Assessment of Substrate Performance and Column Geometry in Aeration of Hatchery Water Supplies

J. Mark Shrimpton

Salmonid Enhancement Program
Department of Fisheries and Oceans
1090 West Pender Street
Vancouver, B.C. V6E 2P1

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PREFACE

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ABSTRACT

Aeration trials were performed at Robertson Creek, Nitinat and Big Qualicum facilities. These experiments involved passing water through columns containing a variety of substrates. The oxygen and nitrogen gas concentrations of the inflowing and outflowing waters were measured to determine the aeration efficiency of the various substrates over a wide range of flow rates.

In all columns tested, the oxygen addition and nitrogen removal efficiencies gradually decreased as the water flow rate increased. The optimum substrate depended on the size of the column and the flow rate. The 8.9 cm Flexirings were more effective than the 3.8 cm Flexirings when used with the 30.5 cm diameter column at Nitinat Hatchery, while the 3.8 cm rings were most effective with the smaller 20 cm diameter column at Robertson Creek.

Aeration efficiency was improved, especially at low flow rates, when the columns were segmented at 30 cm intervals to increase the ventilation rate. Efficiency was also improved when care was taken to distribute the inflowing water over the entire area of the top segment. This was particularly important with the toroid substrate and with the larger, 40.6 cm diameter column.

RESUME

Des essais sur l'aération ont été réalisés aux piscifactures de saumon de Robertson Creek, de Nitinat et de Big Qualicum. Dans ces expériences, il s'agissait de faire passer de l'eau dans des colonnes contenant divers types de substrat. On a mesuré les concentrations d'oxygène et d'azote dans les eaux d'arrivée et de sortie pour déterminer l'efficacité de l'aération de divers substrats pour une vaste gamme de taux d'écoulement.

Dans toutes les colonnes mises à l'essai, l'addition d'oxygène et l'élimination d'azote sont devenues graduellement moins efficaces à mesure que le taux d'écoulement de l'eau augmentait. Le substrat optimal était fonction de la dimension de la colonne et du taux d'écoulement. Les anneaux plastiques de 8,9 cm se sont avérés plus efficaces que ceux de 3,8 cm lorsqu'utilisés avec la colonne de 30 cm de diamètre à la piscifacture de Nitinat, tandis que les anneaux de 3,8 cm ont été les plus efficaces avec la colonne plus petite de 20 cm utilisée à la piscifacture de Robertson Creek.

L'aération a été plus efficace, particulièrement lorsque le taux d'écoulement était faible, quand on a séparé les colonnes en segments de 30 cm pour accroître le taux de ventilation. L'efficacité s'est également accrue lorsqu'on prenait soin de répartir l'eau d'arrivée sur toute la largeur du segment supérieur.

INTRODUCTION

Water supplies with gas concentrations near saturation are optimum for fish culture. Groundwater is often undersaturated in oxygen and supersaturated in nitrogen; whereas surface water can be supersaturated in both oxygen and nitrogen. Low oxygen concentrations reduce the carrying capacity of the water supply. Supersaturation of dissolved gases is also detrimental, as it causes gas bubble disease. To approach ideal gas concentrations for fish culture, various aeration devices can be used.

Aeration of water follows four steps (Weber, 1972).

1. diffusion of the gas to the liquid-gas interface.
2. passage through a gas-film on the vapour side of the interface.
3. passage through a liquid-film on the solvent side of the interface.
4. diffusion throughout the solution.

Aeration efficiency is increased if these four steps are accelerated. As the efficiency increases, gas levels more rapidly approach saturation.

This study concerns the packed column method of aeration; a method which utilizes a vertical, cylindrical column filled with loosely packed substrate material. The purpose of the substrate is to create turbulence in the water as it pours through the column, increasing the normally slow rate of diffusion of the gas throughout the solution. For low-solubility gases, such as oxygen and nitrogen, the rate of gas transfer is limited by the liquid interface (Weber, 1972). Creating turbulence minimizes this thickness by breaking the water into droplets, thereby increasing the gas transfer area (Wheaton, 1977).

Unlike other aeration methods, such as U-tubes and plunge pools which can cause supersaturation (SIGMA, 1979), one of the benefits of the packed column is that the air-water mixing occurs at atmospheric pressure and water saturation levels are always shifted towards equilibrium. The intent of this study is to determine the aerating efficiency of various substrates under a wide range of flow rates.

ANALYTICAL METHODS

All oxygen concentrations were measured in duplicate using the azide modification of the Winkler technique (APHA, 1980). Reagents (2 ml manganous sulfate and 2 ml alkali-azide) were injected below the surface of the water in the 300 ml dissolved oxygen bottles so reagents would not be lost when stoppering the bottles.

Thus a 100 ml volume actually represented 98.667 ml of the water sample Vs:

$$Vs = 100 \text{ ml} \times \frac{300 - 4}{300} = 98.667$$

1.0 ml of N normal sodium thiosulfate is equivalent to N x 10^{-3} gram equivalent weights of iodine which in turn is equivalent to N x 10^{-3} gram equivalent weights of oxygen. Since the equivalent weight of oxygen is 8, 1.0 ml of N normal sodium thiosulfate is equivalent to 8 N x 10^{-3} gram or 8 N mg of oxygen. If the volume of the water sample titrated is Vs (ml) and the volume of sodium thiosulfate titrant required is Vt (ml) then the concentration of oxygen per liter of solution C (mg/l) is:

$$C = (8000 \text{ N Vt})/Vs$$

In this study the volume titrated was 100 ml (this represented a sample volume Vs of 98.667 ml) and 0.010 N sodium thiosulfate titrant was used. Thus the relationship between the oxygen concentration C (mg/l) and volume of titrant Vt (ml) was given by:

$$C = 0.8108 \times Vt$$

To increase accuracy and to decrease the error due to iodine loss after acidification, the volume for titration was measured using a 100 ml volumetric pipette. 400 ml of (commercially prepared) 0.025 N sodium thiosulphate were diluted in a 1 L volumetric flask at 20°C to accurately prepare 0.010 N sodium thiosulphate.

Because all the measurements were taken in the field, special care was taken in the transportation and storage of the reagents. All samples were fixed immediately and titrations were done within two hours of sampling.

Total excess gas tension was measured using a Novatech Designs Ltd. tensionometer. This unit was zeroed in the atmosphere prior to each set of tests and was allowed to equilibrate for about 20 minutes in the sample before readings were taken.

Total gas pressure (TGP), percent oxygen and percent nitrogen values were calculated using relationships described by McLean and Boreham (1980). These calculations were performed on a micro-computer located at Big Qualicum using the TGP program (Kling, et al., 1985). In this program, the partial pressure of carbon dioxide is assumed to be negligible. Argon is considered to be in constant proportion with nitrogen and is included in the percent nitrogen measurement (D'Aoust and Clark, 1980).

Barometric pressures were measured using a calibrated, hand-held aneroid barometer, while water temperatures were measured using a calibrated mercury thermometer with 0.1°C graduations.

The effectiveness of each aeration device was expressed in terms of the gross aeration coefficient "G" (McLean and Boreham, 1980). This parameter, along with the inflow oxygen concentration "Xi", determines the outflow concentration "Xo":

$$Xo = 100 - (100 - Xi)e^{-Go}$$

In the case of groundwater supplies, where oxygen is usually undersaturated ($Xi < 100\%$) and nitrogen is often supersaturated ($Ni > 100\%$), G can be calculated from:

$$\text{Oxygen:} \quad Go = \ln(100 - Xi) - \ln(100 - Xo), \quad Xi < 100\%$$

$$\text{Nitrogen:} \quad Gn = \ln(Ni - 100) - \ln(No - 100), \quad Ni > 100\%$$

where: Xi, Xo, Ni and No are the oxygen and nitrogen levels (in % saturation) at the inflow and outflow of the aerator.

MATERIALS TESTED

SUBSTRATE

The materials and substrates used in trials at the various facilites were:

1. Small, expanded aluminum screens (5 mm x 13 mm aperture).

2. Large, rolled, expanded aluminum screens (16 mm x 44 mm aperture).

3. 2.5 cm saddles
   - Super Intalox, plastic, crescent shaped with scalloped edges.
   - Norton Company.
   - Calgary, Alberta

4. 2.5 cm rings
   - Koch Flexirings, plastic, sectioned cylinder.
   - Koch Engineering Company.
   - Calgary, Alberta

5. 3.8 cm rings
   - Koch Flexirings.
   - Koch Engineering Company.
   - Calgary, Alberta

6. 5.0 cm rings
   - Koch Flexirings.
   - Koch Engineering Company
   - Calgary, Alberta

7. 8.9 cm rings
   - Koch Flexirings.
   - Koch Engineering Company
   - Calgary, Alberta

8. 8.9 cm rings
   - Glitsch Ballast Ring, plastic, sectioned cylinder.
   - Glitsch Canada Ltd.
   - Uxbridge, Ontario

9. toroids - Plastic, doughnut shaped.
- Fabco Systems.
- Surrey, B.C.

ROBERTSON CREEK COLUMN

A packed column used to aerate groundwater in the steelhead incubation room was used in the aeration trials performed at Robertson Creek. The column was constructed from 20.3 cm polyvinyl chloride (PVC) schedule 40 pipe (cross-sectional area of 0.03 m^2) and was divided into four 31 cm segments with 10 cm spaces between the segments for ventilation (Fig. 1). It was attached by screws to angled aluminum, which in turn was bolted to the ceiling. The column could be quickly disassembled and repacked to change substrates. Water was introduced by a 5 cm diameter pipe directed downward and centered over the column. It was important to ensure that the 5 cm pipe was on an upward incline to prevent air bubbles from flowing into the pipe and getting trapped at the low flow rates. Had this occurred, the water would have been partially aerated after the inflow measurements were taken but before it had reached the column for testing.

NITINAT TOWER

The aeration tower at the Nitinat facility consists of 20 segmented packed columns. Each packed column was constructed from 30.5 cm diameter PVC pipe (cross-sectional area of 0.07 m^2). The first segment of each column was 60 cm long and the remaining six segments were all 30 cm long (Fig. 2). The top half of the first segment was used to distribute the water by placing three layers of screens approximately 5 cm apart. The first screen was large rolled expanded aluminum, with 16 mm x 44 mm apertures. The second layer consisted of a fine aluminum screen with 1.5 mm x 8 mm apertures, placed on top of a large screen. The third layer of screens was the same as the second. The rest of the first segment was filled with substrate. A large expanded aluminum screen was placed at the bottom of each segment.

The second and third segments were filled with 25 cm of packing. The top 5 cm of each segment broadened to form a funnel to catch the water passing through the column. The fourth segment was fitted with a plastic garbage bag in order to pool the water. The water could then be sampled directly out of the fourth segment.

Inflow conditions were measured at the well. A garden hose was attached to a valve and was used to fill a 10 L bucket which held the probe, siphon and thermometer during measurements.

At low flow rates the 17 cm diameter inlet pipe was not comletely filled with water and there appeared to be air-water mixing. Although this would be beneficial for the aeration of water, possible aeration before the first segment of the column may have caused performance of the substrate to appear better than it actually was. Since this factor was consistent for all three

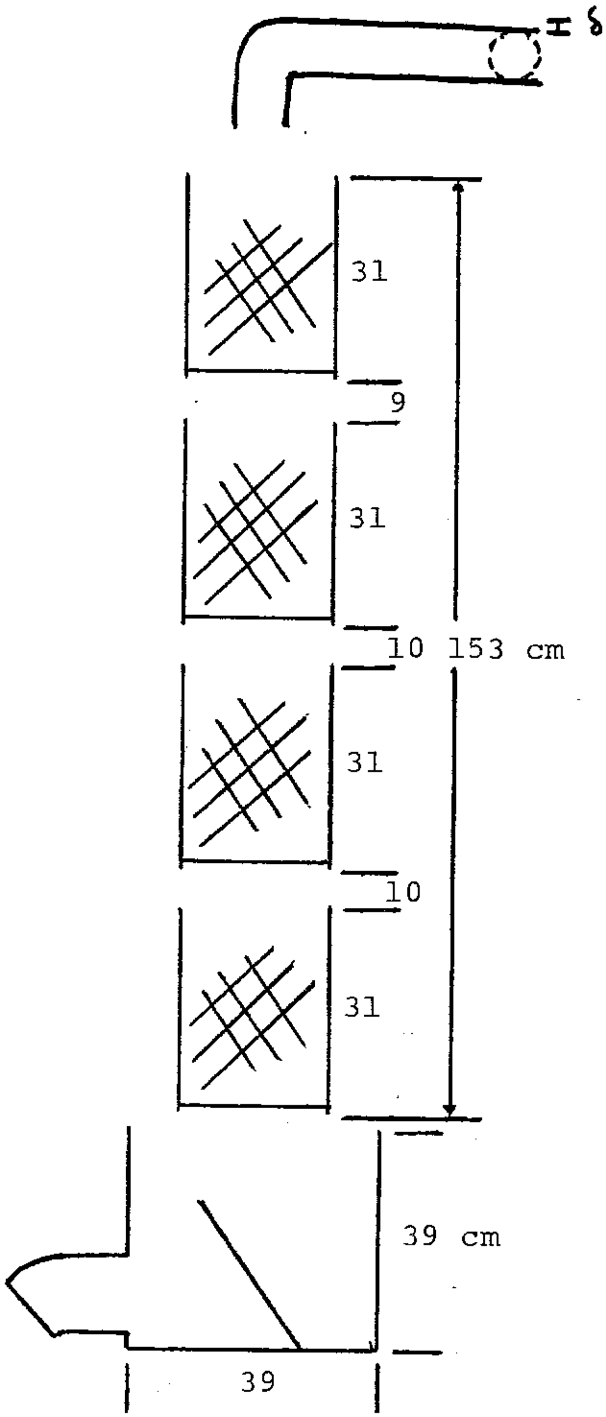


Fig. 1. Diagram of 20 cm diameter column used during the aeration trials at Robertson Creek Hatchery.

δ indicates a small rise in elevation to increase backpressure and prevent bubbles at slow flows.

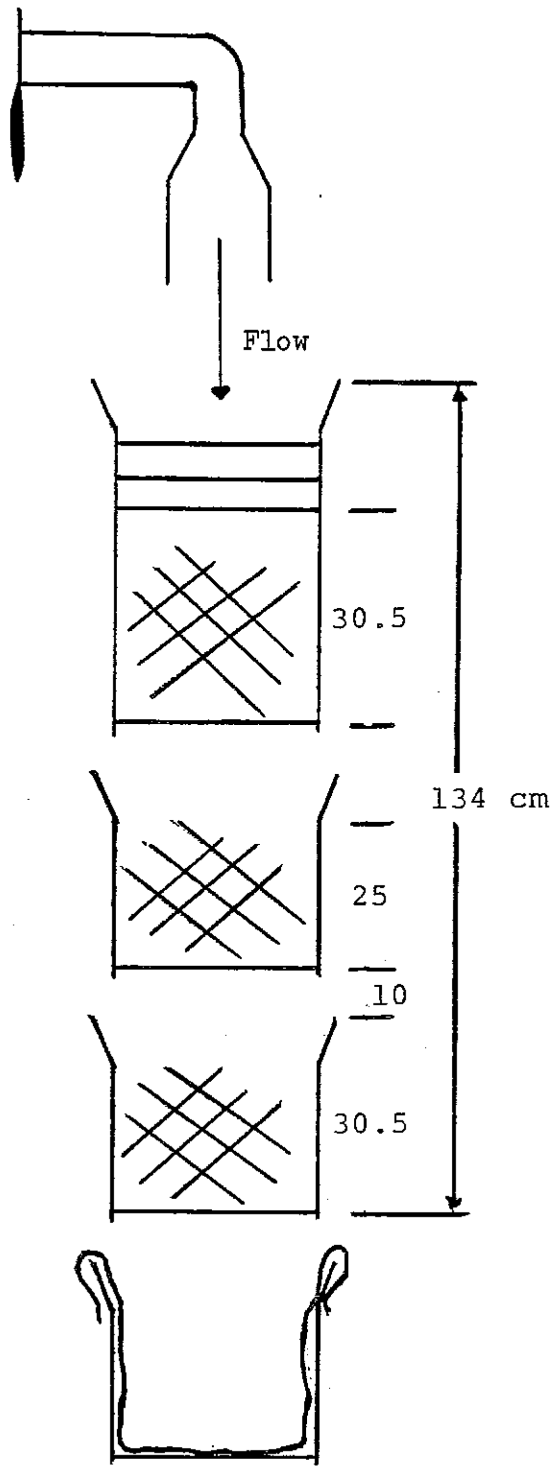


Fig. 2. Diagram of the aeration column tested at Nitinat Hatchery.

substrates tested, it would not affect comparison between them. However, comparison of performance values between two different columns may not be valid. As flow rates were increased apparent aeration within the inlet pipe was eliminated.

The bottom of each segment had a small lip which extended 1 cm into the bucket and held the screens in place. It was observed that for all three substrates there was a funnelling effect of the water as it left each segment. As the water hit the lip, it was redirected toward the center of the column. This problem could be rectified in future columns by removing the lip. Two rods positioned 90° to each other could provide enough support for a screen and substrate.

BIQ QUALICUM COLUMN

The hydraulic head requirement for a conventional packed column to strip supersaturated gases is not attainable at Big Qualicum unless a pump is used. There is approximately 1.0 m of head to work with; thus, the packed column had to be shorter and wider than the normal tower design. The packed column designed for testing at Big Qualicum was a cube (74 cm on each side). A 15 cm diameter PVC inlet pipe ran vertically up through the center of the substrate (Fig. 3). The area of the column minus the area of the inlet pipe was 0.53 m^2. This column sat on top of a head trough which was raised 3.5 m above the ground in order to supply the incubation building by gravity.

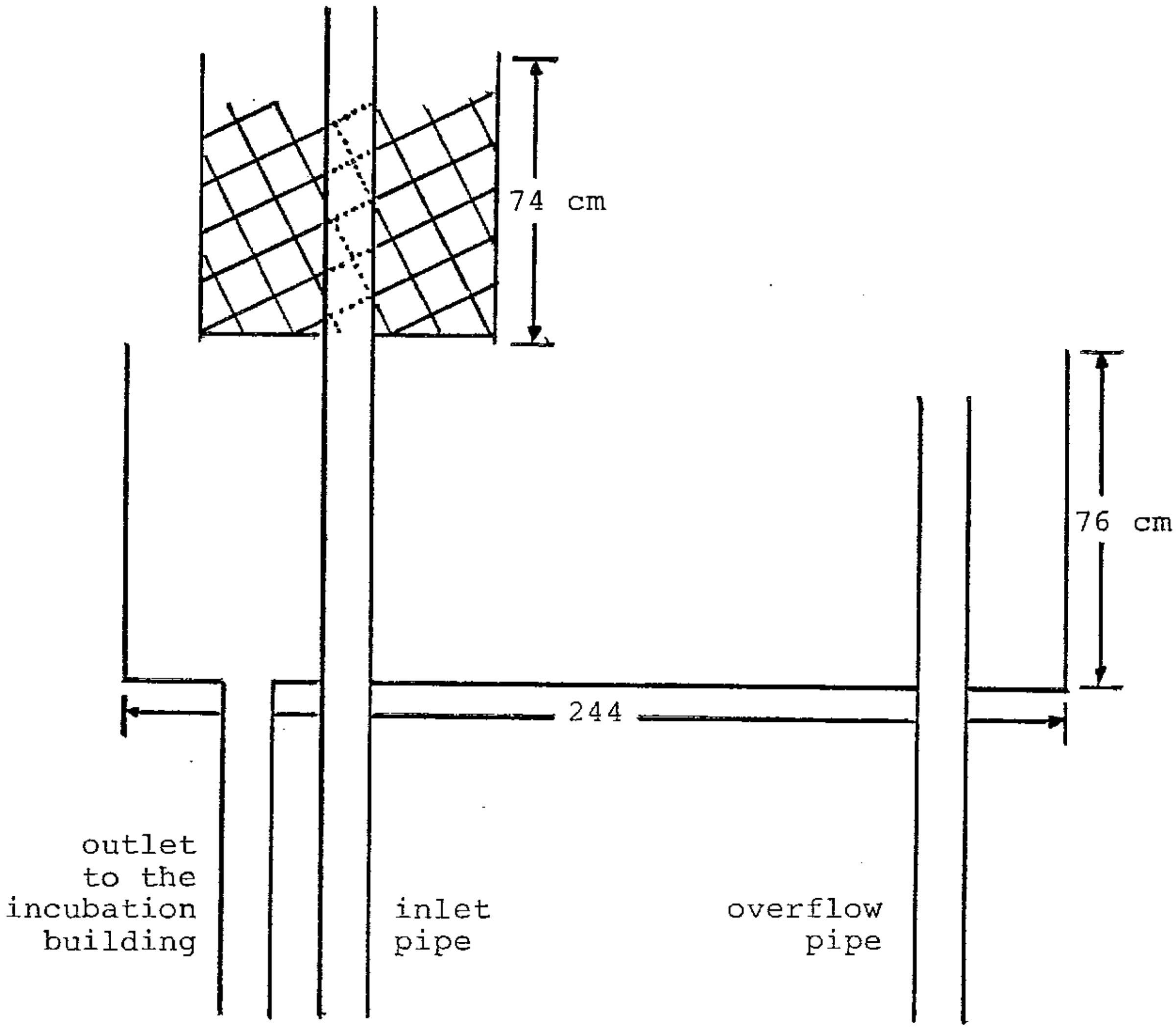
TRIAL DESCRIPTIONS AND RESULTS

ROBERTSON CREEK

Unaerated groundwater (from well #1 or #3) was pumped into the column. A valve on the inflow line was used to control flow rates, which were determined using a calibrated 100 L plastic bucket and stopwatch. The valve was set for a given rate, and then not altered throughout the trial. This was important when directly comparing different substrates at the same flow rate, because substrate efficiency is affected by water velocity in the column.

Unaerated groundwater was used in order to obtain low oxygen and high nitrogen levels. Low oxygen levels in the inflow increase the accuracy in the measurement of the gross aeration constant. Due to the logarithmic behaviour of gas exchange, increases in oxygen concentration from aeration are more easily measured the further the initial values are away from saturation. As the oxygen concentration of the water approaches saturation, it becomes increasingly more difficult to add more oxygen to the water and consequently improvements in aeration performance become much harder to detect.

Fig. 3. Diagram of the aeration tank and head trough built at Big Qualicum Hatchery.



Substrate Efficiency Trials

The object of these trials was to determine the best substrate for aeration by measuring the performance of the segmented 20 cm diameter column as a function of column packing and flow rate.

For each of the five flow rates, aeration performance was measured with the column empty and filled with various types of packing. The column trials were:

1. Empty column (no screens)
2. Small screens (in the top of the first segment and bottom of all the segments)
3. Large screens (used in all subsequent trials)
4. 2.5 cm saddles
5. 2.5 cm rings
6. 3.8 cm rings
7. 5.0 cm rings
8. 8.9 cm rings
9. toroids

From well #1, the maximum flow rate used was 195 L/min (6019 L/min m^2). The lowest flow rate used, 23 L/min (710 L/min m^2), was chosen to give some indication of the performance of the column at very low water velocities, as may be encountered during incubation of eggs and alevins in incubator trays. The three intermediate flow rates, 150 L/min (4630 L/min m^2), 95 L/min (2932 L/min m^2) and 49 L/min (1512 L/min m^2), were chosen to represent a good range of flows for aeration efficiency determination.

Performance of the small screens was marginally better than that of the large screens (Table 1). However, this improvement was within experimental error and consequently the difference between the two screen sizes is not significant. Theoretically, large screens should improve air flow down the column because they allow water to pass through easily (Fidler, 1983). They should also enhance the performance of the substrate by preventing the water from pooling at the bottom of each segment. Hence, all aeration trials in this study were performed using large screens.

The 2.5 cm saddles, 2.5 cm and 3.8 cm rings were consistently the most efficient substrate for the flows tested. The 30 cm long, 20 cm diameter segments were too small to efficiently pack with 8.9 cm rings, as only eight rings would fit in a segment. The toroids exhibited very little tendency to distribute water since the water could be seen flowing unimpeded down the center of the column. The best distribution was exhibited by the saddles, since the tendency for them to pack densely forced the water to spread over the entire cross-sectional area. The 2.5 cm and 3.8 cm rings also showed good distribution characteristics.

The 3.8 cm rings gave the best overall performance for the addition of oxygen and removal of nitrogen (Fig. 4). This substrate is presently in use in the aeration columns at Robertson Creek.

Difficulty in approaching saturation can be seen in these trials. At 195 L/min the empty column raised the dissolved oxygen from 58% to 87% of saturation (Table 1). Placing screens in the column, improved performance and dissolved oxygen levels were increased to 89% of saturation. Packing the column with saddles raised the oxygen saturation to 95.7% of saturation. The 3.8 cm rings were slightly more efficient and brought the oxygen saturation to 96.3%. Although this increase greatly affected the aeration coefficient, it was only a difference of 0.04 mg/L oxygen and was difficult to measure. If the inflow dissolved oxygen had been lower, the slight difference in aeration performance would have resulted in a greater increase in the oxygen concentration, which would have been more easily measured.

Another groundwater source (well #3) provided an opportunity to measure the column efficiency with lower dissolved oxygen (<3.0 mg/L) and higher nitrogen saturation (118%) values than well #1. The three substrates which had previously performed the best: saddles, 2.5 cm and 3.8 cm rings, were tested at 38.5 L/min (1188 L/min m^2) and 19.5 L/min (602 L/min m^2). Unfortunately, the maximum flow obtained using this well was only 38.5 L/min.

All three substrates brought the nitrogen saturation levels below 103% and raised the oxygen saturation levels above 90%. For the two flow rates tested the 2.5 cm rings performed the most effectively.

Although the 2.5 cm rings outperformed the 3.8 cm rings at these low flow rates, the 3.8 cm rings performed consistently over all flows tested using well #1. It was felt that if higher flows could have been achieved, the performance of the 3.8 cm rings would have exceeded that of the 2.5 cm rings.

Improved Distribution System Trials

The object of these trials was to examine the performance of different substrates in the 20 cm diameter packed column with an improved distribution system. Three flow rates were tested; 200 L/min (6173 L/min m^2), 95 L/min (2932 L/min m^2) and 20.4 L/min (630 L/min m^2). These flows were chosen because they represented the full range of flows possible at Robertson Creek with the existing water supply.

In an attempt to approach ideal distribution for the 20 cm diameter packed column, a 20 cm depth of saddles was placed in the top segment of the column. In previous aeration trials it was noted that saddles were the most effective substrate for distributing water evenly over the entire cross-sectional area of the column. The depth of saddles required for effective distribution was determined visually. Once the distribution system had been set up, it remained unaltered throughout the trials (Fig. 5).

The remaining three segments were packed with substrate. Water samples were taken before and after the distribution system (sample site 1 and 2), after the first segment containing substrate (site 3), and at the outflow of the column (site 4). The substrates tested were: 3.8 cm rings, 8.9 cm rings, saddles and toroids. Performance of each substrate was determined by calculating Go for

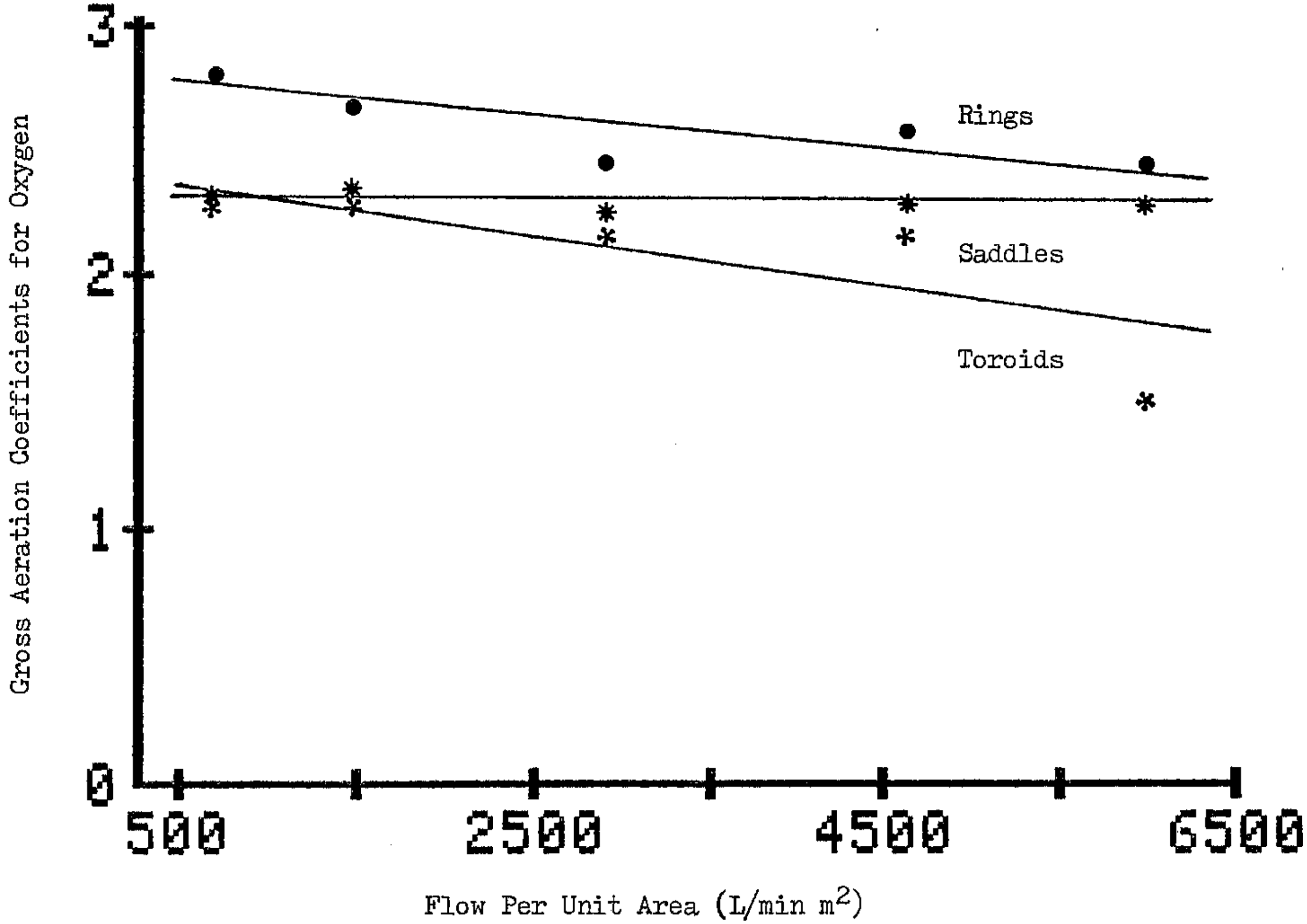


Fig. 4. Gross aeration coefficients for oxygen as a function of flow per unit area using the 3.8 cm rings, saddles and toroids in the Robertson Creek Hatchery column.

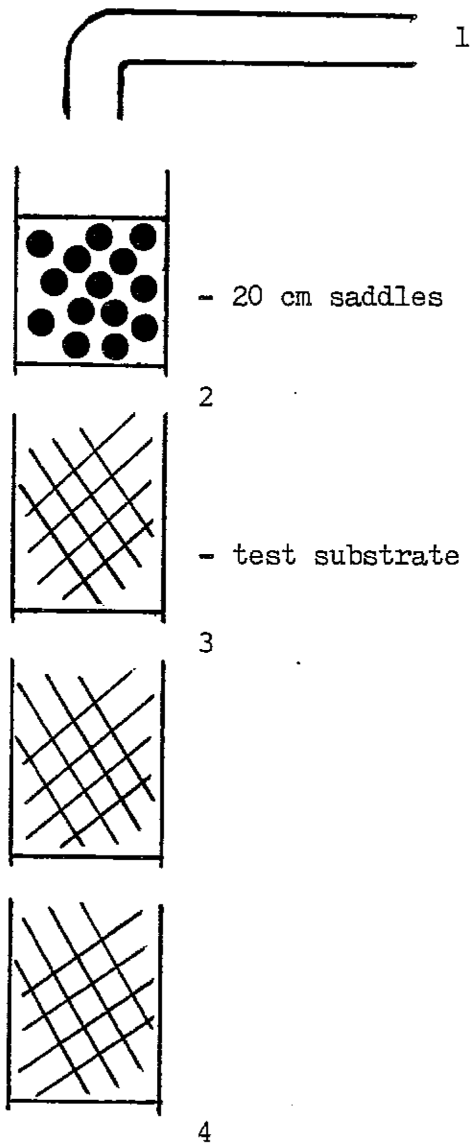


Fig. 5. Diagram of the column configuration used during the Improved Distribution System Trials.

The first segment consisted of 20 cm of saddles to form a distribution system, in an attempt to measure substrate efficiency with nearly ideal dispersal of water.

Water conditions were measured at positions 1-4.

the distribution system, the second segment and the third and fourth segments combined. To compare the performance of the Improved Distribution System Trials to previous aeration trials, the gross aeration constant was calculated for the entire aeration system.

Of the four substrates tested, the 3.8 cm rings consistently gave the best performance (Table 2). With a good distribution system, the toroids performed better than in previous tests. This substrate had a greater efficiency than the saddles at 200 L/min, but still appeared to channel the water down the center of the column. Even though the 8.9 cm rings exhibited good distribution they did not perform as well as the other three substrates. The flow rates at Robertson Creek may be the limiting factor in testing the 8.9 cm rings and they may perform well at flow rates higher than could be achieved at this site.

It should be noted, that the performance of four segments filled with 3.8 cm rings could not be improved by sacrificing the top segment to acheive better distribution. It would appear that for the small columns at this facility, the 3.8 cm rings are the optimum substrate.

Suffocation Trials

The object of these trials was to determine whether segmentation increased aeration performance, and whether various flow rates affected oxygen suffocation in the packed column. Tests were performed using saddles and 3.8 cm ring substrates.

To determine relative aeration of the segmented column as opposed to a closed column, the spaces between segments were blocked. This was accomplished by removing the aluminum funnels (used to channel water between segments and avoid excess splashing) and filling in the gap with a 20 cm diameter ring cut and ground to fit the space as closely as possible. Masking tape was applied to ensure that the ring did not move and to seal the column.

For each of the three flow rates tested: 195 L/min, 94 L/min and 19.5 L/min, the degree of ventilation was changed as follows:

1. closed column: all of the air spaces between the segments were sealed. The only openings were at the inflow and outflow of the column.

2. 1/3 ventilated: the 10.2 cm air space between the third and fourth (bottom) segments was open.

3. 2/3 ventilated: the air space between the second and third segments was also open.

4. segmented column: all the air spaces were cleared.

With the saddles, the efficiency of oxygen addition and nitrogen removal was unaltered by the degree of ventilation at the highest flow rate of 195 L/min. Ventilation had a minimal effect on aeration performance at 94 L/min (2901 L/min m^2); there was an increase in the efficiency of oxygen addition, but the nitrogen removal did not change significantly (Table 3). However, ventilation had a strong positive effect on the aeration efficiencies of both oxygen and nitrogen at 19.5 L/min, the lowest flow rate tested.

Rings were tested in the same manner except that only two flow rates were assessed (199 L/min and 20 L/min). Results followed a similar pattern to that observed with the saddles. At the lowest flow tested, the gross aeration coefficient increased significantly for both oxygen and nitrogen as the column ventilation increased (Fig. 6). At the highest flow rate the effects of segmentation were less beneficial.

These results indicate that column segmentation is more important for low flow rates. It is possible that at high inflow velocities, sufficient air is dragged in through the top of the column to prevent suffocation.

Large Diameter Column Trials

The object of the Large Diameter Column Trials was to determine the efficiency of different column dimensions. It was calculated that a column with a diameter of 40.6 cm would have to be 30.5 cm high to have the same volume of packing as the existing 20 cm diameter segmented column. If the water could be ideally distributed, then theoretically the contact time for water with air would be similar in both columns. To improve the distribution of water entering the column, the inlet pipe was fitted with a T-junction and two 90^{o} angles to direct the water into two streams. A 20 cm depth of saddles was also added to the inlet to improve distribution. A plastic bucket (cross sectional area of 0.13 m^2) was packed to a height of 30.5 cm with substrate (Fig. 7). Although the wider column had slightly less volume that the 20 cm diameter column, it held more of the 8.9 cm rings.

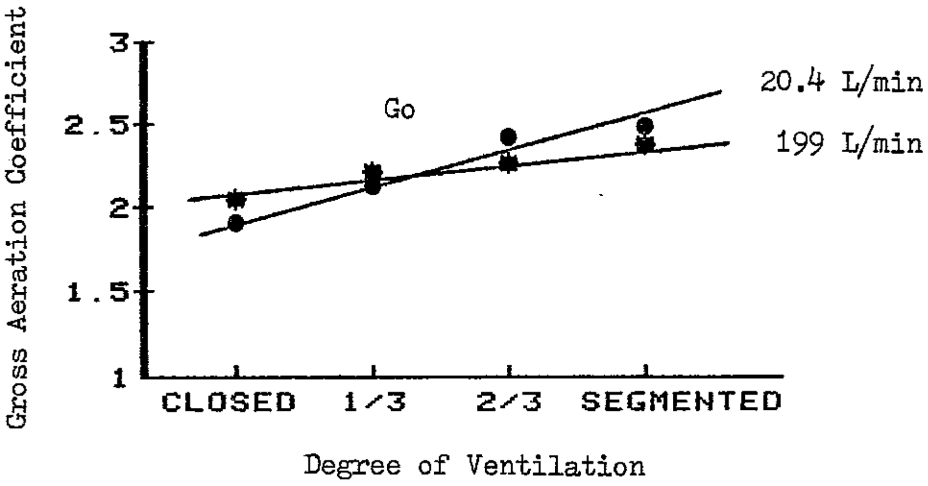
To compare the results with the 20 cm diameter column, flow rates of 208 L/min (1604 L/min m^2) and 96 L/min (740 L/min m^2) were tested. Lower flow rates could not be tested since bubbles of air were observed coming from the inlet pipe indicating that aeration was occuring before the water entered the column.

In three trials, the four substrates tested were 3.8 cm rings, 8.9 cm rings, saddles and toroids. The first trial utilized a distribution system consisting of 20 cm of saddles held between two expanded aluminum screens. All screens were 16 mm by 44 mm expanded aluminum. This column required that all the air needed for aeration be dragged in through the top of the column and was an attempt to determine the relative effect of suffocation. Flow rates of 208 L/min and 96 L/min were used in this trial.

The second trial was run only at 96 L/min. The distribution system and top screen were removed to determine performance of the substrate alone.

The distribution system was replaced for the third trial and 1.9 cm ventilation holes were drilled at 3.5 cm intervals between the bottom screen of the distribution system and the substrate. This trial was performed at 96 L/min.

The results from the Large Diameter Column Trials reinforced conclusions drawn during the Suffocation Trials (Table 4). With the exception of the 8.9 cm rings, the substrates all performed slightly better at 96 L/min when ventilated. The increase in performance was thought to be significant since it is consistent



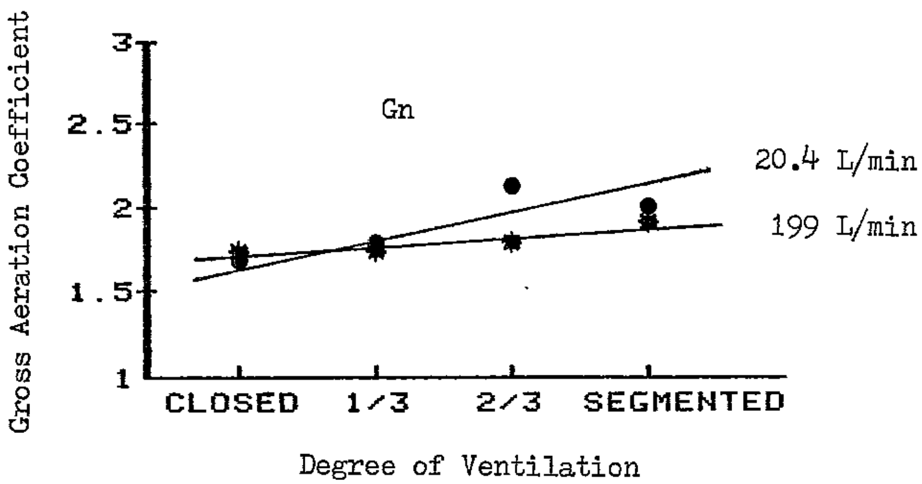


Fig. 6. The effect of suffocation on aeration efficiency as a function of column ventilation using the 3.8 cm rings at 199 L/min and 20.4 L/min.

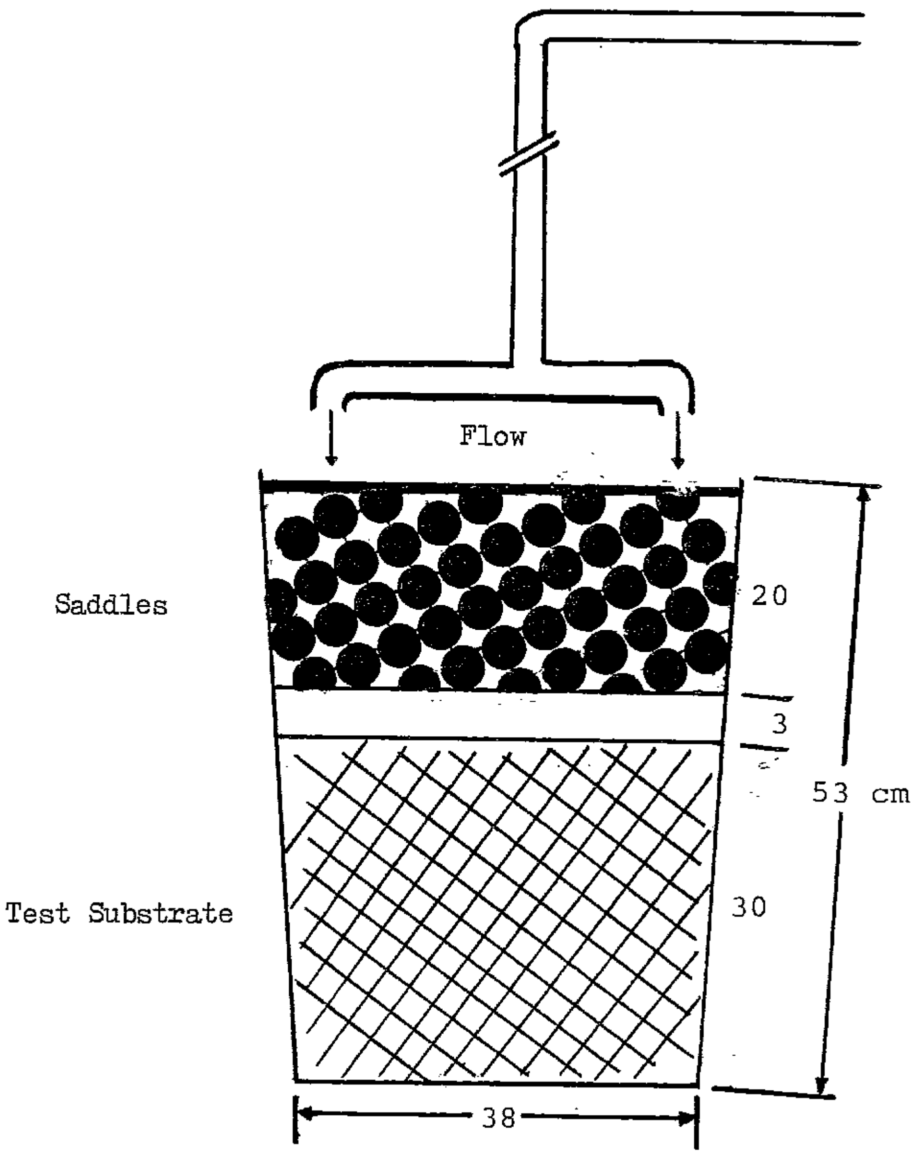


Fig. 7. Diagram of large diameter column (40.6 cm) constructed at Robertson Creek Hatchery.

The top layer of the column consisted of a 20 cm depth of saddles to improve water distribution. A 3 cm space between the distribution system and the substrate was to allow for ventilation.

for the three best performers; 3.8 cm rings, saddles and toroids. The performance of the 8.9 cm rings was similar in both trials.

Splashing was a significant problem with the ventilated wide diameter column. Water flowed down the column in two streams along each side and consequently ran out some of the ventilation holes. This problem was aggravated by the tapered walls of the plastic bucket.

The results from trial 3 (distribution and ventilation) were the best overall; however, the calculated gross aeration constants were much lower than those calculated for the 20 cm diameter column. This was due mainly to the problem of distributing the water. Even with 20 cm of saddles, the water remained in two streams below the inlet pipes. Clearly a better distribution system is required. The wider column performed poorly. Less than half of the cross-sectional area was used and the value of G may only represent half of the possible column aeration efficiency. The distribution system is critical in wide columns and until this can be improved, their performance cannot accurately be determined.

NITINAT

Aeration Trials

Water from well #4 was used to test the existing aeration tower at Nitinat Hatchery. This well had a maximum flow of 37 L/sec (2220 L/min). There was no simple method for determining the flow rate to the column directly; thus the flow rates were calculated by dividing the flow meter value of well #4 by the number of columns that were open, giving an approximation of the actual flow rate through the test column. However, since the test column was the first column fed by the inlet pipe, the flow was probably greater than the calcuated flow. This would not affect comparison between substrates tested at Nitinat because it was constant for all the substrates. Four flow rates were tested:

1. 8 columns open - 280 L/min (3836 L/min m^2)
2. 6 columns open - 370 L/min (5068 L/min m^2)
3. 4 columns open - 555 L/min (7603 L/min m^2)
4. 3 columns open - 740 L/min (10137 L/min m^2)

The dissolved gas levels in the well water remained stable throughout testing. Since there was no trend in successive inflow measurements, they were averaged to decrease measurement uncertainty. The average value was used to calculate the gross aeration constant.

For all flows tested, the 8.9 cm Flexirings performed consistently better than the 3.8 cm rings and the 8.9 cm Glitsch rings (Table 5). The denser packing of the Flexirings broke up the water flowing down the column more effectively than the less densely packed Glitsch rings. The 8.9 cm Flexirings are currently the substrate used in the aeration tower at Nitinat.

Contrary to the findings at Robertson Creek, the 8.9 cm rings outperformed the 3.8 cm rings. In the 20 cm diameter column at Robertson Creek, the 8.9 cm Glitsch rings were packed at a density of 800 rings/m^3. In the 30.5 cm diameter column at Nitinat the 8.9 cm rings were packed more densely at 1040 rings/m^3. The packing was 1.3 times as dense at Nitinat and thus was probably more effective at breaking up the flow.

The 8.9 cm rings are recommended by the manufacturer for aeration at high flows; the 3.8 cm rings for moderate to low flows. The two lowest flow rates at Nitinat were similar to the two highest flow rates at Robertson Creek. Data collected at Robertson Creek and Nitinat indicated that for small columns, small rings performed better than large rings. However, the large rings performed better in a larger column.

Water temperature may have also contributed to differences in substrate performance between the two sites. The tests at Robertson Creek were carried out at 15°C, whereas at Nitinat the water temperature was 9°C. Since aeration efficiency increases with temperature (Weber, 1972), comparing column performance at Robertson Creek and Nitinat is difficult.

BIG QUALICUM

Aeration Trials

At flows greater than 14 m^3/s, gases tend to become supersaturated as water passes over the falls above the incubation building reservoir on the Big Qualicum River. The total gas pressure (TGP) commonly reaches 106%. However, in the summer months when river flows are approximately 1.5 m^3/s, the TGP is only 102% and therefore not a problem. An attempt was made to determine the efficiency of the new packed column even though the TGP was so close to saturation.

Three flows were tested:

1. 350 L/min - 661 L/min m^2
2. 770 L/min - 1454 L/min m^2
3. 1840 L/min - 3476 L/min m^2

Flows were determined by measuring the time to fill a container of known volume. Only the 8.9 cm Glitsch rings were tested.

Inflow measurements were taken at the incubation building reservoir. Bubbles of air from the waterfall above are carried into the reservoir and through the pipes to the incubation building. Thus, the TGP is usually higher in the incubation building than in the reservoir, and the column performance was probably greater than was observed.

The results of the testing were not conclusive since gas pressures were so close to saturation. However, results showed that the TGP was lowered slightly, indicating that the column was removing some excess gas (Table 6). The error in the performance analysis is greatly increased when gas levels are near saturation.

Hence, column performance measurements should be repeated at a time of year when gas levels are higher.

Water entered the packed column by overflowing the top of a vertical stand pipe. This system proved to be effective at distributing the water. At the lowest flow rate of 350 L/min, the water hit the top screen in a circular stream 30 cm in diameter. As the flow increased, distribution also increased and at 1840 L/min the packed column with no substrate in it showed good distribution. If the sides of the packed column had been higher, splashing could have been avoided at the high flows and the inlet pipe could have been raised slightly to improve distribution at low flows.

UNCERTAINTY IN MEASUREMENTS

In measuring the efficiency of the packed column aerators assessed in this study, special care was taken in both the collection and testing of water samples. Oxygen analysis was carried out by means of the modified Winkler test (duplicate samples) and TGP was measured using a calibrated tensionometer. Although there was good agreement between duplicate water samples, it was felt that an attempt should be made to measure the uncertainty in the gross aeration coefficient directly. Knowledge of this uncertainty is especially important if small improvements in performance are being sought.

Uncertainty was assessed by making independent measurements of performance on a 20 cm diameter column packed with saddle substrate. To make the estimate of uncertainty realistic, the column was disassembled and repacked between trials. In this way all the variability associated with constructing and packing the column was reflected in the test results. The repeat trials extended over three days (Table 7). It was attempted to keep flow constant (flow was maintained between 94 and 97 L/min); temperatures ranged between 14.5°C and 15.45°C while the barometric pressure varied between 748 and 752 mmHg.

Results were as follows:

<u>Oxygen</u>	<u>Nitrogen</u>
n = 8	n = 8
Mean gross aeration coefficient: Go = 2.2675	Gn = 1.6163
Standard Deviation: S = 0.0858	S = 0.1896
<u>95% Confidence Interval</u>: $Go \pm \frac{(2.365)\ S}{\sqrt{n}}$	$Gn \pm \frac{(2.365)\ S}{\sqrt{n}}$
or 2.2675 ± 0.0717	or 1.6163 ± 0.1585
or Go ± 3%	or Gn ± 10%

The standard deviation reflects subtle differences in packing the column, distributing the water, conditions of the test and errors in sampling and analysis. Even with eight independent measurements of column performance, the uncertainty associated with Go and Gn was ± 3% and ± 10% respectively. It is clear that a single assessment of a particular column involves a high degree of uncertainty.

Applying the standard deviation measured for saddles to other substrates may not be valid: packing a column with saddles in a reproducible way may be more difficult because of the way this substrate compresses. However this analysis gives at least a rough idea of the uncertainty involved in our measurements.

CONCLUSIONS

1) With the 20 cm diameter packed column aerators at Robertson Creek Hatchery, the 3.8 cm Flexirings were the most effective substrate tested over flows ranging between 19.5 L/min and 200 L/min.

2) In all substrates tested, the performance gradually decreased as the flow rate increased. During the Robertson Creek trials with 3.8 cm Flexirings, the Go value dropped from 2.79 to 2.44 as the flow rate increased from 23 L/min to 195 L/min.

3) Sacrificing the top segment of the Robertson Creek column to improve the distribution of the inflow water over the cross-sectional area of the column, did not improve the performance of a column packed with 3.8 cm Flexirings.

4) Column segmentation (10 cm air spaces between 31 cm segments) improved aerator performance at low flow rates. Therefore segmentation is justified if the column is going to be operated over a wide range of flows.

5) Water distribution is critical in large diameter columns. Hence the measurements made during this study could not be used to assess the performance of this type of aerator. Further testing is required with an improved distribution system.

6) The tests at Nitinat Hatchery showed that the larger 8.9 cm substrate performed better than the smaller 3.8 cm substrate. This was undoubtedly related to the larger diameter column (30.5 cm) in use at this hatchery.

7) The large diameter aerator at Big Qualicum Hatchery could not be adequately assessed because the gas levels in the inflow water were too close to saturation at the time the tests were performed. Testing should be repeated in the early spring when supersaturation levels are much higher.

8) Measurement of aerator performance in the hatchery setting involves a high level of uncertainty. If practical, repeat

measurements should be performed using inflow water with gas concentrations as far from equilibrium as possible.

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REFERENCES

American Public Health Association. 1980. Standard Methods for the Examination of Water and Wastewater. 15th Ed. Byrd Prepress, Springfield, VA. 1134 p.

D'Aoust, B.G. and M.J.R. Clark. 1980. "Analysis of supersaturated air in natural waters and reservoirs." Trans. Amer. Fish. Soc., 109:6 pp 708-724.

Kling, A.E., C.J. West, C. Cross and W.E. McLean. MS 1985. Fishculture information system for hatcheries. Dept. Fish. Oceans, Vancouver, B.C. 175 p.

Fidler, L.E. MS 1983. Analysis methods applicable to the prediction of hatchery water conditioning system characteristics. Rep. Dep. Fish. Oceans, Vancouver, B.C. 149 p.

McLean, W.E. and A.L. Boreham. MS 1980. The design and assessment of aeration towers. Rep. Dep. Fish. Oceans, Vancouver, B.C. 63 p.

SIGMA Resource Consultants Ltd. MS 1979. Aeration methods for salmonid hatchery water supplies. Rep. Dep. Fish. Oceans, Vancouver, B.C. 64 p.

Weber, W.J. (Jr.) 1972. Physicochemical Processes for Water Quality Control. Wiley-Interscience, New York, N.Y. 640 p.

Wheaton, F.W. 1977. Aquacultural Engineering. Wiley-Interscience, New York, N.Y. 708 p.

TABLE 1

AERATION TOWER PERFORMANCE TRIALS AT ROBERTSON CREEK HATCHERY USING A 20 CM DIAMETER COLUMN WITH VARIOUS TYPES OF PACKING. FLOW RATES THROUGH THE COLUMN WERE VARIED BETWEEN 195 AND 19.5 LITERS PER MINUTE. "GO" AND "GN" DENOTE THE OVERALL AERATION COEFFICIENTS FOR OXYGEN AND NITROGEN RESPECTIVELY.

	SAT	BAR	AV.DO	TEMP	TGP	O2 %	N2 %	GO	GN
	MMHG	MMHG	MG/L	C	%	%	%		
WELL #1									
195 L/MIN (Q/A=6019)									
INFLOW	-25	755	5.80	14.95	96.63	58.03	106.91		
EMPTY COLUMN	-2	755	8.66	14.90	99.73	86.56	103.27	1.14	.75
INFLOW	-20	754	5.80	15.00	97.30	58.17	107.72		
SMALL SCREENS	-1	754	8.90	14.85	99.87	88.98	102.80	1.33	1.01
LARGE SCREENS	0	754	8.90	14.90	100.00	89.07	102.94	1.34	.97
INFLOW	-19	754	5.78	15.20	97.44	58.22	107.88		
SADDLES	1	754	9.55	14.95	100.13	95.68	101.36	2.27	1.76
INFLOW	-29	754	5.72	15.10	96.09	57.50	106.36		
2.5 CM FLEXIRINGS	2	754	9.55	15.05	100.27	95.89	101.48	2.34	1.46
3.8 CM FLEXIRINGS	7	754	9.59	15.05	100.94	96.29	102.22	2.44	1.05
INFLOW	-25	754	5.66	15.15	96.63	56.95	107.19		
5.0 CM FLEXIRINGS	2	754	9.51	15.10	100.27	95.59	101.56	2.28	1.53
INFLOW	-27	754	5.53	16.10	96.35	56.79	106.88		
8.9 CM GLITSCH RINGS	0	754	8.88	16.10	100.00	91.19	102.38	1.59	1.06
INFLOW	-25	754	5.55	16.15	96.62	57.06	107.16		
TOROIDS	-1	754	8.82	16.05	99.86	90.48	102.40	1.51	1.09
150 L/MIN (Q/A=4630)									
INFLOW	-25	752	5.64	15.60	96.62	57.46	107.04		
EMPTY COLUMN	-6	752	8.29	15.50	99.19	84.27	103.19	.99	.79
INFLOW	-23	751	5.74	15.60	96.88	58.55	107.09		
SMALL SCREENS	-2	751	8.72	15.55	99.73	88.86	102.66	1.31	.98
INFLOW	-23	751	5.78	15.55	96.88	58.90	107.00		
LARGE SCREENS	-1	751	8.68	15.55	99.86	88.45	102.94	1.27	.87
INFLOW	-18	749	5.68	14.65	97.56	56.91	108.37		
SADDLES	0	749	9.55	14.60	100.00	95.59	101.22	2.28	1.93
INFLOW	-23	750	5.84	15.45	96.88	59.46	106.84		
2.5 CM FLEXIRINGS	-1	750	9.47	15.40	99.86	96.32	100.85	2.40	2.09
INFLOW	-21	750	5.86	15.45	97.15	59.67	107.13		
3.8 CM FLEXIRINGS	-1	750	9.53	15.40	99.86	96.93	100.69	2.58	2.34
INFLOW	-24	750	5.80	15.40	96.74	58.99	106.80		
5.0 CM FLEXIRINGS	-2	750	9.41	15.35	99.73	95.61	100.87	2.23	2.06
INFLOW	-24	749	5.78	15.40	96.74	58.87	106.82		
8.9 CM GLITSCH RINGS	-3	749	9.16	15.35	99.59	93.19	101.34	1.80	1.63
INFLOW	-17	749	5.70	14.60	97.69	57.05	108.51		
TOROIDS	0	749	9.49	14.60	100.00	94.99	101.37	2.15	1.83

TABLE 1 (CONT'D)

	SAT	BAR	AV.DO	TEMP	TGP	O2 %	N2 %	GO	GN
	MMHG	MMHG	MG/L	C	%	%	%		
95 L/MIN (Q/A=2932)									
INFLOW	-17	749	5.66	14.55	97.69	56.59	108.63		
EMPTY COLUMN	-4	749	8.41	14.55	99.46	84.09	103.58	1.00	.88
INFLOW	-18	749	5.60	14.60	97.56	56.05	108.60		
SMALL SCREENS	-2	749	8.86	14.55	99.73	88.59	102.73	1.35	1.15
INFLOW	-19	749	5.49	14.55	97.42	54.89	108.74		
LARGE SCREENS	-3	749	8.76	14.55	99.59	87.59	102.82	1.29	1.13
INFLOW	-19	749	5.49	14.55	97.42	54.89	108.74		
SADDLES	-1	749	9.53	14.50	99.86	95.18	101.15	2.24	2.03
INFLOW	-31	751	5.41	14.62	95.80	54.03	106.92		
2.5 CM FLEXIRINGS	0	751	9.63	14.60	100.00	96.13	101.07	2.47	1.87
INFLOW	-30	751	5.47	14.65	95.94	54.66	106.92		
3.8 CM FLEXIRINGS	0	752	9.63	14.60	100.00	96.00	101.10	2.43	1.84
INFLOW	-30	752	5.49	14.60	95.94	54.73	106.91		
5.0 CM FLEXIRINGS	-1	752	9.51	14.60	99.86	94.81	101.25	2.17	1.71
INFLOW	-29	752	5.51	14.60	96.08	54.93	107.03		
8.9 CM GLITSCH RINGS	-2	752	9.16	14.60	99.73	91.32	102.00	1.65	1.26
INFLOW	-20	749	5.49	14.60	97.29	54.95	108.55		
TOROIDS	0	749	9.47	14.55	100.00	94.68	101.45	2.14	1.77
49 L/MIN (Q/A=1512)									
INFLOW	-50	752	3.57	14.95	93.24	35.86	108.49		
EMPTY COLUMN	-15	752	7.24	14.95	97.97	72.73	104.71	.86	.59
INFLOW	-49	752	3.69	15.00	93.37	37.11	108.33		
SMALL SCREENS	-10	752	8.25	14.95	98.65	82.88	102.87	1.30	1.07
INFLOW	-48	751	3.69	14.95	93.50	37.12	108.49		
LARGE SCREENS	-10	751	8.15	14.95	98.65	81.98	103.11	1.25	1.00
INFLOW	-48	751	3.75	15.00	93.50	37.76	108.32		
SADDLES	-6	751	9.34	15.00	99.19	94.05	100.59	2.35	2.65
INFLOW	-60	749	3.00	15.05	91.85	30.32	108.20		
2.5 CM FLEXIRINGS	0	749	9.45	15.00	100.00	95.42	101.26	2.72	1.87
INFLOW	-56	749	3.12	15.10	92.39	31.57	108.56		
3.8 CM FLEXIRINGS	0	749	9.41	15.10	100.00	95.22	101.31	2.66	1.88
INFLOW	-54	749	3.14	15.12	92.67	31.79	108.85		
5.0 CM FLEXIRINGS	-2	749	9.32	15.12	99.73	94.35	101.20	2.49	2.00
INFLOW	-53	749	3.28	15.15	92.80	33.23	108.64		
8.9 CM GLITSCH RINGS	-6	749	8.82	15.12	99.19	89.29	101.85	1.83	1.54
INFLOW	-47	750	3.81	15.05	93.63	38.46	108.29		
TOROIDS	-3	750	9.28	15.05	99.59	93.68	101.21	2.28	1.92

TABLE 1 (CONT'D)

	SAT	BAR	AV.DO	TEMP	TGP	O2 %	N2 %	GO	GN
	MMHG	MMHG	MG/L	C	%	%	%		
23 L/MIN (Q/A=710)									
INFLOW	-64	748	3.10	15.40	91.29	31.61	107.15		
EMPTY COLUMN	-18	748	7.66	15.40	97.55	78.12	102.75	1.14	.96
INFLOW	-66	749	3.06	15.30	91.03	31.10	106.96		
SMALL SCREENS	-12	749	8.09	15.30	98.37	82.22	102.70	1.35	.95
LARGE SCREENS	-15	748	7.97	15.30	97.96	81.10	102.47	1.29	1.04
INFLOW	-64	750	3.04	15.25	91.32	30.82	107.40		
SADDLES	-2	750	9.20	15.20	99.73	93.17	101.51	2.32	1.59
INFLOW	-60	750	3.18	15.35	91.86	32.31	107.69		
2.5 CM FLEXIRINGS	1	750	9.41	15.30	100.14	95.50	101.41	2.71	1.70
INFLOW	-60	750	3.16	15.32	91.86	32.08	107.75		
3.8 CM FLEXIRINGS	0	749	9.43	15.30	100.00	95.83	101.15	2.79	1.91
INFLOW	-58	749	3.14	15.35	92.12	31.94	108.11		
5.0 CM FLEXIRINGS	-3	749	9.18	15.30	99.59	93.29	101.31	2.32	1.82
INFLOW	-65	749	3.08	15.30	91.17	31.30	107.08		
8.9 CM GLITSCH RINGS	-7	749	8.82	15.30	99.05	89.63	101.59	1.89	1.49
INFLOW	-62	750	3.02	15.25	91.59	30.62	107.79		
TOROIDS	-2	750	9.16	15.25	99.73	92.87	101.59	2.28	1.59
WELL #3									
38.5 L/MIN (Q/A=1188)									
INFLOW	-10	756	2.86	11.30	98.66	26.33	117.88		
SADDLES	2	756	9.97	11.25	100.27	91.68	102.59	2.18	1.93
INFLOW	-10	756	2.84	11.30	98.66	26.15	117.93		
2.5 CM FLEXIRINGS	0	756	10.30	11.25	100.00	94.71	101.45	2.64	2.51
3.8 CM FLEXIRINGS	3	756	10.14	11.25	100.40	93.24	102.35	2.39	2.03
19.5 L/MIN (Q/A=602)									
INFLOW	-17	757	2.61	11.20	97.72	23.94	117.33		
SADDLES	0	756	10.32	11.30	100.00	95.01	101.37	2.72	2.54
INFLOW	-10	756	2.72	11.30	98.66	25.04	118.22		
2.5 CM FLEXIRINGS	1	756	10.36	11.30	100.13	95.37	101.44	2.78	2.54
3.8 CM FLEXIRINGS	0	756	10.24	11.30	100.00	94.27	101.56	2.57	2.46

TABLE 2

PERFORMANCE OF THE 20 CM DIAMETER COLUMN AT ROBERTSON CREEK HATCHERY WITH IMPROVED DISTRIBUTION SYSTEM. THE TOP SEGMENT OF THE COLUMN WAS PACKED WITH SADDLES IN AN ATTEMPT TO DISTRIBUTE THE WATER UNIFORMLY OVER THE CROSS-SECTION OF THE COLUMN. GO AND GN DENOTE THE INDIVIDUAL AERATION COEFFICIENTS FOR OXYGEN AND NITROGEN PER SEGMENT. "G" DENOTES THE OVERALL AERATION COEFFICIENT, CALCULATED FROM INFLOW AND OUTFLOW DATA (SAMPLE SITES 1&4).

		SAT	BAR	AV.DO	TEMP	TGP	O2 %	N2 %	GO	GN
		MMHG	MMHG	MG/L	C	%	%	%		
WELL #1										
3.8 CM FLEXIRINGS										
INFLOW	200 L/MIN	-10	755	6.45	15.15	98.65	64.82	107.67		
DISTRIBUTION SYSTEM		-5	755	7.78	15.10	99.33	78.10	105.00	.47	.43
OUTFLOW 2ND SEGMENT		-2	755	8.70	15.10	99.73	87.33	103.06	.55	.49
OUTFLOW 4TH SEGMENT		0	755	9.57	15.10	100.00	96.07	101.09	.59	.52
								G=	2.19	1.95
SADDLES										
INFLOW	200 L/MIN	-9	755	6.65	15.10	98.79	66.76	107.32		
DISTRIBUTION SYSTEM		-5	755	7.86	15.05	99.33	78.82	104.81	.45	.42
OUTFLOW 2ND SEGMENT		-2	755	8.68	15.05	99.73	87.04	103.14	.49	.43
OUTFLOW 4TH SEGMENT		0	755	9.43	15.05	100.00	94.56	101.49	.43	.37
								G=	1.81	1.59
8.9 CM GLITSCH RINGS										
INFLOW	200 L/MIN	-10	755	6.63	15.05	98.65	66.48	107.23		
DISTRIBUTION SYSTEM		-5	755	7.89	15.05	99.33	79.12	104.73	.47	.42
OUTFLOW 2ND SEGMENT		-3	755	8.51	15.05	99.60	85.33	103.42	.35	.32
OUTFLOW 4TH SEGMENT		0	755	9.32	15.05	100.00	93.46	101.78	.40	.33
								G=	1.63	1.40
TOROIDS										
INFLOW	200 L/MIN	-9	754	6.71	14.75	98.79	66.94	107.27		
DISTRIBUTION SYSTEM		-4	754	7.95	14.75	99.46	79.31	104.85	.47	.40
OUTFLOW 2ND SEGMENT		0	753	8.74	14.75	100.00	87.30	103.41	.49	.35
OUTFLOW 4TH SEGMENT		2	753	9.57	14.75	100.27	95.59	101.56	.53	.39
								G=	2.01	1.54
3.8 CM FLEXIRINGS										
INFLOW	95 L/MIN	-7	753	6.75	14.75	99.05	67.42	107.48		
DISTRIBUTION SYSTEM		-3	753	8.13	14.75	99.59	81.21	104.51	.55	.51
OUTFLOW 2ND SEGMENT		0	753	8.94	14.75	100.00	89.30	102.88	.56	.45
OUTFLOW 4TH SEGMENT		2	753	9.63	14.75	100.27	96.19	101.40	.52	.36
								G=	2.15	1.68
SADDLES										
INFLOW	95 L/MIN	-6	752	6.79	14.80	99.19	67.99	107.50		
DISTRIBUTION SYSTEM		-3	752	8.13	14.80	99.59	81.41	104.46	.54	.52
OUTFLOW 2ND SEGMENT		0	752	8.92	14.85	100.00	89.41	102.85	.56	.45
OUTFLOW 4TH SEGMENT		1	752	9.55	14.85	100.14	95.73	101.35	.45	.37
								G=	2.01	1.71
8.9 CM GLITSCH RINGS										
INFLOW	95 L/MIN	-7	752	6.79	14.85	99.05	68.06	107.31		
DISTRIBUTION SYSTEM		-3	752	8.13	14.85	99.59	81.49	104.44	.55	.50
OUTFLOW 2ND SEGMENT		-1	752	8.70	14.80	99.86	87.11	103.29	.36	.30
OUTFLOW 4TH SEGMENT		0	752	9.41	14.80	100.00	94.22	101.58	.40	.37
								G=	1.71	1.53

TABLE 2 (CONT'D)

		SAT	BAR	AV.DO	TEMP	TGP	O2 %	N2 %	GO	GN
		MMHG	MMHG	MG/L	C	%	%	%		
3.8 CM FLEXIRINGS										
INFLOW	20.4 L/MIN	-9	754	6.83	14.70	98.79	68.06	106.98		
DISTRIBUTION SYSTEM		-3	754	8.37	14.70	99.60	83.40	103.93	.65	.57
OUTFLOW 2ND SEGMENT		0	754	9.18	14.70	100.00	91.48	102.31	.67	.53
OUTFLOW 4TH SEGMENT		2	754	9.71	14.70	100.27	96.76	101.25	.48	.31
								G=	2.29	1.72
SADDLES										
INFLOW	20.4 L/MIN	-8	754	6.85	14.70	98.92	68.26	107.09		
DISTRIBUTION SYSTEM		-2	754	8.43	14.70	99.73	84.00	103.95	.68	.58
OUTFLOW 2ND SEGMENT		0	754	9.16	14.70	100.00	91.28	102.36	.61	.52
OUTFLOW 4TH SEGMENT		2	754	9.71	14.70	100.27	96.76	101.25	.50	.32
								G=	2.28	1.74
8.9 CM GLITSCH RINGS										
INFLOW	20.4 L/MIN	-5	754	6.91	14.85	99.33	69.08	107.39		
DISTRIBUTION SYSTEM		-1	754	8.43	14.80	99.87	84.19	104.07	.67	.60
OUTFLOW 2ND SEGMENT		0	754	9.00	14.80	100.00	89.88	102.73	.45	.40
OUTFLOW 4TH SEGMENT		2	754	9.53	14.80	100.27	95.17	101.67	.37	.25
								G=	1.86	1.49
WELL #3										
3.8 CM FLEXIRINGS										
INFLOW	20.4 L/MIN	-5	756	3.24	11.45	99.33	29.93	117.77		
DISTRIBUTION SYSTEM		0	756	6.91	11.40	100.00	63.76	109.65	.66	.61
OUTFLOW 2ND SEGMENT		2	756	9.00	11.40	100.27	83.05	104.88	.76	.68
OUTFLOW 4TH SEGMENT		3	756	10.32	11.40	100.40	95.23	101.82	.63	.49
								G=	2.69	2.28
8.9 CM GLITSCH RINGS										
INFLOW	20.4 L/MIN	-12	756	3.06	11.30	98.39	28.17	117.05		
DISTRIBUTION SYSTEM		-4	756	6.83	11.25	99.46	62.80	109.23	.66	.61
OUTFLOW 2ND SEGMENT		0	756	8.37	11.25	100.00	76.97	106.15	.48	.41
OUTFLOW 4TH SEGMENT		2	756	9.83	11.25	100.27	90.39	102.93	.44	.37
								G=	2.01	1.76
TOROIDS										
INFLOW	20.4 L/MIN	-9	756	3.14	11.30	98.79	28.91	117.36		
DISTRIBUTION SYSTEM		-1	756	6.93	11.25	99.87	63.72	109.49	.67	.60
OUTFLOW 2ND SEGMENT		1	756	8.59	11.25	100.13	78.99	105.79	.55	.49
OUTFLOW 4TH SEGMENT		3	756	10.16	11.30	100.40	93.53	102.27	.59	.47
								G=	2.40	2.03

TABLE 3

PERFORMANCE OF THE 20 CM DIAMETER COLUMN AT ROBERTSON CREEK HATCHERY, SHOWING THE EFFECTS OF SUFFOCATION. FLOW RATES RANGED FROM 199 TO 19.5 L/MIN. SADDLES AND 3.8 CM FLEXIRINGS WERE USED AS THE SUBSTRATE.

	SAT	BAR	AV.DO	TEMP	TGP	O2 %	N2 %	GO	GN
	MMHG	MMHG	MG/L	C	%	%	%		
SADDLES									
195 L/MIN (Q/A=6019)									
INFLOW	-14	750	6.12	15.95	98.10	62.98	107.45		
CLOSED COLUMN	0	749	9.18	15.95	100.00	94.60	101.48	0.00	0.00
INFLOW	-13	749	6.16	15.95	98.23	63.48	107.49		
1/3 VENTILATED	0	749	9.20	15.95	100.00	94.81	101.42	0.00	0.00
INFLOW	-13	749	6.18	16.00	98.23	63.75	107.42		
2/3 VENTILATED	0	749	9.22	15.95	100.00	95.01	101.37	0.00	0.00
INFLOW	-14	749	6.16	16.00	98.10	63.55	107.30		
SEGMENTED	0	750	9.20	16.00	100.00	94.78	101.43	0.00	0.00
94 L/MIN (Q/A=2901)									
INFLOW	-13	750	6.12	16.10	98.23	63.19	107.57		
CLOSED COLUMN	-1	750	9.16	16.10	99.86	94.57	101.31	1.91	1.75
1/3 VENTILATED	0	750	9.16	16.10	100.00	94.57	101.48	1.91	1.63
INFLOW	-17	750	6.04	16.10	97.69	62.36	107.10		
2/3 VENTILATED	0	751	9.20	16.10	100.00	94.86	101.41	1.99	0.00
SEGMENTED	1	751	9.24	16.10	100.14	95.27	101.47	2.07	1.57
19.5 L/MIN (Q/A=602)									
INFLOW	-18	757	6.24	15.90	97.58	63.56	106.64		
CLOSED COLUMN	-1	757	9.24	15.90	99.87	94.11	101.44	0.00	0.00
INFLOW	-18	757	6.08	15.90	97.58	61.93	107.07		
1/3 VENTILATED	0	757	9.34	15.90	100.00	95.13	101.34	0.00	0.00
INFLOW	-16	757	6.14	15.90	97.85	62.54	107.25		
2/3 VENTILATED	0	757	9.43	15.90	100.00	96.05	101.09	0.00	0.00
INFLOW	-16	757	6.16	15.92	97.85	62.77	107.19		
SEGMENTED	0	757	9.51	15.90	100.00	96.86	100.88	0.00	0.00
3.8 CM FLEXIRINGS									
199 L/MIN (Q/A=6142)									
INFLOW	-19	756	6.30	15.95	97.44	64.32	106.26		
CLOSED COLUMN	-1	756	9.34	15.95	99.87	95.36	101.11	2.04	1.73
1/3 VENTILATED	0	756	9.41	15.95	100.00	96.07	101.09	2.21	1.75
INFLOW	-19	756	6.32	15.95	97.44	64.53	106.21		
2/3 VENTILATED	0	756	9.43	15.95	100.00	96.28	101.03	2.25	1.80
SEGMENTED	0	756	9.47	15.95	100.00	96.69	100.92	2.37	1.91
20.4 L/MIN (Q/A=630)									
INFLOW	-10	756	6.16	15.95	98.65	62.89	108.18		
CLOSED COLUMN	0	756	9.26	15.90	100.00	94.44	101.52	1.90	1.68
1/3 VENTILATED	1	757	9.40	15.80	100.13	95.54	101.40	2.12	1.77
INFLOW	-12	757	6.30	15.70	98.39	63.89	107.57		
2/3 VENTILATED	0	756	9.53	15.70	100.00	96.78	100.90	2.42	2.13
SEGMENTED	1	756	9.55	15.70	100.13	96.98	101.02	2.48	2.00

TABLE 4

PERFORMANCE OF THE LARGE DIAMETER (40.6 CM) COLUMN AT ROBERTSON CREEK HATCHERY. A DISTRIBUTION SYSTEM OF SADDLES WAS POSITIONED ABOVE THE SUBSTRATE IN ORDER TO IMPROVE PERFORMANCE OF THE VARIOUS PACKINGS.

	SAT	BAR	AV.DO	TEMP	TGP	O2 %	N2 %	GO	GN
	MMHG	MMHG	MG/L	C	%	%	%		
DISTRIBUTION SYSTEM WITH SUBSTRATE									
208 L/MIN									
INFLOW	-17	756	6.59	15.95	97.71	67.28	105.82		
3.8 CM FLEXIRINGS	0	756	8.94	15.95	100.00	91.28	102.36	0.00	0.00
INFLOW	-14	756	6.61	15.95	98.11	67.49	106.28		
8.9 CM GLITSCH RINGS	-1	756	8.74	15.95	99.87	89.23	102.73	0.00	0.00
INFLOW	-13	756	6.65	16.00	98.25	67.97	106.32		
SADDLES	0	755	8.84	16.00	100.00	90.47	102.57	0.00	0.00
INFLOW	-14	756	6.67	15.95	98.11	68.10	106.12		
TOROIDS	0	756	8.92	15.95	100.00	91.07	102.41	0.00	0.00
96 L/MIN									
INFLOW	-15	755	6.63	16.10	97.98	68.00	105.97		
3.8 CM FLEXIRINGS	-1	755	8.92	16.10	99.87	91.48	102.13	0.00	0.00
INFLOW	-13	755	6.65	16.10	98.25	68.20	106.26		
8.9 CM GLITSCH RINGS	-2	755	8.76	16.10	99.73	89.84	102.40	0.00	0.00
INFLOW	-13	755	6.67	16.10	98.25	68.41	106.20		
SADDLES	0	755	8.90	16.10	100.00	91.28	102.36	0.00	0.00
INFLOW	-12	756	6.67	16.05	98.38	68.24	106.42		
TOROIDS	0	756	8.92	16.05	100.00	91.27	102.36	0.00	0.00
SUBSTRATE WITH NO DISTRIBUTION SYSTEM									
96 L/MIN									
INFLOW	-13	751	6.49	16.15	98.24	66.99	106.57		
3.8 CM FLEXIRINGS	-1	750	8.80	16.15	99.86	90.95	102.27	0.00	0.00
INFLOW	-13	750	6.55	16.15	98.23	67.70	106.37		
8.9 CM GLITSCH RINGS	-2	750	8.53	16.15	99.73	88.16	102.84	0.00	0.00
INFLOW	-13	750	6.55	16.15	98.23	67.70	106.37		
SADDLES	-1	750	8.76	16.15	99.86	90.54	102.38	0.00	0.00
INFLOW	-12	750	6.55	16.15	98.37	67.70	106.55		
TOROIDS	0	750	8.74	16.15	100.00	90.33	102.61	0.00	0.00
DISTRIBUTION SYSTEM WITH VENTILATED SUBSTRATE									
96 L/MIN									
INFLOW	-16	755	6.49	16.20	97.84	66.70	106.14		
3.8 CM FLEXIRINGS	-2	755	8.92	16.20	99.73	91.68	101.91	0.00	0.00
INFLOW	-15	754	6.55	16.20	97.97	67.41	106.12		
8.9 CM GLITSCH RINGS	-2	754	8.70	16.20	99.73	89.54	102.48	0.00	0.00
INFLOW	-14	754	6.55	16.20	98.11	67.41	106.29		
SADDLES	-2	754	8.92	16.20	99.73	91.80	101.88	0.00	0.00
INFLOW	-15	754	6.55	16.20	97.97	67.41	106.12		
TOROIDS	-2	754	8.86	16.20	99.73	91.18	102.04	0.00	0.00

TABLE 5

PERFORMANCE OF THE 30.5 CM DIAMETER COLUMN AT NITINAT HATCHERY (3 SEGMENTS), PACKED WITH VARIOUS SIZES OF RINGS. ALL VALUES OF GO AND GN, THE GROSS AERATION COEFFICIENTS, WERE CALCULATED FROM THE AVERAGE INFLOW VALUES FOR NITROGEN AND OXYGEN.

	SAT	BAR	AV. DO	TEMP	TGP	O2 %	N2 %	GO	GN
	MMHG	MMHG	MG/L	C	%	%	%		
AVERAGE INFLOW	12.5	763	7.77	9.13	101.66	67.33	110.80		
8.9 CM FLEXIRINGS									
INFLOW	13	763	7.74	9.20					
280 L/MIN (Q/A=3836)	3	762	10.60	9.20	100.40	92.13	102.64	0.00	0.00
370 L/MIN (Q/A=5068)	1	763	10.54	9.20	100.13	91.48	102.47	0.00	0.00
555 L/MIN (Q/A=7603)	3	763	10.46	9.20	100.40	90.79	102.99	0.00	0.00
740 L/MIN (Q/A=10137)	4	763	10.42	9.15	100.53	90.33	103.28	0.00	0.00
8.9 CM GLITSCH RINGS									
INFLOW	14	763	7.74	9.20					
280 L/MIN	5	763	10.48	9.20	100.66	90.96	103.28	0.00	0.00
370 L/MIN	4	763	10.48	9.15	100.53	90.85	103.14	0.00	0.00
555 L/MIN	4	763	10.38	9.10	100.53	89.88	103.40	0.00	0.00
740 L/MIN	5	763	10.24	9.10	100.66	88.67	103.89	0.00	0.00
3.8 CM FLEXIRINGS									
INFLOW	13	763	7.76	9.05					
280 L/MIN	6	763	10.30	9.05	100.80	89.08	103.95	0.00	0.00
370 L/MIN	5	762	10.22	9.05	100.66	88.50	103.93	0.00	0.00
555 L/MIN	5	762	10.18	9.05	100.66	88.16	104.03	0.00	0.00
740 L/MIN	5	763	10.18	9.00	100.66	87.93	104.08	0.00	0.00
INFLOW	10	763	7.82	9.05					

TABLE 6

PERFORMANCE OF THE 74 CM CUBE-SHAPED AERATOR AT BIG QUALICUM HATCHERY, PACKED WITH 8.9 CM GLITSCH RINGS.

	SAT	BAR	AV. DO	TEMP	TGP	O2 %	N2 %	GO	GN
	MMHG	MMHG	MG/L	C	%	%	%		
INFLOW	20	755	11.57	9.10	102.68	101.24	103.11		
350 L/MIN (Q/A=661)	14	755	11.35	9.20	101.88	99.56	102.54	ND	0.00
770 L/MIN (Q/A=1454)	15	755	11.33	9.10	102.01	99.14	102.82	ND	0.00
1840 L/MIN (Q/A=3476)	13	755	11.37	9.00	101.74	99.25	102.45	ND	0.00

* ND = NOT DETECTABLE

TABLE 7

DETERMINATION OF UNCERTAINTY IN MEASUREMENTS - USING SADDLES AS A SUBSTRATE.

		SAT	BAR	AV.DO	TEMP	TIME	TGP	O2 %	N2 %	GO	GN
		MMHG	MMHG	MG/L	C		%	%	%		
94 L/MIN (Q/A=2901)											
INFLOW	JUNE 1	-19	749	5.49	14.55	15:25	97.42	54.89	108.74		
OUTFLOW		-1	749	9.53	14.50	15:35	99.86	95.18	101.15	2.24	2.03
94 L/MIN											
INFLOW	JUNE 2	-28	752	5.55	14.65	11:35	96.21	55.39	107.08		
OUTFLOW		0	752	9.47	14.62	11:50	100.00	94.45	101.52	2.08	1.54
97 L/MIN (Q/A=2994)											
INFLOW	JUNE 8	-52	749	3.67	15.20	13:15	92.94	37.22	107.75		
OUTFLOW		-2	749	9.24	15.20	13:45	99.73	93.70	101.37	2.30	1.73
97 L/MIN											
INFLOW	JUNE 8	-50	749	3.63	15.15	14:15	93.21	36.77	108.21		
OUTFLOW		0	749	9.24	15.15	14:40	100.00	93.60	101.74	2.29	1.55
97 L/MIN											
INFLOW	JUNE 8	-49	749	3.71	15.22	15:10	93.34	37.64	108.15		
OUTFLOW		-1	749	9.22	15.15	15:35	99.86	93.40	101.62	2.25	1.62
95 L/MIN (Q/A=2932)											
INFLOW	JUNE 10	-59	748	3.10	15.40	08:50	91.97	31.61	108.02		
OUTFLOW		0	748	9.18	15.40	09:15	100.00	93.62	101.74	2.37	1.53
95 L/MIN											
INFLOW	JUNE 10	-57	749	3.18	15.45	09:50	92.26	32.42	108.16		
OUTFLOW		0	749	9.16	15.45	10.15	100.00	93.39	101.80	2.32	1.51
95 L/MIN											
INFLOW	JUNE 10	-59	750	3.22	15.45	10:55	91.99	32.79	107.73		
OUTFLOW		0	750	9.16	15.40	11:20	100.00	93.17	101.86	2.29	1.42
									MEAN	2.2675	1.6163
									S.D.	0.0858	0.1896