DIFFERENCE IN DEPOSITIONAL BEHAVIOR OF HYPOPYCNAL AND HYPERPYCNAL FLOWS IN THE CONTEXT OF CONTINENTAL MARGINS

BY

ANDREW REHN

THESIS

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Advisor:
Professor Gary Parker

ABSTRACT

The conditions necessary for the development of continuous shelf systems, such as those on the continental margin, are not fully understood. Motivated by the observation that continuous shelf-like benches are found on the continental margins in oceans, but not in most lakes, it is proposed that salt is necessary for the creation of continental shelves. This may be characterized in terms of the difference between hyperpycnal and hypopycnal conditions. The former prevails when the incoming flow is denser than the water of the receiving basin; the flow plunges to the bottom of the lake and forms a bottom density flow. The latter prevails when the incoming flow is lighter than that of the receiving basin; the flow rides on the surface water of the receiving basin to form a surface plume. Sediment-laden rivers which enter a saline receiving body, such as the ocean, usually are not dense enough to plunge. Instead, they create buoyant hypopycnal plumes, which lose momentum so that the sediment falls out of suspension locally. Sediment-laden rivers that enter lakes typically can plunge to create hyperpycnal flows, i.e. turbidity currents, which can run out to the bottom of the lake driven by gravity and sediment re-entrainment. Experiments were run in the Ven Te Chow Hydrosystems Laboratory at the University of Illinois in Urbana-Champaign in order determine the role of dissolved salt in the receiving water in controlling the behavior of the incoming flow. A small flume was constructed, with an upstream experimental region of dimensions 61.0 cm (2 feet) in height, 15.2 cm (6 inches) in width, and 243.8 cm (8 feet) in length, and a deeper and wider downstream tank to dampen reflection of any current that runs into it. Twelve experimental runs were performed with matching input conditions; six hyperpycnal with fresh water in the tank, and six hypopycnal with saline water in the tank. The runs were divided into sets of similar total duration, and after each set was completed sediment deposits on the platform were measured. The results of the experiments show that given the same input conditions it is possible for hypopycnal flows to deposit more sediment proximal to the inflow point, whereas hyperpycnal flows carry more sediment downslope. Results show that in the area of deposition outside of a small region near the diffuser, hypopycnal flows deposit twice as much sediment as hyperpycnal flows. Near the diffuser, hyperpycnal flows deposited slightly more sediment, however over the entire measurement area the hypopycnal flows deposited more. One caveat for these results is that sediment deposition inside the diffuser, which guided the flow

into the flume, was not measured. Inclusion of measured values of deposition in the diffuser and could change the results. The particle size distributions of the deposit on the bed were also measured. For hyperpycnal flows, the median particle size of the deposit exhibited steady fining in the downstream direction, while for hypopycnal flows median particle size followed no particular pattern. The results indicate that it is possible that salinity is a driving force for the development of continental shelves. That is, salinity tends to force hypopycnal conditions which creates a tendency for sediment to deposit in the nearshore zone instead of going into deep water. This deposit could eventually build up to wave base to form a shelf-like feature, which could then be elongated along shoreline by alongshelf sediment dispersal processes.

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CHAPTER 1: INTRODUCTION

1.1 Continental Margins

A continental margin consists of a coastal plain, a shelf, a slope and a rise, as depicted in Figure 1 and explained in Pinet (2011). The coastal plain is the subaerial land on the landward side of the coast. The shelf is the shallow (0 to around 150 meters deep) region of ocean that can extend from a few kilometers to up to 100 kilometers offshore of the coastline. At the outer edge of the shelf is the continental slope, a steeper region with a slope of between 3 to 6 degrees (O'Grady et al., 2000). The continental slope descends into the continental rise. The rise is a deeper, less steeply sloped region, ultimately terminating in the abyssal plain, which is the deepest part of the ocean, excluding trenches, and is largely flat.

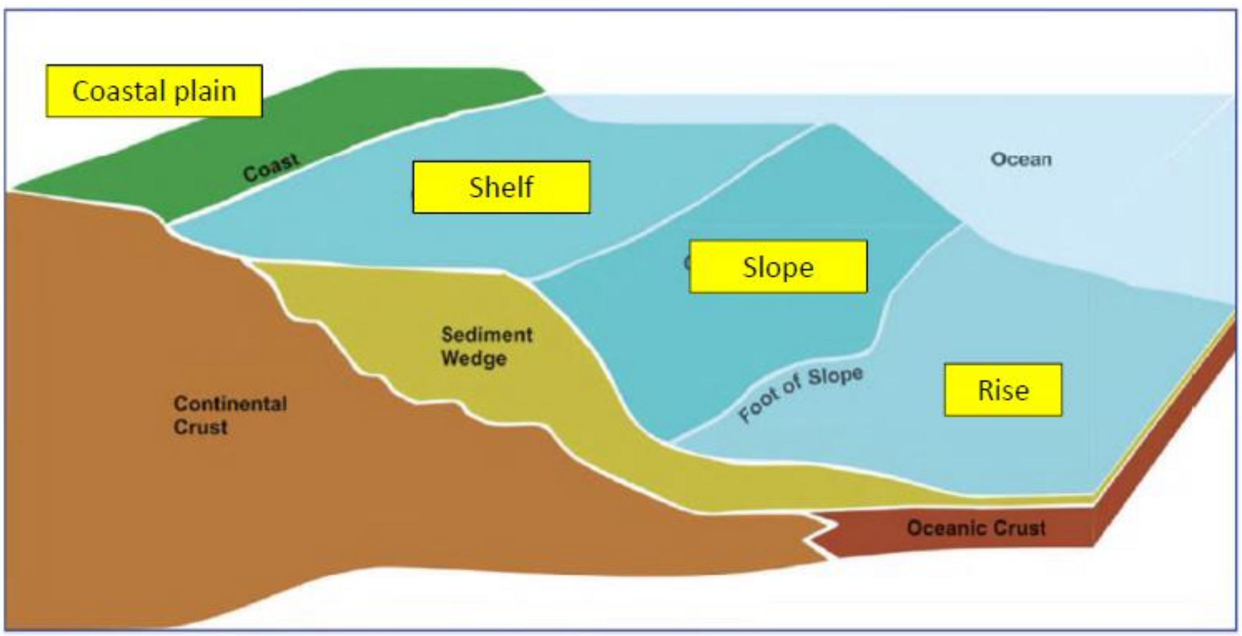

Figure 1 - A typical continental shelf.
(http://www.science.gc.ca/0A615682-E1A2-448E-B87E-CF90931F7160/ecs.jpg)

Margins take one of three basic shelf patterns; passive, convergent and foreland (Swift and Thorne, 1991). In this thesis, we consider a mechanism for the building of passive shelf margins, such as the margin in the north, west and south portion of the Gulf of Mexico (See Figure 2, adapted from Swift and Thorne, 1991). Passive margins are hinged on their landward side, and experience subsidence due to thermal contraction of the margin basement (Pitman, 1978). Meanwhile, sediment deposits on the margins, and as the rate of subsidence due to thermal forces decreases, the subsidence due to the weight of deposited sediment on the margin increases. The result is a seaward thickening deposit of sediment.

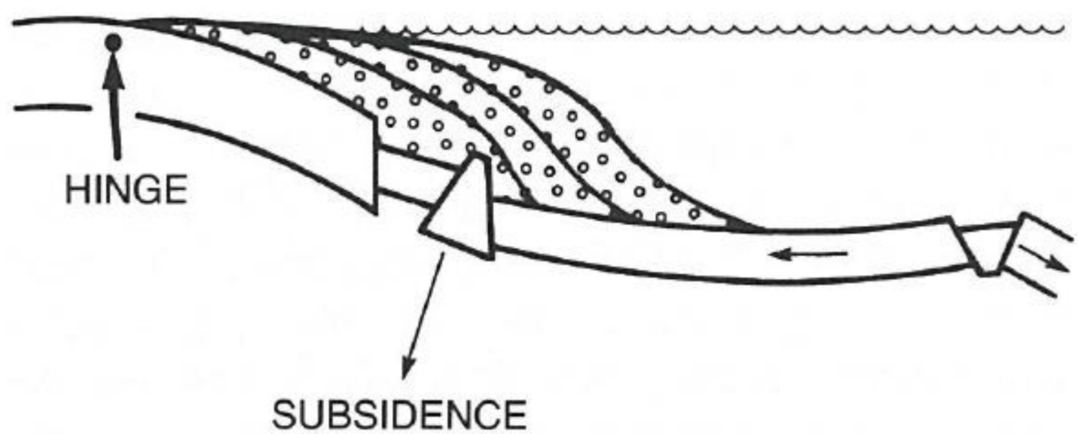

Figure 2 - A diagram of a passive margin.

A set of geohistorical factors have been identified as the dominant controls of margin development (Swift and Thorne, 1991). Five forcing factors have been identified as the dominant controls. The factors, notated similarly to Sloss (1962), are the rate of sediment input **(Q)**, the type of sediment i.e. grain size **(M)**, the rate of sea level variation **(R)**, the rate of dispersive sediment transport **(D)**, and the fluid power **(P)** available to remove sediment from the shelf area. These factors are considered in a historical context, so for example the sediment delivery rate is considered in terms of mass delivery per year. Swift and Thorne (1991) suggest that shelf sedimentation is predictable on a geological time scale, and represents a driver toward a steady-state condition, or regime. The stratigraphic record can show a variety of regimes for a particular margin, revealing changes in the relevant geohistorical factors over time. The characteristics of an equilibrium slope can be predicted by means of an understanding of the relationships between these geohistorical factors.

Of these factors, the supply of sediment **(Q)** may be the most crucial of the forces driving margin growth. Carvajal et al. (2009) thoroughly examined the role of sediment supply in driving margin growth. They found that for ancient shelves, progradation rates are correlated to sediment supply; margins with higher rates of progradation also have more volume of sediment delivered. Their study was focused on shelf-margins which receive sediment primarily through river and delta systems, as opposed to shoreline erosion, oceanic currents from outside the shelf, or cross shelf incision. Shelf-margins fed by rivers are also the focus of this report.

Numerous studies have suggested that the form of the shelf can achieve a steady state (Swift and Thorne 1991). Sediment which deposits on the shelf floor builds up until it is shallow enough that the energy due to wave action resuspends the sediment. The depth at which this occurs is called wave base. This floor is maintained by the wave action, and the excess sediment flows down the slope toward the deep sea. This suggests the possibility of a shelf form that is created by a balance between the fluid power P and the sediment supply Q. In a simplified model, the prograding shelf, known as a clinoform, was found to have a fixed form translating in space, given fixed and steady input conditions (Parker 2006).

Shelf margins often form a continuous bench around the coastline of a continent. One theory for why continuous benches occur is that continental shelves are drowned coastal plains that were exposed during a time of lower sea level (Muto and Steel 2002). However, this theory does not explain why shelves form a continuous bench around continents that connects discrete deltas. A potential explanation for the continuous bench is the idea of lobe switching (Olariu and Bhattacharya 2006). Over time, river mouths will move as rivers undergo avulsion. The changing position of the mouth of a river can create local benches, and over time the river may 'fill in the gaps' with a multitude of local benches forming a continuous bench.

Except in a few cases, continuous bench like shelves do not occur around lakes. One notable exception is the Red Sea, which has carbonate shelves, but negligible sediment delivered from rivers. Siliciclastic margins are not found in lakes. However, lakes would seem to satisfy all the conditions discussed above for the formation of continuous benches such as the continental shelves of the ocean. Lakes exhibit water level rise and fall, such as Lake Mead in Colorado, but no benches (Parker 2006). Rivers entering lakes can also exhibit lobe switching. If these are the driving factors for continuous benches, then why is it that lakes do not have them?

1.2 Density Flows

Thus far, the discussion of sediment delivery has been in broad terms as a rate of sediment delivery, without consideration of the way that sediment is delivered. In this thesis, the point of focus is not what happens to the sediment after it has deposited, but instead on the type of flow that delivers the sediment to the shelf. Here we explore the idea that the density-driven flows caused by the difference in density of the sediment-laden river water and the receiving body can be crucial to the existence of the shelf. Perhaps this difference can explain the presence of benches in the ocean but not in lakes.

Density flows occur when two fluids of differing densities meet. In this thesis, density flows due to sediment and salt are considered, but density flows can occur in any setting where density differences exist, such as those due to temperature or contaminants such as oil. In the natural environment, density flows are observed frequently in the region rivers meet their terminal bodies of water. Most rivers carry sediment loads, making them denser than fresh water alone at the same water temperature. Where a river meets a freshwater lake, the sediment in the river often deposits locally to form a delta, with the remaining finer sediment plunging to form a turbidity current. This turbidity current carries the finer sediment to the bottom of the lake (Kostic and Parker 2003). This turbidity current is an example of a hyperpycnal flow, i.e. a plume which flows along the basin floor because it is denser than the ambient water. Hyperpycnal flows are driven by their own density, the slope of the bed they flow over, and the re-entrainment of bed sediment.

Most rivers are composed of water that is less dense than the saline water of the ocean, and thus a river that flows into the ocean forms a buoyant plume on the ocean surface, called a hypopycnal flow. A hypopycnal plume is a surface plume driven by the momentum of the sediment flow, but lacks access to a sloped bed or a sediment supply as driving forces, so the sediment in the plume eventually comes out of suspension and deposits. In some cases, the deposition of sediment is enhanced by a process called fingering which is driven by double diffusion (Stommel 1958; Turner 1967). In some experiments conducted at the Ven Te Chow Hydrosystems Laboratory, a secondary hyperpycnal plume has been observed to develop below the hypopycnal plume (Parsons et al., 2001).

In some cases, the sediment-laden river water entering the ocean will be dense enough to form a hyperpycnal flow. In a study of over 150 rivers worldwide, Mulder and Syvitski (1996) found that 66% of rivers can produce a hyperpycnal flow with a 1000-year return period. This will happen with moderate frequency in highly erodible areas, and in other areas during floods which can cause the river to carry enough sediment to be denser than saline ocean water. Notably, this has been found to happen with the Huang He River in China the Yellow River, named for its sediment content), and also in other places across the globe with high relief and erodible terrain, such as in Taiwan, parts of the US, Turkey, New Zealand and more. However, the 20 largest rivers in the world do not and seemingly cannot meet the conditions for the formation of hyperpycnal flows. For simplicity in this thesis, hypopycnal flows are considered as typical of the ocean setting, and hyperpycnal flows as typical of the freshwater lake setting.

1.3 Motivation

The motivating question for this study is; why are shelf-like structures observed in passive continental margins but not in lakes? Our hypothesis is that fluvial input of terrigenous sediment through hypopycnal flows abet the formation of continuous shelves. In the case of river flow that plunges to directly form a downslope-flowing turbidity current, this current can run out to deep water, so that the sediment bypasses the near-shore zone. In the case of hypopycnal plumes, however, the sediment might be expected to rain out nearer to the shoreline, so providing source material for the formation of a continuous bench. This hypothesis is in part supported by the fact that continuous shelves are absent in lake environments, where hypopycnal flows are much less likely to occur.

The first step to answering this question is to understand the differences between the deposition pattern of hyperpycnal and hypopycnal flows given similar input conditions. Here we do not address the issue of the formation of a continuous bench directly. Instead, we consider a simplified configuration in which we can study the difference nearshore depositional patterns between hypopycnal and hyperpycnal flows. Our configuration includes a vertical direction and an offshore direction, but no alongshore direction. We wish to see if in our simplified configuration, hypopycnal conditions from a river abet nearshore deposition. We hypothesize that if this is the case, the bed might build up to wave base, and alongshore distribution processes could connect this deposit from delta to delta to form a bench.

An experimental facility was built to run hyperpycnal and hypopycnal flows using the same input conditions with a receiving body that is either fresh or saline and the measure the sediment that deposited. Videos of typical runs are available on the web through Professor Gary Parker's webpage. The tank was built at the Ven Te Chow Hydrosystems Laboratory at the University of Illinois in Urbana Champaign, and the experiment was run throughout the summer of 2015.

CHAPTER 2: METHODOLOGY

2.1 Experimental Design

The experiments were designed to evaluate the differences between the deposition of hyperpycnal and hypopycnal flows caused by a sediment laden inflow entering a body of water that is either fresh or saline. For these experiments, the receiving body was a rectangular tank with a width of 15.2 cm (6 inches), and a depth of 20.3 cm (8 inches) in the upstream, increasing to 43.2 cm (17 inches) in the downstream due to a sloping bottom. Hyperpycnal experiments had a freshwater receiving body, and hypopycnal experiments had a saline receiving body. Each type of experiment (hyperpycnal/hypopycnal) had three sets of runs. After each set, the deposition of sediment on the bed was measured. The sets were: a) a set of three runs at 8 minutes each, b) another set of two runs at 12 minutes each, and c) a third set consisting of one run for 24 minutes. Therefore, the total time in each set of runs was approximately 24 minutes. The naming convention adopted for the experiments is shown in Table 1. The runs labeled 1, 2 and 3 were approximately 8 minutes, the runs labeled 4 and 5 were approximately 12 minutes, and the runs labeled 6 were approximately 24 minutes. The exact duration of each run is listed. All runs were completed with an inflow of 0.5 liters per minute. The specific gravity of the inflow varied between 1.018 and 1.022 due to the addition of sediment to the fresh water, which was always salt-free. The specific gravity of the receiving water was 1.00 for the hyperpycnal experiments, and approximately 1.03 for the hypopycnal experiments (due to salinity). The experiments are summarized in the table below:

Table 1 – A description of naming conventions adopted in this document. This experiment is made up of 12 runs of 2 different types of flows: hypopycnal and hyperpycnal. The runs are combined into six sets.

Run Summaries			
	Inflow	**Duration**	**Bed Measurement Set**
	Specific Gravity	Minutes	-
Hypo1	1.022	8.67	HypoSet123
Hypo2	1.0185	8.57	HypoSet123
Hypo3	1.0185	8.25	HypoSet123
Hypo4	1.0185	14.30	HypoSet45
Hypo5	1.022	12.20	HypoSet45
Hypo6	1.021	24.00	HypoSet6
Hyper1	1.019	8.00	HyperSet123
Hyper2	1.018	7.88	HyperSet123
Hyper3	1.019	8.17	HyperSet123
Hyper4	1.021	12.48	HyperSet45
Hyper5	1.019	11.95	HyperSet45
Hyper6	1.0185	24.00	HyperSet6

In addition to measurements of bed deposition, for the first run of each set, mid-run samples were taken of the sediment at various points in the sediment flow. Mid-run samples were collected with a siphon or a large pipette (turkey baster), depending on the volume needed. These samples were analyzed for particle size distributions and, in the case of Hypo1, also for sediment concentrations. Mid-run samples, inflows, and bed measurements were analyzed for particle size distributions using a device known as a “LISST”, the details of which are explained below in Section 2.4 below.

2.2 Experimental Facility

The experimental facility, shown in Figure 3, is a cast acrylic tank with an upstream section where the experiment and measurements were performed, and a downstream section to receive water and dampen any reflection of sediment-laden flows. A slotted aluminum frame around the tank provides strength and stability. At the time of the experiments, the tank was located on the east end of the Ven Te Chow Hydrosystems Laboratory (University of Illinois Urbana-Champaign), below the platform of the Margins Basin therein (see http://vtchl.illinois.edu/). The upstream section, called the Shelf Tank, has internal dimensions of 61.0 cm (2 feet) in height, 15.2 cm (6 inches) in width, and 243.8 cm (8 feet) in length. The downstream section, called the Abyssal Tank, has internal dimensions of 152.4 cm (5 feet) in height, 30.5 cm (1 foot) in width, and 121.9 cm (4 feet) in length. The Shelf Tank connects to the Abyssal Tank so that the tops of the two tanks are level. The Shelf Tank contains a platform with an adjustable support, making the slope of the bed platform variable. For these experiments, the platform was raised 7.6 cm (3 inches) at the downstream end and 30.5 cm (12 inches) at the upstream end, creating a fall of 22.8 cm (9 inches) over the 243.8 cm (8 feet) of the tank, or a 9.37% slope.

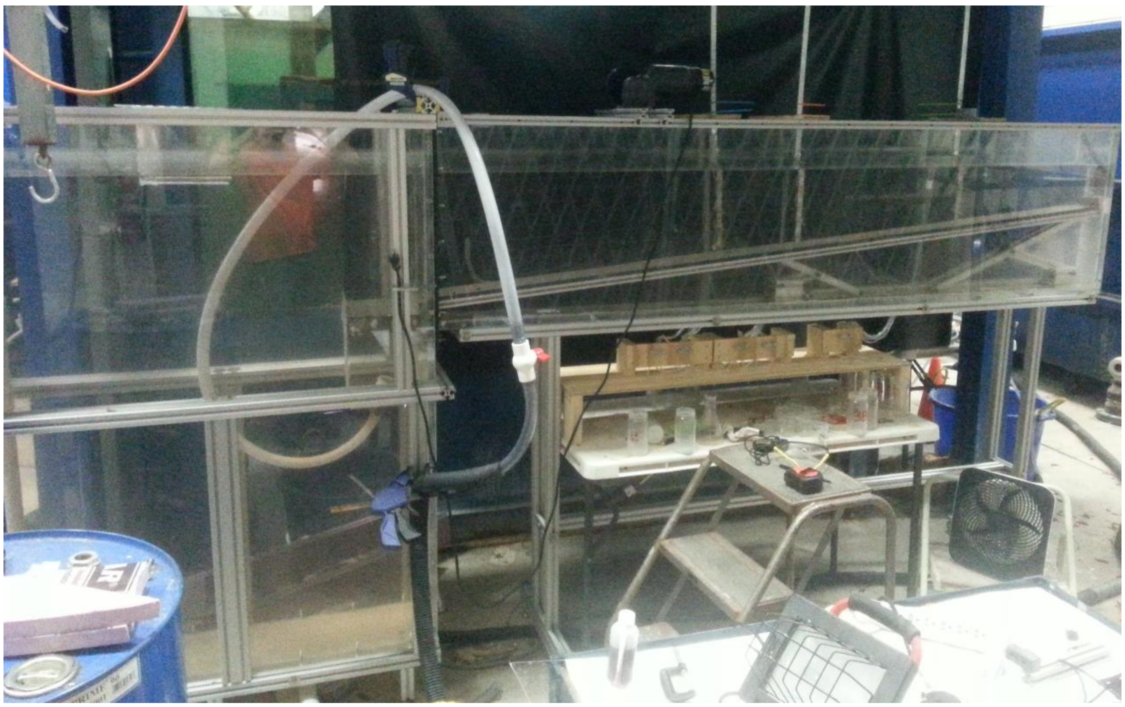

Figure 3 – An image of the experimental facility, including the usual lab mess surrounding the tank. The upstream Shelf Tank is on the right, and the bed platform is clearly visible. The left end corresponds to the downstream Abyssal Tank, and the long hose leaving the tank is the downstream siphon used for the hyperpycnal flow condition.

At the end of the platform, just inside the Abyssal Tank, is a small rectangular plastic box with no top and a siphon in the bottom. It is designed to collect sediment that leaves the platform during the hyperpycnal experiments that would otherwise reflect and cloud the tank. The box was custom-made at the Champaign Urbana Community Fab Lab, using a laser cutter and acrylic. The siphon was run at extremely slow flow rates, just enough to mitigate reflection of sediment flows back into the experimental region. The Abyssal Tank also has a standpipe which regulates the water level, and helps to prevent reflection in the hypopycnal case.

Sediment was prepared in the mixing tank on the south side of the Margins Basin. The mixing tank was filled to a minimum of 10 gallons before running so that the impeller can stir the mixture properly. To prepare for each run, sediment was added to the mixing tank, stirred, and measured until a specific gravity of approximately 1.02 was read using the hydrometer. There was some variation in this process, and any specific gravity in the range 1.018 to 1.022 was deemed acceptable for these experiments.

Sediment was pumped from the mixing tank to a diffuser inside the Shelf Tank with a peristaltic pump. The diffuser was also custom-made from acrylic at the Champaign Urbana Community Fab Lab. For the hypopycnal case, the diffuser was placed just under the surface of the water, and for the hyperpycnal case the diffuser was placed on the bed. After each run, the sediment in the tank was left to settle until the water was completely clarified. When a full set of runs was completed and settled, bed measurements were collected. Exact times for settling were not measured, but the water always completely clarified by the next day.

2.3 Sealing the Platform

The platform inside the tank was designed to be able to change slope; therefore a permanent seal along the sides of the platform was not possible. During initial hyperpycnal experiments, notable amounts of sediment would spill over the sides of the platform, and it was deemed necessary to seal the edges of the platform. A product known as Poly Foam Caulk Saver was pushed between the platform and the wall on one side of the tank while the tank was full. This created enough pressure on one side of the platform to seal both sides. When the tank was drained, the walls of the tank would compress slightly, inelastically crushing the foam insert, which would not re-expand when the tank was refilled. Therefore, the foam caulk had to be replaced each time the tank was drained.

The platform was not sealed for the hypopycnal experiments. There were no visible sediment leaks during the hypopycnal experiments, so sealing was not considered necessary. However, in future experiments, I recommend sealing the platform for both hyperpycnal and hypopycnal experiments.

2.4 Particle Size Distributions

A device called the LISST (Laser In-Situ Scattering Transmissometery) was used to measure particle size distributions (PSD) for these experiments. The LISST is capable of rapid particle size distribution measurements, taking only a few minutes to set up, run a sample, and clean the machine before running the next sample. The LISST model in the basement of the Ven Te Chow Hydrosystems Laboratory is a LISST-ST. A thorough consideration of the LISST can be found in the Master's thesis of Franciso Pedocchi Miljan at the University of Illinois.

The results from this instrument were compared to results from another device marketed under the name "Mastersizer". The Illinois State Geological Survey has a Mastersizer device that can be used for a fee. Measurements of the particle size distribution of the same sediment were taken with both devices. The devices were found to give similar results, with some differences. A sample of sediment collected on May 4th was used to evaluate the two devices. The results are shown in Figure 4. I assumed that the Mastersizer is the more accurate of the two devices, and took its results as the baseline results. The D_{50} grain size (size such that 50% of a sample is finer) measured by the LISST is in agreement with that measured by the Mastersizer. However, the two disagree around the D_{20} and D_{80} measurements, and at very small particle sizes. However, the difference in results between the two devices is small enough to motivate using the LISST for the bulk of the analysis, given that it is free to use, and can run dozens of samples in one day.

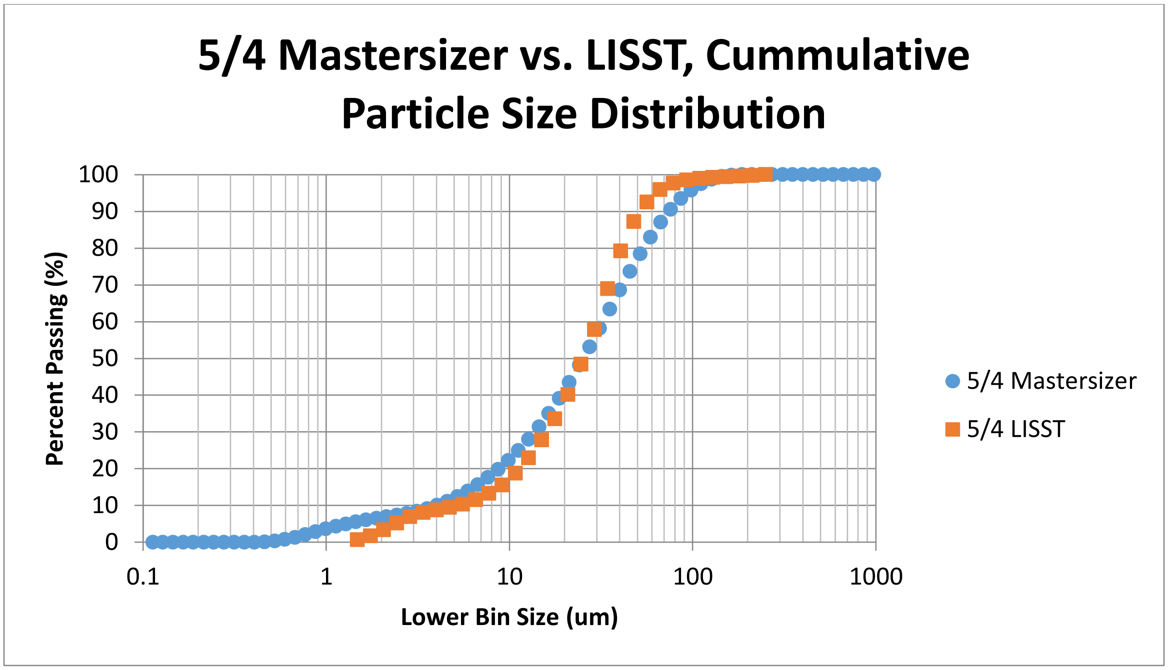

Figure 4 – Particle size distributions of a sample taken on May 4th, 2015 measured with the LISST (orange) and the Mastersizer (blue).

The LISST measures particle size distributions in 32 bins, ranging from a median bin size of 1.44 microns to 231 microns. The particles in each of these bins are measured as a density with units of micrograms per liter. Each run of the LISST gives 3 measurements. The first measurement was always used because it should be the most accurate, as the results will slowly change as the particles settled. The LISST was run twice for each sample to check results and ensure redundancy. If the results show did not show good agreement, it was run again (if possible, depending on if there was enough sample sediment left to run). The first of the three measurements from each pair were averaged and taken as the final result for the particle size distribution for each sample.

The percent of the total mass in each bin was calculated by taking these density bin values and dividing each bin by the total sum of the densities across all bins. The particle size distribution in terms of percent passing was then calculated by incrementally summing the percent in each bin, starting from the bottom. The upper bin size was used for the particle size distributions, starting from 1.48 microns to 250 microns. This methodology was followed for all of the particle size distributions in this thesis.

2.5 Inflow Sediment

The sediments used for this experiment were ground quartz from the AGSCO Corporation. Many attempts were made to find the proper sized sediment to get an acceptable (i.e. measurable and reproducible) amount of deposition. Three different sizes of sediment were purchased from the AGSCO Corporation for the experiments, #325, #1250 and L205A. These sediments have a D_{50} of 20, 10 and 4 microns, respectively. The largest of these sediments, #325, was selected for the final experiments. Finding the right sediment was particularly troublesome in the hypopycnal case. In initial test runs for the hypopycnal experiments, no deposition would occur and the sediment would remain suspended in a dense layer, not settling out for hours. To solve this problem, the sediment had to be 'washed' to remove part of the finer sediment. This involves filling a bucket with the sediment and water, stirring thoroughly, and then waiting for the larger particles to settle. The fines are then siphoned from the top of the water column, leaving a relatively larger distribution behind.

This method was refined while in the process of running the experiments. For the hypopycnal flows, the excess inflow left in the mixing tank was returned to the settling bucket, and allowed to resettle, and then the water was siphoned off again. Essentially, the particles were rewashed after each run. This resulted in hypopycnal inflow particle size distributions that showed significant variation from run to run. The hyperpycnal inflow particles were only washed once, and therefore show significantly less variation.

Figure 5 depicts particle size distributions of the unwashed sediment, and also particle size distributions for the inflows of the 12 experiments measured with the LISST. The hypopycnal experiments are shown in blue and the hyperpycnal experiments are shown in orange. The unwashed sediment is the thick black line. Measurements for Hyper2 were lost and are not included in the figure. In general, the washed sediment is actually finer than the unwashed sediment, except at smaller particle sizes, indicating that the washing process was successful at removing the ultra-fine particles, but removed some of the larger ones as well.

The figure also highlights some of the variation in the hypopycnal inflow particle size distributions. Hypo2, Hypo5, and Hypo6 all seem to have similar distributions to the hyperpycnal inflows, but the other three hypopycnal runs have some significant variation. In particular, the inflow for the first hypopycnal experiment (Hypo1) was significantly coarser than the unwashed sediment. Also notable is Hypo4, which is significantly finer than any of the other inflow distributions. This may be an error in measurement, as it was sampled after the experiment had finished running, and some intervening settling may have occurred.

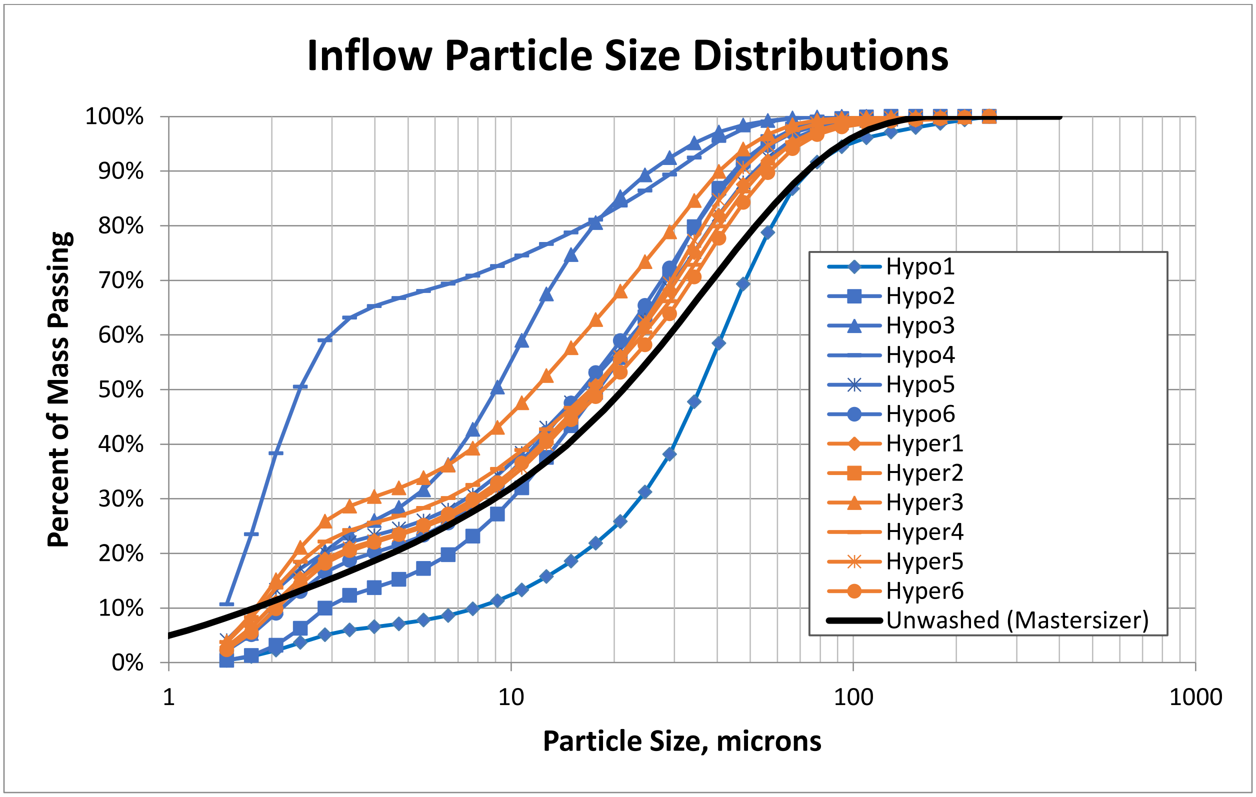

Figure 5 – Particle size distribution of the inflow for each of the 12 runs measured with the LISST, and the unwashed particle size distribution measured with the Mastersizer.

The D_{20}, D_{50}, and D_{80} values are reported in Figure 6. In all cases besides Hypo1, the unwashed sediment has a larger D_{80} and D_{50}. The D_{50} is fairly consistent for Hypo2, Hypo5, Hypo6 and all of the hyperpycnal experiments. Other inflows have some differences that may have impacted the results. A more consistent method for setting the size distribution of the inflow sediment should be employed throughout in future experiments.

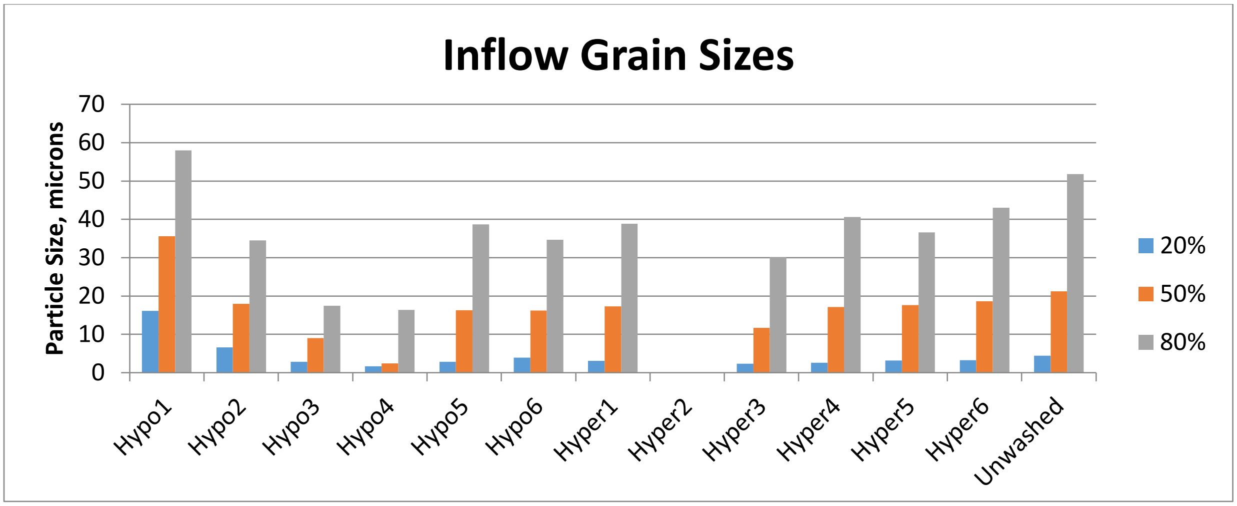

Figure 6 – Inflow D_{20}, D_{50} and D_{80} grain sizes for the inflows for all 12 runs, excluding Hyper2, which was inadvertently not collected.

2.6 Bed Measurement

The bed platform was divided into 12 segments in order to measure the pattern of sediment deposition. Each measurement segment, excluding the first segment, was chosen to be exactly 20 centimeters long. The first segment is 25 centimeters to account for the extra 5 centimeters of the 245-centimeter bed. Sediment was removed from each of these segments and the amount of deposition was measured. The amount of deposition was evaluated by mass instead of a measured depth of deposition because the thickness of deposited sediment was too small to accurately measure on a length scale. Measuring mass gave a more accurate description of the amount of sediment deposited, regardless of any compaction of sediment on the bed.

The sediment on the bed was isolated using a custom-made plastic chamber, which was lowered onto the bed segment being measured. This prevented the nearby sediment that was not yet being measured from being disturbed. Then, the sediment was scraped into a small pile using a small piece of plastic (my student ID in this case). The sediment was piled in order to be quickly siphoned into a bucket.

Measuring the sediment siphoned from the bed proved to be a challenge. Two methods were utilized during the experiments. The first method attempted to directly measure the mass of sediment which deposited by extracting, drying and weighing the deposit. The second method involved siphoning all the sediment and some fluid from a segment, and estimating the sediment contained in that mixture using a hydrometer and scale.

2.6.1 Bed Measurement Method 1

For the first method, the sediment was extracted using a siphon and poured into a filtering bucket. The bucket had a hole in the bottom, and the entire bucket was lined with an industrial-sized coffee filter to capture the sediment while the water drained away. The filters were then brought to an oven to be dried and weighed to determine the mass of deposition.

This method had three major problems that ultimately lead to it being abandoned part way through the experiments. First, the sediment that was used in this experiment ranges from at least 1 micron to over 100 microns. The filters weren’t rated to any particular size, but a Google search has lead me to believe that the expected filter size should be able to capture 20 micron-sized material, meaning all sediment below 20 microns would be lost. Measurements of particle sized distributions show that about 30% of the mass of the deposits were below 20 microns. This was also observed in practice, in so far as the water that drained through the filter would leave behind sediment upon drying.

Secondly, the process of siphoning the sediment from the bed into the filter bucket required approximately 3 liters of water to be siphoned with the sediment. In the case of hypopycnal flow, this water would be extremely saline. The salt from this water would remain after the water was evaporated in the sediment oven. This caused measurements of the mass of the sediment to be inaccurately large.

Finally, the oven that was used to dry the sediment samples broke, and alternative ovens were not available in the time frame necessary for the experiments, so a different method for measuring bed deposits had to be devised. Unfortunately, the first method had already been used for the first set of hypopycnal experiments (HypoSet123), and the samples for the second set (HypoSet6) were already on filters waiting to be dried when the oven broke. Samples were not saved between experiments, so it was impossible to check measurements after changing methods. This may have caused some discrepancies in the data, as is discussed later on.

2.6.2 Bed Measurement Method 2

A second method was developed to measure the deposit on the bed, using bulk measurements of mass, volume and density. This method was used for HypoSet45, HyperSet123, HyperSet45, and HyperSet6. The sediment was siphoned off the bed into a 4-liter bucket. The bucket was marked off every half liter, and the marks were verified using a scale and water with a known temperature and mass. The bed samples were siphoned off the bed and into the bucket. The samples contained all of the sediment in a measuring segment, and an arbitrary amount of water, i.e. however much was required to extract all the sediment. The samples were then weighed and the volume was measured. Then, the mixture in the bucket was stirred thoroughly to resuspend the sediment, and a sample from the bucket was siphoned into a graduated cylinder and the specific gravity was measured using a hydrometer. The graduated cylinder was used because it is tall and thin, ideal for measuring the specific gravity with a hydrometer using the least amount of water.

Using the parameters measured, and a few parameters known in advance, it was possible to determine the mass of sediment in the sample. The density ρ_t, volume V_t and mass M_t of the mixture were measured. The density of water ρ_f and density of the sediment ρ_s are both known. Together, these parameters can be used to calculate the mass of sediment M_s in a sample extracted from the bed using this formula:

$$M_t = M_s + M_f$$

$$M_t = M_s + \left(\rho_f (V_t - V_s)\right)$$

$$M_t = M_s + \left(\rho_f \left(\frac{M_t}{\rho_t} - \frac{M_s}{\rho_s}\right)\right)$$

$$M_s = M_t \left(\frac{1 - {\rho_f}/{\rho_t}}{1 - {\rho_f}/{\rho_s}}\right)$$

This method was ideal because only two quantities, ρ_t and M_t, needed to be measured. The total mass was measured using an Adam Equipment LBK 12a Weighing Scale, which is accurate to a gram. The density was measured with a Fisherbrand Hydrometer. The measurements of the hydrometer were not as precise as would be ideal, since the hydrometer becomes very difficult to read when the specific gravity of the fluid being measured is close to that of pure water. Specific gravities near 1 were read accurately to only about 0.001 units of specific gravity. At high specific gravities, the precision improved to 0.0005, which is the accuracy of the hydrometer. A more precise hydrometer, in particular when close to 1.0, is recommended for future work. The use of this hydrometer resulted in some zero mass measurements in regions that had nonzero deposition, due to inability to read any value other than a specific gravity of 1.0.

This method needed to be modified in the case of the hypopycnal experiments which included saline ambient water. In this case, the density of the fluid is no longer a known value, since it is composed of both water and salt. Instead, it has to be measured. A calibration curve was developed that relates salinity to specific gravity. The salinity was measured with a YSI Exo1 Multiparameter Sonde. The calibration curve is shown in Figure 7.

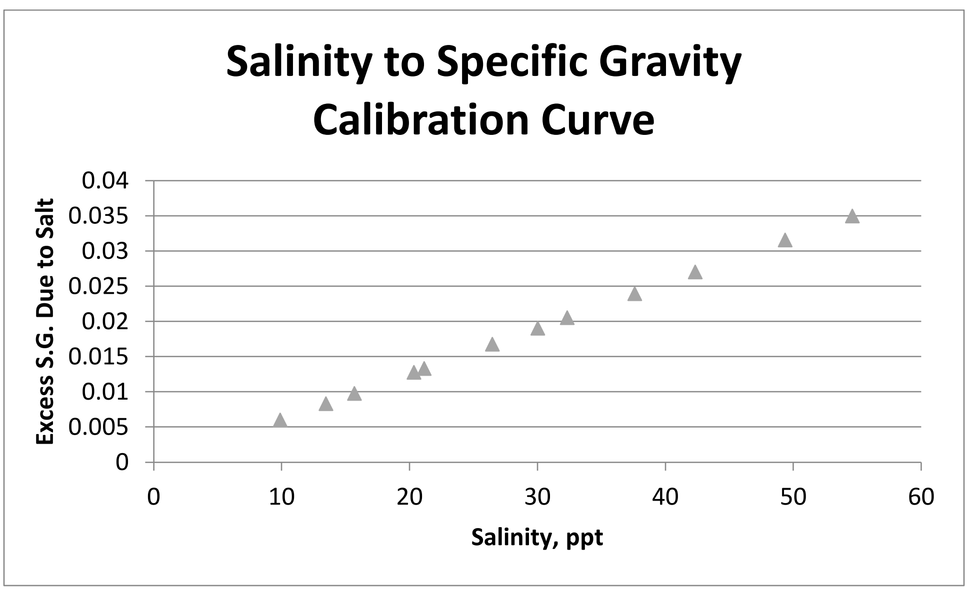

Figure 7 – Calibration curve which relates salinity in parts per thousand measured with a salinity probe to specific gravity measured with a hydrometer. The specific gravity is represented as excess specific gravity, meaning actual specific gravity – 1.0.

The fit for this set of data takes the form:

$$SG_E = (0.6471 \times Sal - 0.3941)/1000$$

where SG_E is the excess specific gravity due to salt and Sal is the salinity measured in parts per thousand. Therefore, the density of the fluid is given by:

$$\rho_f = \rho_w(SG_E + 1)$$

where ρ_w is the density of fresh water, and ρ_f is the density of the water-salt solution. Therefore, the same formula can still be used to compute the mass of sediment in the sample, except the value for ρ_f is the water plus the salt:

$$M_s = M_t\left(\frac{1 - {}^{\rho_f}/_{\rho_t}}{1 - {}^{\rho_f}/_{\rho_s}}\right)$$

CHAPTER 3: RESULTS

3.1 Observations of Hypopycnal Flows

The hypopycnal flows consistently exhibited some unexpected characteristics, including a partial conversion into a hyperpycnal flow, with both flows occurring simultaneously in the same run. Figure 8 depicts the evolution of a hyperpycnal flow.

At the start of the hypopycnal run, the sediment leaves the diffuser in a thin plume that is about a few centimeters thick. In a few moments, small strands of sediment begin falling from the plume, in a process called fingering. When the fingers in the upstream portion reach the bed, they begin to form a diffuse turbidity current. Around when this occurs, the fingers in the downstream portion of the flow begin to drift back upstream. As the turbidity current grows and moves downstream, the fingers begin to drift back upstream. The top-most layer of sediment in the plume is moving downstream, but below that the fingers are moving upstream to the area just in front of the diffuser where the sediment in the fingers is swept downward into the turbidity current. The end results is two flows, one hyperpycnal and one hypopycnal, moving downstream, and a layer of fingers in between that drifts upstream. Usually, the hyperpycnal flow formed during such initially hypopycnal runs lifted off the bed about half-way down and became interflows. As the experiment continues, the flume becomes too clouded to observe anything.

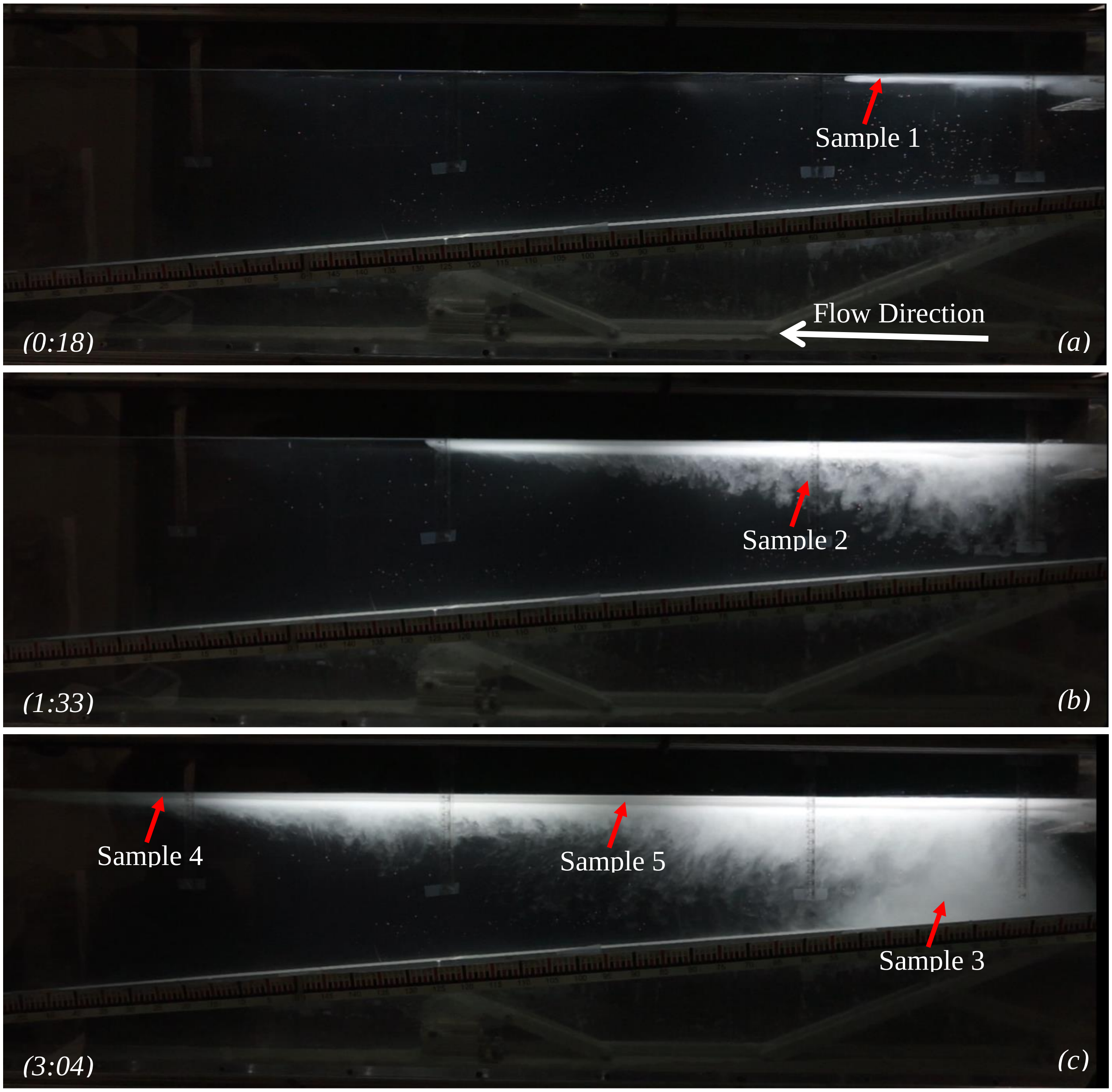

Figure 8 - These figures (*a* through *e*) depict the evolution of a typical hypopycnal flow in the tank. Locations of samples taken during the experiment are marked on the images, as well as the time from the beginning of inflow. Figure 6(a) shows the initial hypopycnal plume, before fingering begins. Figure 6(b) shows the fingers as the plume moves downstream. Figure 6(c) shows the incipient hyperpycnal flow as the fingers reach the bed and accumulate. Figure 6(d) shows the hyperpycnal and hypopycnal flows coexisting as both move downstream. Figure 6(e) shows the hyperpycnal plume as it begins to separate from the bed to form an interflow.

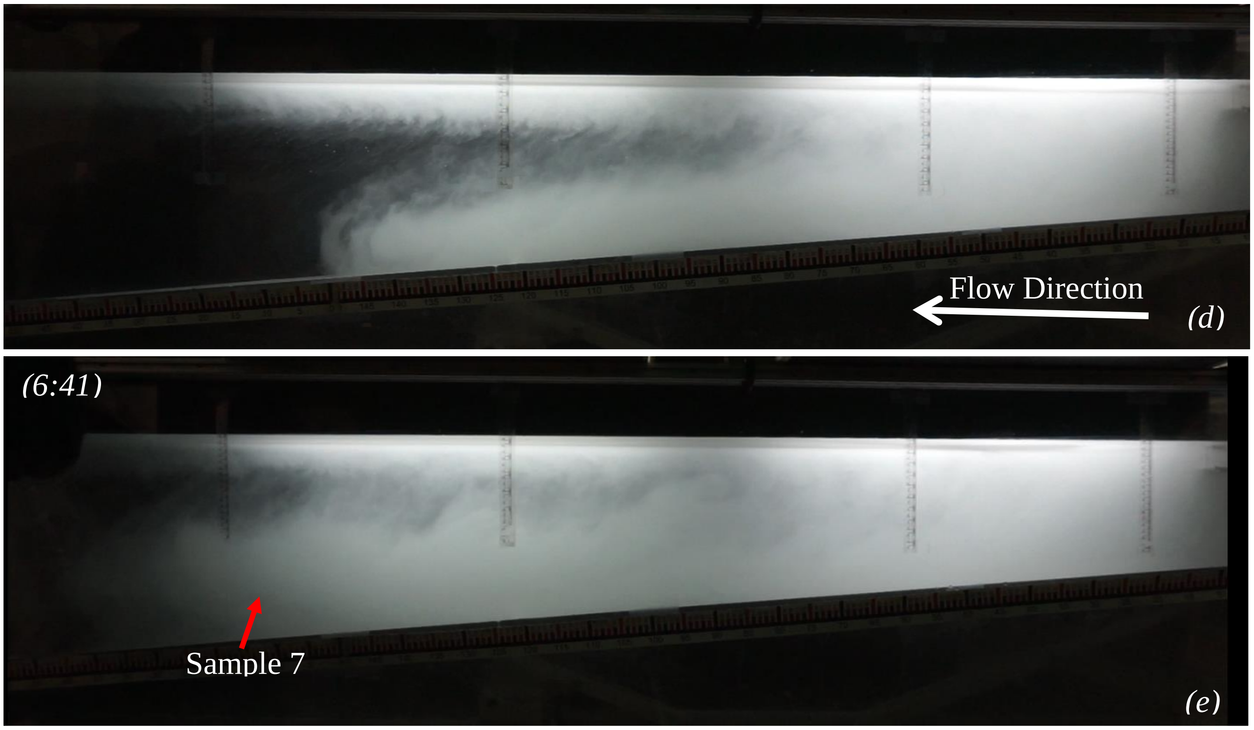

Figure 8 (continued)

In order to more fully understand what is happening at different parts of the flow, samples of sediment-laden water were taken from the flow and were analyzed for particle size distributions. The samples were taken with either a siphon or a large pipette (turkey baster). The locations of sampling sites were chosen opportunistically to characterized observed features, e.g. the front of the plume or a finger of sediment water descending from the plume. These locations are marked on Figure 8.

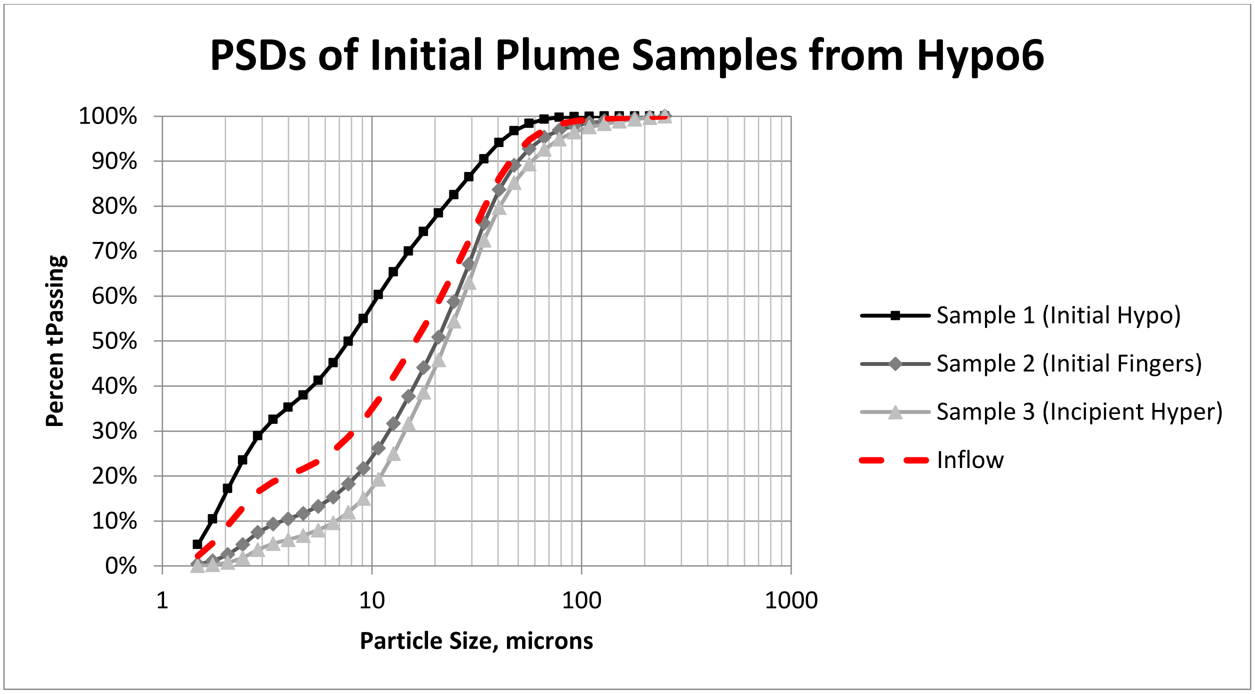

Figure 9 – Selected particle size distributions of initial plume for samples taken from Hypo6 near the beginning of the experiment. Locations depicted in Figure 6(a) and (b).

Figure 9 depicts the particle size distribution of the inflow as well as the hypopycnal plume, the fingers and the initial hyperpycnal flow, depicted in the bottom right of Figure 8(c). The initial hypopycnal plume (Sample 1) is composed of finer particles than the inflow, with a median grain size D_{50} of 7.5 microns, while the inflow D_{50} is about 17 microns. This indicates that the large particles begin separating from the flow very quickly. Indeed, the fingers (Sample 2) and the incipient hyperpycnal plume (Sample 3) have particle size distributions slightly coarser than the inflow.

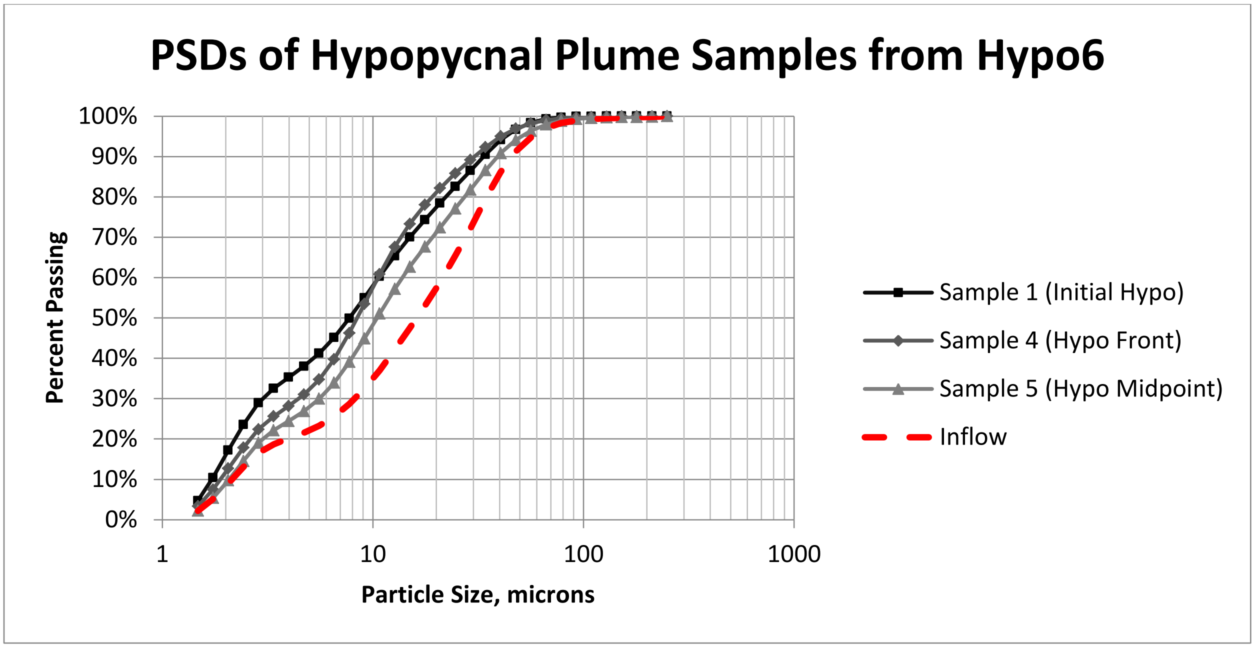

Figure 10 – Selected particle size distributions of the hypopycnal plume for samples of suspended sediment taken during run Hypo6. Locations depicted in Figure 6(a) and 6(c).

Figure 10 shows the particle size distributions of suspended sediment in the hypopycnal plume three minutes into the experiment, when the front of the plume had reached about halfway down the Shelf Tank. Sample 4 corresponds to the front of the plume at this time, and Sample 5 corresponds to the middle of the plume, between the front and the diffuser, at about the same time. The PSD of Sample 1, corresponding to the plume just after the start of the experiment, is also plotted for comparison. The difference between Sample 4, taken at 3:04 in the middle of the experiment, and Sample 1, taken at 0:18 at the beginning of the experiment, shows how the composition of the front of the plume has changed in time. The PSD at the front of the plume did not notably change in composition in the time between Samples 1 and 4, as is seen by the similarity between the distributions of Samples 1 and 4. The differences between Sample 4 and Sample 5 reveal how the composition of the plume varies in space, since they were taken at the same time. The sample at the midpoint is a little coarser than that at the front. Both the samples are finer than the input sample. Again, this is to be expected, since the larger particles are likely to drop out of suspension more quickly and thus more proximally to the diffuser.

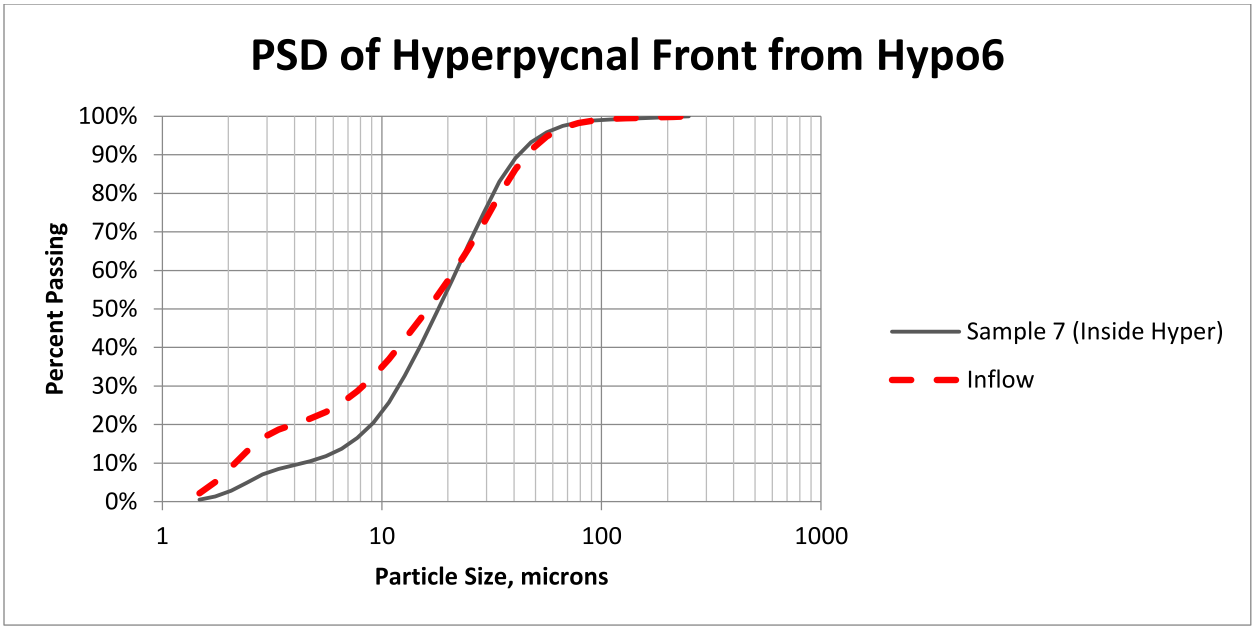

Figure 11 - Selected particle size distributions for samples of suspended sediment taken from the hyperpycnal front during run Hypo6. Locations depicted in Figure 6(a) and 6(e).

Figure 11 shows the particle size distribution of a sample (Sample 7) taken from within the hyperpycnal flow that formed as sediment-laden water from the hypopycnal flow sank to the platform and ran down it. The sample was taken later in the experiment, about the time of the image in Figure 8(e). Also included in the figure is the particle size distribution of the inflow. The hyperpycnal flow itself has a particle size distribution that is of similar composition to the inflow. The D_{50} of the sample from the hyperpycnal flow is the same as the D_{50} of the inflow, i.e. about 17 microns. The D_{20} of the inflow is, however, significantly finer than the D_{20} of the hyperpycnal plume, at 4 microns and 9 microns respectively.

3.2 Observations of Hyperpycnal Flows

As opposed to hypopycnal flows, the behavior of hyperpycnal flows is quite well understood in the literature. The behavior of the runs in these experiments corresponded to expectations based on the literature. Figure 12 depicts snapshots of run Hyper2, a typical hyperpycnal experiment. The hyperpycnal front progressed down the sloping bed, shedding small vortices, as is typical of turbidity currents. After the front passed the length of the Shelf Tank, a steady stream of sediment-laden water continued to flow down the slope, shedding more turbulent eddies along the way. At the downstream end of the shelf-tank, the turbidity current plunged into the abyssal-tank.

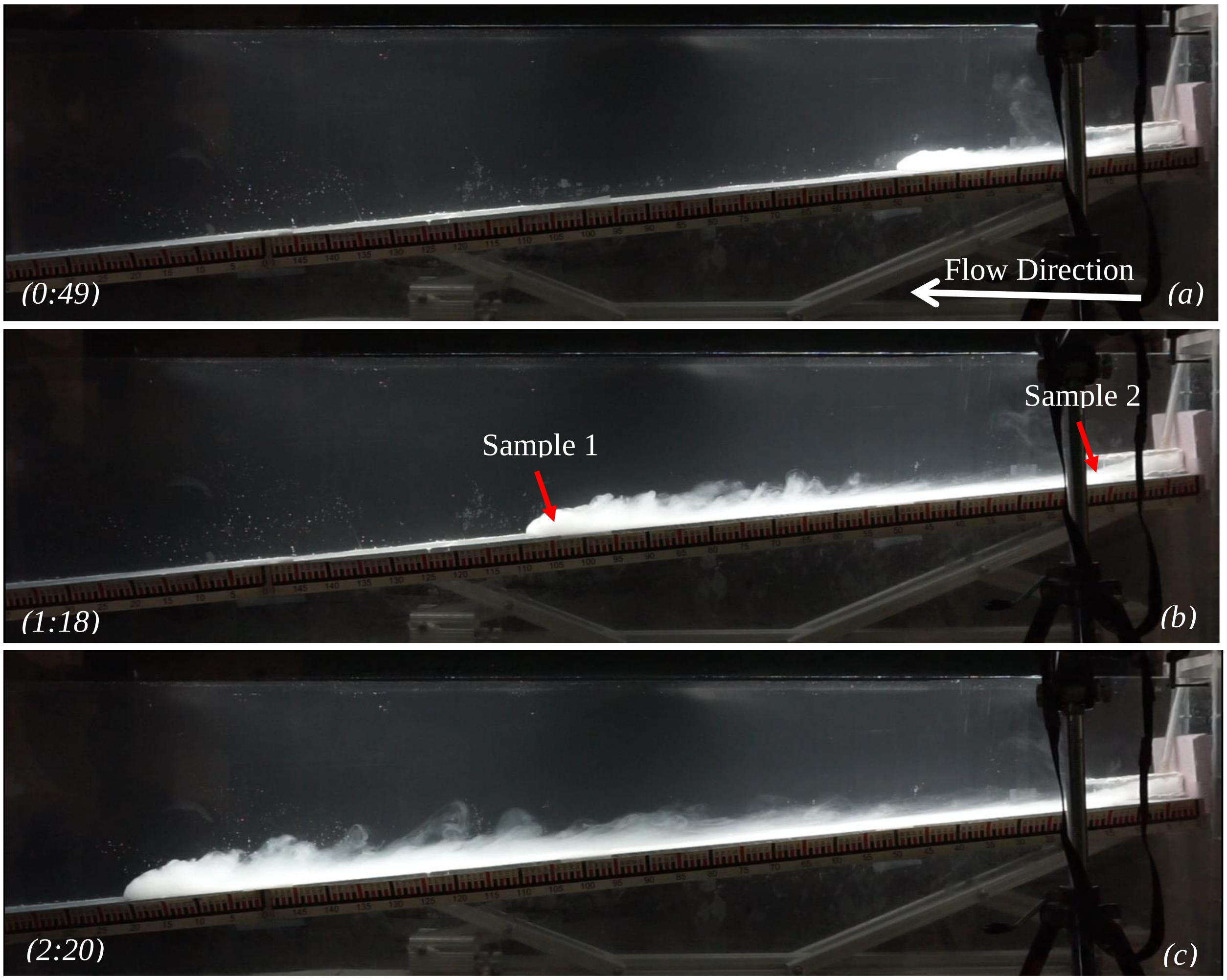

Figure 12 - These figures (a through d) depict the evolution of a typical hyperpycnal flow in the tank. Locations of samples taken during the run are marked on the figure, as well as the time elapsed since inflow began. Figure 10(a) shows the initial density current. Figure 10(b) shows the same hyperpycnal flow when the front has moved farther down the sloping platform. Figure 10(c) shows the front and flow behind as it approaches the end of the sloping platform, and features shedding vortexes. Figure 10(d) shows the flow after the front has passed out of the Shelf Tank.

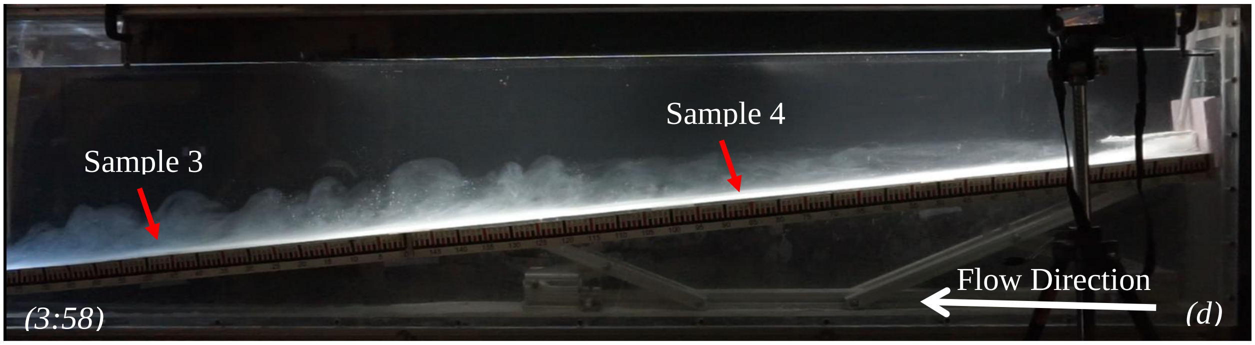

Figure 12 (continued)

The particle size distributions in the flow at a number of locations were sampled during the runs. The samples were taken with either a siphon or a large pipette (turkey baster). Sample sites were chosen opportunistically to characterize the flow e.g. the front of the flow, or alternatively relatively high concentration zones in the middle region of the flow. The sample locations are shown on Figure 12. The locations sampled were; Sample 1, the front of the flow when the flow reached 90 centimeters downstream; Sample 2, the flow in the diffuser; Sample 3, the front at 180 centimeters; and Sample 4, the flow at approximately halfway between the diffuser and the front when the front was 180 centimeters downstream. The flow passing out of the diffuser was also sampled. The particle size distributions obtained from the samples, shown in Figure 11, show a systematic behavior for the sediment to become finer downstream. . The particle size distribution of suspended sediment at the diffuser was nearly identical to the inflow. Downstream, the particle size distribution of suspended sediment becomes finer, and the farther downstream the measurement is, the stronger this fining was found to be. A similar pattern of downstream fining was observed in the sediment deposited on the bed, as discussed later in this thesis.

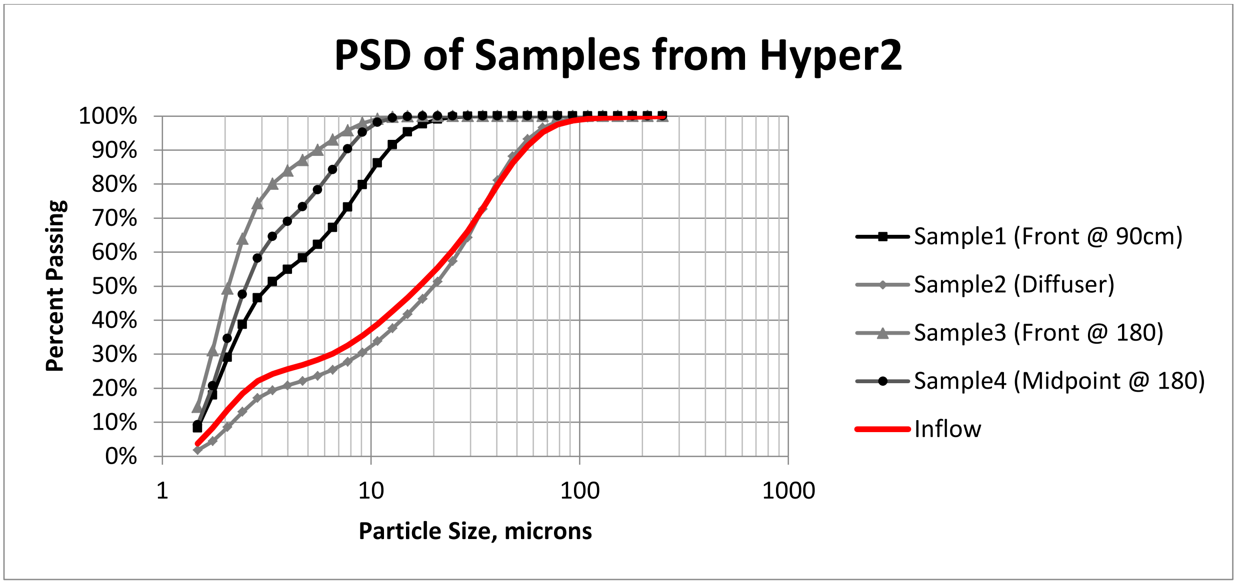

Figure 13 - Particle size distributions of suspended sediment for samples taken during run Hyper2.

3.3 Bed Deposition Measurements

One purpose of these experiments is to compare the patterns of sediment deposition on the platform from flows generated from hyperpycnal versus hypopycnal conditions. The results for the mass of sediment deposited on the bed from all 12 experiment runs are presented in Table 2. This table shows the streamwise range of each of the 12 bed segments for which samples were taken, the mass deposited in that segment in each set of runs, and the total mass of deposition in each set of runs. In addition, the total sediment mass inflow and the percent of that inflow retained on the platform is also recorded in the table.

Table 2 – Summary of bed deposit mass measurements for all sets.

Bed Deposits				Hypopycnal			Hyperpycnal		
	Range Start	Range End	Range Mid	Hypo123	Hypo45	Hypo6	Hyper123	Hyper45	Hyper6
Segment	*(cm)*	*(cm)*	*(cm)*	*(g)*	*(g)*	*(g)*	*(g)*	*(g)*	*(g)*
1	0	25	12.5	13.0	44.0	31.4	16.2	50.0	42.4
2	25	45	35	16.9	26.1	24.2	17.3	38.5	29.7
3	45	65	55	10.8	21.2	18.5	10.3	19.1	15.3
4	65	85	75	10.6	20.2	15.1	5.2	10.5	10.4
5	85	105	95	10.1	15.0	15.9	4.8	8.4	10.4
6	105	125	115	8.8	11.7	12.8	2.9	6.5	8.8
7	125	145	135	9.1	13.0	11.1	2.1	8.4	4.7
8	145	165	155	7.1	14.1	10.7	1.2	5.8	6.8
9	165	185	175	6.2	15.0	11.9	1.1	6.8	5.3
10	185	205	195	3.9	11.9	11.3	0.9	3.8	4.1
11	205	225	215	3.1	12.3	9.5	0.0	3.9	3.9
12	225	245	235	2.1	8.9	9.4	0.0	7.5	6.3
		Total Deposition (g):		101.5	213.5	181.8	62.0	169.0	148.2
		Total Input (g):		402.2	427.2	404.0	360.0	392.1	355.9
		Percent Retained:		25.2%	50.0%	45.0%	17.2%	43.1%	41.6%

The total mass input of sediment I_S was calculated by measuring the density and duration of the inflow from the mixing tank, and calculating as follows:

$$I_s = Q_I \times T_d \times \rho_I \times \left(\frac{1-\rho_f/\rho_I}{1-\rho_f/\rho_s}\right)$$

where Q_I is the flow rate of the pump, T_d is the duration of the inflow, ρ_I is the density of the input water-sediment mixture, ρ_f is the density of ambient sediment-free fluid (which might contain dissolved salt), and ρ_s is the density of the sediment. The total input was calculated for each run and then summed for all of the runs in a particular set. The variation in the total input for each set of runs is mostly due to differences in inflow density and inflow duration. Densities fell in a range of specific gravities between 1.018 to 1.022. Additionally, the duration of inflow for each set should have been a total of 24 minutes, but some of the experiments lasted longer than intended. In order to account for these differences in total input, the results were analyzed in terms of both total deposition and total deposition as a percentage of total input.

The total deposition and total input were used to calculate a percent retained on the platform, as opposed to the sediment that traveled beyond the platform into the downstream tank. Here we observe a few interesting trends, highlighted in Figure 14, which shows the percent retained for each set of runs. First, in all cases, the hypopycnal flows retained somewhat more sediment in terms of percent of the inflow than the hyperpycnal flows of the same number and duration. For the cases of HypoSet123 and HyperSet123, which were both three stacked runs of 8 minutes each, we see the smallest amount of retention, at 25% and 17% respectively. The most sediment was retained in the cases of two stacked runs of 12 minutes, HypoSet45 and HyperSet45 at 50% and 43% respectively. The longest single runs of 24 minutes, HypoSet6 and HyperSet6, were both similar to the runs with two stacked deposits, but with slightly less retention percentages, i.e. at 45% and 41% retain respectively. If we consider the difference between hypopycnal and hyperpycnal results from similar sets in terms of absolute difference divided by the average of the two values, computed as follows,

$$Difference = \frac{|Hypo - Hyper|}{(|Hypo| + |Hyper|)/2}$$

we see that the hypopycnal flows deposited notably more sediment. This difference is 38% between HypoSet123 and HyperSet123, 15% for HypoSet45 and HyperSet45, and 9% for HypoSet6 and HyperSet6. One significant caveat, discussed in greater detail in Section 3.5, is that some of the sediment was deposited in the diffuser, and this sediment was not measured in computing the total deposition. There is some reason to believe that the amount deposited in the diffuser may have been more in the hyperpycnal case than in the hypopycnal case.

A curious feature of the runs can also be seen in Figure 14. In the case of the hypopycnal runs, the percent of input sediment retained was lowest in the case of the stacked deposits of three runs, higher in the case of the deposit of a single run, and highest in the case of the stacked deposits of two runs. The deposits of the hyperpycnal flows show this same behavior. The reason for this is unclear. It makes sense that sets with multiple short runs would deposit less, since some amount of start-up time is expected as the front travels down the platform. However, it can be seen that this trend is not monotonically increasing as number of runs decreases.

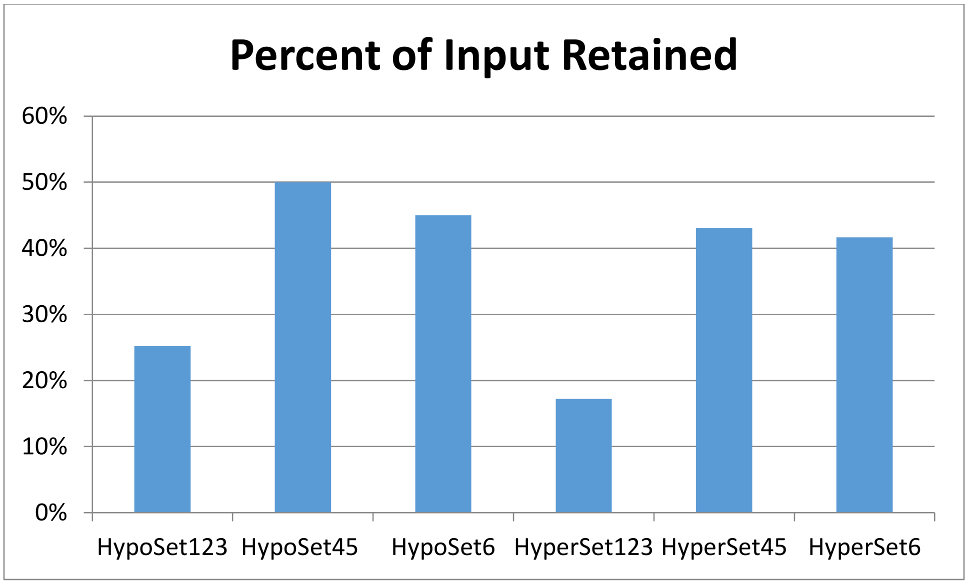

Figure 14 – Percent of input retained for all sets of runs, as defined as total mass deposited over total mass input.

3.4 Bed Deposit Consistency

While not quantitatively measured, a notable difference in the consistency of the deposition between the hypopycnal and hyperpycnal experiments could be observed. The hypopycnal deposit was light and fluffy, and seemed to move as individual particles. The hyperpycnal deposit was thicker and clumpy, and peeled away more like a single layer. One possible reason for this difference is the manner of deposition. The thick hyperpycnal flows might have created a thicker deposit, while the hypopycnal flows might have slowly settled out of the water column. Another potential reason is the difference in density of the ambient water in the hypopycnal versus hyperpycnal runs. The effective weight of the sediment in the hypopycnal case was less. This may have reduced the compaction rate of sediment on the bed.

3.5 Error in Bed Measurements

There is one notable caveat that must be added to the results presented here. The values for sediment deposited do not include sediment which deposited inside the diffuser. The diffuser was not identified as a potential source of significant sediment deposition until the final experiment run, Hyper6, which was the first time significant deposition was observed. This is shown in

Figure 15. The amount of deposition seen in the figure is very large compared to the amount of deposition typically seen on the bed. Other sets may have had similar amounts of deposition, but in so far as the diffuser was removed at the end of each run, there was not a full 24 minutes of deposition in the diffuser. The impact of this on the results is that the hyperpycnal experiments actually retained a significantly larger percentage of their input than reported, but much of this was confined to the upstream diffuser.

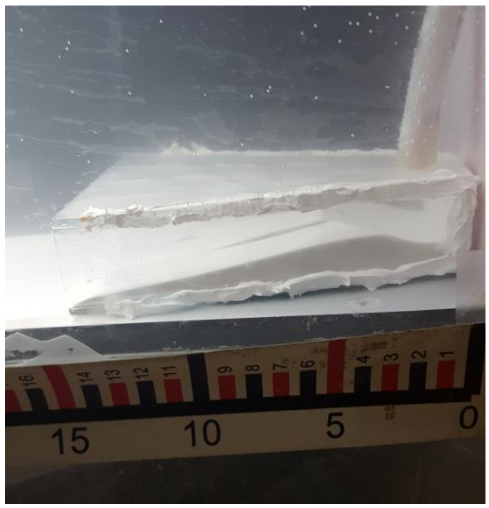

Figure 15 – Deposition in the diffuser after run Hyper6.

3.6 Spatial Mass Deposition Measurements

Figure 16 depicts the mass deposited along the bed for all six sets of experiments. The distance from the upstream end of the tank is plotted on the abscissa. The values on the abscissa increase from right to left in order to match the view of the tank in all photo and video documentation. The hypopycnal results are plotted in orange and the hyperpycnal results are in blue. The symbols match experiments of similar number and duration, so for example, HypoSet123 and HyperSet123 are both marked by squares. Recall that the total input and total deposition for each of these experiments vary from set to set.

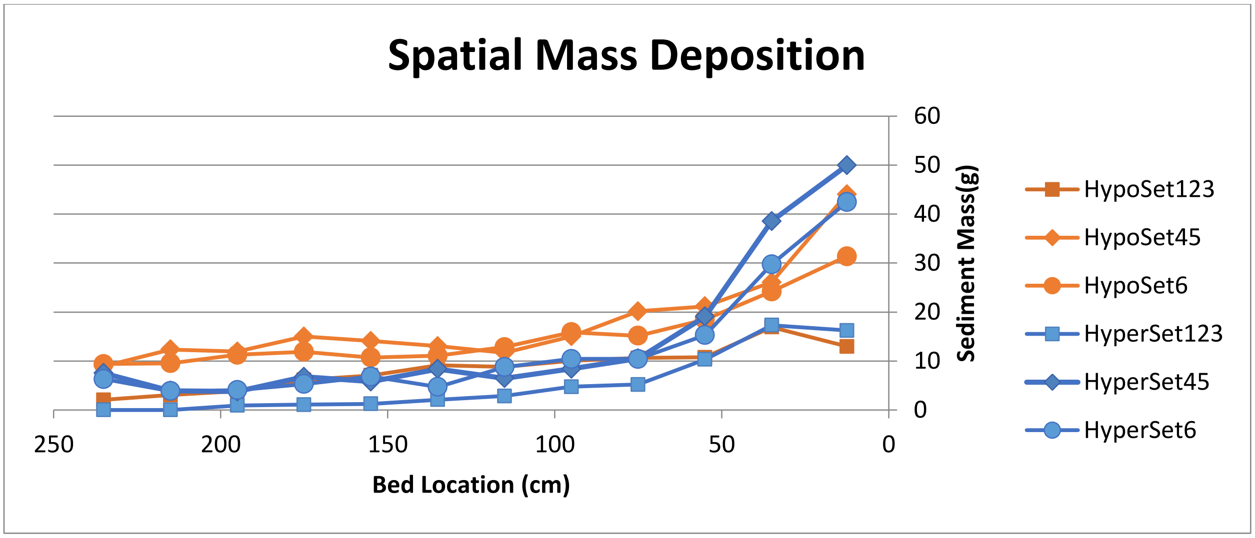

Figure 16 – Sediment mass deposited at twelve locations along the bed, for all six sets of runs.

Both hyperpycnal and hypopycnal flows deposit more sediment upstream, and then slowly decrease in deposition mass per unit area downstream. However, the deposits of the hyperpycnal flows were weighted more toward upstream, with a tendency for the deposit to become sparser. The hypopycnal flows deposited sediment more evenly throughout the platform, more than the hyperpycnal downstream of the 55 centimeter mark, and more overall. Both types of flows, however, showed deposits that tended to become sparser downstream. Note that the two zero values for deposition in the HyperSet123 set are due to the inability of the bed measurement method to measure small amounts of deposition. There was in fact a continuous deposit of sediment across the entire bed in all sets.

Due to inconsistencies in the input conditions, the hypopycnal runs all had more total input, as a result of slightly higher input density, longer run durations, or both. Figure 17 depicts the mass of the sediment deposit in each segment normalized by the total sediment input. By normalizing with the input, we remove any bias toward characterizing the hypopycnal flows as more depositional based on raw numbers. By summing the total percent of inflow deposited in each segment, we get the percent retained, shown in Table 2. Normalizing the deposition in terms of the input does not change the conclusions of the experiment. The hypopycnal flows still deposit more sediment downstream of the 55 centimeter mark, and less sediment upstream than hyperpycnal sets, and in addition deposit more sediment overall.

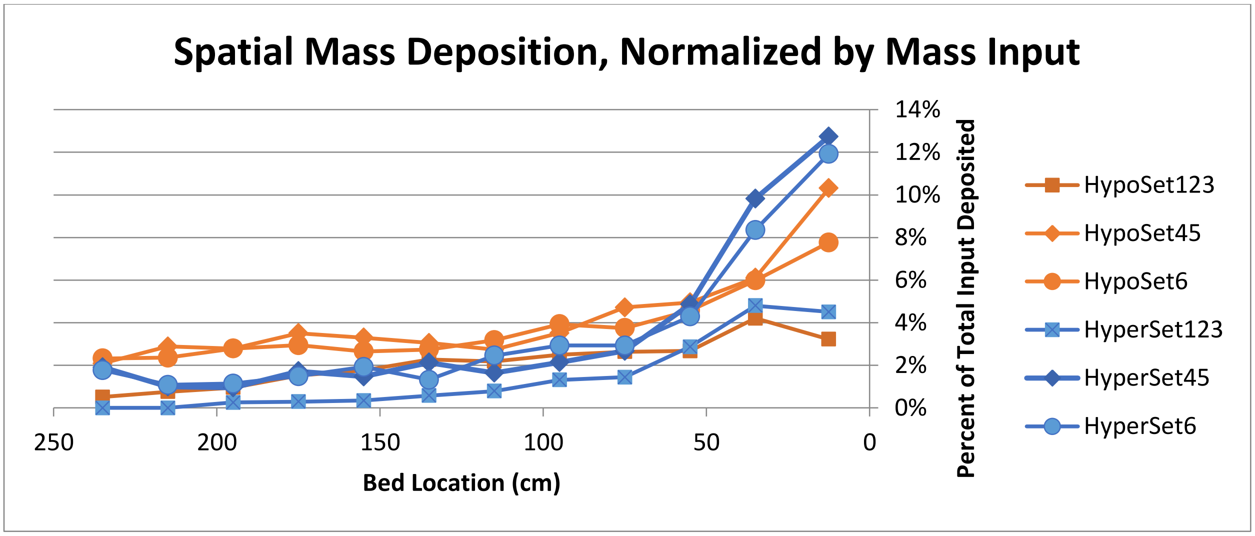

Figure 17 – Sediment mass normalized by the total mass input.

Next, consider just the segments downstream of 55 centimeters, beyond which the hypopycnal flows show a tendency to deposit more than the hyperpycnal flows. Here, the hypopycnal flows deposit on average nearly twice as much of their input sediment as the hyperpycnal flows, in terms of percent of input deposited. In the reach from 55 centimeters to the end of the platform, the three hypopycnal sets were found to have deposited an average of 23.5% of their inflow sediment. The hyperpycnal sets on average were found to have deposited 12.6% of their inflow in the same region. Figure 18(a), (b) and (c) on the following page show the relative difference in percent of input deposited of similar hypopycnal and hyperpycnal sets. Even though the total amount of sediment deposited varies greatly depending on the type of set (25% of input for HypoSet123 and 50% of input for HypoSet45, for example), the difference in deposition between hypopycnal and hyperpycnal sets was fairly consistent. The hypopycnal flows deposited approximately 1% of the input sediment more than the corresponding hyperpycnal flows in each of the ten 20-centimeter segments downstream of 55 centimeters.

Upstream of the 55-centimeter mark, the hyperpycnal sets showed more deposition than the corresponding hypopycnal sets. The hyperpycnal flows deposited an average of 21.4% of their inflow sediment upstream of the 55-centimeter mark, while the hypopycnal flows deposit only 16.6% of their inflow sediment in this region. The hyperpycnal deposits upstream of the 55-centimeter mark would be further increased if the unknown deposition within the diffuser was included. As noted above, this deposition was not measured, but was observed to be significant.

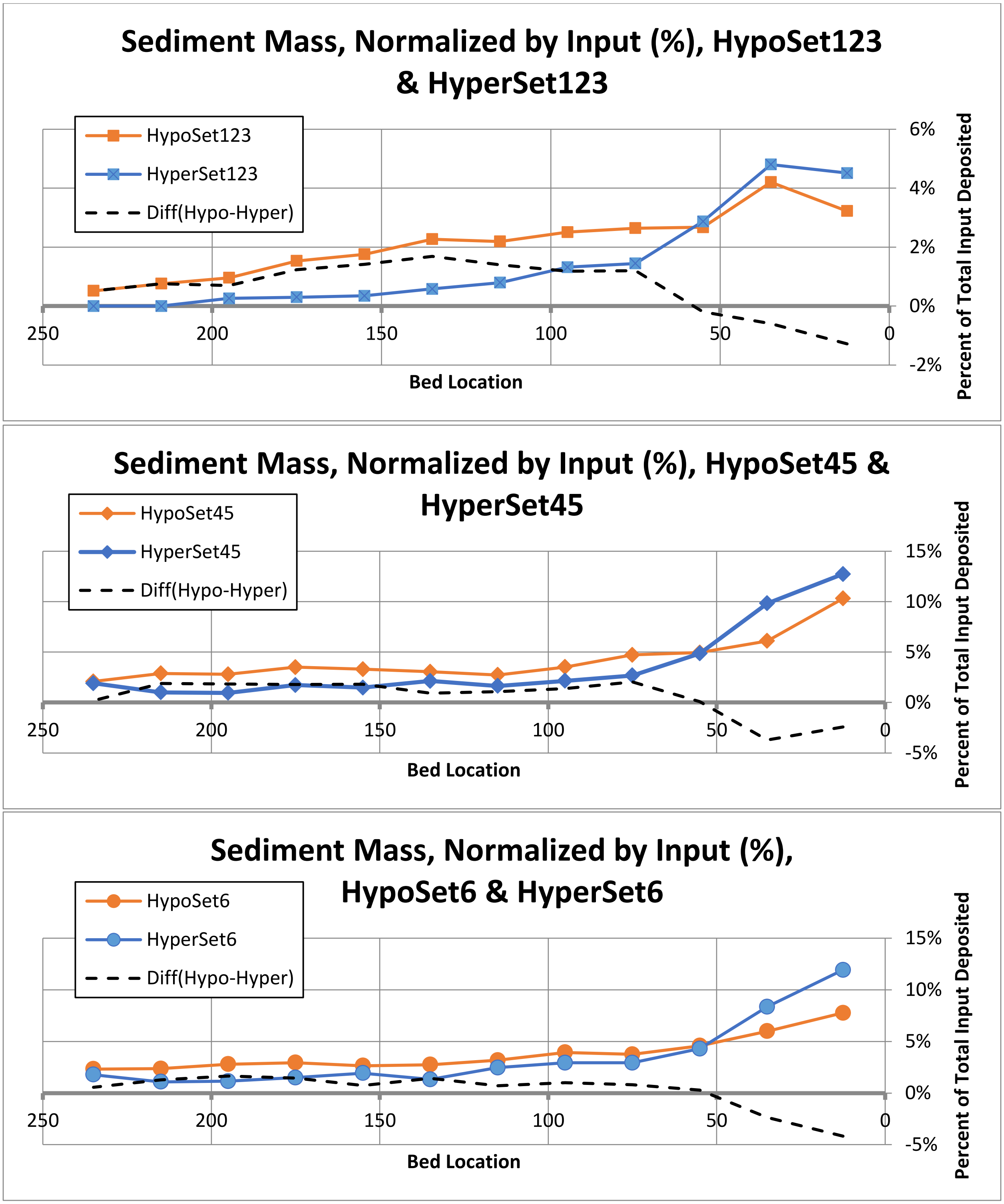

Figure 18 – Normalized sediment deposited, broken into sets of similar number of runs and duration. Figure 16(a) is for sets of 3 runs at 8 minutes (HypoSet123 and HyperSet123), Figure 16(b) is for sets of 2 runs of 12 minutes (HypoSet45 and HyperSet45), and Figure 16(c) is for sets of 1 run of 24 minutes (HypoSet6 and HyperSet6).

3.7 Particle Size Distributions of Bed Deposits

The LISST was used to study the particle size distributions (PSD) of deposits at each segment along the bed and compare them to the inflow particle size distribution and against each other. The values of median size D_{50} of these measurements are shown in Figure 19. The bed deposits from hyperpycnal runs show a highly consistent pattern of downstream fining, while the hypopycnal run deposits are erratic, not following a clear pattern. The D_{50} of the deposits from the hypopycnal sets are on average much larger than the D_{50} of the deposits from the hyperpycnal sets. One possible explanation of this difference is the sediment which deposited in the diffuser. In the hyperpycnal case, it seems plausible that the coarsest sediment had already deposited in the diffuser, and so was not taken into account in this analysis of bed deposit size distribution.

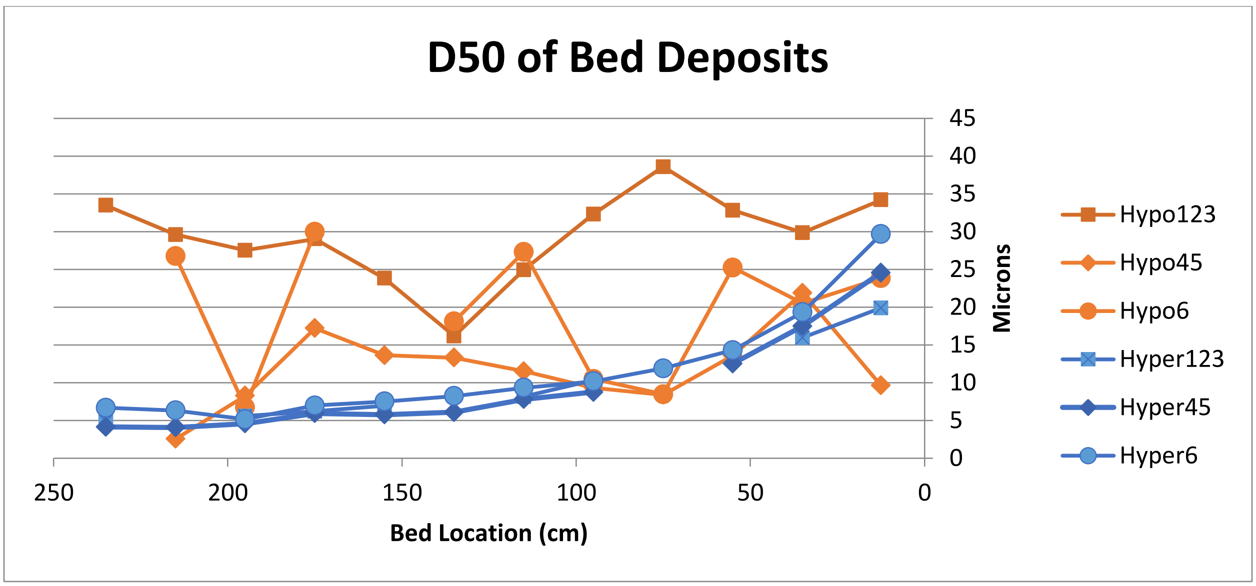

Figure 19 – Median grain size of samples taken from each bed segment for all 6 sets.

However, the input sediment PSD was not the same for all of these runs. Each run had a different D_{50} input value, and this should be reflected in the deposits. Additionally, the bed deposits in a set are made up of multiple runs, each of which had its own input D_{50}. To account for this, the D_{50} values of the inputs for sets with multiple runs were averaged. The data are shown in Table 3. Note that the inflow data for Hyper2 was missing, so it was omitted from the average. These average input D50s were used to normalize the data by dividing the D_{50} at each bed location by the average D_{50} of the respective inputs.

Table 3 – Mean D_{50} of input sediment for each set of runs.

Inflow D50 Grain Size			
Run	**D50**	**Mean D50**	**Set**
(-)	(micron)	(micron)	(-)
Hypo1	35.6	20.9	Hypo123
Hypo2	18.0		
Hypo3	9.0		
Hypo4	2.4	9.4	Hypo45
Hypo5	16.3		
Hypo6	16.2	16.2	Hypo6
Hyper1	17.3	14.5	Hyper123
Hyper2			
Hyper3	11.7		
Hyper4	17.1	17.4	Hyper45
Hyper5	17.6		
Hyper6	18.6	18.6	Hyper6

The normalized results are shown in Figure 20. The comparison between the hyperpycnal run deposits and hypopycnal run deposits reveals the same pattern as described in Figure 19: the hyperpycnal deposits show values of D_{50} which slowly decrease downstream, whereas the downstream trends in the hypopycnal deposits are erratic. However, looking at the data this way, it is apparent that the majority of the hypopycnal bed deposits have median size D_{50} coarser than the inflow D_{50}, and the majority of the hyperpycnal deposits have a D50 finer than the inflow D_{50}. This suggests that in the hypopycnal case, the smaller particles were not depositing locally, and were leaving the Shelf Tank. In the hyperpycnal case an orderly pattern of downstream fining was observed.

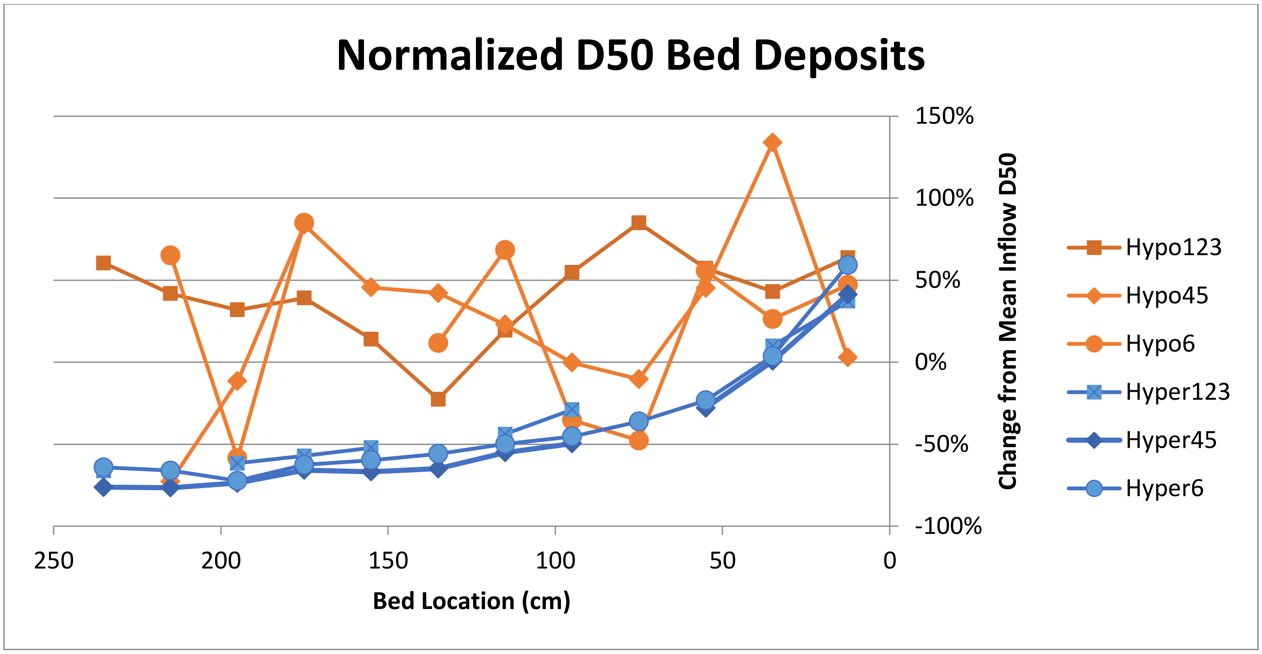

Figure 20 – Median grain size of bed deposits for each of the sets of runs, normalized by the mean median inflow grain size for each set.

CHAPTER 4: CONCLUSIONS

Experiments were run to compare hypopycnal and hyperpycnal flows and their depositional characteristics. The deposition of sediment on a sloped platform was measured. Flows were video recorded. In hypopycnal cases, a secondary hyperpycanal flow tended to form along the platform as sediment deposited from the surface plume. The hyperpycnal flows moved down the slope and flowed into the deep downstream tank, as expected. Both flow types, however, created measureable sediment deposits on the sloping platform.

Overall, the hypopycnal flow deposited more sediment on the platform and less sediment delivery to the deep tank downstream of the platform, with the caveat that sediment in the diffuser at the upstream end was not measured. The hypopycnal deposit was more evenly spread across the entire platform than the hyperpycnal deposit, but both flows deposited more sediment upslope near the diffuser than downslope. The mean particle size of the hyperpycnal deposits steadily decreased in the downslope direction, while the mean particle size of the hypopycnal deposits followed no obvious pattern. The results suggest that hypopycnal conditions might favor the deposition of sediment proximal to the sediment source (corresponding to a river mouth), whereas hyperpycnal conditions might favor the delivery of sediment into deeper water offshore.

CHAPTER 5: FUTURE WORK

The majority of the work that went into this thesis involved calibrating the experiment and finding the right set of input conditions. After finishing the final experiments, I found that I was well prepared to do a second more complete set of experiments, but I no longer had the time to do so. However, I have several recommendations to a future experimentalist.

First, I would repeat the same (or a similar) set of experiments from this thesis for varying bed slopes. The support for the platform inside the tank is designed to be able to accommodate different slopes, but some new holes need to be drilled into the support structure to set it to a different slope. I expect that changing the slope will have minimal impact on the hypopycnal experiments, but a very significant impact on the hyperpycnal experiments.

Second, the sediment which deposited in the diffuser needs to be accounted for in future experiments. I would redesign the diffuser to be shorter, so as to reduce the amount of sediment that deposits within the diffuser. I would also have the hose enter the diffuser from the back instead of the top, so that the flow is not directed downward when it enters the tank. Lastly, I would devise a way to measure the sediment that does deposit within the diffuser.

Third, I recommend a single wash of the sediment for the entire set of experiments. Rewashing the sediment between runs changes the distribution, and reduces the consistency of the input particle size distributions. For future experiments, in a single wash, I suggest preparing enough sediment for all runs, both hyperpycnal and hypopycnal.

Fourth, I would consider a new method for measuring the sediment deposited on the bed. Physically isolating, drying, and weighing the sediment is the most accurate method, but finding a suitable filter that does not lose sediment and works quickly is a challenge. The bulk measurement method using the hydrometer appears to be reasonably accurate, but a more accurate hydrometer might improve the results, especially at small specific gravities.

Fifth, I would seal the platform for all experiments. It is unlikely but possible that a significant amount of sediment might have slowly leaked off the sides of the platform during and after the hypopycnal runs. This was overlooked during the experiments discussed here, and should not be overlooked in future experiments.

Lastly, I would like to make myself available to anyone interested in continuing this work in my experimental facility. Please contact me if you are working on these experiments.

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