# Physical Characteristics of Feed and Fecal Waste from Trout Aquaculture: Part 2:

# Settling Characteristics and Scouring Velocity Estimates of Aquaculture Waste to Validate “DEPOMOD”

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## Introduction

The physical characteristics of feed and fecal waste products from trout aquaculture are important to the development of improved effluent treatment methods, and for the regulatory control of ‘open’ system technologies (e.g. cage farming), which is based in part, on the dispersal characteristics of wastes in the receiving ecosystem. The physical characteristics of most interest include the settling characteristics and size distribution of particles. These characteristics provide the fundamentals for wastewater treatment in land-based aquaculture facilities (Youngs and Timmons 1991) and for the modelling of waste dispersion and the benthic footprint of cage-based aquaculture facilities (Cromey, Nickell and Black 2002).

In our earlier study, the physical characteristics of feed and fecal waste generated by 400 gram rainbow trout fed three commercial diets were determined. (Moccia, Bevan and Reid 2007). Since our earlier study, there has been a substantial increase in the cost of fish meal and fish oil and a reduction in the cost of alternative vegetable oils resulting in increased opportunities for alternative ingredients in fish feed (Naylor et al. 2009). Our initial study showed differences in the settling rates of fecal waste of trout fed three commercial diets with similar raw ingredients. This study expands the data set of the main physical characteristics of the feed and fecal waste produced by larger, market-sized rainbow trout approximately 1 kg, fed diets containing varying levels of fish oil and canola oil.

## Methods

The study was conducted at the Alma Aquaculture Research Station of the University of Guelph between February and March 2010. A domestic strain of rainbow trout, *Onchorhyncus mykiss* (Walbum) were used, average weight 1.23 kilograms (2.71 pounds). Fish were initially allocated to four 2-metre semi-square fibreglass holding tanks (1,600 litres volume). From these holding tanks, 15 fish were randomly allocated to four 2-metre semi-square fibreglass tanks (1,600 litres volume) and acclimated to the respective diets for a minimum of 14 days. Four experimental diets (6mm pellets) were provided by Martin Mills Inc., Elmira, Ontario. The control diet (Diet1) consisted of a standard commercial trout formulation with herring oil as the major source of dietary lipids. The remaining three diets had increasing proportions of the herring oil replaced with canola oil (Diet 2, Diet 3 and Diet 4). In addition, a preliminary trial using a commercial diet (Martin Classic Sinking Fish Feed 6 PT) was carried out for reference. Fish were fed 0.9% body weight daily. Each tank was supplied with aerated well water (8.5ºC, 30 $L.min^{-1}$). Computer controlled incandescent lights provided a natural, ambient photoperiod and lighting regimen.

Fecal samples were obtained by transferring fish overnight (1630 – 0830 hours) to 1-metre semi-square fibreglass tanks (350 litres volume), supplied with aerated well water (8.5ºC, 15 $L.min^{-1}$). The discharge pipe from each tank was modified with an acrylic plastic container within which a stainless steel ladle was placed allowing collection and transfer of feces with minimum physical disturbance At 0830 hours on each sampling day, the acrylic container was removed from the discharge pipe, and excess water was siphoned off to leave approximately 100 ml of undisturbed and intact feces. A settling column was manufactured from a vertically mounted acrylic tube (152 cm height, 10.6 cm diameter) with a conical discharge port controlled with a ball valve. It was filled with aerated well water (8.5ºC). A portion of the collected feces was gently introduced into the top of the settling column, and 11 sequential samples of settled feces were collected from the discharge port over a 60 minute period. The sampling time, duration and volume collected were recorded. Each sample volume was filtered (Whatman glass fibre filter, type 934/AH) and dried (103 – 105ºC) to determine the dry weight of the settled feces. The sum of the dry weights of the 11 fecal samples was taken as the total mass, from which the individual sample mass-fraction was then determined. Fecal settling velocity was calculated knowing the distance travelled and the time taken, using the method described by Wong and Piedrahita (2000) to adjust for changes in distance travelled (i.e. water column height) as sequential sample volumes were removed. The mass-based settling velocity curve was produced by plotting fecal settling velocity against (1-cumulative mass-fraction). Fecal samples were collected during four separate trials to provide a mean value for each experimental diet and the standard non-experimental reference diet. The mean % mass-fraction of feces settled at each sample period was compared using Tukey's Honestly Significant Difference (HSD) test (SAS 9.2 for Windows). The level of significance was set at $P<0.05$.

The settling velocity of individual 5mm and 6mm feed pellets were determined by recording the time taken to travel 100 cm of free-fall distance in the acrylic settling column previously described.

Preliminary measurements of fecal scouring velocity were determined using a fibreglass hatchery trough (length 220 cm x width 40cm x depth 10 cm) with modified inflow and outflow to ensure linear water flow characteristics. Fecal samples were placed within the static water column and water flow was increased until movement of feces was observed. The respective flow velocity was determined from an average of a) the overflow rate and b) timing a neutrally buoyant object over a 50 cm distance adjacent to the placed feces.

## Results and Discussion

Approximately 90% of the fecal material settled during the initial 40 seconds of collection, corresponding to a settling velocity exceeding $3.5 cm.sec^{-1}$ (Figure 1 & Table 1). Comparison of the mean percentage mass fractions of feces settled over the 11 sampling periods showed no significant differences  between fish fed the respective diets ($P>0.05$, Tukeys HSD test).

**Figure 1.** Comparison of mean % mass fraction of rainbow trout feces that settled over different sampling periods. Data points are the average of four trials.

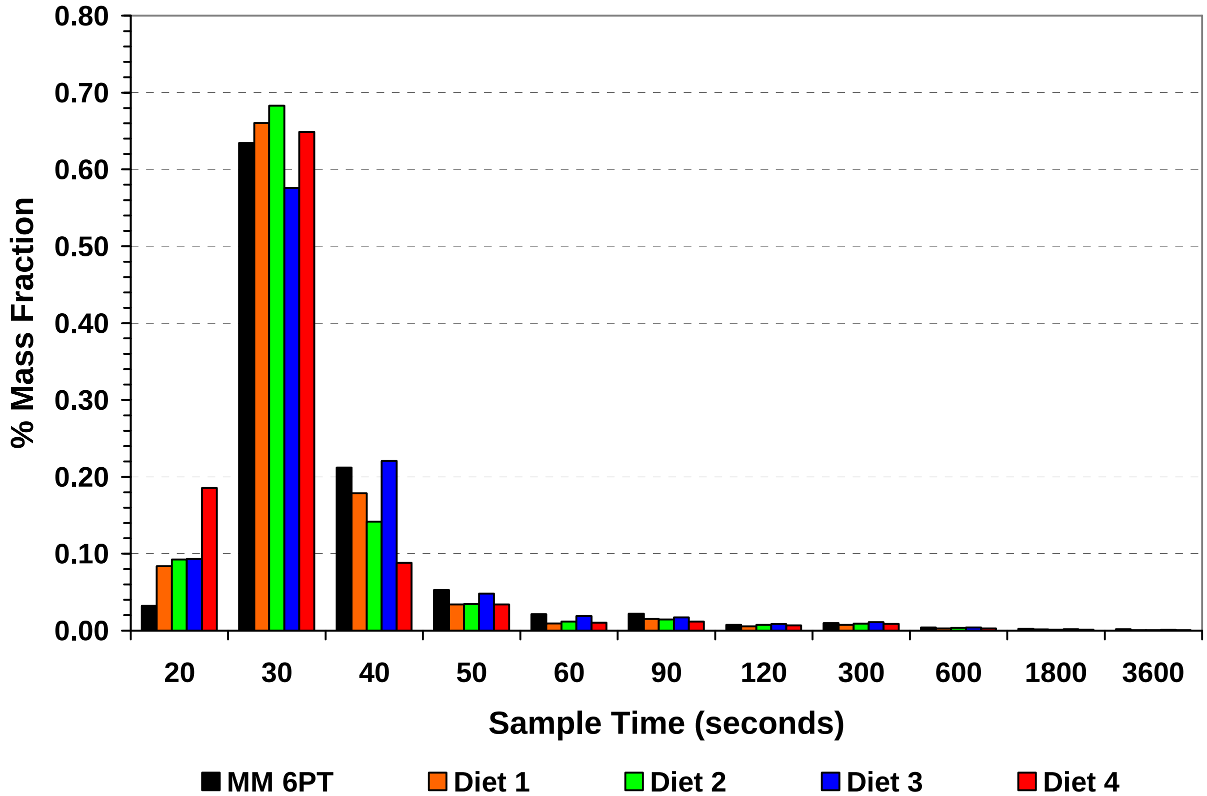


**Table 1.** Comparison of mean % mass fraction of rainbow trout feces that settled over different sampling periods.

| Sample Time (sec) | MM 6PT | | Diet 1 | | Diet 2 | | Diet 3 | | Diet 4 | |
|---|---|---|---|---|---|---|---|---|---|---|
| | Mean | SD | Mean | SD | Mean | SD | Mean | SD | Mean | SD |
| 20 | 3.2 | ±2.1 | 8.4 | ±9.1 | 9.3 | ±7.1 | 9.3 | ±7.1 | 18.6 | ±11.6 |
| 30 | 63.4 | ±10.0 | 66.0 | ±22.5 | 68.3 | ±13.6 | 57.6 | ±11.2 | 64.9 | ±11.5 |
| 40 | 21.2 | ±8.5 | 17.9 | ±12.2 | 14.2 | ±7.1 | 22.1 | ±7.9 | 8.8 | ±3.5 |
| 50 | 5.3 | ±0.7 | 3.4 | ±2.4 | 3.4 | ±1.8 | 4.8 | ±2.6 | 3.4 | ±1.8 |
| 60 | 2.1 | ±0.3 | 0.9 | ±0.4 | 1.2 | ±0.4 | 1.9 | ±1.2 | 1.0 | ±0.2 |
| 90 | 2.2 | ±0.2 | 1.5 | ±0.6 | 1.5 | ±0.8 | 1.7 | ±0.7 | 1.2 | ±0.5 |
| 120 | 0.7 | ±0.2 | 0.6 | ±0.2 | 0.7 | ±0.4 | 0.8 | ±0.4 | 0.7 | ±0.3 |
| 300 | 1.0 | ±0.1 | 0.8 | ±0.4 | 0.9 | ±0.5 | 1.1 | ±0.4 | 0.9 | ±0.5 |
| 600 | 0.4 | ±0.1 | 0.3 | ±0.2 | 0.3 | ±0.1 | 0.4 | ±0.1 | 0.3 | ±0.1 |
| 1800 | 0.2 | ±0.1 | 0.1 | ±0.1 | 0.1 | ±0.0 | 0.2 | ±0.1 | 0.2 | ±0.2 |
| 3600 | 0.2 | ±0.1 | 0.1 | ±0.1 | 0.1 | ±0.0 | 0.1 | ±0.0 | 0.1 | ±0.0 |

The corresponding mass-based settling velocity curves of individual fecal collections from rainbow trout fed four experimental diets and the commercial diet are presented in Appendix, Figures 4a – 4e. The data are plotted on a semi-log scale and a quadratic equation provided a best fit to the curve (Appendix, Table 4). The fitted curves are very flat for settling velocities less than 1 $cm.sec^{-1}$ and show a steep increase in settling velocity between 3.5 and 7 $cm.sec^{-1}$. reflecting that the settling velocity of most of the fecal material.

Combining the data from the five trials (four experimental diets and one commercial diet) provides an estimate of the average mass-based settling curve for feces from 1.2 kg rainbow trout (Figure 5). The average settling velocity of rainbow trout feces for three commonly reported mass fractions of 0.2, 0.5 and 0.8 are 4.2 $cm.sec^{-1}$, 5.9 $cm.sec^{-1}$ and 7.2 $cm.sec^{-1}$, respectively (Table 2). These values are very similar to the 3.9 $cm.sec^{-1}$, 6.1 $cm.sec^{-1}$ and 7.7 $cm.sec^{-1}$ observed for "Feces 2 [1]" in our initial study (Moccia et al. 2007, see Appendix, Figure 5).

The median value of 5.9 $cm.sec^{-1}$ exceeds the value of 3.5 $cm.sec^{-1}$ used in DEPOMOD (Cromey et al 2002). This increased settling velocity estimate would result in a decrease in the potential sediment footprint. For example, a cage site in 70m of water and average current velocity of 2 $cm.sec^{-1}$, the predicted fecal dispersal distance would be reduced from 60m to 35m. Associated with the reduction in dispersal distance there would be a corresponding increase in the deposition depth. In shallower water and/or with slower current profiles the differences would be reduced.

[1] Diet manufactured by Martin Mills Inc.

**Figure 2.** Mass based settling velocity curves for trout feces from fish fed four experimental diets and a commercial diet. Data are mean ±SD.

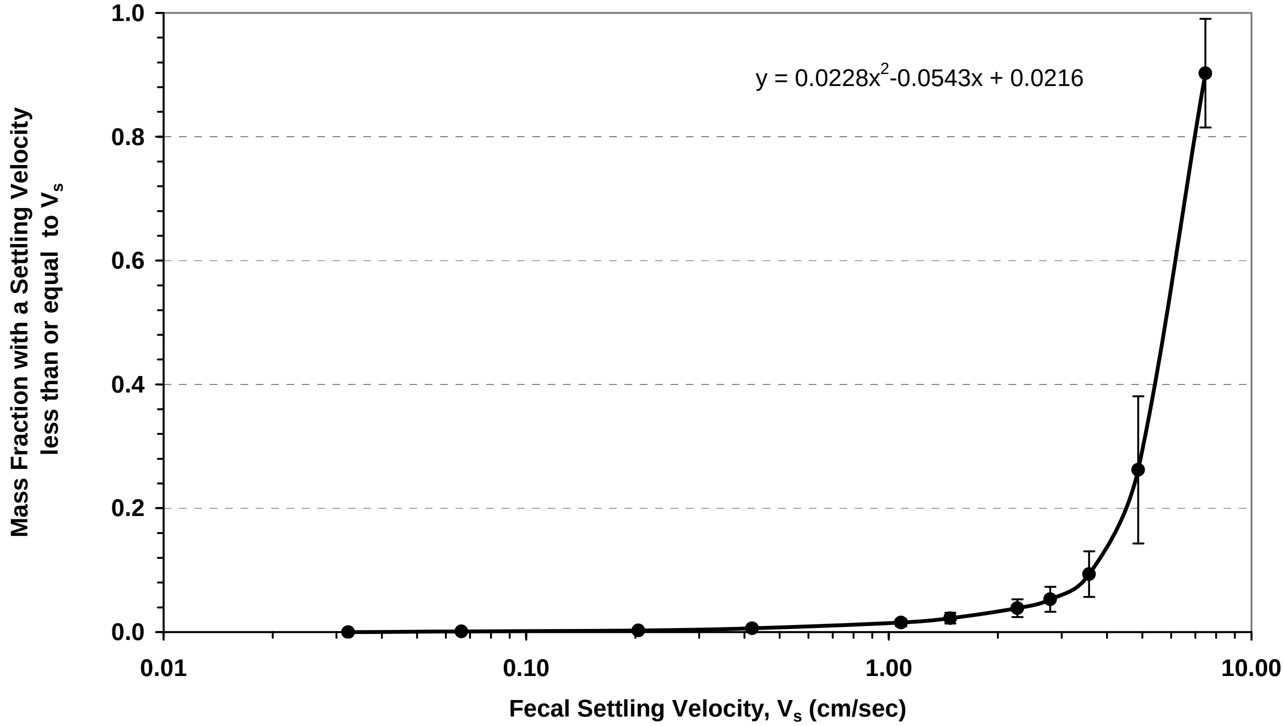


**Table 2.** Settling velocity of rainbow trout feces for selected mass fractions. Data are mean ±SD.

| | MM 6PT | Diet 1 | Diet 2 | Diet 3 | Diet 4 | Average |
|---|---|---|---|---|---|---|
| Fecal Mass Fraction | Fecal Settling Velocity ($cm.sec^{-1}$) | Fecal Settling Velocity ($cm.sec^{-1}$) | Fecal Settling Velocity ($cm.sec^{-1}$) | Fecal Settling Velocity ($cm.sec^{-1}$) | Fecal Settling Velocity ($cm.sec^{-1}$) | Fecal Settling Velocity ($cm.sec^{-1}$) |
| 0.2 | 3.97 ±0.20 | 4.27 ±0.38 | 4.31 ±0.30 | 4.03 ±0.40 | 4.57 ±0.30 | 4.23 ±0.36 |
| 0.5 | 5.67 ±0.13 | 5.93 ±0.25 | 5.97 ±0.18 | 5.80 ±0.30 | 6.31 ±0.38 | 5.94 ±0.32 |
| 0.8 | 6.90 ±0.09 | 7.14 ±0.29 | 7.18 ±0.19 | 7.09 ±0.27 | 7.58 ±0.48 | 7.18 ±0.35 |

The settling velocity of 5mm and 6mm feed pellets averaged 9.87 ±1.30 cm.sec$^{-1}$ and 8.67 ±2.12 cm.sec$^{-1}$, respectively (Figure 3 and Table 3). These values are similar to the 9.63 ±2.12 cm.sec$^{-1}$ reported previously for three commercial 5mm diets (Moccia et al. 2007).

**Figure 3.** Settling velocity of individual feed pellets (5 mm and 6 mm diameter).

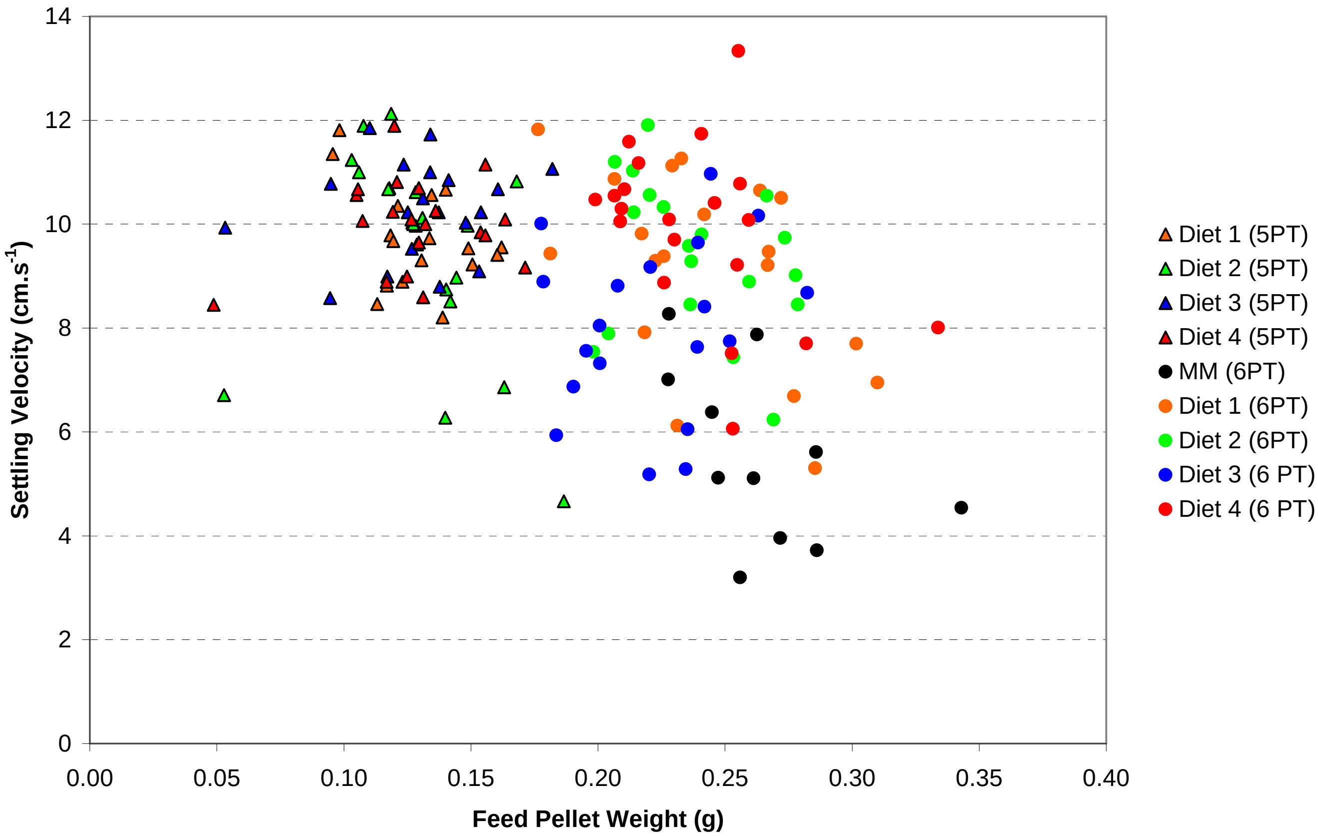


**Table 3.** Average settling velocity of 5mm and 6mm trout feed pellets. Data are mean ±SD.

| Size | MM 6PT | Diet 1 | Diet 2 | Diet 3 | Diet 4 | Average |
|---|---|---|---|---|---|---|
| 5 mm | NA | 9.8 ±0.9 | 9.4 ±2.1 | 10.3 ±1.0 | 10.0 ±0.9 | 9.9 ±1.3 |
| 6 mm | 5.5 ±1.7 | 9.1 ±1.9 | 9.4 ±1.5 | 8.0 ±1.7 | 9.9 ±1.7 | 8.7 ±2.1 |

The scouring velocity for individual trout fecal pellets averaged 4.1 $cm.sec^{-1}$ (SD ±0.71), with a range of 2.7 – 5.5 $cm.sec^{-1}$ and 5.5 $cm.s^{-1}$ for fecal pellets placed collectively on the substrate. The observed values are close to the minimum since the substrate was a smooth surface with a very low bed roughness or friction coefficient when compared to many fish culture tanks and natural benthic surfaces (Tchobanoglous and Burton, 1991; Gilley et al. 1992). Our preliminary scouring velocity estimate of 4.1 $cm.sec^{-1}$ is greater than the estimated 1.6 – 3.8 $cm.sec^{-1}$ for solids between 0.25 – 1.5 mm (Stechey and Trudell 1990) and 3.6 cm.sec-1 for 0.16 mm particles (Youngs and Timmons 1991); but less than the 10 – 40 $cm.sec^{-1}$ range suggested by Boersen and Webster (1980) and the 9.5 $cm.sec^{-1}$ used by DEPOMOD (Cromey et al 2002).

In conclusion, this study supports our contention that fecal settling velocity for large rainbow trout (400 to 1200 grams) is higher than generally recognised, with 50% of the mass settling at 5.9 $cm.sec^{-1}$. Our estimates of scouring velocity are preliminary, but suggest that the *minimum* scouring velocity of settled trout fecal material is approximately 5 $cm.sec^{-1}$ and deposits on natural substrates could at least double this value.

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# Appendix

**Figure 4a.** Mass based settling velocity curve for trout feces from fish fed Martin Mills 6PT. Data points are the average from four replicate trials, vertical lines show standard deviation

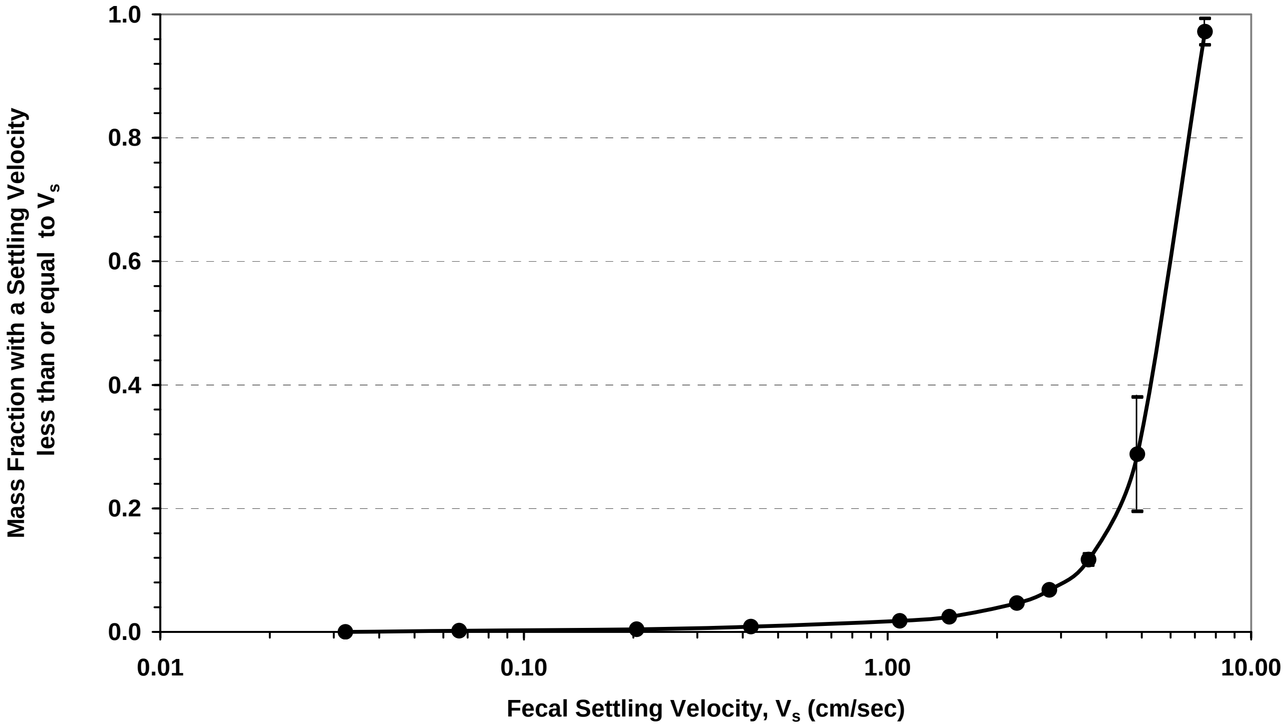


**Figure 4b.** Mass based settling velocity curve for trout feces from fish fed Diet 1. Data points are the average from four replicate trials, vertical lines show standard deviation.

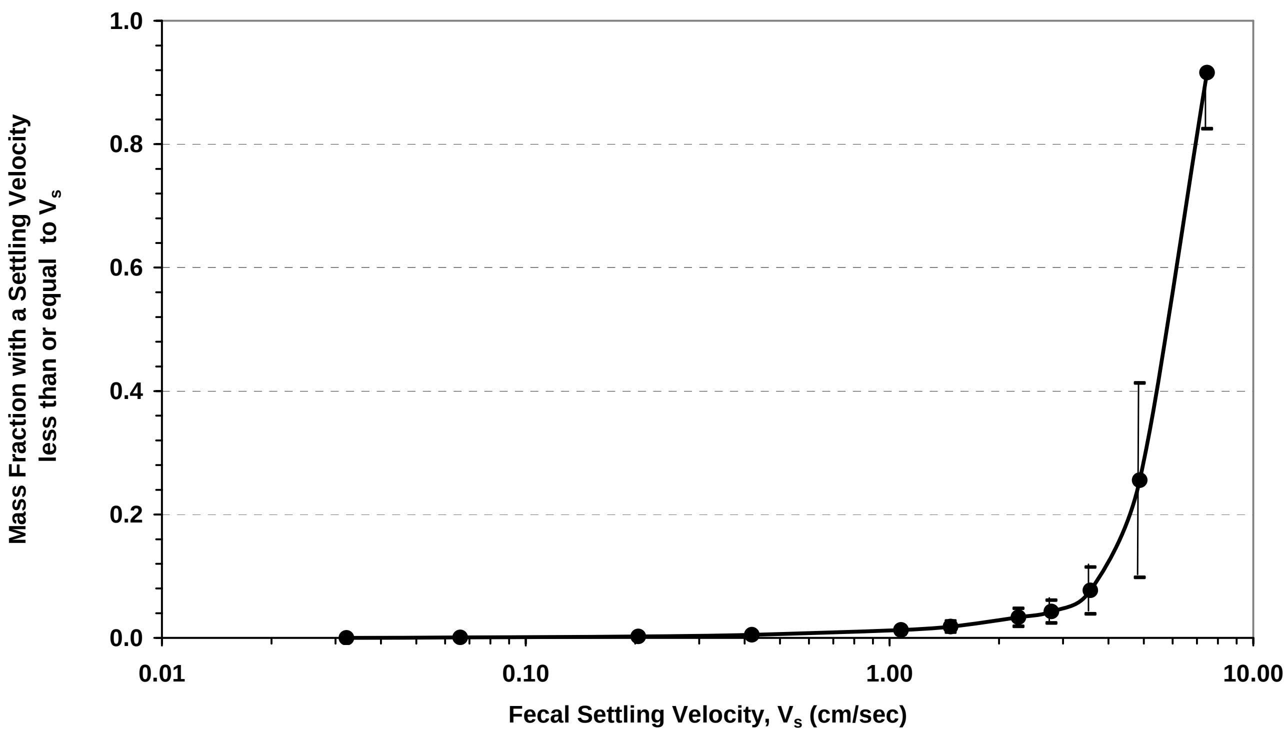

**Figure 4c.** Mass based settling velocity curve for trout feces from fish fed Diet 2. Data points are the average from four replicate trials, vertical lines show standard deviation.

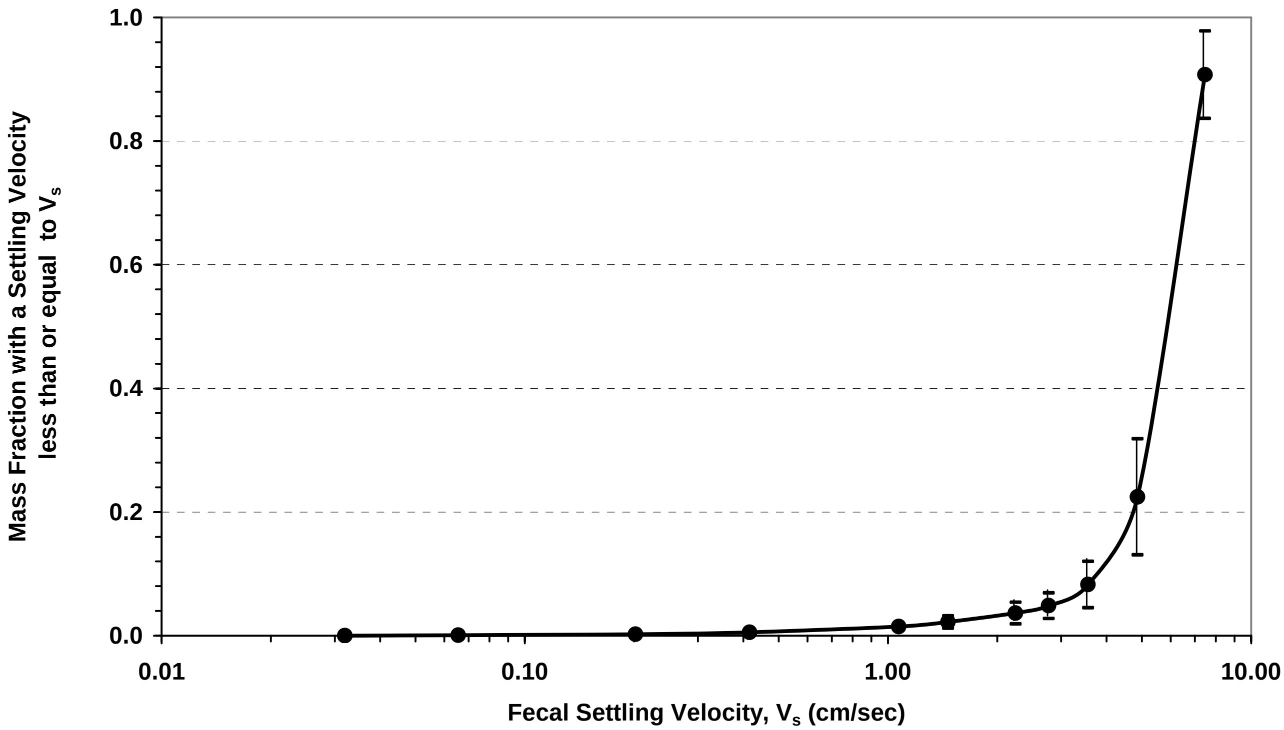


**Figure 4d.** Mass based settling velocity curve for trout feces from fish fed Diet 3. Data points are the average from four replicate trials, vertical lines show standard deviation.

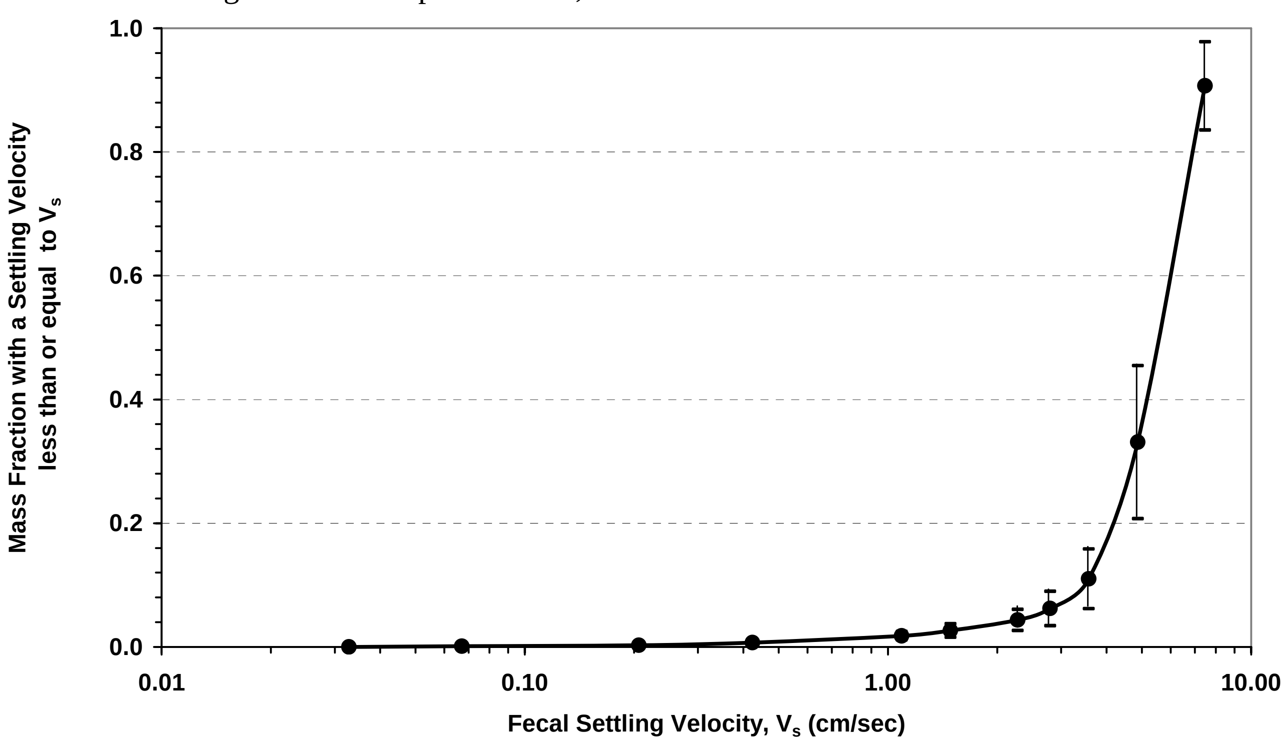

**Figure 4e.** Mass based settling velocity curve for trout feces from fish fed Diet 4. Data points are the average from four replicate trials, vertical lines show standard deviation.

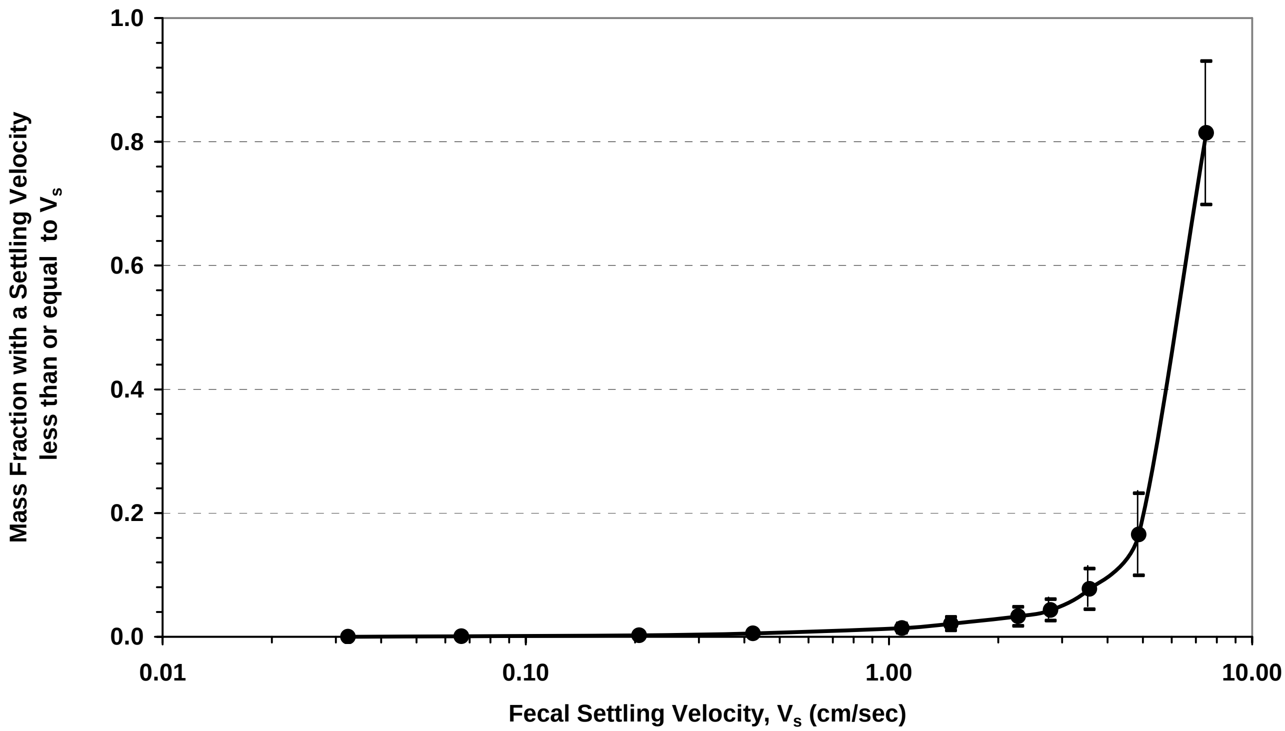

**Table 4.** Parameters for quadratic equation ($Ax^2+Bx+C=0$) describing settling velocity curves for rainbow trout feces.

| Equation coefficients | | | | Feed type | Fish Weight |
|---|---|---|---|---|---|
| A | B | C | $R^2$ | | (grams) |
| 0.0150 | 0.0062 | 0.0159 | 0.99 | 5mm diet 1 | 400 [1] |
| 0.0149 | -0.0124 | 0.0201 | 0.99 | 5mm diet 2 | 400 [1] |
| 0.0060 | 0.0934 | -0.0169 | 0.98 | 5mm diet 3 | 400 [1] |
| 0.0239 | -0.0533 | 0.0224 | 0.99 | 6mm MM regular | 1,230 [2] |
| 0.0241 | -0.0624 | 0.0236 | 0.99 | 6mm diet 1 | 1,230 [2] |
| 0.0238 | -0.0628 | 0.0255 | 0.99 | 6mm diet 2 | 1,230 [2] |
| 0.0213 | -0.0403 | 0.0150 | 0.99 | 6mm diet 3 | 1,230 [2] |
| 0.0217 | -0.0609 | 0.0263 | 0.98 | 6mm diet 4 | 1,230 [2] |

[1] Moccia et al. 2007
[2] This study

**Figure 5.** Mass based settling velocity curves for trout feces from fish fed three commercial diets. Data points are the average from two tanks of fish sampled on three occasions (from Moccia et al 2007).