Morning Session 2

John McMahon:  All right. Well, welcome back, and I would like to introduce our next two presenters, who are Dr. Andrew Simon and Dr. Natasha Bankhead. Sir, and lady.

Andrew Simon:

Thank you, good morning. I hope everyone has their coffee. I’d like to thank, or we’d like to thank the organizers for inviting us to present.

And as you’ll notice, that the title of this talk is slightly different than what you have in your program. We thought, just in the context of what we heard over the previous day, that we would provide a summary of kind of the work that we have done when we were at the National Sedimentation Lab over the past dozen years, or so.

So let’s start with the idea of looking at the processes that would affect stream banks and/or levees. So we think generally in terms of these process domains.

So stability is decrease by soil moisture, due to the weight of the soil in the bank, the development of pore water pressures, any kind of hydraulic erosion, which would tend to increase the angle of the bank, and the downslope gravitational component, and pore water pressure, which we’re finding is one of the most important variables.

Fred did a very good talk on the issues with seepage and pore water pressure. And we think of stability, we can increase stability for a particular bank by evapaid transporation, so the removal of moisture from the soil, and issues regarding root reinforcement, drainage, anything to lower the pore water pressure, and to increase the value of matrix suction, which to strengthen the soil, and anything that’s lining the bank, or the levee surface, to increase the resistance to hydraulic erosion.

But I wanted to kind of dispel some myths. We’ve heard some things regarding whether the work regarding stream banks is applicable to work involving levees.

So let’s start with this: studies of stream bank processes and the role of vegetation do not apply to levees. So I’d like to dispel that rumor.
“There is limited data on the tensile strength of tree roots by species.” In fact, there is quite a substantial library of data on that.

“Root distributions and typology of roots are not documented.” Now, granted, there is not a lot of this stuff, but there is a fair bit in the literature.

“Geotechnical data is assumed.” My comment is that it doesn’t necessarily have to be.

“Root reinforcement and stability cannot be modeled.” So these are things that we’ve able to accomplish.

But finally, this is, as the previous speakers have talked about, a very, very complex issue. And a number of speakers have mentioned that we have to look at this on a case-by-case basis.

And there is much more to be learned, and much more to be refined about this work.

And I just wanted to show you, just real quickly, just some of the stuff that we have done over the past twelve years that is in the peer review literature regarding root reinforcement modeling.

These are from Journals out there, whether it’s Water Resources Research, Ecological Engineering, Geomorphology, including textbooks. And in applied studies, where we’re looking at kind of the net effects of vegetation on stability, looking at the effects of increasing erosion by removing vegetation, or decreasing erosion by adding vegetation, some additional studies.

So let’s start looking at this whole idea of, “Can banks and levees be grouped together in terms of the same process domains?” So let’s break it down into the different processes.

We initiate with hydrologic processes. And we have vertical infiltration, say, from precipitation falling on the stream bank. And vertical infiltration falling on the top of a levee. Well, those processes would be the same.

The same with lateral infiltration from stream flow, those would be the same on those two surfaces.

Evapotranspiration at the soil/air interface, and in fact, this process would probably be more important on levees, because we have the free air side on both sides of the levee.

Transpiration, if there’s vegetation, would obviously be effective on both surfaces.

Now, if we start looking at hydraulic processes, the fluid sheer, stream flow, is going to effective on both. Lateral seepage moving streamward, okay, from precipitation falling, and then moving streamward, would be applicable to both.

Where we have a difference is what Fred was showing us just early. This is the lateral seepage landward. We don’t get that in stream banks, because we have a solid mass behind it.
But piping, we get in both of these. Fluid drag from roughness, be it from, whether it’s rock, vegetation, large wood, that’s going to be the same process in both.

And finally, the geotechnical processes, the shear strength of the soil, or the levee, is going to be the same, or the same way of analyzing it. Issues with pore water pressure, issues with matrix suction above the water table, root reinforcement, would be analyzed the same way. Surcharge would be analyzed the same way. And windthrow would be analyzed the same way.

So really, the only process difference to process domain that we don’t have on banks, that we do have on levees, is what Fred was talking to us about, it’s that seepage issue moving landward.

So if we look at vegetation, whether we’re looking at stream bank considerations or levees, we can break this up into the issues regarding the above-ground biomass and the below-ground biomass.

We can also break it down into these separate process domains. So we have geotechnical processes, where we’re dealing with things like surcharge. Where most studies have shown that surcharge is negligible on stream banks, the below-ground geotechnical effect is reinforcement.

Hydrologically, we have interception, evapotranspiration, which is a very important process in strengthening soil conditions, below-ground, we do get increased infiltration rate, and increased infiltration capacity below root zones.

But we also get, on the other hand, increased matrix suction. The lowering of the water table as the moisture is drawn out of the soil.

Hydraulically, which is important in terms of stabilizing the surface of a bank or a levee, we get the increased ruptus from vegetation, which is going to reduce sheer stresses. And we’re going to be reducing the applied sheer stress that is actually operating on the grains, because the thread of the sheer stress is pushed away from the surface.

And similarly, we’re going to get increased critical sheer stress of the material, because of the binding effect of the roots.

So if we look at a potential failure plane on a bank or a levee, these are the forces that are going to be affecting sheer strength. And it’s going to be true for a bank or for a levee.

We have cohesion, which is that electro-chemical bonding between the particles, the normal load, so this is the downslope gravitational force perpendicular to the failure plane.

Friction, so interparticle roughness, so really, we’re talking about the cohesive strength, the frictional strength, pore water pressure, which will reduce effective friction.

And then, finally, above the water table, this force called matrix suction, which is similar to the force provided by a plant when it’s withdrawing moisture from the soil, or when we’re sucking water through a straw. It helps bind the soil together.
And this is why we don’t see failures in the summertime. The sheer strength of the soil changes throughout the year.

And we’ve been able to quantify this using these defining processes into a factor of [unintelligible] equation, which is part of our bank stability model.

So we look at hydraulic and geotechnical effects of vegetation, we’re talking about hydraulically reducing the available shear stress, and/or increasing the shear resistance to particle detachment. So these are important components in terms of hydraulic erosion.

But geotechnically, the trees will increase the sheer strength from root reinforcement, and it will increase the resistance to failure by gravity, by reinforcement, and the removal of moisture from the soil.

Now, we may want to think that vegetation has all these wonderful effects, but there are also negative effects of vegetation as well. And we split them out into mechanical and hydrologic.

So on top, in green, we have stabilizing effects. And the mechanical issue there is increasing strength due to roots. But the destabilizing effects, potentially, can be surcharge, which we’ve seen, well, we haven’t seen yet, but many studies have shown is negligible.

And what Dr. Peterson was showing us, that windthrow, particularly in the Central Valley, may not be an important issue.

Hydrologically, we can think about canopy interception, or the potential reduction of delivery of water to the surface, transpiration. And then the negative effect would be the increased infiltration rate and capacity, so the acceleration of water to depth.

The problem becomes, then, is not what these individual effects do, it’s that what are the net effects when we start putting these all together? Are they consistent in various locations? Or do we really have to look at this on a case-by-case basis?

So if we think of geotechnical stability, in terms of the factor of safety, which is how it is always analyzed, we’ll look at the resisting forces over the driving forces. If that value is greater than one, theoretically, it’s stable, less than one, it’s unstable.

And what I have in green here are the forces that can be potentially affected by vegetation. So on the resisting side, again, soil sheer strength can be increased by root reinforcement. Matrix suction, on the other side, in the driving forces, the additional weight of water in the bank could be affected by vegetation and potentially surcharge from the weight of the plants on the bank.

So we did some work years ago out on Goodwin Creek in Mississippi, which is about twenty miles from our office in Oxford, which is, by the way, the center of the universe, according to the mayor.
And so we looked at things like rainfall interception, transpiration, to identify whether we were going to get these either positive or negative effects.

And we did this under three different scenarios. We had a bare surface, we had one that was covered in grasses, and another, as you can see, under a mature forest.

We had pore water pressure, and tensiometers put in at five different layers under the bank under each of these treatments, so we can look at what the difference was in these cases.

So here we have canopy interception. On the Y axis, we have event throughfall. So this is what was coming down under the canopy. And on the X axis we had event rainfall total.

And you can see that the angle of these is about forty-five degrees, which basically means they were about the same.

So in this particular study, only two percent of the rain that hit the top of the canopy, or would have hit the top of the canopy, didn’t make it to the soil surface. That’s not to say that the canopy didn’t affect rainfall intensity.

But ultimately, we’re not as concerned about that, in terms of slope stability analyses. We’re concerned about the volume of water that meets the surface. So canopy interception was not a big issue.

This is the idea behind matrix suction. That horizontal line represents the groundwater table. And we can see, below the groundwater table, pore water pressure increases with depth, and matrix suction, which is really negative pore water pressure, increases with distance above the water table.

So the question then becomes, what is the role of vegetation in terms of increasing the cohesion? And you can see it here in this equation. This is a piece of the Friedland Equation, which shows apparent cohesion is the sum of the effective cohesion, or the cohesion just due to the soil skeleton, plus this matrix suction component.

And you see if we have negative pore water pressures, we put a negative value into, it’s on both sides. A negative value into the minus [musse] of W, then we get an increase in the strength of the bank. So this is really how this works.

So here’s the data from Goodwin Creek. In the beige, which you can barely see, or I can barely see it here, represents the bare soil. The blue is Eastern gamma grass, and these were young grasses. And then under the mature forest canopy.

So on top you see 30 centimeters, and you see that actually, under the trees, in the upper 30 centimeters, they are wetter, pretty much throughout the year, until you get into the summertime, where the roots start providing removal of moisture from the soil, and very high matrix suction rates, which you can see on the left hand side of the plots.
A meter down, it’s a little bit different. And it’s still kind of variable as to whether it is drier or wetter under the trees.

But as we get down depth at 2 meters, or 2.7 meters, a couple of things show up, is that in these cases, even though the roots did not go down that deep, the hydraulic gradient under those roots were causing matrix suction values much greater than under the bare soil, or under the grass soil.

At the end of the year, we actually had what we could call negative, or destabilizing hydrologic effects from the trees, because they do add up very quickly, much quicker than under the other surfaces.

The other take home message here is that you can see, once they dry out, that’s the dark green line for the trees, at depth, you don’t even see the effects of the other rainfall events, okay? So you can maintain potentially these greater suction values even during the wet season.

So the hydrologic findings in this example is that only about two percent of the rain was intercepted and didn’t reach the soil surface. The trees do, in fact, increase infiltration rate and capacity, so do increase hydraulic conductivity in the upper 30 centimeters to a meter.

But down below, in the area, you know, two to three meters below the surface, they can maintain very high matrix suction values. And that means increased strength, even throughout the wet season.

So we started taking a look at how different species vary in terms of evapotranspiration they can provide. So these are some cans that we set up, or culverts that we stuck on end in the back of the sedimentation lab.

We put tensiometers in 30 centimeters and 70 centimeters down. And we used common repairing species from our part of the world. We used a sycamore, black willow, and river birch. And you see the plots on the right.

The upper plot is from the 30 centimeter value, the lower one from the 70 centimeter value. The red, or maroon, or whatever color line that is, you can see, that is the value for matrix suction in the bare soil.

And then the other three lines represent the matrix suction being provided by these saplings. And they were very young saplings. So you can see, there’s quite a substantial amount of evapotranspiration going on, which would have increased the strength of the soil.

When we did this over a couple of seasons, these are Natasha’s results, we saw that the changes in apparent cohesion, when we added this to the Friedland Equation, got up to about an increase of three to five KPA.
And if we think of the amount of cohesion, say, in a silt or a clay soil, that’s about a hundred percent increase in the amount of strength of that bank, and that’s simply provided by evapotranspiration.

Obviously, this reinforcing effect is greater in the summer, or, let’s say, the dry season, than the wet season. And it’s kind of an interesting analogy that that kind of increase in strength is about the same as the root reinforcement you would get from a five to twelve-year-old tree. So it’s quite significant.

The other kind of process we may want to think about is the effects of vegetation on hydraulics. It alters the boundary layer, it alters the lamina flow, it alters turbulence along the boundary of the channel, and so that turbulence is then dominated by vegetation rather than boundary-induced.

It creates coherent flow structures, and it increases flow resistance, lowers velocities, and therefore lowers sheer stresses, and tends to trap sediment.

It’s an additional component of drag, obviously, similar to what Chris Peterson was talking about, with drag forces in air, water is just another fluid. This is the equation for drag force. And again, the drag coefficient is the key variable in here.

Some of the issues regarding the drag force, as Chris said with regard to air, we have to get a sense of whether we’re looking at individual trees in terms of drag force, or if we have enough trees, say, a forest, that is really like a bulk property of drag force.

This is some research by Heidi Nepf and Vivoni in 2000. And what we’re looking at here are the velocity distributions, whether we have emergent vegetation on the bottom. So this is where the vegetation is coming out of the flow. And you can see that the velocities are very, very low throughout the profile.

And that the major thread of stress or velocity changes with regard to the distance from the bed, relative to whether the vegetation is just submerged, or deeply submerged.

The take home message here is that we look at things like effective stress. If we look at $\tau_{sub-zero}$, which might be the stress being provided by the fluid, the effective stress actually acting on the grain is a function of what we call grain roughness, $M_{sub-g}$, squared, divided by the boundary roughness in general.

So as an example, if we have a roughness of a channel of say, .035, which is fairly typical, if we have a vegetation on that bank, we’re going to be reducing the effective stress acting on those grains by about eighty percent. And that’s huge.

And the way we can look at the effects of this, this is within our bank stability model, this is where we’re looking at the amount of till erosion in a particular meander bend. And in this particular case, we’ve got about seventy-five Pascals of shear operating along this surface of this bank toe.
And we predicted an erosion based on the resistance of those materials of about a meter squared. But if we were to have vegetation, and we look at the effective stress being applied, the effective stress actually operating on the grains goes down to about fifteen Pascals, and greatly reduces the erosion.

So again, this is an effect of the vegetation on surficial processes. This is more of Natasha’s work. We did submerged jet tests on root-permeated soils versus bare soils. And we can see that it doesn’t take a lot of roots. We have the volume of roots on the Y axis there, and the scour volume on the X axis, to create a great increase in the amount of volume that would be, well, actually, a reduction in the amount of material that would be eroded.

So again, the vegetation, the below-ground biomass here, is providing a strengthening influence because it’s providing an increase in the critical sheer stress.

We did some additional tests on rooted and non-rooted blocks that had failed the upper Truckee River in Trout Creek, just over the hill, up there in Lake Tahoe. And if I can point you to that first column of numbers, which critical sheer stress and Pascals, you can see that the non-rooted soils have a critical sheer stress of about an order of magnitude lower than those that are in the rooted soils.

So an important message with regarding the potential for hydraulic erosion. Okay.

**Natasha Bankhead:**

Okay. I’m going on, talking about work that we’ve done on root reinforcement over the years. If we have to calculate root reinforcement within a stream bank, or a levee, or a soil, a slope, we need to know several things.

So if you look at the equation in yellow, this is from Wu Wei-tau, 1979, you can see we need to know the tensile strength of the roots, $C_{sub r}$. And we need to know how many roots are in the soil, and the diameters of those roots. So what is the area of roots crossing a particular sheer surface within a particular slope?

The term in parentheses is related to the angles of the roots, and how they cross the sheer plane. And in general, we can simplify that to be 1.2. So really, we need to know the strength of the roots, and how many there are, and what their diameters are.

So we’ve done a lot of this work over the years. We’ve looked at about twenty to twenty-five riparian species across the United States. We go out and use a root puller. We generally look at the side of a bank where we can see some exposed roots. The roots are still actually attached to the tree.
We will attach the load cell and displacement transducer to each root using a u-bolt. And then we will crank on that root until it breaks, and measure the displacement and calculate the tensile strength of each root, and relate that back to the diameter of each root.

So as I said, we’ve done this with multiple species. Each curve here is a simplification of some of the species we’ve done. This is only about half of the species we have a database for.

The points aren’t on here because it would look very confusing. But for each line, there are between fifty and hundred roots that we’ve cut, that we’ve measured.

As you can see, there are specific differences between the species. And sycamore comes out as being a particularly strong species where we are, in Mississippi.

The grasses actually tend to have slightly stronger tensile strength per unit area for the small roots. But those tensile strengths rapidly decline with bigger grass roots.

But what’s very important here is that the smaller roots actually have a higher tensile strength per unit area. So we can’t just ignore the small roots. If you had a thousand small roots that made up the area of one bigger root, you would actually have a much higher strength.

So potentially, grasses with very high root densities can provide a large in cohesion to the bank of the levee.

Here we’ve got some plots of a number of roots versus that. When we do these studies, we also measure the diameters, the numbers of roots within the different layers, and we separate them out by different root size classes. So we can see how much contribution there is from the different size classes.

This is the same plot, but for grasses. In the previous plot, you would have seen there were maybe in the order of hundreds of roots over the top meter. When it comes to grasses, there can be thousands of roots. And as I said, because these small roots have such high tensile strength, this is very important.

So if we then look at a one-meter high bank, or levee, in this case, it’s made of silt, and it’s fully saturated, without vegetation, you can see the factor of safety is .98. So that bank is failing when no vegetation is added.

And then we simply went through with our model and added different species. And you can see how the factor of safety increases for these different species we’ve added.

On the end we have a mature Oregon Ash that’s a twenty-eight-year-old tree, and you can see the dramatic increase in factor of safety that’s added by this tree.

There are some assumptions with the equation that I showed you in the first slide. The equation of Wu assumes that all the roots are lined perpendicular to the sheer plane.
It assumes that the full tensile strength of the roots is mobilized at the time the soil fails. And it assumes all of the roots are well-anchored and break rather than simply pulling out of the soil. So basically, it assumes that all the roots break at once.

As a replacement for this as part of my PhD work, I put together a progressive root-breaking model. The theory of this comes from the materials industry. There are very simple rules. Basically, an initial load is distributed evenly between the roots. This load is increased until one of the roots breaks.

And then the load that was carried by the broken root is redistributed to the remaining root, and so on, until the whole bundle of roots has failed.

As you can see here, the results of Rip Root Model provide very different estimates from the original Wu Equation. The Wu Equation dramatically over-estimates.

In each case here, we added two hundred roots. The distribution of roots was typical that you would see in the field, so lots of small roots with a few large roots.

You can see the Rip Root estimates are, in general, about a quarter of what the Wu estimates are in this case.

To validate the Rip Root Model, we conducted direct sheer tests in the laboratory. We had ten control samples with no roots, and thirty samples with switch grass roots.

After each sheer test had finished, we would take the sample apart and measure it, and count the number and diameter of those roots, so that we could then use the Rip Root Model to calculate what value of reinforcement it would have predicted.

Here are the results. The orange line shows the predictions from the Wu Equation. The Rip Root Model line is in the burgundy color, and the Sheer Box Tests are in green.

So you can see, the Wu Equation overestimated by six hundred to a hundred percent in these cases. And this is published in Water Resources Research.

So we’re confident going forward that the Rip Root Model provides a more accurate representation of the root reinforcement effect within a sheering soil.

We then added the Rip Root Model to our Bank Stability Model, BSTEM. This is a 2-D wedge and cantilever failure model. It can incorporate tension cracks, there’s a search routine for failures, it included hydraulic toe erosion, increased sheer stress in meanders, as Andrew mentioned, accounts for grain roughness.

We can have complex bank geometries with up to five layers. It handles both the positive and negative pore water pressures, confining force from flow, and we can also include now the vegetation effect through the Rip Root Model.
So here’s a little example of us using the Root Reinforcement Model within the BSTEM. Just click on the button, you add your depth of roots within your bank. You select your species from our drop-down box, you select the plant’s age and the percent contribution to the assemblage.

And then it will tell what the predicted root reinforcement is according to Rip Root, and then it will also provide the Wu Equation, just as a comparison.

So you can add an assemblage of species, you can select different ages, so you can very well represent what is actually on your bank or levee.

We can also use this in a design process. So in this case we have a one-to-one slope. The geometry is stable, but as we increase the height of the water table, we find that this bank is now unstable. We have a factor of safety in the bottom right corner of .67, so that bank is failing.

In this case, we added Black Willow to this bank, and you can see that the bank is still unstable, the value is still less than one. It’s back to safety .81.

So we tried different vegetation. And in this case, if we added River Birch or sycamore, finally, we have a stable bank.

Now, the effective vegetations do vary by age, obviously. Here we did some work where we plotted out occlusion due to roots, and that changes by age for different species. And then we also plotted underneath the factor of safety and how that changes.

And so if you look at the orange line on the bottom, that’s a conditionally stable bank, with a Factor of Safety of 1.3. And if you read across the Y axis, and then down to the X axis, we can predict what age of each individual species is required for a stable bank.

So if you went down and planted Black Willow, for example, that’s the dotted line on the bottom, we can say it might take fifteen or sixteen years before that bank was actually stable.

This is something we can do in the design process to see how long it’s going to take for vegetation to have an effect.

So again, going back to what Andrew talked about, the combined effects, we have mechanical effects, and we have the hydrologic effects.

On the bottom here is a Factor of Safety with no vegetation whatsoever. And then we have the green line with the grass cover, and then the mixed tree cover, as Andrew had shown before.

Here’s the same plot, but we’ve just separated out the mechanical from the hydrologic effects. We can see that they hydrologic effects are dramatically higher than the mechanical effects at certain times of the year.

But sometimes during the wetter period, the hydrologic effects aren’t actually acting at that time. However, the mechanical effects carry the stability through that period. So the Factor of
Safety is still higher for the vegetated banks than the control, even when the hydrologic effects are not effective.

So just, finally, we have done a little work on the Sacramento River and its tributaries. The map on the right shows descent reach failing of the stream banks.

And you can see that there are significant problems on the Sacramento River. There are places where there’s a lot of instability, in particular, places where there is no toe protection in place.

And we did a little modeling study with, or a large modeling study, with the Bank Stability Model. We modeled fifty sites, and we modeled fifty years into the future for each of those sites, to see how much lateral erosion would predicted for the banks, and whether that would impinge upon the current locations of levees.

And in some cases, some of the levees were predicted to be in potential danger under that time frame.

So in conclusion, we know that the interactions between vegetation and levee stability are complex. They involve multiple processes and mechanisms, and they vary spatially and temporally. So there are site-specific differences, specie-specific differences, and differences without the year, and over a range of years.

The hydrologic effects of vegetation can be considerable. They produce by far the greatest reinforcing effects for the soil. But this varies throughout the year, and may not be at maximum when stability is most critical.

Root reinforcement is more constant throughout the year. The roots can provide stability at the times of the year when the Factor of Safety is most critical, and is a more constant reinforcing effect.

As we’ve shown you, all of these factors, all of these processes, can be measured, they can be quantified, they can be modeled. We’ve modeled many of the processes with Rip Root and BSTEM. And other processes can also be modeled, such as we saw earlier with the seepage, and surcharge, and windthrow.

Questions:

**John McMahon:** Thank you, Dr. Bankhead, and Dr. Simon. So, questions for Dr. Bankhead, or Dr. Simon? Okay. I see one question in the back, there.

**Donald Gray:** Donald Gray. You mentioned the main differences and similarities between levees and stream banks. And one of them was in the lateral flow conditions, namely, that you don’t normally get exfiltrating lateral seepage in a stream bank.

However, in places like the bayou stream banks in the Houston area, you get rapid rises and falls of the stream level, you do indeed get exfiltrating flow in stream bank, which is a major cause of stream bank problems.
Andrew Simon: Don, are you talking about water moving from the channel into the bank?

Donald Gray: Yes. The stream flow there is controlled by discharges from dams. And you can have a very sudden increase in the water level in the stream bank, and then just as quickly, it goes down very rapidly, the so-called “Sudden Draw Down Condition.”

And that produces exfiltrating flow, which is what you have in levees, essentially.

Andrew Simon: Right. I think probably the way we should have stated.

Elaine: Andrew, can you approach the mike?

Andrew Simon: I’m sorry. Probably what we should have said is that the process involving piping and the development of that hydraulic grading, that could create hydraulic erosion through that process. Whereas, in the bank, you would get that moving streamward, but you would not necessarily have that process landward, even though that water would be moving through.

John McMahon: One more question for the doctors? Okay. Well, thank you very much.

So our next presenter is Dr. Dirk Van Vuren from UC Davis. And sir, I’m going to load your presentation up as you approach. And off we go. So, Dr. Van Vuren.

Dirk Van Vuren:

Good morning. My talk today is based upon two basic concepts, one is that many species of mammals, a surprisingly large number, excavate underground burrows for various reasons, various uses, and at various times of the year. And some of these species live on levees.

Now, having holes in a levee generally isn’t a good idea. And there are three basic kinds of impacts that mammal burrowing may have on levees. One is that burrows might become conduits for water. Another is that even if they aren’t conduits for water, some of these underground chambers can be relatively large, and as a result they may collapse, compromising the structural integrity of the levee.

And even if neither of those two things happen, all that digging on a levee surface can promote soil erosion that alters the levee profile. Now, the problem we face is little is known about the underground characteristics of mammal burrows.

Here is the burrow entrance to a California ground squirrel burrow. And that’s what we see above ground. Here is an artist’s characterization of what might be going on below ground, kind of a whole town, a whole city going on underground, with branches, and chambers, and multiple entrances, various other species living in there.
And of course, what we don’t want to have happen is animal burrows mostly or partly penetrating a levee.

The second basic premise is that mammals are known in many cases to respond to habitat change. Not all species of mammals do, but many do. So it’s reasonable to suppose that mammals that live on levees might be influenced, in terms of distribution and abundance, by vegetation change on the levee.

So the basic objectives of my talk this morning, one is to summarize what we know about burrow dimensions of certain species of mammals that live on levees, and to determine habitat associations of these species, and the two species I’ll be talking about are the California ground squirrel, very common in California, known to live on levees, and its burrowing is considered a major threat to levee integrity.

Also and including bodice pocket gopher, not widely considered to be a threat to levees in California, however. They are very abundant, including on levees. And they are known for their soil excavating abilities.

Let’s talk a little bit about each of these species, their natural history. The California ground squirrel eats leaves, seeds, and fruits. And it feeds only above ground. They are also only active during the day. And something that is very important about ground squirrels in general, especially the California ground squirrel, is they use vision to detect predators.

In fact, when you see a squirrel, if it’s not running away, they’re often standing up. And what they’re doing is scouting the area for predators, because their whole predator defense is based upon being able to see a predator soon enough to be able to escape into a burrow, and their burrows are very important as and escape from predation.

So they dig these burrows for shelter from rainfall, extreme temperatures, and especially from predators. And these burrows are often used for a long period of time, maybe multiple years, sometimes, decades, in the case of some squirrel species.

Now, what are the habitat relations of California ground squirrels? Actually, never been studied. It’s not known. However, there are a number of anecdotal accounts from the old time naturalists who say things like, “You never see them in dense brush. They avoid dense trees. They like open areas. They like grasslands,” and so forth.

Bodice pocket gopher eats leaves and roots, both the species are primarily herbivores. A big difference between the two is that California ground squirrels feed entirely above ground, bodice pocket gophers feed almost entirely below ground. Basically, they dig to eat.

And so they can be active any time, day or night, but they remain underground to avoid predators. You rarely see them above ground. And the way they access food is by digging tunnels. And what they’re trying to do is get at the roots and tubers of especially green herbaceous vegetation.
And it’s so risky above ground they’ll often pull, you see this in cartoons, they’ll grab the plant from below and pull it underground. But this actually does happen. And again, they burrow primarily to feed, unlike California ground squirrels.

They do, and this is what bodice pocket gopher burrow looks like, a portion of their burrow system is for the same purpose as a California ground squirrel, a living area. But most of their tunnels they did once, exhaust the food, and abandon them.

And those tunnels are often backfilled because dirt deposition is a big problem for gophers. They have to put that dirt somewhere. And so a lot of it goes into backfilling tunnels. But some of it gets pushed out on the ground, as we’ll talk about in just a moment.

Like California ground squirrels, habitat relations actually haven’t been quantitatively studied. They are known to occur in a wide variety of habitats. And the thinking is that probably, it’s where sufficient food is available, is the main determinant of gopher distribution.

And it’s especially important for gophers, because some energetic studies show that it costs roughly a thousand times as much energetically to burrow one meter as it does to walk the same distance on the ground’s surface. So gophers need to encounter food when they’re digging these feeding tunnels to make the burrowing worthwhile.

Okay. We went to the literature to find out what we know about the burrow dimensions of these two species. You know, relatively little is known about mammal burrow dimensions for one reason: it’s a lot of work to dig them up and measure them.

But for California ground squirrels, a number of tunnels have been dug up. Nine to thirteen centimeters in diameter. A little bit bigger than the body size of the species. The length, the mean length of these twenty-eight burrows was seven and a half meters. And the longest one of these that was measured was forty-two meters. You can see there’s a skewed distribution.

And we can take a look at that frequency distribution and, what you can see is, that the means kind of doesn’t mean a whole lot. It’s not very representative, neither is the median, which is four and a half meters.

Really, there’s two points to be drawn from this distribution. One is, a lot of burrows are two, three, four, maybe five meters long. A lot of California ground squirrel burrows aren’t very long, but some can be very long, out to forty-two meters. So the potential for a relatively long burrow is there, although it may not occur very often.

A few people have mapped these burrow systems. Oh, and I also forgot to mention length means total length of all tunnels in the system. And depth is the depth of the nest chamber, if that’s reported by the author, or the deepest point in the burrow system if it’s not.

And burrow depths actually aren’t all that deep. Sixty centimeters is the mean, with a maximum of six feet, you know, a little under two meters. So they aren’t all that deep.
This is really, apparently, a typical configuration for a California ground squirrel burrow. This is a vertical projection, a planned view. Around the margin are meter marks for scale. There are some numbers with arrows in there. Ignore those, that’s where the author put some instrumentation.

But you see two entrances, and a nest chamber. A very common configuration, you know, three, four, five meters long, at the most, but some look like this. This is something like twenty or twenty-five meters long, all the tunnels added up. Thirteen entrances, two, three, maybe four nest chambers. So some of these burrow systems can be relatively complex.

What’s the potential threat of California ground squirrels? Probably piping, but also burrow collapse. You can see in that figure in the lower right, there’s a fairly large nest chamber toward the center of that system, half a meter or so in diameter. And that one could be vulnerable to collapse if it were inside of a levee.

I want to just talk for a minute about ground squirrels in general. We surveyed the literature of all North American ground squirrels, and ground-dwelling squirrels, such as prairie dogs, to try to get an idea of what sorts of factors influence burrow dimensions for squirrels in general.

Soil type, some evidence that the softer soils, burrows are longer, harder soils, they’re shorter. Although a sandy soil becomes too loose, the squirrels can’t construct a burrow at all because it collapses. And in fact, people have found that in very sandy soils, the presence of a clay layer may influence the structure of the burrow system.

In a couple of instances, varied species burrowed down through loose, sandy soil, encountered a clay layer, and then seemingly, preferentially burrowed just underneath that clay layer, with that clay layer serving as a roof for their burrow system.

So the presence of these harder, especially clay, layers when in looser soil, may influence where the burrow is, and perhaps how long it is.

Burrow age is an important one. It’s kind of hard to measure this, because to measure a burrow, you destroy it. But pretty good evidence that the longer a burrow is occupied, the longer it becomes. And a squirrel may dig a burrow, die, and that burrow system is still there, and is a highly desirable habitat.

And so animals, subsequent generations of animals may inhabit that burrow system and enlarge it progressively. Body size, larger species construct longer burrow systems, it makes sense. The underground portion of home range, they require more space.

And then, social behavior, the more social species have longer burrow systems, probably because there are more members of the species living in that system. And in fact, it’s probably a good thing we don’t have prairie dogs living on levees in California because they’re fairly large and highly social, and their burrow systems average two to three times as long as the average for California ground squirrels.
Let’s talk briefly about bodice pocket gophers, diameter, four to six centimeters, just about the same size as their body size. Maximum length of a system that’s been dug up is a hundred and two meters. Most of them are not that long. The depth, they’re typically very shallow because these are mostly feeding tunnels to access the roots of plants. They’re only, you know, probably thirty centimeters or less most of the time in depth.

But what’s important is, all of that digging, the gopher has to have some place to put that earth. Some of it is used to backfill old tunnels. A lot of it is just pushed out onto the ground, like the gopher mounds that many of you are familiar with.

And if you have a dense population of gophers, that can result in quite an extent of soil disturbance. And one study showed that, on average, a quarter of the surface area is disturbed earth. Another study looked at all that churning going on underground, with backfilling and excavating, and all that, and estimated twenty-two cubic meters per hectare of soil was disturbed. And this is by an average population of bodice pocket gophers.

So potential threat to soil erosion, just all that churning and disturbance, may result in erosion that alters the levee profile, and, possibly piping, they can construct long burrows. They’re smaller in diameter than California ground squirrels, and typically backfilled. But still, that possibility is there.

So let’s move to habitat associations. What sorts of habitat conditions or manipulations might alter the distribution or abundance of these species? Our study area was located on levees near Sacramento. We had a basic approach. We surveyed these levees for occurrence of these two species of burrowing mammals. And we used burrows, and number of burrows as indicators of occurrence and abundance.

We’d see ground squirrels from time to time. We didn’t actually count squirrels or gophers. We counted burrows, and used those as indicators of mammal abundance, and then compared occurrence and abundance with associated habitat features.

Our sampling unit was a levee segment, which is just a fifty meter long stretch of a levee, you know, delineated at a perpendicular, so it’s kind of a cross-section of a levee. And we would locate these randomly, use a compass to mark out the access, and then perpendicular lines for flagging.

And then searched the entire levee surface in that segment, toe-to-toe, and count all mammal burrows. Sometimes this is on our hands and knees. We wanted to find all of them.

We then assessed habitat at three basic spatial scales. Our main scale, we called the Macro Habitat Scale, that’s the levee segment itself, across the whole segment. And we wanted to know what vegetation features, or habitat features on the segment influenced the occurrence or abundance of our two mammal species.
And we used a visual, ocular estimate, it’s called, of percent cover. So we kind of stepped back, eyeballed the whole segment, and assigned, you know, percentages to each basic habitat type. It’s a quick approach that’s actually relatively accurate with a little bit of practice.

But we also wanted to know, okay, if we find a burrow on a segment, where is it on that segment in relation to habitat features? So one idea is, is the animal here or not? The other is, if it’s here, where is the burrow in relation to basic habitat features? We called the Micro Habitat Scale.

And we did the same approach, estimating percent cover of various vegetation types within a five-meter radius of the burrow entrance.

And then a third question we had was, okay, do land uses adjacent to the levee influence the occurrence of, actually in this case, just ground squirrels, on the levee segment? And so we estimated the percent cover of adjacent land uses within a seventy-five meter radius of the segment on the land side only.

And seventy-five meter radius, some studies have shown that’s about how far California ground squirrels will forage from their burrow.

Okay. Let’s take a look at some results. We surveyed a total of a hundred and sixty-six segments across twelve levee districts. And there’s actually more segments. We’ve done more for the landscape analysis. That analysis is preliminary. I’ll show you some preliminary results. But mostly, what I’ll be showing you is for the one hundred and sixty-six segments for the Macro and Micro Habitat Analysis.

And we counted thirty-nine thousand burrows, about six thousand ground squirrel burrows, and thirty-three thousand gopher burrows. We thought we would find a species from a variety of mammals. It was just primarily these two species, and then a handful of carnivore burrows, too few to analyze.

Our basic result, let’s start with the Macro Habitat Analysis. Again, this is a levee segment. Now, we intended to treat the levee segment as a unit. But it turns out, on quite a few levees, the habitat on one side is very different from the habitat on the other side. And we didn’t want to mix up those results and obscure some important relationships, so we did separate analyses for each side.

Our first question is, does the species occur or not? One burrow or more means occurrence. No burrows means absence. We used logistic progression. And it turned out we had five basic habitat types, tree cover, is just a percent tree cover, and what we found is there is a negative relationship, meaning the greater the percent of tree cover, the less likely we were to have one or more burrows of California ground squirrels.

A similar relationship on the land and water side. Leaf litter, we also found a negative relationship, and we think the reason for the negative relationship with tree cover is visual occlusion, visual obstruction. It’s thought that California ground squirrels, and ground squirrels in general, because they rely on vision to detect predators, aren’t very happy about being in cluttered habitats where predators could be hiding in the branches, or behind the trunks, or whatever.
The negative relationship with leaf litter probably is because leaf litter is associated with tree cover. So, you know, they’re not independent variables. But we suspect that leaf litter may have something of an independent effect on its own, because leaf litter we encountered was very compacted, and may be difficult to burrow in. Also, it’s noisy when the squirrels are running around on it, and possibly, they’re avoiding the substrate because it may attract the attention of predators.

Our three other basic habitat variables, shrub, grassland, and barren, found no relationship with squirrels. Now, we wanted to do the same analysis with bodice pocket gophers, presence/absence, logistic progression. We couldn’t, because bodice pocket gophers were found on almost every one of the 166 levee segments. You have to have some where they’re absent in order to do the comparison.

We did a second analysis, using ranked correlation. Again, at the Macro Habitat Scale, to determine if abundance, as indicated by number of burrows. So the logistic progression analysis was one or more burrows compared with no burrows.

In this analysis we’re actually counting the number of burrows, which for California ground squirrels could be as high as fifty or a hundred. And with gophers, you know, a lot more than that on some segments.

You know, same sorts of variables, with California ground squirrels, again, a significant relationship for tree cover on the land said, but not on the water side. We don’t know why that’s so. The same relationship, again, with leaf litter, as well. And shrubs, no relationship, but shrubs on the water side, we had a positive relationship, so the greater the shrub cover, the more the burrows.

And this is a little surprising because shrubs are woody vegetation that can provide visual occlusion. We can think of two reasons. One is, some of these shrubs provide foods that squirrels may find attractive, and may be worth the predation risk, like blackberries.

But also, we found one study, based upon a ground squirrel that lives in Idaho, the Great Basin ground squirrel, that found some evidence that it’s not just shrubs, but shrub configuration, and that some shrubs may be low enough to provide the visually unobstructed view, but also be something the squirrel can dive into to deter a predator attack.

So shrubs under some circumstances, in our results, and the results from Idaho, may be an attractive habitat component for squirrels.

Grassland, positive relationship on one side of the levee, but not the other. It’s an open habitat and provides a good food source. They eat mostly herbaceous vegetation. And no relationship with barren habitat.

With gophers, the same analysis, with gophers, we’ve got a negative relationship for trees and leaf litter on both sides of the levee, just like California ground squirrels, but we think for a very different reason. Gophers do not use vision to detect predators. They’re underground almost all the time.
So why are they avoiding habitats with leaf litter and trees? We think the reason is food availability. Trees shade the ground, decreasing the density of herbaceous vegetation. And leaf litter itself is very alylopathic. It can prevent germination of herbaceous vegetation. So we think the reason that gophers are less abundant in areas with lots of trees is, there’s no herbaceous vegetation in the understory for food, or very little of it.

Mixed results with shrub cover. Grassland, we have a positive relationship, and we there because food is so important for gopher burrowing. They eat herbaceous vegetation, and grassland is where that’s most abundant.

At the Micro Habitat Scale, again, we’re asking, okay, where is the burrow opening on the levee in relation to habitat characteristics? First, this is the average across all these five-meter diameter circles. Okay, great. But what we really wanted to do was compare that to what’s available on the levee segment, to get at choice.

And we got that availability from our Macro Habitat Scale analysis, so we have a notion of what’s available on the segment, and we can average that and do what’s often called a use versus availability analysis. And the data we just saw are under that use column. And the availability data are the average across all 166 segments, across the entire segment.

And you can divide the two and get what’s called a Preference Index. And the idea is, if squirrels or gophers are locating their burrows at random, making no choice, then use and availability ought to about match. So you ought to have about a one-to-one ratio.

If your ratio is much greater than one, then that indicates preference, that the animal is seeking out that habitat element. If it’s much less than one, then that suggests avoidance, the animal is avoiding that habitat element.

And we did this in two layers because the percentages for this comparison have to total to one hundred. So we had a canopy layer, which is at the bottom, and the ground layer, which we’ll take a look at first. So tree bowl is what we have at the ground layer.

What we find is that squirrels seem to be avoiding tree bowls as places to locate their burrows, and leaf litter, and showing some preferences for shrubs. Again, we’ve seen kind of a mixed role of shrubs in habitat selection by ground squirrels elsewhere. And a preference for barren areas, presumably because of greater visibility.

At the canopy level, avoidance, and here, it’s the vertical projection of the shadow that will be cast by that tree at noon, is how we estimated this. So there’s tree cover and everything else, which we call open. And again, avoidance of tree cover, kind of pretty close to one-to-one for open areas.

For gophers, again, the same sort of comparison, and fairly similar results, avoiding tree bowls and leaf litter as locations for constructing the burrow entrance. And pretty close to one-to-
one for shrub, grassland, and barren. At the canopy level, avoidance of tree cover, and a little bit of evidence of preference for open areas.

And then, finally, let’s take a look at the habitat associations at the landscape level. These are preliminary results. And here it’s only squirrels. And we’ll take a look first at occurrence, so logistic progression. Nut crops, worked for primarily walnuts, but some almonds. Not strongly a positive relationship, so if there’s a nut crop within seventy-five meters over here, there’s more likely to be one or more ground squirrel burrows on the levee here.

Fruit crop, no significant relationship, or annual crops, or rice. Uncultivated showed a negative relationship, which is a little bit surprising, except that several of those segments which we put in uncultivated were wetlands. And water is a barrier for squirrels. So we’re going to rethink some of these categories, and then redo the analyses.

But so far it looks like, presence of nut crops, especially walnuts, results in a greater likelihood of squirrel burrows on the levee. And the same with the Correlation Analysis, again, squirrels only, and on the land side, the same relationship.

So to summarize, squirrel can dig burrows long enough to pass partly, or even completely through a levee. They usually don’t dig burrows that long, but they have the potential to do so. Gopher burrowing can result in displacement of large volumes of soil, potentially increasing the rate of erosion of the levee surface.

And our basic Macro Habitat findings, that decreased covers of trees and leaf litter was associated with increased occurrence and abundance of squirrels and an increased abundance of gophers. As you recall, we couldn’t do the occurrence analysis.

In terms of the Micro Habitat Scale, when locating the openings of their burrows, both species avoided trees and leaf litters, and generally preferred more open habitats.

And at the Landscape Scale, nut crops, especially walnuts, adjacent to the levee were associated with a greater likelihood of occurrence and greater abundance of squirrels on the levee.

And finally, conversion of tree-covered habitats to grassland should increase habitat quality for both squirrels and gophers. And with that, I thank you. I would be happy to take questions.

Questions:

**John McMahon:** Thank you. So, questions? Yes, ma’am, on my left, your right.

**Female Voice:** How did you define shrub? Was it by stature or by species? In other words, would a small willow be a shrub, or would it be a tree in your analysis?

**Dirk Van Vuren:** That’s actually a good question. And I believe it was primarily by stature. I think we went a meter and a half or two meters, something like that.

**John McMahon:** Yes, sir?
**Male Voice:** Thank you very much. That was very interesting. One of the observations last year along the Missouri was that the wetted back slope of the levees had a tendency to move the badgers up the slope.

So we used burrowing as an indicator of how the wetted zone was. Did you find any correlations in your study to previous events of that possible behavior?

**Dirk Van Vuren:** No, I don’t think we did, but that’s a very interesting observation. You mentioned badgers. And badgers occur in California. And we were kind of hoping we would see some badger burrowing in our surveys, but never did.

Badgers feed by digging out ground squirrels and gophers. And so their excavations are probably an indicator of where the ground squirrels and gophers are on the levee.

**John McMahon:** There’s another question here in the front. And this will be the last question.

**Male Voice:** Dirk, when you were doing your overview initially, you talked the depth of the ground squirrel holes being about 1.7 meters deep at maximum. Was that only flatlands? And how might it change when they start digging into levees?

Do they just go along the slope of the levee? Or do they dig back into the levee?

**Dirk Van Vuren:** That’s a really good question. And it’s always difficult in interpreting literature, because some people measure perpendicular to the surface, and some people measure vertically from the surface.

And actually, there was a paper done trying to get at that notion of burrows in an embankment. So that’s not the answer to your question. The answer to your question is, well, the first answer is, it varies in how these studies measured that distance.

In answer to your second question, what is the configuration of burrows? I think that typically, when it’s on level ground, there’s a steeper angle down, and then that angle eases up. But when it’s in a levee face, there’s much less of an angle initially. And then the burrow levels out.

And so I think that’s the major effect. And I should mention that I had thought that there would be a thermal protection reason for a deeper burrow in hot climates or cold climates. You know, the deeper you go, the more thermal protection.

It turns out that’s not the case. And the reason appears to be that it only takes thirty or forty centimeters, about a foot or a little more, of soil, for a squirrel or burrowing animal to gain all the thermal protection it’s going to get from that layer of soil. Burrowing deeper does no good.

**John McMahon:** Well, Dr. Van Vuren, thank you very much.
So our next presenter is Dr. Gerald Bawden, who is with the USGS. And sir, are you going to load, or do want me to?

Gerald Bawden:

Unfortunately, my files are too large to fit on a PowerPoint. So I had to switch to a different media. This is close to a four-gigabyte presentation that I’ve actually had to break up into a couple of different.

I’m going to go fairly fast here, and would like to ask to have the lights dimmed, and the back door closed. These 3-D glasses were handed out. And what I’d like you to do is fold them so that the red is on the left, opposite of our political system.

And whenever you see a logo up on the screen where you’ve got the 3-D glasses there, that image will be in 3-D. I’ve got about four or five animations. Most of them are in 3-D. With some of them, the color may or may not come through, it’s all depending on how dark we’re able to get the room.

Somehow, I only have twenty minutes for the presentation. Peter said that he would allow me another five minutes. I was on the organizing committee, and somehow I must have been playing Angry Birds or something during the time that we were talking about presentation length.

I’m going to be skipping over a lot of details with this, just so that we can go ahead and touch on some of the points, and how we used the ground-based LIDAR for doing a lot of the studies here in Sacramento.

I did a lot of working with Alison, Professor Berry, and Shih-Ming Chung, who gave the presentation yesterday. I worked with Dr. Les Harder with some of the slurry wall that we’ll see this in more detail coming up soon.

Some seepage experiments, I worked with two of those. You can see the people associated with them below. I worked with Allison, West Sacramento Project, another seepage test, a lot of visualization we’re using. I’m an associate researcher at the University of California at Davis, and they’ve got the KeckCAVES. It’s a million-dollar facility to go ahead and do visualization for the sciences.

And I’m part of that team, and we’ve developed a lot of the software which we’re going to be using today.

So that’s on the tree root side. I’m following Professor Van Vuren with looking at the mammal burrows. Some of the questions were how deep do they go in. What we’ve done is, we’ve filled them with grout. We’ve used a couple of different kinds of grout.
The green that you’re seeing here is a traditional concrete grout. The other is a polyurethane grout that’s injected through rods, five-foot-long, pounded in. On a grid, part of the study was to assess how well each of the different types of grouts filled in.

And so the image on the right is a 3-D image that you’re able to go ahead and see what some of this looks like. My animations go into this in more detail. And with this we’ve got two different sites we’re going to look at. One is Cash Creek, California, which is the one that is in 3-D. And the other one is the RD 1500 site, which are the two images on the left, the ones with Diego and Michelle frantically digging out a mammal burrow.

So with ground-based LIDAR, how does this work? Over the course of this project, we’ve used a number of different scanners. The first one used, here in the lower right, this one, and the upper right, are both Optec Laser Scanners.

And the concept is relatively easy. We shoot out a laser light. And I’ll use this right here as an example. And it basically shoots a horizontal light out. It goes to one end, it goes up gear notch, and heads over. We know the speed of light, we know how long it takes it takes it to leave the instrument, out to the ground and back. Therefore, we have a distance.

It fires out on a grid, therefore we have all the angles. And so with a matter of minutes and hours, what we’re able to do is go ahead and scan the landscape and construct a complete three-dimensional image of whatever our target is.

The other two scanners that have here, this is a Leica scanner, courtesy of Navco. And this is a brand new scanner that I bought a short time ago. All of these have a 360 degree rotation, where it kind of goes over like this, and then it slowly rotates around. So you’re able to get a 360 degree above and below, and all around.

The strengths of those is a very high-level density, in close, but the distance, the maximum distances are on the order of fifty meters. The first two instruments that I showed, the Optex, I’ve gotten out well over a kilometer with those instruments.

So with these particular projects, what we want to do is look and image below the land surface. For the mammal burrows, we injected the grouts. And for the tree roots, what we need to do is basically, is what Alison and Shih-Ming showed yesterday, using an air knife and slowly excavate off the soil.

And so what we did, is we came in, scanned it before we had any of the excavations. We were able to get kind of the base line level of the levee. And we established a reference frame. And it’s all depending on what instrument we’re using. Some of the reference frame were like these spheres, in the upper left hand corner there, you can see some white spheres.

This is the Cal Expo Site, where we’ve got a variety of different spheres, including the one in back, which is large on that we used for long-range scanning. For the Twitchell Island site, we just put magnets on the trees and we were able to go in from there.
And this is the RD 1500 site in the lower right. That’s PVC pipe. The laser is very sensitive, it’s an infrared laser. It’s sensitive to PVC pipe. I get a very positive return from it. And so what I’m able to do, then, is the diameter of the PVC, get a best-fit sphere to that, no, sorry, cylinder to that, the center of the cylinder is a vector. Where two vectors cross-sect, you’ve got a unique point.

So I can see the top of this PVC pipe cross from anywhere study area, and I always know that it’s in the exact same area. Until a loader dumps a bunch of soil on this point down on the lower right hand corner. We completely lost that, but that’s why we have redundancy.

And so you go out, you collect a bunch of data. This was using the new post-range scanner, where it scans about a million points per second. Here, each one of the different colors that we’re seeing up there is a different laser scan setup.

Here are fifteen setups, with just over five hundred million data points. For this project we have nine hundred and eight-seven million, so basically, one billion data points that we’re using to analyze this.

How does this translate into advancing our science? On some of the mammal burrows, we have .1 to .2 millimeter spot spacing on the mammal burrows, which equates out to, what, sixty-two thousand points per square meter. So there’s a lot of data.

So once we scan it, we go in and align it. With the new scanner, we have the ability, we’ve got an onboard camera, to where we’re able to go ahead and uniquely coregister the images with it. So each data point now has an x, y, z, as well as an intensity, which the infrared laser return, as well as an RGB. So this is remote sensing. We’ve got a lot of extra information within here.

So once the data are aligned, using the number of different approaches, then what we’re able to do is go ahead and work with it and visualize it.

This will be a 3-D animation at the Twitchell Island site, what Michelle Shriro showed yesterday, with a couple of small little exceptions. One, the colorized data points represent the land surface, or some of the blue on the trees that we’re off to the side, that’s basically where the pixels were a little too small and we just have sky points.

The white that we’re seeing is the original position of the tree before it fell over. So we’re actually going to be looking at time series here. So go ahead and put on the 3-D glasses, we will work our way through this animation.

Fairly soon you’ll be able to see the trench coming right up through the center. This is some of our reference frames, which I have not yet deleted from this data set.

So the end of the trench’s process is the control. And this is, coming up, the oak tree that we were observing. It’s on the left. And the one that fell over is ultimately on the right.

And you can see the one that we’re observing, we have reference, two spears on it.
Now, to show you kind of the high-quality resolution that we have, there’s a number of new fractures that formed in the levee, and we’re able to go ahead and zoom in tight. And so those cracks that we’re seeing right through there are newly-formed fractures.

Now, I was able to do something that was not possible when we were out there, due to environmental issues. I went through with a digital chain saw and chopped down all the elderberry bushes, which are an endangered species.

So I could do that in the virtual world. And it worked quite well. And so now, what Michelle had wanted to do, is do this, and also get rid of the poison oak that was out there.

The white that we’re seeing right through here is the original position of the tree just before the experiment started. And the color off here, is where the tree fell over during the experiments.

We’ll go ahead and move forward with that. There’s tripod legs, on my tripod at one time. These spheres here have a diameter of approximately ten centimeters, four inches.

Now, there were a number of cracks and fractures that formed. And this location right down here, this hole here is where one of the [besiometers] were, I believe. And you’ve got cracks coming through here that opened up during the course of the experiment. And this is some of the measuring sticks, they stuck out to help keep track of it.

And now we’ll end looking at it from the exact other side. So the angles that Michelle were showing yesterday, here’s the original tree position right through here, and then this is where it’s been tilted off to the side, where some of the major branches are now supporting it under water.

Okay. Go ahead and take off the glasses. And these are some photographs of things that we saw. In the upper left hand corner is where we had the instrument that was placed in. You can see some of the crack measurements. In the lower left hand corner, those were just the small fractures that were opening up just on the top of the roadway.

But not all the fractures were new. You can see where my foot is in the lower right. That’s grass that had grown into one of the fractures that had been reactivated.

A lot of what I do, my background is actually, real quick, geophysics, and I look at very subtle changes. And so what we’ve done here, is we’ve precisely aligned the very first scan on April 19th with the last set of scans on June 6th, and then did a difference of them. And sort of what we’re doing is, we’re looking at difference of plus or minus centimeters, we’ll say two inches.

And if we note, yesterday Michelle showed that there was actually a crack between, right through here in which she saw vertical motion. Guess what? We see that, as well. This side over here dropped down, she said three-eighths of an inch, which is .95 centimeters. I have approximately one centimeter down. So we completely agree.
However, she’s only doing point measurement here. I’m actually doing it over a much larger area. The uplift that we’re seeing over here is from, they basically pushed dirt, from the construction, they just made piles in off to the side.

So we’ve got very detailed sub-centimeter change detection that we’re able to do with this technology.

The other thing that Michelle asked was, she’s doing some wind modeling with it, and she wanted to know what the cross-sectional area, both [Matthew’s] cross-section. So this is looking straight down on the landward tree, where you’ve got the top of the levee, these dotted lines above, and then below, and the larger outline is actually that of the tree surface projected down to the ground, and you also have the tree trunk.

And if we take a closer look, what we’re able to do is model the outmost foliage, created a wire mesh to it, and then calculated the centroid. So now what we’re able to do is find out where it’s moment of inertia is for the wind modeling.

And so we’re able to look at that both in a number of different angles, we’re able to look at maximum height, the 3-D centroid is off on the left, here. And you can actually see that due to the tilt in the tree that the centroid is actually offset from the tree trunk itself.

I’m going to switch gears now to look at the pocket levee, this initial project that Professor Barry and Xu-Ming showed yesterday. The upper image shows what it looked like before any excavation. We have the two oak trees in the center. We’ve got a cottonwood off to the right, and there’s another cottonwood out of sight to the left.

So our work flow here was fairly simple. We did a prescan before all the excavation started. And then at a number increments throughout the excavation, we came out and rescanned.

The technology is very much like taking in a floodlight. If I shine the floodlight right now in the audience, you’re going to cast shadows from the base of your bodies. Or if I do it here with my podium, I’ve got a microphone that’s going to cast a shadow here.

So what I have to do is come at it from another angle, and rescan to go ahead and fill in those shadows. So we used on average eight to ten angles around here, just to make sure that we were able to minimize as many shadows as possible.

So they would do their work, they’d end midday, we’d come scan the afternoon, they’d begin work the following day.

And here’s a non-3-D animation. We’ll kind of show you what the raw data looks like. This is just a number of scans that we did. We have the initial pre-scan that’s included in here, where you’ve got the tree, the extent of the tree.
And I’m going to come in with a digital saw and change things. Now we chopped down the tree. The black lines are showing Allison’s grid and what she’s worked with. It was a windy day, so we’re see those changes in the position of the screen throughout the day.

You can clearly see the trunk of the tree. You can see the branches coming down. We’re also imaging the land surface. So ground-based LIDAR is not a ground-penetrating technology. We image the land surface, and then we are able to go through and strip off stuff.

So what we’ve done now, is we are flying up through the trunk of the tree, where I think the diameter is just over ten centimeters.

So that gives you a sense of what the raw data looks like, or basically, once we have process, everything is aligned. Then what we do is, we go into the University of California at Davis, the KeckCAVES.

They’ve got a facility, you can see what it looks like through here, in which we’re able to go ahead and truly visualize the data in three dimensions.

And this is us working with the data. You put the goggles on. And what I do is, go in there, isolate all the mammals burrows or tree roots, and then ultimately save them off so that we can go ahead and do some analysis.

So like, if you go ahead and put the glasses on. And we’re going to take a look at a tree that was not on top of a levee, although it may look like it’s on top of the levee. I took the artistic license to show, this was one of our first trees that we excavated just south of the University of California at Davis on flat land.

The data points that we’re seeing off on the left are the levee surface out at the pocket. But again, this tree was just used to kind of show as a control tree, and what a typical one looks like.

The top of the tree is going back, and bottom of the tree is coming up towards you. And we’ll have a chance to look at the radial and distribution of these particular tree roots.

So now we’re looking straight up the trunk. And I’m going to slide off, and I’m going to get out that digital chain saw again. This is the exact same tree, where I chopped the top off.

And a couple of patterns that I’d like to point out. Notice that for the most part, all the roots are heading out uniformly, just kind of like the spokes on a wheel. We’re not seeing any dominant roots or great taper heading off in any particular direction.

Now I’m going to switch modes with the visualizations that we’re looking at as more of a surface map. And we’re going to fly down and take a look at the tree roots down on the two trees that Allison showed yesterday.

So the small black points that we’re possibly seeing in the background are a down-sampled levee.
I’m going to go ahead and pause here for a moment.

Just looking straight down, this is parallel to the levee surface, so this is the greatest slope through here, very thick roots that tend to be more parallel to levee and less so perpendicular.

Now we’ll go ahead and look at it from the edge, where it appeared from the side profile, down to a depth of about twenty centimeters is where, at least for this Valley Oak tree, on the uphill side, the roots did not penetrate down and into the levee, it stayed relatively shallow.

Now I’m going to go ahead and change colors on this, where the blue and the red are the Valley Oak. And the yellow is a cottonwood, actually two different cottonwood roots that went through it.

So now we’re looking at the particular tree, we’ve got, as Allison pointed out, these trees tended to have larger, I guess, tap roots, or pseudo tap roots, much larger than what we saw in a complete flatland environment.

The red that’s coming in on the left is the other oak that we excavated. The root pattern is different because it’s actually further downslope from the initial one. The other one is about a meter and a half closer to the steep part of the levee, of which the root pattern is different.

Now we’re going to rotate around. And again, the yellow is the cottonwood. And that was one that we’re going to talk about more in detail.

Earlier on, the initial use for this was actually to quantify. They were going to use the Polhemus data. And so the Polhemus sphere is in yellow. And the red is the LIDAR. And for the most part, we had reasonable fit.

But there was some warping of the data, especially in the northern quadrant, where you could see through here, where the yellow Polhemus is inside the actual root, versus what we measured with the Ground-based LIDAR.

Go ahead and compare the two. The Ground-based LIDAR, the data density, the number of scientific questions, the biometric parameters that we were able extract from here, are significantly higher with the Ground-based LIDAR that what we would ever get from the Polhemus data.

For example, one of the things that Germaine talked about yesterday was vectorization. We developed an approach that’s typical used in industry to go ahead and map pipes, to go ahead and use this for mapping the center of the roots.

And so with it we’re able to find the mathematical center of the data set, and be able to define the roots. And then from there, you’re able to go ahead and categorize them by branching, or anything else.
There's a lot that we can go ahead and do with this data, from the biomorphic characterization. We have GPS data, so we actually know what the relationship of this data set is with respect to the sun. So the solar activity, I think that was a question that was brought up yesterday, really look at the taper, the length as a function of diameter, branching, all sorts of things, a number of which Xu-Ming is doing right now.

What I’d like to do is go ahead and have you put the 3-D glasses back on. This is not an animation yet. But what we found here is that the cottonwood roots coming through here, the one coming in from the right was from a tree off to the right, and then this one on the left was a cottonwood tree that’s behind my shoulder maybe about fifteen meters.

And so Les went through and wanted to find out, what was the impact of this cottonwood. So now we’re going to go ahead and take a look at a new animation.

Up in the front, these are the two oak trees that we were just looking at. And all the yellow are from the cottonwood. Again, free roots from different cottonwoods that came up and over. This happened to be one that’s forty-five meters off to the south from here, that ended up coming up through the oak trees, then up to and penetrating through the slurry wall.

So now what we’re looking at is the complete three dimensional relationship of the tree roots with respect to the slurry wall. And the light points that you’re seeing in front of your eyes are from the levee surface. This is a ground squirrel hole. This ground squirrel preferred the slurry wall over the sandy soils on the side, much more rigid and, I guess, sturdy house.

Looking straight down, you’re going to be able to go ahead and see the different penetrations where the roots come up. Some of the roots do not penetrate. Others cross through, up, and over.

Now we’re looking down inside the slurry wall, where you can see the white right here, is the ground squirrel wall, where it was inside the wall.

And I think Les was maybe drunk when he decided, “Let’s go ahead and follow some of these roots on the other side.” And he followed one of the roots a good distance down the levee and found where it penetrated.

That’s the root that’s outside under the poster, that has a bow on it. I think I’ll let Les describe more about that, instead of taking his thunder.

But these are the root systems in 3-D.

Now we’re looking at the end of the roots. We go on. We also worked at Cal Expo, where we developed a new way of identifying different soil horizons by using infrared bright paint. So the blue that we’re seeing here are the soil horizons. The green is the tree trunk, and the yellow is the mammal burrows.

So speaking of mammal burrows, I’m going to have to switch over to the other presentation. And we’ll quickly touch on some of the mammal burrow work.
Here the site is RD 1500. A lot of ground squirrel production. In fact, if you look right under the instrument, we have these two very large mammal burrows, we also have some gopher tracks over here.

And this is one of the 3-D scans. What we did is, we took spray paint and spray painted the different grout types, one green and the other one magenta. And from that, we were able to go ahead and isolate that in the Ground-based LIDAR.

So here is one of the mammal burrows on the water side. And this is what it looked like from the side. So this is one of those really large entrances. And here’s what it looks like in Ground-based LIDAR.

So what we’re able to do is see the land surface, and then all the other features in and around it. We’re able to calculate its length going back, or its depth below the surface.

So go ahead and put on the 3-D glasses. We’re going to do another animation, where we’re looking at this complex.

There are a number of things that we found with this that 3-D allowed. One of the things I found was a number of different particular layers, preferred depths in which we’re seeing that they’re burrowing.

So we’ve got a lower layer here. There’s a platform through here, a mid-level one. And there are a number of entrances that relatively go down fairly steep, and then they come to a platform. And then they start branching out from those platforms.

The pipes and the rods that we’re seeing here are the injection pipes for the polyurethane grout. So now we’re flying over, start looking at a lot of the complexity that we have with this. Some of the grouting, the traditional grout, again, was green, and then the polyurethane was magenta.

Here is some of the spray paint that we used. Some of the magenta filled in some of the air gaps that were just above the burrow holes from the regular grout. And others actually filled in possibly collapsed chambers.

Now you’re able to start seeing some of the different layering that we have, and different runs.

This right here is an entrance that goes down at a fairly steep angle, and then it takes an 180 degree turn and heads back. And we’ll go ahead and end up with this particular animation, looking at that one mammal burrow that goes fairly far back. I think it’s five to seven meters back from the surface.

And now we’re able to see it with respect to the actual levee surface itself.
Just a simple screen shot, very complex tunnel networking, and again, this is some of the layering that I talked about, where there’s definitely preferred horizons. I’m sure it’s likely associated with the soils.

The other site we did is Cash Creek, and it’s a much lower levee surface. And what we were able to do is actually colorize with depth below the levee surface. This is doing a vertical measurement, straight down, kind of like taking a plumb bob versus what the length is in from the side.

And so we’ve got zero to a hundred and ten centimeters, or in the yellow, you can see, approximately where the feet depth is.

One thing to really point out here is that there is a mammal burrow, a depth of about forty centimeters, or I guess, eighteen, twenty inches, that goes from, this is the land side, over to the water side, clearly, penetrating the levee all the way through.

And this is just a zoomed-in one. You can see down low, we have penetrations well over a meter below the levee surface.

So this is another 3-D animation. It may or may not work well because the colors, this one also works fine without the glasses on. What we’re doing is, we’re just quickly going to fly through, take a look at a number of the features. This is one of the entrances from the landward side. There’s an orchard right behind us.

Another entrance up on the levee itself.

And now you can start getting a sense for how the penetration is going, what the angles are with respect to both the surface, and also with the horizon, or horizontal.

We’ve got a mammal burrow entrance right here that drops down fairly steep.

I know I’m pushing my time a bit.

This is a fairly large stand at depth, that’s probably about three-quarters of a meter. We’re approaching over two meters deep for some of the larger burrows.

And now we’re going to be able to take a look, and hopefully we’re going to be able to see some of the, again, at this site here, we’re also having some preferred depths beneath the levee surface, in which we’re seeing the tunneling and the burrowing. And we’ll also be able to see that burrow that heads all the way across the levee from one side to the next side.

There’s definitely a higher concentration of mammal burrows on the land side versus the water side at this particular location. But there is an orchard on the land side.

So now we’re looking up under the ground. The lines above are the levee surface. And that’s the tunnel that’s transcending, going fully across the levee.
And I’m going to go ahead and pause it here, just for the sake of time, as soon as we end up right here.

So like the RD 1500 site, there’s definitely complex burrowing, tunnels come off. Here they’re taking off 120 degrees, and you’ve got right angles.

So one of the things we wanted to do is calculate what’s the volume of material that was removed from it? And so like we did with the trees, we went through and vectorized the mammal burrows. We did it for the polyurethane versus the concrete-based grout.

And from it, we were able to go ahead and calculate the length. So with the traditional grout we had 260.5 feet, or close to 80 meters. And a very similar length, but a little bit less, with the injected grout.

One of the big issues with the injected grout is that it collapsed with time. It shrank. It’s a water base. And so it goes in, it fills it up, and then it collapses down. So if we’re trying to just directly measure the volume of that, it’s not possible.

So what we ended up doing is taking roughly a two-foot-long section. And where we had a hundred and thirty thousand data points, which works out to about five thousand data points per linear inch of this mammal burrow, we turned it into a wire mesh.

By the way, that’s a lot of data. And it’s too much to actually do a volume calculation on, so we dumbed it down, then we dumbed it down, then we dumbed it down, until we ended up coming up with approximately 3,500 point vertices. And then from that we were able to go ahead and calculate the volume for that one section.

And since we knew what the length was, we were able to go ahead and extrapolate that out to the full area. So the traditional grout type was roughly fifteen, sixteen cubic feet worth of material, or void space that that occupied. And with the injected grout, approximately thirteen cubic feet of material there.

And this is just of the linear tunnels. You have the dens, of which we did not include in this particular process. We started a method where we’re trying fitting spheres to it, but it did not work.

So this issue is something, as we know, across the country. And with that, I’ll take questions. Thank you.

**Questions:**

**John McMahon:** So, questions. That’s a statement, not a question. Yes, sir, right here in the near front.

**Male Voice:** Well, I’ll just say, “Wow,” for everybody, because that was very awesome.

**Gerald Bawden:** Thank you.
Male Voice: The question I have is, on the Cash Creek, I’m just curious how wide that levee is, and if you guys had difficulty finding the burrow that went all the way across, or it just happened to be?

Gerald Bawden: Okay. I’ve got the first part of your question as basically, how wide the levee is. And I think that the levee is about two meters wide at the top, and probably about two meters tall.

Compared to RD 1500, which is a real California levee, this is a much smaller one.

And the second question?

Male Voice: Was it just random that you happened to find one that went all the way across, or did you have to search for it?

Gerald Bawden: We actually had scoped out another location, and spent a fair amount of time further up. And then there was a nesting hawk that basically, meant that we couldn’t be there.

And so we ended up just randomly choosing this spot within a day or so, doing quick reconnaissance, so this was just a blind test. We had no idea what we were going to find. But we had all of the equipment lined up to survey. So this was a true blind test.

John McMahon: Okay. A question in the back to my right. Yes, sir.

Male Voice: Yes. I was wondering if you know these sites you selected compare to sites throughout the region. Are these representative? Or something of an exceptional case?

Gerald Bawden: If I understand your question right, are these sites representative throughout the region? I’m not the expert with that. I’m the technology guy. But we can say with the Cash Creek, that was just a randomly chosen site.

And the RD 1500 happened to be really close to the reclamation district’s office. So it was a very convenient spot to work.

Peter Buck: This is Peter Buck. I just wanted to make a comment that Diego Cobos is actually going to be giving a presentation after lunch, which will describe the methods that he used that were presented here, some of the images that were presented here today.

So I believe that’s at 1:40.

John McMahon: That was the original schedule. One more question before lunch. All right, on the front here.

Male Voice: Thank you very much. That definitely had a “Wow” factor. Have you done the same kind of investigation for larger burrowing mammals, like beaver or nutria? Especially the
nutria, which we find in the Northwest, seem to burrow right at the normal water surface, and burrow into the levee and then up into elevated caverns and stuff like that.

**Gerald Bawden:** That sounds like an excellent research project. I basically have developed the technique and approach here, and would love to collaborate. Let’s talk afterwards.

**John McMahon:** Well, thank you very much, Dr. Bawden.

So I’m going to invite Gary Estes to come forward and issue some instructions with respect to the disposition of the glasses. And then we’ll break for lunch. We’ll take an hour. And we’ll reconvene at 1:20. Gary.

**Gary Estes:** Just leave your glasses on the table, and remind people who are doing continuing education units for ISA and SAF, you need to sign in today. That’s all. Thank you. Do you want to give instructions about where to go for food?

**John McMahon:** Yeah. So the food is, as was yesterday, it’s behind me, as I stand on the podium here, or the dais. And so around to the left, around to the right, out the back door. Enjoy.

**John McMahon:** One of the things that, you know, has come up as yesterday and today have unfolded is, clarifying some things. And I want to ask Mr. Joe Countryman to make a clarifying statement regarding something that might have been misheard, or whatever. Mr. Countryman, Joe, thank you.

**Joe Countryman:** Yes. We got a comment that I had indicated that the current decertification for PL8499, that the state has received was based on vegetation. And I don’t believe I said that, but if I did, I apologize.

The current decertification was based on encroachments. But at the same time, the Corps has indicated that the slack that has been given on the vegetation on the levees was no longer going to be allowed.

And so all the levees that had vegetation on them in future were going to be found to be decertified. And the point that I was addressing, not the fact that the 17 current ones had some encroachments, but that the future, that the vegetation was going to exclude the levees from PL8499 rehabilitation. So that’s the clarification.

**John McMahon:** Thank you for that clarification.