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UNDER STEADY FLOWS

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ABSTRACT

Settling and erosion experiments were carried out on a size range of fish feed pellets using an annular flume (Mini Flume). A strong positive correlation was observed between settling rate and pellet dimension (pellet length, pellet diameter, and equivalent sedimentation diameter). Erosion thresholds also showed a strong positive correlation with pellet dimensions. Experiments were also carried out to examine the effect of number of pellets on erosion threshold of two sizes. The results show an asymptotic increase in erosion threshold with increasing number of pellets present, possibly due to sheltering effects. In addition, the chemical composition of the pellets was analyzed in terms of water, organic, carbon, and nitrogen contents as well as stable carbon and nitrogen isotopes. The results arising from this study will provide information regarding potential tracers of waste feed material and help validate model predictions associated with the dispersal of waste material.

INTRODUCTION

Hailed as a viable alternative to the further depletion of dwindling natural salmon stocks, aquaculture programs have rapidly expanded in many parts of the world (Seymour and Bergheim, 1991; Beveridge et al., 1997). In the wake of this expansion, many concerns have arisen pertaining to the degree of environmental impact associated with fish farm activities (Gowen and Bradbury, 1987). Organic enrichment due to waste feed pellets and faecal matter may cause alterations to the existing diversity and abundance of benthic faunal communities (Henderson and Ross, 1995) associated with sediment sulphide production (Wildish et al. 2001) and ammonium release beneath fish pens (Hargrave et al., 1993). These concerns have in turn led to attempts to try and understand the nature of this impact (Doughty and McPhail, 1995) as well as the nature of the farm waste that causes it (Merican and Phillips, 1985).

Recently, fish farmers have adopted new feeding strategies to minimize feed loss from cage systems which will act to reduce environmental impacts and operating costs (Seymour and Bergheim, 1991). In the past, uneaten pellets have been shown to comprise anywhere from up to 40% of total farm waste depending on the feeding methods employed (Thorpe et al., 1990). Acoustic sensors (Juell et al., 1993) and subsurface video imagery (Ang and Petrell, 1997) have been developed to help reduce feed loss from cage systems containing automatic feeders by providing a shut-off system once fish feeding activity has stopped. In addition, improving the shape, texture, and digestibility of feed pellets will limit the amount of pellets that may potentially sink through netpen systems. For example, feed losses have been minimized through a newly developed feed type (extruded) that contains a more digestible matrix and that exhibits reduced sinking rates and increased stability in water (Seymour and Bergheim, 1991). This type of pellet results in greater feed conversion rates (ratio of feed to fish growth) since extruded pellets stay intact and remain in the surface feeding zone for longer. However, in the event of feed loss through a netpen system, knowledge of the sedimentation and dispersal of fish feed pellets by benthic transport is essential in predicting potential impacts on the benthic environment.

Quantifying the dispersal of waste through the use of hydrodynamic modeling is

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necessary to define the potential area of benthic impact below farm systems (Cromley et al., 2002a; Stucchi et al., in press). Such models can aid in site selection and serve as both research and monitoring tools to increase our knowledge regarding the processes that lead to benthic impacts. Models have evolved over time from simply predicting fish farm waste accumulation using current metres, bathymetric maps, and fish production data (Gowen et al. 1989) to predicting deposition and subsequent benthic transport processes of waste material through the coupling of complex hydrodynamic models (Panchang et al., 1997; Dudley et al., 2000; Cromey et al., 2002b). Attempts have been made to summarize and compare resuspension values of various types of seabed materials reported across the literature (Cromey, 2002a; Cromey, 2002b). However, results were not standardized according to: 1) the composition of transported material (natural and/or waste); 2) the definition of traction threshold; and 3) the "near-bed" setting used to determine the traction threshold. Inconsistencies between investigations can arise due to a wide scatter in results if methods for defining erosion threshold of known material and determining "near-bed" velocities are not standardized (Sutherland et al. 1998).

Field and laboratory investigations in the past have focused predominantly on the transport of natural sediment which may behave differently to feed pellets that are relatively large in size and low in density. The physical and chemical characteristics of feed pellets will influence predictions regarding the dispersal and fate of the waste material arising from aquaculture activities. However, little information exists regarding the resuspension criteria and benthic transport characteristics of the various types of commercially available feed pellets designed for different growth phase and season. The objective of this study is to determine the physical attributes, sedimentation rates, and benthic transport characteristics of fish feed pellets under controlled flow conditions. The pellets chosen for this study constitute a range of sizes that are typically used throughout the growout cycle of cultured fish and represent a certain component of solid waste material depositing from a fish farm. In addition, the feed pellets were analyzed for attributes that may serve as potential tracers of waste material. With the continuance of such research it should be possible to shed further light on the dispersal

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patterns around fish pens and to develop methods to ensure the sustainability of the aquaculture industry.

METHODS

Sedimentation rates and traction thresholds of feed pellets (5 size categories)

Chemical analysis of feed pellets: Five size classes of Orion fish feed pellets (3.5 mm, 5.0 mm, 6.5 mm, 8.5 mm, and 11.0 mm) were obtained from Moore-Clarke Co., Vancouver, British Columbia (presently Skretting Canada). Three replicate pellets from each size category were analyzed for inorganic content, total carbon, and nitrogen, zinc, and lithium contents. Stable carbon and nitrogen isotopes of the pellets were determined. Inorganic content was determined by placing replicate pellets in a Thermodyne 1400 furnace for 2 hours at 550 °C and calculating the percent ashed weight using both oven-dried and ashed pellet weights. Moisture content was obtained by drying the pellets at 90 °C until a constant weight was reached. The concentrations of zinc and lithium were determined by inductively coupled plasma optical emission spectroscopy, while the total carbon, total nitrogen, $\delta^{13}C$, and $\delta^{15}N$ were determined using a Carlo-Erba CHN analyzer. A VG prism mass spectrometer was coupled to the same type of analyzer for the carbon and nitrogen isotope analysis. A data report by Petersen et al. (2005) contains a more detailed analysis of the trace metal component of the feed pellets.

Settling rates of feed pellets: Pellet length and width were measured on replicate pellets of each size category; 3.5 mm (n=44), 5.0 mm (n=17), 6.5 mm (n=16), 8.5 mm (n=17), and 11.0 mm (n=17). The pellet volumes were determined for each size category by approximating pellet shape to that of a cylinder. Ten pellets were weighed from each size category. The settling velocity and trajectory of the feed pellets were measured and observed visually be timing their fall in a still-water column (diameter = 0.30 m) of freshwater over a distance of 1.0 m. Pellets were settled individually and replicated in triplicate. Settling rate was measured at a depth of 50 cm from the surface to ensure that the pellets had reached terminal settling velocity and stable orientation (Ridley, 2004).

Traction thresholds of individual feed pellets: Traction experiments were carried out in an annular laboratory Mini Flume (described in Amos et al., 2000). The flume has an open base: it is 0.30 m in diameter and is 0.30 m high. The flume is made up of two acrylic tubes attached by a lid and consisting of an acrylic base. The working flow channel has a width of 45 mm, a height of 220 mm and a flume volume of approximately 7 litres. Four small paddles, attached to the base of the movable lid, induce flow in the annulus, while a Compumotor ® digital DC stepping motor, powered by a 24 VDC power supply drives the rotating lid. The speed of the rotating lid was increased in a stepwise manner to provide a controlled range of near bed constant flow speeds. Shear velocities were derived from laser-doppler velocimeter velocity profiles made at 3 locations across the flume (Fung, 1997). An electromagnetic Marsh-McBirney ® current meter measured both azimuthal and vertical components of flow 85 mm above the flume base. Data on current speed and turbidity were logged on a Campbell Scientific ® CR10 data logger at 1 Hz. A Sony ® Handycam 8 mm video-recorder was used to record the erosion process through the clear Plexiglass outer wall of the flume.

The traction thresholds of 5 sizes of fish feed pellets were determined for a range of velocity settings within the Mini Flume. The Mini Flume was filled with freshwater at room temperature (24 ºC) to a height of 22 cm. Three replicates of each feed pellet were performed; individual pellets were examined to avoid any flow interference between pellets. The point of motion during each experiment was defined as the point at which the pellet had moved one pellet length (the traction threshold).

Friction angles of feed pellets: The friction angle (ϕ) of a feed pellet was determined by placing it on an acrylic tilting board submerged in water. The acrylic board was slowly tilted until the specimen moved one particle length under the influence of gravity. The angle of tilt at the point of motion was measured to within $\pm$ 1 º. This measurement was repeated 3 times for each pellet size.

Traction thresholds and saltation characteristics of feed pellets (2 size categories)

Traction thresholds for multiple feed pellets: Two size classes (7.0 mm and 10 mm) of fish feed pellets were collected from a fish farm (Connors Brothers Ltd.) located in the southwest corner of the Bay of Fundy/Gulf of Maine system which straddles the Canadian/US border. The traction thresholds were determined for groups of various numbers for both the 7.0 mm pellets (1, 4, 5, and 10) and the 10 mm pellets (1, 2, 3, 5, and 10). The flow in the flume was increased at programmed velocity settings and the traction thresholds observed.

Transport rates of individual feed pellets: Each flume experiment was recorded on videotape and later analyzed for pellet transport rates. The rolling and saltation phases of transport were recorded for each speed increment from freeze-framed video records. Pellet velocity was determined by counting the number of half frames (30/second) for the pellets to travel past a 6 cm scale located in the field of view. The saltation height and saltation length of the two size categories of pellets were also recorded for each speed increment. Shear velocity was calculated using lid speed using a flume calibration equation, $U\cdot_{crit}$ = (lid speed * 0.54) * 0.141 (Fung, 1997).

RESULTS

Physical attributes and chemical analysis of feed pellets

A slight increase in the carbon to nitrogen ratio was observed with increasing size of pellet, while a slight decrease in stable carbon isotope was observed (Table 1). The stable nitrogen isotope was highest in the smallest (3.5 mm) pellet but little variation was observed in the remaining pellets. The Zinc contents for both the smallest and largest pellet size were slightly higher than those of the remaining pellets; the latter mean value having a large standard deviation.

Settling rates and traction thresholds of feed pellets (5 size categories)

Settling rates and traction thresholds of feed pellets: Table 2 summarizes the physical attributes and settling rates of the 5 size categories of fish feed pellets. Figure 1 shows a non-linear relationship between pellet length and pellet diameter. Note there is a smaller standard deviation of the mean pellet diameter relative to that of

pellet length. This may be important depending on the aspect pellets present to the flow during settling or traction. Settling rates were observed to increase with increasing pellet diameter (Figure 2). A strong positive relationship was observed between settling rates and pellet dimensions (Figure 3A) as well as the equivalent sedimentation diameter (ESD) (Figure 3B). ESD was determined using the relationship of Swamee and Ojha (1991) developed for non-spherical particles:

$$D_s = (3\,C_{ds}\,W_s^2)/4g(s\text{-}1) \tag{1}$$

where W_s is pellet settling rate, C_{ds} is the pellet drag coefficient, g is the gravitational acceleration, and s is the ratio of densities of the pellets and the fluid. Strong relationships were also observed between traction thresholds and length and width dimensions (Figure 4A) as well as the equivalent sedimentation diameter (Figure 4B). A similar result was found between friction angles and pellet dimensions and ESD (Figure 5A and B).

Determination of drag coefficients for settling and sitting feed pellets: The drag coefficient of settling pellets (C_{ds}) was calculated using equation (2) presented by Swamee and Ojhi (1991):

$$C_{ds} = 0.84(\beta^4 + 20\beta^{20})^{-0.25} \tag{2}$$

where β is a shape factor. The values of C_{ds} ranged between 0.66 and 0.86 (Table 2). The drag coefficient for feed pellets sitting on a bed (C_{dx}) was defined in the following equation according to Thompson and Amos (2002)

$$C_{dx} = ((\square_s\text{-}\square)\,V\,g\,\tan(\phi))\,/\,(A_E\,\square\,U_x^2) \tag{3}$$

where $\square_s$ is the density of feed pellets, $\square$ is the density of fresh water,, V is the pellet volume, and ϕ is the friction angle, A_E is the area that eroding drag forces act upon, and U_x is the traction threshold velocity measured at height (x). The surface area of the pellet acted upon by the drag force during sitting (the effective area) was calculated as

half the total area of a cylinder (πrh) minus the area of the two butt-ends ($2\pi r^2$). At the onset of traction of sitting pellets the alignment was perpendicular to the flow. During settling the pellets were oriented with their largest dimension normal to the flow direction, similar to that of shells observed by Thompson and Amos (2002).

Traction thresholds and saltation characteristics of feed pellets (2 size categories)

Figure 5 shows the traction threshold values for different numbers and sizes of Connors Brothers Ltd. feed pellets used in the flume experiments. In general, the traction thresholds for the two size categories of feed pellets increased in an asymptotic fashion with increasing numbers of pellets present. A rapid increase in threshold was observed up to 5 pellets: an asymptote was evident at 0.024 m s^{-1}.

Figure 6 shows the net horizontal transport rates of the two pellet size categories for velocities evaluated at 0.20 m (i.e. the top of the saltation layer). In general, the *net* horizontal speed of a large pellet was *greater* than that of a small pellet which is largely in contradiction to most theories of sediment transport. However, the onset of the rolling and saltation transport phases for the large-sized pellet occurred at a higher current speed relative to that of the small-sized pellet as expected from a Shields-type consideration. The ratio of saltation height to length of a small pellet remained constant (0.1) over the range of velocity settings, while that of the large pellets gradually decreased from the ratio of 0.1 over the velocity range.

DISCUSSION

Potential tracers of fish feed pellets, such as, 1) carbon to Nitrogen ratios, 2) stable carbon and nitrogen isotopes, as well as 3) zinc and lithium ratios were determined. The carbon to nitrogen ratios observed in the feed pellets fall within the range of pellet C:N ratios observed in other investigations (Findlay and Watling, 1994). However, the overlap between pellet C:N and sediment C:N (Bornhold, 1978) suggests that this ratio may not be suitable as a tracer for feed pellets in the sedimentary environment (Table 1). In terms of the stable isotopes, the carbon isotope values of the

feed pellets are similar to those reported in Ye et al. (1991) and Sutherland et al. (2001) and slightly higher than those reported by Hansen et al. (1991). Sara et al. (2004) have shown that both farm-derived carbon and nitrogen sources can be isotopically detected through water column and sediment sampling within the vicinity of a netpen system, suggesting their usefulness as at tracer of waste material. The geochemical (lithium) normalization of a heavy metal (zinc) has been shown to be capable of identifying fish farm wastes in sediments associated with aquaculture operations (Yeats et al., in press). The high zinc contents observed in pellets combined with the normalization technique allows one to separate naturally-occurring and tracer zinc concentrations observed in sediments; an important component in tracking the movement of pellets *in situ*.

The relationship between pellet settling rates and pellet diameter observed in this study follows a similar trend to those observed by Findlay and Watling (1994), Cromey et al. (2002a), and Chen et al. (1999) where settling rates increased with increasing pellet diameter. Figure 2 shows that the settling rates measured in this study fall within the higher range of the compiled data set of settling rates standardized by pellet diameter. Chen et al. (1999) has shown that salinity and diet composition, including standard (20 to 24% oil) or high-energy (28 to 30% oil) formulations, influence settling rates along with pellet size (Chen et al., 1999). The pellets used in this study were considered a "winter diet" that contains a high-energy formula designed for salmon, while the experiments were carried out in a freshwater environment.

Pellet diameter proved to be the best predictor of settling rates relative to pellet length and equivalent sedimentation diameter (Figure 3A and 3B). Although Findlay and Watling (1994) found that pellet dimensions (length and diameter) did not serve as good predictors of pellet sinking rates, Chen et al. (1999) showed strong relationships between pellet diameter and settling rates. In this study, the smaller standard deviation of the width measurement relative to that of the length measurement (Figure 1) may be responsible for the high correlation between settling rates and pellet diameter. The smaller standard deviation associated with pellet width is probably influenced by extrusion process which involves a belt containing extrusion holes of a constant

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diameter. It is also interesting to note that pellet width does not increase linearly with pellet length, suggesting that the cylindrical shape of the pellet is transitional from a disc to a rod (Figure 1).

The traction threshold or onset of particle motion is an important parameter that is used widely in numerical models assessing particle transport (Lavelle and Mofjeld, 1987). The flume-derived traction thresholds of feed pellets observed in this study provide a range of values useful for predicting tidal or storm-induced bedload transport following the initial descent of pellets from a fish farm operation. To date a size-averaged pellet settling rate (2 to 12 mm) along with a single particle traction threshold, characterized by a limited particle size range (2 to 6 mm) and a low settling rate (3.4 cm s^{-1}), have been used in waste dispersal models (Cromey et al., 2002a; Cromey et al., 2002b). Predictions of the dispersal of waste feed pellets using a single settling rate or traction threshold value may over- or under-estimate the net deposition of waste material and area of potential benthic impact. The relationships between traction threshold and pellet length, pellet width, and equivalent sedimentation diameter observed in this study reveal a strong influence of pellet dimensions on traction thresholds (Figure 4A and B), supporting the notion that single values may not provide accurate model predictions. The departure from 1:1 in Figure 3B suggests that pellet shape has a residual effect on sedimentation diameter not accounted for in equation (3).

The values observed in this study cannot be generalized due to the paucity of information existing in this field. Caution should be taken when summarizing erosion thresholds of various substrate materials reported across the literature since resuspension thresholds, methodologies, and shear-stress determinations may not be standardized (Sutherland et al., 1998). Near-bed resuspension thresholds measured across a range of near-bed water depths (1 to 2.5 m) were not standardized according to bed shear stress by Cromey et al. (2002b). Furthermore, differences in methodologies for determining erosion thresholds as well as the criteria for erosion thresholds were not considered before comparisons were carried out. It is erroneous to equate the dispersal of a labeled tracer based upon grab sampling around a point

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source (Cromey et al., 2002b) with a study measuring the transport of a mixture of both natural and waste material through in situ flume deployments and defining resuspension at a height of 18 cm (Dudley et al., 2000). The results from this study will allow one to determine the dispersal of intact pellets during the initial stages of descent and benthic transport, which may be different from *in situ* transport assessments of accumulated waste within the sedimentary environment.

Since shape, density and roughness of the pellets were fairly consistent across the size range of pellets used in this study, it appears that size largely influences settling rates and traction thresholds of pellets. These findings differ from those of other studies examining the properties of other large particles, such as shells, where roughness, density, and shape change with increasing size or growth stage of shells (Amos et al., 2000). The drag coefficients of settling pellets were calculated according equation 2 (Swamee and Ojha 1991) and ranged between 0.68 and 0.86 (Table 2). This equation is applicable only to particles of high Reynolds numbers (Re > 300) and cylindrical shape factors (Allen, 1985): our results were above the minimum Re. The values of C_{ds} derived herein compare to those drag coefficients of cylindrical particles presented by van Rijn (1990) Internal consistency in results was evaluated by the sample calculation of Fs/Fd = 1/tan(phi) (Thompson and Amos, 2002), where Fs is the drag forces on the settling pellet, and Fd is the drag force on the pellet at incipient motion while sitting on the bed. This relationship was satisfied (Table 2) and whilst not proving that the drag estimates are correct, at least demonstrates internal consistency between particle behaviour in the various modes of motion.

The drag coefficients (evaluated for z = 8.5 cm) of pellets sitting on a bed were calculated according to equation 3 (Thompson and Amos, 2002) and ranged between 1.65 (smallest pellet) and 2.87 (largest pellet). The drag coefficients have been normalized to a height of 100 cm (C_{d100}) for comparative purposes (Table 2). The mean value is 5.73×10^{-3}, which is about twice that used by Sternberg (1972) for rough/rippled beds but close to those of pebble-covered tidal channels. The larger drag on the pellets results from the larger area of exposure to flow. This illustrates that estimates of drag based on average bottom roughnesses may underestimate by

50% and hence could underpredict dispersal and transport.

The pellet dimensions were also plotted against friction angle (Φ) defined as the critical angle in which the onset of motion takes place as a pellet slides one pellet-length down a tilting plate (Figure 5A and B). Since friction angle is important in determining the moment balance of forces on a grain (weight and fluid drag forces), it is considered to be an important parameter in bedload transport processes (Bagnold, 1966)

The number of pellets residing in a group also influences traction thresholds as Figure 6 shows that the pellet traction thresholds increased in an asymptotic fashion with an increase in number of pellets present regardless of pellet size. The apparent traction threshold was higher when more particles were required to be in motion simultaneously, suggesting that a group of pellets may not act independently but as one body altering drag and momentum loss. As a result a turbulent eddy influencing 10 pellets simultaneously (per unit area) would need to be higher than that influencing 1 pellet. These results have also been observed for the onset of motion of organic-sediment aggregates in flume studies (Sutherland et al., 1998).

Waste-particle transport models should also account for the dispersal of fish feed pellets through bedload transport in the form of rolling or saltation following the onset of movement (Figure 7). In this study, both the horizontal speed and onset of saltation of the large-sized pellet was slightly greater than those observed of the small-sized pellet. In addition, the transport of saltating particles did not assume a standard saltation height to length ratio of 0.1, typical of saltating particles (Abbott and Frances, 1977). For example, while the ratio of saltation height to saltation length of the small-sized pellet remained at 0.1 throughout the experiment, the saltation height of the large-sized pellet did not increase with increasing saltation length.

The majority of investigations to date have focused solely on quantifying solid waste production (Merican and Phillips, 1985) and the accumulation of organic material at the seabed directly below net-pen systems (Trojanowski et al., 1982; Kelley, 1993; Troell and Berg, 1997). Transport (Panchang et al. 1997; Dudley et al. 2000) and mass-balance models (Kelly, 1995) can be used to predict pellet dynamics and the nutrient

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status of both freshwater and marine environments inhabiting aquaculture system. A range of settling rates and transport thresholds for various size categories of fish feed pellet types were reported in this study. These transport coefficients will help improve the parameterization of benthic dispersion of waste material using transport models (Dudley et al. 2000; Cromey et al. 2002), which have been shown to be sensitive to the critical shear stress for waste resuspension (Panchang et al. 1997). In addition, this study also reports feed pellet composition to provide potential tracers for tracking the dispersion of waste feed pellets. Both of these pellet components, chemical composition and transport characteristics, are essential in determining the dispersal field of waste material, validating model predictions, and assessing benthic impacts. Both the regulatory group and the fish farm industry would gain from the protection and preservation of the aquatic environment (Doughty and McPhail, 1995).

ACKNOWLEDGMENTS

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Figure Legend

Figure 1: The relationship between width and length parameters for 5 size categories of fish feed pellets (Moore-Clarke Co.). The error bars represent one standard deviation.

Figure 2: The relationship between fish feed pellet settling rate and pellet diameter.

Figure 3: The relationships between pellet settling rate and pellet dimensions (Moore-Clarke Co.). Regressions are presented for settling rates and measured length and width parameters (A) as well as calculated equivalent sedimentation diameters (B). The error bars represent one standard deviation.

Figure 4: The relationships between pellet traction thresholds and pellet dimensions (Moore-Clarke Co.). Regressions are presented for traction thresholds and measured length and width parameters (A) as well as calculated equivalent sedimentation diameters (B). The error bars represent one standard deviation.

Figure 5: The relationships between pellet friction angles and pellet dimensions (Moore-Clarke Co.). Regressions are presented for frction angles and measured length and width parameters (A) as well as calculated equivalent sedimentation diameters (B). The error bars represent one standard deviation.

Figure 6: Traction thresholds for the simultaneous movement of different numbers and sizes of feed pellets (Connors Brothers Ltd.)

Figure 7: The relationship between current speed and the net horizontal speed of feed pellets (Connors Brothers Ltd.) in both rolling and saltation phases of transport. The current speed was measured at 22 cm above the bed.

Table 1: Chemical constituents of fish feed pellets of 5 size categories.

Description	Orion 3.5 mm	Orion 5.0 mm	Orion 6.5 mm	Orion 8.5 mm	Orion 11.0 mm
Carbon to Nitrogen ratio	5.33 (0.36)	5.66 (0.47)	6.40 (0.47)	7.52 (0.05)	7.94 (0.39)
$\delta^{13}C$	-20.88 (0.26)	-21.33 (0.13)	-21.85 (0.65)	-21.98 (0.06)	-22.02 (0.11)
$\delta^{15}N$	12.47 (0.39)	10.04 (0.34)	9.92 (0.86)	10.99 (0.18)	10.24 (0.86)
Zinc content ($\mu g\ g^{-1}$)	94.63 (2.39)	79.43 (2.74)	85.30 (3.43)	78.17 (3.19)	137.33 (28.89)
Lithium content ($\mu g\ g^{-1}$)	0.17 (0.24)	0.00 (0.00)	0.00 (0.00)	0.00 (0.00)	0.00 (0.00)

Table 2: Physical attributes, sedimentation rates, traction thresholds, and friction angles for fish feed pellets of 5 size categories.

Description	Orion 3.5 mm	Orion 5.0 mm	Orion 6.5 mm	Orion 8.5 mm	Orion 11.0 mm
Length (m)	0.0044 (0.0005)	0.0071 (0.0007)	0.0095 (0.0005)	0.0118 (0.0010)	0.0136 (0.0010)
Width (m)	0.0035 (0.0001)	0.0053 (0.0001)	0.0064 (0.0002)	0.0085 (0.0002)	0.0109 (0.0002)
Mass (kg)	0.00004438 (0.0000060)	0.0001674 (0.000023)	0.0003021 (0.000029)	0.0006936 (0.000053)	0.001291 (0.00009)
Settling Rate [W_s ($m\ s^{-1}$)]	0.105 (0.0136)	0.145 (0.0142)	0.140 (0.0279)	0.161 (0.0129)	0.201 (0.00809)
Drag Coefficient (Settling Pellet)	0.658	0.743	0.858	0.791	0.678
Drag Coefficient (Pellet on seabed)	1.65	2.10	2.87	1.93	2.05
Drag Coefficient (normalized to 1 m)	0.0057	0.0057	0.0057	0.0058	0.0057
Critical shear velocity [U_{crit} ($m\ s^{-1}$)]	0.00437 (0.00035)	0.00559 (0.00053)	0.00587 (0.00066)	0.00596 (0.00040)	0.00719 (0.00013)
Friction angle (degrees)	23.3 (1.52)	21.0 (2.64)	21.3 (2.08)	18.0 (1.0)	19.0 (1.0)

THE SETTLING BEHAVIOUR AND BENTHIC TRANSPORT OF FISH FEED PELLETS UNDER STEADY FLOWS

T.F. Sutherland, C.L. Amos, C. Ridley, Ian G. Droppo and S.A. Petersen

ABSTRACT

Settling and erosion experiments were carried out on a size range of fish feed pellets using an annular flume (Mini Flume). A strong positive correlation was observed between settling rate and pellet dimension (pellet length, pellet diameter, and equivalent sedimentation diameter). Erosion thresholds also showed a strong positive correlation with pellet dimensions. Experiments were also carried out to examine the effect of number of pellets on erosion threshold of two sizes. The results show an asymptotic increase in erosion threshold with increasing number of pellets present, possibly due to sheltering effects. In addition, the chemical composition of the pellets was analyzed in terms of water, organic, carbon, and nitrogen contents as well as stable carbon and nitrogen isotopes. The results arising from this study will provide information regarding potential tracers of waste feed material and help validate model predictions associated with the dispersal of waste material.

NWRI RESEARCH SUMMARY

Plain language title
Fish feed pellet behaviour during settling and erosion experiment.

What is the problem and what do scientists already know about it?
Aquaculture of fish is a large national and international industry. Fish are feed pellets which are not always consumed by the fish and will deposit on the bottom of the pens or be transported outside of the pens into the surrounding aquatic environment. These pellets can represent a significant loading of nutrients and can represent a significant volume of fish farming waste. The hydrodynamics and impact of fish pellets on the aquatic environment is unknown. This paper provides important information for the modeling of fish pellet transport/erosion.

Why did NWRI do this study?
This is a joint study with DFO (Vancouver) and SOC (Southampton Oceanography Centre). NWRI's expertise was used in the determination of the fish pellets settling behaviour. This work will be of value for modeling the impact of fish farming on aquatic environments. Of particular interest is in the prediction of the spatial extent of this impact.

What were the results?

A strong positive correlation was observed for settling rate and erosion threshold with pellet dimension. Erosion threshold was also found to increase with an increasing number of pellets present, likely due to burial and sheltering. This study demonstrates that the composition of fish feed pellets can provide potential tracers for tracking the dispersion of waste feed pellets. Both pellet chemical composition and transport characteristics are essential parameters in determining the dispersal field of waste material, validating model predictions, and assessing benthic impacts.

How will these results be used?

The results of this study provides information on potential tracers of waste feed material and will help validate model predictions associated with the dispersal of waste material. Both the regulatory group and the fish farm industry would gain from the protection and preservation of the aquatic environment.

Who were our main partners in the study?

DFO (Vancouver) and the Southampton Oceanography Centre.

SÉDIMENTATION ET TRANSPORT BENTHIQUE DES GRANULÉS DE NOURRITURE POUR POISSONS DANS UN RÉGIME D'ÉCOULEMENT ÉQUILIBRÉ

T.F. Sutherland, C.L. Amos, C. Ridley, Ian G. Droppo et S.A. Petersen

RÉSUMÉ

Des expériences de sédimentation et d'érosion ont été menées sur des granulés de nourriture pour poissons de diverses tailles dans un canal expérimental rotatif (Mini Flume). Nous avons observé une forte corrélation positive entre le taux de sédimentation et la dimension des granulés (longueur, diamètre des granulés et diamètre équivalent de sédimentation). Les seuils d'érosion présentaient aussi une forte corrélation positive avec les dimensions des granulés. Nous avons aussi réalisé des expériences pour étudier l'effet du nombre de granulés sur les seuils d'érosion pour deux tailles. Les résultats ont mis en évidence une augmentation asymptotique du seuil d'érosion avec la hausse du nombre de granulés présents, ce qui peut être dû à un effet protecteur. De plus, nous avons analysé la composition chimique des granulés en termes de teneur en eau, en matière organique, en carbone et en azote, ainsi qu'en isotopes stables du carbone et de l'azote. Les résultats obtenus vont fournir de l'information sur les traceurs potentiels des déchets de nourriture et aider à valider les prédictions fournies par les modèles sur la dispersion des déchets rejetés.

Sommaire des recherches de l'INRE

Titre en langage clair
Comportement des granulés de nourriture pour poissons pendant une expérience de sédimentation et d'érosion.

Quel est le problème et que savent les chercheurs à ce sujet?
L'aquaculture des poissons est une grande industrie à l'échelle nationale et internationale. On nourrit les poissons avec des granulés qui ne sont pas toujours consommés et vont se déposer au fond des parcs ou être emportés à l'extérieur et se répandre dans le milieu aquatique environnant. Ces granulés peuvent représenter une charge importante de matières nutritives et constituer un volume notable de déchets aquacoles. Nous ne connaissons pas le comportement hydrodynamique et l'impact des granulés de nourriture sur le milieu aquatique. Notre étude apporte une information importante pour la modélisation du transport et de l'érosion des granulés.

Pourquoi l'INRE a-t-il effectué cette étude?
Il s'agit d'une étude conjointe menée par le MPO (Vancouver) et le SOC

(Southampton Oceanography Centre). L'expertise de l'INRE a été mise à contribution pour l'étude du comportement de sédimentation des granulés de nourriture pour poissons. Ces travaux seront utiles pour modéliser l'impact de la pisciculture sur le milieu aquatique. L'aspect particulièrement intéressant est la prédiction de l'étendue spatiale de cet impact.
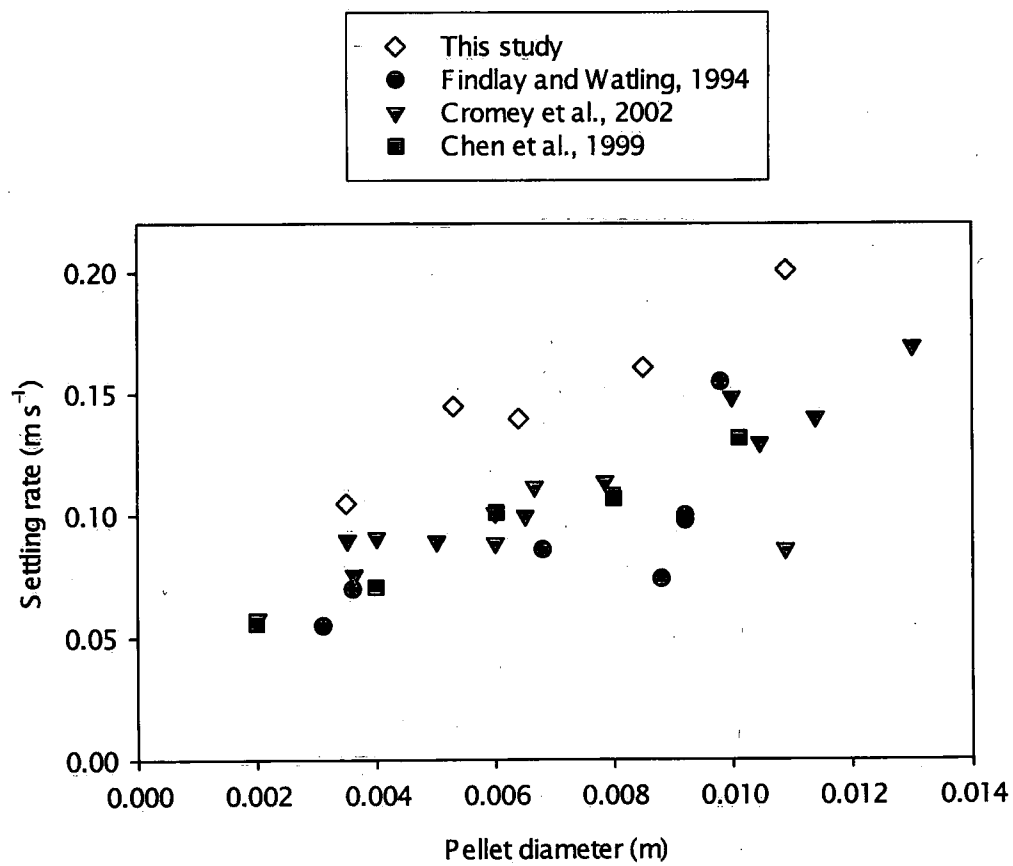
Quels sont les résultats?

Nous avons observé une forte corrélation positive du taux de sédimentation et du seuil d'érosion avec la dimension des granulés. Nous avons aussi trouvé que le seuil d'érosion augmente avec la hausse du nombre de granulés présents, ce qui est vraisemblablement dû à l'enfouissement et à l'effet protecteur. L'étude démontre que la composition des granulés de nourriture pour poissons peut fournir des traceurs potentiels permettant de suivre la dispersion des granulés perdus. La composition chimique des granulés et leurs caractéristiques de transport sont deux paramètres essentiels pour déterminer le champ de dispersion des déchets, valider les prédictions des modèles et évaluer les impacts sur le benthos.
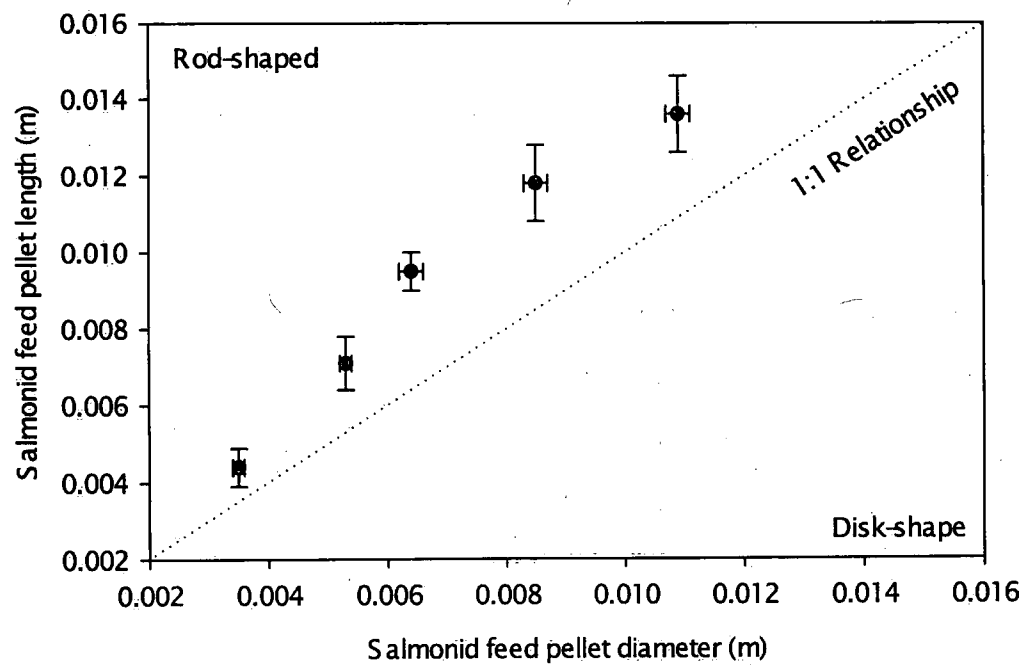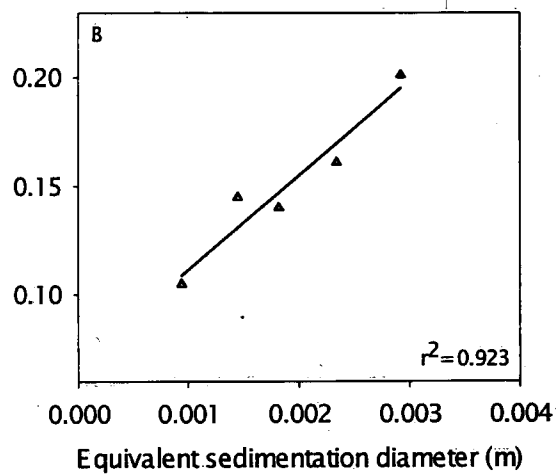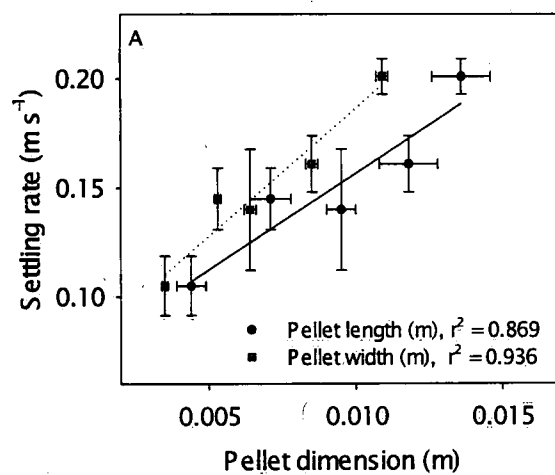
Comment ces résultats seront-ils utilisés?

Les résultats de l'étude fournissent de l'information sur les traceurs potentiels des déchets de nourriture rejetés par l'aquaculture et vont aider à valider les prédictions des modèles sur la dispersion des matières rejetées. Tant les pouvoirs publics que le secteur de l'aquaculture ont à gagner de la protection et de la préservation du milieu aquatique.
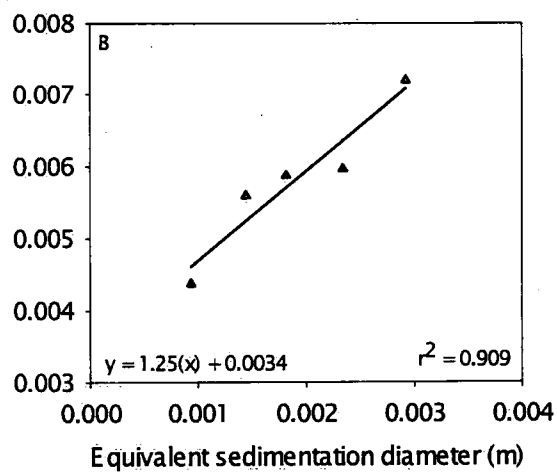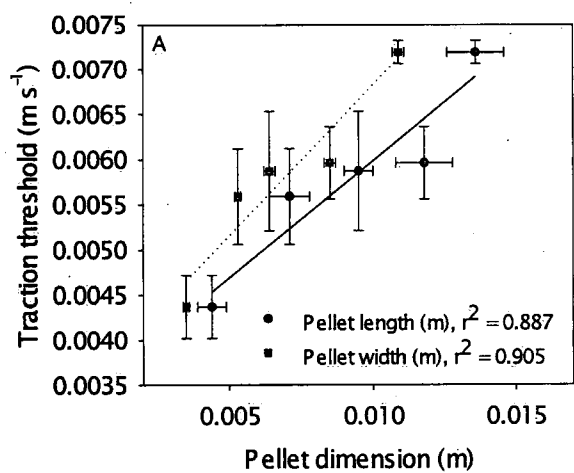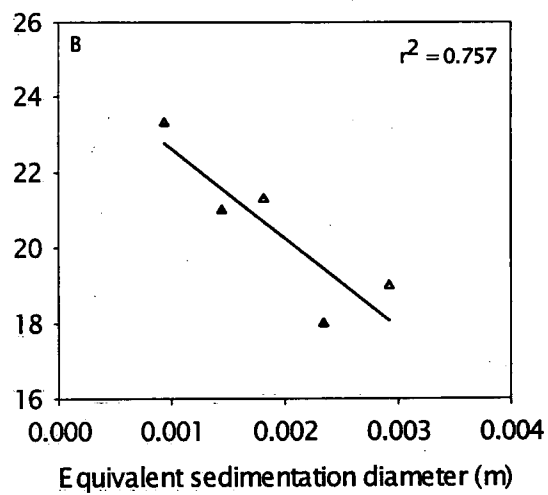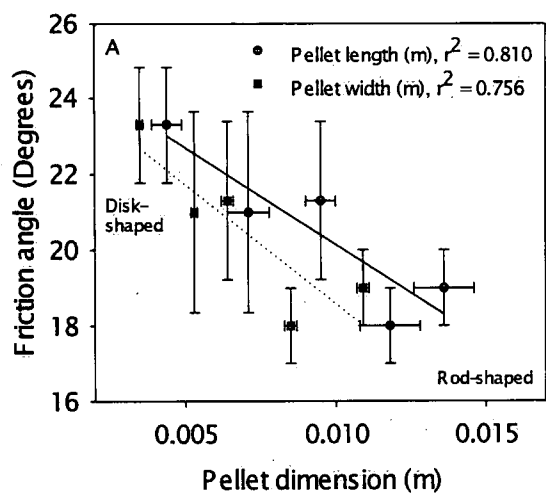
Quels étaient nos principaux partenaires dans cette étude?
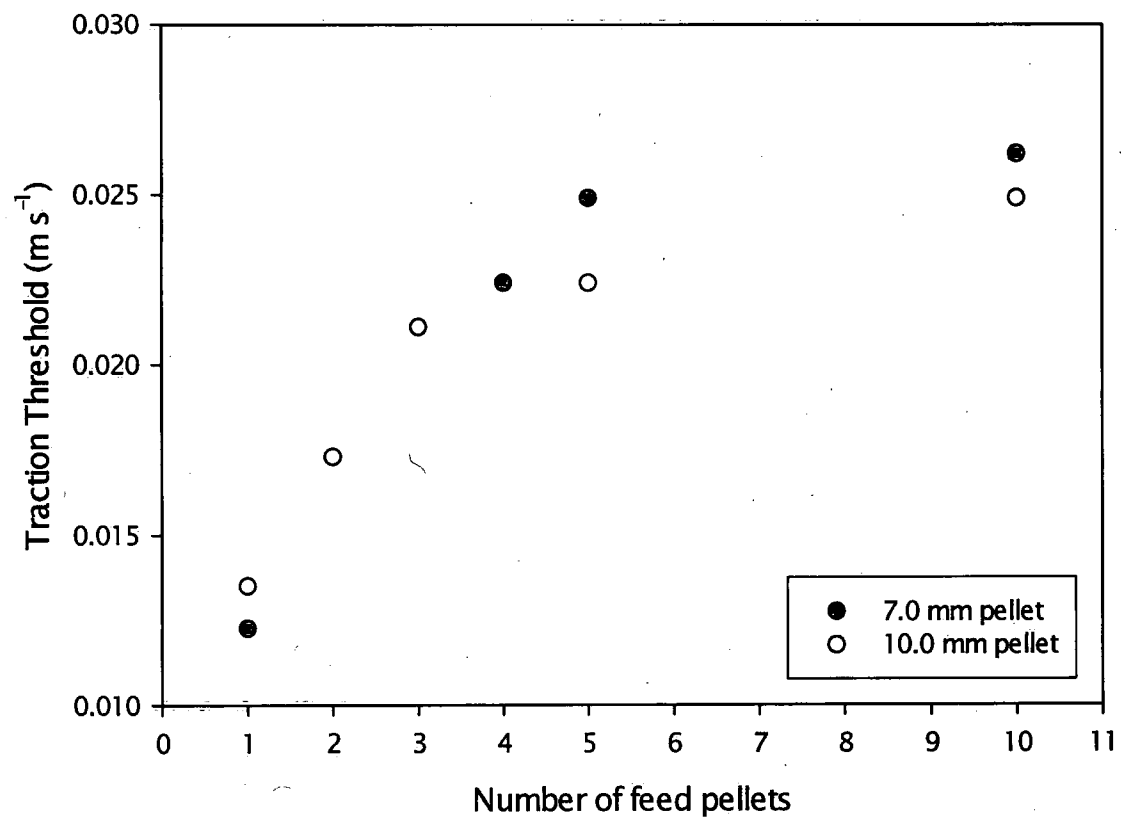
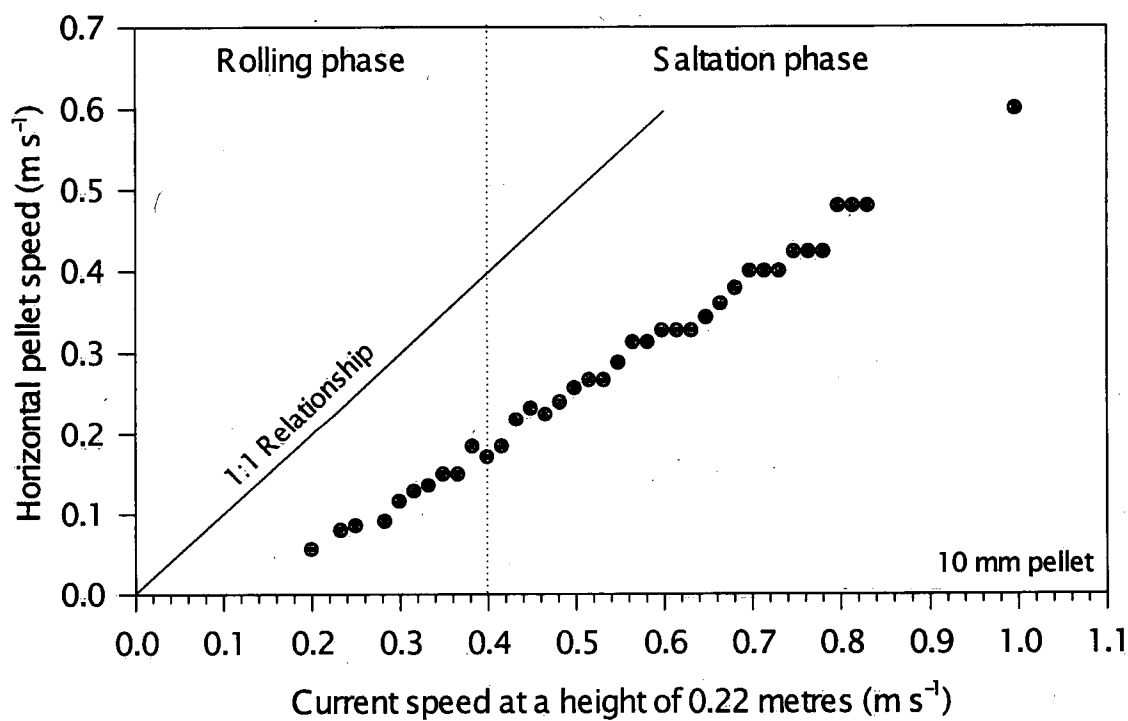MPO (Vancouver) et le Southampton Oceanography Centre.

Legend:
◇ This study
● Findlay and Watling, 1994
▼ Cromey et al., 2002
■ Chen et al., 1999

Y-axis: Settling rate (m s^{-1})
X-axis: Pellet diameter (m)

A

Settling rate (m s^{-1})

Pellet dimension (m)

- Pellet length (m), r^2 = 0.869
- Pellet width (m), r^2 = 0.936

B

r^2 = 0.923

Equivalent sedimentation diameter (m)

A

Traction threshold (m s⁻¹)

- Pellet length (m), $r^2 = 0.887$
- Pellet width (m), $r^2 = 0.905$

Pellet dimension (m)

B

$y = 1.25(x) + 0.0034$

$r^2 = 0.909$

Equivalent sedimentation diameter (m)

Figure showing two scatter plots of horizontal pellet speed versus current speed at a height of 0.22 metres. The upper plot is for a 7.0 mm pellet and the lower plot is for a 10 mm pellet. Both plots are divided into a "Rolling phase" and a "Saltation phase" and include a "1:1 Relationship" line.

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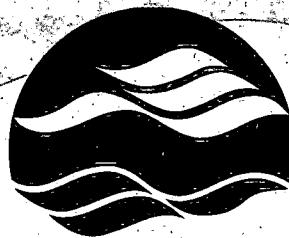
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