Joe Devries: We're going to take a little bit of a look at hydraulics here and what I'd like to start out with is looking at some levees and I've got a variety of pictures. One of them came from DWR of different types of conditions along levees. So, this is up at river mile 99 on the Sacramento River -- some rock along the water, some vegetation above it. Here at river mile 6.4, highly vegetated -- hard to see where the bank is actually. Again, a little less dense vegetation but pretty highly vegetated levee bank and 44.7 again on the Sacramento River. A picture from the Feather River where there is sort of mixed vegetation but shrubs and some trees. Another picture from the Feather River where there is some really good sized rock on the right hand side here and it sort of goes into a little less dense vegetation into highly dense vegetation along the river bank. I was looking for places where I could really identify riprap along the Sacramento River and it took me a little bit of work to find a place I could get a picture. This is on the main stem of the Sacramento left bank, some place below hood and what's interesting I think is that vegetation is trying to get itself established here in the rock along the riverbank. And, I thought I ought to put this one in because this is sort of an unusual condition along here. It looks like it was a riverbank that had essentially concrete lining along it that is becoming flexible lining now due to probably settlement of the levee, but it's changing its characteristics there a little bit.

So, I would like to talk about what happens in terms of floodway conveyance -- the capacity of the river to carry flow with vegetation effects, implications for near bank erosion, the effects of vegetation free areas is next to levees. I found some information about erosion around trees and suppression of waves in areas that were vegetated and I don’t want to steal anything from the next speaker who will talk about primarily boat wakes, but there is some information about wind wave and boat wake waves and how they influence what happens on the levee. Well, basically, and some of you are hydraulic engineers -- you know this -- but, water flows down hill so gravity is the driving force and basically the resistance to flow is what happens along the boundaries of the conveying system, the river bed and banks and hydraulic engineers use Manning's equation along with an empirical coefficient we call Manning's N to express this boundary surface roughness. Manning's equation is the thing we use to characterize resistance and in its simplest form, it involves relating the discharge -- cubic feet per second -- to this empirical coefficient the Manning's N, along with some of the physical characteristics of the cross section. Hydraulic radius, which is the cross sectional area, the flow area divided by the wedded perimeter, that part of the channel that's in contact with the water.

So, we have the hydraulic radius and we have the flow area again in this equation and then we multiply that by the square root of the energy slope, which is approximately the same as the water surface slope in the river and that's the relationship that relates roughness characteristics, geometric properties and the energy loss in the system. And, one of the things when I've looked at river sections is that we typically don't do a very good job of showing what they really look like because most rivers are really quite shallow and very wide. They are very wide with respect to the flow depth and the riverbed itself makes up most of the wedded perimeter, the boundary that the flow is going along and the banks, including the levees, comprise just a small fraction of the wedded perimeter. And, if we look at the effects of vegetation on levees, we're really looking at a small contribution to the overall flow resistance. So, I tried to plot a picture of what an undistorted plot -- if we keep the vertical dimension the same as the horizontal dimension for this particular section of the Sacramento River, it is really very wide and not very deep, even at flood stage, which is basically what I'm showing here. In the typical way, at least hydraulic engineers like to look at pictures and cross sections where we distort the plot so we can actually see all the points in the cross section and get an idea of what the depth looks like. But, it is really this little area -- let's see if I can get the curser up here -- maybe not. Oh, there it is. Up along the edges here where we have resistance due to vegetation on the levees on each side and really the whole width, the whole bed has a much larger effect on the hydraulic resistance. And, being an engineer, I wanted to find some way to quantify this.

I didn't really have the opportunity to run large scale models so I picked out some typical cross sections for a central valley river. So, I've got a cross section that I took and had levees and basically a reasonable looking cross section of the Bear River and the Yuba River and again, I'm plotting these with a 4 to 1 distortion so I can get them into a recognizable plot here and read the scales. And, I also looked at the Feather River cross section -- a Feather River cross section and a cross section from the Sacramento River and I pulled off a cross section of the Feather that's part of I think a levee setback area. So, in this case, it is very wide relative to the depth and I plotted the upper plot of the Feather River cross section at a 20 to 1 distortion so I could get it on a plot so I could see the values quite easily. The Sacramento River, which as you go past Sacramento, is more like a canal than a river. It is roughly trapezoidal and cross section has really uniform slopes in the levee and looks less like a natural levee. Fortunately, we have the yellow [unintelligible] passage or the flood plain but it is basically more like a big conveyance canal. Okay, now I want to look at what the effect of vegetation on levees -- I got this paper by one of our speakers here today. Dwyer is co-author on this -- where they looked at various types of vegetation at levees and I wanted to consider a fairly high density of vegetation on the water side over to the left side there in contrast to then with a situation where there would be a low roughness coefficient on that area next to the levee itself.

And, I did this analysis sort of using the standard program for river analysis, the Hydrologic Engineering Center River Analysis System, a program called HECRAS, sort of the general purpose tool for river analysis. I made some runs with these four typical cross sections with and without vegetation on levees, so represented that by or high end values with the vegetation on the levee in that particular area and low in values with no vegetation or basically grass type of surface. And, I looked at what the difference in the conveyance capacity would be for the typical river section at capacity -- how much flow it could carry. I also looked a little bit -- because HECRAS provides some way to evaluate velocity distribution and I took a little look at that as well. And, for my computations on the Feather River, which was that very wide section, whether or not we had high vegetation on the levees, really produced a very small reduction of the conveyance, so I had really only 1.6% reduction on the conveyance, where we went up 5 on the Bear, 3 on the Yuba, 2 on the Sacramento River. One of the things of course that is going to happen if we remove vegetation or dense vegetation next to levees, is we are going to increase the velocity in the banks and we'll have potential for additional scour and you can see some of the effects from this sketch I stole from [unintelligible] on velocity profile. So, if you have low vegetation, you get low velocity right at the bed surface.

If you have trees with no low limbs, you get a higher velocity through there and lower velocity above and mixed vegetation gives you that sort of glass shape there. So, in my HECRAS analysis, I looked at an end value for the low roughness of being .035 the banks and the velocities in that calculation were about 1.5 feet per second. If we look over on the right side with a high end value, .08 velocities were reduced down to .6 feet per second and so it was contrast between two different types of banks -- low roughness in the previous one and high roughness in this one. I'll go through these slides of some wave run up fairly quickly here but one of the major factors affecting erosion on levees is the fact that we get wind waves that when they impact the levee, will run up the levee surface of the slope -- same thing happens with boat wakes. Different types of surfaces respond differently and grass levees are basically like a smooth or concrete surface. The runoff is the highest and is not attenuated at all. Shrubs and trees attenuate the trees to some degree. Vegetation also provides additional erosion protection. Rock and riprap provide the greatest degree of protection. The Dutch have done some studies of this and it is quoted in a Corps paper, that you can knock the waves down to about half their height, an attenuation of about .5 to .6. You are going to hear about grass mats and using grass on levees. Grass mats provide high erosion resistance and this is due primarily to the structure of the root layer and not the thickness of the layer of the grass or the leaves or the stems above the ground. And, the consensus primarily of the Dutch experience, plant roots are important in keeping the particles of soil together. A well rooted grass mat can resist one to two days of sand exposure, to flood velocities.

Poorly rooted mats may fail within a few hours and I think what's important from a California perspective is that you need an actively growing perennial grass and I think what works well with grass levees in Holland is that it rains every month in Holland and you get good irrigation. I've got one minute so I'm going to move through this and basically you'll hear about this. There is a study done by the Corps of Engineers on the effects of tree stand for protecting levee embankments, primarily from winds and wakes. If you don't have branches down in the water, the wave reduction is small, maybe 9 or 15 % of the wave height. If you have tree stems that have branches down in the water, the maximum wave attenuation is about 45%. Since I'm out of time, I'm going to skip over this case study. It's an interesting study. You can find it on the internet -- the Williams River in Australia and they've revegitated the river where they were restoring vegetation -- I'll go back one here -- to provide bank resilience and roughness to stabilize the banks. They recognized that vegetation along the river would increase the hydraulic resistance during flood events and this could potentially increase flood heights and reduce flood protection. So, to wrap this up, basically my pros and cons relative to hydraulics with vegetation on levee, is that levee armoring with properly designing woody material and vegetation will slow flood water velocities near the banks, dissipate weight energy, reduce scouring potential, increase soil strength and the con of course, is you are going to have minor decreases in the river conveyance capacity on the wide channels. On narrow channels, the decrease is going to be a little more significant. Thank you.