THE INFLUENCE OF BED ROUGHNESS ON PARTIAL ALLUVIATION IN BEDROCK CHANNELS

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By

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CERTIFICATION OF APPROVAL

I certify that I have read *The Influence of Bed Roughness on Partial Alluviation in Bedrock Channels* by Jennifer Rebecca Davis, and that in my opinion this work meets the criteria for approving a thesis submitted in partial fulfillment of the requirements for the degree: Master of Science in Geoscience at San Francisco State University.

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THE INFLUENCE OF BED ROUGHNESS ON PARTIAL ALLUVIATION IN AN EXPERIMENTAL BEDROCK CHANNEL

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The extent of alluvial cover on a bedrock channel bed strongly influences the efficiency of river incision, and can affect the quality of habitat for aquatic ecosystems. The extent of partial cover is commonly modeled as a simple function of sediment supply relative to the transport capacity of the stream, although other factors are likely to be important, particularly the roughness of the underlying bedrock surface. Here I report results of laboratory experiments investigating the influence of bedrock channel topography on extent of alluvial deposition. The results are compared to observations made of conditions in natural partially alluviated bedrock channels. The experiments were conducted in a model river with concrete beds of varying roughness conditions. Sets of experiments were conducted varying sediment supply rate for different roughness and shear stress conditions. I used a laser microtopography scanner to measure the bed topography and quantified bedrock roughness as the standard deviation of bed elevation relative to bed slope. Maps of alluvial cover were used to calculate percent cover. A comparison of sediment flux out of the channel to sediment supply into the channel was used to determine partial cover state of equilibrium. I found that low-roughness beds require a relatively high sediment supply before alluvial patches form, and as supply increases, can accommodate only low levels of partial alluvial cover before runaway alluviation rapidly converts the bed to an aggrading alluvial condition. In contrast, highly rough bedrock surfaces partially alluviate at very low sediment supplies and allow stable high fractional bed coverage. All else equal, rougher beds accumulate higher percentages of alluvial cover. Comparing these results to natural channel settings will involve scaling standard deviation of elevations by some factor, such as sediment grain size or channel width.

I certify that the Abstract is a correct representation of the content of this thesis.

Dr. Leonard Sklar, Chair, Thesis Committee

December 18, 2013
Date

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I recently saw a quote (attributed to Buddha) that perfectly sums up my feelings about this thesis.

> *"In the confrontation between the stream and the rock, the stream always wins; not through strength, but through perseverance"*

I have had to overcome many obstacles to get to this final moment. Owing to shear persistence and the overwhelming support of many people, I have finally made it. I want to sincerely thank everyone who contributed to this success, (there are so many!)

…we did this together.

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1.0 INTRODUCTION

1.1 Purpose and significance

River incision into bedrock is a fundamental geomorphic process, cutting valleys and canyons and setting the rate of landscape evolution (*Whipple, 2004*). The sediment that rivers carry strongly influences bedrock incision rates (*Sklar and Dietrich, 2004*). Coarse sediment that moves as bedload provides tools for abrasion of underlying bedrock, but when supplied at sufficiently high rates can form transient alluvial deposits that prevent erosion of underlying bedrock. Hence, as bedload sediment moves through a channel, it plays two roles: 1) providing tools to erode and 2) creating cover to protect from erosion (*Gilbert and Dutton, 1887; Sklar and Dietrich, 1998, 2001*). As a river transports sediment, grains not small enough to be held in suspension hop and roll along the bed, moved by turbulent currents that lift and drop them. When coarse grains drop and hit exposed bedrock, they contribute to erosion. But if they hit a patch of motionless alluvial cover, the alluviation functions as protection from erosion. Alluvial cover thus limits the erosional efficiency of a river. And, because river incision is a key erosional process responding to tectonic uplift, understanding what controls the extent of alluvial cover in a channel is important for evaluating landscape evolution in tectonically active settings.

The percentage of bed cover by alluvium also has ecologic significance. For example, fish populations depend on the amount and size distribution of gravel alluvial cover available for spawning habitat (*Kondolf and Wolman, 1993*). Dams trap gravel sediment and change flow regimes, resulting in degradation of channels downstream of dams and loss of fish spawning habitat (*Ligon et al., 1995*). To develop a plan to restore alluvial habitat, it is important to understand what controls the extent of alluvial cover, and distinguish the effect of dams from background conditions.

At any point in time, the surface of a river channel in a mountain drainage basin can be exposed bedrock, completely covered in alluvium, or partially alluviated. Figure 1 shows three bedrock channels spanning the full range of possible degrees of alluvial cover. The purpose of this study is to investigate the relationship between sediment supply rate and the percentage of alluvial cover on bedrock river channels. In particular, I focus on the role of the roughness of the bedrock surface, and how roughness interacts with sediment supply to influence partial alluvial cover.

Investigating this question is essential for gaining insight into how stream conditions affect sedimentation in rivers. My goal is to contribute to the development of a mechanistic model for predicting the distribution of bedrock and alluvial channels, and also to explain the partially-alluviated condition.

1.2 Previous Studies

Most previous studies of the transition between bedrock and alluvial bed conditions have classified channels as one of the two end members, alluvial or bedrock (*Howard and Kerby, 1983; Montgomery et al; 1996, Massong and Montgomery, 2000*). The partially alluviated condition has received less attention. However, many channels in tectonically-active landscapes are partially alluviated and function as a hybrid between the two end members. However, even when a channel is fully alluvial, bedrock is typically not far from the surface, and the alluvial mantle is thin (*Johnson et al., 2009*). Considering this observation, it may be more appropriate to think of most mountain rivers as bedrock channels that have some percentage of their bed covered by alluvium.

Howard and Kerby (1983), Montgomery et al. (1996), Howard (1998), and *Massong and Montgomery (2000)* investigated the spatial and temporal distribution of alluvial and bedrock channels, but none of these studies focused on the specific mechanisms that control fractional alluvial bed cover. Each of these studies assumed that the threshold between bedrock and alluvial conditions depends on transport capacity (a measure of the amount of sediment a river can move) and sediment supply. From this assumption, bedrock channels are the result of high transport capacities and alluvial channels are the result of low transport capacity, relative to sediment supply. Transport capacity increases with increasing channel slope and discharge, which is the volume of water flowing through a river channel cross-section per unit time. Discharge scales with drainage area; larger watersheds produce larger discharges, so drainage area can be used as a proxy for discharge (*Howard, 1998*). Thus, as first proposed by *Howard and Kerby (1983*), there may be a critical ratio of channel slope to drainage area at which a transition in channel type is expected.

Using this slope-area model, *Massong and Montgomery (2000)* made predictions of channel type for channels throughout a single drainage basin. However, data they collected in the field did not neatly fit the model, and more than 60% of the time the model incorrectly predicted channel type. They therefore suggested that local boundary controls (variations in sediment supply, grain size, and roughness elements), which are not included in the model, have significant influence on the extent of alluviation or bedrock exposure in a given channel. They concluded that their model alone cannot accurately classify a channel.

The notion of a partially alluviated channel bed is central to the theory for river incision into bedrock by saltating bedload as first proposed by *Gilbert and Dutton (1887)*, and quantified by *Sklar and Dietrich (1998, 2001, 2004)*. They made the simple assumption that the fraction of the bed covered with alluvium (F_a) is a linear function of sediment supply (Q_s) divided by the sediment transport capacity (Q_t)

$$F_a = \frac{Q_s}{Q_t} \qquad (1).$$

When sediment supply exceeds transport capacity, the bed aggrades. In this equation, channel roughness affects transport capacity, however bedrock roughness is not explicitly represented.

In a related experimental study, *Sklar and Dietrich (2002)* explored the relationship between sediment supply and bed cover in a laboratory flume. Their empirical results showed that deposition began at some sediment supply rate below the transport capacity of a fully alluvial bed. As sediment supply increased, the percentage of cover increased linearly with supply rate, until finally, at high supply rates, the linear relationship became unstable and alluvial cover rapidly proceeded to 100%. *Sklar and Dietrich (2002)* called this “run-away alluviation”, and suggested to be due to a positive feedback, where increasing alluvial cover increases roughness compared to the bare bedrock bed, and decreases the flow velocity at the bed, consequently reducing transport capacity.

1.3 Hypotheses

My project was designed to investigate the role of bedrock roughness in mediating the relationship between sediment supply and the percentage of alluvial bed cover as described by *Sklar and Dietrich (2002)*. The roughness of the channel bed should have two effects on partial alluviation: 1) slowing the flow thus reducing transport capacity, and 2) creating pockets for mobile sediment grains to come to rest in. At a coarse scale, bed irregularities create “form” drag, much the way bedforms, bars and bends do in alluvial channels (*Simons and Richardson, 1963*). At a finer scale, rough rock surfaces create friction similar to the “skin” drag created by sediment particles. For a sediment grain, this finer scale of roughness creates the friction angle that sets the threshold shear stress of grain motion and limits the sediment transport rate for a given shear stress. These two types of roughness, form and skin, add together to create the overall roughness that slows the flow. The topography of bedrock channel beds can be irregular across a wide range of scales (*Richardson and Carling, 2005*). As a result, dividing the roughness into form drag and skin drag is not as straightforward as in an alluvial channel. A simple metric for the irregularity of a bedrock channel bed is the standard deviation of bed elevation (z)

$$S_z = \sqrt{\frac{\sum_{i=1}^{n}(z_i - \bar{z})^2}{n-1}} \tag{2}$$

where $\bar{z}$ is the mean elevation and n is the number of elevation points. This has the advantage that it can be easily calculated from a topographic survey of a bedrock river bed or flume bed. In my study I use S_z to represent the roughness of the bedrock surface.

I tested two sets of hypotheses (Figure 2). First, for a given slope, discharge and sediment grain size, when the roughness of the bare bedrock surface is less than that of an alluvial bed, there should be a threshold of deposition, a sediment supply rate that must be exceeded for partial alluvial cover to occur. Conversely, when the bedrock roughness is greater than the alluvial case, there is no threshold; partial alluvial cover will occur for any non-zero sediment supply rate, as assumed in Equation 1.

Second, once the threshold for alluvial deposition has been exceeded, the percentage of the bed covered with alluvial patches should increase linearly with increasing sediment supply. A stable, equilibrium partial cover condition will occur when the sediment flux entering a river reach (or experimental river channel) is equal to the flux of sediment exiting the reach. For a given equilibrium flux, the percentage of bed cover will be greater for larger bedrock roughness.

1.4 Organization of the thesis

There are two discrete components to this study, a field survey and set of laboratory experiments. The field observations of bedrock channels were intended to support the laboratory experiments by providing a natural basis of comparison. However, because it is difficult in the field to isolate roughness from the other variables that influence partial cover, I did not attempt to test my hypotheses in the field. Therefore, in the sections that follow below, I first present the field methods and results, and then the laboratory methods and results. In the discussion I consider both sets of results together.

2.0 FIELD METHODS

2.1 Site Locations

My research was part of a larger collaboration with a research team from MIT, led by Professor Kelin Whipple and Joel Johnson, a PhD student in the Whipple lab. The overarching goal of our collaboration was to better understand the influence of sediment supply on rates of river incision into bedrock. Together, we selected two field sites for intensive study (Figure 3): Swett Creek, east of the Henry Mountains, Utah, draining Mt. Hiller, and Desha Creek on the north side of Navajo Mountain, Utah. These sites were selected because they have a large contrast in sediment supply but similar underlying bedrock.

Both sites are located within the Colorado Plateau geologic province. The Henry Mountains and Navajo Mountain were formed when magma intruded into Triassic – Jurassic sedimentary rock and formed diorite laccoliths, approximately 20 – 30 Ma. The difference between the two areas is that in the Henry Mountains, erosion has exhumed the diorite core of the laccolith, while at Navajo Mountain, no intrusive rocks are exposed at the surface. As a result, sandstone-bedded channels draining the Henry Mountains are supplied with abundant quantities of highly durable diorite gravel, whereas channels underlain by similar rock in the Navajo Mountain area are supplied only with weak sedimentary rocks that weather primarily into sand. Thus, the two sites provide an opportunity to observe the effects on bedrock erosion, and the roughness created, of a large contrast in the supply of coarse bedload material.

The reach of Swett Creek selected for detailed study is a human-made slot channel blasted into massive, unjointed Navajo Sandstone bedrock (Figure 4A). The channel was built to carry a diversion of the stream flow from the original channel as part of Utah's Department of Transportation construction of Hwy 276 during the 1970s (Johnson et al., 2010). It has vertical bedrock walls over 10 m high. The channel reach we surveyed begins at the mouth of a culvert under Hwy 276 and extends approximately 65 m to the downstream end of the slot where the bedrock walls end. There the channel is incised as it drops steeply down to the confluence with the original channel.

Immediately upstream of the culvert, the stream had a fully alluviated bed at the time of our visit. At the mouth of the culvert, the first 25 m of our surveyed reach was also completely alluviated. The rest of the surveyed reach was partially alluviated. The incised step had no alluviation and the channel immediately downstream of the confluence was completely alluviated.

At the Desha Creek site (Figure 4B) I surveyed a partially alluviated reach of natural channel cut into thickly bedded Kayenta Sandstone bedrock. The reach extends 24 m from a bedrock step at the upstream end to a river bend downstream. I visually observed a higher percentage of alluviation at the upstream and downstream sections of the reach.

2.2 Total Station Surveys

At each site I used a Topcon Total Station (Figure 5) to do a comprehensive survey of the channel beds (Figure 6). Each point was recorded as an x,y position and a vertical elevation value. At both sites I recorded survey points along the length of the reach in the center of the channel to record data for a longitudinal profile.

I also took points across the width of the channel to characterize across-channel cross sections (Figure 7). At Swett Creek, a more detailed survey involved recording cross section points every 5 meters down the length of the channel. These points were labeled as bedrock, alluvium, or contact between bedrock and alluvium. Then sediment was dug to expose the bedrock underneath alluvial patches where across-channel cross sections were surveyed starting at 35 m downstream of the culvert (Figure 6A). Points were recorded to characterize the bedrock surface beneath the alluvial patches (Figure 7). At Desha Creek, only three across-channel cross sections were made (Figure 6B): upstream end, middle, and downstream end of the surveyed reach. There was very little sediment along these cross sections.

To supplement the data characterizing the roughness of the bedrock channels, additional points were then taken at each site on exposed bedrock patches throughout the partially alluviated section. Points were chosen as high points, low points and breaks in slope.

2.3 Mapping Alluvial Cover

To make a map of alluvial cover that shows percentage of the bed covered at the Swett Creek location (Figure 8), I recorded the locations of alluvial patches using a measuring tape. I measured the distance across the channel from the right bank, between the edges of the alluvial patches, and to the left bank. The upstream section (0-18 m downstream) was completely alluviated so no measurements were taken other than the width of the channel. In the partially covered section from 18 m to 26 m downstream, cross channel measurements were made every 2 m. From 26 m to 68m downstream, where the pattern of partial cover became more complex, cross channel measurements were made every 1 m. The frequency of cross channel measurements was increased in the downstream section to better characterize the more complex geometry of patch cover there.

At the Desha Creek location, no percent cover maps were made. Instead, I made a visual estimate of the percent cover in the surveyed reach, as well as in the reaches immediately upstream and downstream of the surveyed reach.

2.4 Pebble Counts

Pebble counts were done at both locations using the standard Wolman point count method (*Wolman, 1954*). Pebbles were chosen randomly as I walked along transects across the channel. Every two steps, the sediment particle directly in front of the toe of my boot was selected and measured along its intermediate axis and recorded (mm) (Appendix 1). If the sediment chosen was greater than 4 mm along the intermediate axis, the value was recorded as diameter in millimeters. Sediment grains finer than 4 mm were recorded as "<4mm". This fine sediment was not further distinguished as it would be immediately suspended in flow and not contribute to bedload sediment. Additionally, rock type was also noted if it could be determined.

3.0 FIELD RESULTS

3.1 Percent alluvial cover

Figure 8 illustrates the percent alluvial cover measured at Swett Creek (Appendix 2). The alluvial cover immediately downstream of the culvert covered 100% of the channel bed for the first 28 m of the reach. Downstream of that, from 28 m to about 70 m downstream, the reach was partially covered. Figure 8 plots percent alluvial cover with distance downstream. The data show that from 28 m downstream of the culvert to approximately 55 m downstream of the culvert the percent alluvial cover generally decreases with distance downstream (Figure 9, Table 2). The last part of the reach, from 55 m to 70 m downstream, the data is somewhat more scattered, but percent cover generally increased.

At the Desha Creek site, the visually estimated cover was different in three distinct sections. The section upstream of the surveyed reach had approximately 40 –

50% alluvial cover. The surveyed section was chosen because it had very sparse alluvial cover, approximately 5%. Downstream of the surveyed section alluvial cover increased again, covering approximately 50 – 60% of the bed.

3.2 Grain Size Distribution

Pebble count data were used to create a cumulative percent finer grain size distributions (GSD) for Swett Creek surveyed reach, the reach upstream of the surveyed reach and culvert, and the reach upstream of the surveyed reach at Desha Creek (Figure 10). Sediment less than 4mm were excluded from the calculations based on the assumption that fine grains would become suspended in flow great enough to move the coarser material as bedload.

Analysis of pebble count data at the Swett Creek site reveals that GSDs in the surveyed flume reach were slightly coarser than the reach upstream of the surveyed reach and culvert (Figure 9). The median 50th percentile grain size (D50) for the surveyed reach was 20 mm. The 84th percentile grain size (D84) 40mm (Table 1).

At Desha Creek site, the sparse alluvial cover in the surveyed reach essentially consisted of sediment too fine (<4 mm) to be considered.

3.3 Longitudinal Profile

The Swett Creek site long profile can be broken into 3 sections: the culvert, the alluviated section of the channel downstream of the culvert and the partially alluviated section of the channel at the downstream end of the reach. When analyzed separately, the slopes of all three sections varied only slightly. The slope of the alluviated section, 0.0264, was consistent with the slope of the culvert 0.0262. The slope of the partially alluviated section was only slightly less steep at 0.0234. The average slope using all the points from the 2 channel sections, not including the culvert, was 0.0229 (Table 1).

3.4 Roughness

Data from the total station surveys were used to quantify roughness by calculating the standard deviation of local elevation differences from that predicted by the mean bed slope. At Swett Creek site, the standard deviation of elevations was 0.522 ft (Figure 11A). The standard deviation of elevations from Desha Creek site was 0.790 ft (Figure 11B).

Roughness values were also calculated for individual across-channel cross sections surveys and compared with percent alluviation along those cross sections (Figure 9, Table 2). The data shows that downstream decreasing alluvial cover correlates with decreasing roughness, suggesting a positive relationship.

4.0 LABORATORY METHODS

4.1 The flume

For the laboratory modeling portion of this project, I used an experimental model river channel, or "flume", at the University of California Berkeley's Richmond Field Station. Figure 12 shows a schematic of the flume. The flume channel is 6 m long and 0.3 m wide, with clear plastic walls 0.25 m tall. For the removable channel bed, artificial bedrock was created out of concrete, using a 10:1 ratio of fine sand to Portland cement (Figure 13A). The flume is built on a pivoting platform so that slope angle can be changed. Water is pumped to the upstream end from sump tanks underneath. A series of valves allowed me to control the discharge of water into the flume channel.

The sediment size I used was uniform 5 mm diameter grains consisting of mostly sub-rounded to rounded chert and quartzite, with some granitic clasts. Sediment is supplied to the stream at the upstream end of the channel by a motor driven auger feed system (Figure 13B). The supply rate can be adjusted by varying the speed of the auger. Sediment and water exit the flume at the downstream end box (Figure 13C), which is equipped with two baskets attached to load cells, designed to catch and weigh the sediment flux out of the flume. The water drains back into the sump and is cycled through the system. Sediment is manually vacuumed from the baskets and dumped back into the sediment feed supply.

The flume is also equipped with a rolling instrument carriage that can traverse the length of the channel. Mounted on the carriage is a micro-topography laser scanner (Figure 13D) used to generate topographic maps of the bed, and a point gauge for measuring water surface profiles. The micro-topography laser scanner consists of a HeNe laser pointed at the bed and reflected back to a photo diode array in a 35 mm SLR camera. Driven by a computer program, this device took measurements in a 5 mm grid pattern across and along the channel with a resolution of < 0.2 mm horizontal, ~ 2 mm vertical.

4.2 Creating and measuring roughness

A key goal of my project was to test if I could achieve stable partial cover for a given channel bed roughness in the flume. I started with a planar, very low roughness concrete bed (Figure 14A). During the drying and curing process of making the concrete, a resistant cement crust formed on the concrete bed. In order to achieve a more uniform bedrock substrate for erosion by the moving sediment, this hard layer was chipped off, producing a slightly rougher initial surface. The bed was scanned with the micro-topography laser scanner to record data for the baseline topography. A series of preliminary runs varying sediment feed and duration were done, allowing the bed to erode naturally to create increased roughness.

Another concrete bed was created for the second and third sets of experiments. It was also made from a 10:1 ratio of fine sand to Portland cement. This time I was trying to achieve a very rough initial surface. To do this, I used egg carton shaped foam covered with plastic film as a mold for the concrete. The result was a surface with an exaggerated quilted appearance with a pattern of rounded peaks and valleys (Figure 14B). This initially very rough surface also evolved over time from erosion. Data from micro-topography laser scans done after each run were used to calculate roughness for the evolving bed.

4.3 Mapping partial cover

To map the location of alluvial patches and calculate percent alluvial cover, I placed a transparent grid over the top of the flume channel (Figure 15). Looking down on the flume bed through the transparent grid, I mapped what I saw onto a paper grid template by marking which grid boxes were alluviated. Percent cover was then calculated from the percentage of boxes on the grid marked as alluvial. For the very rough egg carton bed runs, often there would be one or two grains in many depressions. This small amount was not enough to mark as an alluviated grid box, but still made a significant contribution to the overall percent alluvial cover. In these cases, definite patches were identified as places where sediment accumulation covered more than one depression and ridge in between and their locations were marked on a grid template. A description of "other" cover was also recorded on the grid template sheet as well as an estimated percent of "other" cover. Total cover was calculated to be patch cover percent plus "other" cover percent. An example of a composite set of maps for the entire flume length is shown in Figure 16, with the border of the alluvial cover superimposed on a set of photographs along the flume length.

4.4 Experimental runs

Over the course of the laboratory portion of this project, many experimental runs were conducted (summarized in Table 3). The runs were numbered as sets. The run numbered 101 was a first attempt to gather data, after which we decided to change the method and also the number set. Run 201 was a single experiment using the planar essentially zero roughness bed. The set of experiments using low roughness bed were numbered 300 – 306. Runs using an initially very high roughness "egg carton" bed were numbered 400 – 410. Runs were designed to investigate the threshold of deposition for a given roughness and whether stable partial alluvial coverage could be achieved for a given roughness and sediment supply. To do this, I varied the sediment supply rate to the flume with an initial roughness and fixed channel slope and discharge. For most of the partial cover runs 101, 201, 305 – 306 and 401 – 405, the shear stress was 2.9 Pa with discharge of 0.0275 m^3/s and slope of 0.0056. For the last set of runs 406 – 410, shear stress was increased to accommodate a higher sediment supply with the intention of trying to achieve a higher percent cover on the high roughness bed. For these runs, the slope was increased to 0.0073 and discharge was increased to 0.0323 m^3/s. The resulting shear stress was calculated to be 5.0 Pa. The conditions and goals of each run set are described in detail in the following paragraphs.

Run 101

This was the initial experiment to try to achieve stable partial cover in the simulated bedrock channel. The goal was to examine the possibility of steady state partial cover if the percent cover was high. I completely covered the channel bottom with sediment and then started the water, slowly allowing the discharge to reach 0.0275 m^3/s. At this point, I cleared sediment from a section approximately 10 cm wide and 30 cm long mid-way down the channel and mid-stream. The opening quickly filled with sediment. I tried a second time with a larger opening in the sediment (10 cm wide and 100cm long). This opening evolved rapidly changing shape and size, splitting into multiple openings, finally completely alluviated again. During this time, 9 maps were made and water surface profile was measured 3 times. I did not calculate percent cover for these maps as it did not seem to be stable or moving toward stability at any point throughout the run. The water surface profile data were not plotted but notes indicate an undulating water surface with a hydraulic jump at the downstream end.

Run 201

Starting with an initially planar very low roughness bed with no alluviation, this run was an experiment to find the threshold of alluviation at this essentially zero roughness condition by adding sediment to the flow at a supply below transport capacity and then increasing the supply rate until sediment began to stop on the bed. At the maximum sediment supply rate achievable using the automated sediment feed, no sediment was stopped on the channel bed. To achieve a higher sediment supply I manually added additional cups of sediment where the feed entered the channel.

Run Set 301 – 304

These runs were completed as roughness evolution experiments intended to investigate erosional effect on bed roughness. For all of these experiments high discharge was used and sediment was allowed to erode the channel bed without any alluviation. Starting with high sediment feed and shorter duration, each subsequent run used decreased sediment supply and increased duration. The bed was scanned before the run 301, between each run, and after run 304. Data from bed scans were used to determine roughness values and compare how and where roughness had changed.

Run Set 305 – 306

Using the experimentally evolved bed, runs 305 and 306 were done to find threshold of deposition and achieve stable percent cover on a bed of some roughness greater than the initially planer very low roughness bed. I varied sediment supply, but kept shear stress (slope and discharge) constant. Again scans of the bed were made to determine roughness value.

Run Set 401 – 405

For the next set of runs, I changed the bed to the very rough concrete bed I made using an egg carton mold. The slope and discharge of the channel were not changed. During these experiments, I varied sediment supply rate to test for the threshold of deposition and achieve stable partial cover at different percentages.

Run Set 406 – 410

For the last set of runs, I used the initially egg carton very rough bed which had evolved to be somewhat less rough during the previous set of runs. I increased shear stress by increasing the slope to 0.0073 and the discharge to 0.0323. These settings were constant for all runs 406-410. With these new conditions, I again varied sediment supply rate to try to determine the threshold of deposition and achieve different stable percent covers.

5.0 EXPERIMENTAL RESULTS

5.1 Time series of run conditions

For each run, I plotted the data collected over the run duration. The resulting plots illustrate how conditions changed during the run. For example, Figure 16 (Table 5) is a plot of data collected from Run 403. Data from sediment supply (flux in) and flux out over time are plotted, as well as calculated amount of sediment stored in alluvial cover over time. The times when mapping of alluvial patch cover took place are also indicated. This plot shows that sediment supply was increased from 0.1 lb/min to 0.2 lb/min shortly after the run began. A map was made of the sediment cover in the channel while during the period before sediment flux out began to exit the end of the channel. At this sediment supply, the flux out did not begin until 45 minutes into the experiment. Once sediment began to exit the channel, another sediment cover map was made while the rate of flux out continuously increased. The goal of the run was to map percent cover during a period of equilibrium where flux out equaled sediment supply in with some amount of partial cover and observe if the equilibrium could be maintained. At 95 minutes into the experiment, I turned the sediment feed down to match the calculated flux out rate attempting to stabilize the alluvial cover on the bed. Sediment supply and flux out maintained approximate equilibrium for a period of time during which a third map of alluvial cover was made. Eventually, the flux out began to decrease indicating more sediment was depositing as storage in alluvial cover. This led to a condition of "runaway alluviation" where the bed completely filled with sediment.

5.2 The evolution of bed roughness

Analysis of the data from scanning the bed after erosion runs 301 – 304 showed that resulting roughness evolved differentially throughout the channel. This allowed me to consider the bed to have three sections with differing, approximately uniform, roughness values. The upstream section (the first 2 m of the channel) eroded a deep groove and had the highest value of roughness, 5.1 mm after run 305 and 5.5 mm after run 306. In the middle section (the next 2.4 m of the channel) the groove became less defined and transitioned to less organized roughness with a standard deviation of elevations 3.7 mm after run 305 and 3.9 after run 306. The downstream section (the last 1.7 m of the channel) also evolved a seemingly unorganized roughness and had the lowest roughness value at 3.1 mm after run 305 and 3.2 after run 306.

5.3 The influence of roughness on the threshold of deposition

The threshold of deposition for any given roughness can be determined as the sediment supply rate at which sediment begins to stop on the bed for a given set of channel conditions. Thresholds of deposition were achieved over a range of roughness, from very low to very high throughout the course of experiments. A plot of sediment supply rates with calculated roughness value for each observed threshold of deposition conditions (Figure 17) indicates that rougher beds allow deposition to begin at lower sediment supply rates.

Run 201 was the experiment done to find a threshold of deposition for very low roughness. I assumed I had reached that threshold when I observed grains stopping but without large stable patches forming. This condition was observed with the sediment supply at setting 32.5 plus an additional 1 cup sediment /min added manually. I calculated supply rate to be 10.0 lb/min.

A threshold of deposition for low roughness was observed during Run 305 when deposition first occurred in the downstream channel section. The roughness of the channel at that time was calculated to be 2.94 mm the threshold of deposition at this roughness value was 8.9 lb/min. Similar determinations were made for medium and high roughness thresholds of deposition. Medium roughness value 3.73 mm was estimated from Run 306 middle channel roughness section. Sediment was first observed depositing in this section at a sediment feed rate of 7.0 lb/min. High roughness value 5.29 mm was estimated from the upstream channel section of Run 306. Sediment was first observed depositing in this section when the sediment supply was 5.6 lb/min. Experiments using the very high roughness egg carton bed showed that sediment deposited at any nonzero sediment supply.

5.4 The influence of roughness on partial cover

Percent cover calculated in each of the three channel sections from three maps made during Run 305 are plotted in Figure 18 (Table 7) with corresponding roughness values for each section. The grouping of data points on this plot indicates a relationship between roughness and partial cover, with all other variables held constant. During this run, the three maps that were made showed partial cover percent values distinctly different for each of three roughness sections. The upstream end of the channel with the highest roughness value had the highest percent cover on all three maps while the downstream end with low roughness had no cover on any of the three maps. In the middle section there was the most variation in cover over the course of the run, but all cover values were significantly less than the upstream section and significantly higher than the downstream section. The middle section cover values also increased from map 1 to 2 and from 2 to 3, possibly reflecting a slight increase in roughness in this section throughout the course of the run.

5.5 The dependence of partial cover on sediment supply and shear stress

To determine experimental conditions during which percent cover was at equilibrium when a map of cover was made, I compared the rate of sediment flux out of the channel, using measurement data from the scale weighing the sediment collected in the endbox, to the sediment supply rate into the channel at that time (flux in). If the flux in and flux out rates correlated within 20%, the alluvial cover was considered approximately at equilibrium within the conditions of the experiment.

There were several times during my experiments during which conditions were met so that the data could be considered to represent approximate equilibrium. Figure 19 is a plot of experimental conditions representing equilibrium percent cover. All of the data points (Table 8) result from egg carton bed runs (400-410). The data plot in two groups correlating with the change in shear stress (low shear stress of runs 400-405 to high shear stress of runs 406-410). The trend of each group indicate equilibrium percent cover increased with increase in sediment supply for a given shear stress and roughness.

Applying a trendline to each group, I am able to calculate an equilibrium percent cover predicted to occur for a given sediment supply at each of the two shear stress conditions. Additionally, the position of the groups on the graph show that when discharge and slope were increased, resulting in increased shear stress, a greater sediment supply resulted in a higher equilibrium percent cover.

5.6 Equilibrium Cover

Although there were several experimental condition sets that I could identify in my data as periods of approximate equilibrium, it was more common that data showed conditions not at equilibrium. Figure 20 (Table 9) is a graph of observed experimental conditions plotting flux in relative to flux out and percent measured cover relative to predicted equilibrium percent cover (from trendlines in Figure 19). This graph illustrates each set of observed conditions' relationship to equilibrium. On the graph, the point 1,1 represents equilibrium where flux in equals flux out and percent cover measured equals predicted percent cover. The data points close to the center (within 20%) represent approximate equilibrium conditions. Other points can be grouped into 4 categories represented as quadrants on the plot. Those in each of the four quadrants represent conditions other than equilibrium, i.e., conditions either eroding or alluviating and moving towards equilibrium or away from equilibrium.

6.0 Discussion

6.1 Summary of Major Findings

In taking on this project I set out to collect data that would help answer questions about the relationships between bedrock roughness and percent cover as well as between sediment supply and percent cover. The lab data suggests that bedrock roughness has a positive influence on percent cover; if all other conditions are constant, rougher beds have more cover. Sediment supply also influences percent cover such that for a given roughness, higher sediment supply results in more of the bed being covered with sediment. These results are consistent with my hypotheses. The results from observations I made of natural rivers were not as straight-forward. Visual estimations of roughness and percent cover were that Swett Creek was more rough and had more percent cover than Desha Creek. However, when the data were analyzed, Swett had a lower Standard deviation of elevations than Desha. It became apparent that using standard deviation of elevations alone would not be adequate for quantifying roughness in a natural setting because of the diverse conditions at each river.

6.2 Comparing Field Observations and Lab Results

Although the Swett Creek site appeared to be rougher, the standard deviation of elevations value at Swett Creek was smaller than that of Desha Creek. However, Desha creek was also much wider. Other differences include: bedrock type, grain size distribution and rock type of sediment supplied, bank full depth, and the height of the bank walls. All of these variables make comparing two natural rivers difficult. Additionally, comparing the results from the small scale laboratory model with natural rivers has the same difficulties. The flume results demonstrate that the standard deviation of elevation is a useful metric for characterizing bedrock roughness within a fixed variable situation. However, to make comparisons between natural channels and laboratory results, it will be necessary to scale the standard deviation of elevations value by another metric that integrates the size of the channel relative to the magnitude of roughness features.

Ideally, I believe bankfull depth would be the best choice, because it seems most relevant to the vertical aspect of standard deviation of elevations of the roughness features of a bedrock channel. It is also relevant to the shear stress that transports sediment. However, it is difficult to estimate depth in a natural channel when there is no flow and to measure alluvial cover when there is flow. Moreover, depth varies with discharge and channels are subject to a wide range of discharges. Width is easier to measure for natural channels, and is fixed in the flume. When the standard deviation was normalized by the width of the channel, the resulting dimensionless roughness for Swett Creek site was 0.040. The Desha Creek site dimensionless roughness value was somewhat smaller at 0.021. The maximum roughness in the flume was approximately 6 mm. This value divided by the 300 mm width of the flume is 0.02, very similar to the magnitude of Desha Creek and Swett Creek dimensionless roughness values. This suggests that S_z divided by width may be a useful non-dimensional ratio for scaling bedrock channel roughness, from laboratory to field channels and between field sites.

6.3 Future Research Needs

Further investigations are needed into ways of comparing the roughness of natural streams as well as interpreting experimental laboratory results relative to natural conditions. More field observations should be made to increase the range of data for comparisons.

Laboratory experiments examining the role of grain size distribution would provide useful to add to the data from this study as I did not investigate that as a variable. Additionally, investigation into the spatial distribution and geometry of roughness features would also add to the story of how roughness affects partial cover. A clue that this is an important aspect to consider is in roughness and threshold of deposition sediment supply rates seen in Figure 16. This graph reveals that roughness (S_z) of the egg carton bed and the upstream section of the initially planar bed are very close. In fact the egg carton bed is slightly less rough. However, the initially planar section required a significantly higher threshold sediment supply to achieve deposition, possibly due to the difference in spatial distribution and geometry of the exhibited roughness. The egg carton roughness features were more symmetrical and evenly distributed throughout the channel than the single, deeply incised, slightly undulating groove of the upstream section of the initially planar bed.

7.0 Conclusion

In conclusion, the results from field observations and laboratory experiments gained from this project support my hypotheses. Roughness, sediment supply, and shear stress are all influencing factors for the percentage of alluvial cover in bedrock channels. I observed that threshold sediment supply for deposition to begin depends on roughness. Additionally, rougher beds and higher sediment supply rates resulted in channels with more alluvial cover; while increasing shear stress decreased the amount of alluvial cover for a given roughness and sediment supply.

Standard deviation of elevation proved to be a useful metric for comparing roughness in laboratory experiments where variables could be controlled and the scale did not change. Comparing natural channel observations between different rivers and to laboratory results revealed the need for incorporating another metric to consider scale and other variables into the roughness value in order for it to be useful in a mechanistic model.

8.0 References

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TABLE 1. Summary of field results

Field Site	**Length (m)**	**Average Width (m)**	**Roughness S_z (m)**	**Grain Size Distribution (mm)**	**% Cover**
Swett Creek	40	4.3	0.16 *S_z /width = 0.037*	surveyed reach D50= 11 – 16 D84= 32 – 45 upstream D50= 16 – 22 D84= 32 – 45	~0 to 20m = 100% ~20 to 55m=trend decreased downstream to ~40% ~55m to 70m=trend increased downstream to ~90%
Desha Creek	16	8	0.24 *S_z /width = 0.030*	upstream D50= 11 – 16 D84= 32 – 45	upstream = ~40-50% center roughness detailed = ~5% downstream = ~50-60%

TABLE 2. Percent cover and roughness relative to distance downstream (Figure 9)

Distance Downstream from Culvert (m)	% cover	% cover from survey data	trench roughness S_z(m)
20	87.2		
22	100.0		
24	95.3		
26	100.0		
27	100.0		
28	91.7		
29	86.3		
30	83.7		
31	85.9		
32	100.0		
33	97.6		
34	87.2		
35	81.7	82	0.19
36	63.1		
37	57.3		
38	69.0		
39	85.7		
40	86.3	86	0.22
41	68.6		
42	82.4		
43	81.7		
44	66.2		
45	53.8	54	0.13
46	66.2		
47	51.2		
48	44.0		
49	54.4		
50	52.3	52	0.16
51	64.8		
52	44.0		
53	57.9		
54	46.5		
55	41.9	42	0.27
56	46.6		
57	47.7		
58	56.1		
59	41.7		
60	59.5	59	0.21
61	53.5		
62	97.7		
63	76.7		
64	72.8		

TABLE 2.*(Continued)*

Distance Downstream from Culvert (m)	% cover	% cover from survey data	trench roughness S_z(m)
65	75.0	75	0.23
66	89.8		
67	82.7		
68	40.6		

TABLE 3. Table of grain size distribution data (Figure 10)

Swett - surveyed reach

size class mm	# counted	cumulative #	cumulative %
<4mm	(21)		(11.5) 0
4.0	2	2	1.1
5.6	8	10	5.4
8.0	12	22	12
11.0	17	39	21.1
16.0	39	78	42.4
22.0	32	110	60.0
32.0	29	139	75.5
45.0	24	163	88.6
64.0	12	175	95.1
90.0	6	181	98.4
128.0	2	183	99.5
180.0	1	184	100
256.0	0	184	100

Swett - upstream of the surveyed reach and culvert

size class mm	# counted	cumulative #	cumulative %
<4mm	(13)		(7.4) 0
4.0	15	15	9.2
5.6	15	30	18.4
8.0	20	50	30.7
11.0	26	76	46.6
16.0	19	95	58.3
22.0	22	117	71.8
32.0	17	134	82.2
45.0	11	145	89.0
64.0	8	153	93.9
90.0	7	160	98.2
128.0	2	162	99.4
180.0	1	163	100
256.0	0	163	100

TABLE 3. (*Continued*)

Desha Creek – upstream of the surveyed reach

size class mm	# counted	cumulative #	cumulative %
<4mm	(12)		(8.7) 0
4.0	11	11	8.0
5.6	8	19	13.8
8.0	11	30	21.7
11.0	19	49	35.5
16.0	23	72	52.2
22.0	23	95	68.8
32.0	15	110	79.7
45.0	11	121	87.7
64.0	7	128	92.8
90.0	6	134	97.1
128.0	3	137	99.3
180.0	1	138	100.0
256.0	0	138	100.0

TABLE 4. Summary of experiment conditions

Date	Run #	Bed type	Slope	Discharge (m^3/s)	Shear Stress (N/m2)	Sediment Supply (lb/min)	Duration of run (min)	cover maps #
Run 201 **Goal:** Test for Threshold of deposition for very low roughness bed								
1/1012005	201	initial planar	0.0056	0.0275	2.9	10.03	n/a	0
Runs 301-304 **Goal:** Let sediment erode the initially planar bed; measure change in roughness between each run.								
1/20/2005	301	initial planar	0.0056	0.0275	2.9	8.92	53.5	0
2/1/2005	302	planar eroded roughness	0.0056	0.0275	2.9	6.98	128	0
2/8/2005	303	planar eroded roughness	0.0056	0.0275	2.9	4.22	291.5	0
2/15/2005	304	planar eroded roughness	0.0056	0.0275	2.9	1.46	609.8	0
Runs 305-306 **Goal:** Test for threshold of depostion and equilibrium partial cover for evolved roughness								
2/22/2005	305	planar eroded roughness	0.0056	0.0275	2.9	8.92	n/a	3
3/8/2005	306	planar eroded roughness	0.0056	0.0275	2.9	2.84 - 5.60 - 6.91 -	n/a	3 total - 0 - 1 - 2
Runs 401-405 **Goal:** Increase bed roughness, test for values of threshold of deposition and percent cover for varied sediment supply rates.								
7/1/2005	401	eggshell	0.0056	0.0275	3.7	0.14	n/a	2
7/5/2005	402	eggshell	0.0056	0.0275	3.7	1.17 1.08 0.93	n/a	0
7/18/2005	403	eggshell	0.0056	0.0275	3.7	0.10 - 0.2 0 -	n/a	3 total - 2 - 1

TABLE 4. (*Continued*)

7/20/2005	404	eggshell	0.0056	0.0275	3.7	0.85 - 0.25 - 0.10 -	n/a	4 total - 2 - 1 - 1
7/22/2005	405	eggshell	0.0056	0.0275	3.7	0.47	n/a	4

Runs 406- 410
Goal: Increase shear stress by increasing slop and discharge, obtain higher percent cover for high roughness bed

Date	Run #	Bed type	Slope	Discharge (m^3/s)	Shear Stress (N/m2)	Sediment Supply (lb/min)	Duration of run (min)	cover maps #
7/29/2005	406	eggshell	0.0073	0.0323	5.0	1.16	n/a	3
8/2/2005	407	eggshell	0.0073	0.0323	5.0	1.39	n/a	4
8/3/2005	408	eggshell	0.0073	0.0323	5.0	1.70	n/a	3
8/8/2005	409	eggshell	0.0073	0.0323	5.0	2.16 - 2.00 -	n/a	5 total - 3 - 2
8/10/2005	410	eggshell	0.0073	0.0323	5.0	2.08	n/a	3

TABLE 5. Summary of data measured from run 403 (Figure 16)

time (min)	flux out (lb/min)	sediment supply (lb/min)	storage (lb)
1.6	0.000	0.1	0.0
6.2	0.000	0.1	0.5
6.2	0.000	0.2	0.5
51.8	0.000	0.2	9.6
51.8	0.044	0.2	9.6
80.2	0.044	0.2	14.0
80.2	0.077	0.2	14.0
96.6	0.077	0.2	16.0
96.6	0.077	0.1	16.0
110.1	0.077	0.1	16.3
110.1	0.081	0.1	16.3
157.9	0.081	0.1	17.2
157.9	0.048	0.1	17.2
190.9	0.048	0.1	19.0
190.9	0.048	0.0	19.0
191.1	0.048	0.0	19.0

TABLE 6. Threshold of deposition (Figure 17)

RUN	Sediment Supply (lb/min)	Stdev(Z) (mm)	Bed Type/Section
201	10.0	1.00	Initial planar
305	8.9	2.94	Eroded downstream
306	7.0	3.73	Eroded middle
306	5.6	5.29	Eroded upstream
401	0.1	5.16	Egg carton

TABLE 7. Partial cover relative to roughness (Figure 18) Data is from Run 305.

roughness S_z (mm)	% cover	channel segment	sediment supply (lb/min) set 32	map #
4.93	90.6	up	8.92	1
3.6	22.2	mid	8.92	1
2.94	0	down	8.92	1
4.93	92.9	up	8.92	2
3.6	27.3	mid	8.92	2
2.94	0	down	8.92	2
4.93	93.2	up	8.92	3
3.6	45	mid	8.92	3
2.94	0	down	8.92	3

TABLE 8. Calculating equilibrium cover (Figure 19)

run #	shear stress (Pa)	stress type	flux in (lb/min)	% cover	bed type	status
403	3.700	low	0.1	33.55	Eggshell	almost
405	3.700	low	0.5	49	Eggshell	almost
405	3.700	low	0.5	52.75	Eggshell	almost
406	4.961	high	1.2	33.1	Eggshell	almost
407	4.961	high	1.4	37	Eggshell	almost
408	4.961	high	1.74	35.5	Eggshell	almost
408	4.961	high	1.74	40.75	Eggshell	almost
408	4.961	high	1.74	37.75	Eggshell	almost
409	4.961	high	2.16	66.175	Eggshell	almost
409	4.961	high	2.16	51.1	Eggshell	almost
409	4.961	high	2.16	51.85	Eggshell	almost
409	4.961	high	2	63.325	Eggshell	almost
406	4.961	high	1.2	32.125	Eggshell	equilibrium
406	4.961	high	1.2	37.3	Eggshell	equilibrium
409	4.961	high	2	64.3	Eggshell	equilibrium

TABLE 9. Collapse of equilibrium and non-equilibrium data (Figure 20)

run	shear stress type	sediment supply (lb/min)	flux out (lb/min)	flux out/ sediment supply	% cover	EQ % cover	% cover/ EQ % cover	EQ status
403	low	0.1	0.081	0.8100	34	34	1.00	almost
405	low	0.5	0.47	0.9400	49	51	0.96	almost
405	low	0.5	0.47	0.9400	53	51	1.04	almost
406	high	1.2	1.1	0.9167	33	32	1.05	almost
407	high	1.4	1.21	0.8643	37	37	1.00	almost
408	high	1.74	1.65	0.9483	36	46	0.77	almost
408	high	1.74	1.53	0.8793	41	46	0.88	almost
408	high	1.74	1.51	0.8678	38	46	0.82	almost
409	high	2.16	2.44	1.1296	66	57	1.15	almost
409	high	2.16	2.35	1.0880	51	57	0.89	almost
409	high	2.16	2.27	1.0509	52	57	0.90	almost
409	high	2	1.87	0.9350	63	53	1.19	almost
406	high	1.2	1.2	1.0000	32	32	1.01	yes
406	high	1.2	1.2	1.0000	37	32	1.18	yes
409	high	2	2.01	1.0050	64	53	1.21	yes
403	low	0.2	0.044	0.2200	34	38	0.89	no
403	low	0.2	0	0.0000	30	38	0.80	no
404	low	0.1	0.06	0.6000	53	34	1.57	no
404	low	0.53	0.2	0.3774	46	52	0.88	no
404	low	0.25	0.09	0.3600	51	40	1.28	no
404	low	0.53	0	0.0000	34	52	0.65	no
405	low	0.5	0.37	0.7400	48	51	0.95	no
405	low	0.5	0.18	0.3600	35	51	0.68	no
407	high	1.4	1.14	0.8143	35	37	0.94	no
407	high	1.4	1.11	0.7929	38	37	1.02	no
407	high	1.4	1.09	0.7786	38	37	1.02	no

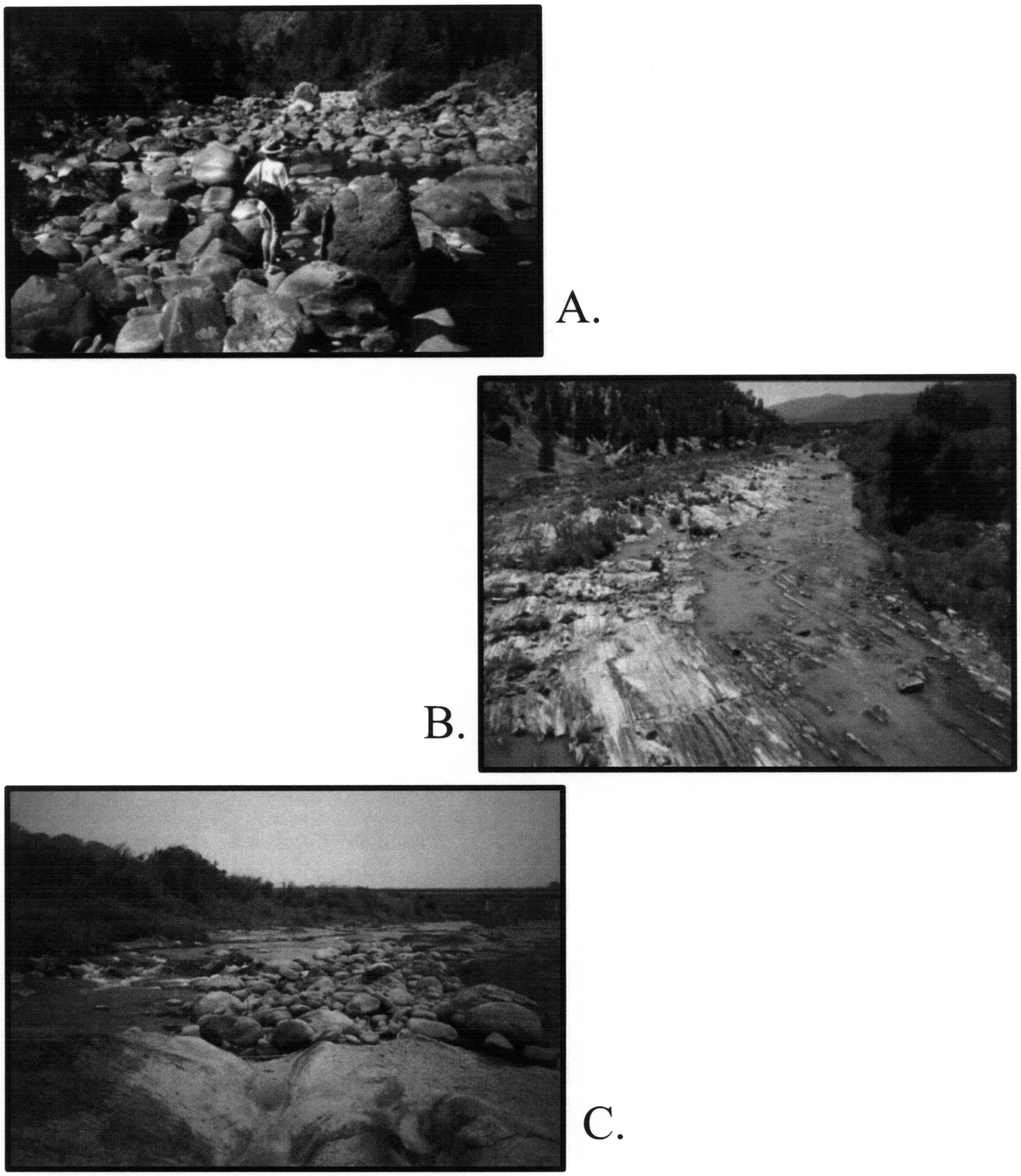


Figure 1: Examples of Alluvial Cover in Actively Incising Rivers

A. Fully alluvial; Ten Mile Creek, Mendocino County, California. B. Fully exposed bedrock, Stoney Creek, Colusa County, California. C. Partially alluviated, Tachia River, Taichung County, Taiwan. (Photos by Leonard Sklar.)

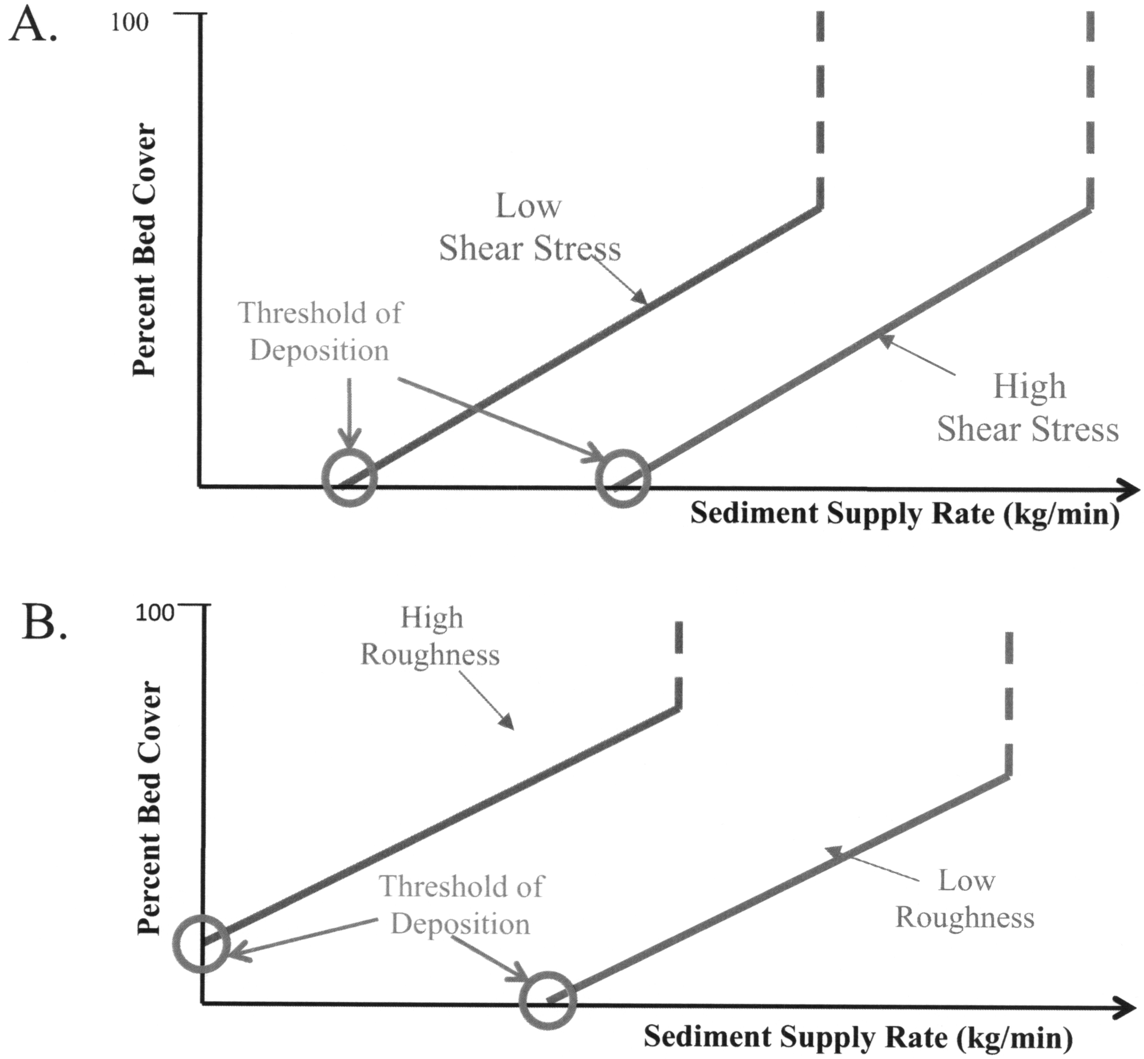


Figure 2: Hypotheses

The diagrams (A and B) above are general representations of my hypothesis regarding relationship between sediment supply rate and the percent of a channel bed that will be covered by alluvium when hear stress and roughness are varied. Both diagrams illustrate my general expectation of a positive correlation between bed cover and sediment supply rate with an eventual period of instability once a threshold percent is reached. Additionally, A. represents my expectation that an increase in shear stress will increase the sediment supply at which deposition will begin (threshold of deposition, b;lue circles) and B. represents my expectation that increasing roughness will decrease the threshold of deposition (blue circles).

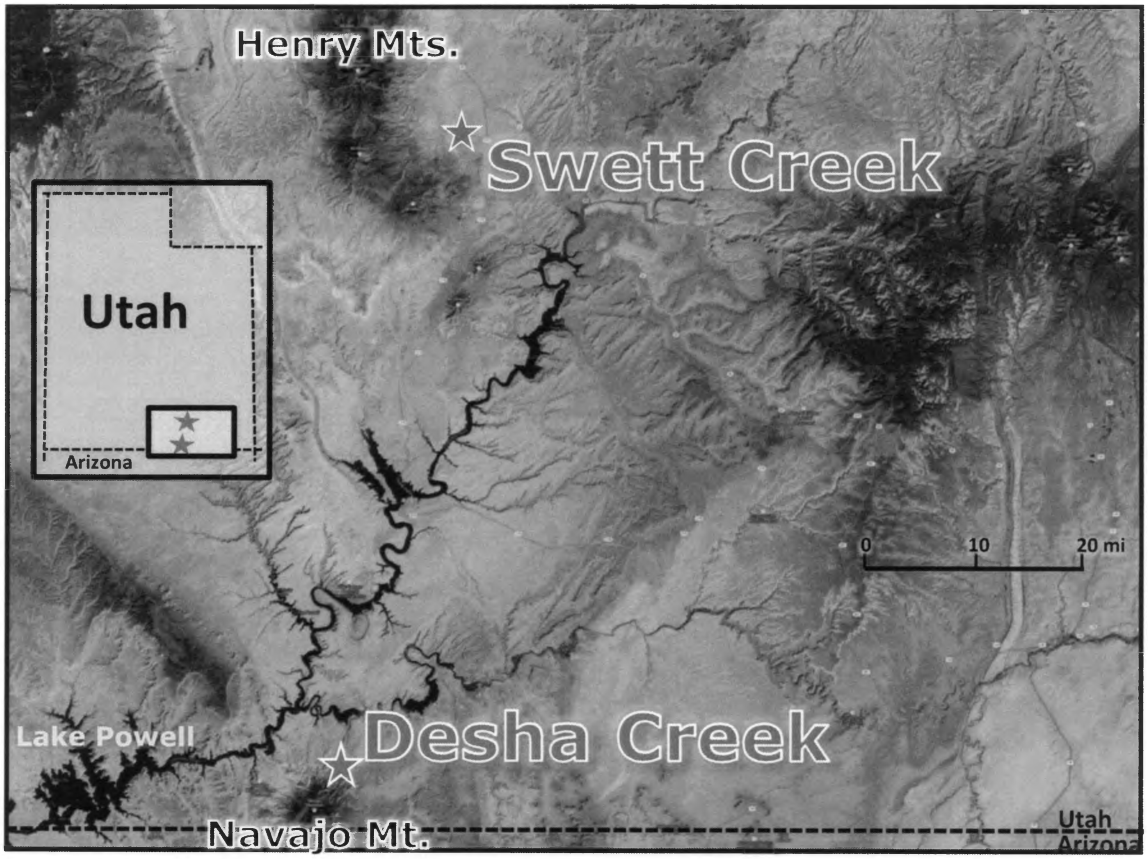


Figure 3: Location Map Showing Field Sites (Red Stars), Henry Mountains, UT, and Navajo Mt, UT. (Terrain photo from Google maps)

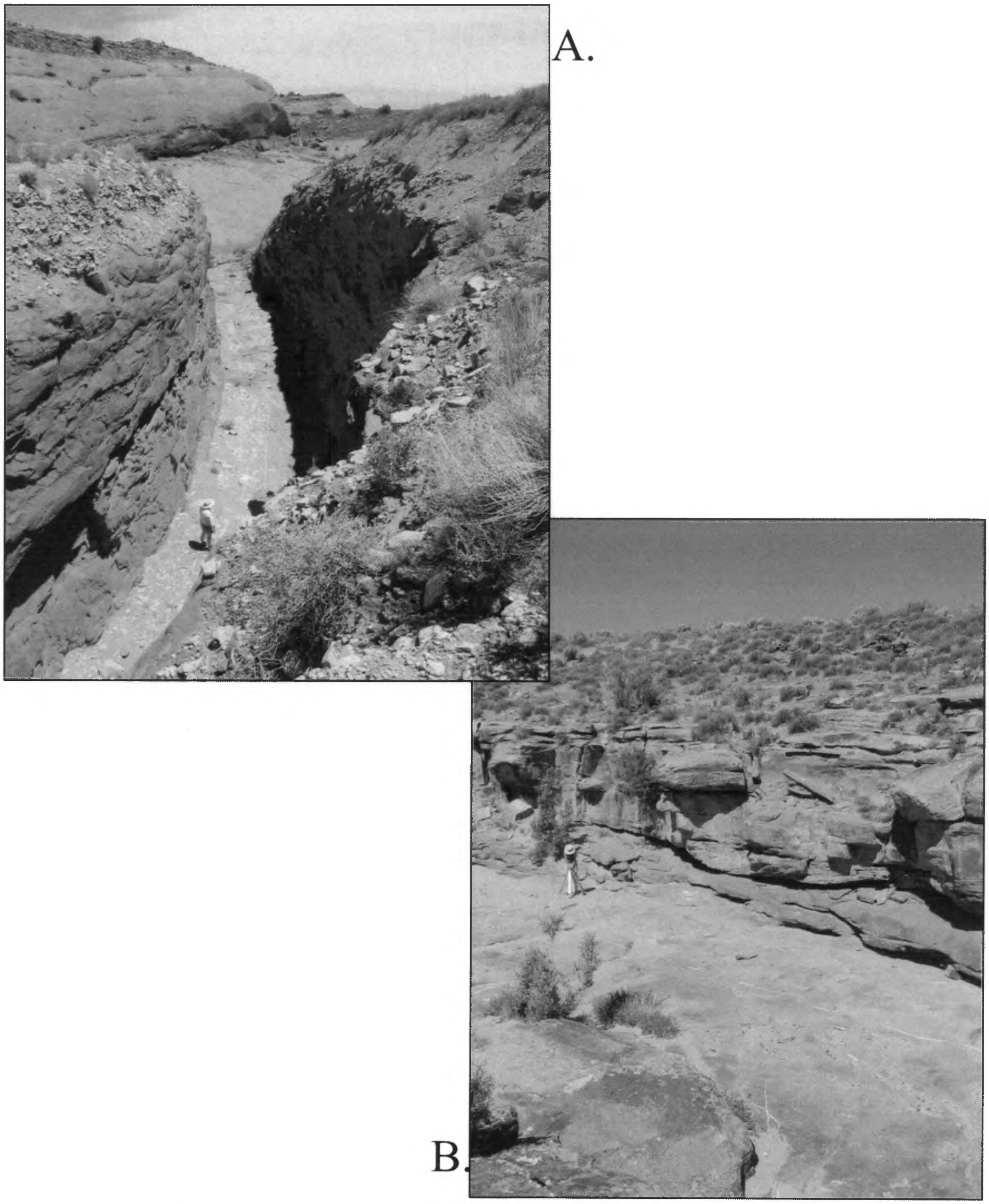
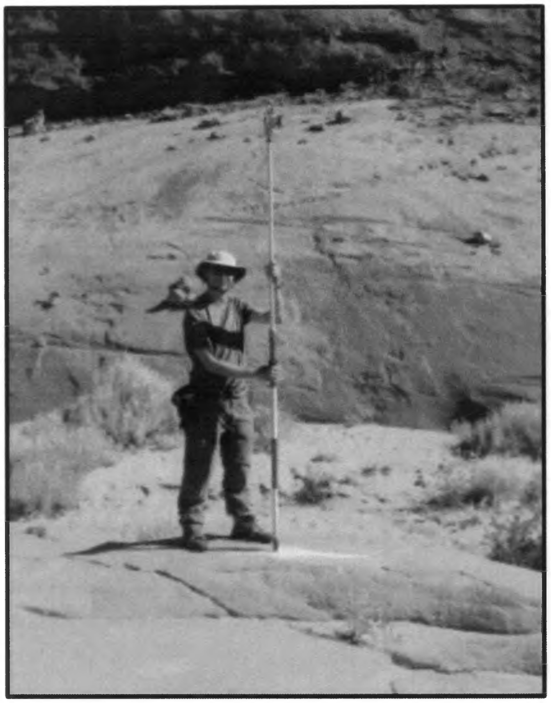
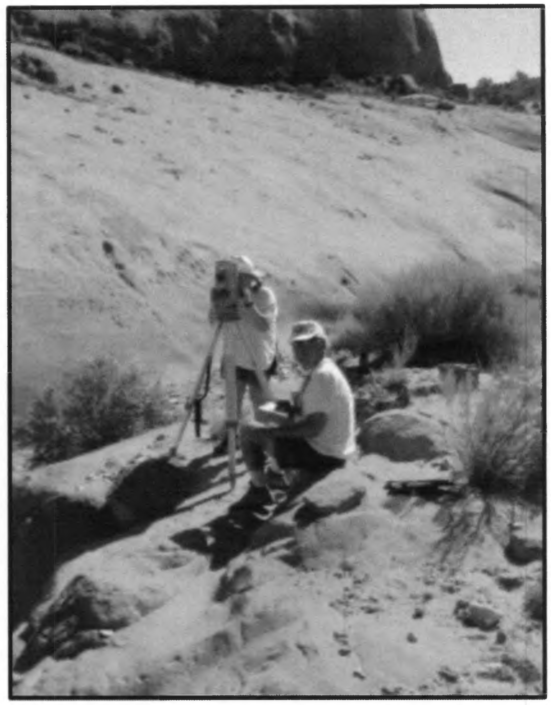


Figure 4: Photos of Field Sites

A. Swett Creek; B. Desha Creek (Photos by Leonard Sklar)



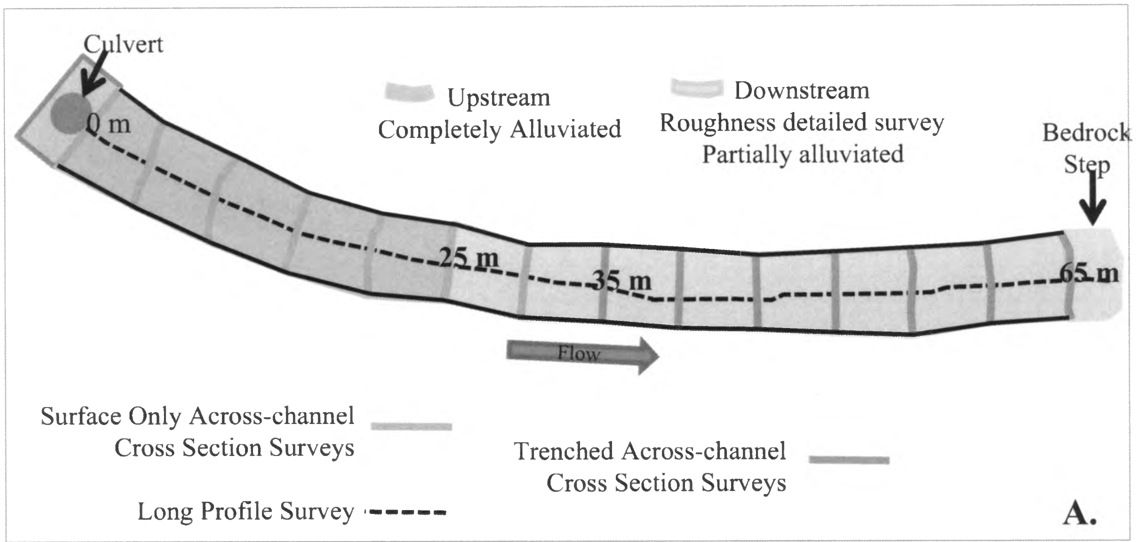
A.



B.

Figure 5: Total Station Survey Equipment

The equipment I used to collect survey data at the field site locations included a Topcon total station (B) and reflector rod (A). The reflector rod is held in position at a point of interest. The total station sends a laser to the reflector and recieves the reflection. The location of the reflector is recorded as x, y, and z (easting, northing, and elevation) relative to the fixed location of the total station. (Photos by Leonard Sklar)



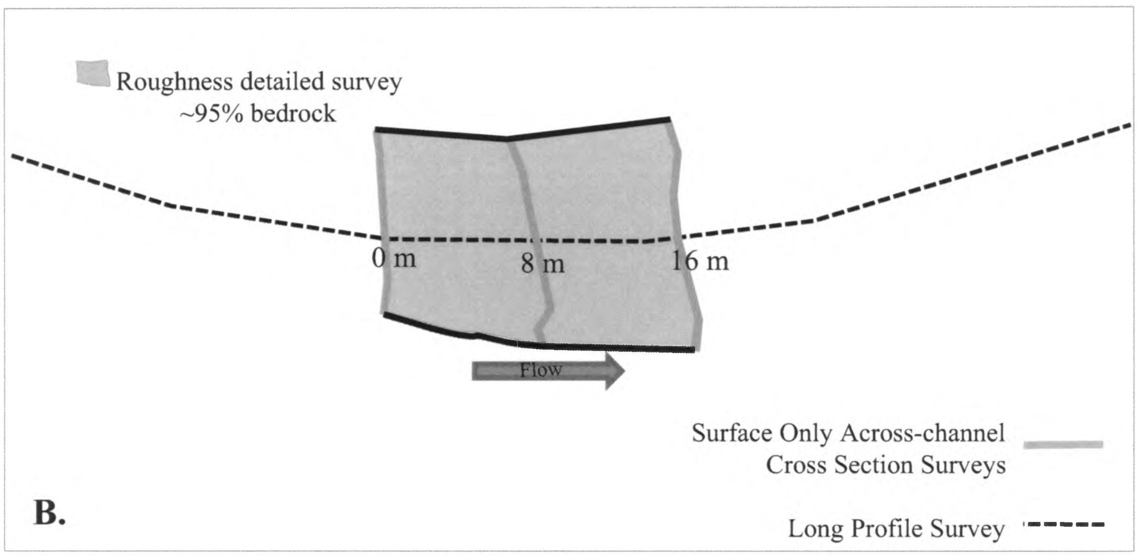
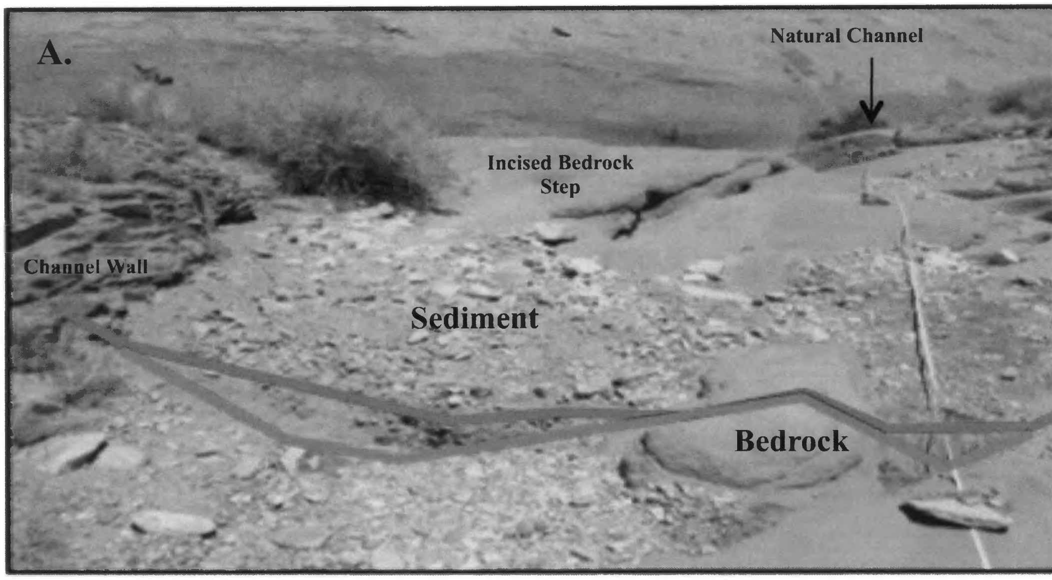


Figure 6: Schematic Maps of Field Sites

A. Swett Creek: illustrating the locations of survey points from across-channel and long profile surveys. Across-channel surveys indicated in orange represent surveys of points taken on the surface over partial alluviation. Across-channel surveys indicated in green represent surveys which were done on the surface and then on the bedrock underneath alluviation after trenches were dug to remove sediment.
B. Desha Creek: illustrating locations of across-channel and long profile surveys.



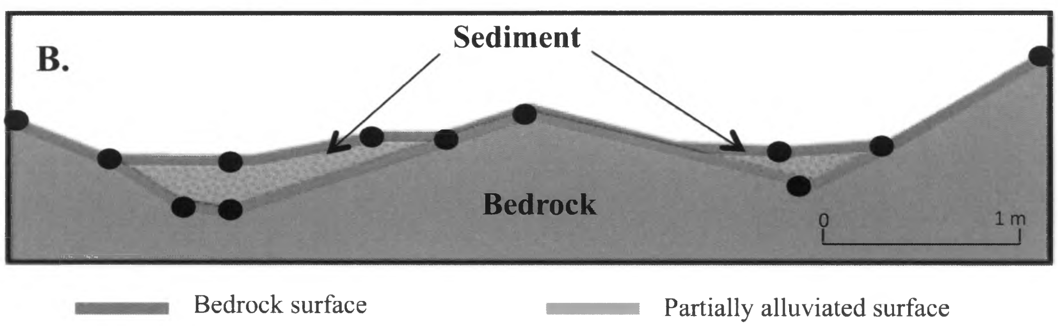


Figure 7: Photo and Schematic Diagram Illustrating an Across-channel Cross Section, Swett Creek

A. Photo taken of the end of the Swett Creek reach looking downstream toward the incised bedrock step and confluence with the natural channel beyond. The red line illustrates the partially alluviated surface as surveyed before sediment was removed. The green line illustrates the bedrock surface surveyed after sediment was removed. (Photo by Jennifer Davis)
B. Schematic diagram of the across-channel surveys from photo above (A). Black dots represent data points.

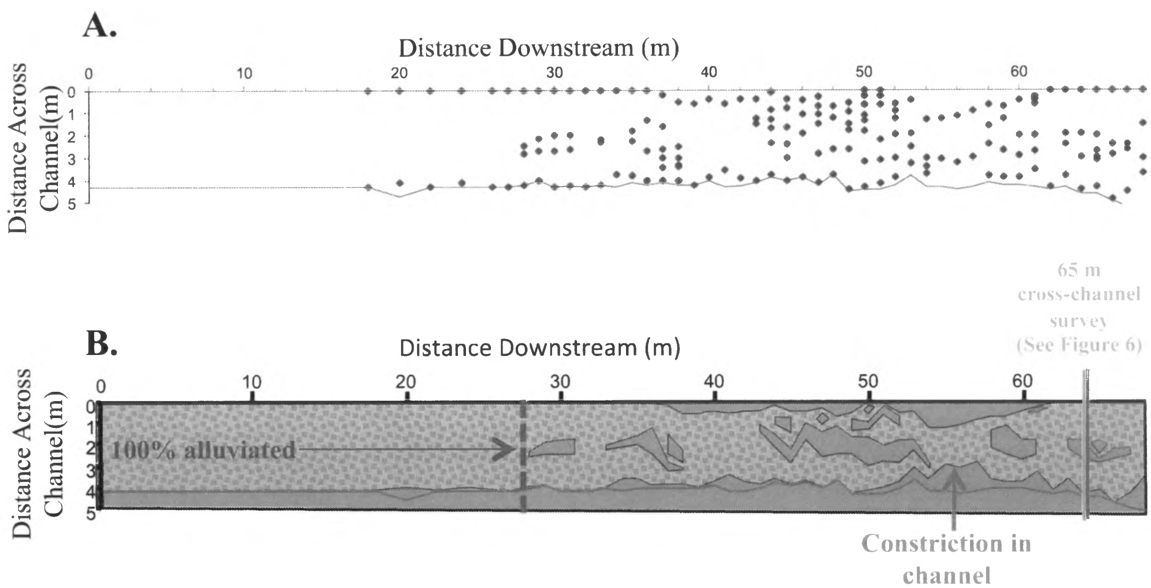


Figure 8: Alluvial Cover, Swett Creek

A. Plot showing data points (blue triangles) used to create alluvial map (B). Brown lines are channel wall boundaries. The x axis is the left bank. The channel in actuality is curved. The straight nature of this diagram is a relict of the method used to calculate values for data points as a distance from the left bank and not actual spatial position relative to each other.
B. Alluvial cover map created by connecting data points to make polygons . Brown polygons illustrate places of exposed bedrock. Gray polygons are areas covered by sediment. The red and green line at 65 m downstream represent the location of the across channel cross section from Figure 6. The end of the completely alluviated upstream section of the channel is represented by a red dashed line.

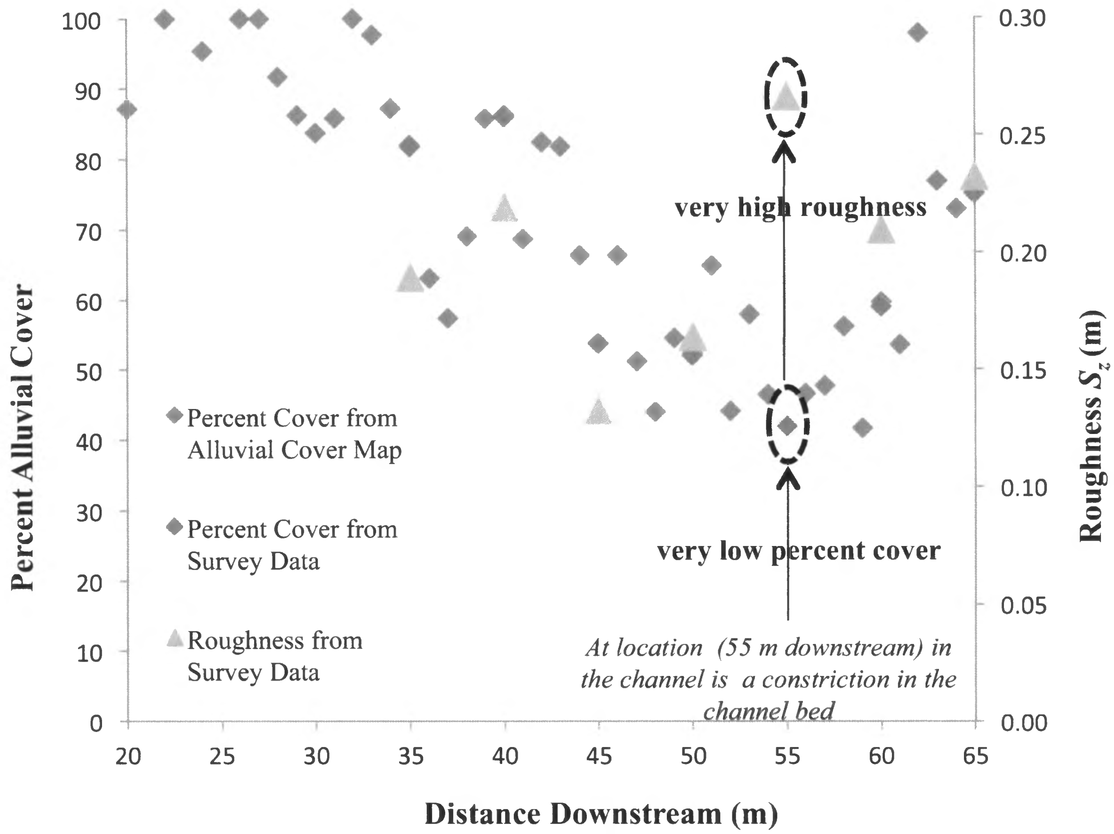


Figure 9: Percent Cover and Roughness Relative to Distance Downstream, Swett Creek

This graph plots three data sets. The blue diamonds are percent cover determined from the alluvial cover map measurements plotted with distance downstream. The red diamonds are percent cover determined from the across-channel survey data plotted with distance downstream. The green triangles are roughness values calculated as the standard deviations of elevation in meters determined from across-channel survey data.Red diamond points are each covering a blue diamond point indicating the survey data percent cover values agree very well with the percent cover values determined from the alluvial cover map measurements of the same distance downstream.

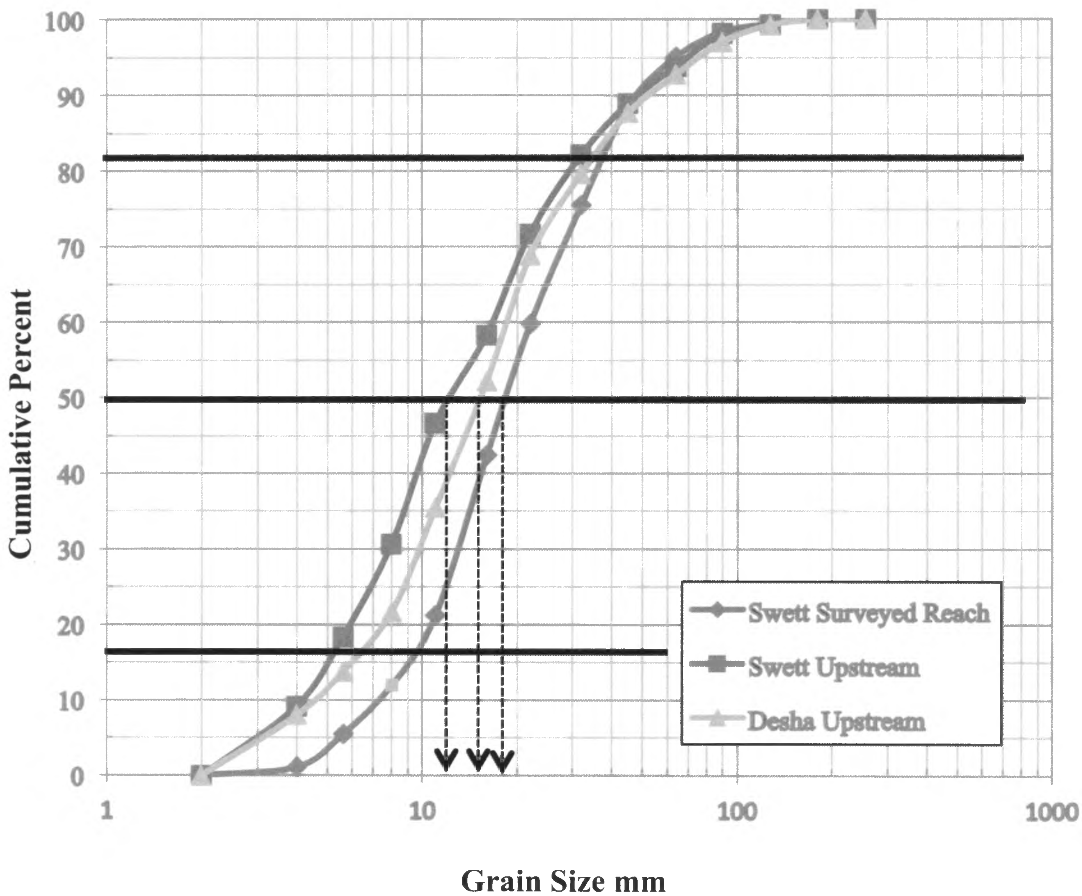


Figure 10: Sediment Grain Size Distributions, Swett Creek and Desha Creek

Grain size distributions from pebble count data are plotted here as cumulative percent finer curves. Blue diamond points represent grain size distribution for the reach of Swett Creek surveyed for roughness. The red square points represent grain size distribution for the reach upstream of the Swett Creek surveyed reach and culvert. The green triangle points represent grain size distribution in the partially alluviated reach upstream of the surveyed reach at Desha Creek.

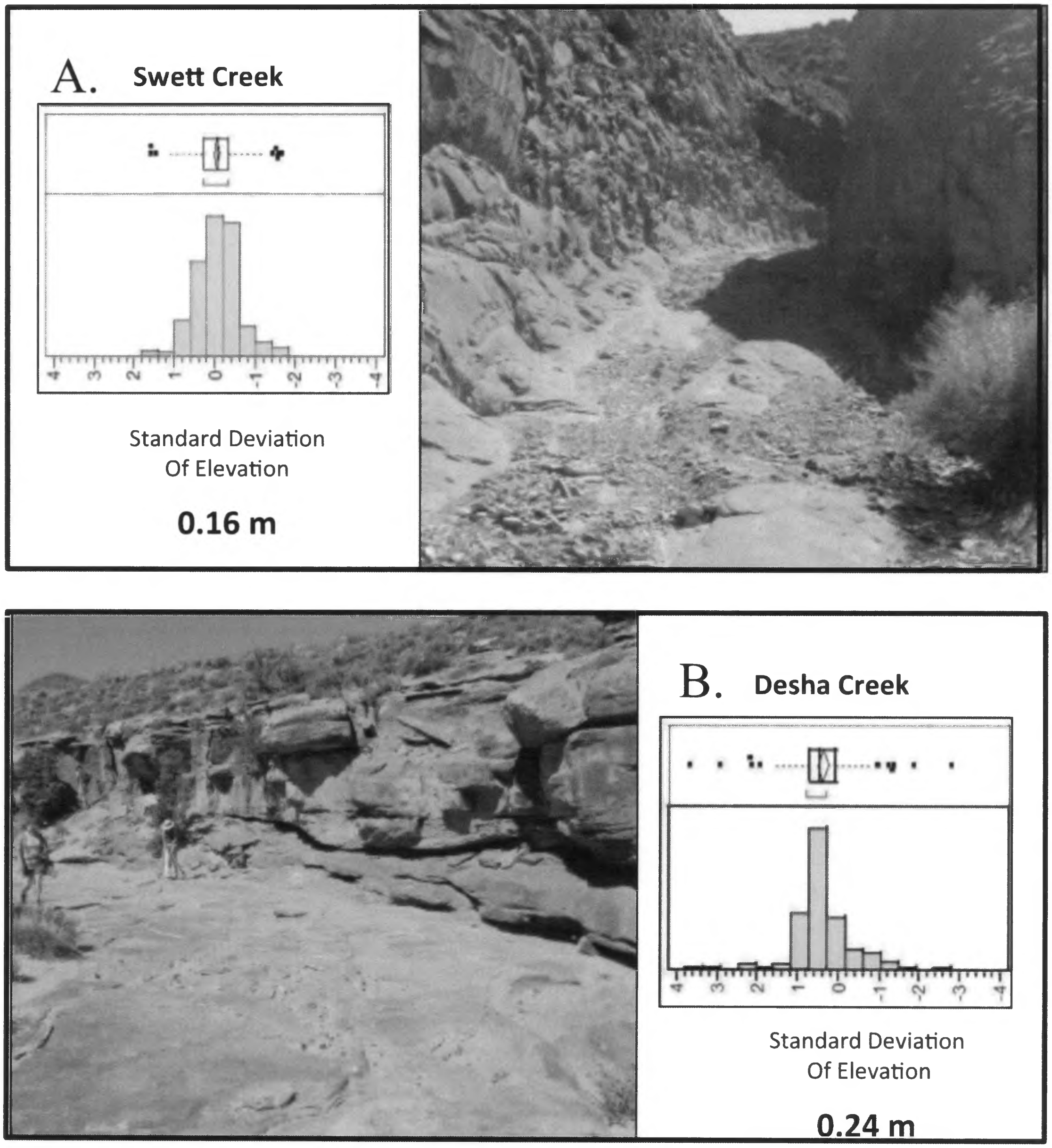


Figure 11: Bedrock roughness of Field Sites

Histograms and photos of Swett Creek (A.) and Desha Creek (B.) field sites illustrate the roughness (S_z) results from surveys of each site.

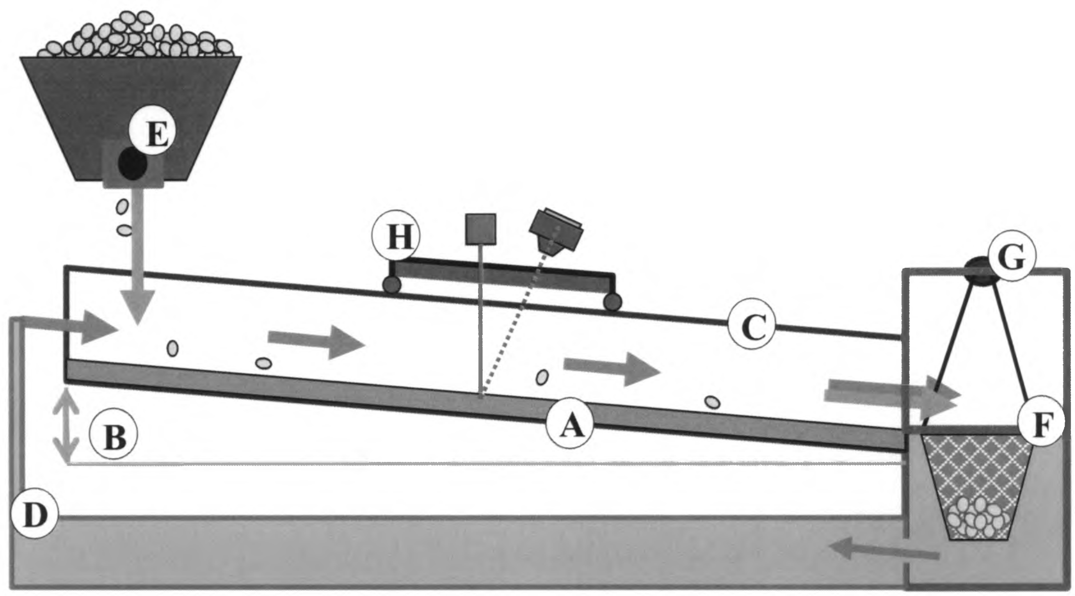


Figure 12: Laboratory Flume Schematic

This schematic diagram illustrates the main components of the model river utilized for the laboratory experiments of this project. A removable channel bed (A) with adjustable slope (B) and transparent plastic walls (C) makes up the channel. (D) Water fed from sumps underneath the flume is pumped to the start of the channel. (E) A mechanical auger feeds sediment from a hopper to the flow at the start of the channel. (F) The end box redirects water to the sump and has 2 sediment collection baskets hanging from digital load cells (G) that weigh sediment flux out of the channel. A rolling carraige with microtopographic laser scanner instruments (H) traverses the length of the channel measures bed elevations for roughness calculations.

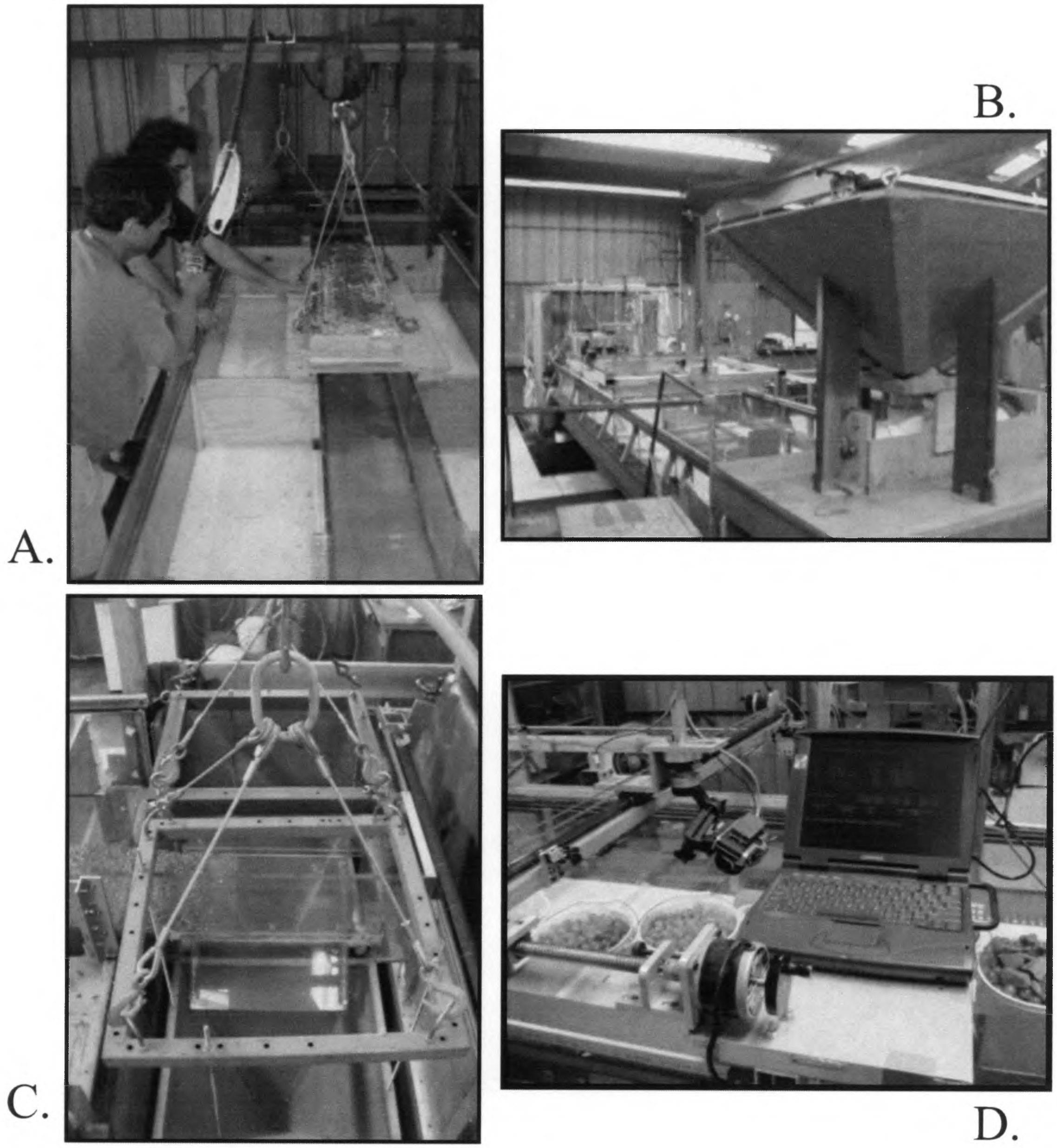
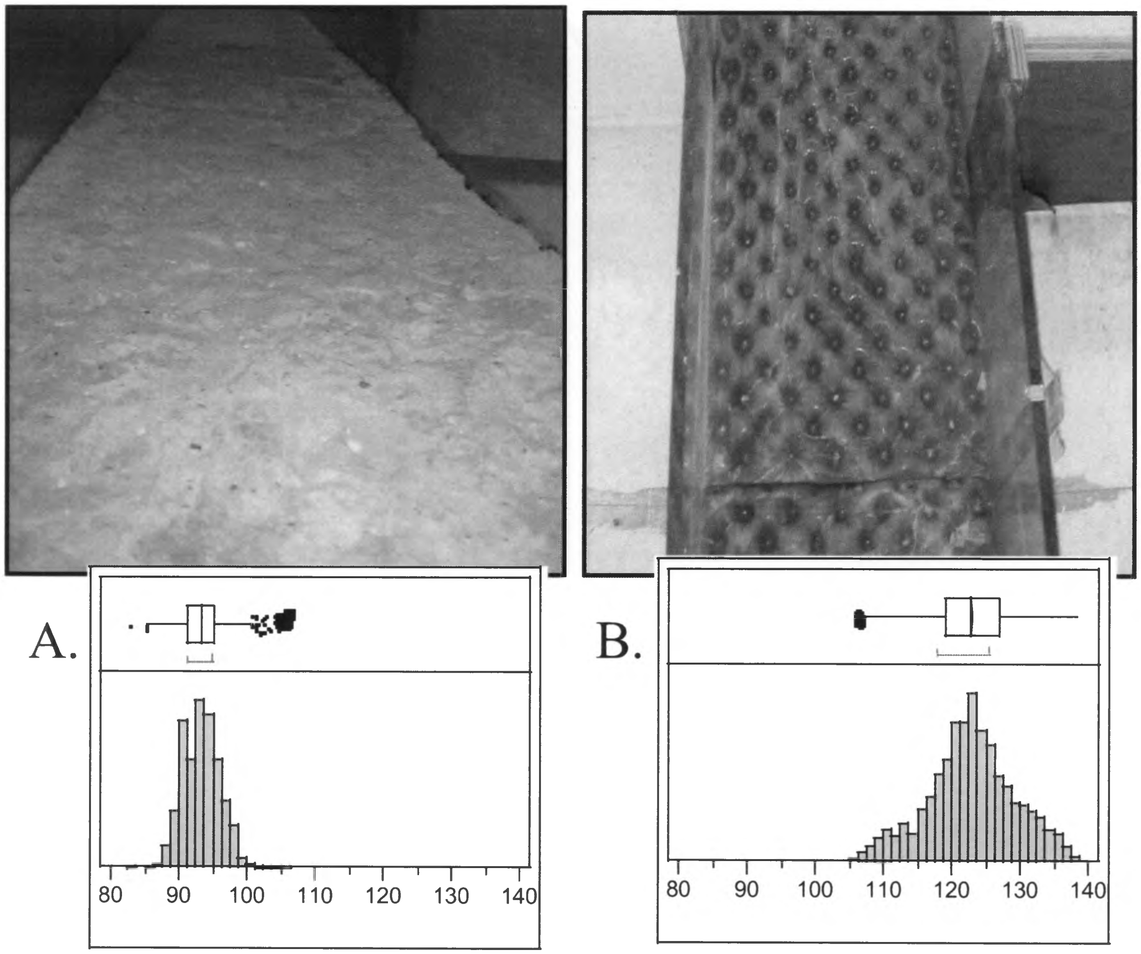


Figure 13: Photographs of Laboratory Flume

A: Installing bedrock bed slabs. B: Sediment supply hopper, flume looking downstream; C: Sediment collection baskets at downstream end of flume; D: Micro-topography laser scanner.



$S_z =$ **2.6 mm** $S_z =$ **6.4 mm**

Figure 14: Laboratory Bedrock Roughness

Photo and histogram showing standard deviation of the smooth, initially planar (A) and very rough, “egg carton” (B) beds created for flume experiments.

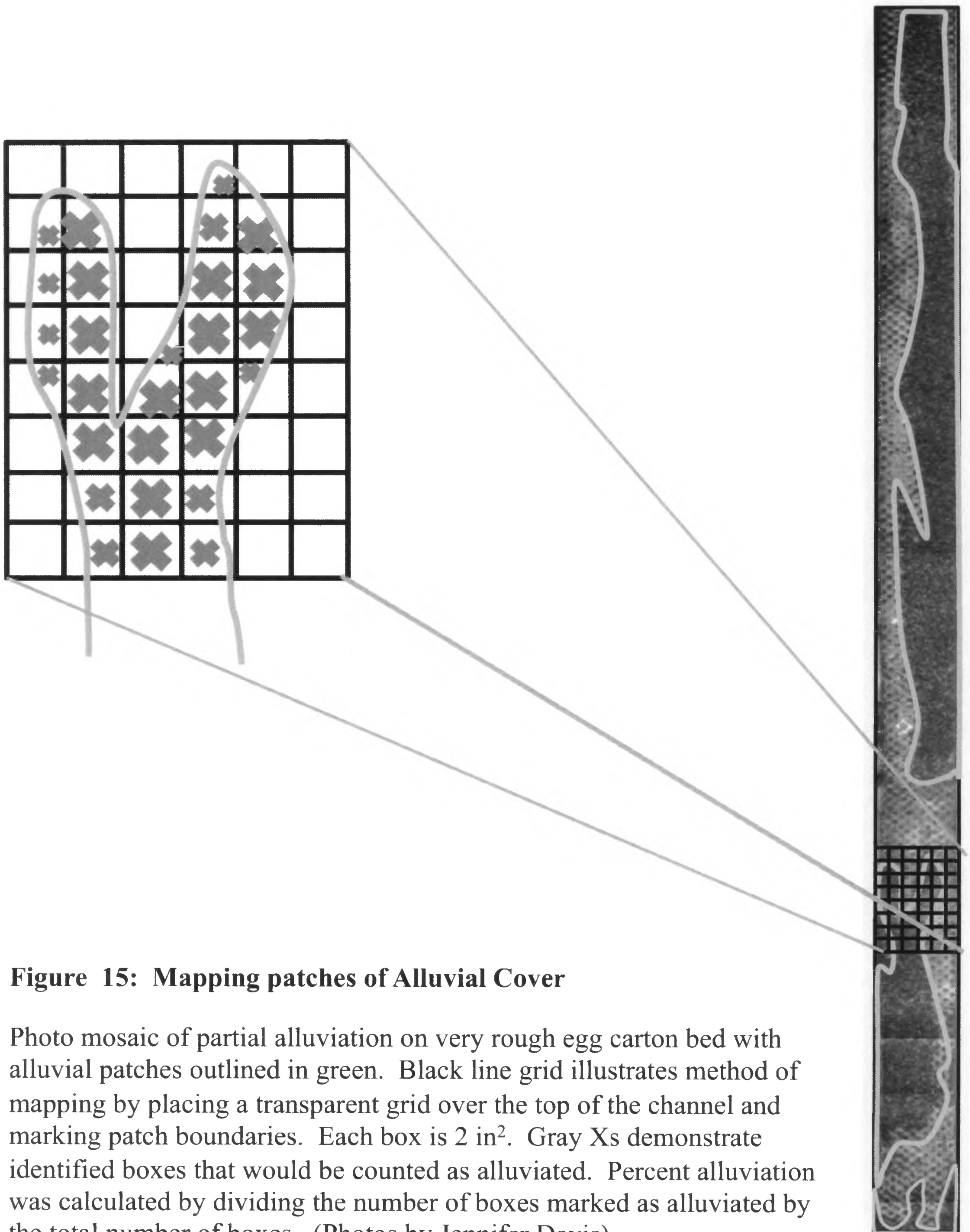


Figure 15: Mapping patches of Alluvial Cover

Photo mosaic of partial alluviation on very rough egg carton bed with alluvial patches outlined in green. Black line grid illustrates method of mapping by placing a transparent grid over the top of the channel and marking patch boundaries. Each box is 2 in^2. Gray Xs demonstrate identified boxes that would be counted as alluviated. Percent alluviation was calculated by dividing the number of boxes marked as alluviated by the total number of boxes. (Photos by Jennifer Davis)

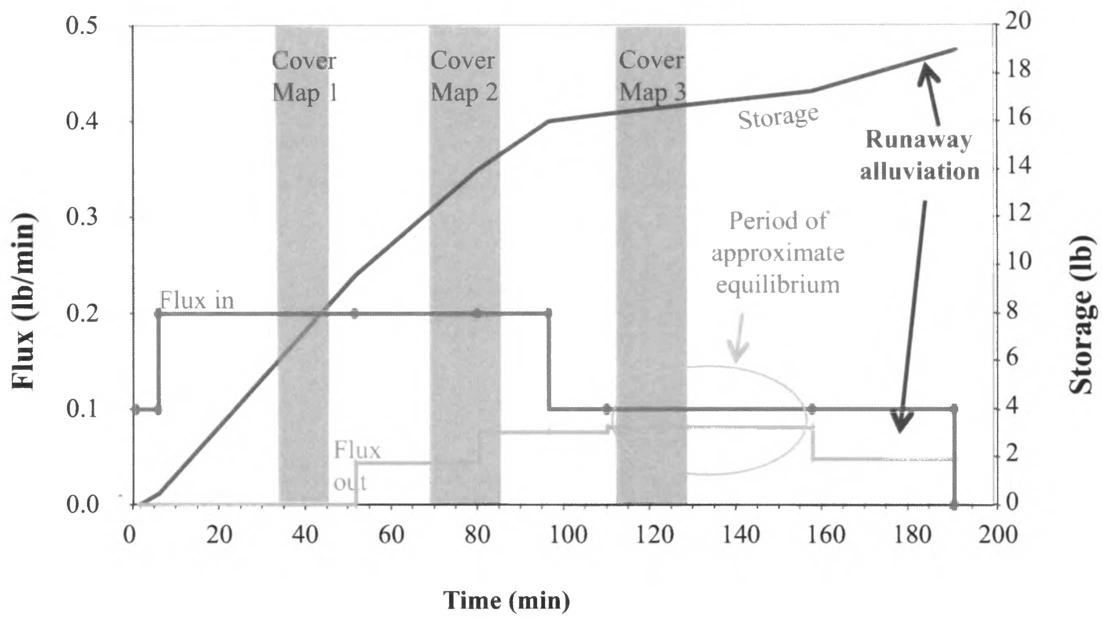


Figure 16: Example Summary of Data Measured from a Run (Run 403)

A time series illustrates the timeline of events and data for run in a graph. It shows sediment supply (red line), flux out (green line), time periods of mapped cover (purple areas) and calculated storage (flux in – flux out). This time series for run 403 indicates an approach toward equilibrium (flux in = flux out), a period of approximate equilibrium (orange circle) and subsequent run away alluviation (labeled in dark blue).

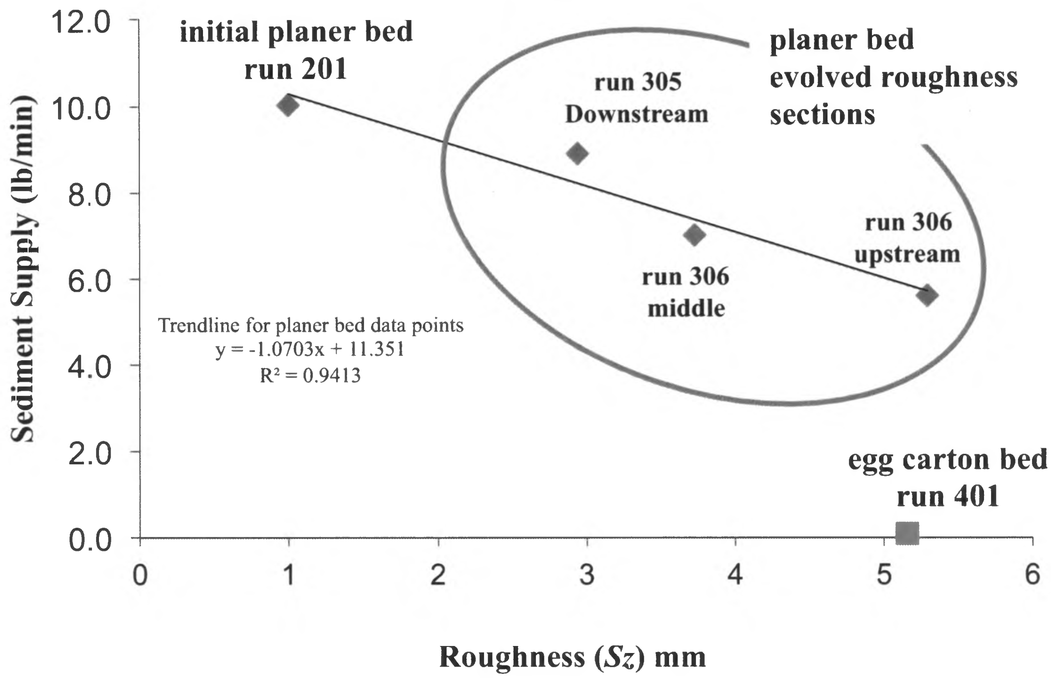


Figure 17: Threshold of Deposition Relative to Roughness

Laboratory results show no deposition occurs until a threshold supply is exceeded. This graph plots the observed sediment supply at which deposition began for different roughness values. The trend of threshold sediment supply rates from the initially planar bed roughness values (blue diamonds) indicate threshold supply depends on roughness. For very rough egg carton beds (red square), deposition began immediately with any non zero sediment supply rate.

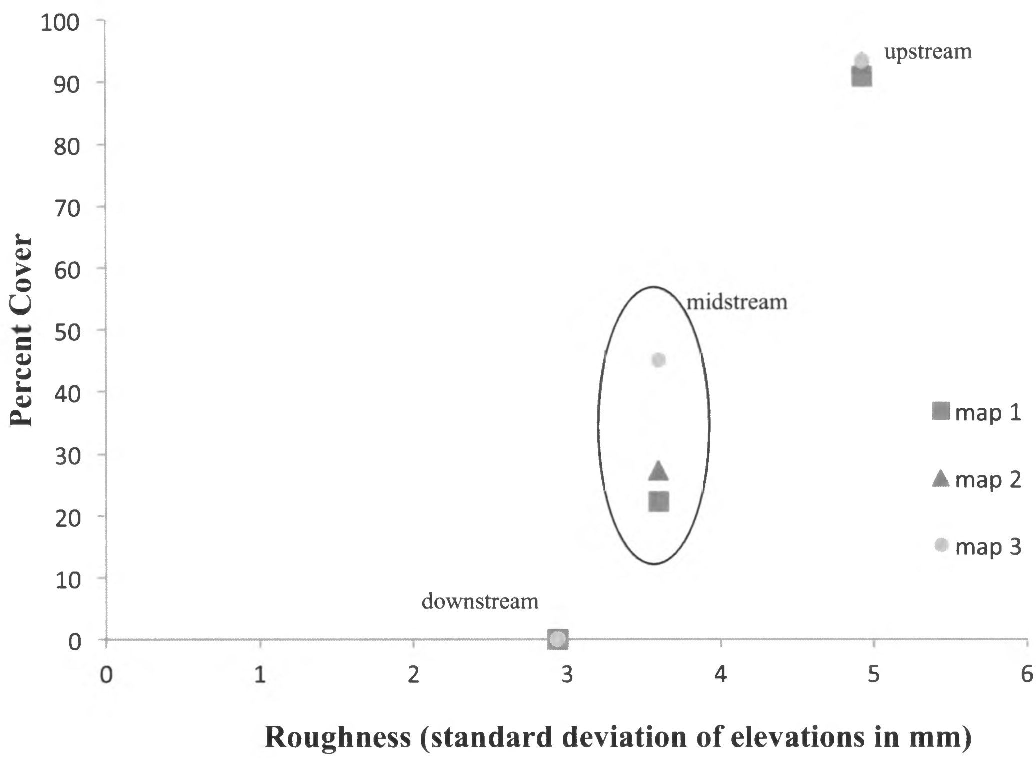


Figure 18: Partial Cover Relative to Roughness

Plot showing the relationship of percent cover to roughness when all other variables are held constant. Data points are from 3 alluvial cover maps made during run 305. Grouping of data reflects 3 different roughness sections (upstream, midstream and downstream) that evolved naturally during the previous set of runs (300-304). All three sections experienced the same sediment supply and shear stress but each developed a different percent cover , indicating rougher beds develop more percent cover, all else equal.

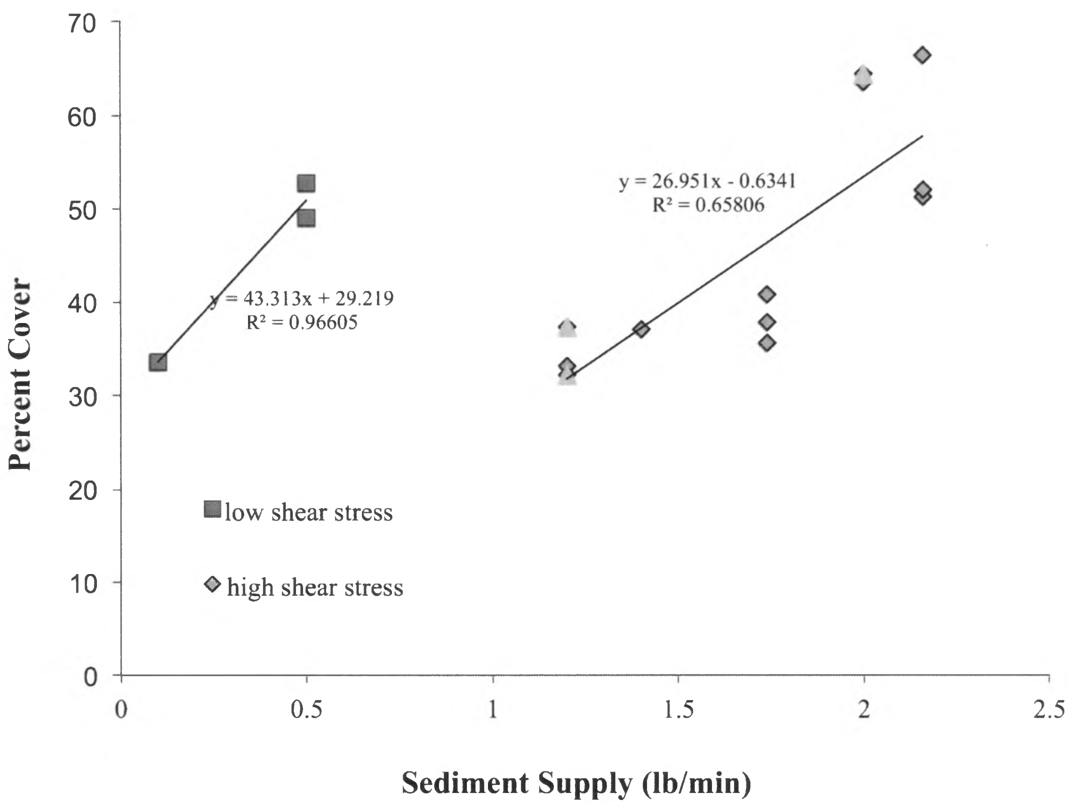


Figure 19: Calculating Equilibrium Cover

Plot of conditions from eggshell runs (400-410) determined to be at equilibrium percent cover for experimental sediment supply. Conditions are considered "equilibrium" when flux out = sediment supply within 20%. Data plots in two groups relative to shear stress conditions. Trendlines applied to each shear stress data grouping is used to calculate predicted equilibrium percent cover for conditions observed during runs 400-410) that were not at equilibrium (Figure 19).

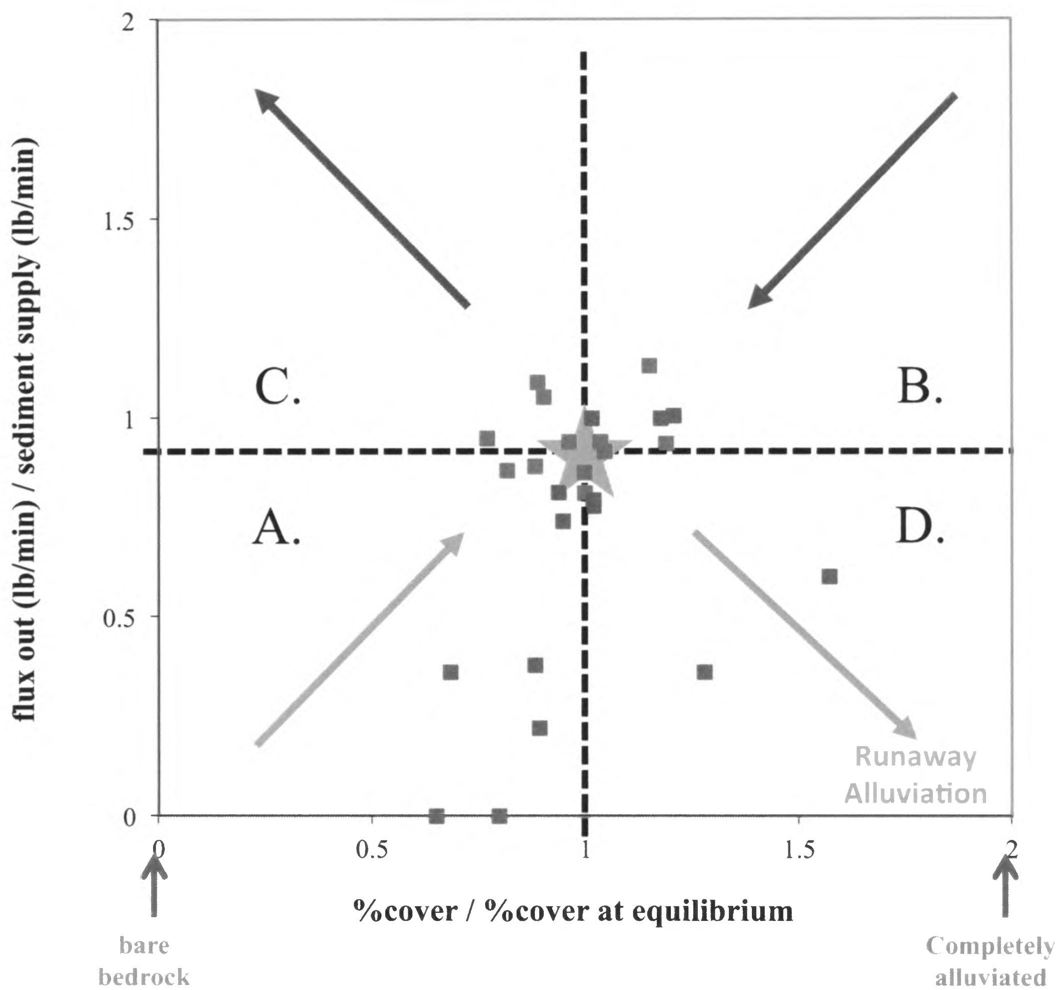


Figure 20: Collapse of Equilibrium and Non-equilibrium Data

The data plotted here are comparing two ratios: Flux out / Sediment Supply on the y axis and % cover measured / predicted equilibrium % cover (calculated from trendline of data in Figure 18). Data points at (1,1) represents approximate equilibrium conditions (blue star). Data points not at equilibrium plot in one of 4 quadrants (A, B, C, D) on the graph. Each quadrant represents conditions in transition either toward or away from equilibrium (green arrows) A. From bare bedrock bed, deposition (green arrow) increasing toward equilibrium cover; B. From completely alluviated bed, erosion (brown arrow) toward equilibrium cover; C. From some partial cover, eroding (brown arrow) toward bare bedrock; D. From some partial cover, deposition(green arrow) toward run away alluviation..

Appendix A: Data for alluvial cover map (Figure 7)

Distance downstream (m)	Bedrock/alluvium contact location distance across channel (m)				
		35	1.8	45	3
		35	2.25	45	4
		35	3.8	46	1.05
18	0	36	0	6	1.9
18	4.29	36	1.35	46	3.85
20	0	36	2.7	47	0.3
20	4.1	36	4	47	0.7
22	0	37	0.2	47	1.05
22	4.3	37	1.6	47	1.5
24	0	37	2.6	47	2.8
24	4.1	37	3	47	4.1
26	0	37	3.45	48	0.7
26	4.3	37	4	48	1.2
27	0	38	0.5	48	2.6
27	4.3	38	2.5	48	3.75
28	0	38	3	49	0.55
28	2.45	38	3.3	49	0.95
28	2.8	38	3.4	49	1.5
28	4.2	38	4	49	1.75
29	0	39	0.6	49	2.6
29	2.15	39	4.2	49	4.4
29	2.7	40	0.4	50	0
29	4	40	3.85	50	0.25
30	0	41	0.6	50	0.65
30	2	41	3.55	50	1.1
30	2.7	42	0.4	50	1.35
30	4.3	42	3.9	50	1.8
31	0	43	0.4	50	3.15
31	2	43	1.25	50	4.3
31	2.6	43	1.5	51	0
31	4.25	43	4	51	0.25
32	0	44	0.1	51	0.65
32	4.3	44	0.85	51	2.2
33	0	44	1.3	51	3.1
33	2.2	44	1.7	51	4.15
33	2.3	44	2.35	52	0.6
33	4.2	44	3.75	52	0.9
34	0	45	0.4	52	1.25
34	3.75	45	0.8	52	1.95
35	0	45	1.65	52	3
		45	2.4	52	3.85

53	0.45
53	1.9
53	2.5
53	3.25
54	1.3
54	3
54	3.4
54	3.7
55	1.25
55	3.05
56	1.15
56	3.2
57	0.9
57	2.95
58	0.65
58	1.55
58	2.4
58	3.8
59	0.7
59	1.25
59	2.65
59	3.85
60	0.45
60	2
60	2.9
60	3.85
61	0.3
61	0.4
61	0.6
61	2
61	2.7
61	3.5
62	0
62	4.3
63	0
63	1.9
63	2.4
63	3.8
64	0
64	1.9
64	2.95
64	4.4
65	0
65	2
65	2.7
65	2.95
65	3.1
65	4.3
66	0
66	2.4
66	2.85
66	4.85
67	0
67	2.4
67	2.6
67	4.5
68	0
68	1.5
68	3
68	3.65

APPENDIX: B: Table of raw pebble count data from the *surveyed reach* at Swett Creek Field Site. Measurements recorded in mm. rock type recorded if able to identify.

ss= sandstone (red sandstone), gs= green sandstone, ws= white sandstone, less = less than 4mm

15	30	27ss	9	55	16	10	65	less	38 gs
23	16	43	34	less	36	34	100	12	less
16	115	less	6	52	22	22	37	22	56
9	21	68 ws	63	128	81	27	70	18	41
15	145	54	18	51 ss	15	28	20	13	34
7	10	14	less	42	35	51	9	less	45
40	55	5	18	18 ss	20	22	43	24	less
47	30	16	20	17	less	14	35	less	17 ws
16	65	less	82	less	42	29	95	52	30
6	95	54	5	30	19	6	17	25	18
7	65	29	63	31	47	30	15	less	7
less	11	16	34	107	25	10	36	11	9
less	11	18	75	less	34	40 ws	25	15	20
57	11	15 ss	less	55	40	45	41	23	16
16	42 gs	40	7	25 ws	82	6 ss	17 ss	33	20
85	30	55	58	53	16	50 ss	9 ss	21	18
18	35	19 ws	20	42 ss	44 ss	10	10	less	20 ws
29	54	25	12	30	43	29	8 ws	20	12
13	33	18 ss	25	26 ns	22 gs	less	230	18	16
16	75	18	less						

APPENDIX C: Table of raw pebble count data for reach *upstream of surveyed reach* at Swett Creek Field Site. Measurements recorded in mm. rock type recorded if able to identify.

ss= sandstone (red sandstone), gs= green sandstone, ws= white sandstone, less = less than 4mm

19	less	15	60	5	36 ss	50 ss	60 85	90	5
37	6	less	34 ws	7 ws	105	23	15 gs	17	4
18	8	19	20 21	11	60	90	14	less	8
11	35	29	31 ws	5	9	9	12	49	11
less	64	40	114	25	9	10	12 ss	10	25 ws
25	32	26 gs	9	12	6 ws	33 *	7 ss	6	5
22 ss	20	less	37	12	7 ws	31 ws	15	8 gs	4
11	33	5	25 ss	35 ws	40	20	9 ws	22	100
25 ws	40 ss	9	less	less	75	6 gs	48 ws	21	21
16 gs	48	8 ss	70	29 ss	less	4 ws	29 ss	18	9
5	98	5	31	less	33	27	45 gs	6	7
20 gs	124	5 ss	15	45	87 ws	23 ss	less	5 ws	5
23	87	12 gs	14	13	13	11	5	50	7
10	61 ws	11	12	41	11	16	151	15	82 ss
9	15	7	70	22	11	22	6	35 ss	7
19	7 gs	7	less	10	11 gs	9	14	128	8
less	5	16	44	20 ws	8	20	26	230	10
17	38	24	less						

APENDIX D: Table of raw pebble count data from Desha Creek field site Upstream of the surveyed reach. Measurements recorded ad mm.

27	15	10	53	11	66	40	35	51	18
52	36	79	23	14	42	12	24	57	11
14	88	18	25	9	25	25	95	12	27
25	34	less	51	15	14	99	141	25	39
15	10	160	less	21	37	less	31	9	20
18	22	4	less	106	20	51	85	11	40
11	5	less	4	4	12	21	40	4	22
12	7	23	35	83	5	12	11	19	95
54	6	8	less	22	21	20	6	20	16
48	10	24	6	240	15	22	9	16	106
100	8	18	46	72	7	24	4	10	7
29	23	75	less	22	20	42	less	6	4
18	26	12	19	less	4	39	20	4	10
35	24	48	less	170	9	40	19	5	31
less	57	14	less	6	21	19	21	16	36

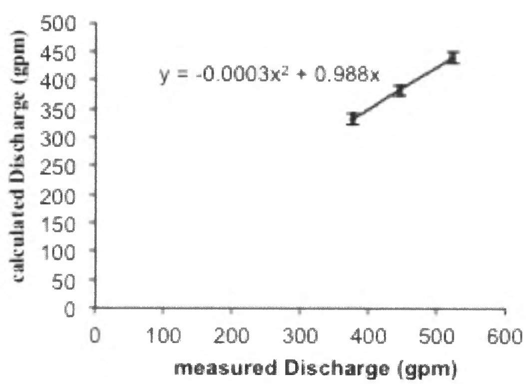
APENDIX E: Discharge calibration

Method for calibrating discharge (Q) meter

1. Start with everything off.
2. Open Head Tank (HT) valves and drain HTs to lowest level without over topping the sump. (sump level~17). *if sump is going to overflow, turn on pump for a few minutes.
3. Close Ht valves.
4. Let the HT depths equilibrate.
5. Measure HT depths.
6. Turn on pump.
7. Start the clock when the water starts into the HTs. (t1)
8. Let the HTs fill to some full level without overtopping. (HTz~75)
9. Turn off the pump.
10. Stop the clock when the water stops.
11. Let the HT depths equilibrate.
12. Measure the HT depths.
13. Use volume of HT and time data to calculate rate.

In Excel, determined the change in volume of water in the tanks using the initial and final height measurements of water in both tanks and the cross sectional area of the tanks. Change in volume was converted from cm^3 to gallons and divided by time it took to change the volume gives a predicted/calculated discharge in gpm. This predicted value was then compared to the Q meter reading.

Discharge meter reading(gal/min)	Discharge calculated from measurements
445	63.2
376	43.6
523	83.2
525	67.1



APPENDIX F: Sediment feed calibration for runs through Run 306. After 306, sediment feed problem, all sediment supply rates calculated from measurements made catching sediment for 1 minute as it was being supplied and weighing caught sediment.

Method for calibrating sediment feed mechanism setting to a rate (lb/min)

1. Ran the flume with some feed setting at high enough discharge so no sediment is stopping (so sed flux in = sed flux out).
2. Turned on capture file to record change in weight of basket. (at this point only 1 basket… load cell1)
3. Fed sediment at settings 5, 3, 1, 10, 15, 20-- each setting for some long amount of time.
4. Turned off capture file…converted to excel format.
5. In excel created column for time for each reading of weight using frequency calculation.
6. Timeline column: first reading at t= value of time interval,l 2nd reading equals 2 times time interval, 3rd reading equals 3 times time interval…etc… where each cell in the column equals the previous cell in the column + time interval value.
7. Made plot of weight vs time. From this plot I determined periods of time where the sediment flux was constant. The curve on the plot would have constant slope…slope = rate (change in weight/change in time).
8. Clipped out data (time and weight) representing each setting and pasted in a new sheet.
9. I made a new plot with data from each setting as separate series and added trendlines to each series, extracting the slope from the equation of the trendline.
10. In new worksheet, made columns setting and rate. I plotted rate vs setting adding trendline. At this point, settings 10, 15, and 20 seemed a little off the linear trend. So I used recorded start and stop times and the total amount of weight change during the entire time running that setting to calculate the rate. Then I plotted these values and they seemed a little better. Using the new values for setting 10, 15, 20 with the other values for settings 1, 3, 5, and 25, I plotted again and added a trendline.
11. I used the equation from this plot rate vs setting to generate another worksheet that predicts a rate for the whole range of settings at ¼ setting intervals.

setting	lb/min
1	0.114
3	0.804
5	1.416
10	2.46
15	4.386
20	5.196
25	6.9

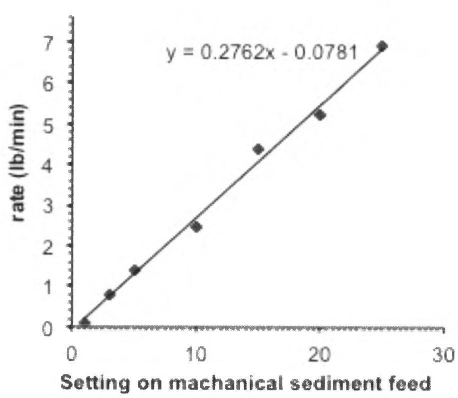
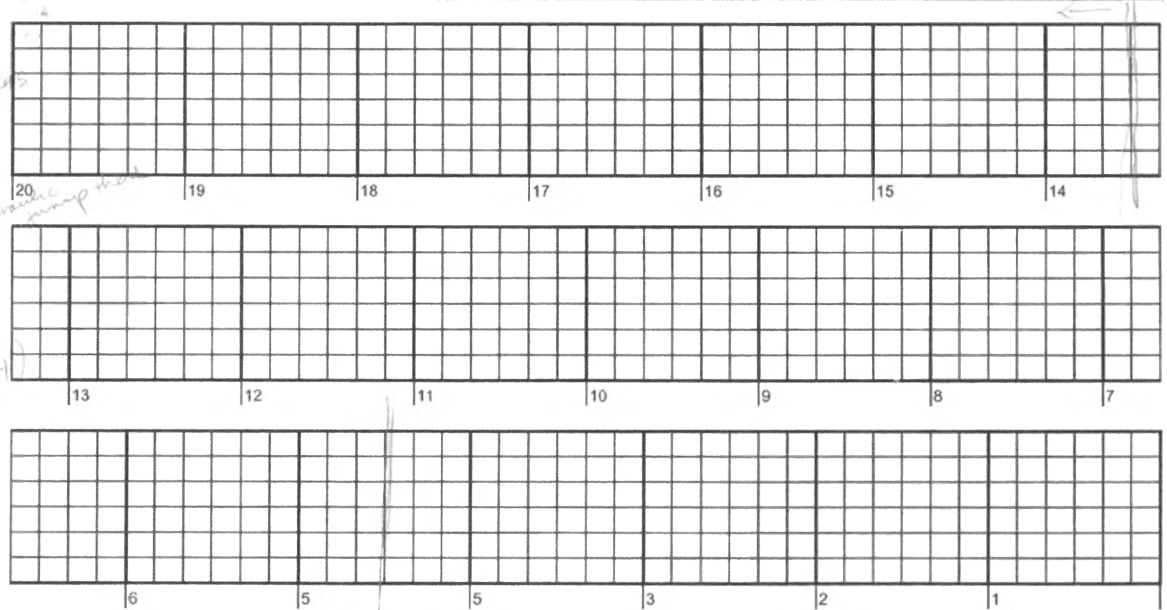


Table used to determine what setting to use on mechanical feed in experiments up to run 306

setting	predicted lb/min	setting	predicted lb/min	setting	predicted lb/min
1	0.35	8	2.29	15	4.22
1.25	0.42	8.25	2.36	15.25	4.29
1.5	0.49	8.5	2.43	15.5	4.36
1.75	0.56	8.75	2.49	15.75	4.43
2	0.63	9	2.56	16	4.50
2.25	0.70	9.25	2.63	16.25	4.57
2.5	0.77	9.5	2.70	16.5	4.64
2.75	0.84	9.75	2.77	16.75	4.70
3	0.91	10	2.84	17	4.77
3.25	0.98	10.25	2.91	17.25	4.84
3.5	1.04	10.5	2.98	17.5	4.91
3.75	1.11	10.75	3.05	17.75	4.98
4	1.18	11	3.12	18	5.05
4.25	1.25	11.25	3.19	18.25	5.12
4.5	1.32	11.5	3.25	18.5	5.19
4.75	1.39	11.75	3.32	18.75	5.26
5	1.46	12	3.39	19	5.33
5.25	1.53	12.25	3.46	19.25	5.39
5.5	1.60	12.5	3.53	19.5	5.46
5.75	1.67	12.75	3.60	19.75	5.53
6	1.74	13	3.67	20	5.60
6.25	1.80	13.25	3.74	20.25	5.67
6.5	1.87	13.5	3.81	20.5	5.74
6.75	1.94	13.75	3.88	20.75	5.81
7	2.01	14	3.94	21	5.88
7.25	2.08	14.25	4.01	21.25	5.95
7.5	2.15	14.5	4.08	21.5	6.02
7.75	2.22	14.75	4.15	21.75	6.09

Date: turned up to 32 Time: Run: 305 Bed Map #:

up

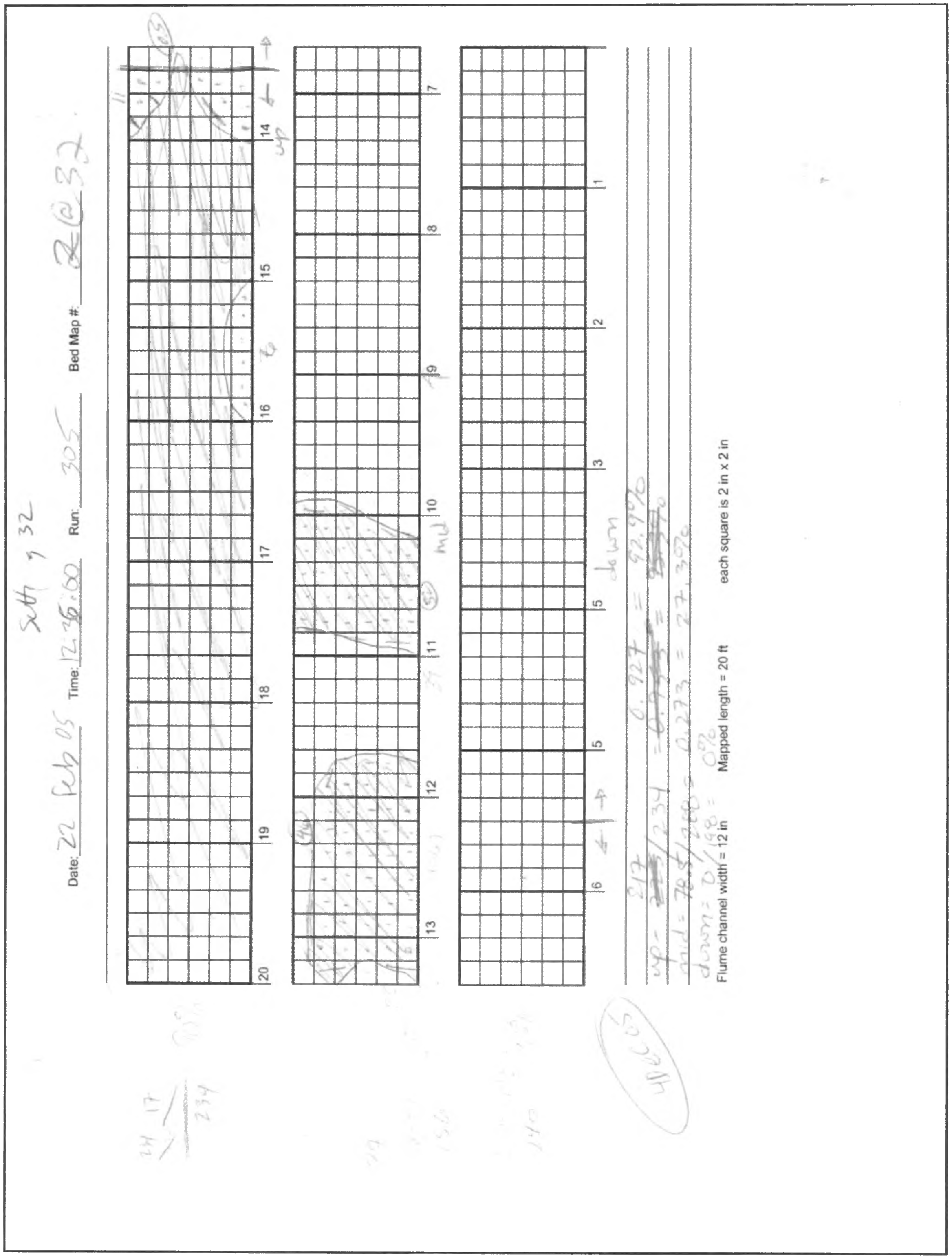


Flume channel width = 12 in Mapped length = 20 ft each square is 2 in x 2 in

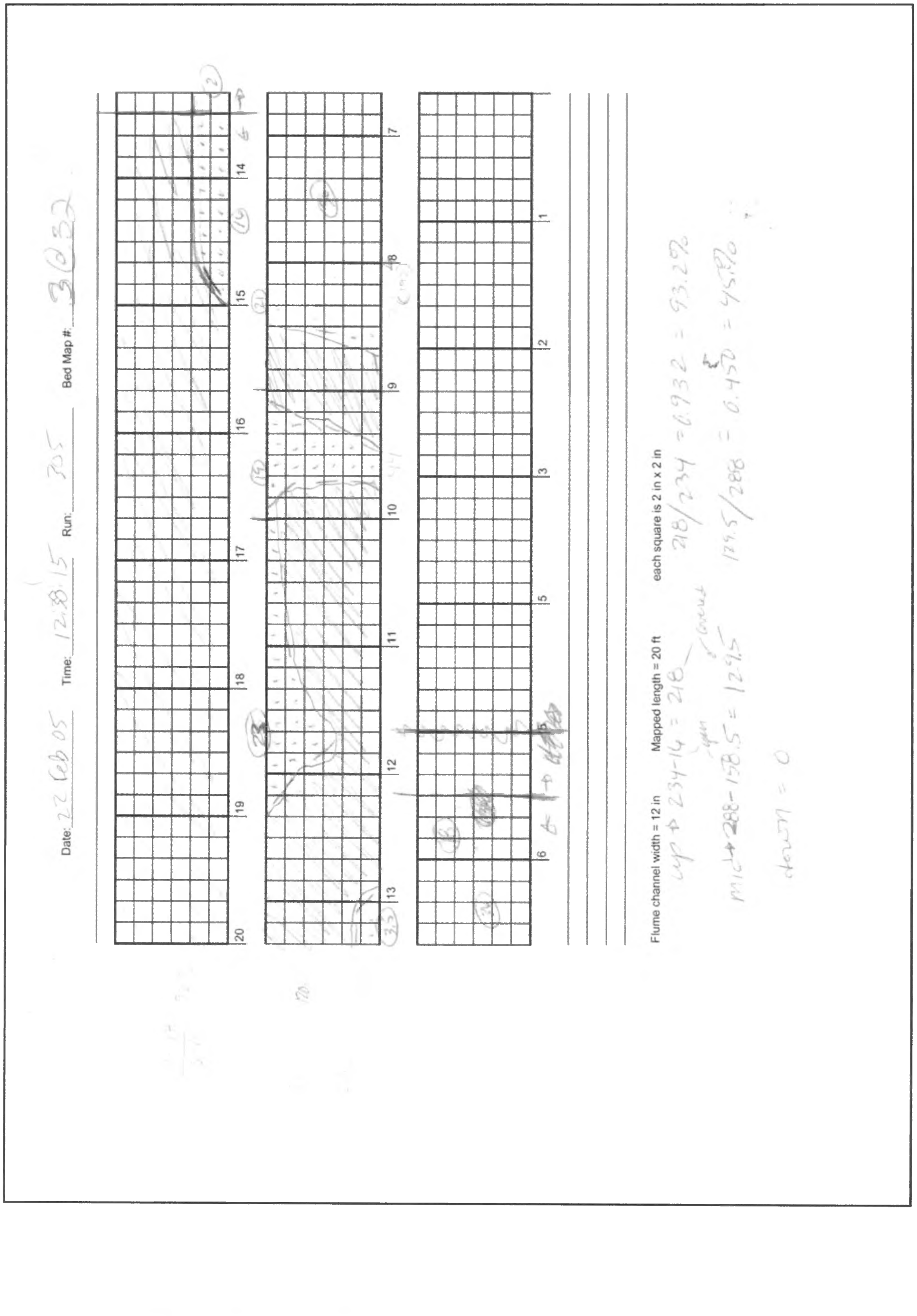
12:29:00

12:31:15
complete
mostly covered
to 12

12:33:15 16 up
complete



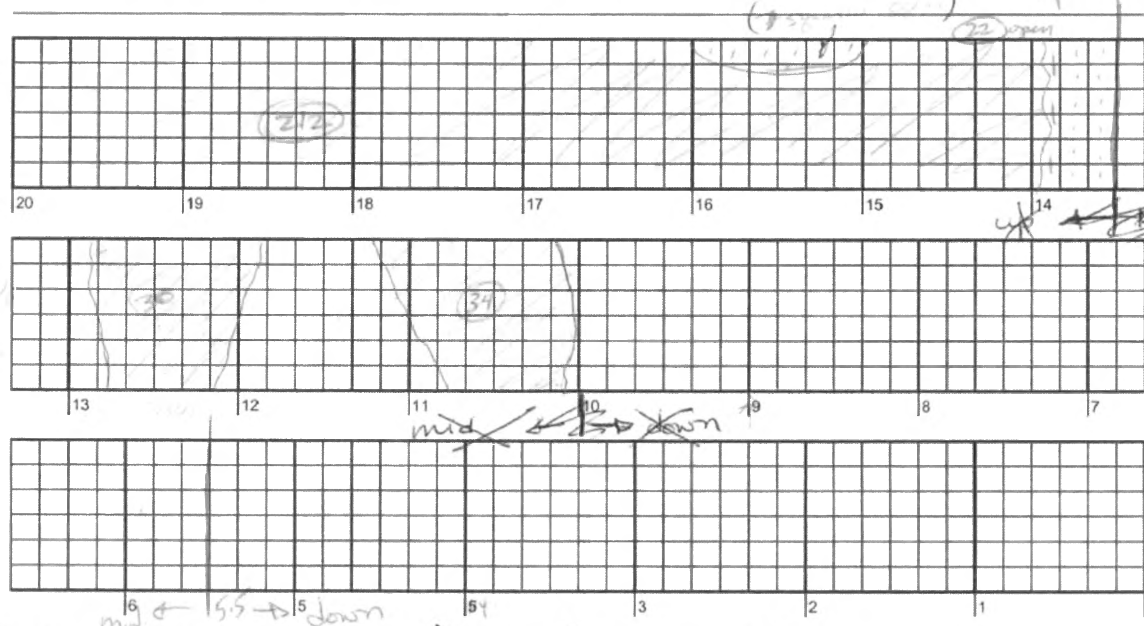
Date:
Time:
Run:
Bed Map #:
Flume channel width = 12 in
Mapped length = 20 ft
each square is 2 in x 2 in


Date: 22 Feb 05
Time: 12:28:15
Run: 305
Bed Map #: 3632
20 19 18 17 16 15 14
13 12 11 10 9 8 7
6 5 3 2 1
Flume channel width = 12 in
Mapped length = 20 ft
each square is 2 in x 2 in
up → 234-14 = 218
218/234 = 0.932 = 93.2%
mid → 288-158.5 = 129.5
129.5/288 = 0.450 = 45.0%
down = 0

Setting 32

Date: 22 Feb 05 Time: 12:34 Run: 305 Bed Map #: 1 @ 32

up ← 13.5 → mid



~~13.5-20 ft up = 234 boxes 212 cover/234 = 0.906 = 90.6%~~

~~10-13.5 ft mid = 126 boxes 64 cover/126 = 0.508 = 50.8%~~

~~0-10 ft down = 360~~

Flume channel width = 12 in Mapped length = 20 ft each square is 2 in x 2 in

4 Dec 05

13.5 - 20 ft up = 234 boxes 212/234 = 0.906 = 90.6%

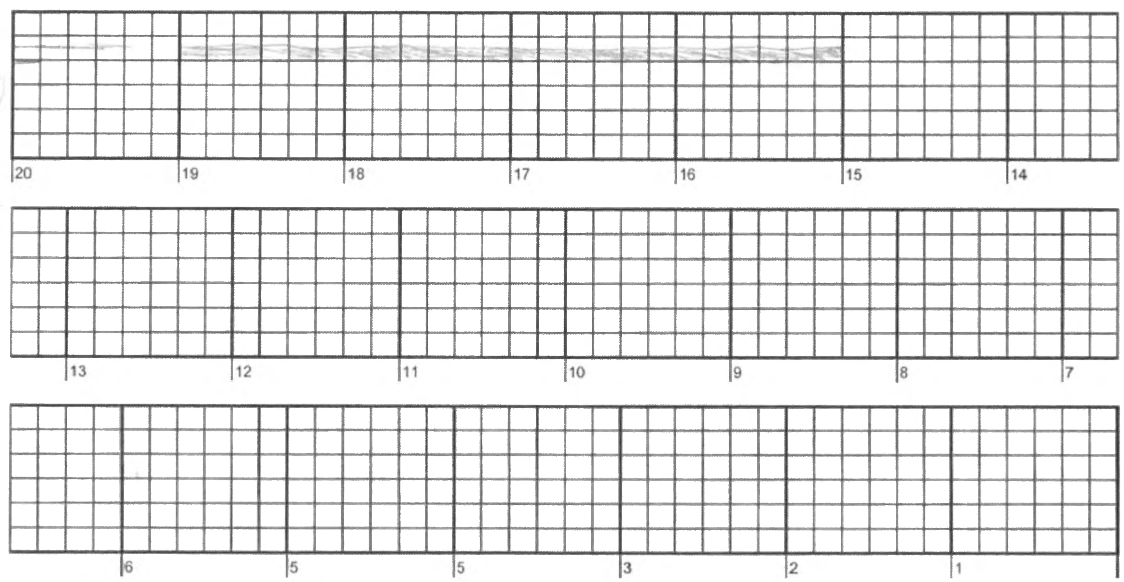
5.5 - 13.5 ft mid = 288 boxes 64/288 = 0.222 = 22.2%

0 - 5.5 ft down = 198 boxes 0/198 = 0%

Date: 22 Feb Time:________ Run: 305 Setting 25 Bed Map #: 1 @ 25

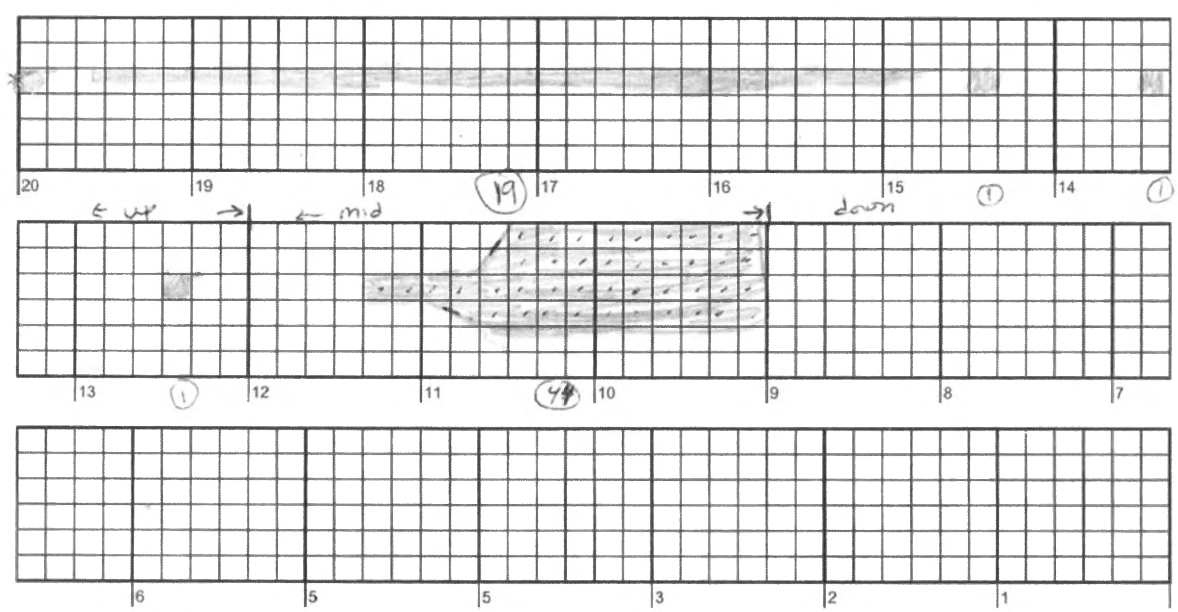
grass-shaped
1-1½ wide
19 to 15
~ 4 ft long

Somewhat less shaped
~ 20.5 – 19 long
1 – 1½" wide



Flume channel width = 12 in Mapped length = 20 ft each square is 2 in x 2 in

Date: 8 March 05 Time: 1:52 - 2:10 Run: 30e Bed Map #: 1



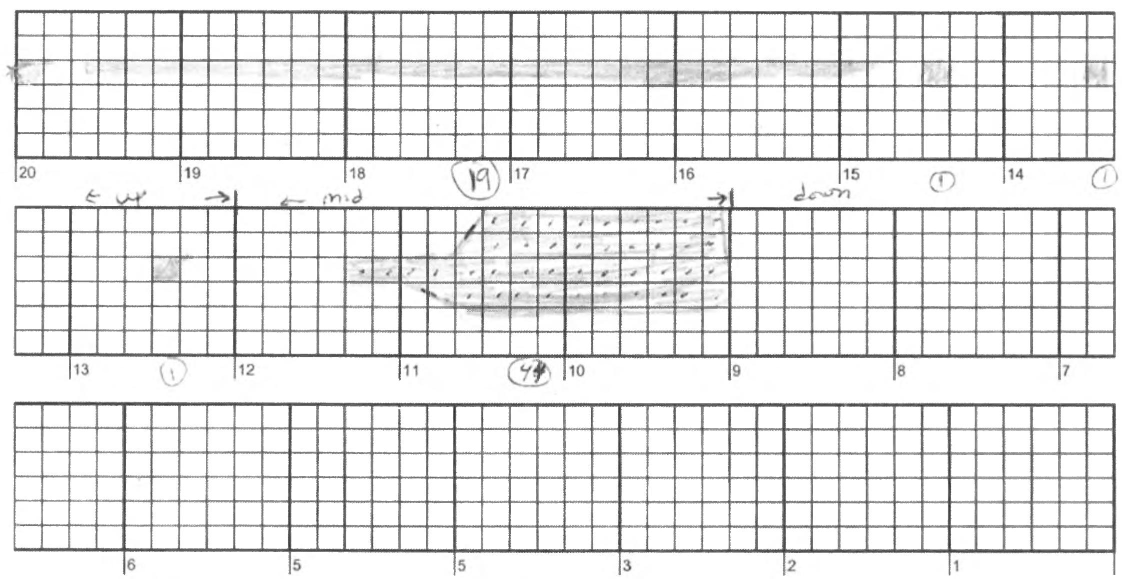
grout is pretty much covered most of time
15-17.5
antidune type wavy watersurface

Flume channel width = 12 in   Mapped length = 20 ft   each square is 2 in x 2 in

total boxes = 720   total cover boxes = 65   65/720 = 0.0903 = 9.0%

	Possible			
up 20-12	288 boxes	cover = 22 boxes	22/288 = 0.076	= 7.6%
mid 12-9	108 boxes	cover = 44 boxes	44/108 = 0.407	= 40.7%
down 9-0				

Date:________ Time:________ Run:________ Bed Map #:________



Flume channel width = 12 in   Mapped length = 20 ft   each square is 2 in x 2 in

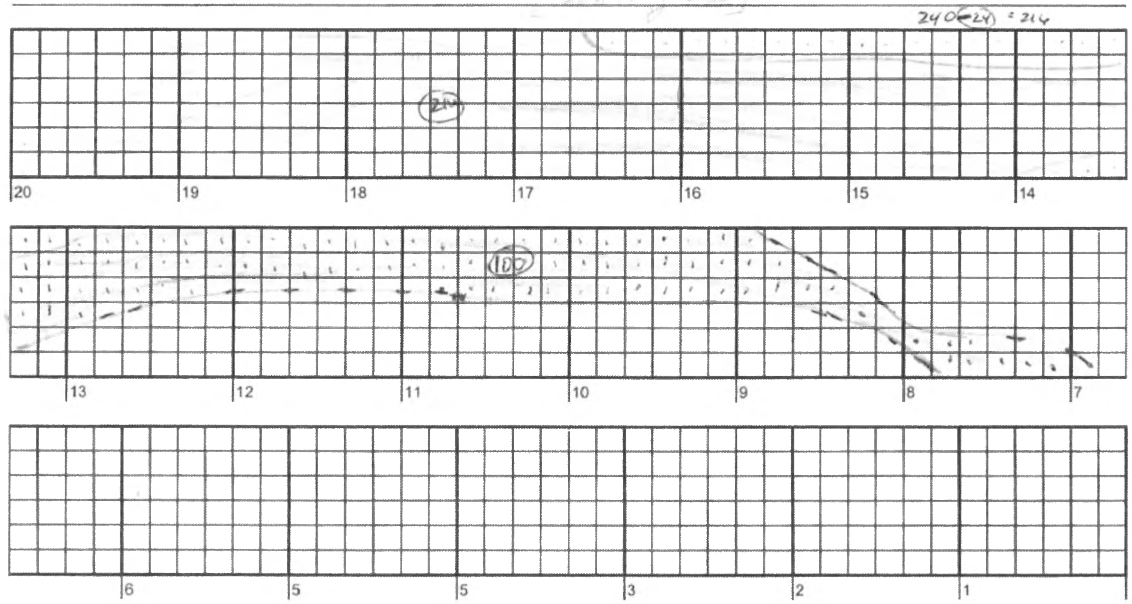
total boxes = 720   total cover boxes = 65   65/720 = 0.0903 = 9.0%

	Possible				
up 20-12	288 boxes	cover = 22 boxes	22/288 =	0.076	= 7.6%
mid 12-9	108 boxes	cover = 44 boxes	44/108 =	0.407	= 40.7%
down 9-0					

Date:________ Time:________ Run:________ Bed Map #:________

(Setting 20)

240 − (24) = 216



Flume channel width = 12 in   Mapped length = 20 ft   each square is 2 in x 2 in

4 in²/box

up

47%

in² area poss	box possible	
576	144 box	up cover (20 → 16) = 141 boxes (4 in²) = 564 in²
1296	324	mid cover (16 → 7) = ~~75 + 100 box~~ = 175 box (4 in²) = 700 in²
1008	252	down cover (7 → 0) = 0 boxes

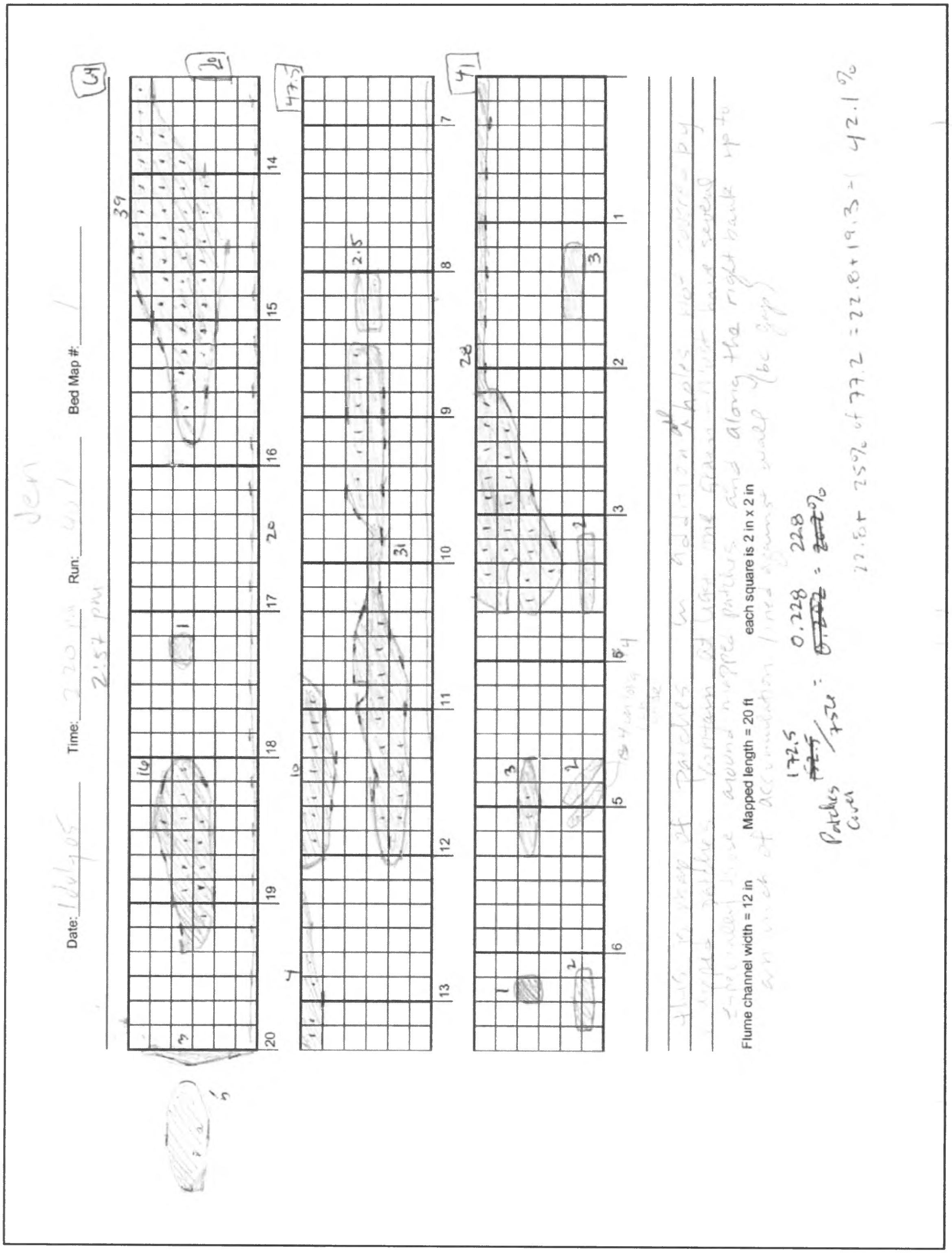
total cover 216 + 100 = 316 (4 in²) = 1264 in²

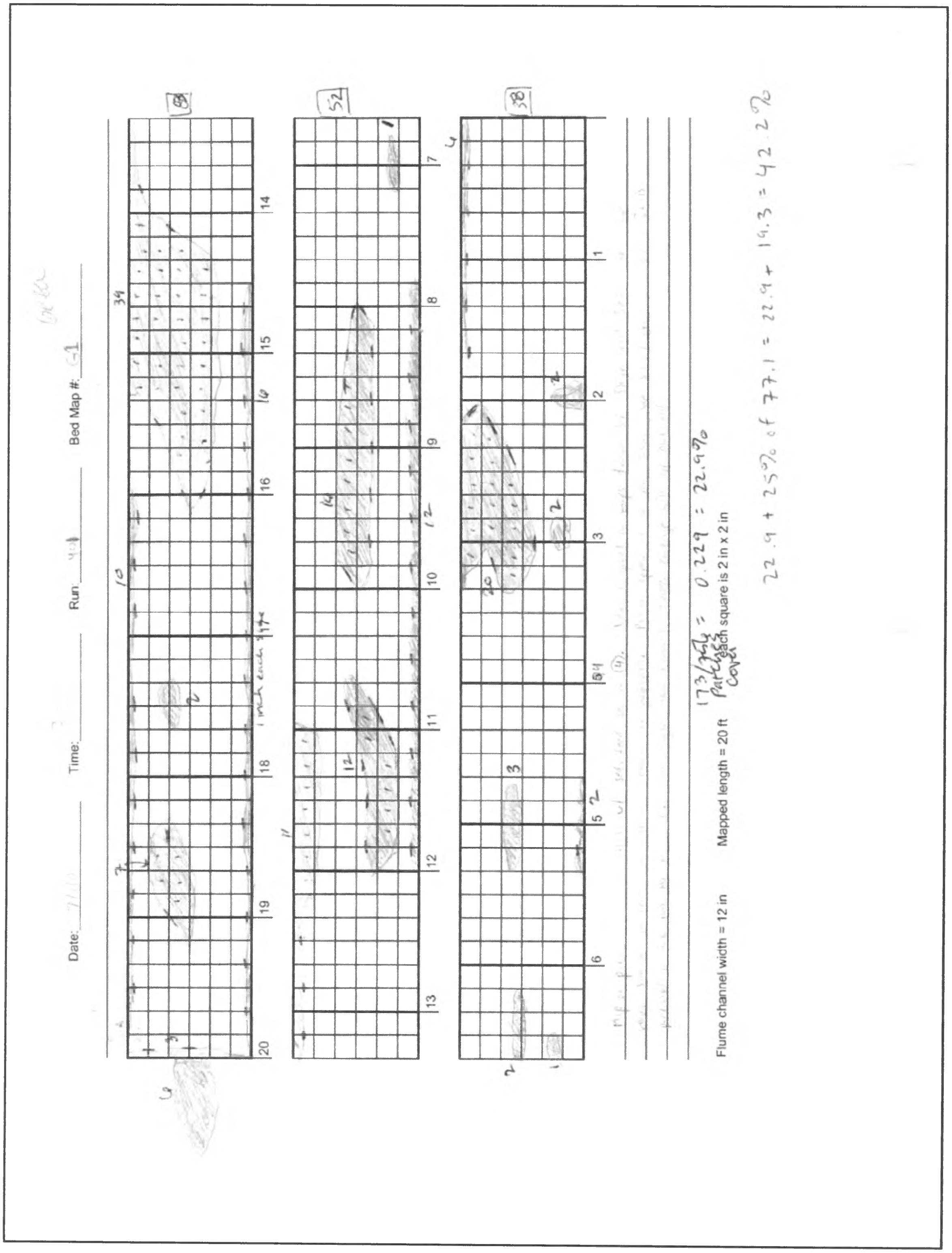
total boxes = 720   total area = 2880 in²

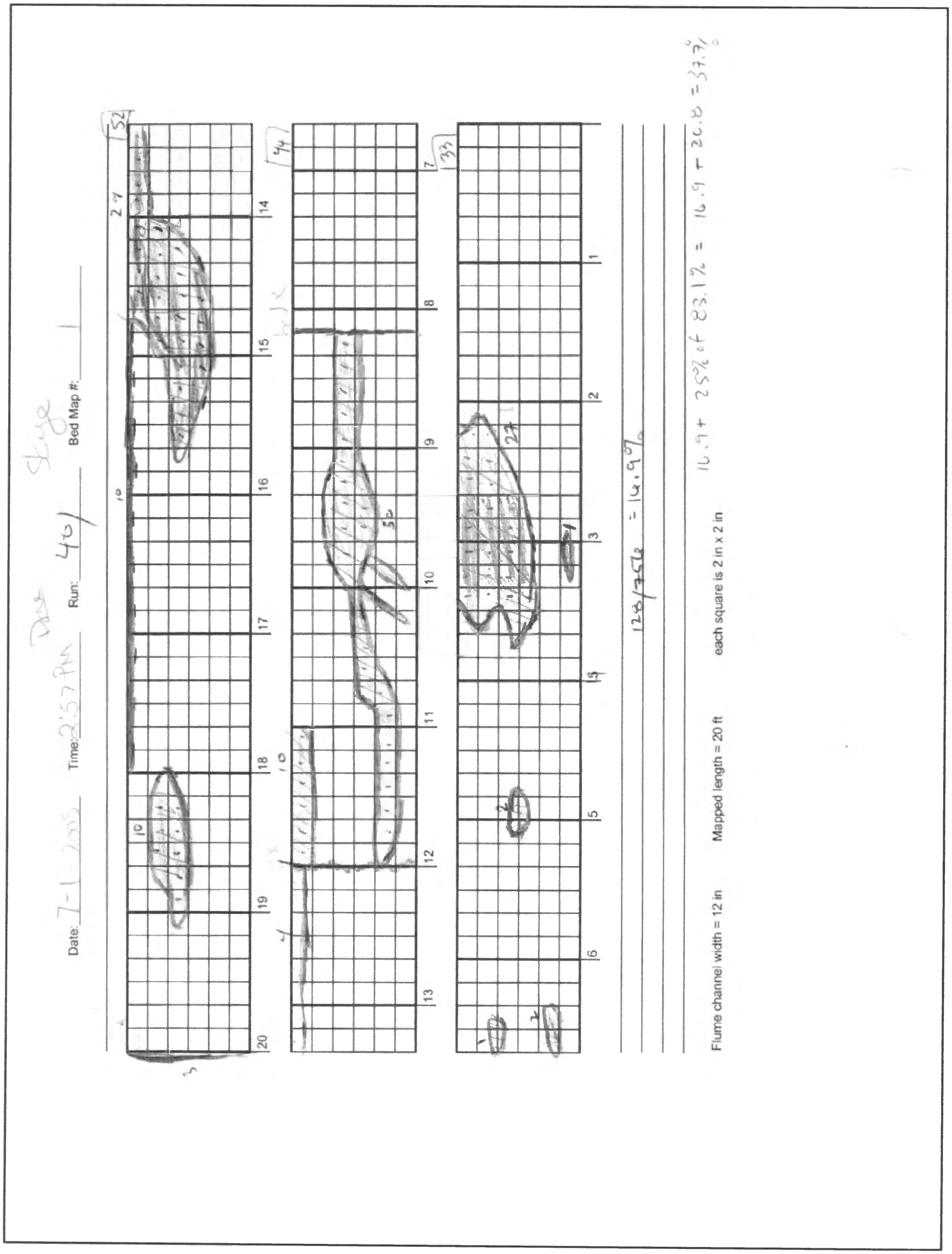
$\frac{1264}{2880} = 0.439 = 43.9$

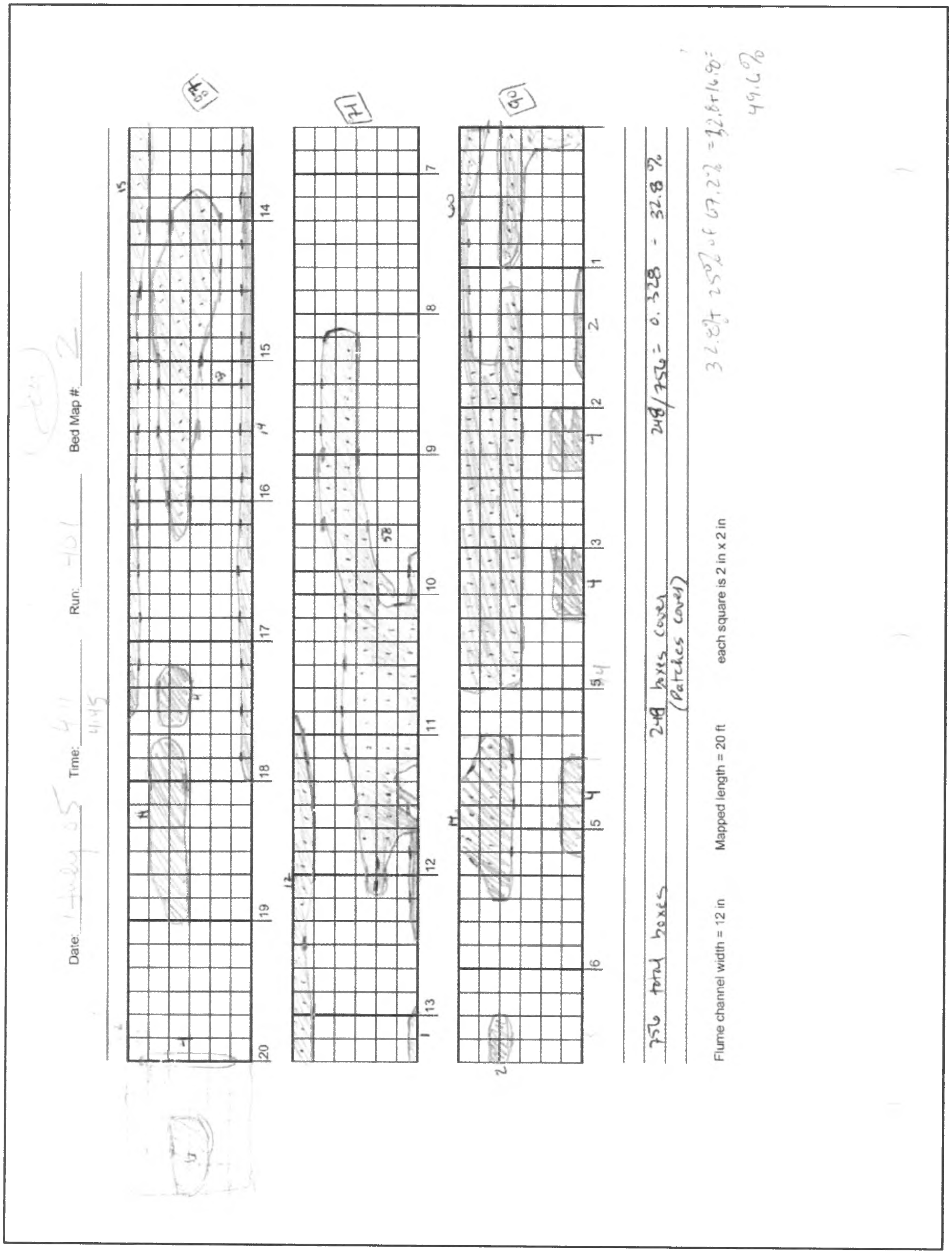
$\frac{564}{576} = 0.979 = 97.9\%$

$\frac{700}{1296} = 0.540 = 54\%$


Date:
Time:
Run:
Bed Map #:
Flume channel width = 12 in
Mapped length = 20 ft
each square is 2 in x 2 in

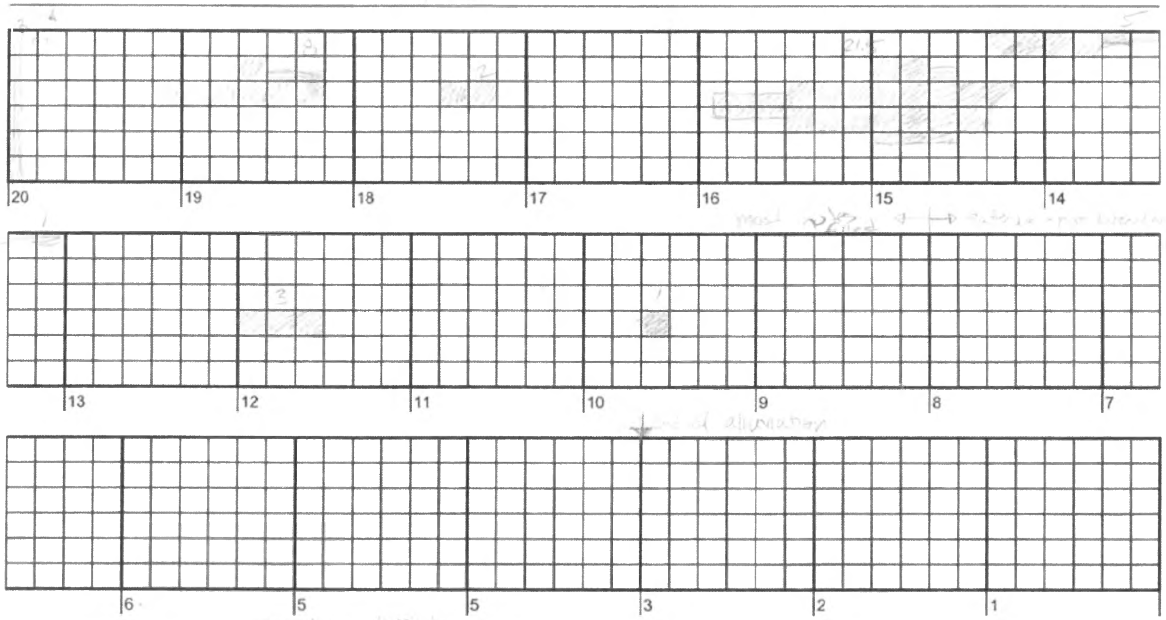

Date:
Time:
Run:
Bed Map #:
Flume channel width = 12 in
Mapped length = 20 ft
each square is 2 in x 2 in
22.9 + 25% of 77.1 = 22.9 + 19.3 = 42.2%


Date: 7-1-2015
Time: 2:57 PM
Run: 40
Bed Map #: 1
128/756 = 16.9%
16.9 + 25% of 83.1% = 16.9 + 20.8 = 37.7%
Flume channel width = 12 in
Mapped length = 20 ft
each square is 2 in x 2 in



Date:
Time:
Run:
Bed Map #:
Flume channel width = 12 in
Mapped length = 20 ft
each square is 2 in x 2 in

Date: 15 Time: 1:12 Run: 4U3 Bed Map #:



what with estimate of 15% + patch,

468 Boxes possible in section $52/750 = 6.9\%$

with most holes filled and all patches ~25% → $468 - 52 = 416$ $\frac{416}{468} = 0.89 = 89\%$ ≈ 25% of 89% = 22.2%

Flume channel width = 12 in   Mapped length = 20 ft   each square is 2 in x 2 in

180 Boxes scattered holes filled ~ 10% → 10% of 180 = 18%

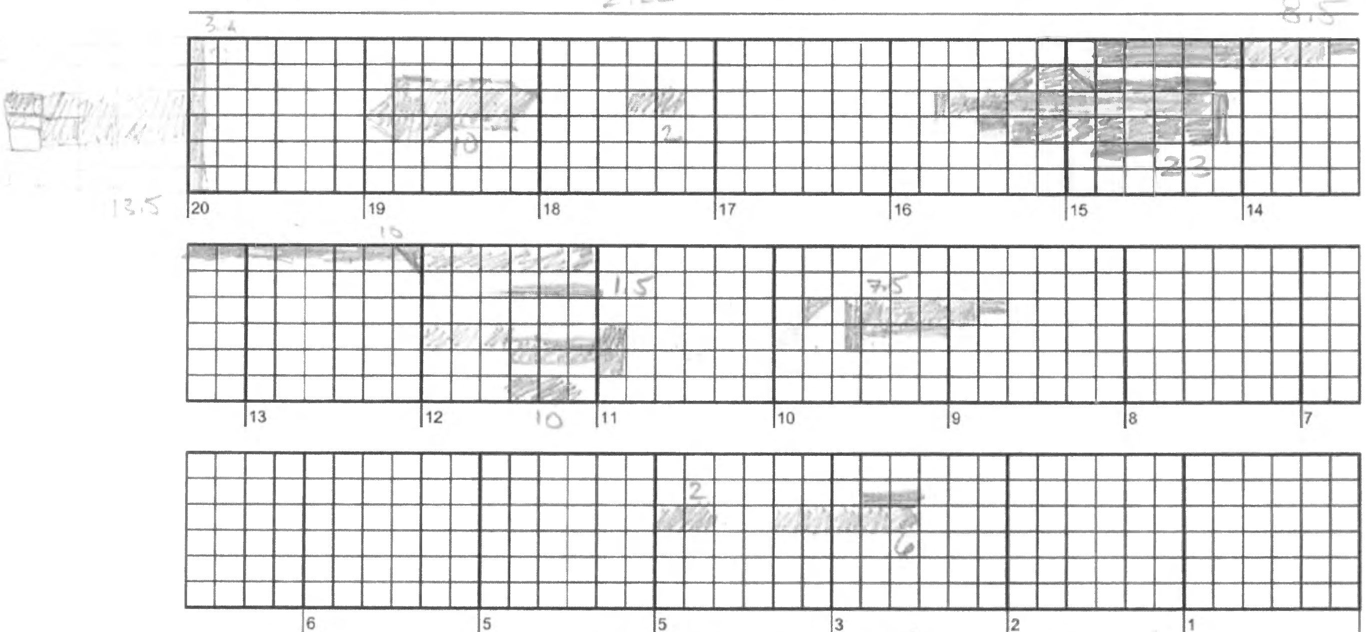
and 108 Boxes no cover

6.9% patch cover + 22.2% most holes filled cover + 18% scattered holes filled cover = 47% ?

doesn't seem right... how about est. getting ~15% cover in addition to patches

1.9% + 15% of 93.1% = 1.9 + 14.0 = 20.9% so is this a better estimate

Date: 18 July 05 Time: 2:03 2:20 Run: [illegible] Bed Map #: 2



most every hole has some grains

(750 boxes)
21 ft

Flume channel width = 12 in Mapped length = 20 ft each square is 2 in x 2 in

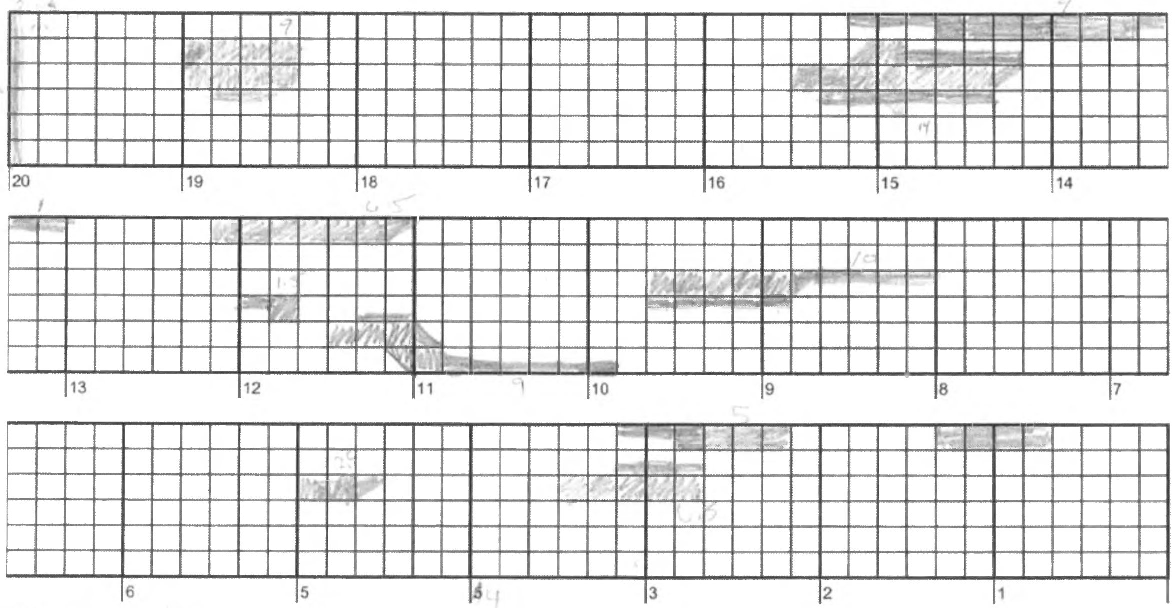
38.5 boxes cover

$\frac{88.5}{750}$ = 11.7%

not including [illegible]

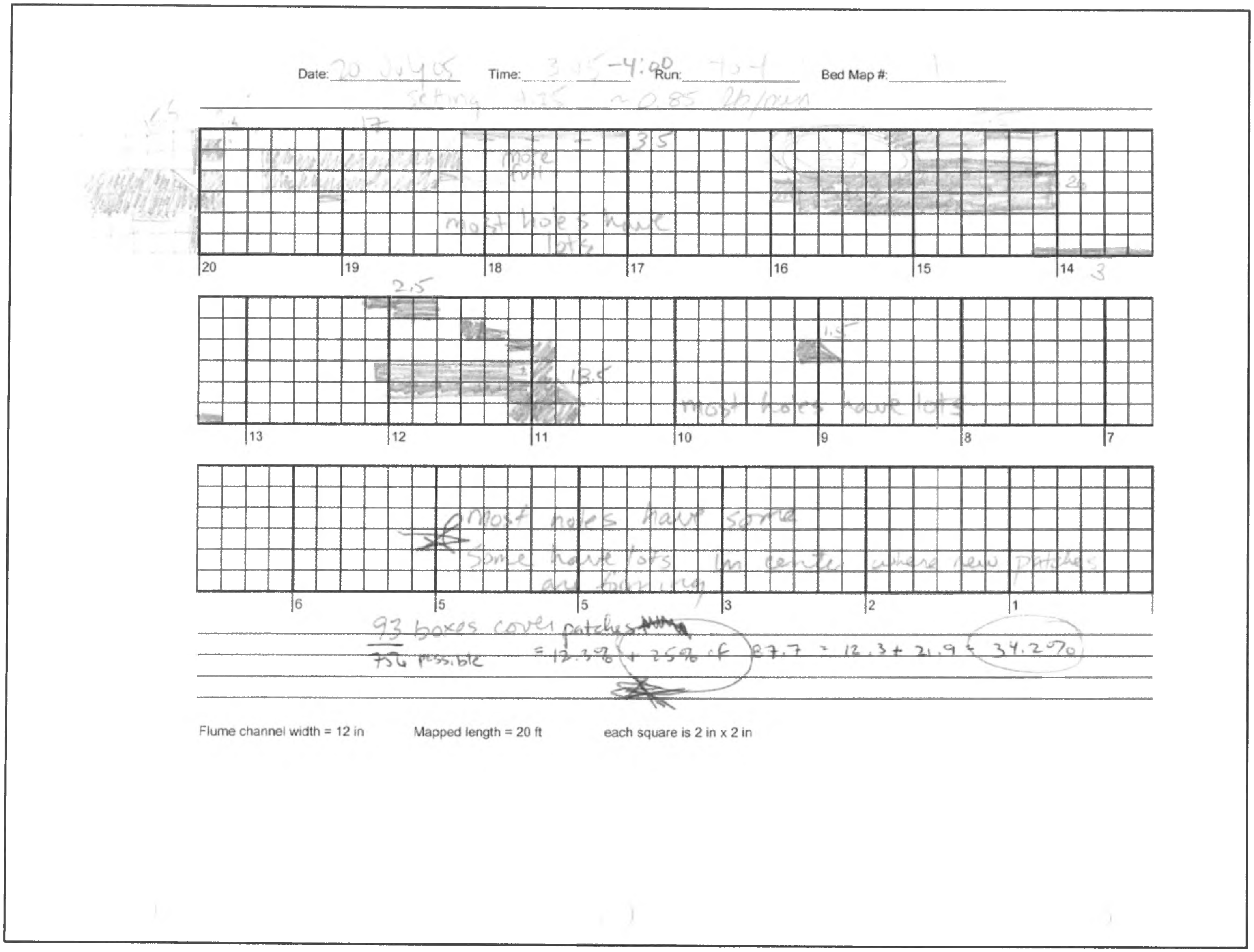
+ 25% of 88.3% = 11.7 + 22.1 = 33.8%

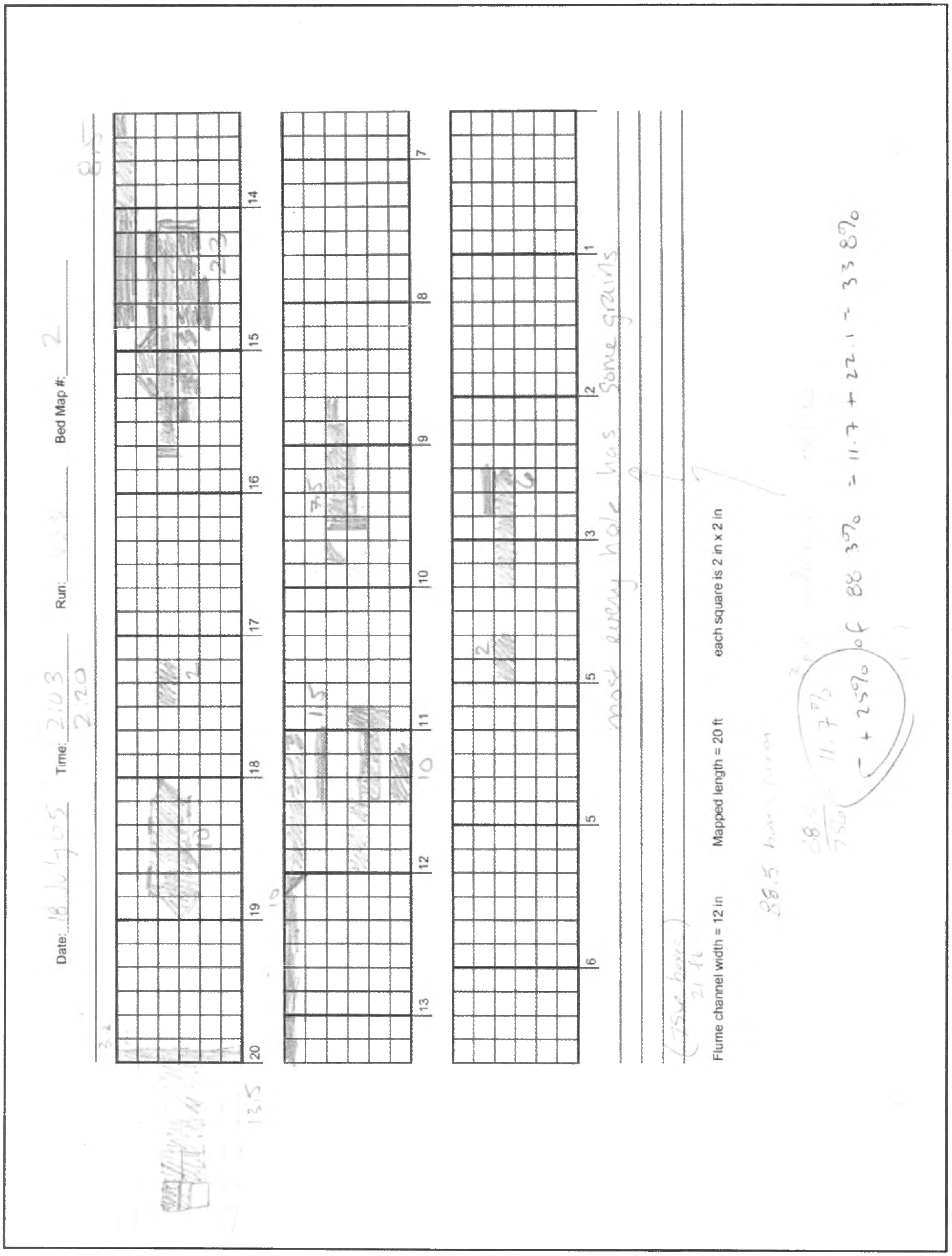
Date: 13 July   Time: 3.03   Run: ____   Bed Map #: ____



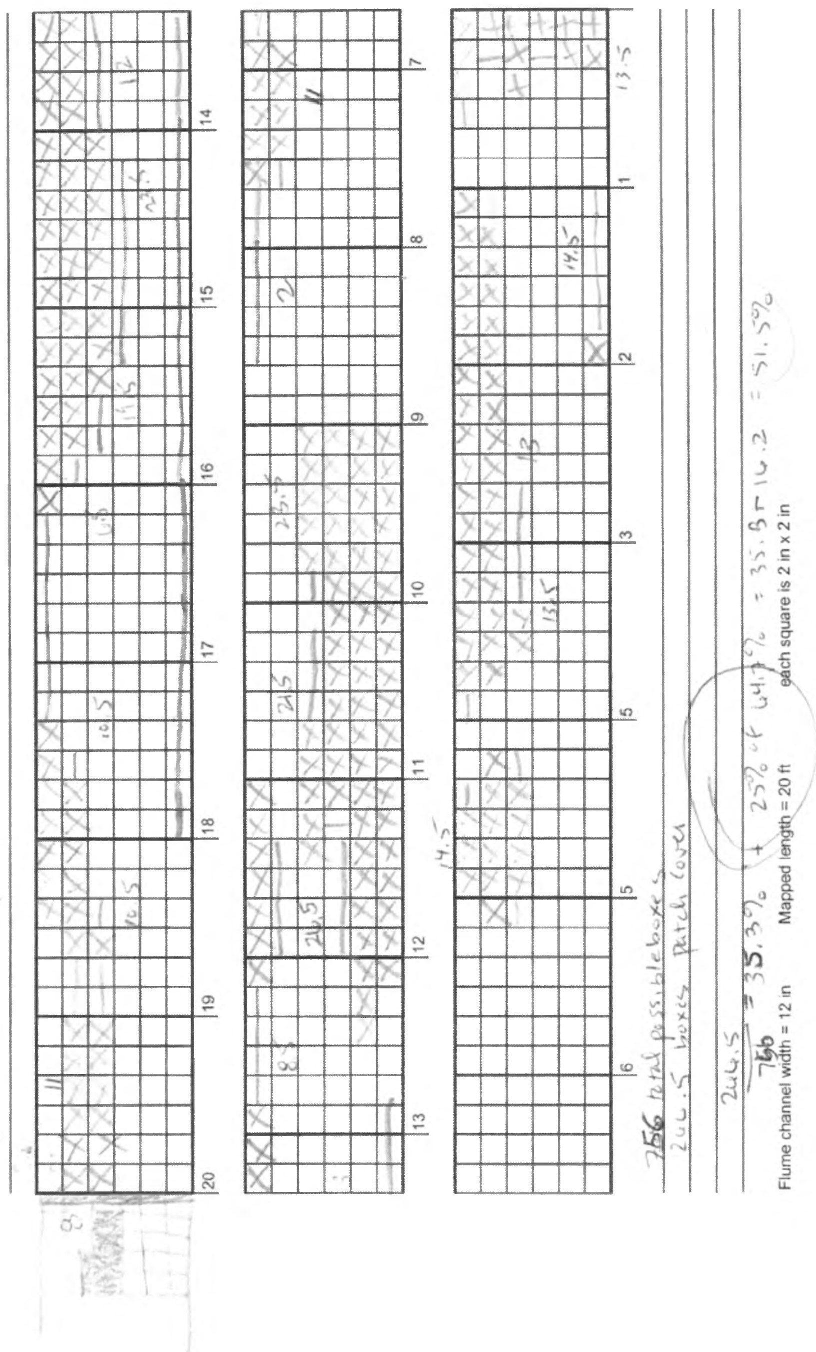
756 boxes possible
86 boxes scored
86/756 = 11.4 % not including filled holes not connected
+ 25% of 88.6% = 11.4 + 22.2 = 33.4%

Flume channel width = 12 in   Mapped length = 20 ft   each square is 2 in x 2 in

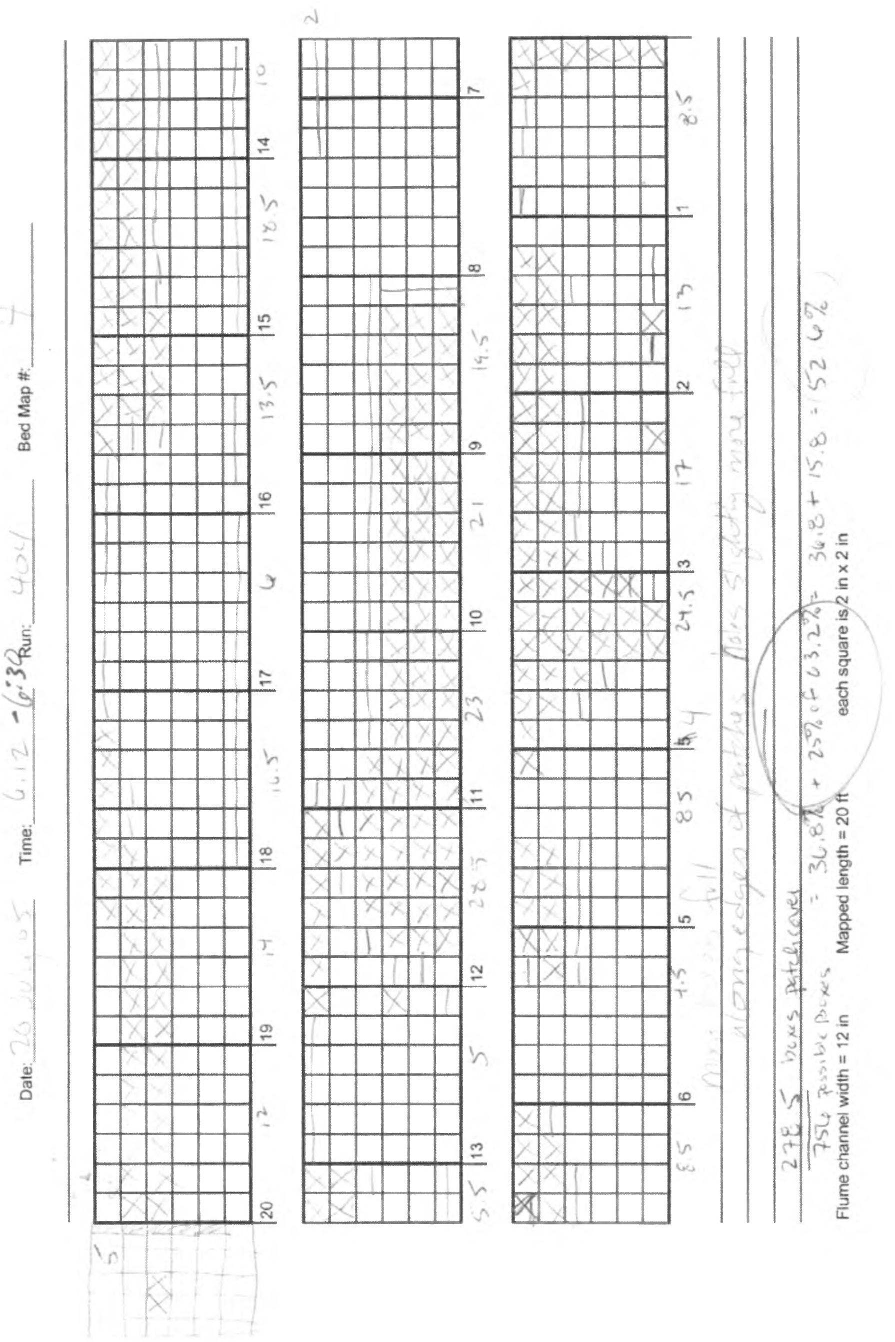

Date: 20 July 05
Time: 3:45–4:00
Run: 4
Bed Map #: 1
setting 1.25 ~0.85 lb/min
20
19
18
17
16
15
14
13
12
11
10
9
8
7
6
5
5
3
2
1
more fur
most holes have lots
3.5
2.5
13.5
1.5
most holes have lots
most holes have some
some have lots in center where new patches are forming
93 boxes cover patches
756 possible
= 12.3% + 25% of 87.7 = 12.3 + 21.9 = 34.2%
Flume channel width = 12 in
Mapped length = 20 ft
each square is 2 in x 2 in



Date: 18 July 05
Time: 2:03 2:20
Run:
Bed Map #: 2
most every hole has some grains
Flume channel width = 12 in
Mapped length = 20 ft
each square is 2 in x 2 in



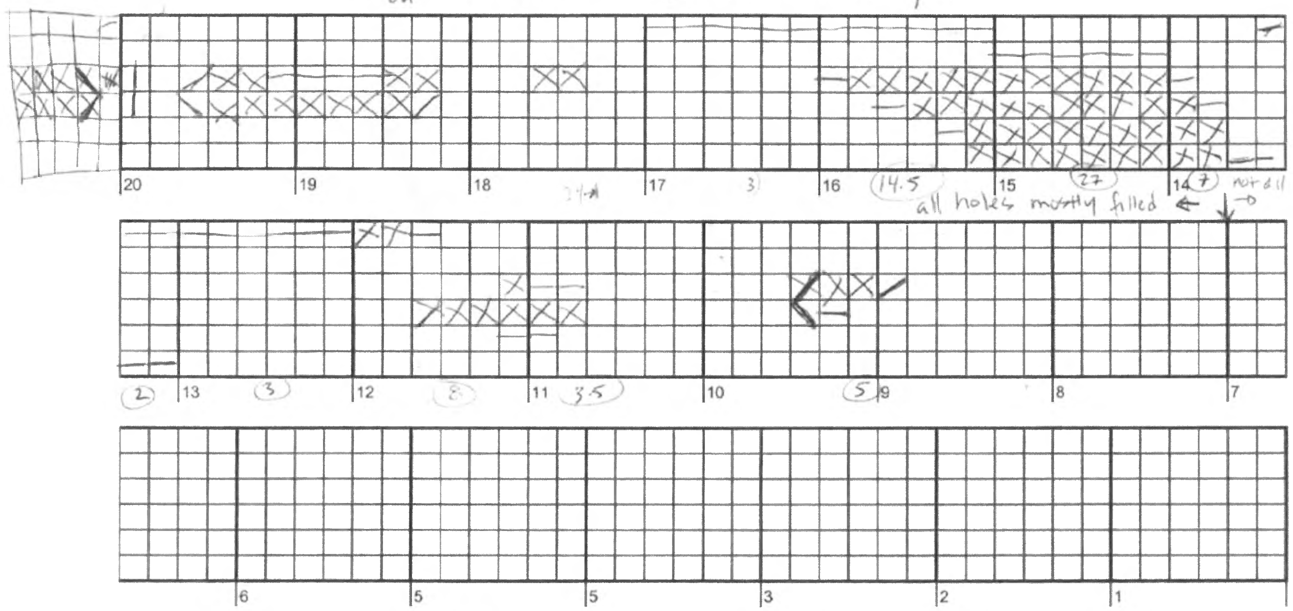
Date: 20 July 05
Time: 5:18-5:38
Run: 404
Bed Map #: 3
756 total possible boxes
244.5 boxes patch cover
Flume channel width = 12 in
Mapped length = 20 ft
each square is 2 in x 2 in



Date:
Time:
Run:
Bed Map #:
Flume channel width = 12 in
Mapped length = 20 ft
each square is 2 in x 2 in

Date: 22 July 05 Time: 12:55 1:04 Run: 405 Bed Map #: 1

flux in - 0.5 lb/min flux out - none yet

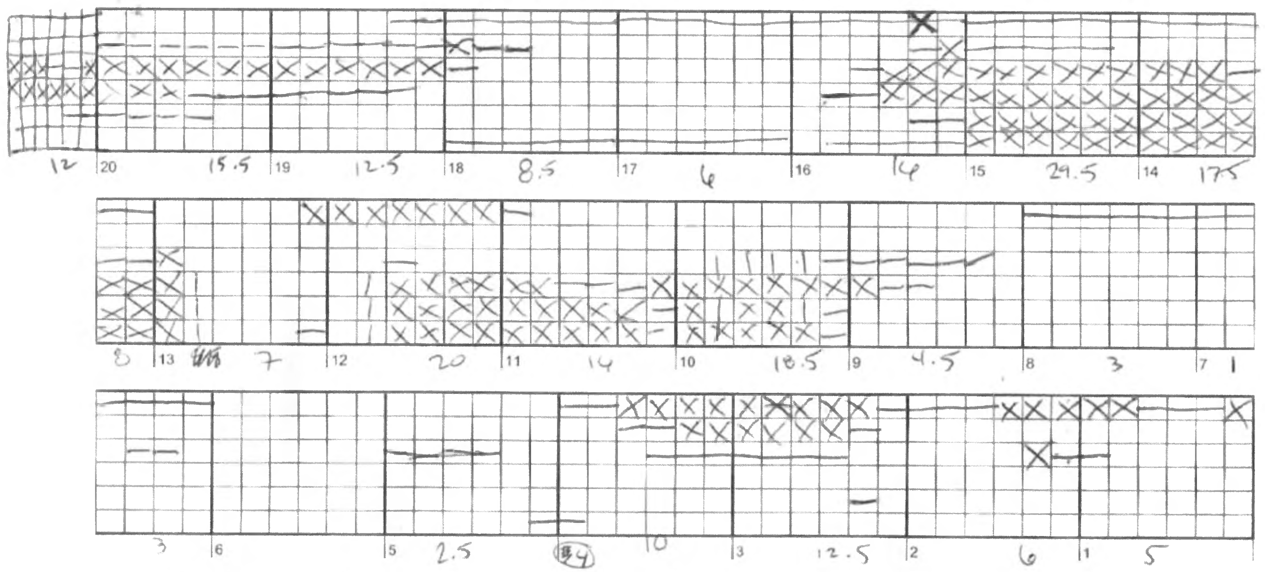


97 boxes covered by patches / 756 total boxes possible = 12.8%

Flume channel width = 12 in Mapped length = 20 ft each square is 2 in x 2 in

Date: 22 July 05 Time: 1:41 2:01 Run: 405 Bed Map #: 2

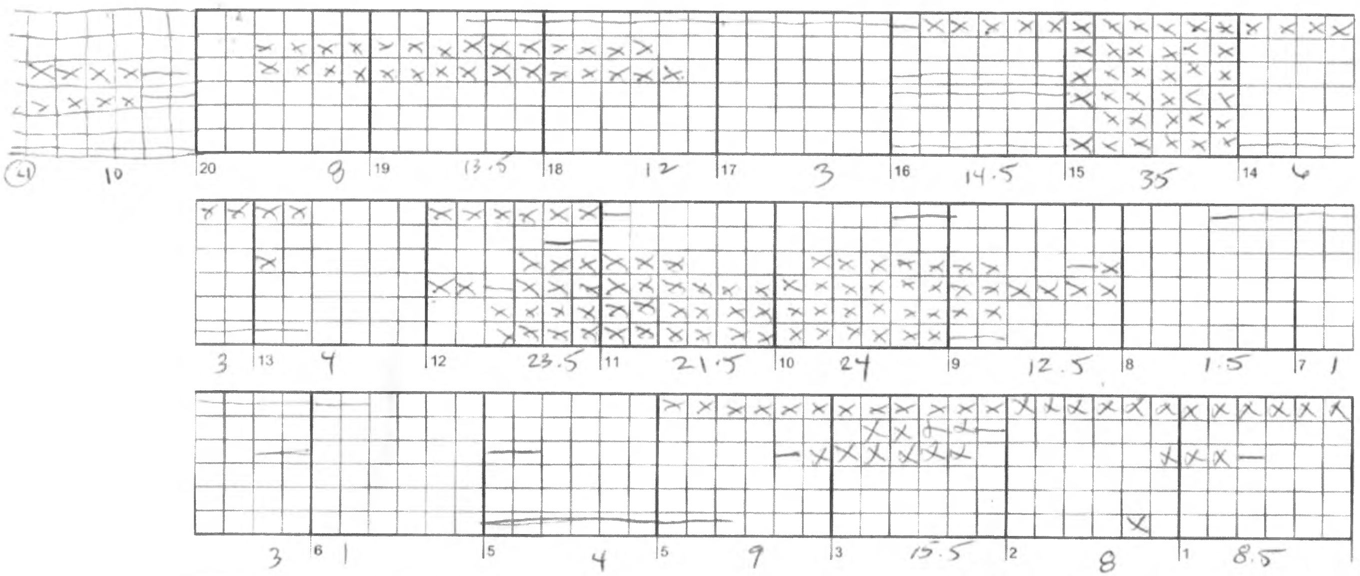
Set 4.25 = 0.5 lb/min flux out = ~0.3 – 0.4



$\frac{234.5 \text{ patch covered boxes}}{756 \text{ possible boxes}} = 31.0\%$

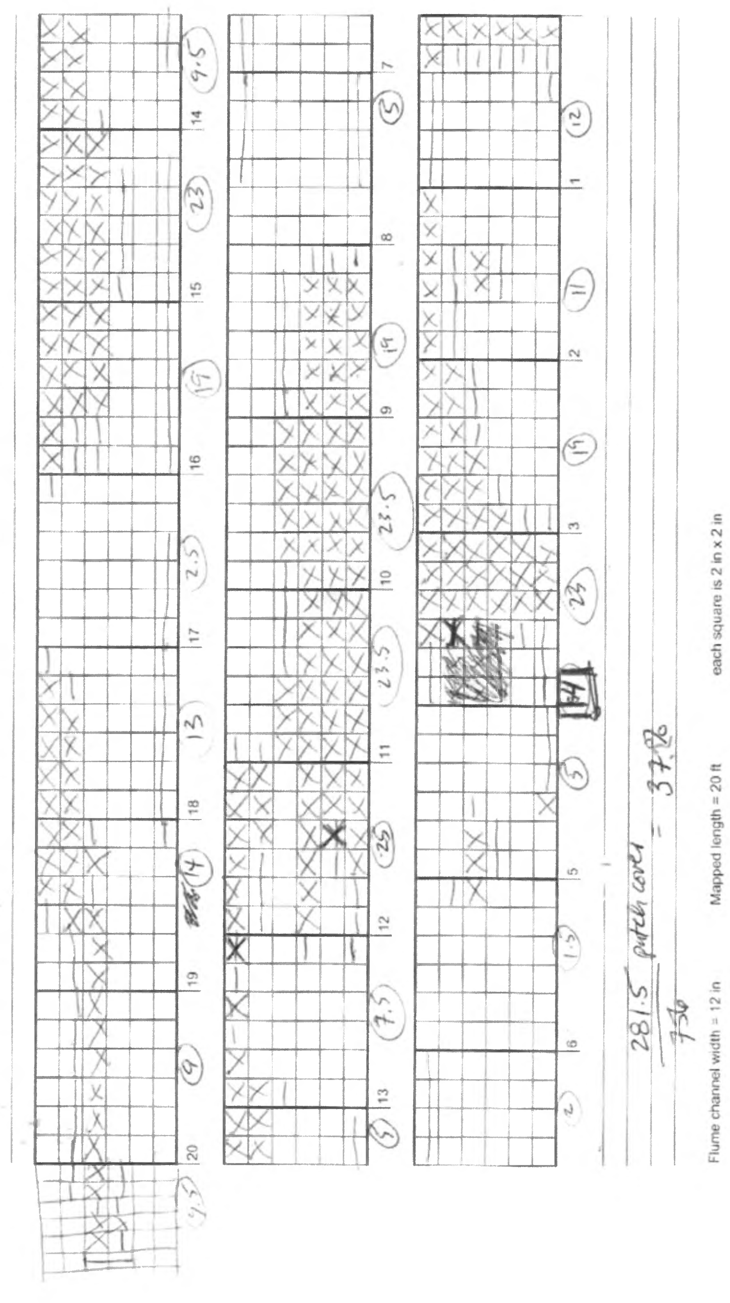
Flume channel width = 12 in Mapped length = 20 ft each square is 2 in x 2 in

Date: 22 July 2005 Time: 2:40 pm -3:05 Run: 405 Bed Map #: 3



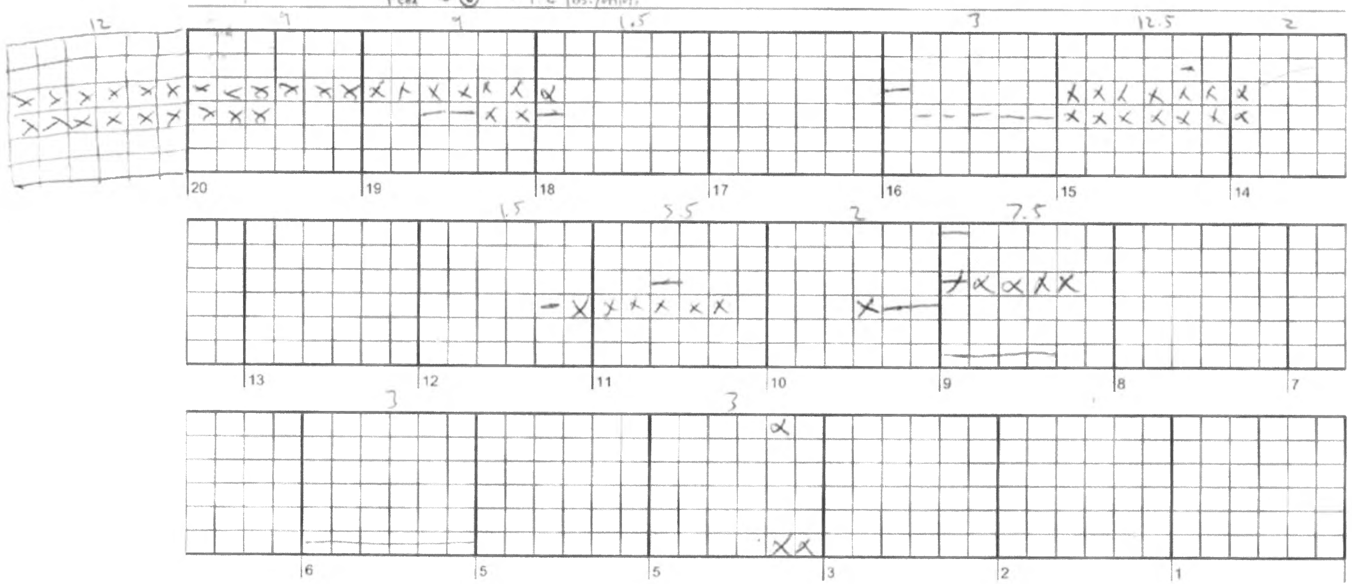
242 patch covered boxes
756 possible boxes = 0.32 = 32%

Flume channel width = 12 in Mapped length = 20 ft each square is 2 in x 2 in


Date: 22 July 05 Time: 3:40-4:00 Run: 405 Bed Map #: 4
Flume channel width = 12 in
Mapped length = 20 ft
each square is 2 in x 2 in
281.5 patch cover
750

Date: 29 JULY 05 Time: 12:56:00 - 1:06:00 Run: 406 Bed Map #: 1

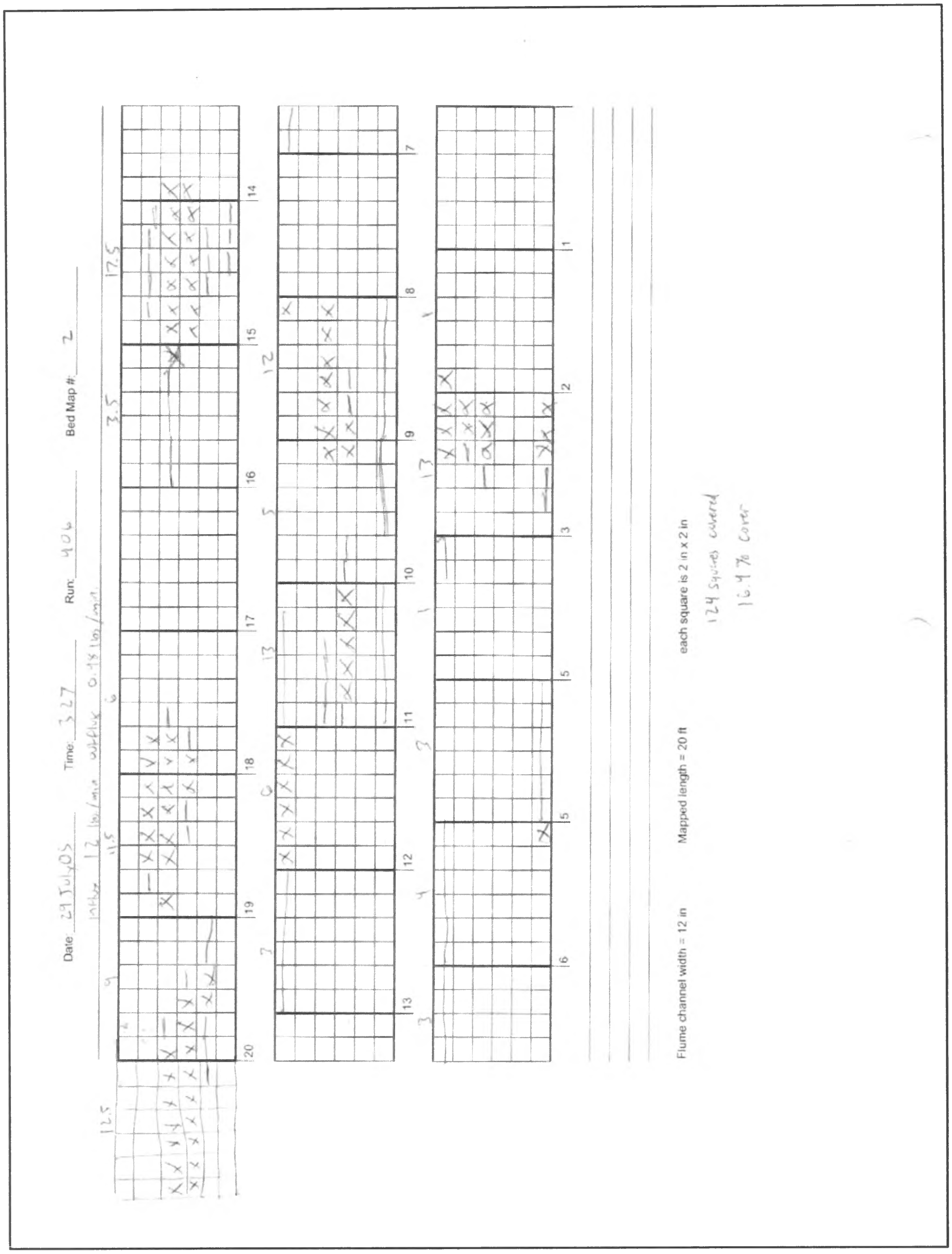
Feed = ⑥ ~ 1.2 lbs./min.



Flume channel width = 12 in Mapped length = 20 ft each square is 2 in x 2 in

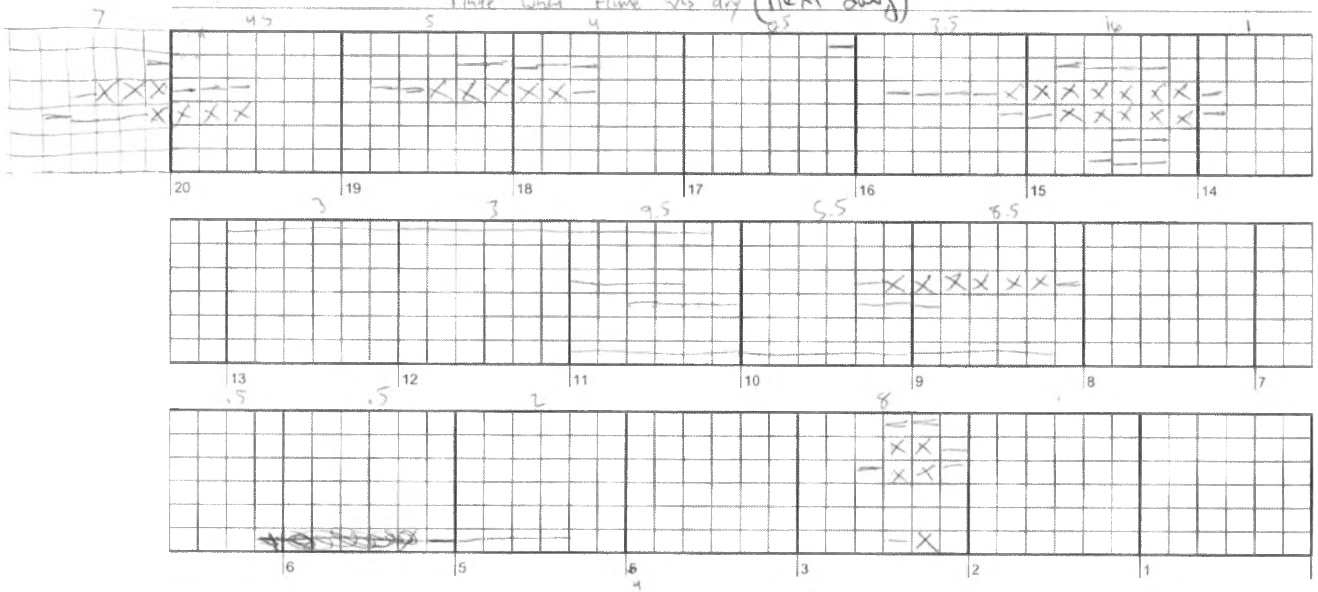
71.5 squares covered

9.5 % cover


Date: 29 July 05
Time: 3:27
Run: 406
Bed Map #: 2
Inflow 1.2 lbs/min outflux 0.98 lbs/min
Flume channel width = 12 in
Mapped length = 20 ft
each square is 2 in x 2 in
124 squares covered
16.4 % Cover

Date: 1 Aug 2005 Time: 12:23 pm Run: 406 Bed Map #: 3

Made when flume was dry (next day)



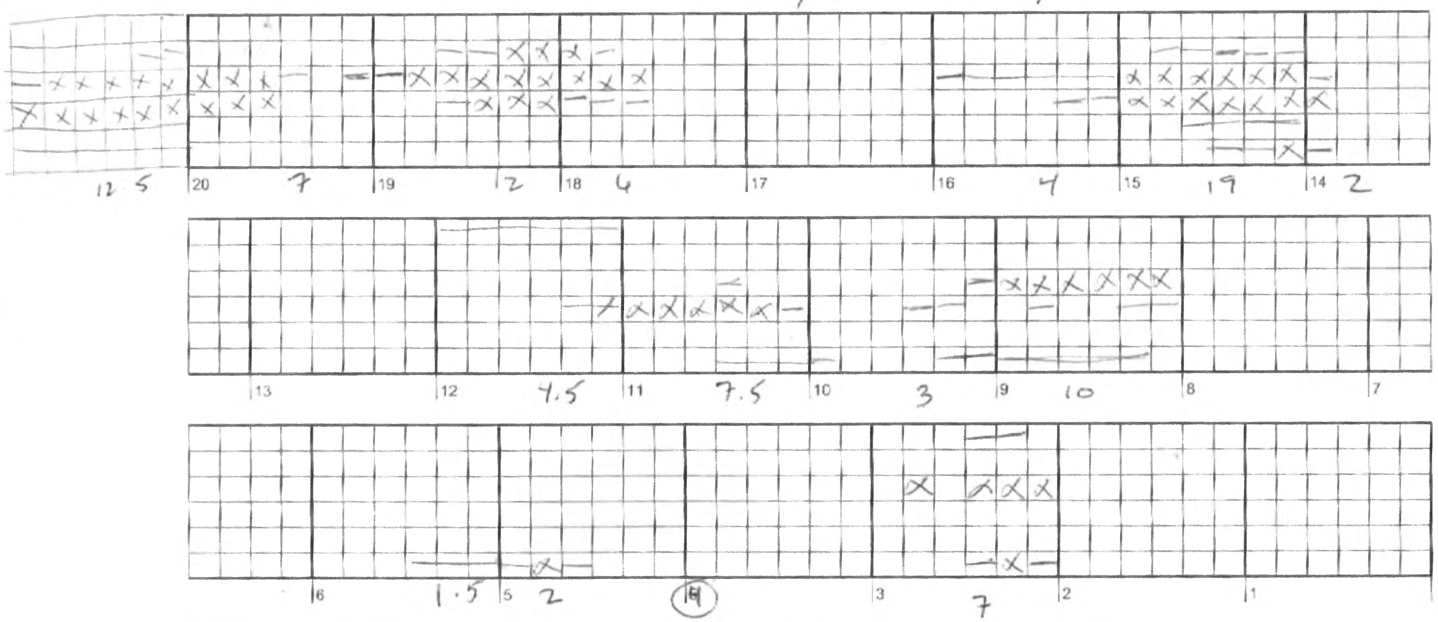
Flume channel width = 12 in Mapped length = 20 ft each square is 2 in x 2 in

82 squares covered

10.85 % cover

Date: 2 Aug 05 Time: 1:14-1:35 Run: 407 Bed Map #: 1

Geza Setting 6.5 ~1.4 lb/min



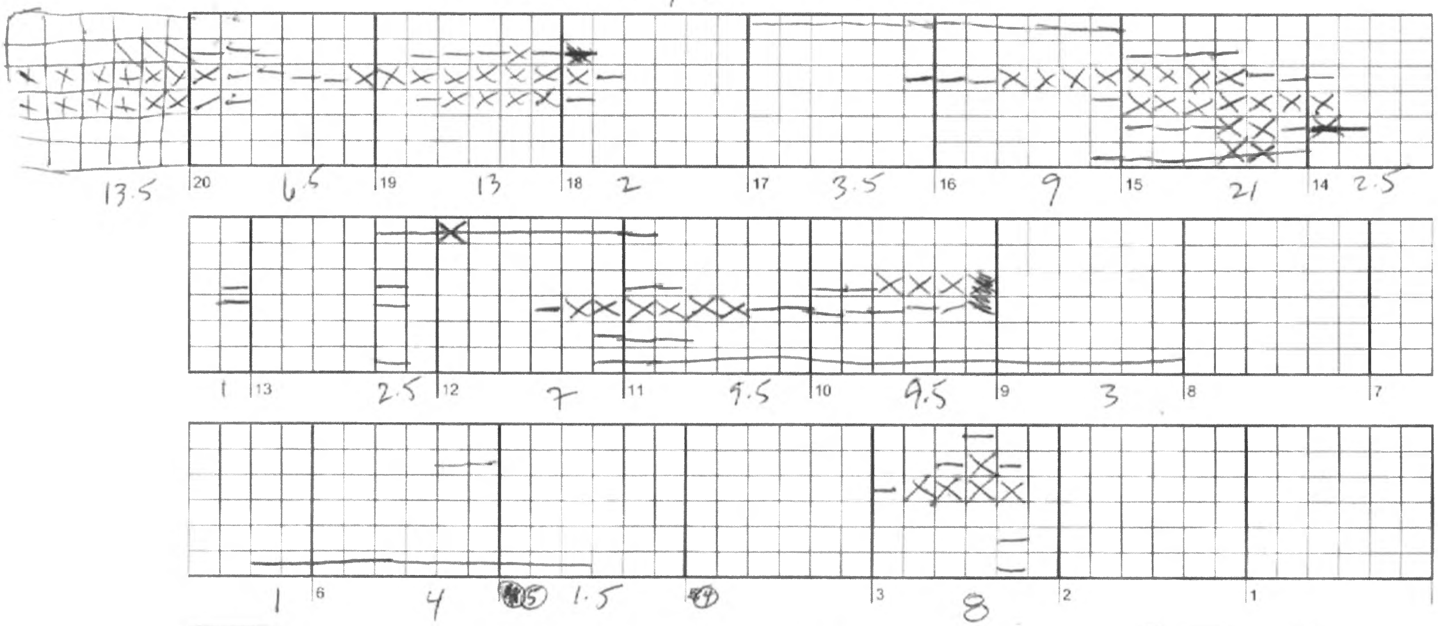
98 boxes cover
756 possible boxes

98/756 = 13%
0.1296

Flume channel width = 12 in Mapped length = 20 ft each square is 2 in x 2 in

Date: 2 Aug 05 Time: 2:00-2:18 Run: 407 Bed Map #: 2

fan setting 4.5 ~1.4 lb/min



118/756 = 0.156 = 15.6%

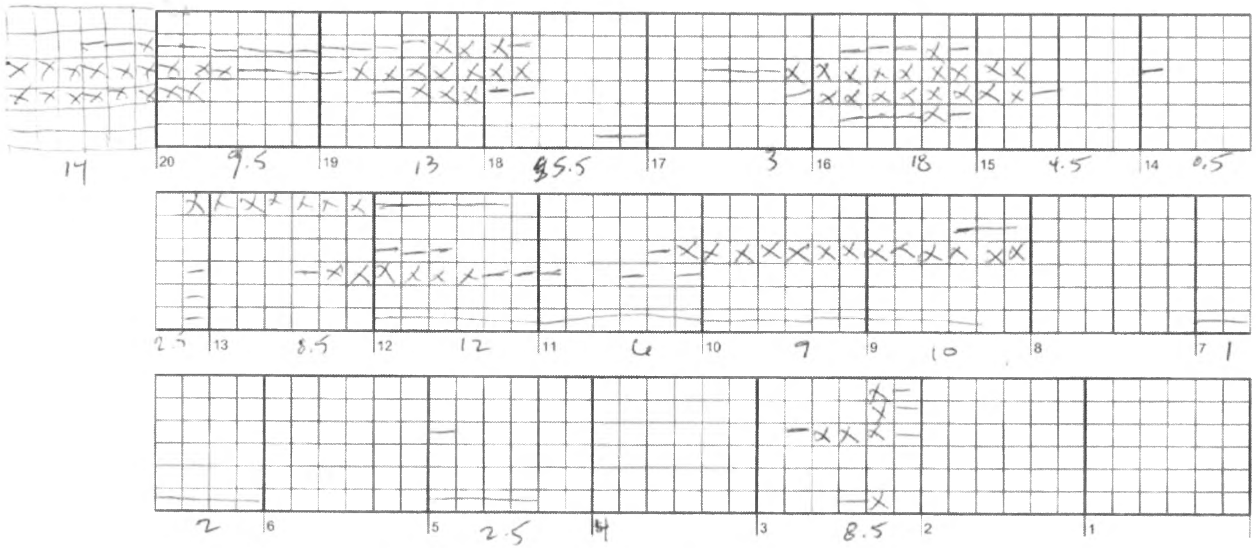
118 Boxes cover
756 possible

Flume channel width = 12 in Mapped length = 20 ft each square is 2 in x 2 in

more of individual holes are filled
Some patches bare
downstream between 8 ft marker more holes not filled
also right side from 18-21 holes empty
and between 10-9 right side
otherwise most holes filled.

Date: 2 Aug 05 Time: 3:04 - 3:24 Run: 407 Bed Map #: 3

Geza



130 Covered
756 possible

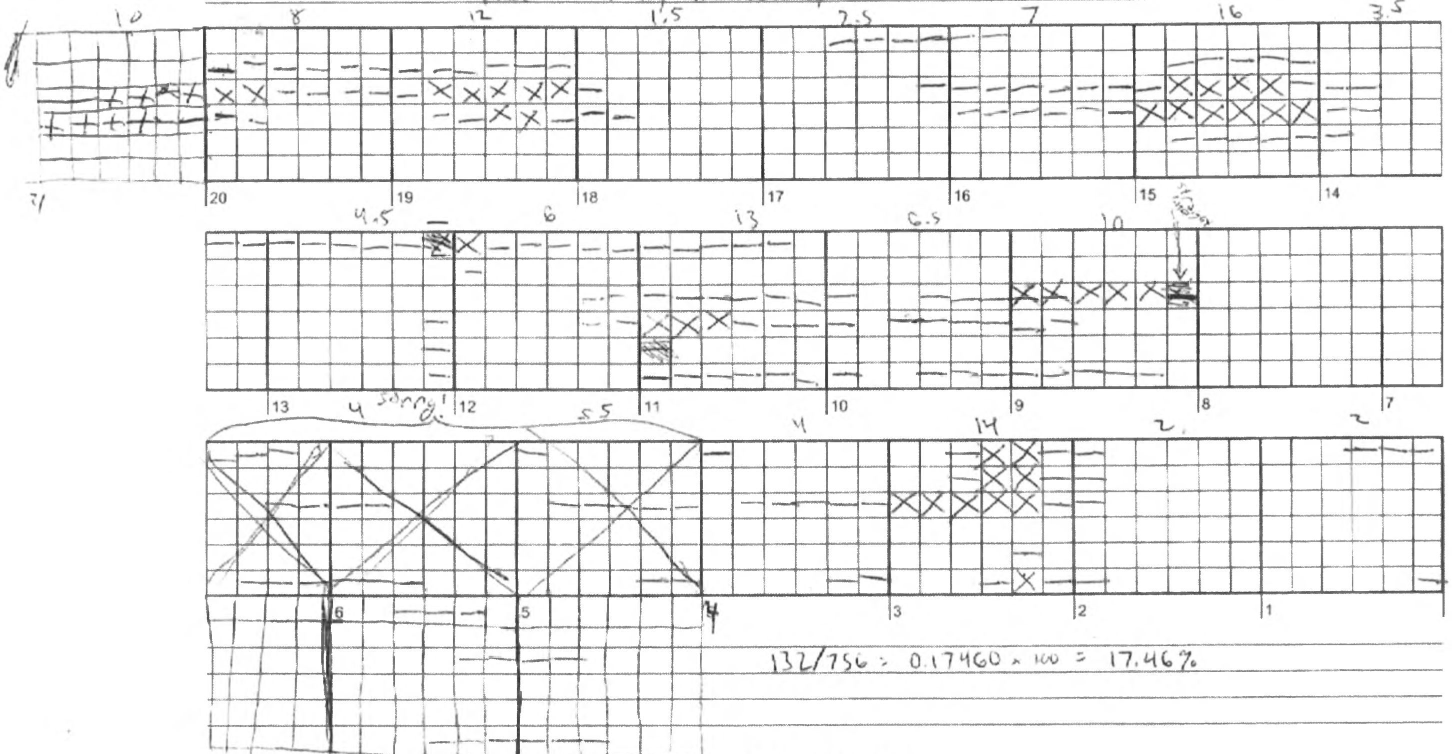
$130/756 = 0.172 = 17.2\%$

Flume channel width = 12 in Mapped length = 20 ft each square is 2 in x 2 in

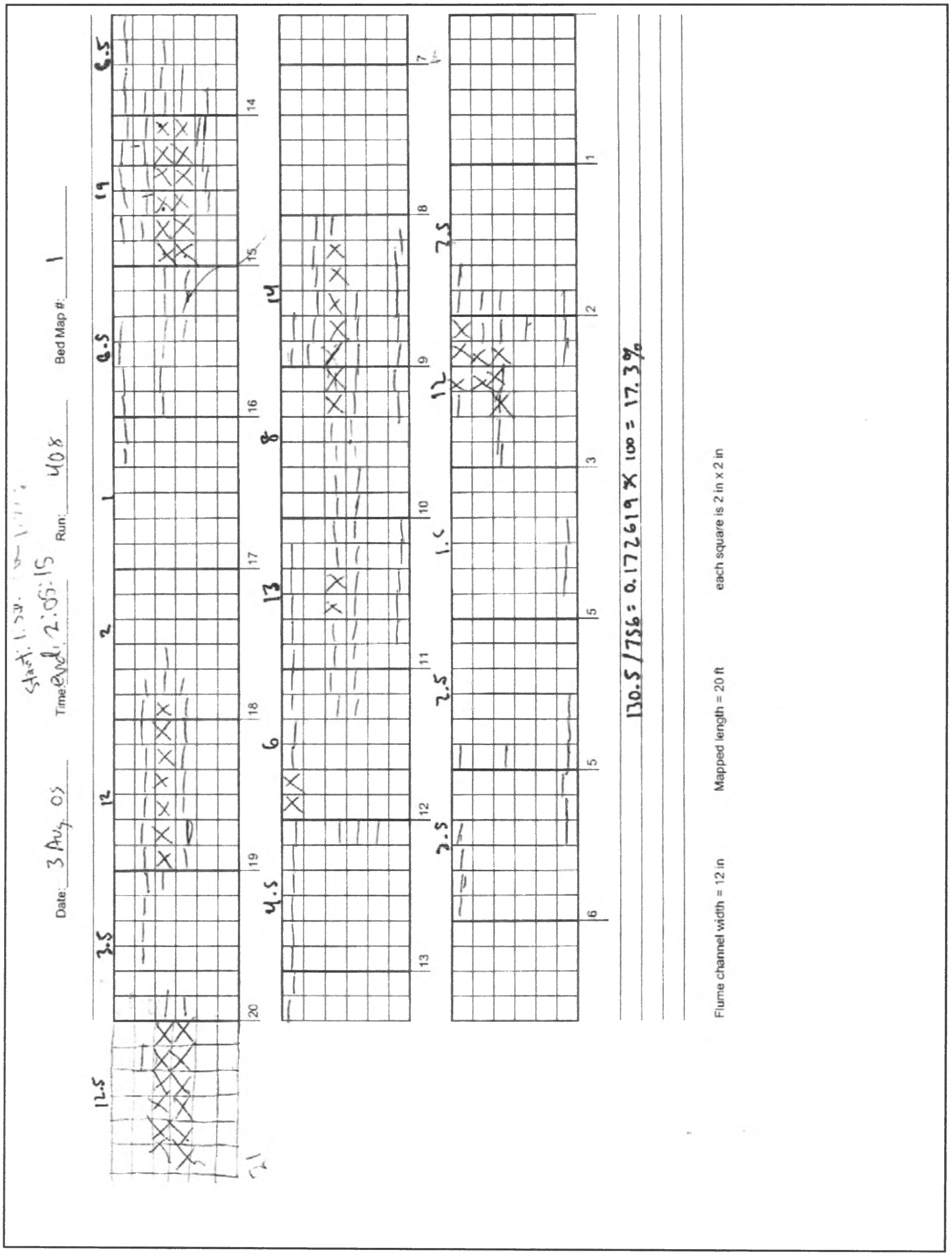
Same hole fill description as bed map #2

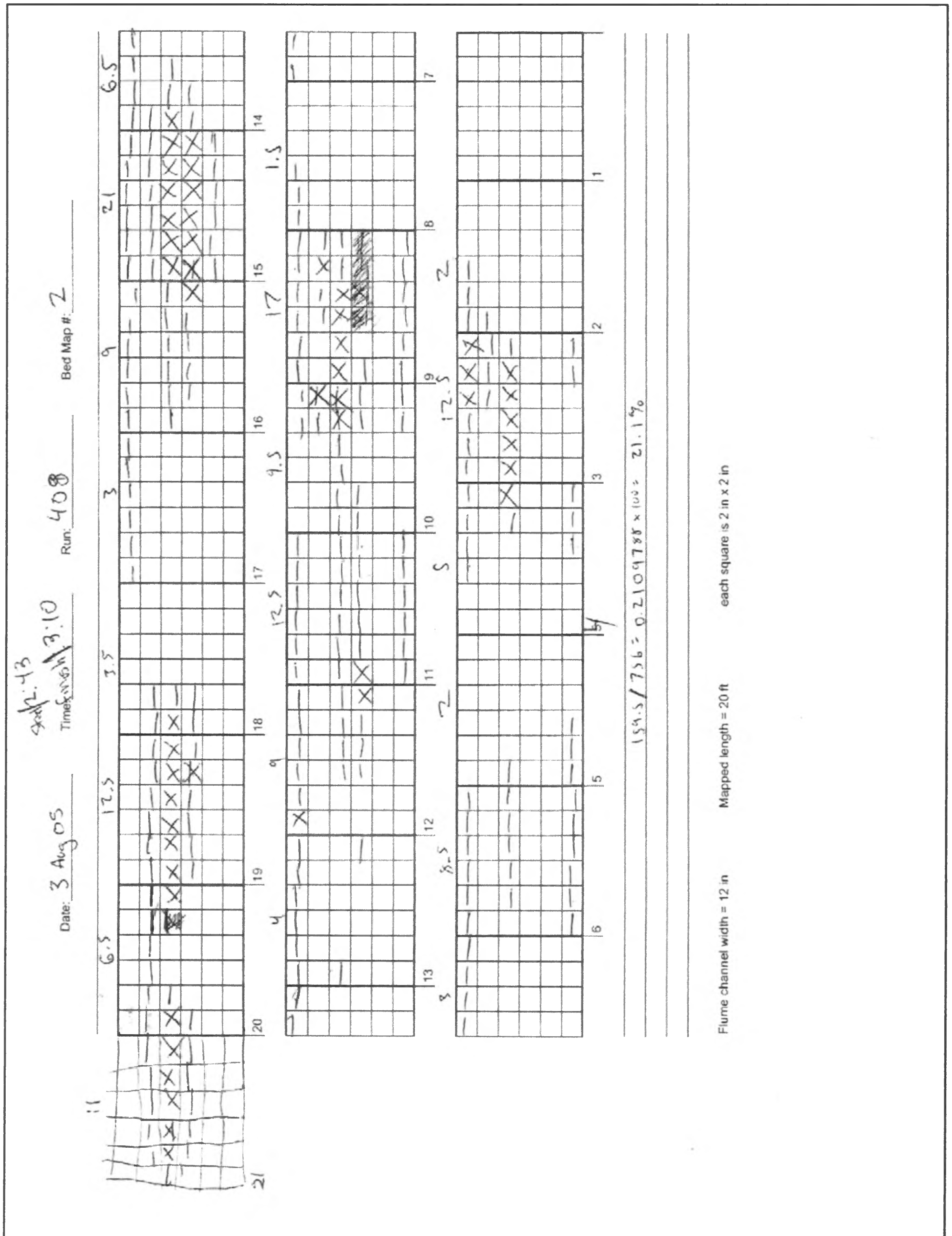
Date: 3 Aug 05 Time: ________ Run: 407 Bed Map #: 4 or 5 (7)

Made the next day after run. by Jonathan

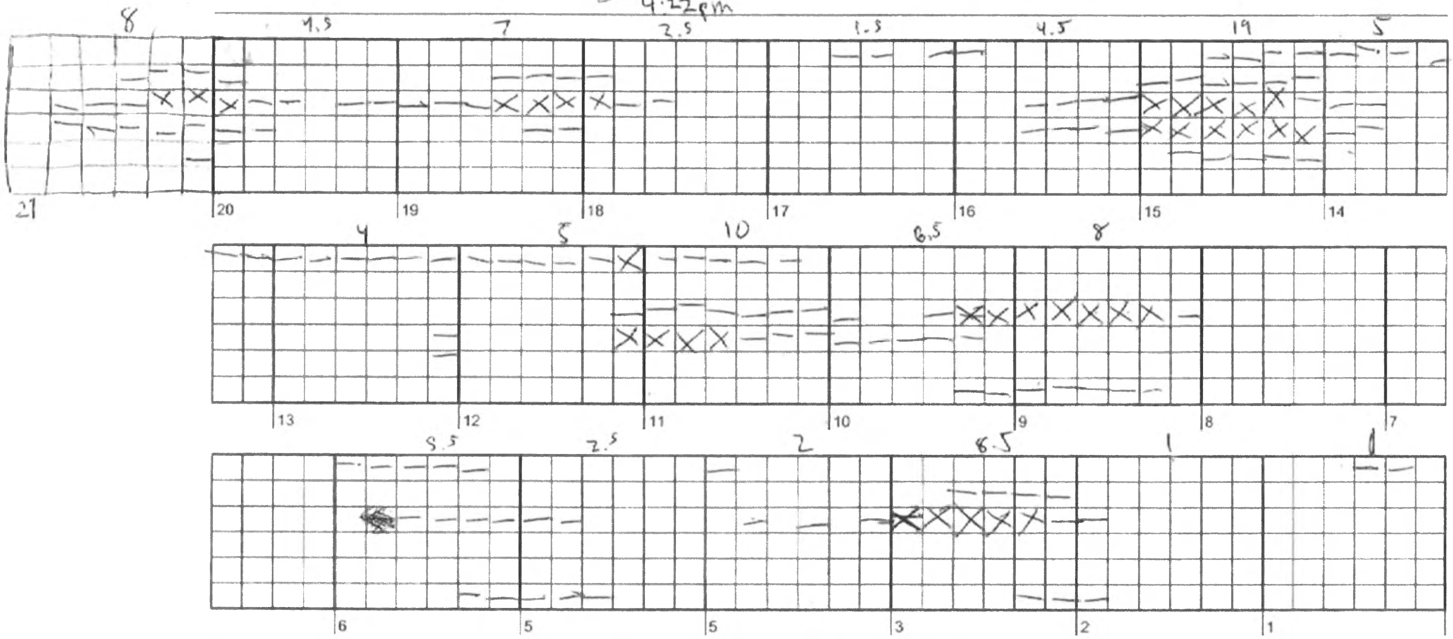


Flume channel width = 12 in   Mapped length = 20 ft   each square is 2 in x 2 in


Date: 3 Aug 05
Time: end 2:05:15
Run: 408
Bed Map #: 1
130.5/756 = 0.172619 X 100 = 17.3%
Flume channel width = 12 in
Mapped length = 20 ft
each square is 2 in x 2 in

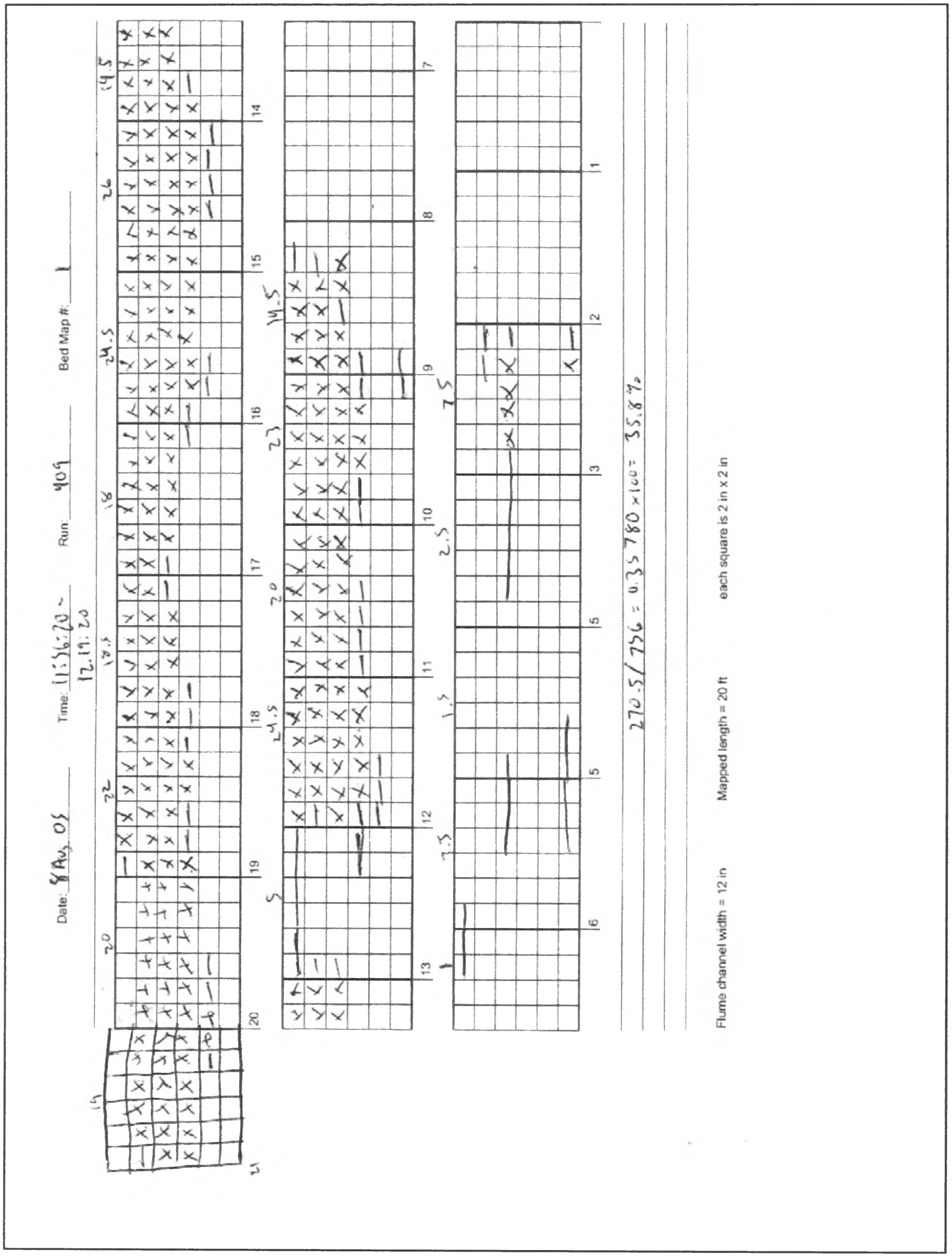

Date: 3 Aug 05
Time: start 2:43 finish 3:10
Run: 408
Bed Map #: 2
159.5 / 756 = 0.2109788 × 100 = 21.1%
Flume channel width = 12 in
Mapped length = 20 ft
each square is 2 in x 2 in

Date: 8/3/04 Time: start 4:00pm (flume, ft) end 4:22pm Run: 408 Bed Map #: 3

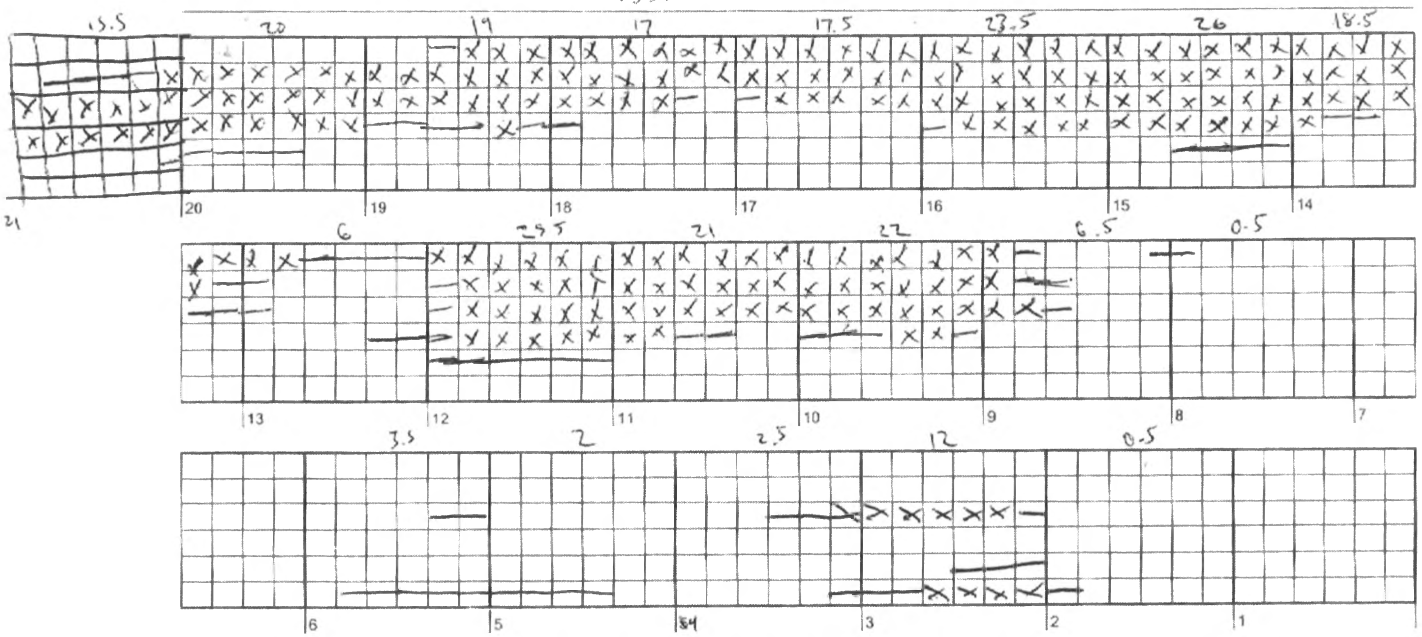


106/756 = 0.1402116 × 100 = 14.02 % cover

Flume channel width = 12 in Mapped length = 20 ft each square is 2 in x 2 in


Date: 8 Aug 05
Time: 11:56:20 ~ 12:19:20
Run: 409
Bed Map #: 1
270.5 / 756 = 0.35780 × 100 = 35.8%
Flume channel width = 12 in
Mapped length = 20 ft
each square is 2 in x 2 in

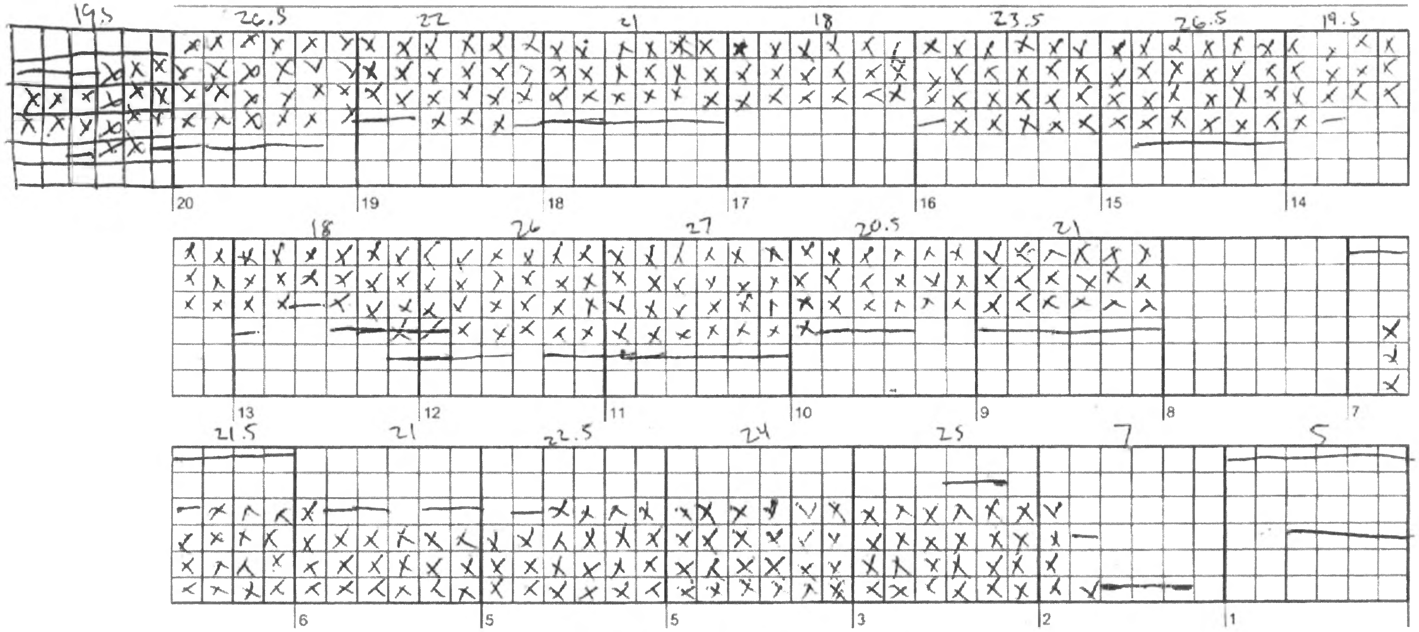
Date: 8 Aug. 05 Time: 13:21:15 - 13:34:40 Run: 409 Bed Map #: 2



263/756 = 0.34788 × 100 = 34.8 %

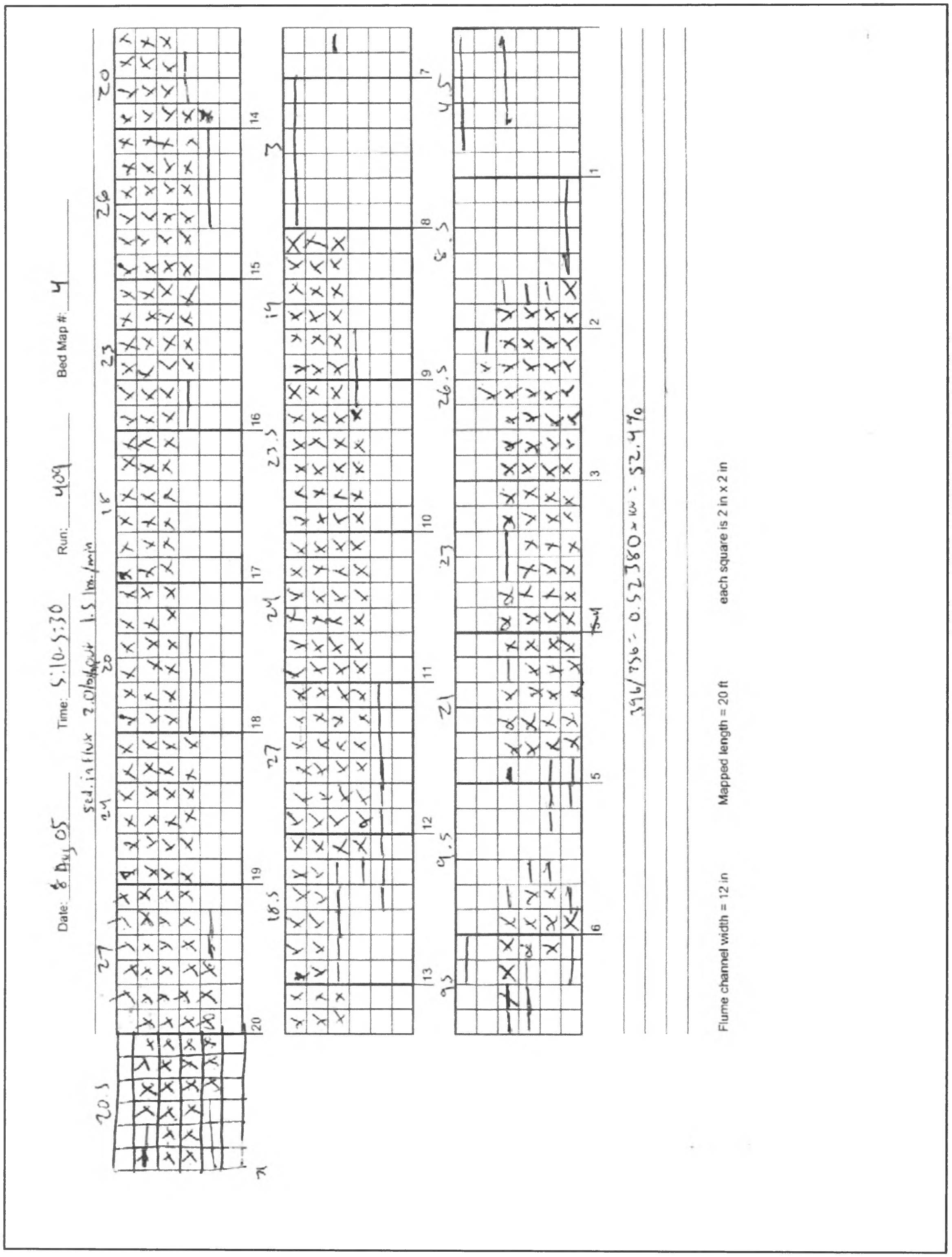
Flume channel width = 12 in Mapped length = 20 ft each square is 2 in x 2 in

Date: 8 Aug. 05 Time: 3:00-3:22 Run: 404 Bed Map #: 3



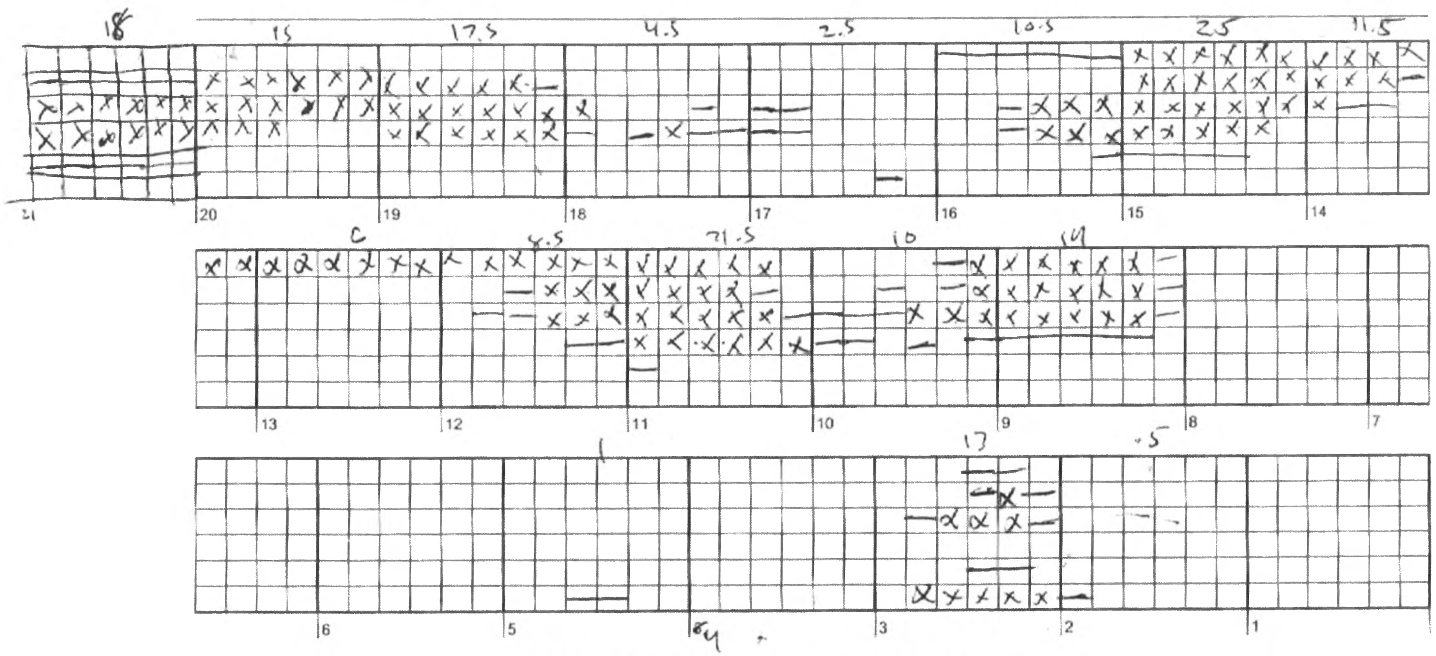
413/736 = 0.548741 x 100 = 54.9%

Flume channel width = 12 in Mapped length = 20 ft each square is 2 in x 2 in



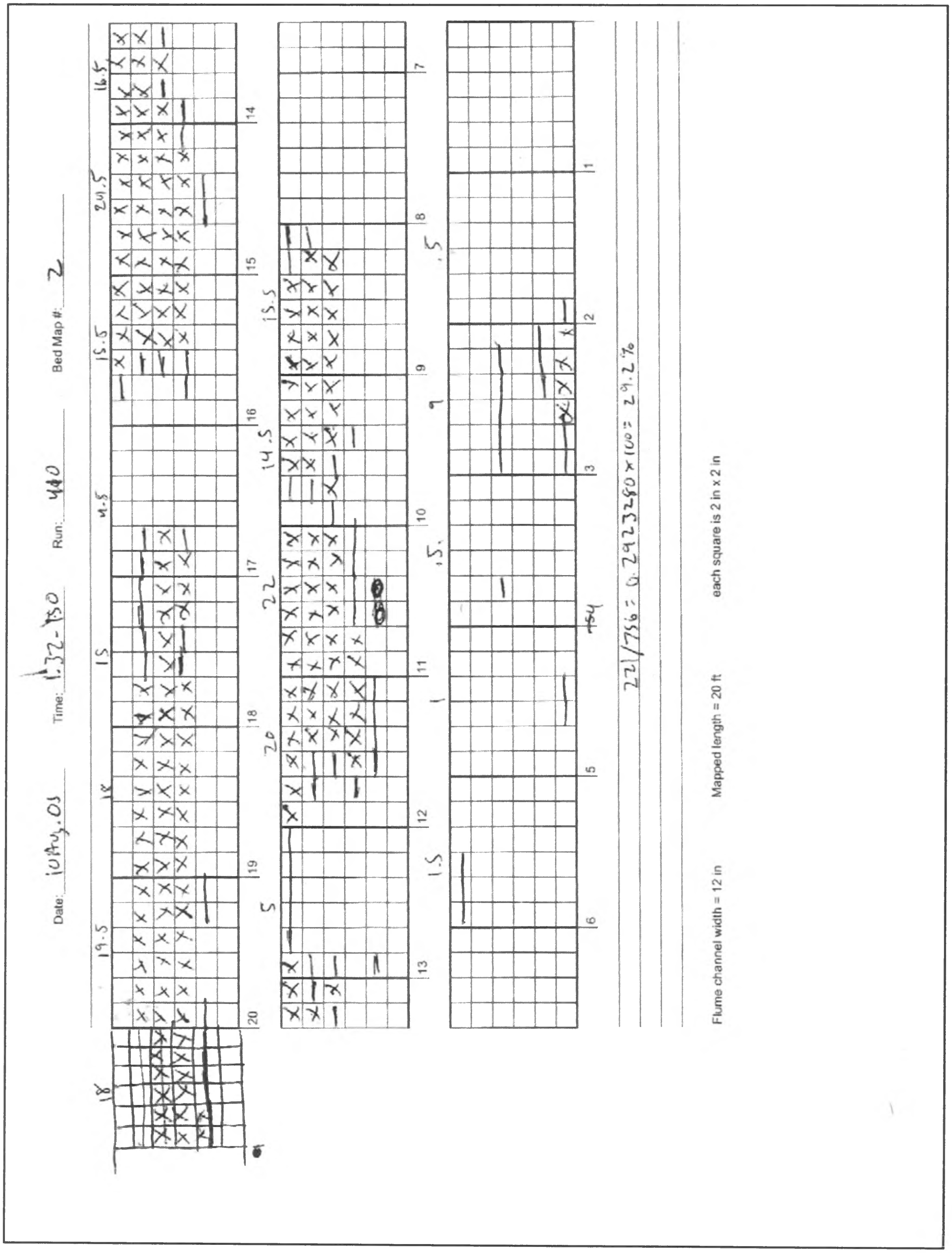
Date: 8 Aug 05
Time: 5:10-5:30
Run: 409
Bed Map #: 4
396/756 = 0.52380 × 100 = 52.4%
Flume channel width = 12 in
Mapped length = 20 ft
each square is 2 in x 2 in

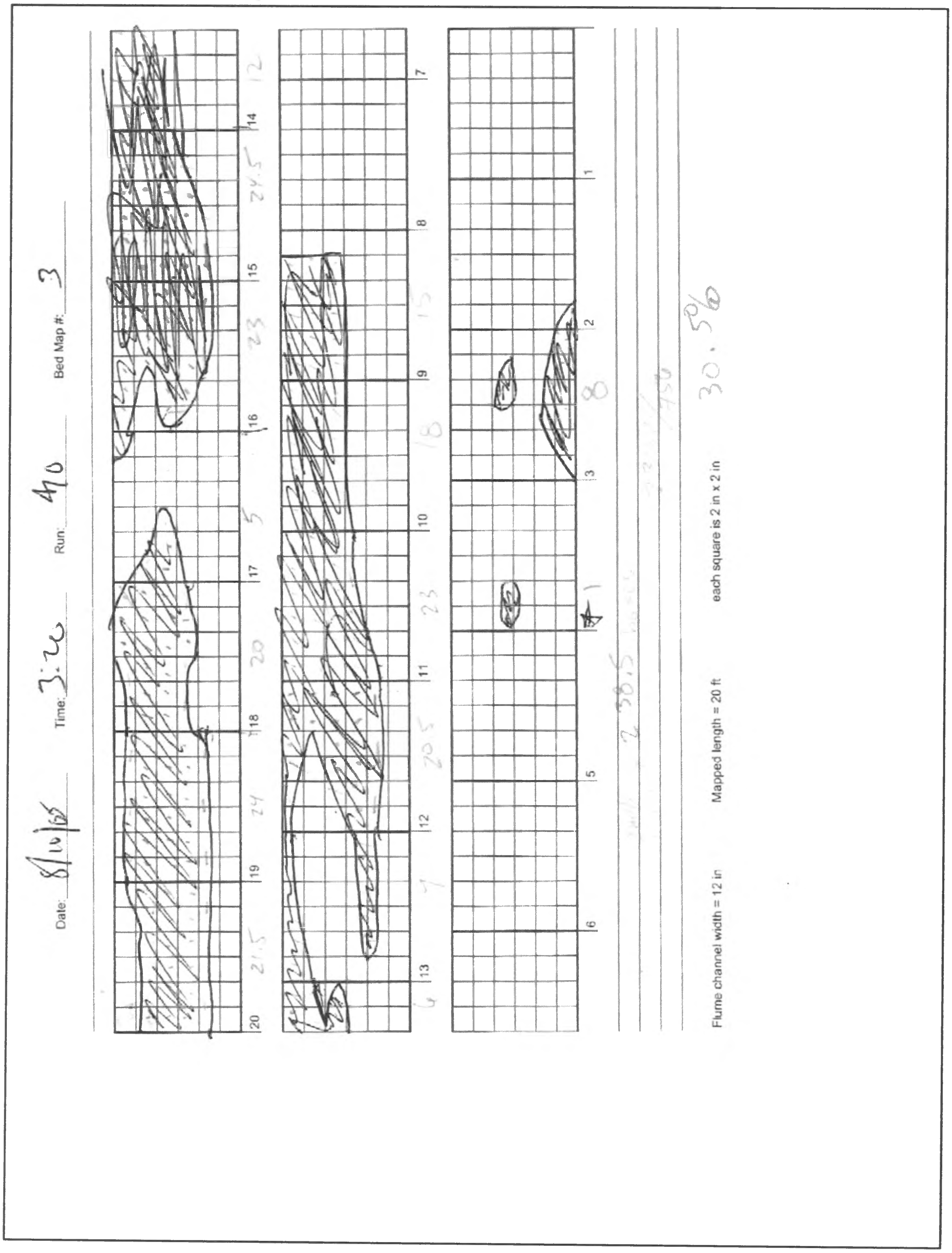
Date: 10 Aug 05 Time: 11:52 - 12:05 Run: 410 Bed Map #: 1



179/756 = 0.23677 x100 = 23.7%

Flume channel width = 12 in Mapped length = 20 ft each square is 2 in x 2 in


Date: 10Aug.05
Time: 1:32-1:50
Run: 440
Bed Map #: 2
22/756 = 0.2923280 × 100 = 29.2%
Flume channel width = 12 in
Mapped length = 20 ft
each square is 2 in x 2 in


Date: 8/10/05
Time: 3:20
Run: 40
Bed Map #: 3
Flume channel width = 12 in
Mapped length = 20 ft
each square is 2 in x 2 in