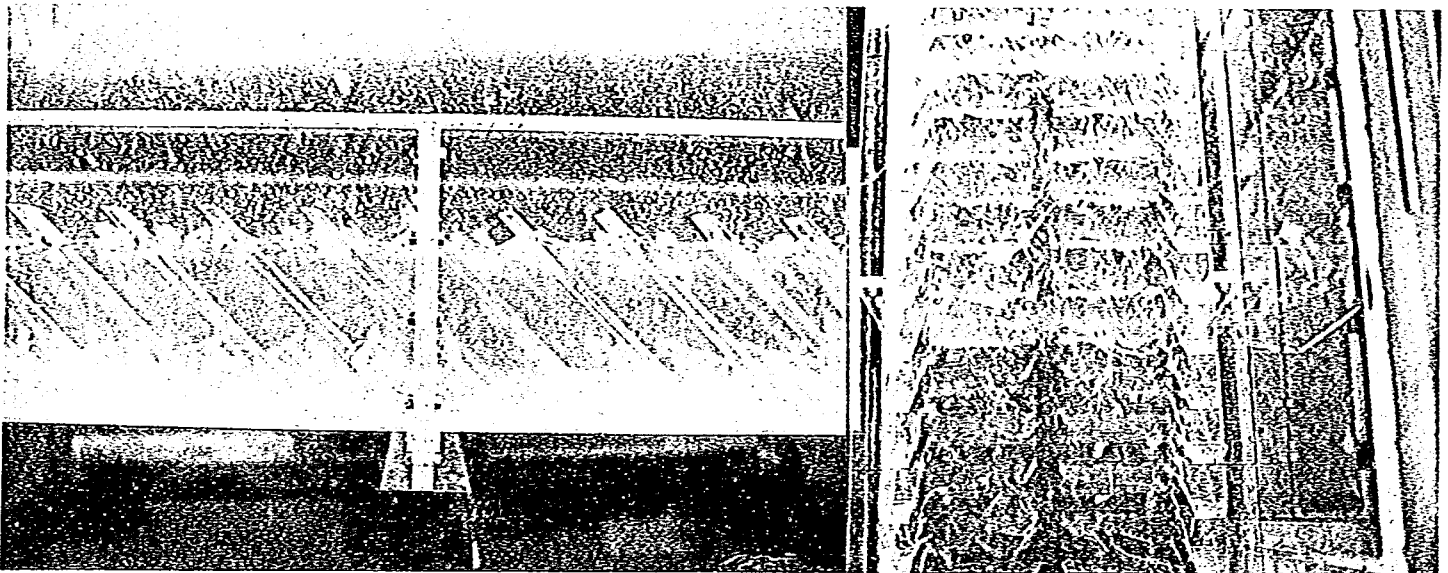
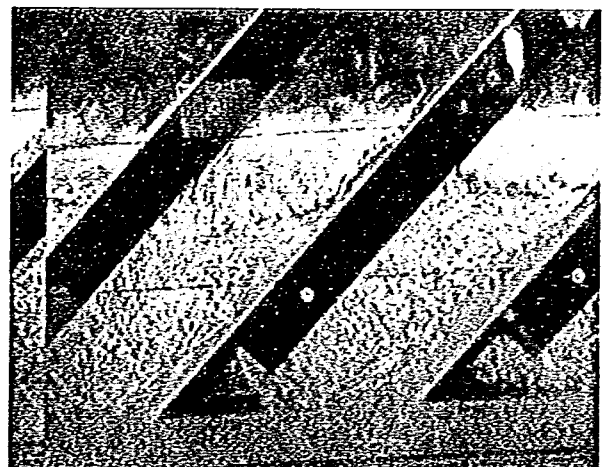


Photo 4 Flow in Model 4

Photo 5 Flow in side pockets in
Model 5



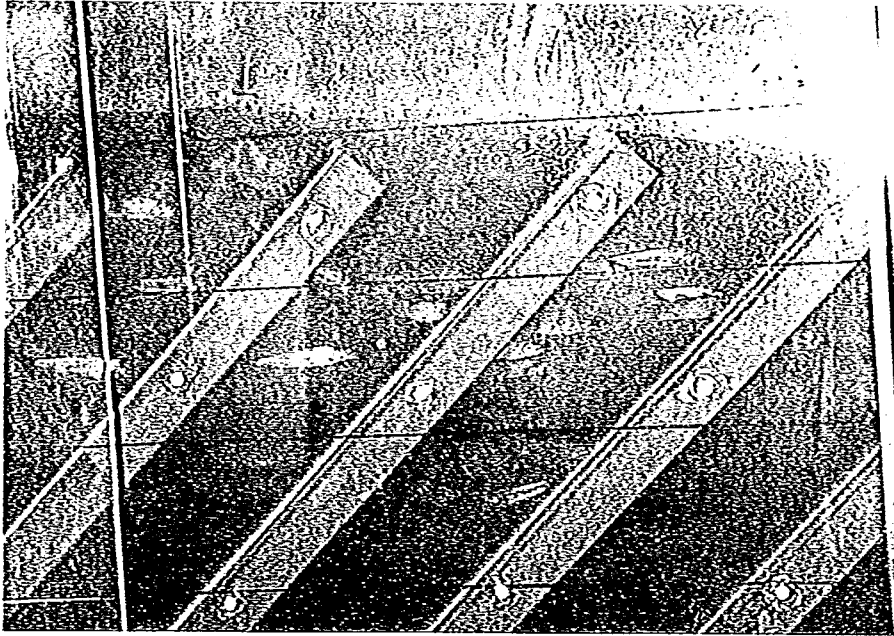


Photo 6 Ayu fish waiting to go up in downstream pool



Photo 7 Ayu fish resting in the side pocket

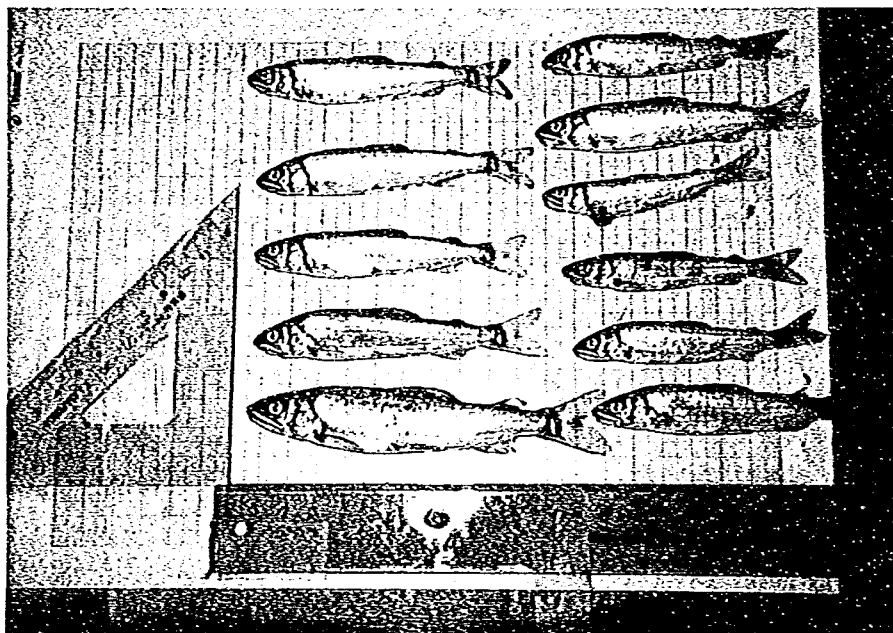


Photo 8 Some of the successfully ascended Ayu fish

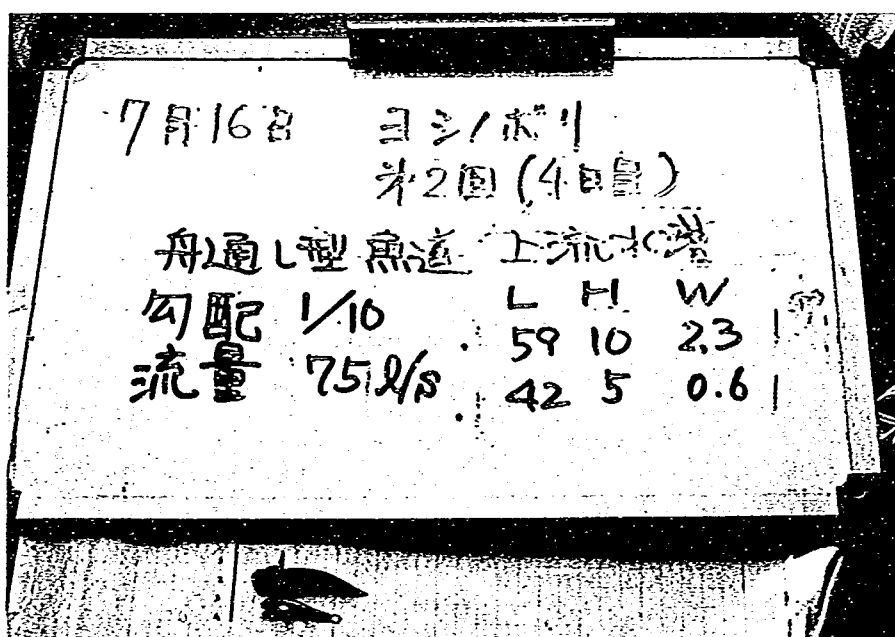


Photo 9 Successfully ascended Yoshinobori fish

APPENDIX B: Summery of Experimental Data

Water Depths along the Fish and Boat Pass Channel (Model 1)

Model 1	Slope = 1/25			Slope = 1/20		
Q l/s	20	30	40	20	30	40
Baffle No:	Depth cm	Depth cm	Depth cm	Depth cm	Depth cm	Depth cm
1	8.7	10.8	13.4	8.2	9.6	11.7
2	7.6	9.4	12.3	7.0	8.1	9.7
3	6.5	8.3	11.6	5.8	8.1	10.0
4	6.7	8.8	11.9	6.2	8.8	10.8
5	7.4	9.7	13.1	7.5	9.0	11.8
6	6.5	9.9	13.2	6.0	8.2	11.8
8	5.8	9.5	14.6	6.2	8.2	10.8
10	6.3	9.8	14.8	6.6	9.1	12.5
12	6.8	10.0	15.1	6.5	9.4	12.4
14	6.4	10.3	14.7	5.8	8.5	12.7
16	6.1	9.9	14.7	6.8	-	13.2
17	6.6	11.0	14.9	6.5	9.2	12.8
18	6.4	10.8	14.9	6.5	-	13.0
19	6.5	10.4	14.6	6.5	8.9	12.8
20	7.2	10.2	14.5	6.4	8.3	12.5
21	6.9	10.3	14.5	6.0	8.3	12.5
22	7.4	10.1	14.0	6.0	8.3	11.9

Water Depths along the Fish and Boat Pass Channel (Model 2)

Model 2	Slope = 1/25			Slope = 1/20		
Q l/s	20.2	30	40	20.2	29.5	39.5
Baffle No:	Depth cm	Depth cm	Depth cm	Depth cm	Depth cm	Depth cm
1	11.0	14.2	16.4	11.0	14.0	16.2
2	10.1	12.9	16.1	9.7	12.8	15.2
3	10.2	11.8	15.3	9.4	12.6	14.6
4	10.1	13.2	15.8	10.0	12.5	14.9
5	10.1	13.3	15.8	10.3	12.5	15.2
6	9.9	12.9	15.4	9.5	12.2	15.5
7	10.1	13.2	15.4	10.0	12.0	14.5
8	10.2	12.9	15.7	10.3	12.1	14.3
9	10.2	12.4	15.6	9.8	12.1	14.8
10	10.2	12.6	15.9	10.0	12.0	15.0
11	10.4	12.4	15.8	10.2	12.0	14.7
12	10.7	12.3	15.6	10.4	12.0	14.5
13	10.7	12.2	15.4	10.4	12.1	15.0
14	10.4	12.4	15.7	10.0	12.2	15.5
15	10.2	12.2	15.9	10.1	12.5	15.6
16	10.4	12.4	15.6	9.8	12.4	15.4
17	10.4	12.5	15.8	10.6	12.5	15.0
18	10.2	12.0	15.6	10.0	13.2	15.1
19	10.2	12.2	15.3	10.2	13.5	14.5
20	10.0	12.0	14.0	9.8	13.8	14.6
21	9.9	12.1	14.4	10.0	14.3	14.9
22	9.2	11.5	13.3	9.3	14.8	14.8

Water Depths along the Fish and Boat Pass Channel (Model 3)

Model 3	Slope = 1/25			Slope = 1/20		
Q l/s	20.6	29.9	40	20.8	31	39.9
Baffle No:	Depth cm	Depth cm	Depth cm	Depth cm	Depth cm	Depth cm
1	12.24	14.72	16.86	11.89	14.54	16.57
3	11.30	13.29	15.71	11.04	13.07	14.99
5	11.70	13.94	16.55	11.44	13.65	16.15
7	11.99	13.37	15.75	12.08	13.02	15.22
9	11.63	13.81	16.28	11.09	13.17	15.15
11	11.76	13.27	15.38	11.15	12.70	15.30
13	11.58	13.63	15.81	11.29	13.26	14.93
15	11.45	13.35	15.63	11.14	12.96	14.90
17	10.90	12.72	14.53	10.56	12.73	14.82
19	10.75	12.51	14.87	10.67	12.94	14.91
21	10.15	12.13	14.43	10.51	12.96	15.39
22	9.43	11.73	13.44	9.82	12.58	15.22

Water Depths along the Fish and Boat Pass Channel (Model 4)

Model 4	Slope = 1/25			Slope = 1/20		
Q l/s	20.6	29.9	40	20.8	31	39.9
Baffle No:	Depth cm	Depth cm	Depth cm	Depth cm	Depth cm	Depth cm
1	14.12	17.86	20.14	14.05	16.85	19.55
3	13.96	17.25	19.94	13.78	15.54	19.10
5	13.81	17.69	20.32	13.51	16.98	19.77
7	13.86	18.38	21.07	14.05	17.27	20.45
9	14.11	18.54	21.10	14.12	17.55	20.74
11	14.12	18.59	21.61	13.54	17.80	21.05
13	14.51	18.73	21.85	14.17	18.38	21.15
15	14.52	18.86	21.73	14.11	18.49	21.25
17	14.33	18.67	21.67	13.48	18.30	21.12
19	14.56	18.82	21.42	13.38	17.99	20.97
21	15.17	18.34	20.97	12.86	17.21	19.89
22	14.90	18.22	20.36	12.18	16.80	19.06

Water Depths along the Fish and Boat Pass Channel (Model 5)

Model 5	Slope = 1/10		
Q l/s	50	75	100
Baffle No:	Depth cm	Depth cm	Depth cm
1	14.20	15.80	16.70
10	13.40	15.60	16.60
20	13.60	15.40	16.40
30	13.60	15.40	16.80
40	13.60	15.60	16.40
50	13.60	15.60	16.40
60	13.60	15.40	16.20
70	14.00	16.00	17.20
80	14.40	17.60	20.20

Measured Velocity Data (Model 1, Slope: 1/25)

Q = 20 l/s

Baffle No.	Y cm	A	B	C	D
1					
	7.5	25.3	47.02	49.12	53.44
	5.0	27.58	58.45	56.17	58.14
	2.5		56.32	43.77	58.82
Baffle No.	Y cm	A	B	C	D
5	10.0				
	7.5				
	5.0	50.65	84.1	87	94.99
	2.5		72.49	68.23	96.74
Baffle No.	Y cm	A	B	C	D
10	10.0				
	7.5				
	5.0	48.7	77.59	100.47	110.55
	2.5		65.89	80	118.05
Baffle No.	Y cm	A	B	C	D
17	10.0				
	7.5				
	5.0	47.3	78.73	96.65	114.56
	2.5		66.45	78.72	121.36
Baffle No.	Y cm	A	B	C	D
21	10.0				
	7.5				
	5.0	10.89	72.25	105.33	118.67
	2.5		52.41	82.66	111.82

Q = 30 l/s

Baffle No.	Y cm	A	B	C	D
1	10.00		35.3	53.14	56.38
	7.50	49.31	66.13	63.78	63.44
	5.00	5.31	72.01	65.44	67.37
	2.50		68.05	47.18	65.96
Baffle No.	Y cm	A	B	C	D
5	10.00				
	7.50	66.22	90.16	90.9	97
	5.00	48.25	67.55	84.05	97.38
	2.50		50.3	59.74	93.42
Baffle No.	Y cm	A	B	C	D
10	10.00				
	7.50	63.62	74.48	94.32	106.34
	5.00	46.81	49.88	80.55	102.77
	2.50		37.75	63.94	85.99
Baffle No.	Y cm	A	B	C	D
17	10.00		51.89	66.79	31.32
	7.50	70.69	65.92	90	103.41
	5.00	62.53	45.06	78.42	77.26
	2.50		26.21	41.05	75.83
Baffle No.	Y cm	A	B	C	D
21	10.00		9.87	34.43	45.93
	7.50	85.57	79.66	74.14	102.56
	5.00	84.94	56.78	65.18	84.92
	2.50		35.88	41.54	89.13

Q = 40 l/s

Baffle No.	Y cm	A	B	C	D
1	12.5		41.55	61.15	64.87
	10.0	65.14	76.32	72.26	71.85
	7.5	33.17	81.71	75.17	71.48
	5.0	7.27	78.43	70.87	73.66
	2.5		70.06	49.81	70.52
Baffle No.	Y cm	A	B	C	D
5	12.5	35.2	59.09	80	84.07
	10.0	74.05	90.56	87.18	85.25
	7.5	52.32	79.02	80.22	80.6
	5.0	32.19	60.19	51.94	75.64
	2.5		41.92	30.96	71.15
Baffle No.	Y cm	A	B	C	D
10	12.5	85.37	87.35	88.51	89.98
	10.0	75.44	70.7	78.55	76.48
	7.5	65.24	58.63	52.11	64.81
	5.0	51.71	45.57	46.45	50.61
	2.5		34.26	19.29	45.44
Baffle No.	Y cm	A	B	C	D
17	12.5	102.19	96.14	87.81	74.77
	10.0	92.28	84.59	64.46	55.3
	7.5	83.75	65.33	44.16	37.82
	5.0	70.91	53.17	27.83	23.83
	2.5		43.2	11.07	25.7
Baffle No.	Y cm	A	B	C	D
21	12.5	80.36	65.57	79.67	76.88
	10.0	106.08	97.35	72.07	53.47
	7.5	97.84	81.85	52.47	37.24
	5.0	87.39	72.93	38.61	29.4
	2.5		60.89	21.44	30.81

Measured Velocity Data (Model 1, Slope: 1/20)

Q = 20 l/s

Baffle No.	Y cm	A	B	C	D
1	12.5				
	10.0				
	7.5		43.18	47.72	49.76
	5.0	39.53	55.78	55.57	55.23
	2.5		60.74	46.31	57.04
Baffle No.	Y cm	A	B	C	D
5	10.0				
	7.5				
	5.0	45.22	74.27	84.74	97.06
	2.5		80.45	79.2	102.08
Baffle No.	Y cm	A	B	C	D
10	10.0				
	7.5				
	5.0	19.61	64.58	81.44	73.47
	2.5		68.05	88.34	119.88
Baffle No.	Y cm	A	B	C	D
17	10.0				
	7.5				
	5.0	7.21	73.26	78	111.97
	2.5		69.66	65.92	119.09
Baffle No.	Y cm	A	B	C	D
21	10.0				
	7.5				
	5.0	9.4	46.41	84.37	111.24
	2.5		86.32	74.21	123.71

Q = 30 l/s

Baffle No.	Y cm	A	B	C	D
1	10.0			58.84	59.47
	7.5	53.77	73.19	70.24	67.57
	5.0	24.85	77.5	70.63	71.5
	2.5		75.51	52.37	70.07
Baffle No.	Y cm	A	B	C	D
5	10.0				
	7.5	62.2	80.59	98.51	106.36
	5.0	55.26	92.23	96.62	112.32
	2.5		58.16	69.32	110.76
Baffle No.	Y cm	A	B	C	D
10	10.0				
	7.5	60.01	78.79	90.22	116.87
	5.0	56.58	72.19	110.27	126.6
	2.5		33.49	84.97	121.56
Baffle No.	Y cm	A	B	C	D
17	10.0				
	7.5	42.52	60.91	99.88	125.24
	5.0	55.26	50.48	116.25	132.37
	2.5		28.18	89.8	112.65
Baffle No.	Y cm	A	B	C	D
21	10.0				
	7.5	64.97	61.39	90.11	102.58
	5.0	58.3	58.87	113.93	144.54
	2.5		35.04	91.72	125.23

Q = 40 l/s

Baffle No.	Y cm	A	B	C	D
1	12.5				
	10.0	78.85	79.12	74.17	73.99
	7.5	41.13	84.33	80.79	77.5
	5.0	7.27	82.72	74.56	79.56
	2.5		82.05	55.76	75
Baffle No.	Y cm	A	B	C	D
5	10.0	67.04	78.12	51.81	99.1
	7.5	79.63	91.86	85.56	114.78
	5.0	58.19	73.39	106.72	106.38
	2.5		53.56	92.89	100.27
Baffle No.	Y cm	A	B	C	D
10	10.0	81.39	90.7	95.63	100.79
	7.5	75.42	76.03	83.45	108.24
	5.0	58.13	55.55	73.2	78.85
	2.5		35.39	41.92	69.84
Baffle No.	Y cm	A	B	C	D
17	10.0	84.15	78.19	77.68	80.27
	7.5	80.12	61.83	58.4	81.69
	5.0	79.15	57.72	28.33	63.67
	2.5		56.72	16.64	48.6
Baffle No.	Y cm	A	B	C	D
21	10.0	91.06	77.35	84.68	94.21
	7.5	94.53	74.77	58.55	73.26
	5.0	99.88	74.06	40.12	65.06
	2.5		71.93	32.14	55.19

Measured Velocity Data (Model 2, Slope: 1/25)

Discharge: 20.2 l/s					
Baffle No.	Y cm	A	B	C	D
1	10	55.85	53.91	52.71	55.91
	7.5	50.57	55.64	59.30	52.57
	5		21.42	57.04	48.64
	2.5				52.91
Baffle No.	Y cm	A	B	C	D
5	10	37.87	75.50	83.20	71.36
	7.5	25.32	53.24	86.76	67.90
	5		37.71	77.62	49.38
	2.5				41.45
Baffle No.	Y cm	A	B	C	D
10	10	28.99	55.91	87.22	68.90
	7.5	27.07	53.31	88.89	47.38
	5		43.44	71.23	41.31
	2.5				23.85
Baffle No.	Y cm	A	B	C	D
17	10	11.06	71.06	81.69	69.70
	7.5	17.26	77.89	90.42	65.17
	5		72.56	68.37	49.71
	2.5				31.58
Baffle No.	Y cm	A	B	C	D
21	10	5.00	58.37	94.95	60.17
	7.5	10.00	70.16	76.50	72.10
	5				48.18
	2.5				38.33

Discharge: 29.2 l/s					
Baffle No.	Y cm	A	B	C	D
1	12.5	59.75	67.2	63.57	60.72
	10	36.07	70.04	65.83	64.38
	7.5	29.67	68.57	68	55.01
	5		29.26	62.56	40.14
5	2.5				32.53
Baffle No.	Y cm	A	B	C	D
5	12.5	48.36	63.34	81.79	78.31
	10	43.18	61.17	89.05	71.44
	7.5	24.34	37.11	83.77	61.51
	5		22	72.58	50.03
10	2.5				39.09
Baffle No.	Y cm	A	B	C	D
10	10	40.9	59.25	98.11	83.41
	7.5	20.79	34.23	89.64	69.74
	5		16.24	78.22	53.61
	2.5				33.5
Baffle No.	Y cm	A	B	C	D
17	10	48.48	59.54	85.41	88.76
	7.5	27.05	38.36	87.79	67.3
	5		17.15	80.05	51.63
	2.5				40.19
Baffle No.	Y cm	A	B	C	D
21	10	54.94	70.06	98.38	92.8
	7.5	28.69	44.39	91.4	76.7
	5		16.64	74.14	60.21
	2.5				44.55

Discharge: 40 l/s

Baffle No.	Y cm	A	B	C	D
1	15	64.19	70.62	67.48	65.74
	12.5	57.3	74.59	71.47	69.48
	10	54.95	72.53	71.32	68.82
	7.5	45.97	73.48	70.42	56.25
	5		66.48	54.48	34.47
	2.5				21.46
Baffle No.	Y cm	A	B	C	D
5	15	56.58	61.45	87.26	88.14
	12.5	57.93	81.93	94.69	84.09
	10	33.36	66.62	91.31	76.11
	7.5	22.44	52.39	84.97	66.62
	5		17.92	76.08	52.74
	2.5				45.09
Baffle No.	Y cm	A	B	C	D
10	15	53.02	64	83.92	90.06
	12.5	58.84	81.84	96.29	97.9
	10	47.62	62.04	69.66	75.23
	7.5	34.74	42.75	72.85	70.8
	5		29.43	50.27	55.86
	2.5				42.2
Baffle No.	Y cm	A	B	C	D
17	15	62	64.64	72.9	81.17
	12.5	63.75	75.37	69.48	89.68
	10	63.64	58.28	59.34	78.63
	7.5	60.22	45.53	43.61	55.74
	5		38.6	38.82	44.42
	2.5				40.21
Baffle No.	Y cm	A	B	C	D
21	12.5	71.8	70.37	73.84	90.49
	10	82.66	67.69	85.59	81.6
	7.5	79.47	60.37	63.11	59.53
	5		43.73	51.54	56.67
	2.5				50.28

Measured Velocity Data (Model 2, Slope: 1/20)

Discharge: 20.2 l/s

Baffle No.	Y cm	A	B	C	D
1	10	62.47	55.47	54.92	53.81
	7.5	57.22	55.86	53.05	50.36
	5		40.65	41.32	37
	2.5				31.33
Baffle No.	Y cm	A	B	C	D
5	10	59.13	66.36	93.55	87.26
	7.5	46.64	53.48	98.34	66.13
	5		37.01	83.65	49.53
	2.5				27.52
Baffle No.	Y cm	A	B	C	D
10	10	35.54	68.8	96.86	80.32
	7.5	33.36	71.31	91.43	62.24
	5		36.72	66.58	46.01
	2.5				32.37
Baffle No.	Y cm	A	B	C	D
17	10	22.07	75.03	94.24	74.45
	7.5	15.18	81.35	91.83	58.09
	5		70.23	62.93	37.89
	2.5				24.72
Baffle No.	Y cm	A	B	C	D
21	10	27.36	68.45	76.44	77
	7.5	25.38	79.99	95.68	69.85
	5		50.44	67.14	51.21
	2.5				31.94

Discharge: 29.2 l/s

Baffle No.	Y cm	A	B	C	D
1	12.5	49.87	53.94	53.84	57.91
	10	67.66	63.98	64.57	64.8
	7.5	60.33	63.11	67.32	63.81
	5		55.26	57.93	43.57
	2.5				28.71
Baffle No.	Y cm	A	B	C	D
5	10	61.52	83.18	106.83	86.88
	7.5	36.56	46.33	102.5	69.37
	5		27.55	78.57	55.86
	2.5				35.75
Baffle No.	Y cm	A	B	C	D
10	10	55.3	75.92	109.67	102.94
	7.5	32.14	48.29	102.79	85.3
	5		38.77	91.79	58.06
	2.5				37
Baffle No.	Y cm	A	B	C	D
17	10	50.04	72.87	108.85	94.27
	7.5	31.26	57.92	91.86	74.25
	5		33.24	72.78	59.58
	2.5				39.85
Baffle No.	Y cm	A	B	C	D
21	12.5	51.66	68.36	93.22	88.81
	10	45.92	63.04	87.33	78.96
	7.5	24.17	43.44	66.84	59.38
	5		29.32	48.92	50.47
	2.5				37.79

Discharge: 40 l/s

Baffle No.	Y cm	A	B	C	D
1	15	17.66	45.47	59.94	66.86
	12.5	74.97	72.07	72.98	74.04
	10	65.04	77.18	75.66	74.6
	7.5	55.52	73.7	70.85	67.33
	5		53.27	61.39	40.12
	2.5				27.98
Baffle No.	Y cm	A	B	C	D
5	12.5	83.22	95.44	103.05	94.68
	10	54.34	67.05	101.63	83.89
	7.5	36.12	47.93	92.36	73.64
	5		26.05	80.93	55.84
	2.5				29.15
Baffle No.	Y cm	A	B	C	D
10	12.5	74.89	85.76	114.02	106.09
	10	60.14	59.16	94.7	91.12
	7.5	34.08	41.71	77.14	75.9
	5		22.34	77.72	64.77
	2.5				43.07
Baffle No.	Y cm	A	B	C	D
17	12.5	83.04	86.66	108.31	107.79
	10	77.49	66.78	88.07	85.42
	7.5	62.01	51.13	71.93	67.86
	5		33.65	65.9	57.35
	2.5				39
Baffle No.	Y cm	A	B	C	D
21	12.5	93.9	94.45	95.45	88.67
	10	88.2	73.49	88.64	84.75
	7.5	78.53	52.62	59.69	75.44
	5		37.59	50.37	57.63
	2.5				41.63

Measured Velocity Data (Model 3)

Slope 1/20

Q l/s	Y cm	A	B	C	D
20	9.0	16.4	35.0	78.7	65.7
	7.5	21.9	45.1	84.4	60.3
	5.0		50.5	84.2	55.6
	2.5				54.8
	0.5				27.6

Q l/s	Y cm	A	B	C	D
30	10.00	24.1	62.8	106.8	87.9
	7.50	32.6	67.8	100.7	71.0
	5.00		57.3	94.1	67.7
	2.50				47.5
	0.50				28.2

Q l/s	Y cm	A	B	C	D
40	12.5	54.1	76.7	97.7	114.8
	10.0	39.3	56.7	94.3	108.8
	7.5	16.9	34.7	73.7	97.3
	5.0		25.3	69.4	83.8
	2.5				75.1
	0.5				36.2

Slope:1/25

Q l/s	Y cm	A	B	C	D
20	10.0				68.7
	7.5	23.6	43.3	82.8	56.1
	5.0		45.0	83.6	50.3
	2.5				53.1
	0.5				34.5

Q l/s	Y cm	A	B	C	D
30	12.5				89.1
	10	30.6	61.3	107.6	67.8
	7.5	14	32.2	94.2	56.5
	5		14.2	83.2	44.3
	2.5				25.1

Q l/s	Y cm	A	B	C	D
40	12.5	48.8	76.9	106.9	105.8
	10.0	29.8	50.3	102.2	91.7
	7.5	12.4	33.2	83.5	79.2
	5.0		17.8	78.5	66.1
	2.5				53.4
	0.5				33.4

Measured Velocity Data (Model 4)

Slope:1/25

Q l/s	Y cm	A	B	C	D
20.6	12.5	33.2	50.6	68.3	69.9
	10	19.6	42.9	71	58.7
	7.5	9.2	27.6	58.4	49.5
	5		4.9	7.8	36.1
	2.5				22.6
	0.5				10.6

Slope:1/20

Q l/s	Y cm	A	B	C	D
20.7	12.5	46.8	62.7	82.9	80.6
	10	31.6	41.4	69.2	79.9
	7.5	15.8	24.4	60.3	49.7
	5		6.9	19.1	43.1
	2.5				26.4
	0.5				11.2

Q l/s	Y cm	A	B	C	D
31	15	58.6	62.2	45.6	58.3
	12.5	55.4	46.2	42.5	60.1
	10	30.7	30.3	46.4	32.8
	7.5	19.5	19.6	28.4	33.8
	5		4.5	7.4	24.8
	2.5				12.4
	0.5				10.1

Q l/s	Y cm	A	B	C	D
30.3	15	71	65.7	82.9	75.9
	12.5	62.9	55.2	74.1	61.2
	10	55.9	34.5	47.2	56.8
	7.5	37.3	23.3	39	44.5
	5		2.2	8.2	29.8
	2.5				24.9
	0.5				15.4

Q l/s	Y cm	A	B	C	D
40.6	17.5	73.5	63.1	46.4	53.7
	15	68.1	54.7	34.4	37.6
	12.5	54.4	55.1	30.2	18.3
	10	51	41.2	20.8	11.8
	7.5	38.4	44.1	15.2	7.7
	5		7.2	2.6	10.4
	2.5				10.9
	0.5				6

Q l/s	Y cm	A	B	C	D
40.6	17.5	83.5	71.5	59.1	54.1
	15	74.4	64.9	36.6	30.3
	12.5	63.5	58	25.7	24.4
	10	59.9	50.2	22.6	13.4
	7.5	56.6	43.3	18.3	11.9
	5		9.8	3.6	10.8
	2.5				16.2

Measured Velocity Data (Model 5, Slope: 1/10)

Q = 50 l/s

Q l/s	Y cm	A	B	C	D	E
50	12.5	81.8	129	152.6	143.7	147.7
	10		130.1	145.6	148.7	126.7
	7.5				107.9	115.3
	5					94.6
	2.5					52
	1					46.7

Q l/s	Y cm	A	B	C	D	E
75	12.5	111.8	120.6	163.5	176.4	166.5
	10		155.8	184.1	159.3	150.7
	7.5				132.1	123.1
	5					95
	2.5					79.6
	1					49.2

Q l/s	Y cm	A	B	C	D	E
100	15	126.3	165.3	196.6	183.6	184.2
	12.5	103.4	149.6	182.5	179.1	174.7
	10		112.3	159.3	157.4	152.9
	7.5				129.8	134.1
	5					101.6
	2.5					73.7
	1					56.4

APPENDIX C: Ascending Experiments Data

Avu fish ascending data																	
Q = 50 l/s						Q = 75 l/s						Q = 100 l/s					
Passed Fish			Not Passed Fish			Passed Fish			Not Passed Fish			Passed Fish			Not Passed Fish		
Body length	Body width	Weight	Body length	Body width	Weight	Body length	Body width	Weight	Body length	Body width	Weight	Body length	Body width	Weight	Body length	Body width	Weight
(cm)	(cm)	(g)	(cm)	(cm)	(g)	(cm)	(cm)	(g)	(cm)	(cm)	(g)	(cm)	(cm)	(g)	(cm)	(cm)	(g)
10.5	1.7	8.6	10.7	1.9	10.4	9.3	1.4	5.6	10.4	1.8	7.2	12.7	2.1	14.8	11.8	1.9	11.4
10.5	1.7	11.3	9.8	1.6	7	9.0	1.5	4.8	10.7	1.7	7.7	11.2	1.9	10.1	11.7	1.9	10.6
10.2	1.5	8.2	9.2	1.4	5.2	14.0	2.5	17.7	12.1	2.0	12.0	10.3	1.7	7.8	8.8	1.2	4.2
10.5	1.6	9				9.6	1.6	6.5	9.1	1.4	4.0	11.0	1.7	7.9	10.7	1.6	8.5
10	1.4	7.3				11.5	2.0	11.5	9.0	1.5	5.0	11.9	1.8	10.5	8.7	1.4	4.7
8.9	1.3	5.1				9.8	1.6	6.1				10.3	1.7	7.8	9.1	1.4	5.5
10	1.5	7.3				9.2	1.5	5.2				11.2	2.0	10.0	10.5	1.6	7.8
10.7	1.5	8.7				10.3	1.9	7.9				10.3	1.6	7.1	12.6	2.1	13.6
9.8	1.7	7.2				10.4	1.7	8.0				10.9	1.7	8.9	10.7	1.6	8.6
10.5	1.6	8.9				10.2	1.8	7.1				8.9	1.4	4.8	9.6	1.5	6.1
11.5	1.9	11				10.2	2.0	8.4				12.0	2.0	11.9	10.1	1.4	6.7
11.3	1.7	10.3				10.1	1.8	7.4				10.7	1.7	7.7	10.1	1.4	7.2
10.5	1.6	8.3				12.2	2.1	11.4				12.7	2.2	13.4	11.0	1.7	8.2
9.5	1.3	5.8				10.4	1.8	7.3				11.0	1.9	10.5	11.2	1.7	9.4
10.5	1.7	9				9.3	1.5	5.2				8.7	1.4	4.5	10.2	1.6	6.8
9.5	1.5	6				9.6	1.7	6.4				10.2	1.7	7.4	8.5	1.2	4.0
11.2	1.8	10.1				10.2	1.7	7.4				8.7	1.4	4.6			
11.5	2.1	12.4				9.1	1.7	5.7				9.9	1.5	7.1			
10.9	1.6	9				9.6	1.6	6.8				9.5	1.4	5.8			
11.2	2.1	11.9				10.4	1.8	7.3				9.5	1.4	5.8			
10.8	1.6	9.4				9.6	1.8	6.6				10.5	1.6	7.5			
11.2	1.9	10				9.9	1.7	6.6				9.7	1.6	6.3			
10	1.4	7.5				12.5	2.1	12.1				11.5	1.9	10.1			
10.2	1.6	8.1				9.4	1.6	6.1				10.0	1.6	7.0			
9.7	1.4	6.2				10.7	1.8	9.8				8.9	1.4	4.3			
10.5	1.6	8.4				8.6	1.4	4.2				9.1	1.5	5.4			
10.5	1.7	9.3				9.4	1.5	5.6				12.0	2.0	11.5			
9.5	1.3	6.1				8.8	1.6	5.0				11.9	2.0	12.6			
10.2	1.5	7.8				10.3	1.9	8.4				9.5	1.6	6.2			
10.5	1.7	9.9				10.3	1.8	7.1				11.4	1.8	10.2			
10	1.6	7.4				9.5	1.5	5.4				11.1	1.8	8.0			
11	2	11.1				11.4	2.0	9.7				10.0	1.5	7.2			
9.5	1.5	6.9				10.6	1.8	7.8				9.4	1.5	5.7			
9	1.4	5.1				10.3	2.1	9.6				11.2	1.7	9.5			
10.5	1.7	8.8				9.1	1.5	5.3				11.6	1.9	9.6			
9.7	1.5	6.3				9.1	1.6	5.3				11.6	2.0	10.6			
8.7	1.2	3.9				9.1	1.7	5.6				11.5	1.7	6.7			
8.5	1.3	4.1				8.9	1.4	4.4				10.3	1.6	7.7			
8.1	1.2	3.9				9.6	1.7	7.2				10.0	1.6	6.6			
8.8	1.4	4.8				8.6	1.5	4.3				10.8	1.6	6.9			
10.3	1.7	8.4				9.5	1.6	5.8				9.7	1.6	6.7			
10	1.7	7.6				8.4	1.5	4.0				8.3	1.5	5.0			
9.2	1.6	6				9.0	1.4	4.1				11.9	2.1	12.0			
9	1.5	4.9				12.2	2.0	11.8				9.4	1.5	5.9			
9.5	1.6	6.3				10.7	2.1	9.6				10.7	1.7	8.3			
8.5	1.4	3.8				10.0	1.8	7.4				12.3	2.1	13.1			
10	1.6	7.3				10.3	1.7	6.6				9.1	1.6	6.2			
7.4	1	2.8				10.0	1.7	6.8				9.6	1.7	6.7			
10	1.6	7.2				10.0	1.8	6.6				12.6	2.0	13.0			

Continued...

11	2	10.6
10.2	1.6	7.7
9.8	1.5	6.7
10	1.6	7
10.4	1.7	8.5
9.6	1.6	6.4
9.2	1.5	5.9
10.5	1.7	8.6
7.3	1.1	2.8
9.3	1.4	5.3
9.9	1.7	8
10.2	1.6	8.2
10.4	1.8	9.5
11	2	10.4
10.2	1.8	8.6
10.1	1.5	7.7
9	1.3	4.7
7.4	0.9	1.6
10.8	1.9	9.9
10.5	1.8	9
8.8	1.7	8.2
10.1	1.4	5.5
10.5	1.7	9.3
9.9	1.6	7.4
9.5	1.4	6
9.1	1.3	5.4
10.2	1.6	8.3
9.5	1.4	6.7
8.7	1.4	4.7
6.6	0.8	1.7
7.5	1.1	3
10.5	1.7	9.1
10.2	1.5	6.3
10	1.7	7.8
10.2	1.8	9
9.8	1.7	7.7
10.4	1.8	9.5
9.7	1.5	7.3
10	1.6	7.8
10.1	1.6	7.8
7.5	1	3.1
10	1.6	7
9.2	1.6	5.9
9	1.5	5.2
7.2	1.1	2.8
10.5	1.9	9.9
10	1.5	6.9
8.8	1.4	4.9
9.1	1.5	5.2
9.7	1.5	6.5
10	1.5	8.6
8	1.2	2.9
10.2	1.6	8
7.6	1.1	2.7
6.5	0.8	1.7
9.5	1.4	5.6
9.2	1.5	5.3
10.5	1.9	9.7
10	1.6	7.4
8.7	1.4	4.3
10	1.9	7.5
Total	110	3

Total

10.6	1.9	8.5
9.2	1.6	5.0
10.4	1.8	7.7
10.4	1.8	7.4
9.3	1.7	5.9
9.3	1.5	5.3
10.0	1.6	6.2
10.8	1.7	7.6
9.4	1.6	6.0
9.0	1.1	3.6
9.1	1.7	5.4
12.1	2.2	12.2
11.1	2.0	9.1
10.0	1.8	6.8
10.1	1.8	7.3
9.0	1.5	4.5
11.5	2.1	10.3
9.5	1.7	6.2
10.0	1.9	7.4
10.4	1.9	8.3
12.2	2.1	12.2
11.2	1.9	9.1
9.7	1.7	6.4
11.0	1.9	8.5
10.0	1.8	7.2
9.2	1.5	5.0
10.0	1.7	6.5
11.8	2.1	11.6
10.1	1.6	6.5
9.3	1.6	5.3
12.0	2.1	12.0
11.3	1.9	9.0
10.9	1.8	8.7
10.1	1.6	7.3
10.1	1.6	6.8
9.4	1.4	4.0
9.6	1.7	5.6
10.0	1.5	6.1
9.5	1.7	5.7
10.2	1.7	6.8
10.1	1.7	6.6
10.3	2.0	8.3
8.8	1.6	4.5
9.3	1.6	5.7
10.4	1.9	7.8
9.1	1.8	6.1
9.6	1.8	6.7
9.8	1.6	5.6
10.0	1.8	7.3
10.5	1.8	8.0
10.1	1.7	6.9
9.6	1.7	6.6
10.2	1.8	7.5
9.0	1.5	5.1
8.4	1.2	3.6
8.8	1.3	3.9
8.8	1.6	4.7
Total	106	5

Total

8.2	1.3	3.8
10.8	1.9	8.9
12.7	2.1	14.2
11.2	2.0	10.9
12.0	2.1	11.7
8.5	1.4	4.6
11.0	1.8	9.0
9.5	1.5	5.6
11.1	1.9	9.2
11.5	2.1	12.3
8.3	1.4	3.6
11.2	2.0	10.1
12.2	2.1	12.2
11.5	2.0	10.5
10.9	1.8	7.9
11.3	1.9	9.2
11.3	1.9	9.6
10.1	1.6	6.5
11.6	2.0	10.8
9.5	1.7	6.0
9.1	1.3	4.8
9.3	1.4	5.0
11.3	1.8	9.3
10.1	1.8	8.0
10.4	1.7	8.4
9.1	1.5	5.2
9.7	1.7	7.1
10.8	2.0	9.7
10.2	1.6	7.3
9.8	1.6	6.8
10.0	1.6	7.8
10.1	1.7	7.5
11.3	1.9	10.3
9.9	1.7	7.4
11.3	2.0	11.0
12.4	2.2	12.8
9.3	1.5	5.3
10.0	1.7	7.1
8.8	1.3	4.6
9.8	1.8	7.3
9.5	1.7	6.1
9.6	1.6	5.9
8.8	1.5	4.9
Total	92	16

Yoshinobori fish ascending data

Q = 75 l/s						
Passed Fish			Not Passed Fish			
Body length	Body width	Weight	Body length	Body width	Weight	
(cm)	(cm)	(g)	(cm)	(cm)	(g)	
5.0	8.0	1.3	5.6	0.8	1.9	
5.0	6.0	1.3	5	0.7	1.3	
4.9	6.0	1.1	5.1	0.7	1.4	
4.4	6.0	0.9	6.3	0.8	2.4	
4.5	7.0	1.1	5	0.6	1.2	
5.0	8.0	1.2	4.6	0.5	0.9	
4.5	5.0	0.9	4.8	0.6	1.1	
5.7	8.0	1.9	4.8	0.5	1	
5.3	6.0	1.5	4.8	0.6	1.1	
5.7	9.0	1.7	4.8	0.6	1.1	
4.0	4.0	0.7	4.9	0.6	1.1	
5.2	6.0	1.5	5.8	0.8	2.3	
4.7	5.0	1.0				
5.1	5.0	1.3				
1st day passed fish	14					
	5.0	0.6	1.3			
	5.5	0.7	1.7			
	5.0	0.5	1.2			
	5.3	0.7	1.5			
	4.2	0.5	0.6			
	5.1	0.6	1.3			
	5.0	0.6	1.2			
	5.1	0.6	1.1			
	5.9	0.8	2.1			
	5.3	0.7	1.5			
	5.9	0.8	2.3			
	4.7	0.6	1.0			
	4.8	0.6	1			
	5.3	0.7	1.5			
	4.5	0.5	0.9			
	4.8	0.5	1			
	4.5	0.6	1			
	2nd day passed fish	17				
		4.2	0.5	0.7		
4.1		0.5	0.6			
3rd day passed fish	2					
	33		12			
Total						

1st day passed fish

2nd day passed fish

3rd day passed fish

Total

APPENDIX D: Research papers published so far out of the present study

Sampath Kumar Gurram and Josuke Kashiwai, "Laboratory Evaluation of Fish and Boat Pass channel for passage of Ayu fish (*Plecoglossus Altivelis*), 3rd International symposium on Eco-Hydraulics, Salt Lake City, USA, July, 1999, Proceeding on CD-ROM.

Sampath Kumar Gurram, Josuke Kashiwai and Tenri Nonaka, "Hydraulic Testing of Fish and Boat Pass Channel", presented at 28th IAHR Congress held at Graz, Austria, in Aug.1999, Proceedings Abstract Volume pp.312, Papers on CD-ROM.

Sampath Kumar Gurram and Josuke Kashiwai, "Hydraulic characteristics of a Denil type fishway and its feasibility for Ayu and Yoshinobori fish" Submitted to the international journal of Regulated Rivers, Research and Management, John Wiley & Sons.