

Douglas Sherman: Please let me begin by thanking the organizers for the great job they've done putting this event together. This is pretty spectacular. I want to say how privileged I feel to have been invited and also to be able to represent my co-authors on the science team. I want to note that particularly because this is part of the record, that almost all of us were at the University of Southern California when this project began and in particular the listing of NASA and East Bay Mud have current affiliations with two of our former students, does not represent in any way an endorsement of these findings. I am going to summarize very quickly about ten years of research in different phases. The first three parts of this project have been sponsored primarily by the California Department of Boating and Waterways. The last two projects listed here were also sponsored by CALBO and partially underwritten by Hart, Incorporated, a consulting firm in Walnut Grove, proprietor Jeff Hart is somewhere over here. Thank you Jeff. I appreciate that. What we've been trying to do over the years is get a good handle on how much bank erosion is occurring in the Delta out of a variety of locations and how much of that erosion might be the result of boat wake activity. When we first undertook this project, we did so with the proviso that we are allowed to make conservative estimates of boat wake impacts wherever possible and by conservative, I mean in our context, to maximum potential impacts of boat wakes. So, I'll run through this quickly.

First, our long term monitoring program. We'll talk about our efforts to monitor boat traffic, particularly with the inventory of boat sizes and speed, characteristics of wakes in terms of the energy in individual boat wake and their ability to mobilize and remove sediments from the banks. We'll talk about our project to map and characterize eroding water lines and we'll talk about the last two topics which are probably most germane to this symposium and that is to model the effects of surrogate vegetation, i.e., brush bundles and real vegetation and in this case, non-woody vegetation [unintelligible] stems. I do have a pointer here but I'm not sure I'm going to use it yet. We established an erosion pin network that

comprises 44 sites scattered throughout the Delta and here we sort of put the sites on this map in three categories. One are those on maintained levees, a second set are unmaintained levees. Unmaintained levees in this case are those that surround some of the drowned islands for reasons that I don't understand are still called islands. Mildred Tract, Mildred Island, for example, and others and then a set for mid-channel islands. We have 4 to 12 erosion pins on each one of these sites. They are all monitored four times per year. We have ten years of data for the oldest sites. Some of our newest sites which are replacements for reclaimed sites only have two years of data and we measure vertical and horizontal change on each of these. We try to distribute these across the Delta and we've also distributed them according to the [unintelligible] of environmental processes that we think are most likely to be controlling bank change at those sites. I'll talk more about that in a second.

This is the erosion pin concept. It's pretty simple. They don't actually look as pin-like as this. These are just iron rebars, little yellow caps pounded into the bank. When we go back to visit these sites, if the pins are sticking out, we measure how far they stick out and we pound them down flat again. If they are buried, we have metal detectors to find them. We dig a hole and measure how deeply buried they are and fill the hole back up again. When we picked the sites, and this is part of our conservative approach to this, we picked sites that were visually, actively, and rapidly eroding. So, we have picked a cross section of some of the most rapidly eroding sites in the Delta and across the slough here, you can get a sense of what some of those sites look like. When we saw a site like that, we got to it, put the pins in. You can notice at the upper part of the site up here, someone has actually planted trees as an attempt to stabilize that. For some of the process distribution, we also put a series of sites in some of the Delta backwaters where there is minimal to no boat traffic, there is minimal river flow and there are minimal wind waves and so we have several sites, I think four or five in the vicinity of [Railroad Cut] -- this is near Walnut Grove for those of you who are familiar with the area -- and

this is kind of the background rate of Delta levee changes where there is a slow rise and fall of water due to tidal exchanges and some discharge and it's just the slow dissolution of mud banks. We have others where we have strong currents, boat wakes, wind waves, medium tide.

We have a whole number of these sites. This is a location on the Sacramento River a few miles below Walnut Grove. This is south where Georgiana Slough splits off from the Sacramento River. You get a sense of what a typical site looks like. Along here, we went by boat and we saw bare earth exposed between the trees and we put pins in there. And, so this is what it looks like. For the most part, the location to the left hand side of this diagram, are the older ones. The ones to the right hand side are the newer ones and we can see that for a Delta wide statistical look at this, we are averaging about .13 meters per year of horizontal bank erosion and about .03 meters per year of vertical erosion. We see one site in particular where there have been very, very rapid horizontal accretions, about 50 centimeters a year for the duration of this study. That is on the inside of a meander bend. It's an over seeping meander bend and so that there is accretion going on there as part of the Georgiana Slough tries to round off the corner. If you exclude that site, all the erosion values go up by about a centimeter a year. We can see that we have a number of sites where the horizontal erosion rate exceeds 20 centimeters per year, about 8 inches. Because we go back four times a year, we've been able to put some seasonal signatures on these data and this is a bit more tenuous but we think we're starting to get a pretty good signal here. And, the typical characteristic we see here is that there is usually a reduction in the erosion rate or a slight accretion during the winters followed by a little bit more erosion than in the summers. So, here we can see summer erosion, summer erosion, summer erosion. These half stripes represent each summer season bracketed by Memorial Day in May and Labor Day in the fall. What's going on here are two things that cause that wintertime erosion. One are the flood deposits of poorly consolidated muds, which we do measure. Also, if we get bank collapse in the wintertime, that

shows up in our summer measurement as accretion because material has fallen across our pins, which are all put in the lower part of the profile.

I want to give you a tale of two sites and I 'm sorry I'm going through this quickly. It's hard summarizing it. You can ask me questions later if you are interested. Sites 5 and site 17 which are on opposite side of Georgiana Slough. This is what site 5 looked like in September of 2000. We've instrumented this site to actually measure boat wakes. This site is unusual in that there is a relatively wide mud platform unvegetated in a low cut bank behind that. On the opposite sit of Georgiana is site 17. we can see two large unvegetated scallops. If you look carefully, you can see that these have been modified. Jeff Hart had been here putting his brush bundles, basically ruining the site for us -- thanks Jeff. On this side, you can see the coloration slightly different. This had been a demonstration project by the Corps of Engineers where they put in broken gravel and then planted it with small trees. If you look at this site today on both sides, it is heavily vegetated, partly because of the effects of the brush bundle and partly because of the tree plants there. If you look how they behave through time, we've got site 5 here and we can see relatively steady erosion through time until we get to this point in the summer of 2004, when the bank collapsed. We had a large bank failure burying our pins. Of course we measured this again as accretion and slightly after that, Jeff Hart put a brush bundle here where the vertical green bar is and we can see that after that point when the brush bundles are involved, we start to get fairly rapid response, dramatic accretion at this site. Across the slough at site 17, we can see that between the summer of 1998 and 1999, we had dramatic erosion. That's the removal of the unconsolidated gravels. Once the gravels are out of that scallop, the erosion rate slows down substantially. We can see brush bundles installed in 2000 and we have kind of a tapering off of the erosion rate.

At this site there were also some large woody debris put in there and plantings and the site began to revegetate itself and by about the summer

of 2005 and continuing, we started to get accretion at this site. I point these sites out because by picking sites where obvious and dramatic erosion is occurring, none of our sites by definition were then vegetated and this is one of the very few sites that has revegetated itself during this study period. We've also been trying to actually find out how much erosion can be caused by the boats per se and there are several ways we've approached this. Over several summer holiday weekends, we videotaped radar gunned boat traffic. We counted all the boats, measured the impact of the wake using pressure transducers to measure wake height, current meters to measure the loss that's associated with them, optical back scattering sensors to measure sediment concentration and from these data, which we've not finished yet, we are trying to sort of develop an atlas of boat impact on the bank. We've also done two experiments. In one case, we drove a boat past one point 500 times -- that was kind of fun -- so then we did it 1000 times. It's not as much fun as it sounds, really. The novelty wore off after about ten times, but we had to do it this amount to actually try to drive some kind of bank change that we can measure so we can get a sense of what does this do. In all these cases -- and I don't have a picture of this -- we loaded the back of the boat with graduate students and concrete blocks to try to get the boat to mush through the water to generate the largest waves that we could. These are some sample data. Up here, we see a current meter record. This is the period leading up to the passes of the boat. Here we see the velocity fluctuations caused by the wake itself. Here we have the record from the optical back scatter and sensor. This is measuring the increase in suspended sediment concentration caused by the impact of that boat wake on site 5, one of the locations that I showed you earlier.

The main photograph -- this is site 5, you can just see the probe of the top of the current meter there and the suspended sediment that had been stripped off of this bank. We have published one paper on this that discusses the impact of 7 particular boat wakes that were controlled by us and now we're trying to span this to be more generic. For a couple of

summers, we measured boat traffic, in some cases with and without the measurements. Labor Day 2000, Memorial Day, Fourth of July and Labor Day 2001. The N equals the number of boats that went by. A couple of anomalies here -- Fourth of July, 2001 was in the middle of the week so we had unusually low traffic and for those of you who have been around for awhile, you may remember Labor Day 2001 -- it was a really crappy weekend. It was cold and it rained. So, those are anomalously low values. So, we can convert based on our profile measurements about how much erosion occurred and we can see that for all of those studies, we get between a little bit less than one-hundredth of a millimeter, up to about .2 millimeters per boat passage. For our 500 and 1000 boat passage experiments, we get erosion rates of .03, .01 and .05 millimeters per boat passage. These are fairly broad scale numbers and the variance is because for each one of these sites, we have numerous micro profile and we get different values depending on which stuff we look at, so we are still trying to agglomerate those data. To couple this with those weekend boat counts and those impacts and trying to find out and get some sense of what the total boat traffic is like, I'm going to show you a video if this works.

I've been pretty stressed about this. We have a video camera set up on Georgiana Slough. It monitors from sunrise to sunset everyday. It has a motion detector in it so that when it detects the motion of a boat going by, it saves the preceding and the succeeding -- the preceding 10 seconds and the succeeding 20 seconds and so we can see what happens here if this works. That didn't work. I'll try it again. Here we go. Watch the wake bounce off the far bank. One of the problems here in the Georgiana Slough in particular is that the channel is so low, there is substantial wave reflection off both sides of this. The far bank is vegetated and we can see that waves are reflecting off that vegetated barrier. And, so I have graduate student who spends all his free time going to this video trying to characterize the size of the boat, the direction of the boat, the type of the boat. And we are developing algorithms that will let us estimate the boats

speed from these videos so we can compare it to our other data sets. This is what the boat traffic has looked like since October 1, 2006. Our goal here is to try to get one year of data. We are about five weeks away and we're hoping that camera doesn't get taken in the meantime. We can see the effects of holiday traffic here. This is the Columbus Day weekend. This is Memorial Day, Fourth of July and we're ramping up now. This is through last weekend -- and hopefully we'll get a nice turnout for Labor Day weekend this year. We'll see. Passages so far of 2833. We read online it was something on the order of the 3000 boat passages per year. Now, another one of our fun activities was to map the characteristics of the water line for 800 miles of levees in the Delta. This maze of orange indicates the levees that we've mapped. They are all categorized as 9 different bank types and we use these as one indicator of potential erosion vulnerability. I want to say a few things about this again. This is a very conservative estimate. We don't actually know what these levees are made out of.

What we did was categorize what we could see at the water line. These are some of the categorizations -- partial rock, partial concrete, unprotected, which means we can see bare exposed bank with little or no vegetation, trees or vegetation. Now, if you have blackberry bushes that are growing down across the riprap -- and we can see no riprap at the water line, we categorized that as vegetation, so that in all of our cases, we have made conservative estimates of what the bank type is. If there is rock underneath that and we don't see it, we don't categorize it as rock. This is an overview of the Delta that we've mapped. If you see colors here that are in red or blue, that means that they are protected by some combination of rock or concrete. Those have minimal susceptibility to boat wake erosion and we're not talking about overall levee integrity -- water line susceptibility to boat wake erosion. We've done a breakdown on the bank types. We have about -- of the 800 miles that we've categorized, 75 miles that are unprotected -- this is bare exposed soil or

sand that does include a few beaches -- 65 miles that are vegetated. This is non-woody material usually. And, 50 miles of what we call trees. Now, for us, trees include three different things. One, where the branches and leaves of the tree are down into the water, two, where the water line comprises the root masses of the trees, or if there are down trees in the water and the down trees provide a substantial barrage of boat wakes, we also consider that to be a treed water line. This map shows the distribution of the 5's, 6's and 7's. 5's are trees, 6's are vegetated and 7's are unprotected. This is a fairly good snapshot of the areas that are most vulnerable to boat wake and I guess by extension wind wave erosion in the Delta. You can see that the central core area is pretty well protected. It's mainly some of these fringe areas.

Many of these, in fact, are not really amenable to boat traffic. We had to only go a few miles an hour to try to get through the snags and about the only boats we saw were some hardy bass fisherman. This is Georgiana Slough. Just to give you an example, Georgiana Slough is probably the highest boat traffic area with the least protection. This site here where our tract departs from the curve, this is the meander bend where we are getting all the accretion and we couldn't get closer to the bank because of shoreline. This mapping project just finished this July. When we quality control these data, we'll kind of stretch that path out to match the shoreline better. The last two parts -- brush bundles and Tule stems. We had two students with master [unintelligible] trying to look at some of the effects of shore protection and boat wake, and mitigation structures. The brush bundles -- I don't know if Jeff Hart invented these but he's put I don't know how many miles along parts of the Delta. This one is notable because it is a relatively small section. It's anchored between two trees where there is a large v shaped scallop behind those, behind the trees -- that's what it looks like from the land side. We put a series of pressure transducers and current meters here -- a set inside the brush bundles and a set outside the brush bundles to measure how efficiently the brush bundles can reduce the transmission of boat wake energy to the banks.

We have a control for the data. We were able to put those pressure transducers in before the brush bundles were in place so our control site is that location without brush bundle. I have drawn two red lines on here. The vertical red line is the normalized water depth. That is the water depth relative to the crest elevation of the brush bundle plus the height of a typical boat wake and so that at $H=1$, the average boat wake will not have any water come across the top of that. The horizontal red line is an energy ratio.

That is the ratio of the energy measured at pressure transducers near the bank divided by those measures outside of the bank. And so that if the values are scattered around 1, that means there is no attenuation and if the values are less than 1, that means there has been attenuation. We can see for the control there is no real pattern there for -- oh, I've lost the cursor again. Where we have the brush bundles in place, we can see that under all water levels, there is a reduction in boat wake energy. So, only about 50 % of the energy is transmitted through the bundle even with water well over that, and when we have low water levels, somewhere in the order of only 10 or 15% of the boat wake energy gets through. Now, this has important implications for vegetation. We don't really have tree root systems that behave like brush bundles in terms of the transmission of energy through them. However, what we do have are root bundles that have the same kind of wave reflective capability as the brush bundles. And, so most of the energy that is lost here is not turbulent dissipation through the brush bundle per se, it's reflection back off of the outer surface into open water. We think that is a reasonable surrogate for how root bundles at the water line behave. The Tooley stem experiment was designed exclusively to see how valuable the self-conscious planning [unintelligible] might be to reduce boat wake energy -- by extension, wind wave as well -- the same principles are involved here. This is based on some of the concepts first noted by Markel and Dean. In their studies, they weren't looking at flexible vegetation. They were looking at woody vegetation, but it was the best hand we had to get this process started.

Where dissipation should be a function of the stem size, the stand at density and the width of the stand. I won't spend a lot of time on these equations.

There are only a couple of variables here that are critical. H_0 is the wave height outside of the vegetation stand, H_x is the wave height at any given location x within the stand, the variable x itself is how far you are within the stand from the outside. A is a little more complicated. It represents C_D drag coefficient of the stems themselves, D_s is stalk diameter, so we basically have a common drag coefficient here 3π , F^2 (squared) is the spacing between the stalks and H is the water depth. Now, Dean's model was originally designed for tsunami modeling and storm surge modeling across through forests, but we tried to apply it here. This is what Dean's model predicted. We did 10 data runs of five boat passes each. We measured the wake height through the stand at two meter intervals over a 10 meter distance total. Between each set of runs, we send out the Tules. We did a methodical reduction in Tule density. When we cut them we measured their stem diameter. This spray of red line represents 10 % decreases so that at this point, we have about 50% stem density and up here we have no reeds left in our stand. Then, we compared these with Dean's predictions. This is our observers that predicted wave heights. Our score was 51%. There is a lot of variability here but still, this is a bit better than a shotgun blast. I've drawn the red lines in here to show that we actually measured, observed a little more attenuation than Dean's model predicted. So, where we had an observed wave height of .15 meters, Dean's model predicted we should see .24 and so we actually have a bit more dissipation by the reeds that his model would predict. So, to kind of summarize these findings -- and I do want to emphasize these are preliminary findings because we still are involved in this project and some of these numbers are going to change as we wrap this up.

The average erosion rates for the unprotected sites in the Delta are about 13 centimeters a year for horizontal erosion, 3 centimeters a year vertical

erosion. Those are again conservative toward the high side. The boat wake erosion averages about 9 centimeters a year. That number we got at by taking the average of all of our per boat passages and multiplying them by 3000. Now, this is a good number and a bad number. I mean it's good in the sense that for the sites on the Georgiana Slough we don't actually measure that much erosion anywhere and so it's a good number because we've actually overestimated the erosion caused by boat wakes. It's a bad number because we are not getting a realistic number yet but we're still working on that. There are about 200 miles or less of levees in the Delta we think are vulnerable to some degree to boat wake erosion. Brush bundle dissipated about 60% of wake or wind wave energy and the tooley stems -- this is a relatively thin stem, a thinly populated stem, not very thick -- dissipates between 15 and 30% of the wake energy. So, thank you very much.