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Keynote

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What I'm going to talk about in the 30 minutes that I have is to look at what are some of the key challenges for water and food security; I'm going to look at what evidence we have on the relationship between water resources and economic growth, which is surprisingly little as you'll see. I'm going to very briefly describe a scenario modeling methodology that we use at IFPRE to look at the longer run in terms of water resources, food security, and climate change, and other aspects. I'll present a few, sort of the baseline or business as usual results from that analysis. Then I'm going to introduce what we think are the key water policies, technologies, and investments that could really shift those kinds of trendlines and potentially make things better in the future. I'll describe those in just a bit of detail, then I'll put together an alternative scenario to that baseline in which we basically asked the question, can sort of plausible improvements in those policies, technologies, and investments actually make a difference for water and food security. Then I'll end with just a few conclusions.

So what's going to be influencing food security and water in the long run? We generally look out as far as 2050 on our own results, and this shows some results even further out. Look at the left side here, a couple things to note is that obviously population growth is still growing and it's almost all in developing countries which have a high propensity to consume more food. So given increase in income in Africa or Asia is going to require a lot more food demand then say in Europe or United States where there is very

* Please see the corresponding paper and/or presentation available at http://www.kansascityfed.org/publications/research/rscp/rscp-2016 for additional detail and referenced charts.

little growth.

So populations are also becoming much more urban as you can see in the green line of the urban population crossing the orange line of rural population already, and rapidly outpacing that. And that's going to shift demand a lot more to processed foods, and away from staple foods as we'll see in a moment. I think the graph on the right-hand side, I think, is kind of stunning. This looks out to 2100, and as you can see more than 70 percent of future population growth is going to be in Africa. And that's really going to be one of the key markets in the future, not only for U.S. agriculture but for agriculture in general, and getting incomes up enough to actually demand the food that's needed is going to be a huge challenge. Other than that, there is growth in Asia as you can see on the right-hand side, and then much less elsewhere in the world. GDP per capita, as you can see on the left-hand side, we average in the thousands of U.S. dollars per year, this is real terms, green for the world, and then orange in the developing countries, as you can see, the per capita demand is going to more than triple by 2030 in developing countries. And again, they are growing two to three times faster in terms of per capita income growth than in developed countries. So again, that's a huge part of the demand is going to come from that.

The trends that I've mentioned also are going to indicate as I said a considerable shift in the patterns of demand. Look at the right-hand side there, you get coarse grains, rice, and wheat in OECD in blue, and developing countries in orange. This is a shorter-term between 2010 and 2021, but you're already seeing how relatively slow demand in commodities like rice and wheat and much higher demand in livestock. You see beef, poultry, pork there, and then fish as well. And also very high demand for things like sugar and oil as you get that transformation of diets in the developing countries. Coarse grains hold up in demand better because of the huge demand for coarse grains for livestock. You can see a snapshot of how that happens. It's basically inevitable it seems that when incomes in countries increase, people want to eat more meat. This is a snapshot of one year, but it shows the per capita

consumption of meat on the vertical axis against GDP per capita or its national product per capita in 2011. As you can see, the developing world—India, Indonesia for example are shown there, and all the African countries and South Asian countries are clustered in that lower part—have very low demand for anywhere from four to five to 15 kg per capita, whereas US, China, and others are far out in 60 up to 120 kg per capita. One of the key things that determines food prices is to what extent the developing countries move out along that line, and it certainly looks like they're moving that way quickly, but probably we don't expect them to go all the way to North American style diet.

How about on the supply side? What is it on the supply side it's going to influence the ability to meet the demands that we see? Obviously one of the key supply drivers is climate change and climate variability. Work that we've done and other institutes show that by 2050 production of key staples could be 10 to 20 percent lower compared to what it would be without climate change in 2050. So there's going to be strong pressure on production from climate change, and then variability shocks have difficult long-term impacts as well. Water and land scarcity, waters what we'll be talking about more. Land scarcity is also a big issue now. There's not that much and left that can be economically exploited. Brazil and Argentina have a lot of it, and the rest of it is in Africa, and the ones in the land in Africa is very poor quality. In addition, expansion of land runs into driving up greenhouse gas emissions dramatically, so there's a lot of social pressure as well as economic costs to try to expand land. So we don't expect much from that. Competition of biofuels, as everyone knows, does put some pressure on the supply for food, but that seems to be a pressure that's waning a little bit now.

On the positive side, some of the key shifters, and I'll have a few more when I talk about water as well, obviously investment in agriculture research is one of the main areas that can drive productivity growth. Pretty much worldwide that slowed down dramatically over the past 20 years. Government public research isn't investing enough in agriculture

research, and the private sector has also slowed down pretty much. It's a bit cyclical, going up when you get high prices like in 2008 and 2011, but has slid off dramatically again since then. Science and technology policy is going to be one of the really key efforts in terms of how fast we can get new varieties for example, discovered, developed, and delivered. And here are some of the key turning points, could be in the area of intellectual property rights, regulatory systems, and extension. But one of the possibly really important changes that could happen this year is if the new gene editing, or so-called CRISPR technologies, can avoid the regulatory overload and huge opposition from NGOs and things, GMOs, so that could be a big turning point in terms of becoming more efficient and generating new yield growth. It's probably going to be determined over the next two or three years.

On the water policy side, I think we have here in the United States but also throughout the world, developing new water whether for irrigation or for water and sanitation is increasingly costly, seven times more than what it was say 30 years ago. So there's a lot of constraints to developing that and developing new systems. In addition, and perhaps even more important, is the incredibly wasteful use of already developed water supplies. Again, some in the United States, and other developed countries, even worse in the developing world, which is been driven by subsidies on water itself and energy that pumps groundwater as well, and end up resulting in way more water use than is necessary. That's contributed to depletion of groundwater, water pollution, and declining water quality and much of the world as well.

Then we have again climate change and extreme weather. What's the evidence? Is water outside of agriculture that important in terms of economic growth? Obviously it's important for many aspects outside of agriculture. The evidence on the impact of water on overall economic growth is pretty mixed. This was a comprehensive synthesis of what's been written and known about impacts precipitation variability, runoff, or water availability, drought, and flooding with respect to per capita GDP growth. And again, all the signs are in

the so-called right direction; variability in rainfall does tend to be correlated with slowing of economic growth; increased water availability through runoff has a strong positive impact; then droughts and floods also have negative impacts. But the amount of economic growth explained is fairly small, it strongest in the poorest countries and countries that already have high water stress or high dependence on agriculture. Economies like the United States, it's not that big of a deal; obviously it can have local or regional impacts when you have significant water scarcity but it doesn't overall influence economic growth that much.
A couple other recent studies, one done by the World Bank and the other using the GTAP model at Purdue University, looked at forward-looking evidence, at what would happen with water scarcity in the future. The World Bank, CJ Miles computed a general equilibrium model that shows again that there are economic consequences but they are heavily concentrated in the developing world and in the poorer countries, including the Middle East, the Saharan region in Africa, and Central and East Asia where water scarcity is the most damaging. The GTAP model I think also provided a lot of good insights. Again, they showed that there are negative impacts from future water shocks, that the economic feedback effects limits that substantiality. Obviously regents can take advantage of trade to adjust compensation of agriculture income and specialize in other commodities. So one of the important things that comes out of these kinds of studies is that we need to keep global trade open, and not give into the kinds of protectionist that we've been seeing. So these kinds of adjustment effects, including through markets, significantly dampen those effects.
But how about in the broader, or on the sense of food security and agriculture? Here we have, I don't want to go into details on this, it's described a little more in the model and I can always provide a lot of detail on this for others, this is the impact modeling suite that we've developed at IFPRI, it's a link system that includes not only economic partial equilibrium models which is the original model, but also hydrological models, water use and crop simulations, and linked to climate change outcomes.

So I think the key thing to note here is that there is a water supply and use model directly integrated with the food supply and demand model so that we simultaneously can assess what's happening in the water sector, and how that water sector is influencing food and agriculture sector. Again, we can talk about that in more detail at some point.

Let's look at some previous results, we call it BAU, or the business as usual baseline scenarios. Here's just a couple of examples of projections for the cereals and for meats out from 2010 to 2050. We are finding, and obviously we have a. Now where prices are down a bit, but I think it's worth noting that these lower prices are still significantly higher than they were in the early 2000's. I think some people have forgotten that we are still at higher prices than we've had for a while. But we project more increases in cereal prices under the baseline, or without climate change it's the bottom black line, and even their you can see about a 10 to 20 percent further increase in real cereal prices. With climate change, you get an average increase as much as 40 percent for cereals. So real prices going up which of course is a boon for American farmers, and others with aggressive expert markets, not so good for food security in the developing world. Meat prices, as you can see, also going up 10 to 20 percent depending on assumptions. Fruits and vegetables, again, 10 to 30 percent and pulses roots and tubers, it's up, that are very important in developing countries diets, and particularly also going up anywhere from 10 to 20 percent over time with significant impacts of climate change.

What does this do to hunger? And again, this is our baseline, the same baseline that I just showed you, if the so-called shared socioeconomic pathway to medium economic growth pathway that's in the IPCC scenarios under RCP 8.5 which is just the name for our relatively rapid climate change scenario. So here we do see real improvements in reducing hunger, and you can see East Asia specific, South Asia, and sub-Saharan Africa are the key areas where you have hunger in the world. So we are seeing progress from the blue line, the blue bars, which is 2010 out to 2050 without climate change in the orange, and then

with climate change in the gray. You see also the climate change does have that negative impact, increasing population risks of hunger relatively at 2050 without… And again some people say, "well that's pretty good, were really going after hunger," but most of the targets for hunger in the international community is to try to eliminate hunger by 2030. Yeah I've never thought those were very realistic targets, but this is as you can see here very poor performance relative to those kinds of targets. So we really have to do better on these kinds of indicators of hunger.

So what kinds of policies, investments might work to make things a little better off? Look particularly at the water sector, but also as it relates to land and food. One of the key areas, and again, this is one of the best things that we could do to increase water use efficiency, really is somewhat outside of the water sector per se. It's through plant breeding, that increases the plant biomass per unit of water to both more efficient transpiration, and the efficiency of biomass growth per unit of transpiration. In a sense, the poster child of this was the semi-semi dwarf rice varieties and wheat varieties that led the green revolution in Asia and Latin America which produced a lot more rain for the same amount of water, or less water. But there is still the potential to do this. I think there's various degrees of optimism or skepticism about what can still be done to get more productivity per unit of water. I think there is still quite a bit that can be done based on the science that I read, including effective breeding for drug tolerance and other traits to get more yield per unit of water. So the key things are availability of diverse genes, that it's unlikely that were going to do really well on this simply by traditional plant breeding techniques, but we are going to need biotechnology, including micro -assisted selection, cell and tissue culture, and again, coming back to the point that gene editing should come through in a big way. Transgenic breeding seems to be off the table and some of the developing world, but we keep working with governments to try to develop regulatory systems there that would make those credible for the developing countries. But many of these systems have unscientific and regulatory

system that basically rule out GMOs. Hence again, the potential importance of gene editing.

The other, of course, as you all know, is adoption of new irrigation technology and farming systems. Of course, farmers have many reasons to adopt advanced technologies, drip and sprinkler irrigation, precision farming, conservation agriculture. But all of these technologies are now starting to move outside the developed world as well, so we're seeing a spread of drip and precision farming also in some of the more rapidly growing parts of the developing country as well, plus they provide increased income, convenience, laborsaving, and lower pumping costs for the individual farmers. I think one thing we always have to take account of is that these kinds of improvements at the field level or irrigation system level, are not necessarily having great big real systemwide benefits. For any new technology that's adopted, whether it's drip for example or you can have several outcomes based on that one. Because the interconnectedness of water was in the basin. One, it can save water that would otherwise have evaporated unproductively or have gone to sinks, and that does provide the kind of net system benefits whereafter in terms of water saving and productivity. But then, they can easily just divert water that's otherwise used by farmers downstream where return flow gets diverted and that that just shifts the benefits from one farmer to another. The others that you see a lot in the United States, for example, it increases the water used by increasing the profitability of irrigation for the individual farmer, so that farmer actually uses more water rather than less. So again, that's why we don't see the kinds of benefits in the long term of water use efficiency that you might expect for water productivity from these technologies.

So what do we have to do to try to get those technologies and farming systems to generate broader benefits not just to the farmers. Obviously, the key is going to be to promote water allocations that recognizes the hydrological realities and this interconnectedness. To do that, well specified tradable water rights is likely to be the way to go in order to optimize economic value and the productivity of water. And at the high level,

were going to hear a lot more about this Mike Young who is speaking tomorrow morning. These are some of the high-level conditions that Mike has identified in his exciting work he's doing now, and for years, that you need to have perpetual rights for individual users of all allocations made in the river basin or systems, that you have to do a lot of homework to get the measurements right, actual allocations in any given season, that they be based again on solid evaluation of how much water is there, and you need a transparent process and accounting system that accounts for evaporative losses and environmental outcomes as well. Michael will tell you how we can make this kind of system work here in the United States as well as elsewhere.

Obviously, there's big constraints to set up this kind of water rights and trading system. Even in the United States, politics is very difficult, as many of you know better than I do; in developing countries, it becomes even harder, and this is where we need the greatest improvement in efficiency. Its high cost of monitoring and measuring water, because infrastructure there and institutions are very weak, so you may need to invest a lot just to get to where you can do that. You often also have these huge irrigation systems that service a lot of small farmers, so that makes it even tougher to measure and manage water rights and trading. You also run into long-standing practices and beliefs that water is supposed to be a free good, so it can't be charged for. That has powerful meaning in many developing countries. You also have entrenched interests, you know, the irrigation bureaucracies in many developing countries benefit from existing system of subsidies and administer water allocations where they can generate income from their cells in the way they allocate water. So a transparent system is a big threat. Because of that, the development of well-specified water rights and trading in developing countries in particular is likely to be a medium or even a long-term process, but something that really has to get a move on rapidly. The current system of inefficient, subsidy-driven water allocation is a huge problem.

The other area is in capital investment in irrigation water, and here that includes

of course new investments in irrigation water supply—I already noted that those are increasingly expensive— but substantial potential does exist for irrigation in many regions of the world, particularly Africa where work we've done has identified 16 million hectares, so some 32 or 33 million acres of profit of large-scale irrigation, and up to 50 million hectares as small-scale irrigation. So considerable potential there if policies can be put in place.

There's also a huge amount of investments that need to be done in water treatment and sewage. Estimates from the World Health Organization have shown $23 billion per year to get global access to improve water and sanitation, and up to $135 billion to actually have in-house pump water supplies. So there's a huge investment deficit as well.

Let me quickly run through a scenario to look at whether these water policies and technologies investments I just went through can actually make a difference in the longer run. Here we run an alternative scenario with the model I described earlier, where we put in place assumptions that we have higher water-use efficiency gains through improvements in industrial and residential water use, but also in agriculture as well. So the agriculture ones are due to drought resistant varieties and other advances in research, reduce non-beneficial evapotranspiration to better management, and reduce losses to sinks for that same reason.

That ends up with we've done an estimation of the 15 percent improvement in water use efficiency at the basin level in 2050 compared to the baseline. We regard that as a possible increase, but one that of course can be debated by hydrologists and so forth. We also estimate that the enhance research and development based on those investments increases the productivity of crops and livestock, and also through effects on the general economy, the overall economy, increases GDP growth per year from about 3.2 percent globally to about 3.6 percent because of the improve productivity in agriculture and water sectors.

So what happens under this scenario? First of all, we can get substantial

improvements in reducing irrigation and water consumption. So you're going to get it at the baseline level, if not just the farm level. A couple of interesting things here. In most countries, you're getting somewhere between 5 percent and 15 percent reduction when you combine the various scenarios. But an interesting alternative, outlier really, is South Asia and Central Asia, here you actually end up consuming more water and irrigation, and that's because of the efficiencies in the non-irrigation sector and urban and industrial sector are high enough that they actually release water back to agriculture in those sectors. So without those kinds of efficiencies, you're seeing a huge movement of water out of agriculture and into the urban areas. So we can reverse that.

What happens to the cereal prices? You saw earlier that the projections of increasing prices—here we can see under this scenario, you get a significant reduction in 2050 compared to those prices we showed. So we can almost wash out for rice, wheat, and maize or corn, those long-term increases we saw, but we have less improvement for other grains, millet and sorghum, which don't rely on irrigation much anyway. These changes in productivity growth and income growth, end up increasing per capita cereal consumption in the developing world as well, and the developed also, anywhere from 6 percent to 8 percent. So you do see important gains in food security through cereal consumption, and that's driven home by the reduction in risk of hunger that I showed you in 2050 compared to that baseline. So you get reductions of as much as 40 percent in sub- Saharan Africa, over 30 percent in East Asia and Pacific, Latin America, and South Asia. So those kinds of improvements, if we really get at them in terms of improving water-use efficiency and productivity, can make huge differences in the future.

So just to finally summarize a few points. Water scarcity is going to be increasing in much of the world, and together with climate change and other factors that I noted, will cause relatively slow growth in agriculture productivity and slow progress and reduction in hunger under the current business as usual situation.

Looking at a plausible scenario, we can all judge whether it is plausible or not since some of my colleagues here might have some thoughts about that, but a plausible scenario for water and crop productivity growth significantly improves those water and food security outcomes. The combination of policies that we implemented in the scenario with water include efficiency growth through, for example, water rights and trading, new water technologies and farming systems, investment in crop research to increased yields with respect to both water and land, and some increase in irrigation. Water policy and reforms such as I'm talking about, I've alluded to that earlier, has to be tailored to underlying conditions—levels of development, agro-climatic conditions relative to water scarcity, and levels of ag intensification and degree of water competition. Obviously, you're not going to have the same policies put in place anywhere, though the broad types of policies are as I've described earlier.

The other point is that solutions are difficult and take time, political commitment, and money, so observing a need to push forward rapidly in these areas to catch up with the evolving environment for water and agriculture. Thank you.

General Discussion
Moderator: Nathan Kauffman
Assistant Vice President and Omaha Branch Executive
Federal Reserve Bank of Kansas City

Nathan Kauffman: Mark, this has obviously been an issue you've spent a lot of time looking at through your career. You know, you showed some of the projections going out 2010 out to 2050. If you are looking at this and doing those kinds of projections say 20 years ago, can you give us some sense of where we stand today? Are you surprised? Is this something, are we better off or worse off? What kind of position are we in today relative to where we thought we might of been 20 years ago?

Mark Rosegrant: Yeah that's a great question. In fact, we've been doing some of these kinds of projections since 1995. It shows how long I've been hanging around. But you know, it was a simple model in those days, we've developed a lot more work along those lines. What we found is that in those days we were doing fairly simple your optimistic/pessimistic/medium scenarios. And what we're finding out is actually, where we are today is more like what we thought the pessimistic scenario would look like. I think the reasons for that is that productivity growth has slowed faster than we had anticipated in what we thought would be the baseline. GMOs have never come in the way people thought they would in those days; the collapse of the Soviet Union shut down or dropped agriculture production worldwide for many years. The biofuels, I think did contribute to a slowdown, not in the production, but in food security for a while, so that was a factor, although I think that's washing out pretty well now. But I think climate change has come on more strongly than people thought in those days, so I think that's also depressed progress relative to what we know now.

Nathan Kauffman: To that point about climate change, you know, you mentioned that a couple of times, and if we're putting together a symposium, you can have a symposium

on climate change and spend a week or more talking about some of the things in some of the assumptions built into that. Could you talk a little bit about what can be done to better understand the impact of climate change as it relates to water availability, and what's being done in that arena to think about being able to plan a little bit better and make some forecasts as it relates to climate change? I know as you looked at some of your bands with the gray shaded regions, there's some dramatic variations. So what kinds of things might be done to still get a better sense of what those impacts might look like?

Mark Rosegrant: Yeah, and it's interesting that the long-term projections that the general circulation models do are much more consistent for temperatures than they are for water. So water resource availability, rainfall has been much more difficult to project than temperatures. It's not clear that there's going to be… I mean, supposedly in the next round of these IPCC scenarios there is some improvements, and they are also trying to look at their ability as well. But I think were a bit trapped in to having much more uncertainty in the water sector than we've had in the past. Of course, that also makes it very difficult to invest, you know, you could argue generically it would be good to invest in more storage when you have more variability, but you don't know yet where that storage is going to be needed. So you're going to have to have very adaptive and short-term responses in the water sector.

Tom Rooney, Waterfind: We are from Australia, and also have a company here in California, specializing in water market development, and water software and accounting tools. They are very interested your paper and looking to do a little deep dive into the World Bank's forecast for the decreases in irrigation water consumption over the next 35 years. Fascinated about that, about just where that decrease is going to be coming from, because in the last 20 or 30 years, we've obviously seen quite a strong increase in demand for irrigation consumption. In your paper, you do say, which I think it's a great paper, that globally we are going to be reliant upon heavier or creating greater efficiency or production out of existing landmass. We see irrigation as being a great part of doing that, converting non-irrigated to

irrigated land, increasing production. Yet still, your slide here in trying to engineer irrigation is suggesting globally we're going to see a decline in irrigation water consumption. So I'm just wondering are you using the same World Bank data for that, or is that your own data?
Mark Rosegrant: So yeah, the graph that showed the decline in consumption is the one where we've implemented, we've published a number of improvements, so that when already has built in the kinds of recommendations that I made in terms of water efficiency and agriculture productivity efficiency. The long projections in the baseline, which unfortunately I didn't show here for water, are for increasing consumption of water over time, so increasing consumption use. But what we try to show there is that you can bring down, bend that curved back down a little bit with those kinds of efficiency gains from improved water trading and through water use efficiency.
Chris Hartley, United States Department of Agriculture: I enjoyed the paper as well. I guess my question is, I saw lots on production and on creating efficiencies of crops as well as irrigation management. I didn't see so much on behavioral changes, and those would either be consumer in the processing phase as were talking about things like food waste, which may be account for up to 30 percent current global production. If that really does equate to about 24 percent of global water, 24 percent of fertilizer use, and 24 percent of land, why don't we look for behavioral changes to try and match some of the shortfall that were seeing.
Mark Rosegrant: No, that's a great point, and you're right, I didn't get into that in this particular paper. But we have been looking at that also, and it's an extremely important question. The post-harvest losses, not my group but another group at IFPRI, is working with FAO to get better, improved estimates on those. I think some of the numbers you see are exaggerated, but there's still a lot of improvements that can be done. Grains, it could be more like 10 to 20 percent, and then maybe 25 percent or 30 percent for vegetables. That's still very important. The question is how much of that can be economically recovered, but I think you're right, something like 10 percent of the food supply could be recovered through better

policies, and anywhere from investment in better infrastructure in the developing world, set policies that allow the use of restaurant or cafeteria food that wasn't eaten— obviously, there's lots of issues for legal liability and things— but those kinds of policies could help a lot. Another area that's getting a lot of attention, particularly among climate change analysts, is substantial dietary change where you would have large reductions in meat consumption in the developed world, and we've done scenarios looking at what that would mean. It does help on food security. The issue there is, what is the policy lever? You can have educational programs, and school cafeteria programs. The question is, do we then start getting into meat taxes or fat taxes, and of course, that's a huge controversial issue. But I think looking at sort of noncoercive ways to change some of that behavior could be very helpful. So you're right, there's a whole group of climate change analysts who say the only way we can meet the targets, for example, that were set in Paris, is through massive changes in diets, and nothing you can do on the production side will succeed without that. So it's a very hot issue right now, and thanks for bringing that up.

Nathan Kauffman: Mark, could you talk about, you had showed a slide where one of your alternative scenarios relative to the business as usual suggested that the largest reduction in prices was going to be in corn. Could you talk about what are some of the drivers of that in your alternative scenarios?

Mark Rosegrant: Yeah, let's see, the corn. So that was partly because the alternative scenario slows meat consumption a little bit, it doesn't have a huge one there. Also because there's more potential for productivity growth in corn, so we got a little higher hit on corn there, not necessarily in the U.S., and Ken Cassman can tell us more about that later, but there's very substantial gap's and productivity on corn in the rest of the world that could be exploited more rapidly than some of the other crops.

Steve George, Fremont Farms: I have a question on one of the inputs you used. Since you're using the population projections for 2050, there was an article that came out last or that

said, it was an outlier article that said some people think those population projections are way too high in sub- Sahara Africa, that they looked at some of the population densities that you arrived at and they would rival Hong Kong and it was totally unrealistic when most people just use those carte blanche. Do you make any modifications to those? Have you had a chance to look at those on a country by country basis to see if they look realistic? And generally, what's your opinion on those populations projections because that has a big impact on certain areas that you're dealing with in your analysis.

Mark Rosegrant: Yeah, sort of the standard for population projections has usually been the United Nations projections, and I think those are the ones that are potentially too high in Africa. Were using the projections that were done by a group and it's in the IPCC the Intergovernmental Panel on Climate Change. They've had a group of demographers looking at them. So we ended up using theirs, and they do have a somewhat lower rate of growth in Africa, although African population growth still dominates, in total, other regions of the world. We also can do, and we haven't done recently, we can do scenarios where we do alternative population growth, and that's a huge factor obviously in determining the balance in the future. Thanks.

Steve George: So for the models that you're using, you think the sub-Saharan Africa is pretty realistic?

Mark Rosegrant: I think it's solid, but it's not low growth. I haven't seen that paper, I'll have to check it out.

Steve George: How far apart were those two projections roughly? Was that half 1 billion roughly between the one you're using and the World Bank projection?

Mark Rosegrant: Total, you have half a billion, and I think about 300 to 400 million and that was in Africa I think. I'll have to double check.

Steve George: And you're also obviously very close to the climate models. What is your opinion on some of the modifications made to the models recently to explain the pause in

the last 10 years and some of the warming statistics? Have you had a chance to comment on some of those?

Mark Rosegrant: I haven't looked at those, but where the hottest, I don't know if it's really going down. We've had like 10 years in a row of the hottest temperatures ever on average.

Steve Gabriel, Farm Credit Administration: You had mentioned that both public and private spending on agriculture research are slowing down or are down. I was wondering what would be, do you have any idea why the private sector is spending less on research? Is it push back there getting on GMO, acceptance of GMOs, and what thoughts you have on that.

Mark Rosegrant: Yeah, I think that is one of the key factors. Of course, they also really follow commodity price trends quite a bit, I mean, with some lags and so forth. So until about the early 2000's, as you all know, commodity prices have been going down for basically 30 years. And that really dampened investment. Then we had some increase in the early 2000's and the big spikes that really got people reinvesting again. Even the public sector tends to follow those. The donor agencies tend to follow those prices as well, surprisingly well. So that was important. But I think a lot of it is this politics around GMO has cost a lot of potentially important lines of research with strong value propositions, sort of private companies. That has dampened their enthusiasm for investment.

Ken Cassman, University of Nebraska-Lincoln: This question was sparked by the one about population. So in these models, have we elevated them yet to the level were population growth rates are sensitive to economic growth rates? Because your scenario showed 3.6 percent economic growth versus 3.2 percent; taken over 40 years or so, that's quite a bit. And we know that population growth rates are most sensitive to the age at which a woman has her first child. We know that that's very sensitive to education level, and we know that education level is highly sensitive to income level. So can we, are the models sufficiently robust to get that interaction, and would it be important to get better projections?

Mark Rosegrant: We haven't done that. I don't think any of these kinds of global models have that, partly because there are so many intervening variables that you mentioned about education, fertility. But obviously economics is very important for that. I think that something actually that we ought to put on the list to look at more carefully. A quick point would be that that would further make these reforms even more effective, because in addition to the direct impacts through the ag and water sectors, you'd be pushing down a population growth, so you'd get even more favorable results from those kinds of scenarios. So that's a great point too.

Session 1: Long Term Trajectories

Speaker: Kenneth Cassman*
Emeritus Professor of Agronomy
University of Nebraksa-Lincoln

Thank you very much. It is a pleasure to be here. There is an underpinning paper to what I'm going to say. Because I'm limited to 20 minutes so it is going to be very fast. Substance is underneath, but it's in the paper.

So these are rates of gain on a global level of our major crops, the three major cereals. Soybean would also fit a similar pattern, I mean all your major crops do. But the siding feature here is the fact that global gain and yields is decidedly linear. And so there's a tyranny there as you know that the relative rate of gain is always decreasing because there's a constant rate of increase on an ever increasing average. And the bottom line is that those rates of gain today are 1.2 percent and decreasing, if they continue as those trajectories indicate, are not enough to produce the food we need under the scenarios Mark showed on existing farmland. That means they must accelerate, otherwise there will be massive expansion of agriculture. Moreover, and if you look on a country basis, there's a large number of countries where the yields have actually stagnated for many crops. And we published that that amount is about 31 percent of total global production today of the major cereals comes from countries where statistically significant decrease in the rate of yield, and in some cases a complete stagnation.

Now, the key here and I want you to think about, and going back here, take a look at the maize line of increase there, the red dots. They had a constant rate over all those years, and the fact is that globally the inflation-adjusted investment in maize breeding has quadrupled, so that it means the rate of gain per unit of investment in breeding has been reduced by 75 percent. Now the outcome of slower growth in, or growth and yields that is less than demand, is that if you're going to feed people is that you expand the area harvested.

*Please see the corresponding paper and/or presentation available at www.kansascityfed.org/publications/research/rscp/rscp-2016 for additional detail and referenced charts.

And this shows global, again, numbers for the harvested area. Now this can include double and triple cropping in some areas, but most of that increase since 2001 or 2002--by the way these were all spline regressions with statistical efficient showing not penned in numbers. Most of the increase in area is due to expansion of crop area, and we're expanding agricultural area at a rate that is faster than at any time in human history. What's more, the more important point is, whereas in the 1980s and 90s, the middle of that graph, we were meeting demand by increasing yields on existing land production base, we are now meeting demand equally by expending area. So there's been a cataclysmic change. When you hear about low food prices, yeah, we can clap our hands we are back down to more moderate prices, but it hasn't been the way it was in the 90s and 80s from increasing yields. It's a lot to do with expanding production. Ninety percent of that expansion is due to five crops shown there on the right— rice, maize, wheat—six crops, I can't count. Soybeans, sugarcane, and oil palm. It tells you what the world is asking for in terms of its grocery basket. Now it seems to me that if were interested in a sustainable future with agriculture, and we would like to constrain agriculture on an existing land base as much as possible without expanding into sensitive bio-diverse, carbon rich habitats like rain forests, wetlands, grasslands, savannas it seems to me that one of the things you'd like to know is what's the yield production capacity for every hectare of existing farmland. It seems to me like that the public good, we should all know it, and as you think strategically about the future, it can kind of help you look at a roadmap for where there are opportunities. At a country level, it's not that we're promoting self-sufficiency. I know I'm amongst economists. We know, we don't do that. But every country does need to think about its food security and where food will come from, and by having this kind of data, you can look at future scenarios, trade trajectories, export opportunities, or import requirements. Furthermore, it's critical to inform policies and investments in research and development.

The last part of my career was spent trying to develop a tool that can do that, and

it's the Yield Gap Atlas. You can publicly access it there. It's a very simple concept, that the good Lord gave every piece of ground a certain potential yield based on things you can't modify by management. And that's the amount of sunlight that falls during a period when crops can grow, the temperature during that period, and the water supply that's either rainfall or rainfall supplemented by irrigation. That's unmodifiable, and that determines the potential yield, and we're actually quite good at being able to simulate that for our major crops. But if you have the data on climate, including solar radiation, etc., your actual yield at the farm level is determined by things that limit that potential— nutrient deficiencies, imbalances, pests, etc. so if you do that, and you go to the Atlas, you'll see that we've got about 25 countries now with some very good bottom up, this is a new way of doing it, hasn't been done before; we use primary data to the extent possible, we developed the very unique upscaling method to be able to do this, very robust.

The target for a population of farmers isn't the potential yield ceiling, that's not an economically viable proposition due to diminishing return to added inputs and so forth. So a reasonable target that we have found that's quite robust also is about 80 percent of the yield potential ceiling. So if you can simulate that potential, we can estimate where the national production potential is by 80 percent of that value, and that value is on the right here for national production. It's 80 percent of the potential yield. This is Argentina with very good quality data. What you find there for Argentina is that on existing land, because when they expand by the way, there expanding into the Chocon, it's not a rain forest, it's a semi-tropical forest that's considered one of the bio-diverse, carbon-rich habitats that probably we should think about conserving a bit. But anyway, if you were to try to do it on existing farmland, we could reach national production capacity on the right column there, and it turns out that value now is 9 percent, 4 percent, and 9 percent of current global maize exports, respectively. So that's how much Argentina can contribute to global supplies if they brought production up to this 80 percent level. We've started doing it in some countries in sub-Saharan Africa;

these are the results. These are screenshots from the Atlas. The key about our approach is we not only we get mean yield, we get the coefficient a variation in yield. See you get some idea of yield stability. Again, very robust, simulated over years of weather data.

What you find for West Africa is though it has large amounts of rainfall in maize areas, and actually Africa as a whole, much more on average than the corn belt, soil depth and the higher temperature and higher evapotranspiration makes it highly uncertain. I'm going to go here. So this is a plot from the counties in Iowa and Nebraska that produce maize. It's the average yields over a 10-year period, 2001 to 2009; it plots the coefficient of variation versus the average yield for about 100 counties. And you see that the blue set of points is irrigated agriculture in Nebraska. Very high average yields, coefficient of variation typically less than 10 percent. Even in the drought year of 2012, average irrigated maze yields in Nebraska were slightly above average. The red points are Iowa, which is the most favorable rain fed area you can think of. And then Nebraska starts to the west, starts getting into the rain shadow of the Rockies, and it ranges all the way from fairly favorable to very unfavorable where you have low average yields and high variation. It turns out that by our analysis, the first is able to do this, a majority of sub-Saharan Africa falls in what we would call harsh rain fed, which means, for instance in Nebraska, we would never have the robust agriculture we have without irrigated agriculture to stabilize that highly uncertain production environment.

So I want to conclude here, the first set of conclusions, that yeah, irrigated agriculture is sustainable where water withdrawals don't exceed recharge capacity over the medium to long-term, the water quality is maintained. Of course, it requires good governance, and I offer to any of you that aren't familiar with it the Nebraska Natural Resource District's Model of Governance. Can current irrigated agriculture be maintained or expanded? Well, we know, and Mark, we don't have to repeat accepted, my bottom line is that overall best guess, global irrigated agriculture can be maintained, but not likely to be increased significantly.

So what's the scope for improving water use efficiency per se? We're all adults here, we all know that if you increase water efficiency at the crop or field level, it doesn't mean you save water, you know in a watershed, we all know that. However, if you have a set amount of sustainable, rechargeable water, and you want to allocate it as efficiently as possible across as much land as possible, water efficiency becomes very important.

I want to talk a little bit about improved crop management, better irrigation, and crop genetic improvement. This is a model we've used, the water productivity model, used very heavily in Australia as well, but essentially says you have a water supply that is the amount of water in the soil when you plant your crop, the amount of rainfall during the crop that doesn't run off, and any irrigation you apply. So that's your water supply. You can plot grain yield versus that, and when we do we get, look the red line is, a lot of the tales in the paper are about this if you want the guts. But the red line is the target. That's what a great grower at the frontier of technology should be able to do. So any specific yield can be looked at, and you can consider ways to increase yields at the same water use level that would be things like improved agronomy, better genetics, or you can cut back on your water use and apply water more efficiently and lower yields, but do so at less water supply, and of course a combination of both. That's the model. It's robust if you look at real data. These are data from Nebraska. I won't go into details, except for the bottom line. Based on these data, you can reduce water use by 33 percent in this particular natural resource district if you adopted pivot irrigation, improved irrigation, timing based on real-time weather and soil water status, and that can inform policies and decisions made by this NRD when they need to come into compliance because of falling water tables.

What about genetic improvement? And here I'm more sanguine than Mark, because we already have some real data on this. We already know that between our major seed companies, there's been over $1 billion of investment in drought tolerance. Today, in terms of modifying single genes, whether it's by old biotechnology or CRISPR, there hasn't been

any advance that has been tested and published in peer-reviewed journals. We do know that one company has been successful in using what I call in the paper a turbocharged, brute force breeding approach, but that success is no more than you'd expect from a conventional breeding program well applied. It turns out that there published improvement is about 6.7 percent over best available commercial germplasm, and that took an investment of many hundreds of millions of dollars over 10 to 12 years. That's what you'd expect from a robust conventional breeding. My point is there is no silver bullet here. It's going to be a slog, and you've got to talk about improving agronomy as much as improving genetics, and if you don't get that right, then our investments will fall short heavily. And you can see that in looking at what it's taken to maintain a linear increase in maize yields in the United States over the past 45 years.

So I want to call your attention here to the kinds of technologies that have supported this linear rate of gain. Think about back in the 60s when the average rate of nitrogen application to maize corn in the US was 40 pounds per acre. The average today as 160 pounds. Think of the productivity enhancing ability of that increase in nitrogen. Now there's problems with nitrogen, okay. But in terms of enhancing yields, tremendous impact. Think of expansion of irrigated area. Back in the 60s, there was hardly any irrigated area. Today, 15 percent of US maize comes from irrigation on land that was producing the lowest yields in the corn belt. We have integrated pest management, you have transgenic insect resistance, multilocation hybrid testing, this brute force breeding, improved balance of N-P-K. So once you start applying nitrogen, lo and behold, you have other nutrients, there are 17 other essential nutrients that came in soil testing, plant tissue testing, to make sure that growers were applying the right amount in balance of all essential nutrients. I think the most important technologies of the past 15 years, because remember transgenic crops were released in the mid-90s, and since then there's been no significant transgenic crop other than those that were originally released. There's been other cassettes, there's

been other types of BT, there is been other types of herbicide resistance, but no other new technology through biotechnology. What's really been significant in the past 15 years have been precision planters and electronic auto-steer which increase farm productivity, avoid overlapping resources, doubling up on seed and fertilizers are missing altogether, and I think we underestimate the productivity enhancement of these kinds of technologies. The point is that these are earthquake type technologies, and we've been fortunate to have them punctuate this period of time, and all we've done is support a linear rate of gain. What I'm telling you is that we need to accelerate that rate of gain to contain agriculture on existing farmland.

I want to conclude. While there is tremendous potential to close current yield gaps, doing so will not likely reduce expansion of production area without also well-coordinated land-use planning and land-use rules. Likewise, there is enormous potential to improve the water efficiency of agriculture, particularly in irrigated agriculture. But again, it won't help us with declining aquifers unless there is also good governance. Future improvements can be expected from current innovations in both agronomy and genetics, but I will tell you the current business model for seed companies is clearly not tenable. Witness the need to merge, to maintain profits. And though there's tremendous profit in big data, this idea of big data, we haven't seen a business model that can successfully harness it yet. But having said that, I'm a firm believer biotechnology has a huge role to play; it's just not a panacea. Having said that about big data, I am a huge supporter. The only way were going to be able to accelerate yields is by using both tools rigorously coupled with other agronomic and agricultural equipment innovations as well.

I would say, the last point is not just investing in the right mix between genetics and agronomy. This point is larger than that. This point gets to the fact that you've got to accelerate the rate of gain in yields. That is, the linear rate is not good enough. You've got to accelerate it. But you must do so while protecting the environment. I didn't have time

to talk to you about the nitrogen problems, about biodiversity, climate change, greenhouse gas emissions, and so forth. But while we were very good at increasing yields in the past 45 years, we weren't as good at protecting the environment. Going forward that's not tenable. We've got to do both together. And here's what I mean by the priorities.

If it was true that we could agree in this room today that we've got to accelerate yield growth rates and reduce environmental impact of agriculture, then when you prioritize research, you've got to focus on that. What's happened is, and by the way, I can think of thousand ways to increase yields if I don't have to carry the burden of improving the environment. By the way, I can figure out thousand ways to reduce the environmental impact of agriculture if I don't have to increase yields. Unfortunately, we fund research into scientific community separately. You'll never get there. You've got to ask every research you fund to be able to explain how you can contribute to the goal of both accelerating rates of gain and yield and decreasing the environmental footprint of agriculture, together. The problem is that the scientific community that wants to work on reducing the environmental impact, doesn't really like agriculture. They're not interested in productivity. The community that wants to increase yields doesn't really, isn't the community that's going to help on the environment. So that's what's meant by the last point, we have to bring those two together. I'm eminently confident that both goals can be achieved if we do. Thank you very much.

Discussant: Patrick Westhoff
Professor and Director, Food and Agricultural Policy Research Institute
University of Missouri

I'm going to start off by summarizing some of Dr. Cassman's remarks with just translating some of them for those of us who aren't so experienced in agronomy. One of the first things he's pointing out is that linear growth in yields across the world, the global yields for corn, for wheat, for rice, have been pretty much increasing at a constant absolute year-over-year amount each year for the last number of years. So in the case of corn, for example, that translates to roughly one bushel per year as a global average increase. The global average unit for corn is roughly half the U.S. level, increasing about a bushel per year. The area devoted to major crops has increased by 10 million hectares per year, or 25 million acres per year, for the last 10 to 15 years. How much is that? Well how much is our corn acreage? We're talking about in four years time, adding the equivalent of the total U.S. corn acreage to the global total. I'm using global, but probably we can't keep outpacing that growth going forward.

While there is some reasons for the yield growth to be slowing down and percentage terms year-over-year and local disruption, as you've pointed out, being an issue in the Soviet Union when it broke up lots of other parts of the world where you have those sorts of challenges, climate change can be an important future issue, investments in research that don't have the same level of return per dollar of investment that we've seen in the past, and very importantly, something that I tend not to think much about in doing 10 year projections that we do for FAPRI, are biophysical limits and how close we may be or not be to those in particular places on all the real particular crops.

In 2008, he had on his paper that FAO estimated that irrigation accounted for 40 percent of global food supply, and less than 20 percent of land. So the future of irrigation

matters tremendously, obviously. We are unlikely to see bigger increases in irrigated area, perhaps some in sub-Saharan Africa, or perhaps losses elsewhere. We can take steps to increase water productivity as he pointed out by better managing both irrigation and crop reduction. And again, pointing out at the end that, so far at least, supporting conventional plant breeding appears to be generating as much or more benefits in terms of addressing some of those issues as has our more recent focus on genetic engineering. He recommends the importance of appropriate policies, linear improve both genetics and practices, and research to increase crop yields while reducing environmental impacts. So that was by way of summary.

So, I'll talk about one important premise of that discussion. I won't pretend to be able to comment on the agronomics. I'm going to talk about an important premise though. The degree of the challenge depends on just how much we expect future food demand to increase. There's a lot of disagreement about that. I will be the first to tell you I do not know what food demand will be in 2050. That said we find that hard enough to deal with the next 10 years, rather than looking far beyond that. But let me just bring up some important things here. In this paper, you cited a possibility of having an increase in global food production by between 50 percent and 100 percent. The 100 percent figure comes from a paper by Tillman and Company that is comparing the need for food in 2005 to that in 2050. So first, to be clear, that's 2005, not today, and that makes a difference right there. That's the Tillman paper. Then you also said that's based on a statistical model and it looks at calorie protein consumption by country group, income levels, assumed rates of population, a lot of the things that we think are very appropriate to consider. And the growth would be even more than that paper suggests if we have other countries reaching the kind of levels of per capita consumption we have in this part of the world. FAO on the other hand, in 2012, projected food production growth of 60 percent between an average of 2005 and 2007 and 2050. So 60 percent between 2005 to 2007, and the year 2050, a 45 year period of time.

That's a number that is more commonly quoted out there in the press. That report is based on expert opinion, not a formal statistical model. It takes into account both supply and demand constraints, and uses the same population figures as the Tillman paper as far as I can tell. So the difference is entirely in terms of per capita consumption levels going forward. But obviously, a huge difference between 60 percent and 100 percent, as you're looking forward over that 45 year period of time. FAO furthermore projected an increase in cereal production over that period of time a 50 percent for mostly 2 billion tons in 2005 to roughly 3 billion tons in 2050.

Now it's very important to note that since 2005 to 2007, since that three-year average 10 years ago, global production of cereals has increased by 400 million tons, 20 percent. We've already had a 20 percent increase since the point of comparison of that study. So if we still thought that study was exactly the right thing for the future, which implies that the future growth of the world cereal demand between now and 2050 is only 600 million tons, about 25 percent. That's a big difference when we talk about doubling world food production by 2050 and only increasing world cereal production by 25 percent from today's level. Again, I'll tell you why in a second, but I think that's probably lowball figure, but that is actually what the FAO numbers suggest if you take them literally. So it's hard to know who's right obviously, as opposed to what's most likely. The FAO numbers were intended to be a measure of what's likely given current trends not a measure of what's desirable, what needs to happen for food security, is what current trends tend to imply, whereas the other study, the Tillman study, is more where would global food demand be if current income trends were to continue, etc. if there weren't constraints on supplies

So to try to put this into perspective. Let's look back to try to look forward. So between 1980 and 2015, the world's population increased by how much do you think? Sixty-three percent, 63 percent of the last 35 years. World use of major grains and oilseeds, when I say major grains I mean wheat, corn, rice, sorghum, barley, oats, millet, rye, and rich grains.

The nine grains that the USDA maintains our supply and demand database each month. So again that increase, and that's the grains that I'm counting here are soybeans, grape seed, sunflower, peanuts, and cottonseed. So add those crops altogether, the total increase in their production rose 86 percent over this period of time. So that implies an increase in per capita use over the last 35 years of 14 percent; 63 percent increase in population, 86 percent increase in production, and usage I should say is 14 percent for implied per capita use.

Just two factors explain the entire increase in per capita use since 2005, or since the 1980s, over the last 35 years. More recently, biofuels in the United States deliver longer haul, and more importantly by far frankly, China. China is using more grain, more oilseeds in feed rations, those two things combined explain the entire increase in per capita consumption that the world has experienced since 1980. So in other words if you took out China, if you took out ethanol production and consumption in this country, global per capita use of grains and oilseeds in 1980 was 380 kg, today it's 378 kg, essentially the same number in a 35 year period of time. On supply side, and has been talked about already both area and yield have increased. Total grain and oilseeds have increased 11 percent over the period as a whole with most of the increase occurring just the last several years. Average global yields have increased by about 70 percent. Linear growth path as Dr. Cassman pointed out. So therefore, total production increases are consistent with U.S. change that I talked about.

So let's look at ahead now. Looking forward over the next 35 years the U.S. Census Bureau projects a population in 2050 of 9.4 billion. That would be an increase of 30 percent above the 2015 level, and UN's projections that just came out last year; more recently numbers that the others talked about, some of the higher numbers that were talked about in the press on earlier discussion, the talk about 9.7 billion people in the world by 2050. That would be a 34 percent increase from current levels. In the Census Bureau estimates, global population growth slows from the current 1.1 percent per year to roughly 0.5 percent per

year by 2050. So a big slowdown, not just in the absolute numbers being added each year, but in percentage rate of growth. We're currently adding about 78 million people per year to the level population; by the Census Bureau estimates, that drops to 45 million people per year in 2050. Now mind you, these estimates are going to be proven wrong. It's not too hard to give a good estimate of demographics for the next 10 years. Once you start going much beyond that though, very sensitive assumptions make a huge difference.

So the big question I would ask is, how much is per capita use going to increase? Currently, it appears at least to me, that unless there's a major change in policy, unless there's a fundamental change in petroleum markets, we are probably near the end of growth I should say, at least of rapid growth in biofuel production. I may be proven wrong about that but let's take that as an assumption for now. China's per capita growth has been astounding; they probably have more growth to go as their incomes continue to rise, as their diets continue to change, but it can't keep growing at the current pace forever. It can't keep growing at the current pace for 35 years. China will be consuming far more meat per capita than we are. Maybe that happens, but it doesn't seem very likely to me. So eventually there will be some slowdown in China. So biofuels is largely done as a source of risk if you'll take that assumption from me. And of China is bound to slow down at some point, what's our new engine of growth? And yes, we have rising incomes around the world, but are they going to be enough to cause the types of growth we've seen in the past due to China and due to biofuels? So suppose for example that the growth rate of per capita use is about the same for the next 35 years as it has for the last 35 years. With 30 to 34 percent increase in the population, with another 15 percent increase in per capita consumption, rules imply roughly a 50 percent increase in use. So that's more action than implied by the numbers from FAO. FAO's numbers implied something more like 30 percent from current levels, but of course is far less than the higher numbers that were talked about before.

So if yields were to continue to increase in linear fashion, that's a big if, and Dr.

Cassman agrees about that, may not happen, but if they were to continue to rise at a constant year-over-year absolute rate, that suggests roughly 39 percent global yields over the next 35 years for grains and oilseeds, and therefore to match supply and demand you need roughly another 8 percent of area. Again, would you want to get 8 percent of area, could you get 8 percent of area? Those are important questions that we would have to think about hard.

One assumption is to try and suggest or try to feed a hungry and growing world is an easy thing, and I'm not saying that at all. And I'll also be the very first to say the farther you look in the future, the greater the uncertainty actually is. But I do think it's very important because so much that we do depends on the use projections of these assumptions. But we have to come back and look at this more closely. I was just in a meeting a couple of weeks ago in Amsterdam, of other people who also do our sort of work for a living, and I was very pleased to hear that FAO is going to reopen this issue again. And try and look at not just 2050 but even 2080 now because of the time where peak pressure is may happen to be beyond 2050 as it currently appears.

So just to wrap up more briefly, tying this back to water issues, we've been working back since the year 2000 with colleagues from South Africa and other countries in the region. The recent El Nino event as most of you know has done a number on production in that part of the world. In South Africa, for example, its corn production this past year is roughly one-half of what it was two years ago. The country about two years ago was exporting two billion tons of corn mostly to other countries in the region. They use it as a basic staple food for human diets. But now this year, expected to have net imports of two million tons. South Africa is a rich enough country that it can do that and they can keep going without a huge problem. But some of the neighboring countries that have been relying on South African imports, this is a tremendous and horrible problem. Certainly, this water issues is of course very important as we look forward. And you've got other complications

are yellow corn versus white corn, transportation, all the policy issues that all come into play. Even population projections indicate that more than half of the world population growth between 2015 and 2050 occurs in just nine countries—India, Nigeria, Pakistan, Democratic Republic of the Congo, Ethiopia, Tanzania, United States, Indonesia, and Uganda. Again I'll just point out, many of these are African countries where these issues are front and center for food security. Much of the global challenge will be increasing supplies and areas were current productivity is low and water is a very serious concern. Thank you very much.

Discussion with Kenneth Cassman and Patrick Westhoff
Moderator: Cortney Cowley
Economist
Federal Reserve Bank of Kansas City

Les Lampe: My name is Les Lampe. On my own, used to be with Black and Veatch for a long, long time. My question relates to climate change. It appears to me, maybe I misunderstood, that there was some assumption of climate stationarity in terms of these projections. Looking in the past, the rearview mirror, and showing the yield increase, the linear yield increase, and I'm thinking particularly of something like Nebraska where in the western part of the state, the average rainfall is less than 20 inches. In the current climate change projections from the IPCC, show that by the end of the century, the increase in temperature will be between 3 and 9 degrees, maybe 6 or 7 degrees. Well, that takes it from semi arid to arid, and when you saw those blue, non-irrigated corn yields or wheat yields in that kind of a condition, how are all of these, all of these, models and projections and everything else related to that impact of climate change and what that might mean to us?
Kenneth Cassman: The funny thing is, if you were to go to West Nebraska and ask those farmers how worried they are about climate change, they're not very worried. They see as much climate change in the 10 year span that almost is predicted by those models. I think the big picture here is even those IPCC reports, when they look globally, don't see a big change in total food production. That's because there are winners and losers. Remember every climate zone here today will have a proxy in the future climate world somewhere. And so long as those areas have decent soils, that's probably the ace in the holes, how the change in climate overlays with soil quality, but there will be winners that are able to double crop where they were only producing one crop before, plant early or longer maturing hybrids, tremendous adaptation is possible and opportunities with warming climate in many parts of

the world. Poor Nebraska farmers may not be the winners, but globally it's not as dire I think as the social consequences of that.

But having said that, the other problem, and Mark mentioned it, is that these models are not very good at predicting changes in the water regime. Remember that the most important greenhouse gas of all, much more important than carbon dioxide, the nitrous oxide, the methane, is water vapor. So if you do a poor job of predicting water vapor in the face of climate change, that's the reason for large swings in the projection of future climates.

Don Halcomb, Walnut Grove Farms: Dr. Cassman, I think a great speaker is one you agree with. I really appreciate what you said, enjoyed it. But my concern as a corn farmer is that sometimes I feel like I might be working at Sears Roebuck about 30 years ago and not realizing that Amazon's on the horizon, because I wonder if a better corn plant is about equivalent to a better Craftsman wrench. It's really, you know, we may not be seeing where food is going to be produced because earlier you said in your speech that your idea would be to increase agricultural production in a sustainable manner. But what if you'd said you wanted to increase food production in a sustainable manner, it might be a different idea. So my question is, what if food is no longer produced on a traditional farm, but it's produced in a manufacturing plant like Impossible Foods is doing in California making hamburgers? So really my question is, Pat, when are we going to, in our presentation so far, we don't have, there is not an element of looking at alternative food production systems. Could that ever amount to 10 percent or 5 percent of the production, and what would the impact be?

Pat Westhoff: Obviously, questions remain, and I don't have a clue. You raised very important questions, obviously, and I think there's a lot of disagreement out there about just how important some of these alternative things may prove to be. Some things are hype. I mean, obviously, some of these things I don't take very seriously. I think we're going to continue to rely on cereals and oilseeds for much of the world's food supply for a long time to come. But just as 20 years ago, if you had told me that we'd have the level of biofuel that

we have today, I'd say that was crazy. You know, likewise we're going to have something else that's going to come up that's going to be a big surprise to us, so yes we should be trying to get on top of that.

Kenneth Cassman: So I think the key answer is if we can produce the substrate required for our food supply, and I won't even call it corn, with less energy, less environmental damage, in a test tube, or in a manufacturing plant, so be it. But there is where the proof of the pudding will come. So don't get hyped out by the reports. At the end of the day, it's all energy and mass and we can calculate those things very quickly. And if anybody is proposing that they can do it better then you as a corn grower, ask for the underpinning data.

Audience Question: I wonder if the speakers could comment on some of the work by Jesse Ausubel at the Program for the Human Environment at Rockefeller University. So Jesse published a couple of papers on the land sparing capability in the future of agriculture that in fact we may be entering a phase where we're going to decouple sort of land-use from productivity, and we may face a future where we're going to be returning land back to nature as opposed to putting more under the plow. One of the calculations he shows is that as societies become more developed, we actually begin to reduce our meat consumption, our diets begin to dematerialized, and in fact the dematerialization of Western diets can lead to some of this land sparing capability. But I wonder if you guys could comment on that.

Kenneth Cassman: I would just say quickly that you may be right by 2100, but before you can get to a reduction in consumption on a global basis, you've got to get the low income, low consuming countries up to a point where they feel quote "comfortable enough" or secure enough to then look at a transition lower. So I think if you look long enough, it's possible you might be right, but you'll lose the dynamics that you still have to get through that transition period.

Pat Westhoff: Yeah, I will point out that the United States may be one of the places people have looking for this sort of data. Between 2007 and 2012, real quickly, total meat

consumption in this country dropped by about 8 or 9 percent per capita. It's rebounded more than half of that already just since 2012. Prices matter. Elevated meat prices brought down consumption, meat prices have been slack relative to other products and meat consumption has rebounded again. Europe's had relatively flat per capita meat consumption for a very long time. So I do think, yes, you don't keep growing forever, that's certainly true. I think all of our charts would be consistent with that. But I think what we've seen in China and elsewhere, lots of demand for more protein as incomes increase. China, as some of you may be aware, just announced recently they're going to try to push their people to consume less meat for environmental reasons and for health reasons. That hasn't happened yet, but we'll see if that goes anywhere. That can be incredibly important obviously.

John Ambroson, John Deere Financial: I haven't seen any comment yet or talk about correlation between the size of farming operations and the potential efficiency of water usage or productivity. The last 15 years, we've seen a lot of consolidation. If there is a significant correlation, I think about sub- Saharan Africa, India, and China many, many two, three, or five-acre farms, governments wanting those people out on those farms and not in the cities, and is there a likelihood of gaining scale in those areas to address any of these issues?

Pat Westhoff: This is beyond my level of expertise, but I will say my colleagues in southern Africa have been looking at some of these questions. As I understand what they're telling me, obviously the very smallest operations have a difficult time taking advantage of new technology, adapting new practices that would meaningfully increase their production on a larger scale. But it doesn't take much scale to be able to allow those benefits. We don't have to have a thousand acres. Even a 10 to 20 hector farm can start taking advantage of all these things. But I will say this, a huge area of argument in our profession is just what is the scale effects of what is possible and what is not.

Panelist: Christopher Hartley
Environmental Markets Analyst
United States Department of Agriculture

The United States Department of Agriculture has a long-standing relationship with the Bank and a strong commitment to supporting farmers, ranchers, and small business through job conditions and preparing them for our future. Several agencies at USDA contribute to the Department's Drought Resources and Programs. Their contributions range from providing basic science and economic analysis that informs drought policies and programs, to crop insurance and providing infrastructure and technical assistance directly to growers.

Today, my comments will largely focus on recent efforts by the Economic Research Service, the Climate Change Program Office, and the Office of Environmental Markets to address drought. Droughts are among the most costly weather-related events around. In 2012, roughly 71 percent of the counties in the United States were experiencing droughts so severe as to warrant national disaster declarations. It's estimated that $30 billion in damages occurred as a direct result of drought. Nonetheless the damages could have been far worse. In many areas of the country, farmers were able to reduce potential losses by increasing the use of ground and surface water resources for irrigation. Roughly 56 million acres or 7.6 percent of the cropland and pastureland were irrigated in 2012, three-fourths of which are in the western United States where droughts are becoming increasingly common. There again, agriculture supplies about one half of the value of crop sales in the United States, on only 17 percent of the land. Typically, less irrigation water means fewer crops, creating tighter supplies and higher prices, but not always. Despite four years of drought, this has largely not happen in many of the fruit and vegetable crops grown in California where 70 percent of the nations fruits and tree nuts, and 55 percent of its vegetables are grown.

The state's $43 billion in agriculture production has only experienced marginal decline. California's farmers focused limited water supplies on highest value crops, invested in new wells and technologies to increase irrigation efficiency. The immediate result was a relatively small impact on yields, and a decrease in total crop value of less than 3 percent. Similarly consumers have not seen substantial differences in what they pay for food at the grocery store. According to the Economic Research Service, as of June, the outlook for 2016 for slightly lower than average retail food price inflation, with supermarket prices expected to rise between 0.5 and 1.5 percent over 2015 levels. Even the prices for fruits and vegetables, which are dependent upon irrigation, are forecast to increase a maximum 3.5 percent this year.

Factors contributing to the limited impact include the increasingly global marketplace for food to address supply gaps that occur, the strong value of the dollar which has made imports relatively less expensive, and low fuel costs which have kept energy and transportation costs down. Less apparent is that water users rarely pay the full cost of water. Prices typically reflect the energy cost of delivery, and not its resource value or the impact that unsustainable withdrawals can have on the environment. Most of California's aquifers are experiencing severe overdraft and growing demand for water resources, leading many to question the long-term implications for irrigated agriculture. Researchers from the University of California-Davis estimated that farmers use as much as 5.1 million acre feet of groundwater to make up for surface water deficits in 2014. Continued over withdrawal of groundwater can result in the deterioration of water quality, increase pumping costs alongside the lowering water table, and land subsidence. It also substantially contributes to sea level rise. Although the state received normal rainfall in 2016 and many reservoirs are at or above their historical averages, it will take many years of above-average rainfall and reduced withdrawals to replenish aquifers that have been heavily overdrawn.

I guess the question for you is, are recent drought events an indication of what we can

expect going forward? USDA recently issued a major assessment of the effects of climate change on global food security, and found that climate change can undo all of the gains in improving global food security over the last 30 years, placing up to 200 million more people at risk of food insecurity over the next century. The risks are greatest for the poor in the tropics, and are magnified as the rate of magnitude of climate change increases. Projections indicate that 4 percent of the Earth's cropland is currently experiencing drought, and that by the end of the century, more than 18 percent will be as a result of climate change.

The report also showed that this outcome is not inevitable. Building the adaptive capacity, improving the flow of goods and services by breaking down international trade barriers, and mitigating greenhouse gas emissions improved food security outcomes. USDA's Economic Research Service is working to link the latest climate projections, crop production, and economic models to assess the economic impacts of the changing climate and the associated impacts on the agricultural sector and food systems. Recent results suggest that average commodity yields are projected to decline as a result of climate change for corn, soybeans, rice, sorghum, cotton, oats, and silage under both irrigated and dry land production as early as 2020. Corn yields are projected to decline between 8 and 16 percent. Commodity prices will rise as a result of climate change under most climate projections. However despite higher prices, farmer well-being, measured as producer welfare, declines due to declining crop yields and crop returns. Agriculture will face increased water scarcity in major irrigated areas with projected service water rejections ranging from 20 percent to more than 50 percent across areas of the central and southern Mountain, Pacific, and Plains regions by 2060. That does not bode well for groundwater resources. Gains in efficiency and productivity in agriculture water management and utilization can reduce these risks however. Successful management strategies must address the larger drivers, including population growth, economic development, land-use change, improvements in technology, and ensuring that ecosystem function is maintained.

I would like to suggest that market-based solutions provide one of the best opportunities to do so, and can promote more sustainable, equitable, and efficient water use. Market-based approaches can be extremely effective at changing behavior. Market-based approaches create innovative financial incentives for better resource management, and can complement traditional government programs by increasing private-sector investments in rural America, accelerating resource conservation activities and compensating landowners for the public benefits that they provide on private lands. Markets can also support improved environmental quality by allowing society to achieve higher environmental standards at low overall costs. However while markets can do these things, most markets are notoriously thin, and have failed to achieve their potential.

USDA's Office of Environmental Markets was created under the 2008 farm bill to develop the tools and infrastructure needed to facilitate the participation of farmers, ranchers, and forest landowners in the emerging environmental markets for water quality, water quantity, wetlands, climate mitigation, habitat, and biodiversity. USDA's environmental market strategy focuses on catalyzing the potential of these markets through the development of science-based metrics, market infrastructure, and policy that will ensure that markets are credible, robust, and accessible to all landowners. Environmental market activity in the United States currently averages about $6 billion per year, with the bulk of transactions occurring in wetland and habitat markets. Environmental water quality transfers, or sorry, water quantity transfers averaging more than $50 million per year, and intra-agricultural transactions, although not currently tracked, but are easily several times greater than that number. All Western states allow for water transfers. Transfers can include permanent sales, short-term leases, and longer-term leases of water, of surface and groundwater rights. In most cases, Western water markets are local, by trading conducted through bilateral agreements.

In recent years, there's been significant movement towards developing more efficient

market structures and more organized trading platforms for agriculture water. Policy changes that more clearly define who owns what water, including groundwater, and when that water can be stored, withdrawn, or sold to another user could further facilitate water transfers and the most valuable crops, and provide greater incentive for more efficient water use.

In addition to the direct water transfer markets, there is reason for hope that market-based approaches can help improve water-use efficiency. In particular, the growth of consumer-driven agriculture may play a substantial role in agricultural water management. Dietary preference in the United States is becoming increasingly green. People care about where their food comes from and how it's grown. It's not just the foodies, hipsters, or hashtaggers, as the U.S. population has aged and become increasingly affluent, I'm talking about the baby boomers here, consumers have tended to spend more on healthier foods. There is growing evidence that our changing food preferences in the United States may lead us away from the type of luxury consumption, which has made us increasingly obese, and towards luxury conservation where we're willing to pay more on healthier foods grown under more environmentally friendly production practices.

Agricultural producers and markets have taken notice. There's been a proliferation of voluntary labeling efforts, all-natural, organic, local, sustainably harvested, dolphin safe, cage free, grass fed, hormone free, non-GMO, in addition to plenitude of local and regional labels developed to inform or at least to differentiate between products. Given the success of the certified organic program which boasts total retail market of more than $39 billion in the United States, and over $75 billion worldwide, it's not surprising. Similarly the number of farmers markets has nearly doubled in the past 10 years. There are more than 8500 currently operating in the United States, and the Department of Agriculture has invested more than $1 billion in over 40,000 local and regional food businesses and infrastructure projects. There is substantial interest in developing sustainability labels that recognize

water conservation and strong indications that the public is willing to pay a premium for sustainably produced foods. The questions that remains to be answered are: how much are they willing to pay, and is it enough to change production practices?

A few closing observations. Agriculture has been and will continue to be significantly affected by water scarcity. Quantity, quality, and the cost of delivery. Water scarcity is likely to have limited impact on food prices or availability for the US consumers, however in the near-term, it will have significant local and regional impacts in agricultural production. Existing support mechanisms can help offset many of these efforts, but not all. The decline of availability of renewable water resources will put additional pressure on agricultural producers to re-examine cropping decisions, invest in water conserving technology, and find new sources of water. And finally, improving the resilience of agricultural systems to drought will require continued commitments to conservation and the development of innovative, new policies, tools, and practices for adaptation. Thank you for giving me the opportunity to share some thoughts with you.

Panelist: Guillaume Gruere
Senior Policy Analyst
Organisation for Economic Co-operation and Development

I wanted to structure my speech here on three parts. First, talking a little bit, we heard all speakers talking from the agronomy and moving up to policy, and now we're going to go to the international policy area. You know, the growing importance of long-term water issues that I'm seeing in the political debates at the international level, I want to say a few things about that, and then move along to how you characterize this issue, how do you deal with those future or long-term water issues. We heard some solutions more practical, close to the level, but there's another way of framing it, is to look at water security and how to manage water risk for agriculture. So I'll talk about the project on hotspots and then I'll finish with some remarks on the policy side. But again I'm trying to complement what has been said before, and not repeating all the same solutions.

So the first thing I wanted to say is that in my view, although I've been in the water area just maybe three years, there seems to be a growing importance of long-term water issues in the political debate. As witness, we work for 35 governments around the world—it was 34 until last week, and now it's 35—and we have a committee called the Committee of Agriculture that decides what we work on. In a recent discussion in the committee, thanks to maybe Conference of Party last year on climate change, and the sustainable development goals, have grown from those agriculture minister officials towards natural resource as well as climate change. More and more, we are asked to do more on that, and so that's a good sign for us, but it's also a good sign that maybe things are changing, the link between ag and environment might be also shifting a little bit.

We had a minister meeting in April, we have those every five or six years, the last one was in 2010 and this one in 2016. The theme was better policies to achieve a productive,

sustainable, and resilient global food system. So we had about 40 ministers around the table, and it was co-chaired by the US and France, actually Secretary Vilsak was there as well is the Minister of France as the co-chairs. And so the ministers were invited to discuss what are the key issues for the future, and I was expecting a lot on markets because there was a lot of issues on markets in Europe in particular, and much less on environment, although the climate change will come up. It turns out that even those countries that always focus on trade and markets, the ministers of agriculture were actually saying the big issue for us is climate change, and then there's natural resource, and then there's all the other stuff, food security. So was kind of interesting to see, and of course it was all talking, and it wasn't very official, and I hope this will turn into actions, but there might be some impetus to move forward in those regions that we work in.

At the same time, we've seen some move in the business community. We've seen the World Economic Forum for two years citing water risk as a top risk for international economy. We've seen some global companies in the agriculture sector also taking steps to reduce their water footprints. You know about those. You know, InBev, PepsiCo, Coca-Cola, Nestlé, etc. We've also seen some pushing for disclosure of water footprint by those companies. So maybe also going into the banking sectors, we can discuss that in the next two days.

So anyway, there is a demand for more work on long-term water issues in agriculture. So I wish we would reframe those. So what I would suggest as an alternative to what has been presented by Mark and by other speakers here, is to look at it from a water security perspective. Water security here being defined as the avoidance of four types of risk—too much water, not enough water, too polluted water, and the risk for water related ecosystems. So that's how we define water security. Agriculture, of course, is dependent on the three first ones. If you don't have enough water, we are in trouble. If you don't have the right quality of water, you could also be in trouble. And if you have too much water in some cases, you

could also be in trouble.

So we look at that, we had this project that we were asked to work on water risk in agriculture, and we thought there's a lot of risk, there's a lot of heterogeneity in most types of water risk, the future projection of agriculture, the future projection of water, so how can we deal with all this complexity and heterogeneity. We thought it would be useful to look at hotspots. That's what some companies have actually done. They say, well, you know we are talking about water risk, but where is it in my food supply chain where there will be water risk? And so give them that maybe for 10 years some of the companies and policymakers haven't really looked at where the key risks are, or maybe why they have been in some countries but not in others. More on water quality, less on water quantity. So we have this project on future water risk hotspots for agriculture where we define this hotspot approach has been usable at any different level, at the national level if you have a big country, at the subnational level, at the state level, at even the street level. You think of, where are going to be the concentration of risk for agriculture, and where should we put more bucks to get some more results basically?

We also did in this project, we looked at the global scale. We were asked to look at the agricultural production and where are the water risks going to be concentrated in the world in the future. So we used basically a combination of projections from agriculture, from the IFPRI model, the impact of baseline, so meaning, no climate, nothing. That's for agriculture moving forward. And then on the water risk side, since we didn't really have any in-house modeling, we used literature, so we use like 65 papers, 110 measurements of water risk in the future, quality, quantity, and so on and so forth, each of them having red spots here and there on the maps. And you put them altogether and see a frequency of where there was risks are happening, and you end up with three countries that not surprising to everybody that works in water that are China, India, and the United States. When you get more specifically to regions, there are big, mega agriculture countries that also face a lot

of water risk. But when you look more regionally, there's a concentration of risk around agriculture important regions. So the actual so-called hotspots, we focus on this exercise is really Northeast China, northwest India, and the Southwest US.

Then we moved to impacts. So what does it mean if nothing is done? So we are doing currently some modeling at the international trade level, but we're also looking more specifically in those regions what it means based on evidence from the USDA, from other types of projections. So we have a paper on the U.S. Southwest that will come up in the fall we hope. That shows, you know, what is evolution you can expect for agriculture? You know, you think more high-value crop as you've seen in the recent drought, you would see less dairy perhaps, less livestock. You know what can we expect if nothing is done? Of course is not very realistic, but just to give a sense, just like a stress test in a bank, could we do a water stress test in agriculture in those regions and see what happens?

We're moving also in looking at trade because our countries are interested, New Zealand is interested to know what does it mean if China doesn't produce as much, etc. There is obviously differences in those three regions and for their abilities. So even though I'm thinking there are huge risks in those regions, actually California is not the same in northwest India for sure, and Northeast China as well. So we have to take into account the fact that farmers will not respond the same way, that they don't have the same capacity to move, etc.

But there's also a difference in the policy setting. It's quite interesting because, you know, I went to actually those three regions in the last three or four months. In China, we're doing a study on productivity, barriers to productivity growth in the future in agriculture, and that includes water policy actually. What I've seen in China is that there has been some progress on the political level to bring the water agenda more to the forefront and not just supply-side, now moving through regulating water on the demand side, being more efficient, being less pollutant. It doesn't trickle down so far to the rural areas, and it's going

to take more time, but at the central level, there was the number one document which is the official document every year. In 2011, instead of being about agriculture, which is every single year about agriculture, 2011 was about water, because it was a big, big deal. They had to take a position, then they took three red lines to limit the number of water factors. So in China there is some progress. In California, they already passed a big law that is being implemented. Last week when we were in California. Some of us discussed the Sustainable Water Management Act and now it's being implemented right now. It's going to be probably a game changer for agriculture in the future in central California. So it's already there. For us in India, it's perhaps a little bit behind, but there is some impetus to move, but it's still not there, and it still in development.

So to finish, I have a few remarks about the policy side. We've done some work on droughts and floods in the last few years, climate change, water, and ag, and groundwater in the last three years. So we looked at different types of policy at different levels. What I wanted to say here rather than talking about design options, is that two things frame our recommendation. One thing is that we think that there are different actors that are key to this service of resolving those water risks for agriculture. These are farmers of course that are also bearing the risk already and will bear the risk in the future, that has the responsibility to be part of the solution. There is a sector around it that's also taking actions in some cases, but perhaps not enough another's. And then there's the policy makers. So policy makers on the national level, the state level, and also cities taking more and more action with rural areas.

So all of these are to share some kind of a position, part of the responsibility of moving forward. They have different incentives, different response about the public, the government policy should probably step in where the other two actors are either incapable or unwilling to move forward in those challenges.

The second thing I wanted to say is that policies should also look at what's already

being done. There are government policies together today that are inconsistent with this objective of moving toward sustainable goals. You have some policies sporting, say, water intensive activities in food supports, electricity supports in India, for instance, that really are not compatible with us moving towards a more sustainable and productive types of agriculture. So we should also look at the backyard there. So that's all I wanted to say on the policy.

To conclude, these are my three points. I think long-term water issues are growing. Might be just the fashion, but I think it will continue to grow even though the extreme events that we heard about and the concerns are growing everywhere. I don't see just one tool managing water risk for our new culture, identifying and managing water risk, so hotspot approach is just one possibility. And then policy responses should be nimble and targeted taking into account does different actors. Thank you very much.

General Discussion
Moderator: Cortney Cowley
Economist
Federal Reserve Bank of Kansas City

Cortney Cowley: One of the things that struck me as you put together Mr. Rosegrant's keynote with some of the things we heard in this session is the importance of adapting, yet the rate of return, as Dr. Cassman pointed out, on some of the most common adaptations has declined, and that with climate change, a lot of those improvements as Mr. Hartley pointed out, could go away. So my question perhaps for Dr. Cassman again here, or anyone, is: are there some of these improvements that you talked about—the technologies, agronomics, biotechnology— that have better rates of return than others? And are there some that are more, let's say, resistant to climate change?

Kenneth Cassman: Well I think Mark's paper made the key point. That is that anything you can do to increase yields with existing water supply is perhaps the single most climate change adaptive goal you can work on. So the question really becomes I think the nuts and bolts of how you prioritize. You know you talk to scientists, and every scientist has the answer, and their research is best in the world. So you need some way of sifting the kernels from the chaffe, and I guess I'm just going to say here, we don't do a good job of it. I spent a lot of time on research prioritization, and when I look at what the federal government's spending, when I look at what's being spent internationally and in Europe, that is the Achilles' heel, that when you do get public financing, which is harder and harder, for public goods research in agriculture, you've got to spend it wisely, and I would just say that alone is something we've got to focus on like a laser beam and do a much better job.

Mike Young, University of Adelaide: When I reflect over what we've heard from the panel, the comments, and actually the superb paper, looking at essentially yield gaps, there's a

lot of discussion about environment versus agriculture and risks of climate change, of shifting environmental failures. And the question I'd like to ask the panel to think about carefully is, how should responsibility for risk be distributed? What I'm hearing, and this is specifically to the United States, nowhere else, just in the United States, what is the best way to assign risk? And as background, as you think about this, I think one of the most important innovations that really drove water reform actually in my country Australia was the development of a national water initiative that made it crystal clear who was responsible for bearing 100 percent of which risks. The nation agreed that climate change risk would be borne 100 percent by water users without compensation. That was a very clear message. It meant that we had to rebuild our water rights systems so that nobody had a guaranteed right. It's very fundamental, and it drove a lot of investment and a lot of planning. And when droughts came, the impact of drought was much, much less then it is even in this country, the United States. That's because we told people to plan for it, and that's what happened. When you plan for things that don't go wrong, clarity around the tension between environment and agriculture, if that responsibility is borne 100 percent by society, then governments have to plan to purchase rights for the environment. If it's vague that it might be through changes in things like endangered species legislation, the courts might impose costs on you or the state saw private investors might have to go in, then nobody knows what to do, so it's putting to too hard a basket and nobody plans and everything gets worse. So my question to you is, how should risk of change be assigned throughout the United States? Should it be taking 100 percent for everything by the federal government, 100 percent by states, or which bit should be allocated to private resource users?

Christopher Hartley: I'd be happy to take a shot. So if you look at the history of U.S. agricultural policies and production, going back to the 1890s with the progressive conservation movement, the initial feeling really was that the government should help to ensure that society did have the timber and water resources that they required. As a result,

between the wetlands reserve programs, the wildlife programs, the forest reserve programs, roughly one-third of our country is in federal lands. Most of those lands exist out in the west on the frontier, and if you notice the services that they're providing largely are water related and timber related. Unfortunately, they don't necessarily happen to coexist in the same place that those services are needed. Much of our population sits on either of the coasts where those resources are not present. That really does cause U.S. government to look at the need for resource protection, conservation, ecosystem, service provision, however you want to describe it, as something that has to occur jointly between the federal system, which is taking tax dollars to help preserve those things that the general public wants, and the private lands that are generating them. Our property rights system really has gone a long way in both providing those rights, or those responsibilities, to agricultural landowners to protect them. It wasn't really until the 1970s though that we had strong legislation on the books to do that. Over the past 35 years, you can see how that regulation, both through the Clean Air/Clean Water, Endangered Species Act, and several other regulation-based approaches has worked to some degree; it hasn't worked well enough. We need to extend our protections of those things that we feel are important—the clean water, the clean air, the species and habitat—to be more greatly accepted by the private sector, and how do we do that? It would be very difficult in this country to arbitrarily take or assume those property rights. It can be done, but it would be very painful to do it. There's far more likelihood of being able to do that through pricing incentives, through increased participation in greater policy opportunities to make it happen. I don't think that we could follow the Australian lead of assigning 100 percent of the risk to the producers, or to the water users. On the other hand, I don't think that we can wholly assign it to the federal government either, both because we don't have the budget resources to do it or the land base to make it happen. So looking forward, I really think we need to see a combination of approaches. Although it's not an ideal answer, it's one that I think in practice can and will work.

Guillaume Gruere: I think something, but maybe a little bit on the side of that question. There's a lot of discussion about the recently adopted farm bill; I mean some of you may be more aware about the details than I am, but shifting to once more support towards insurance. Other countries are looking at that with a lot of interests, but there's been papers and other literature also saying that because farmers insurance is basically supported more with this new program, that some farmers may not have as much incentive to adapt to climate change, they might also take a risky approach if they're going to be reimbursed if there are risk for their own production. I don't know if that's true, and people here may be interpreting that. But I think it's an interesting debate of shifting income support for farmers towards more of depending on the prices and on the products, which the shift that is happen with this new farm bill, that might happen in others. UK is talking about it when they go out of the EU. So it's a real debate at the ag policy community; I don't know if it's a good thing, but for climate adaptation and water risk it would also have an impact on what's happened.

David Opendahl, Federal Reserve Bank of Chicago: Thinking about water, I don't think I've heard us mention the largest source of water in the world, the oceans, how do those impact the feeding the world, and are there some potential game changers there in terms of technologies or, you know, you hear about lots of things in the past. But it doesn't really seem to be on the agenda right now.

Kenneth Cassman: So I live 7 miles from the first major desalination plant that's come online in the U.S., I don't know, the last decade or so. It's going to supply 10 percent of the water for San Diego, and there are others here, Pat I talked to earlier, that know more about the specific costs. The point is, there is significant water that can be had there. It just means that within the foreseeable future, and the technologies therein, it means if we were to use that for agriculture, it means a substantial increase in food prices.

Guillaume Gruere: I'm not a specialist of desalination either, but I've heard about the experiences in Australia where they have invested so much in desal in some cities, and

then at some, they actually are not using it, and they have to support the cost of investment continuing on. The factories have been built but they're not used as much because water is actually flowing some years. So it's important also to take into account this investment that can take a long time to….

Christopher Hartley: And I don't think you should only look at desalinization. I think there's an awful lot of recycled or reuse water available to wastewater treatment plants. That could potentially provide resources both in terms of added available crop nutrients, and clean water. Tertiary treatment is realistic; it does happen; and there are examples of it throughout the country. Whether that water is used directly on agricultural crops or for human consumption, both are viable options. There are several very good examples in the US where they're taking tertiary treated wastewater blending it with high salinity waters to use water that is available for agriculture. I think we really do have to look at all options, whether it's desalinization or a better use of the water resources that we have.

Pat Westhoff: Actually, I thought the question might've been more focused on aquaculture and what might be the future there. Currently, we've seen just very different trends in ocean catch of fish versus farmer-raised fisheries around the world, and a very major source of growth in meat and fish supplies in China in particular have been from aquaculture domestically farmed. What the future is there are, are incredibly important not just for China and Asia in general, but for Africa as well.

Cortney Cowley: One question I also had was, talk about in the long-term you keeping supply on pace with demand through improving yields. But here more recently, we've been in more an era of production outpacing demand. We've had a couple of years of really good weather all over the world, record production in the US, and then in some of our competing countries, and so my question is, in terms of water and food scarcity, are there any improvements to be made in, say, distribution and storage that can be done in some of these countries where hunger is even more prevalent than in some of the more developed

world? Can any of you comment on that type of the situation?

Pat Westhoff: Obviously treating loss and waste as we talked about earlier, is incredibly important. It's a mixed bag, let me be clear about that. If you reduced to the level of waste at the consumer level for example, that's a way of making existing food supplies go further it probably means lower food prices for farmers though too. You know so the effects are not all one-sided. Those are some of the attempts. But clearly as you're looking forward, it takes only really minor changes in assumptions about future trends on supply or demand to get a very different price environment. I think Mark would probably concur with that. We did some analysis three years ago looking at a very aggregated model, a much simpler model than the impact model maintained by IFPRI, and just tiny, tiny changes in assumptions going forward can be 10, 20, 30, 40 percent difference in food prices when you get out 30 to 40 years into the future.

Kenneth Cassman: With regard to food waste and food losses, I just urge caution in the assumptions about how far that can take us. First off, it requires changes in human behavior with regard to food. There's very little evidence of successful models of doing that. So you're out, and possibly it can occur, but if you're evidence-based, there is not much evidence that large investments in campaigns of some kind for food waste and food loss are very successful. But the bigger point is that I think the numbers, when you say one third of the supply is lost, it doesn't mean that you can gain one third. It means that you can cut it back a little bit. So it's not a large number, and it's highly uncertain, and I think that policymakers, particularly in the countries where food is going to be needed, you mentioned nine countries, Pat. Right? That essentially most of those are not countries where the ministers of our culture, the planning ministries, are going to put much credence in their strategic plans based on assumptions about how much food waste can be cut back.

Christopher Hartley: And I think that raises a larger issue, which is for a lot of these questions, the developed world including the United States, are sitting in almost the

catbird seat. We're talking theoretically about the need for environmental benefits and improvements in water use and water efficiency over the next 10, 20, 50 years. For many of these places that were talking about, they don't have that luxury. It's important that they feed their populations now. It's important that they have the water resources now. And not to do so definitely raises the potential for political instability both in their countries, but also the off flow effects into other countries that surround them. So from that perspective, I think it's all of our problems, and that we really should look more not only from the catbird seat, but really trying to understand what some of those issues are, and what they mean not only for us, but for overall world stability.

Kenneth Cassman: Your comment just provoked something I wanted to comment about, that my colleague Pat talked about. That is, if we go back to the late 90s, if you live long enough, work long enough, you see almost everything again. But in the late 90s, I'm an agronomist, and I would be at these meetings where there were economist telling us about their econometric models, and every one of them in 1999 predicted that the real food prices would decline into the foreseeable future to 2050. Every one. What changed? Well, Pat said it, it was China and biofuels. But China is not going to be there in that extent, and biofuels probably not. But I guess every model today is now predicting very modest, I would say changes. But what's likely to happen, for instance, I don't see how you stabilize the political situation in sub-Saharan Africa, the Middle East, and Southeast Asia, unless development there accelerates. I just don't.

So if that becomes an important policy concern of the West, and if you want to reduce migration of millions of people from leaving where they are and going somewhere else, we're going to have to accept this policy were going to have to accelerate the rate of development in these places so that people are not motivated to leave. And what does that mean? If that really becomes a policy goal of the developing world, it means that the rate of development has to be faster than what were projecting right now. So I guess that means that there is

all kinds of uncertainty in these projections, and I don't think that we should be shooting low and how were looking at the future demand. That's a recipe for disaster. You've got to build in a buffer. It's like humans are an amoeba on a Petri dish. You know how much do they need on a daily basis? Drop it in. It's not like that. Every one of them has a aspiration to eat like we're eating now, and it's probably not a very stable world unless a much larger percentage of the population get there more quickly than we're currently projecting.

Pat Westhoff: Just a real quick comment. I'd agree with most of what Ken just said, but point out that the uncertainty is in both direction. So if you're a banker in the Midwest, worrying about what's going to be land values in the future, yes, we could have a world where food prices increase with one set of implications, and also a very different world. Now several years ago, at the Farm Progress Show, there was a little board put up where people could put on their expected price of corn in five years time. This was in like 2013, I believe. The average price point was maybe six bucks a bushel. If people were making plans around six bucks a bushel of corn, that's what had to happen, it kind of explains how we get to where we are today. There's lots uncertainty in both directions on these things.

Daniel Heady, Kansas Association of Wheat Growers and Kansas Wheat Commission: One thing were dealing within the state of Kansas specifically is the shift in acres from one crop to another, specifically Kansas wheat acres are at their third lowest level since World War I. Were losing a lot of acres to corn due to genetics. You know they can move and grow corn further and further west in Kansas where it's dryer. An aquifer through irrigation and other processes like that has been depleted, and then there's talk about how there's not going to be any water in western Kansas anymore. A lot of that has to do with the shift from wheat acres to corn acres. So I guess, the bigger question I have here is, what you think the long-term effects of, like you are talking about, advanced genetics and how it's important to increase yields, but advanced genetics are also depleting water in western Kansas. So if we see trends like that, you know, is there a long-term impact, which I believe there is, but I'm

sure you guys have much better opinions on that than mine, but is there a long-term impact to that? And what opportunities do you see for crops like wheat and sorghum, which aren't as water dependent as corn? So I'm interested to hear your thoughts on that.

Kenneth Cassman: So if you consider a groundwater aquifer a depreciable asset, and you don't care if you sustain it, then you would not regulate withdrawal rates, and you would use it up for the highest value use at any point in time. And it seems to me that in many parts of our Ogallala aquifer that's what we're doing, and fine, that's one way to do it. In that event, your wheat will come throttling back and very quickly, as the cost of pumping, and aquifer depths decline to where maize is no longer profitable. On the other hand the other way to do it is to identify what the recharge rate is, and allow on average a long-term level of extraction and work on a way in which it allocated within the law. In that way, you would also see a shift back to more wheat I think because you're clearly over drafting now heavily. And so I think wheat has a tremendous future, it's just a matter of time. Someone said today that in Texas, there sustainable goal is to deplete the aquifer to 50 percent of its original capacity, and then the question is what after that? Apparently, they don't really have a plan after that. But that's kind of the goal. So I think it starts with, the answer to your question starts with the governance of the resource, and the market over the immediate term as to what crops are going to be going.

Session 2: Scarcity Beyond the Farm Gate

Speaker: Bonnie Colby*
Professor of Agricultural and Resource Economics
University of Arizona

Thank you so much, it's great to be back in Kansas City after number of years of not having come here. The driver last night pointed out the new free streetcar service that you've gotten in the city. So the streetcar is priced free. I went and took a ride on it early this morning, and it was priced free so that we increase ridership in the city and get it to be more fully utilized resource. For those of you in the room who work on water as most of your profession will recognize that paradigm— pricing a resource well below cost in order to get it actively used and spread economic development in the area. What we haven't done such a good job on, that you may do here in Kansas City with your streetcar, is make a transition to pricing that reflects changing scarcity values over time, and this signals the value of that resource across multiple types of use.

So my job is to provide an overview of points that will lead to a fruitful discussion on other water using sectors, how their water needs and their adaptations to water scarcity have implications for the agricultural sector. And so thinking about who those key non-agricultural sectors are, there is of course the urban sector which would include small businesses, commercial uses, small industry, and residential use within urban areas. The energy sector, very important, I'll emphasize, because any time that we managed to reduce energy consumption where very likely also reducing water consumption in that region. So considering the impacts between water and energy, often referred to as a water-energy nexus, is an important part of our responsibility in thinking about implications for agriculture and addressing opportunities to reduce water consumption in different regions.

So the energy sector doesn't look like a big chunk when we look at the pie charts in a few minutes, and it's very important that it has very direct linkages to water consumption.

*Please see the corresponding paper and/or presentation available at www.kansascityfed.org/publications/research/rscp/rscp-2016 for additional detail and referenced charts.

Industrial sector, which of course is a very broad category, including mining, manufacturing, and all kinds of other industrial operations. Then the environmental sector also won't show significantly on the water withdrawal graphs, that you have in your handouts, but the environmental sector is incredibly important in driving policy and creating different kinds of constraint of water use and all the other sectors, hopefully in general, to support public values related to habitat, clean water and water for recreation.

I'll talk a little bit about adaptation, so scarcity at the general level. We have several other experts on this panel who think hard about municipal and industrial water uses, and will also talk about adaptation. And then I'll also be again emphasizing the theme of water trading as an adaptation mechanism, the ways in which that's influenced agriculture especially in the Western United States where trading is active and has made some interesting changes in incentive signals related to water use. And then simply concluding with the little few thoughts on navigating the changing water future.

So I learned to my dismay that the printouts actually had some problems, but we are, we were able to correct them and show a graph version here in terms of different water using sectors. Okay, water withdrawal by category, pie charts in the world, if you look at U.S. versus the world, you notice agriculture is a much smaller subset of water withdrawals than it is globally. The urban sector is somewhat similar in percentage. Energy sector is broken out in the data that we have at the national level in the United States. Not so for the world sector; to have that level of detail, you'd have to go into much smaller subregions on the world scale. But you can see kind of a general configuration. Urban sector is small as a portion of the pie, but of course important for social stability, for the economic engines that drive those urban areas. And the industrial sector differs quite a bit both in its nature and the amount of water withdrawals it accounts for in the US versus the world.

Water withdrawals by categories in Federal Reserve Bank districts, I picked this to think about of how different parts of the United States differ from one another. We've got

Federal Reserve District 10 which we are sitting in, Kansas City as its headquarters, with urban you said only 4 percent; and then the area that represents the urban Southwest, California, the Pacific Northwest, District 12 has urban use rates of 14 percent of the total. Again, the green area on these graphs isn't large relative to the blue area representing agriculture, but the fact that we have proportionally 3.5 percent more urban water use in some parts of the United States than others has a huge amount of implication for competition for water in the ways that that might be communicated to agriculture. Water use by sector— again, this one focusing on the United States, and this is a very broad brush overview. One of the interesting things we see here is changes in the thermal electric sector, that's the light orange on the bottom of the graph, the way water is been used in that sector over several decades. That's mostly power plant cooling water. Now especially in areas where water costs are increasing, water values are increasingly transmitted through different kinds of incentive signals. There's a lot more emphasis on using that cooling water multiple times and having finer tuned more water, more intensive technologies for recycling cooling water.

You notice the declining per capita use in the United States that began way back in the 1980s is driven by a number of factors, including declining per capita use in the municipal areas, partly that's due to new housing stock, different landscape preferences, also changes in agriculture and in industrial water use. So we have declining per capita use in the United States, and declining use, you can specifically see in the thermal electric sector, and also to a certain degree in the municipal sectors. So this graph is meant to remind you of the point that several other speakers have already raised. As we look at adaptation mechanisms, we want to think about, are we creating net new water available for other uses, or are we merely changing the amount of water that has to be applied but were not increasing the amount that's made available downstream? So I guess the key point here is that water savings approaches, as we call them, it might not free up water for other purposes.

As we think about adaptations, we want to focus where possible on reducing water consumption; we want that water to be available for habitat, that water to be available under a voluntary agreement with an irrigation district or an individual farmer to be able to, for urban use, during a drought for instance. How do we reduce the consumptive aspect of water, not merely the withdrawals aspects? And conveniently, most water data at state, federal, national scales is available on water withdrawals. This is something we're working on in the United States and elsewhere in the world, how can we more carefully account for the consumptive portion of water use and track that when water moves to new uses? Most of our state water, change of water right processes in the United States will look at the consumptive use carefully when a water right is formally changed. This change of water right processes tend to be slow and cumbersome. They're good for permanent transfers like when a city needs a block of water to support urban growth over the long haul, but I would argue that a lot of the economic resilience and the benefits of the ability to adapt to water scarcity comes from short-term transfers made with a little bit of lead-time. For example, in our basins around the world that rely on snowpack, we see in April we've got a lousy snowpack. What are the arrangements we can make in April and May so that the high-value water users can make it through the summer without a lot of economic loss and damage in their regional economies? So as we think about this temporary and intermittent transfers, to keep local economies robust, we've got to be thinking about water savings in terms of withdrawals, and consumption.

So adaptation to scarcity, the water conserving practices and technologies available in the various major industrial uses, as well as in your urban use, and of course as well as in agriculture, are always evolving. They are numerous, they differ by sector, they differ by part of the world. For me as an economist, what I think really is worth focusing on in this group is the incentives that drive those adaptations. What is it that makes a group invest in a different kind of urban water recycling technology? There all the capital expenses. Go

through the process of getting a new plant permitted. What kind of incentives does it require to stretch a region's water supplies in a different way?

So not focusing on the practices and the technologies in this talk, I mentioned them a little bit in the paper, some of the other panelists for the other sessions will also have something to say about that. I would say their incentives are the key. And this little diagram at the bottom is probably familiar to most of you who were dragged through one or two microeconomics classes. When water demand in the region, for example, is moving upward and outward, usually you'd expect price to adjust to reflect that. If you have a system of allocating and managing water where price doesn't reflect the increased value of the water, that's going to have to come out in some other form of incentive. So if water costs and prices don't reflect scarcity, we've got an issue and it's going to have to be some other mechanism that decides who gets water, those existing what I would call now artificially low prices that aren't reflecting scarcity.

So other kinds of incentives that signal water scarcity, one thing economists would love to be able to do is be able to gradually alter water rates over time in a way that sends the scarcity signal that is simply a signal about covering the cost of infrastructure, the energy, and other costs to deliver water. But water costs are paid by end-users in lots of different ways. Many farmers are drawing from private wells. Those costs rely on energy costs. Urban water users pay water bills, many of us in the room get a water bill. There's been some very good studies that show that most of us don't know how to interpret our water bill, and couldn't really say what an additional unit of use within a particular month would cost us so that we could make a decision on whether it's worth it to be using water in that particular way.

So water costs paid by end-users can be useful as a policy instrument to send scarcity signals in certain circumstances, but those circumstances are relatively rare. They're relatively rare in the urban sector; most water utilities change their rates because they've got

to think carefully about the revenue stability, but not really thinking about shifts in water supply and demand in their region, try to signal that kind of scarcity. In my view, that's the best kind of mechanism for signaling scarcity that's changing over seasons and water years in a region, whereas if you do have active trading and water entitlements in a region, and the value of that water goes up and down over time reflecting wet and dry years, reflecting the entrance of a new major water user in the region. And that happens in some areas in the United States.

A third category I've labeled on this slide is all these non-priced mechanisms. We pay for water, but we pay for it lots of different ways. We pay for it through a lot of new mandatory cut back regulations, the kind of things that ask you to water your lawn only every other day or several times a week instead of every day, or regulations for industry, other water users, sometimes through agriculture as well. There is a lot of litigation involving water. I take that as an important signal of scarcity. Additional administrative proceedings debating who's got access to the water under what conditions, when do they have to relinquish some of it for endangered species, and political maneuvering, and civil unrest I think we can't underestimate as a source of tension and a high cost when it comes to water. This particular photo is one of my students brought to my attention and this is in Lima, Peru. It's called the wall of shame which is a very strong name for a structure, but it represents two different parts of the city, one of which has no indoor plumbing, the other which is a relatively affluent area with lots of nice landscaping and the ability to use a fair amount of water in a residential setting. Where you have situations where there's a lot of disparity in access to water in the same area, that leads to a lot of hidden costs— costs for business, costs to society, and the functioning of civil discourse and decision-making as well.

I think one of the things that's come out of the California drought, we may hear a little bit more about this from Ellen, is the public and elected officials became much more aware of the very differential impacts of drought, and the hardships created by droughts, on poor

income and largely minority communities versus on larger, wealthier areas. We could have figured that out if we thought about it ahead of time, but the drought really made it clear that one of the things we needed to think about in addressing water scarcity, and thinking about the values signal that's transmitted for water, is some of these disparities in access, just as we were talking about with food. People in different parts of the world want the kinds of conveniences related to water that some of us, certainly myself, take for granted on an everyday basis. I would consider these incentive-like signals.

I have a file on my computer, it's called "Paying for Water," and you to think it would be one of the databases that I have with other names, about water prices over time and how they've changed over several decades, prices at which water traded, what contributes to the changes in those trading prices. But that failed, "Paying for Water," is the other ways we pay for water. Sometimes it's cost of human health, sometimes it's in the course of civil unrest, whereas between different jurisdictions. So I'm going to argue that will be paying for water in regions where we have water scarcity, and it's up to us to configure how we make those payments, and we come up with sort of an orderly system that signals that through financial incentives, or is it going to be coming out in other avenues.

I happened to be in Barcelona when the tankers had to deliver water to the city because their reservoir levels were too low to put water into the city water delivery system. That was in 2008, and that was also a time when they were having a lot of protests over the potential to build a pipeline that would affect a major river system in that part of Spain, on the Catalan, Catalonia, Catalan, and the Ebro River pipeline conflict. So this was a relatively benign conflict; it certainly shut down business and affected business activity during the days that it was going on. But it's these kinds of conflicts and civil unrest that take a more serious turn, that drive me to think about, can we use the economic mechanisms that we've had in a more clear, more workable fashion so that we avoid these other kinds of disruptions.

So water trading is an important scarcity adaptation mechanism, especially for the urban sector, the industrial sector, the energy sector and the non-agricultural sectors. I would argue that by thinking about capital, water and exposure to risk, and this is already come up in a clear way during some of the previous questions in this conference, we can do better in creating resilient local economies. Regional economies are interdependent; most farm households in the United States and other parts of the world also depend on a thriving nonfarm economy. Sometimes it's because household members have jobs in those other economic sectors; others simply the goods and services that are provided between the farm and nonfarm sectors in a region. So the regional economic interdependence leads me to think we need to do a better job at communicating value signals across the water using sectors.

Long term water trading agreements, that is agreements that are set up to go over decades in which water moves out of agricultural use temporarily and under specific water supply circumstances, are one of the things that I would argue are most useful in terms of stabilizing water supplies for off farm water users such as cities and major industries. And those can be structured also to stabilize variation in net farm revenues. In other words, the payments occur in different ways depending on whether or not it's a year in which the water is actually not being consumed by crops, and the payment is made in years in which it is being consumed by crops. So there could be stability; there are some really nice studies on risk management and farm revenues with these kinds of contracts, and they certainly have an impact in terms of risk for water supplies in other sectors. In the paper, I called those, they have several different names; some days we call them dry year option contracts, contingent contracts, water being used on a temporary and intermittent basis to get a regional economy through what would otherwise be a much more devastating hardship due to drought. So I view the ability to make these specialized kinds of arrangements as a pressure relief valve in a regional water system, interacting between the farm and the

nonfarm sector.

We do have water transactions throughout the Western United States, mostly in isolated pockets where water of particular types of entitlements are traded in specific geographic areas. But I thought those of you who don't make your living thinking about water every day might have interest in seeing some kind of transaction patterns. There are a lot of good statistical models that describe these and how prices work in these different areas. But one thing you'll notice is the environmental volume is kind of the brownish orange at the bottom of these bars. Look how it's grown over the years 1987 through the end of this particular database time period 2010, grown quite a bit, municipal participation. These are leases, by the way, meaning these are short-term transactions; they're not permanent changes in the ownership of a water entitlement. The environmental sector has become much more important over these periods, and the volume changes year-to-year. These happen to be seven particular states in the United States, the Colorado River basin in this case but one could create, and in fact I have similar charts, for all of the states in the West. These in particular are interesting and this is a basin that I work quite a bit in and it's done some great innovative things with regard to sharing risk, and risk of exposure to water supply shortages and money.

So water trading in the Western United States is characterized by a few dozen active areas. These areas primarily started out because cities were growing rapidly; sometimes they permanently bought out farming land back during the 1950s. It was most common to buy large tracts of farmland and transfer the water entitlements for urban use, which generated a lot of ill feeling and economic change in the areas where those occurred. But that was part of the initial impetus for water trading in the Western United States, and then high-value agriculture, another impetus for developing active trading mechanisms, environmental needs, including water quality, endangered species, and habitat needs, the need to meet interstate compact obligations. And tribal water settlements is another important impetus in

the Western United States where you have a tribal reservation with a clear legal entitlement to water that hasn't yet been satisfied in terms of wet water. That can be an impetus for water trading.

Pricing and volume patterns in these areas are rational; that is, you see much more volume traded, higher prices in dry periods. Those trading prices reflect real estate markets, they reflect profitability patterns in agriculture such as changing crop prices, they also reflect changing energy prices. Outside of these active areas, we have sporadic trading and irregular pricing patterns.

Thinking about a changing water future, certainly we need to place emphasis on improving our existing water trading institutions, especially their ability to be responsive in the short term to avoid crises that we can see in April are going to be occurring in a hot, dry summer. What are we going to do, how can we reduce the damage that that situation would otherwise cause in the regional economy? Custom crafted water banks, we have some of them, well you have them all over the West now, operating sometimes within very cumbersome state and federal regulatory systems, have been able to solve local problems in an innovative way. They provide alternatives to farmland buy-in dry programs, they provide streamlined procedures for temporary and immediate water trades. I would say that I'm optimistic. I started working for the California Department of Food and Agriculture on water transfers in agriculture in 1978, and I've seen so much positive change in water policy, and the ability to communicate water scarcity through economic signals, and of course changes in technology regarding water use. So I'm an optimist about navigating this changing water future, but I think it's got to be done through an incentive system. These are some of the generations that we need to think about in being brilliant and innovative in these trading systems. Thank you.

Discussant: Bradley Udall
Senior Water and Climate Research Scientist
Colorado State University

Good afternoon everyone. It's an honor to be at the Federal Reserve. It's an institution which I hold in the highest respect and regard. I want to thank Dr. Colby for writing that paper. It's a really well done job, and has a great set of references in it. I want to talk about each one of her sections in her paper. She talked about water use scarcity and competition; she talked about adaptation options; and the third part was about potential effects on the farm sector. So there are three points I want to make. I want to talk about climate change as it affects scarcity, and I've spent the last 15 years of my life looking at the connection between climate change and water resources. I want to talk about the critical difference in the solutions that are needed for consumptive uses versus non-consumptive uses, and many of these alternative uses outside of ag are actually non-consumptive uses and there is some interesting suggestions about how to solve those problems that don't apply to the ag sector. Then finally, I want to talk about ag's role in providing solutions.

I looked up the Wikipedia page on Fed Speak. Have any of you seen that page on Fed Speak, also known as Green Speak in honor of former Chairman Alan Greenspan. And Chairman Greenspan once said that when he spoke he tried to mumble with great incoherence. You may also remember he testified in front of a senator one time, and the senator said, "I understand you, Chairman Greenspan." And Greenspan said, "If that's the case, then I misspoke." I'm actually going to try and do the opposite about that with respect to climate change in my opening point here. Bonnie's first sentence in her paper talks about climate change, her first sentence. The second sentence in this document implicitly talks about climate change. I actually had to stop working on climate change for a few years because it was so depressing. I'm now back in it because there are solutions at hand that are

optimistic. We actually can fix this. We've had a lot of discussion today about climate change, and Paris even came up. So I'm now an optimist about it. But the reason I originally focused on it is the connection between climate change and water. There is no greater impact that climate change has that is on water resources. If you add energy to the Earth's system, you're going to change the water cycle. It's energy that drives that water cycle. So you're going to end up with more floods and more droughts, changes in water quality, changes in runoff timing, reductions in snowpack. You get the whole litany of changes, and arguably it's the most important set of changes that come out of climate change at us.

There's a term now, stationarity is dead with respect to our water records, with regard to our ability to use the past to predict the future. The story I like to tell best is about British Airways Flight 9. In 1981, this 747 was at 37,000 feet at night over Indonesia and it had the unfortunate occurrence of flying under cloud of volcanic ash. It's the first time this had ever happened to an aircraft. The result was that all four engines shut down, and after four minutes, the captain came on and he said, "Ladies and gentlemen, this is the captain speaking. We have a small problem. All four engines have stopped. We are doing our damnedest to get them restarted; we hope this does not cause you too much distress." I like to tell that story because it's an example of stationarity is dead, right? The past is no longer a guide to the future. And that's what's going on with water resources. All these records that we have that tell us how much water, in what form, what timing, as we perceived in the 21st century, those records are less and less valuable to us, and that's what makes climate change and water so daunting and so difficult to solve.

You know, I just like to put out a plug here for the Federal Reserve, which is, because of all the discussion here on climate change and ag, maybe another seminar that you hold, another workshop like this should be done on ag and climate change. The University of Nebraska at Lincoln right now has a great document out. My own institution CSU is actively getting into this field, and we call it "Climate Smart Ag," and it's a generic term out there,

how does agriculture adapt.

So my second point is going to be about adaptation methods for water scarcity. Bonnie talked a lot about withdrawals, that's the data we have. We have data on withdrawals, and not very good data on consumption. And the fact that we don't know about consumption, the fact that water gets recycled multiple times, if you're in Mississippi downstream, you're drinking somebody else's sewage. Let's be blunt about it. We have utilized natural methods to purify that water, and that's what goes on in the water cycle. It makes accounting very difficult. If you are a city though, most likely a large portion of your use is not consumptive. That water is actually going to get recycled at some other point in time.

That to me gives me some ideas about solutions for this. In the western U.S. now we have two great examples of cities trying to recycle water at a higher rate than naturally occurs. Aurora in Colorado actually built about a $300 million plant. They didn't go quite to direct potable reuse, but they could have if they wanted to. And Orange County has something very similar in California. We have the ability to actually speed up this natural recycling of water. That's not an ability we actually have in the ag sector, right? In the ag sector when you consume water, it's a zero-sum game, and that's where you end up with markets, and all kinds of dry year options and other abilities to try and change a zero-sum game into at least a game where people don't feel like they lose as much and gain as much. So I'm just going to suggest that potentially on the non-consumptive side, we begin to think about other solutions—solutions that allow us to speed up this natural recycling that happens much quicker.

I also want to talk briefly about this notion, the false lure of efficiency, right? Because of the recycling that goes on in water use, there's been this idea for years that somehow if you make one far more efficient that that benefits everybody else without understanding the downstream effects. Now we now know that there are multiple papers out there that if you

install sprinklers, or if you install drip, often times what actually happens to that farm is the consumptive use on that farm goes up, and there's a couple of reasons why that happens if you think it through. One is you remove the labor constraint. All of a sudden you can flip a switch and deliver water as opposed to having to go out and flood irrigated, hire somebody to go out and flood irrigate. And another reason that goes on is you remove a spatial distribution issue. More often than not when you flood irrigate, you under irrigate one part of the field and you over irrigate another. When you install some sort of technological "efficient" solution, all of a sudden that problem goes away. If yields go up using some kind of efficiency technology, your first guess should be used more water. It shouldn't be that somehow you made water appear magically.

Let me end and talk a little bit about ag's role in providing solutions. I bet everybody in the room knows Willie Sutton's famous line about robbing banks. "Why'd you do it? That's where the money is." So in my state, if you're a non-ag user, and you want water, where are you going? You're going to ag to find that water. That's what's going on everywhere. Where I live, ag has 70 or 80 percent of the water. That's where people are going to start looking for where the opportunities are. And the ag sector thus has a very interesting opportunity. Bonnie says in her paper, "The record of water transactions in the western U.S. demonstrates that agricultural sellers and leasers typically command a price that far exceeds the net returns of nonfarm water use." So there is an opportunity there. She also says, "The agriculture sector has a unique opportunity to play a leading role in shaping adaptation to water scarcity."

In some work that I've been doing recently, there are four ways you can come up with water out of the ag sector. One of them is deficit irrigation. In the case of hay crops in the West, which are a predominant use of water in the upper Colorado River basin, something like 90 percent of water in the upper Colorado River basin goes into growing hay, both alfalfa and other grasses. You can deficit irrigate, you can actually cut off midseason and

decide to supply that water somewhere else. That's one option. You can do regulated deficit irrigation, which is a fancy term, for example, growing wine grapes or certain tree crops where you literally water them at certain times of the year and not at others, and you come up with a higher quality crop. So deficit irrigation is one possible way to come up with water. A second way is crop switching. That NGO community in the Colorado River basin is very interested in trying to figure out how to facilitate crops switching with agricultural producers. This is a big lift. You get to change a farmer's entire value system when you do this, and it's not easily done. If the NGO community is interested, especially with regard to alfalfa that's a perennial, that certain parts of the West use 8 or 10 feet of water every year. Could you switch that into some other crop, monetize the water savings, and then continue to grow something else? There are a number of examples of temporary fallowing in the West, Palo Verde Irrigation District on the Colorado River does it. In my state, there is an entity called Super Ditch, which is a conglomeration of about 10 different ditches that's trying to do what we call some rotational fallowing where people won't grow for a year or two in lieu of payments from cities. You can also pursue this efficiency game that I spoke about earlier, but you've got to be careful with what you do because you may very well facilitate increase consumptive use, and you may end up with less water than you have.

Let me end with a case study that actually I don't think has been publicized anywhere, and it's on the South Platte in Colorado, so Eastern slope. Xcel Energy, a large energy provider in numerous states, in our 2002 drought ran out of water in the wintertime. They had never run out of water in the wintertime. The river had previously operated as a free River, you could take whatever you wanted. This is a huge power plant they were trying to get water for. It's a 550 watt, coal-fired power plant, very important to their grid. In 2005, they entered an agreement with what's called the North Sterling Irrigation District, a 25 year agreement that had a small annual charge that went to each irrigator, and then should they decide to invoke this dry year option, about a $425 per acre foot charge. To date, that dry

year option has never been exercised, and the farmer in this irrigation district is now $1.6 million for the better. It's not a bad deal. Xcel gets the reliability they need for the dry year, and the farmers get money for whatever they want to use it for.

So let me conclude with my three points. One, climate change, it's a really big deal when it comes to water resources; it's a big deal with regard to ag. Solutions are at hand; that's a whole other discussion out there, but it's a big deal. You've heard it today from multiple people. Let me make one other quick point on here because I spoke recently at a conference where everybody was talking about climate change, and as soon as I said humans cause climate change, that's when the controversy arose. Scientists have spoken. We know humans are causing this. So let's be on the same page on that. Two, consumptive versus non-consumptive uses. I think it helps to separate those two out and to think about recycling, especially with regard to non-consumptive uses. Finally, agriculture has got to be at the center of solving these problems for these other industries. For example, Florida 14 percent urban, 9 percent energy, but ag has the water and in a healthy, effective government area, we would get ag at the table and figure out how to make a better world for everybody. So with that, I will leave you and I appreciate your time.

Discussion with Bonnie Colby and Bradley Udall
Moderator: Craig Hakkio
Senior Vice President and Special Advisor on Economic Policy
Federal Reserve Bank of Kansas City

Danny Kluthe, Lower Elkhorn Natural Resource District: Brad, I find it kind of interesting, Nebraska has got tremendous aquifers, but back in the 70s they introduced to the Natural Resource District. There is probably 30 some Natural Resource District's, and our job is to monitor and protect groundwater. Now other states can look at us and see what we're doing, but you say going after ag is a good place to look for water. When we are monitoring, and we collect data both spring and fall, we've got a really good handle on what are groundwater is doing. When there's a shortage of groundwater, we allocate, the irrigators get allocated. They've got meters on, and we take care of our groundwater. That's why Nebraska has got the unique and tremendous aquifers that we've got. My question is why don't other states maybe take a look at what Nebraska is doing with the NRDs and maybe follow suit?

Bonnie Colby: I'll put in a plug for the NRDs as well as several of them in the state, a number now, maybe even half a dozen have very innovative trading programs within the NRDs that allow for voluntary movement of water in a way that reduces the impact of dry years, having that downstream compact call facing your area. So it's a good question why there isn't more. I can speak for Arizona in that we chose to regulate highly intensive urban areas, the state and agriculture right around them, and we thought the problem would never spread to outer areas of the states. So in the unregulated part of our state we now have severely declining groundwater levels, investors coming in planting alfalfa from all over the world. So when you want to go into more tightly managed water, you want to think a long ways ahead about whether it ought to be statewide which is what you've done in Nebraska,

although I know that your constraints vary by district on whether you think you can limit it to just specific areas that are currently facing a lot of competition for water.

Bradley Udall: I'm not an expert on the High Points aquifer, but there is one place that the water table is not declining, and it's in the Sand Hills in Nebraska, right? So one place where it's being managed at least for the long-term, whether or not that's a good thing is another matter. If you want to mine it, for example.

Danny Kluthe: Basically, over all of Nebraska it's being managed very well. And when you talk about water banking, I heard a number of the speakers talk about water banking, we are discussing that at quite length, and water banking is awesome and I think we've got to be careful that when farmers want to use that as an income to sell it to somebody, you've got to be very careful that the person who's buying it, that they are not in an area that's already over appropriated. So there's, you know, it's probably a great tool to use, but we've got to be foresighted to find out that we aren't letting something happen that's going to make things even go further south. All of these speakers today were tremendous, a lot of great insight into water, and water is important. People think it's infinite, but it's not. It's finite. So keep up the good work, but I think we've got our work cut out for us when we talk about protecting water and especially groundwater.

Maureen McCarthy, University of Nevada: Bonnie, a question for you. The water trading I think that you discussed and presented in your paper was used by prior appropriations as a method of stimulating the movement of water from senior water rights to junior water rights. So my question to you would be, is it sustainable in areas that don't have that level of prior appropriations? And then, also following on that, is the concept of the beneficial use. Do you see us getting away from the prescriptions of beneficial use so that we can address things like a consumptive versus non-consumptive uses?

Bonnie Colby: So the first question, does water trading make sense where there is not a prior appropriations system? I would say absolutely yes, the economic impetus for

water trading comes from a different tolerance and different degree of cost from being exposed to a water shortage. So even where there is not a difference in seniority and the water entitlements themselves, where you have different types of water users including different kinds of crops. For example, orchards versus some annual row crops. There can still be a strong incentive for trading to occur even just within the agriculture sector. That difference in the costs of what a user bears from exposure to shortage is part of what drives the impetus, especially for trades like the one Brad described with the power plant in the irrigation district. That attempt to build more reliability for the non-agriculture water user in that case, and the revenue stream is stable, the revenue stream for the irrigation water users.

So your second question is about beneficial use. It's true in some parts of the world, and you will hear a lot more about this from Mike, that when there's enough economic benefit created through trading, water users can be willing to move to a different kind of entitlement and water accounting system. They can see that the benefit for the regional economy, and the resilience built in, would or maybe able to get away to some degree from strict reliance on beneficial use. So, we see that actually within water trading systems in the Western United States within some of these local water trading areas. They're doing a different kind of accounting which is how I'm interpreting your question about beneficial use.

Bradley Udall: Let me try and channel Ellen Hanak who I think has written on this. And Ellen, you can correct me because you get a chance to come up. But beneficial use is one of the great tools that prior appropriation has because you can change the definition of it. You can say that some existing uses are wasteful and no longer beneficial, and we don't have that kind of tool with much in prior appropriation. So it's something I would not want to easily give up. Ellen, I'll hear from you later.

Audience Question: So, when you're talking about water transfers, in addition to the impacts to agriculture directly, a goodly portion of that water if it's flood irrigated, goes back

into groundwater recharge. There's a potential for substantial environmental impact of those water transfers as we've seen in the Central Valley, where we can switch either over to more drip irrigated systems in orchards, where we're now expanding the number of acres and were not actually saving water, but we are seeing substantially less recharge of groundwater resources. How do you deal with that when you look at best uses of water and transfers, particularly from agate to urban?

Bonnie Colby: So that's again where we want to pay attention to what a lot of the speakers, including Brad and I both, recognize as you need to look at the consumptive use patterns, what is returning to the aquifer, returning to the downstream surface water system when that farmer changes technology. And water moving outside the watershed where it was originally used in agriculture, of course, is another interesting example, and I think you were referring to that as well. By the way, I would simply say that Chris's job in office exists within USDA is one of the reasons I am optimistic about our ability to solve some of our natural resource problems. There's a specific emphasis on use of incentives, and voluntary trading agreements.

Bradley Udall: The engineer in me would say, to the extent we can, we want to do a full water balance on the transaction in both space and time. And one of the trickiest aspects of Western United States water are these return flows that can show up months after the water was actually diverted. And is that a good, or is it a bad? It depends on your perspective, but you need to account for it in the mass balance.

Panelist: Ellen Hanak
Director
Public Policy Institute of California

Good afternoon. So now, instead of what I was going to talk about, I'm going to talk about beneficial use. I want to thank you first for the invitation to be here. My husband works at the San Francisco Fed, and he was very excited about my coming out here. My first time in Kansas City. So what I thought I do is really kind of focus on the really non-ag part of the economies, and I can do that best by talking about advanced economies, especially California and other western states a bit, Australia, Spain, and the sort of places that have pretty high per capita incomes. I think you'll see quite different challenges in the urban sectors in developing countries where water and sanitation systems in urban areas are challenged in many, many ways that we don't have challenges. We don't have those basic challenges. So thinking about water scarcity in places that are water scarce, and that are used to droughts, and that have variability in their precipitation.

I have five points for you, and my first one is that places like this tend to be pretty well able to handle drought. It doesn't mean they can't get better, they can. And a worse drought can really challenge the system, but it's not a big surprise. So just as a comparison, if you look at the southeast of the U.S. back in the mid-2000's, those of you that remember, Atlanta, Charlottesville, places like that, were in terrible shape, it's because they're not really used to having droughts. So they just did not have a lot of drought planning and drought resilience plans, they didn't have a lot of supply redundancies. Western states tend to have that at this point, and that's true in Australia now. They went through much bigger drought; the millennium drought was longer than they'd been used too so it taxed them and it kind of led to some needs for initial investments and innovations. But that's the basic idea which is why even though the New York Times told you many, many times during the California

drought that the economy was going to collapse, it didn't, and you heard from Chris who was summarizing a little bit on California agriculture which really does need a lot of water, even the ag sector managed to adapt without a whole lot of loss of ag GDP, probably 1 to 2 percent of ag GDP was lost.

In the urban sector, gangbusters, yes we do depend on water, but not in a highly intensive way for most of our activities. That's been partly the shift in a lot of water scarce places toward nonfarm activities that are not highly water consuming. And then, there has been a lot of planning and redundancies and sort of the idea of, now I'm getting to point to, supply portfolio approaches. So a little bit not as sophisticated as what you all who are in the banking sector do, but really thinking about risk return, or in this case, costs versus reliability. So urban areas have a pretty high willingness to pay, and ability to pay, and they've invested in a lot of stuff. So in California, we had a big drought from 1987 to 1992, and that was kind of a wake-up call for the next generation drought resiliency investments. You saw massive investments in additional local and regional storage both above ground, below ground, the ability to store and conserve water, urban areas are able to do that under our water laws, so a lot of investments in reducing indoor water use. In particular, getting water in the ground and getting it into some above-ground reservoirs, and a lot of investments in redundancies in terms of regional interconnections. So, ability therefore, if one supply sources out, you can share with your neighbor and that all works out, and basically really stretching the supplies and diversifying that way.

Then in some places, recycled water use. I'm going to differ with Brad here because I think actually where recycling makes more sense for urban areas, is when it is a consumptive use that's lost. So California happens to have most its population on the coast. That's the really valuable savings because you're keeping the water that you're already highly treating in order to not pollute the ocean, you're treating it a bit more, you're getting it in the ground or into storage, and you're reusing it. The folks that are doing it upstream, and probably the

folks that are doing it in Aurora, they are actually robbing their downstream neighbors often of water supply. So Orange County gets less water now because the folks upstream on the Santa Ana are recycling. That doesn't mean it's not a good strategy from other perspectives, but you have to think about the consumptive use aspect of that.

Second, what you're also seeing is industries that are water intensive investing in needing less water. So you've seen this in the energy sector with a move from the once through cooling to multiple recycling, dry cooling, or sort of what is it called, wet cycle, there is some other reuse kind of technology with that. You're seeing it in the brewing sector in California where the craft breweries for example who are often located in places that don't have a whole lot of water supplies, they have incredibly sophisticated processes for basically reusing as much of the process water as they can, and they can sell that as green water efficient. So there can be some premium on there, you know they can recoup that cost.

Third point is that droughts do provide opportunities to get better at this, and what we're seeing in the California drought are a couple of things. One very interesting thing is in our energy sector where they had thermal electric cooling, and they had not really been looking at their supplies partly because we hadn't had surface water curtailment in a long time in California. So this was a time when there really wasn't water available for them to access, and a lot of concerns about how do you deal with this? So emergency measures were taken to make sure everybody got their water to keep the power plants able to cool. But what's been happening also is more strategic planning about getting on recycle water uses.

What you're seeing in the urban sector, some additional investments in this sort of broadening portfolio, but also I think the big frontier now is going to be figuring out how to have a better pricing strategy, because a lot of them have been in the red. There was so much conservation, partly motivated by a statewide mandate that many of them would not probably have gone that far in conservation on their own based on their local conditions, but what they found was that a lot of the sales went down far below fixed costs and the

ability to cover fixed costs. So now they're having to sort of reboot and figure out how do we still provide pricing incentives and be able to cover our fixed costs, which in the water sector in the urban areas is 70-80 percent typically of total costs. So you have this trade-off between providing price incentives and covering your bottom line.

Fourth point is water vulnerability. You do see it in some places, and one of the speakers mentioned—Bonnie, I think you mentioned this already— you are seeing it not in the big urban areas, you're seeing it in small rural communities. This is where you see stories in the news, "East Porterville in Torre County bought all these dry domestic wells." Small communities, we counted I think about over 100 small systems where they were mostly groundwater dependent, mostly shallow well dependent, where it's dry, the aquifer, the water table is falling, and on top of that people are pumping a lot out of the ground extra in order to keep agriculture production going. So these are shallow wells that are not going to fill up with water anytime soon, and so the shor-term solution to this has just been tracking water and getting water to them, but the longer term solution is really about water solutions for these communities that are more durable and I will say that it's not just a water supply issue, it's often a water quality issue, it's often a sanitation issue, and these are places that cannot pay for it themselves because the combination of low incomes but also zero in scale economies. So, figuring out ways to do that is a real challenge. It's not a large population in the scheme of things, but it is a real human rights issue. I think this is, when we looked Westwide, we weren't seeing that as much in the Westwide drought, but I think you see it definitely in tribal areas, and you're going to see it in a bad long drought in other places as well, in small communities.

And then the fifth and last, and this is been mentioned a bit, and I think it kind of came up in one Mike Young's comments earlier, the environmental impacts of water scarcity —I'm talking ecosystem impacts. This is really more sort of a luxury problem to have compared to a lot of the developing country issues that we've been talking about today.

But in advanced economies, the environment is a normal good; it's something that people care about more as incomes go up; and we have in the American West for example a lot of conservation values and a lot of aquatic ecosystems that need water. And during droughts, these are systems that already have had a lot of water diverted away from them during normal times just because of all the use in agriculture, and to some extent in urban areas, and then in dry times they can really get shorted very significantly.

What we're seeing in terms of conflicts are often not urban/ag, but ag/environment over just the scarce drops of water that are available in some systems right now. That's been the big fight in Congress over the last few years, is whether Congress should legislate something about how we regulate certain environmental flow requirements. And I'll just say in terms of just bringing it back to climate change that rising temperatures is making this more complicated. So what we're seeing across the West—California and the Pacific Northwest—is that keeping water cold for salmon is becoming way more expensive in terms of the amount of water that you've got to store for that. So that's going to be a space to watch in terms of how we navigate that. Thank you.

Panelist: Les Lampe
Former Vice President and Director of Water Resources
Black & Veatch

When it was mentioned I will give a global perspective, I'll just give a little bit of background in terms of my perspective over my career, and try to focus it down into some practical examples.

So adaptation. And with the theme being the climate change, being right here, you know, water is driven by crisis. We know that and it's a matter of whether it's an immediate crisis, you're running out of water, or a long-term crisis for a prolonged drought. You know, we're all here, and what we're trying to do is trying to say, okay, we know there's a crisis, we know it's coming, what can we be doing? But nobody really does anything until it really grabs you. You saw that in the 1950s in the middle part of the country where there was a drought throughout the whole area and a lot of response to it.

As a matter of fact, if you went a few blocks back to the north of here, you would see that there was Union Station just past that Liberty Memorial, you can see right out the window, was underwater in 1951. Huge flood. And the response to that, all kinds of reservoirs were immediately funded upstream from here to control that flooding. But what happened right after the 1951 flood? The drought of 1952 to 1957. Just a terrible drought in the middle part of the country—Texas, Oklahoma, Kansas, up into Nebraska, this whole part of the country had that. So immediately, there was the 1958 Water Supply Act. It allowed entities to sponsor the separable costs to build in water supply storage into federal entities. The state of Kansas jumped all over that and built water supply storage in every federal reservoir, a wonderful thing to do, and that's what a lot of entities did around here. You had those crises that you were dealing with at that time. The 60s on the East Coast, the 70s in California and the UK, internationally I've seen things where it's driven by politics

in Singapore where they import 80 percent of their water from Malaysia, they've developed ocean desalting, new water which is reuse local catchments, and trying to use everything they can from this small island in local catchments. Hong Kong, importing water from mainland China, driven by that to looking at ocean desalting; 85 percent of their toilet flushing comes from ocean water. Things like that.

The one that I think is most relevant here, and I'm going to drill down to a local example, is Australia, and will have a whole session on that tomorrow, but I had a considerable amount of work with the Water Corporation of Western Australia. Any of you that have looked at it, there's kind of an iconic figure that shows the average runoff into the surface water supply system for the Water Corporation. Water Corporation only has like three million people that it serves, it took about a third of the area of the United States, it's just huge geographically. But what happened is that you looked in the 70s, and they were having a full amount of inflows; the 80s it went down to half of that amount of inflow; the 90s it was like 20 percent of that amount of inflow; and by the year 2000, the millennial drought in Australia, they were convinced that they were not going to be a surface water supply system anymore. They developed a Water Forever program, tons of water conservation, they have reuse, they have some local groundwater supplies, two ocean desalting plants, developing a third, and so that's the kind of portfolio and adaptation that we're talking about in terms of dealing with crisis. It should also be mentioned in Australia, just in terms of an example, all the cities are on the coast. So every major city developed an ocean desalting plant. Huge amount of cost, huge energy use, but for a lot of them it's recovered somewhat to where those plants sit somewhat idle. That's another lesson that could be learned in terms of you want that resilience, you want that reliability, but at what cost? Black and Veatch was involved in the Bundamba plant which was in southeast Queensland, and we were convinced just because of the accelerated schedule that that plant cost about 2 to 3 times what it would've had to have cost under a more normal planning

scenario.

What I want to turn to now, and we've talked about it a little bit, is the Colorado River system. In the year 2000 there was excess flows, they had negotiated an excess flow allocation agreement, and by the year 2007, they had negotiated as shortage agreement. But those intervening years were so dry and it persisted that much that they had to turn from excess to a shortage agreement, and how do you allocate shortages? And the trigger, interestingly enough, they have to start reducing water use for Nevada and Arizona is elevation 1075 in Lake Mead. Right now it's at 1072. It's at 36 percent of capacity. So to me, the Colorado River system, where most droughts are relatively quick, unlike in the eastern part of the country it will be a one year drought, maybe 14 months or something like that. The Colorado's River system, they have been in low flows for 16 years now, and it's like watching a train wreck in extremely slow motion. We see it's coming, you know it's happening, but how do you deal with it? The interesting thing about that to is that over that period of time, you know, the Colorado River system has 60 million acre feet of storage, and an average flow of only 15 million acre feet. So they are the only system in the world that has four years of storage available. That's what gives them that ability to say, well gee, maybe next year will be a little bit wetter, and it keeps going down and down and down.

I was fortunate enough to be hired by the seven Basin states through my firm Black and Veatch, and be the project manager for an augmentation study. We looked at a variety of things: Reuse, particularly in Southern California where there is still tons of water going out into the ocean; Basin imports, kind of that political very difficult thing; coal bed methane water; reduced water use from power plants; vegetation control; cloud seeding; ocean imports, like bringing water from Alaska; ocean desalting; conjunctive use with groundwater, the banking type of situation; brackish groundwater, which is most feasible at the Yuma desalting plant in southwest Arizona, and it's being implemented; storm water reuse; and control of reservoir evaporation. Some have some potential to it, but a lot of them

were just kind of like, "Huh? Really? You're going to look at this stuff?" What was not on the table for that particular study was water use efficiency, water conservation, transfers of ag to urban, you know that was sacred, you know we weren't going to look at that, and you weren't going to look at the salt and sea. There was half 1 million acre feet to 700,000 acre feet of ag drainage water flowing in there every year, much higher quality than ocean water that could be desalting and reused, but it's a whole problem of its own dealing with that.

Now there are some Band-Aids that have been done; there's a lot of progress on the Yuma desalting plant, probably creating 80,000 acre feet of water a year with the brackish groundwater mound in southwest Arizona. There is the Carlsbad ocean desalting plant in Southern California producing 50 mgd, roughly 50,000 acre-feet, but those are Band-Aids. The deficit in the Colorado River system will be in the millions of acre-feet per year, where they think the average flow right now is 15 million acre-feet, and I don't think it's that high. You know, you're looking at deficits of 3 to 4 million acre-feet a year, and how do you deal with that?

Where I'm going on this is there's a system that's just been implemented called the Pilot System Conservation System where the major entities, Denver Water, Central Arizona Projects, Metropolitan Water Districts, Southern Nevada Water Authority have contributed money along with the Bureau of Reclamation to go out into the market and say, "Who's willing to not use water and conserve water for the system?" They've gone out and have an initial $9.5 million dollars that's been expended, saving 62,000 acre-feet per year, and the beauty of it legally is you can't the Nevada Water Authority of Las Vegas to pay for water in Colorado, and have under a water right standpoint, a legal standpoint, particularly a public perception standpoint that won't work. So this is system water, it just blows into the system maintains the water level in Lake Mead. I think that's the window to the future for the Colorado River system in terms of using market mechanisms to solve their water problems. The beauty of it to is that the average cost of this water is hundred and $150 per acre foot.

The cheapest of the 160 options looked at in the Basin study was the Unity salting plant that had between $5-600 an acre foot, and right now because that ocean desalting plant being funded by the San Diego County Water Authority is $2,500 an acre foot. Translate that down into cost per thousand gallons per user, and you can see that a lot of these solutions are extremely expensive, and that's where I think this market mechanism getting out there, willing buyers, willing users, and saying, "Are you willing to forgo your use to allow the system to be whole," is what I see is a favorable window to the future. That's my remarks. Thank you for your patience at this time of day to allow me to present that.

General Discussion
Moderator: Craig Hakkio
Senior Vice President and Special Advisor on Economic Policy
Federal Reserve Bank of Kansas City

Dave Anderson, New Vision Group: Just a quick question for Les. What is the short-term and the long-term impact of the Colorado River system? What it sounds like is there is a huge deficit there. Is the train wreck continuing?

Les Lampe: It's my perception, and not everybody would agree with this, but yes the train wreck is continuing. The water managers in the Colorado system are a fascinating group and very innovative, and they've done a lot of things. They had banking among the states, Arizona, California, and Nevada, they have what they call an intentionally created surplus where you can conserve water and save it in Lake Mead, things that were not allowed before. They are allowing Mexico to store water in Lake Mead, and they're doing all kinds of innovative things to get around this issue that they have. But given that, I still see that there is just a huge, profound shortage of supply that's coming down the road, that will take even more dramatic measures. That's where I like this idea of essentially 50,000 of the 62,000 acre-feet thus far contracted were from ag. You don't want to necessarily say were taking water away from ag, but it's a market mechanism to say, from the lower value uses to somebody willing to pay for it, what's the way of going to make it happen. So I think that's the potential solution out there to make the system whole.

Ellen Hanak: I'll just add to that since you mentioned the $150 an acre, foot figure, a lot of that is being paid to irrigated agriculture that that returns for growing alfalfa in that region, or maybe $10-15 per acre foot of consumptive use, so that's a nice positive on the farm accounting ledger.

Bonnie Colby: Maybe just one less thing. We just got some data from the Bureau trying to

update the information from their Basin study from 2012 they were doing their projections based on water use data up to 2008, and were looking forward, and basically at that point you said started to come down some, but they weren't confident in that trend. So the projections that you probably have seen, you have the demanded red going up way, you're likely to be far exceeding supplies. Use has continued to come quite a bit down. So now there's really no very good match between the demand projections and use. Economists will look at the earlier thing and say, "It's not possible for demand ultimately to exceed supply on a long-term basis, so it's going to have to come down." The question is just, you know, what could be on the table at that time, and how do you get the conversation to move toward different kinds of creative demand management?

Steve George, Fremont Farms: In addition to agricultural, were there any other significant users of this market mechanism? Was there anything in terms of industrial use or municipal use? Or was it almost 100 percent ag?

Les Lampe: It was 58,000 acre-feet out of the 62, and I just have a little summary here in front of me. There's some recovery of wastewater effluent that was otherwise lost and being used to recharge the aquifer that's tributary to the river. And then there's another one that's of TON Central Arizona Project, and I'm not sure what that is. That may well be ag water but I'm not sure. So the huge majority of it is ag water, but there are some other things that could be considered in that regard. Part of the difficulties for municipalities and industries, you know, at that price level, it's not worth it for them to enter into it.

Steve George: And then also just curious whether that was actually verified that these agricultural users actually had previously used their water allocation, or they were just giving up their allocation rights they had when they might not have been using the water in the first place, and you're paying for water that hasn't even been used.

Les Lampe: There are protocols, true, that each of the state water agencies try to assure that. Of course, you're always in the water right system in terms of any water right holder, have

they really been using that water or not, or is it unused water that they're giving up anyway. To a certain extent, it could well be that as long as it creates nonuse, and allows water to stay in the system, you know, you're wanting it to actually being given up water use, but if it's a water right that they're still sequestering, maybe it's having the same effect.

Audience Question: Do you have any other examples of the market-based mechanism being used other than the Colorado River?

Les Lampe: Well, I think, and I'll turn it over to the others, but that's what Bonnie's whole background was on. In Colorado, where they were talking about particularly in the Front Range, where you've taken ag to urban use, there's been a huge amount in that, and I'm sure Bonnie has other examples.

Bonnie Colby: Yes, there are at least two dozen active trading areas around the Western states, most of them started out grouped around rapidly growing cities that were permanently buying farmland. Now there's a lot of innovative leasing, other short-term contractual arrangements as Brad described where you use the water on a temporary basis during a particularly water scarce season or water year. This is not to say we have well-functioning water markets; I don't even like to use the term water markets because people think of the stock market, and the urban housing market, and most of our water trading systems don't resemble those.

Ellen Hanak: Maybe just one thing to add about this is that the water markets that one observes, ag is the major source, not the only source, sometimes urban areas will have water that they don't need and they haven't grown into. But ag is also a major buyer in some places, and so in California that's been a very important tool along with the additional groundwater pumping, is water trading in order to keep the higher revenue and permanent crops, and my understanding is that up in Washington state too, they have been trying to do this where there is also diverse agriculture where you've got some fruits and vegetables next to some field crops, and so with the curtailments that they've had, in an effort to get markets going

for that purpose.

Brad Udall: You know, I've heard in Southern California the largest water proprietor there, Metropolitan Water District of Southern California, actually decided to get out of the market of buying water recently in the California drought because they were competing with perennial high-value crops, and Richard Howitt may in fact talk about this tomorrow. It was A) expensive, and B) they didn't like the social problem of trying to compete with ag in this case, on these trees that would otherwise die if they didn't get water. It's an interesting case of ag coming of age in certain areas, of actually being able to outcompete municipal users. Who would've thought that that would ever happen?

Derek Sawyer, central Kansas: Kansas is a first in time, first in right appropriation state, and so keeping that in mind, I thought your [Ms. Colby's] streetcar comparison was pretty ingenious when you opened. And then the more I thought about it, coming from my area, the water we actually pay for is included with the land purchase. That's the way we trade a lot of water rights in our area is actually the trading of land. With that in mind, we're looking at a situation now that's not too far from home with the city that's in a very marginal water area, looking to expand where they can get water from. They purchased a big ranch 100 miles from where they are, and transporting—it's the city of Hayes, I think from your smile you know— but how do you justify or how do you look at a situation when a city is buying land and using, you know they bought a senior water right, transporting all of that water completely out of the Basin, how do you look at that, and how do you look at policy as far as justifying that transfer?

Ellen Hanak: Each western state has its own policy that relate to buying up farmland and transferring the water out of Basin. Some make it very difficult, many don't. Obviously, it's going to change the agricultural structure in your area, and of course what you run into in the agriculture sector is the farmers who sold typically do very well. The returns are much higher than they were earned growing crops both in temporary transfers and leasing water,

and permanent sales of the land, but then you've got that reduced irrigated acreage and the impacts for the agricultural infrastructure. This is a policy decision that every state has handled differently. I know Kansas is working with innovations on the water banking, live in select areas, where the water would stay within—we talk about watersheds, but we can talk about regional economies as sort of that money shed, where you want the benefits from using that water to stay in the broad area where it's generating jobs and economic activity, even though not in agriculture to the same degree. So this is a tough issue, and it's one that's been handled quite differently in every jurisdiction I'm aware of.

Les Lampe: If I can add, offer some brief comments on that. In my limited experience in Hayes, Kansas, it's the Bermuda Triangle of water supply. They were 60 miles from Edwards County where they bought the ranch, from the Ogallala and High Plains aquifer, from Kanopolis Reservoir back to the east where there is a more prolific water supply. They had no groundwater, the Smoky Hill River which flows right by Hayes, was in the late 80s completely dry. Cedar Bluff Reservoir just upstream was essentially dry, and they were in this mode of where in the world can we go? They implemented a banking plan where they're taking their reuse to charge the Luvia aquifer from the Smoky Hill River, and I'm not even sure at this point whether or not they are active in terms of supply in Edwards County, and you'd have to fill me in, Derek, in terms of the status of that. But there is a Water Transfer Act in Kansas, because it was going from the, in Kansas it's called the Arkansas River Basin, every other state it's the Arkansas River Basin, to the Kansas River Basin and they had to comply with that to make the transfer work.

Jay Rempe, Nebraska Farm Bureau: Bonnie, I was wondering if you could expand a little bit on your discussion you just had about trying to protect regional economies. Often times when water markets and transfers come up in Nebraska, the issue of externalities come up. Are there some ways that some of these markets and trading schemes are dealing with that is one question? And then the second question is, Brad, you mentioned return flows, and that's

a tricky area. We have some areas where farmers are adopting sort of pivot technology that's affecting return flows downstream, and the folks downstream aren't too happy with that. Some things that are going on in markets where people are actually paying others not to be more efficient, to protect those return flows.

Bonnie Colby: I'll start with the first question, and then turn it over to you. So juris government, jurisdictions, mostly states, at least in the United States, where there are payments to the area often in a county where the water is being exported out of, or where the county has a certain amount of voice in the process whether the transfer is approved. There are areas where the party who are acquiring the water and importing it out of the area where it used to be used in farming creates economic development and other kinds of funds to help with economic transition. I think especially in a group like this that has so many people in banking and finance, it's important to keep in mind that probably what we want to focus on is not how irrigated acreage is changing, but how the robustness of the economy of the area is being protected. In that case, you could have parties reducing, paying for reduced consumptive use and water, but there's still active agriculture and maybe even by the same farms who have let some of that water become available for other uses. So I guess what I'm encouraging in the conversation is a focus on a different metric, not changing irrigated acreage and keeping up the value in economic production in the area, both in crop production and in the other sectors, because our regional economies are very interdependent. I'll put that as another item for discussion.

Brad Udall: Yeah, I'm not aware of cases where return flows are being protected with sprinklers. I will point out a case that was before the Supreme Court on Tongue River of Montana/Wyoming, the upstream diverters moved the sprinklers downstream, state complained, Supreme Court upheld the upstream use of sprinklers because the compact wasn't specific enough to prevent that increased water use. In our state one other case that's interesting is on the Arkansas, where there is another compact. Our state engineer is very

suspicious of Colorado River farmers installing sprinklers, because of the return flow issues into Kansas. We've been sued and have lost multiple times on this, and so are state engineers are obviously quite cautious about it. So the known impact of sprinklers is common. I'm going to mention one other thing. Drip, it's interesting, the journalists John Fleck told me about the chili growers in Hatch, New Mexico who converted to drip, and you know what happened to the furrow that used to be used for floodwater? It's gone, it now has chilies planted in it. So now you've expanded the acreage effectively in that same field.

Session 3: Investing in Adaptation

Speaker: Susanne Scheierling*
Senior Irrigation Water Economist
World Bank

Thank you very much for inviting me to speak here today. My presentation is co-authored with David Treguer, who is a colleague of mine at the World Bank. World Bank, as you know, is providing lending and advice to developing countries, and is probably the largest owner in the water sector with irrigation accounting for about a quarter or third lending which was last fiscal year about $5 billion. Since we were reorganized about two years ago, we are now organized by sector, and these sectors are called "global practices." So I work in the Water Global Practice in a unit called Synergy and Operations, where we are tasked to provide advice to the colleagues who are involved in the lending and also create and disseminate knowledge. So as part that dividend, I am working on a study on how irrigation water management can be improved in the face of water scarcity, and we are focusing on issues like what does it mean to improve irrigated water efficiency, and productivity, and this invitation to speak here gave us an opportunity to develop some of our thinking further.

Now the rationale for this topic, "Investing in Adaptation," we have heard yesterday quite a few points on it and I would like to recapitulate the four major reasons why this topic is important. First, irrigation is the largest bistro of water. Second, the water use in agriculture is usually low value. So other sectors, that's why allocations could be the most cost-effective way of getting more water. At the same time, there are the projections that irrigation production needs to increase, and that means also the water use arid countries need to increase. And on top of everything is this climate change, with projections additionally of complexity.

In the area of adaptation measures, a right range of interventions are being discussed

*Please see the corresponding paper and/or presentation available at www.kansascityfed.org/publications/research/rscp/rscp-2016 for additional detail and referenced charts.

ranging from on the field to the farm to irrigation systems to the basin level to even higher levels national, international; and these interventions usually are under different objectives. One can say there are three main objectives. The first one is to maintain or increase irrigation production while not worsening water scarcity. The second one is water conservation for reallocation for other uses including the environment and for coping with water scarcity. The third objective is to maintain or increase agriculture net revenues.

So the problem is that often these objectives are not clearly stated when adaptation measures are being implemented, and then the broader results are not assessed, and that adds to the constraints in the adaptation measures, they are not as effective as they could be, and may even lead to unintended and counterproductive outcomes.

So with my presentation, I would like to shed more light on these issues. So what I would like to do first is provide is kind of a preliminary; I would like to discuss some water characteristics which one has to keep in mind when one talks about adaptation measures. Then as a second point, I want to set the stage for this global view of the linkages between irrigated agriculture and water scarcity, then talk about some of these adaptation measures, and then provide recommendations for going forward.

One can argue that water is special in many ways compared to other resources and other commodities. For our topic, one needs to always keep in mind that water is mobile. It moves through the hydrological cycle, and because of that often it's difficult or expensive to establish exclusive property rights. Water supplies are also very valuable and unpredictable, and then combined with the variable local demands, you get very site-specific problems. So when you talk about adaptation measures, they need to be adapted to local contexts. Also, what we have heard yesterday by quite a few speakers is that water is rarely fully consumed in human consumption and production activity. So in every culture, it's not unusual to see that half of the water that you withdraw and apply is returned to the system, and then used by downstream users. So that makes water use, it interconnects water users,

and this interconnectedness becomes more pervasive as water scarcity increases. So it's not right to, and should not think that one gets insights from what is happening on the field or farm level, that this translates right away into what is actually happening at the basin or higher levels. And with these externalities, you have the need for public policy in order to complement these individual activities and reorient them to other social objectives.

Now moving to the global view, the links between irrigated agriculture and water scarcity. It's not easy to make that link for various reasons including the special characteristics of water, the problems of defining water scarcity, and last but not least the availability of water related data. I'm trying to show you what is possible to show. This is the big view with regard to the trends in withdrawals and the share of agriculture is being shown. It is now about 70 percent of the total withdrawals. Also shown, the consumptive uses, and you see agriculture has always more than 90 percent of consumptive use. The rate of growth seems to be decreasing over the last couple of decades, and it seems from OECD countries, some of them have now maintained these withdrawals at a certain level; it's even decreasing also for U.S. We have felt even the agriculture withdrawals are slightly decreasing.

Now with regard to the large countries, with regard to agriculture water withdrawals, this shows the 10 largest with India, China, and United States leading. These 10 countries are also the ones with the largest total withdrawals, and they are among the countries we see the highest area equipped for irrigation, and also among the most populace. I'm also showing, like USV, we talked about this yesterday, it's kind of an outlier with only 40 percent of the total water withdrawals for agriculture. It's due to the large share that is going to the power sector.

Next, I show by country the very close correlation between agriculture water withdrawals and total water withdrawals. You see on the left again the big countries with India on the top, and followed by China and the U.S. Because all the countries are bunched towards the zero point, we also show in local logarithmic terms and you can see this

close correlation. Similar close correlation is between agriculture water withdrawals and area equipped for irrigation. Area irrigation is like the indicator that FAO shows, it's not necessarily the same as actually irrigated area, but this is an indicator that is available and one can play with.

Now moving to water scarcity. In the literature it's defined in many different ways. One of the more common ways is to show the share of total water withdrawals as percentage of the total renewable water resources. It's usually said that if this share is between 20 and 40 percent, then you have water scarcity, and if it's beyond 40 percent you have severe scarcity. You see, especially MENA countries and Central Asia are classified as severely water scarce. Then we try to say what happens if we modify this indicator and we show only agriculture water withdrawals as a percentage of total renewable water resources? When we did that, we were quite shocked to see that the picture looks almost the same. So some European countries like Germany, they don't show any more as water scarce, but all these various water scarce countries are still the same. You notice that some of the countries even withdraw more water for agriculture than their total renewable water resource availability. You wonder how can it be, and these are the countries which have a lot of nonrenewable groundwater withdrawals like Saudi Arabia. So this is kind of concerning.

Caveats apply of course. This may underestimate water scarcity when you look at the big countries like China, when you play with national data, its annual data so it has many scarcity situations at the local level. It does not include water quality issues. You do not have environmental needs incorporated, so water scarcity may actually be even higher. But at the same time one can say it underestimates water scarcity because the return flows are reused, and in the withdrawal date this reuse is incorporated. So let's think of the Nile where the same water may be returned to the Nile and then taking out again several times just within Egypt. So one has to keep this in mind.

In order to show trends, the only available variable is area irrigation where one can find

a good data set over time. So you see this is showing data by region, excluding the advanced countries. So what you see, especially in East Asia, irrigated area increased a lot since 2012. This is mostly China and South Asia, it's mostly India that's increasing, and only in Europe and Central Asia there was a slight decrease recently. That still due to the recovery from the breakup of the Soviet Union which affected the management of these irrigated areas a lot.

Now moving to the adaptation measures. I distinguish between engineering and technological adaptation measures, and the policy and institutional measures. The engineering and technological adaptation measures are the most common. They include measures such as more capital intensive irrigation technologies, improved seed, precision farming to optimize the use of the inputs including water tailored to local conditions. These measures are usually applied and found with private investments, and often supported with public subsidies and technical assistance. So in the US, we are familiar with the Environmental Quality and Incentive program which since 1996 Farm Act is providing cost-sharing to farmers up to 75% including for these irrigation technologies with the official aim of conserving water, and billions have been given to farmers. Similarly, in other countries including emerging market economies such as Morocco, they have for example Morocco National Irrigation Water Saving program. They plan to convert half a billion hectares in the next decade to drip, and will provide up to 100% of subsidies to farmers and the total is US$4.5 billion. So the level of subsidies is amazing. However, we find that this mostly helps to maintain or increase agriculture net revenues.

So I'm talking again about my three objectives. It may maintain an increase in agricultural production, but usually these measures are not good at conserving water for reallocation or for coping with water scarcity. I would like to illustrate that with the example of capital intensive irrigation technologies.

Where a lot of research has been carried out, usually it is assumed that because they have to withdraw and apply less water to the field, that then somehow water is conserved.

But research shows that often they lead to counterproductive effects, including water consumption, but sometimes even increasing water withdrawals in water applications. I probably don't have time to go much through the literature, but it's important to distinguish between situations when return flows are important, where than one should be focusing on the need to reduce consumption. Various studies, almost exclusively carried out in the U.S. because of good data here, relatively good data, studies have shown since the mid-60s that return flows are important, and once you have more efficient irrigation technologies, farmers tend to increase irrigated acreage and then consumption increases, and sometimes even withdrawals and application. So for example, this economic approach was based on the Environmental Quality and Incentive program and data from that, and it shows farmers even increase withdrawals, the overall water use.

In cases where return flows are not so important, like for example the Ogallala Aquifer in areas where it's very deep and return flows, maybe never reach the aquifer or it takes a very long time, then one should focus on reduction in withdrawals. There are some interesting studies that have been carried out, often in Kansas, showing that depending on the situation, depending on the context, sometimes withdrawals increase, sometimes they decrease. But often they increase, also due to crop switches which we heard about this yesterday, this switch to maize from wheat, and maize being a more higher water consumptive crop. Of course, there are exceptions with these adaptation measures.

Then you have measures that directly focus on the variable that you want to change, so when return flows are important, it's consumptive use, if you have for example conservation tillage that directly aims at decreasing evaporation, then you can decrease consumption, and then your measure is fine; it achieves conservation objectives.

So with the moves to policy and institutional adaptation measures, they are increasing in importance. They include a range of measures, ranging from raising awareness to fostering innovations, but also applying economic instruments to balance supplies and

demands. Overall, the emphasis is shifting to demand-side measures. There are two key purposes of these measures: Conserving water because the private sector investments often don't do that; and also to promote these private adaptation measures.

The literature distinguishes between three ways of doing these reallocations. Prices are the first measure. Often, there's a big debate, can prices fall, irrigation water change anything, because a lot of literature shows that the demands for irrigation water are priced unrealistic and then it's assumed that a large price increase would be necessary to reduce irrigation water application just a little bit. But in fact, that is not the case. When you think it's just percentage changes that you look at, so even small increases percentagewise in prices can actually be very effective in reducing consumptions.

Quality-based measures, we have heard about different ways this can be done in the U.S. and in Australia. Theoretically, you can have an efficient location when you just allocate quotas right. Then it can be exchanged to get into water markets. Most of the world does not have water markets. You have these elements of transfer often by administrative decision, often by stealth where farmers are not compensated, only if they are able to put political pressure. So, one needs to keep this in mind, and there's very little research about developing countries and these water transfers, and true wins and a true loses. When you think of the ways of how to promote and align the private adaptation measures, it would be important to state more clearly the objectives of these subsidies for these interventions. Much more assessments should be carried out with regard to the outcomes to avoid counterproductive results. Farmers' adjustments should be guided by regulations. Farmers should be informed if reallocations are planned, especially in developing country settings. Care should also be taken that the risk is not increased for farmers. So for example, when farmers are supposed to move to drip, then they should have higher value crops and then that they are much more sensitive to water related risks. It seems also progress needs to be made with ground water management if there is any progress to be expected from conservation efforts.

So this is my last slide going forward. Actually, progress is needed with the policy and institutional adaptation measures. More research and development funding should go to them and not like also in the last budget, the president's model innovation budget, it was all for technological and engineering measures. Many more assessments should be carried out with regard to the concentrations and what is expected when interventions are carried out, and then evaluate the effects. The right policy framework needs to be taken into account. We've already talked about this yesterday. And I also feel that when you look at how high are these agriculture withdrawals as compared to the total renewable water results, if there's only small shortfalls, it can really lead to economic, social, and environmental crises. And as Ellen had said in California, they were able to manage this drought easily. One has to keep in mind how privileged California is compared to almost every part in the rest of the world with regard to the water infrastructure where they can move the water around. The knowledge infrastructure where they have data, where they have so many university researchers and think tank people who have models, who can check what would be the most appropriate response—all of these things are not available in most other places of the world. So we should keep this in mind and think about, and plan for such events. Thank you very much.

Qiuqiong Huang
Associate Professor of Agriculture and Economics
University of Arkansas

I want to thank you for inviting me. I really appreciate the opportunity to come here, share my thoughts, and interact with such a diverse group of people that are interested in water issues. That's really a good motivation for my water research. I enjoyed reading Susanne's paper, I think she really has done an excellent job summarizing the challenges that are facing the agriculture sector, and adaptation measures. So I think what I will do is to add to her points by bringing some details on what China's government and a China's farmers are doing to deal with the water scarcity problems.

China's ag sector also faced similar problems like the share of water allocated to or used by agriculture sector has declined by more than 90 percent 30 years ago to only around 60 percent nowadays. Some of the supply-based solutions such as the South-to-North, the transfer to not only provide water for the industrial and domestic sectors, they do not provide for agriculture sector. At the same time, the government is also intent on maintaining a high level of foods self-sufficiency. So that just makes increasing crop produced per drop of water the key goal of the government's investment. So one of the measures the government is using is to improve irrigation efficiency. Government has invested billions of dollars in lining canals and extending more efficient irrigation technologies. In this five-year plan which is from 2016 to 2020, the government is quadrupling investment. So the objective is to boost the irrigation efficiency to 0.55 by 2020, from the current level which is about 0.46.

So South China is actually abundant in water resource. North China is the part of the country that is short in water. So that's where we focus most of our research on. The household level data we collect clearly show the impact of those massive investments, so the

percent of this whole area that's serviced by lined canal increased from less than 1 percent to more than 40 percent in 2011. This is mostly happening in the area that uses surface water for irrigation. I'm using the term "so arid" because on most Chinese farms there are much more crop seasons within the year, like first wheat, and then two seasons of rice in a year. So in groundwater areas, we are also seeing increased use of underground pipes and the service water pipes which significantly reduced seepage loss when groundwater was delivered to their fields. But in the data we do not see farmers using more efficient irrigation technologies like sprinklers or drip irrigation. Another technology farmers are using, the drought tolerance variety really gained a lot of grounds and increased from less than 1.5 percent of this whole area in 1995 to now it's used in about 30 percent of this whole area. Another technology that has developed pretty fast is conservation tillage. It's used about 65 percent of this whole area.

So our assessment of those adaptation measures is that they do seem to decrease the total water use at the farm level. The irrigation application rates at the crop level have decreased a lot for wheat and for corn. Of course, we also need to look out for those unintended consequences like studies in the U.S. have shown that if farmers use the saved water to switch to more water intensive crops or expand irrigated acreage, the total water use may actually increase after more efficient irrigation technologies are used. But in our data, we do not see farmers making those adjustments. We do not see a significant change in crop mix. We do not see significant impacts on irrigated acreage, probably because the farm size is still pretty small in China. The average farm size is still about 0.6 hectares. In North China, agriculture is much more irrigated than other parts of the world. In some areas, farmers really have to irrigate every acre that they can get water to. So there may not be much room for those farmers to increase their irrigated acreage.

Our assessment is based on the current condition in China, so a lot of things may

change. One thing we are watching out for is the change in land. So while the government has been pushing to increase farming scale, and that's one of the main goals in the five year plan, this is not something that's going to change overnight. Recent studies show that the average farm size only increased from 0.59 to 0.62 hectares between 2007 and 2013. But we do see the large farm which is defined in the paper by more than four hectares. So that's kind of farm is still a small share, by 2013 still less than 4 percent of cultivated area, but between 2007 and 2013 those kinds of large farms actually doubled in terms of cultivated land. So it is something that may change. So if we do see a significant shift in the land size, farmers may start to take up sprinkler irrigation and those kinds of things. So we may need to come back to reevaluate the adaptation portfolio, and their impacts on water use. This is good news for water economists like me because it means we're never going to be out of a job.

So there's also a challenge in those adaptation measures. One of the challenges I see is the lack economic incentive for farmers to use those measures. So when we calculate the benefit of using those measures, one thing that strikes me is that the majority benefit does not come from water savings. The monetary value of water savings is only one-third or one-half of the monetary value in terms of crop yield gain. Of course, that's true because the price of water is low in China, just like in many other countries. That may explain that for some of the technology we don't see a high adoption rate because the cost is higher than the benefits. Technology alone is not likely to solve the water scarcity problem in China.

The government has also been trying market-based solutions. In the past decades, the government has implemented several water rights trading schemes. So basically, their trading at a sector level between agriculture and the industrial sector has been somewhat successful. But the trading within the farming sector has not achieved the intended goals. We do not see from the data that farmers trade the water rights allocated to them, and the reason is more farmers have determined that any benefit of trading is easily outweighed by the costs of the transaction. So we do see a shift in water policy away from water trading, so

now the government is coming back to look at water pricing.

Water pricing reform has always been the government's policy agenda, and the government has been laying ground for doing a nationwide water pricing reform. Lining the canals, is part of it, and the government has also been investing in adding meters to wells and adding equipment along the canals to measure the volume of water. The pilot reforms have begun, and have really expanded this year. So basically, the water pricing reforms, there are two components. The first component is to set water quotas, and these are set actually at a pretty low level, all the way down to the farm level. And the level of water quality is set based on historical water use, crop pattern, and also the water saving target. So about a 20 to 30 percent reduction in the coming years. The second component is a tiered pricing with a carrot/stick approach. So basically for farmers that exceed their water quota, they are going to pay a lot more, like three times as much for water. They also reward farmers for not using their quota. So basically the record of those pilot reforms is kind of mixed. In some areas, these do seem to work. But we're also seeing others where they are pretty much abandoned the reform after the first year because it is too difficult to calculate the water quota and also the monies and water used. So if the government does want to scale up there reform, they need to revise the format of the reform, and also come up with ways to reduce the cost of implementing water pricing reform.

Another market-based scheme is groundwater market, and this is not something initiated by the government; this is actually coming from the farmers trying to increase access to groundwater. In China, although the state legally owns all the groundwater resources, in rural China the farmers actually have de facto rights. So as long as you have a well, you have access to groundwater. The groundwater markets is informal in the nature, it's mostly farmers who own wells, sell their water to his neighbor or friends. But in the data we do see that farmers who purchase water from groundwater markets have more flexibility in their irrigation. They got to use more water during drought years and they can use less

water when there's plenty of rainfall. So it does seem to help somewhat, but those are really small-scale groundwater markets. Overall, when we look out across technology market base, it may be a technology plus a market-based approach is the answer to China's water scarcity problem. In China, there's always a hand from government too.

So one last point I want to make is that another challenge for adaptation measures is the continuing use of those measures, and the relation of that operation to the business of infrastructure and equipment. I think you in the U.S. will have the same problem. In Arkansas I saw some farmers that used it to pivot, the Asian equipment made the irrigation efficiency drop to below furrow irrigation. So farmers are actually reverting back to furrow irrigation. So in China, mostly the problem is who is, the government investment mostly comes into the installation phase. But after that who is going to continue the investment? Who's going to maintain those village level canals, those are the big problem. That's more so because it used to be, and villages, the village uses the funds from tax, from fees, from revenue of the village enterprise to fund those kinds of irrigation investments. But agriculture taxes were completely eliminated in China by 2006, and a series of fiscal reforms have pretty much taken away the village leader's ability to levy any fee on farmers. In many provinces, they also removed the mandatory labor requirements. So village leaders cannot ask the farmers to work on village projects for free anymore. So basically those changes have left a fiscal void and a labor shortage for irrigation investment in rural China. So that's another issue that the government needs to address in terms of dealing with the water scarcity problem. I think I'll just stop here.

Discussion with Susanne Schierling and Qiuqiong Huang
Moderator: Nathan Kauffman
Assistant Vice President and Omaha Branch Executive
Federal Reserve Bank of Kansas City

Audience Question: Thanks to both speakers; I enjoyed the presentations. My question is specifically on China, and it seems to me that one of the strategic things that China can do that would have a huge impact on water use and agriculture is deciding on the level of food self-sufficiency, particularly with respect to grains for which China has relatively little comparative advantage globally. What can you tell us about what China's explicit goals are with regard to in 10 or 20 years the level of food self-sufficiency they are targeting for the grains—maize, rice, and wheat—which are mostly irrigated in China?

Qiuqiong Huang: It used to be, I don't really remember the exact number, but the level of food self-sufficiency decreased from 95 percent to 90 percent. So the government is kind of adjusting there, adjusting that expectation in terms of that. I don't know what's going to happen in 10 to 20 years. They may reduce that further; it depends on the changing diet, it depends on what happens with trade agreements, all those things. So I do think the government is becoming more flexible in terms of that because they do recognize they may not find the solution to make the alga culture sustainable, because we do have a highly irrigated agriculture.

Audience Question: So I was very interested to hear your assessment that transaction costs are undermining the potential for water transfers in China. I'm interested of that happens on the local scale as well? There are several programs that allot farmers individual water rights based on credits to use the village pumps or the communal pumps. Those rights are based on energy credits or energy allotments which we've understood farmers are able to sell within sector. What's your opinion of the future of those programs and do you think there's

anything that the U.S. can learn from them?

Qiuqiong Huang: I think my comments on the transaction costs only apply for the water transfer within the farming sector. So between agriculture and industrial sector, actually I think there are some degrees of success in terms of that. So in terms of at the farm level, I think the problem right now is that the farms are too small. There are so many farmers, and it's difficult to establish the water rights at the farmer level, and also we have problems, some village leaders are saying that because the supply chain has to be adjusted from year to year, so it just takes them too much time to do those things. They're not willing to do it. So right now in the current condition of China, the water rights trading within the village is not likely to happen. In the future after the farms, if the country starts to be more like USA, large farmers, then that may change. So we may start to look at water rights again. That's why I think the government's policy documents do mention water rights from time to time. I don't know if that answered you're question or not.

Audience Question: Talk a little bit about the World Bank's current portfolio of loans and grants in the irrigation sector, including whether or not they're trying to work to leverage some of these policy and institutional reforms that you correctly pointed out are so important.

Susanne Schierling: Part of the reason of this ongoing study is that some people feel that we do not address these policy and institutional measures enough. When it's about lending, it's not the World Bank who decides how the lending should be designed and what supports should be comprised of. It's based on a discussion with the government. So, for example, in China, we have probably the most advanced checks with regard to achieving real water conservation in a basin, for example, in the northwestern part of China where it's kind of a close basin, and now copper and gold were discovered, so indigenous people non-Chinese people are there some racial issues, and water is now supposed to be taken away for industry. So, there are very interesting arrangements are being carried out with regard

to really focusing on the consumptive use and limiting consumptive use, and making the best use of optimizing consumptive use while transferring water to industry. That includes things like remote sensing because now China has capacity to have even very small fields recognized with remote sensing, and it includes even thinking about formulating water rights in consumptive use terms. It's gotten quite amazing. So, there are such projects when government is ready to pilot new thinking. For example, also Chile of all countries requested to have a loan for institutional reform, or Brazil had a loan like that. But in general, the irrigation projects are still a lot with the lining of canals, improving on farm irrigation systems, and especially in areas where irrigation is expanded like in Africa. It sometimes even subbing fresh with converting rain-fed to irrigated agriculture.

Panelist: John Hamer
Managing Director
Monsanto Growth Ventures

I want to thank the Federal Reserve for inviting me here, my first time here, and for the first two speakers, for their introductions to topics of what are the technological innovations. I joined Monsanto about four years ago after a career in academia, biotech startups and venture capital and private equity. About 4-5 years ago at Monsanto, they had realized that a lot of the innovations that they were going to need to solve, some of the big agricultural problems, were going to be coming from small innovative startups. They weren't necessarily going to be coming out of Montana's own labels, or if from other large corporations where Monsanto will typically license products, but in fact they're going to come out of startups that are going to be innovating very quickly and very rapidly largely because of the ability of a ubiquitous computer infrastructure in the cloud, and the ability of mobile technology to move rapidly on to the farm and elsewhere, and wireless networks.

That farming and technology, particularly technology around farming was going to change very dramatically, and that we could reach a point where bytes and bits were going to actually solve the problems of bushels. So about four years ago, we started Monsanto Growth Ventures with a goal of how can we help entrepreneurs realize the opportunities in agriculture? How can we help them address the really big problems that we're facing? And so we do things like provide equity to small startup companies, we help them form partnerships with Monsanto, so their products can get out there and get the customers around the globe, not just in their own regions. Finally we help them test their technologies on our own seed production footprint. We farm about seven million acres ourselves where we produce all our different seeds, corn, cotton, canola, soy, wheat, as well as we're the world's largest vegetable seed company. And so for an entrepreneur, they can immediately

have seven million acres on which to test their technology. In addition to partnerships in equity, we look for the opportunities to see if these companies at some point would like to join up with us on this journey to try and improve agricultural productivity. So that's what we do a Monsanto Growth Ventures.

I thought I would give you a bit of perspective about Monsanto and what is our water footprint and what are we doing about it since we're a very large seed producer. Most of the seed that we produce is from irrigated acres. What products and partnerships are we forming to help deal with the issues around water and what are stress? And then, as a venture capital firm, and we're based in Silicon Valley. Sometimes we call it "silly valley." But in Silicon Valley, what are we investing in, and what are we seeing emerging on the horizon that is going to have some big impacts? And then finally, I want to leave you with a quick message of encouragement about what we're seeing in the private sector in terms of dollars invested and an excitement about the agricultural sector in Silicon Valley. And this is not just from VC's that are investing specifically in food and ag, but from VCs that are investing all across different sectors of the U.S. economy and how excited they are about food and ag.

So first of all, Monsanto and its water footprint. So, in our R&D units, we spend, we use about a billion gallons. In our herbicide program, about 5 billion gallons. But on our seed production footprint, about 200 billion gallons annually of water. About four years ago, Monsanto made a commitment that we would reduce our water footprint by about 25 percent by the year 2020 based on a 2010 baseline. Every year we report out about how we're doing. We're about 10 percent more efficient than we were previously. We're using a lot of different technologies to try and get more efficient—drip irrigation for example being one, but also remote sensing. So we teamed up with a little company that we actually invested in called Hydro Bio. They use satellite imagery mainly from land sat, but also from rapid eye imagery, and then they use a number of different algorithmic approaches

to calculate what the rate of irrigation should be on certain acreage for certain crops. And Monsanto tested their technology on multiple acres around the world, found out they could reduce the amount of water on those acres by sometimes up to 20 percent right away and still get the same yield and quality of seed. Today, we're rolling out Hydro Bio and Hydro Bio's imaging technology and remote sensing technology across our entire seed footprint at Monsanto. So for our little startup that we invested in, it was fantastic. They immediately had a large enterprise customer that would take their technology global, and for Monsanto was the chance to reduce our water footprint using remote sensing technology. So a real life application of how that would work.

Let me move on and talk about products and partnerships. So one of the partnerships we're most proud of is our collaboration with the Bill and Melinda Gates Foundation, called WEMA, Water Efficient Maize for Africa, where we have freely donated all of our germ plasm that's dry resistant, including our drought guard gene that we developed and launched in the US a couple of years ago. Donated those technologies to the Bill and Melinda Gates Foundation for use in approved water efficiency in African maize production, and it's a partnership we're very proud of and that's been quite successful.

Someone made a comment about brute force breeding. Breeding is probably the number one R&D spend at Monsanto. There's nothing brute force about breeding that's being done today. Every gene on every plant, every nucleotide on every plant, we absolutely know what it is, we know where it's going, we know what we're going to do with it. We have the ability to select recombination events that are extremely rare because we can actually genotype every kernel on a cob of corn before it goes in the ground. And we have machines and technology that we've built in house to do that. And so we've accelerated breeding through genomics and genomic technology that it's almost unrecognizable today. And the precision behind breeding allows us to have the significant yields advantage and bring out new hybrids every couple of years and keeping that curve continuing to grow in terms of yield.

On biotech trades, you can think about Roundup Ready crops and many of you know this story of no-till agriculture and we've a generation of farmers that haven't plowed fields because of the use of Roundup Ready crops and we've preserved topsoil and carbon throughout the U.S. growing regions because of those crops, and we have next generation biotech weed control technologies that are coming through the market and we'll be launching those in the next couple of years.

Finally, we've made a big investment in Drought Guard, and this is the first really new gene that Monsanto has launched besides weed control and insect control for drought resistance that was launched on a half million acres the next year. That grew 400 percent to two and a half million acres in the U.S. We're hoping for another great year with Drought Guard this year. Drought Guard has taught us an awful lot about how to breed for dry resistance. Not necessarily complete resistance, but drought tolerance specifically at anthesis; how to reduce the impacts of drought on yield when it occurs at certain times in the growth cycle of plants. So we're not just discovering genes but using those genes to help us figure out the physiology of drought. Many drought genes that we tested at Monsanto, just simply slowed down growth and wouldn't give yield in the absence of drought. So the drought guard gene really taught us how to go about thinking about how to protect crops from drought. So look for new discoveries coming from Monsanto in that area.

So let me go on to technology and investment? Where do we see some of the impacts that are coming in technology for water use? Probably one of the most exciting is remote sensing. I mentioned Hydra Bio which is using satellite imagery, but let me tell you, the entire satellite constellation around the world is going to change very dramatically in the next few years. There are a number of new startups in Silicon Valley that are not launching $25 million satellites the way our U.S. government does, but launching $100,000 satellites. They're essentially taking the infrastructure of our cell phones and putting it in outer space, and they're not putting one or two; they're putting 70, 80, 100 of these satellites around the

earth that can monitor, not just take pictures of the earth and send them back down, but actually give us real time monitoring of what's going on in different parts of the globe. The impact of that technology on agriculture is going to be extremely exciting.

A couple of companies to watch out for; you can't buy their company stock because these are all private, but Climate Labs was on the cover of Nature not too long ago. They've got 70 birds up around the world right now, at about 7 meter resolution. But look for Astra Digital, look for another company out of Argentina called CitiLogics. They've both launched two satellites now that will be the first of constellations of 20 to 30 satellites that will have one meter resolution with hyper spectral imagery. So it's amazing that this kind of technology is going to be available. You'll essentially be able to look at your crop anytime, anywhere you want to.

Synthetic aperture radar can go right through clouds. Cloud cover will no longer be a problem for being able to monitor crops. Synthetic aperture radar is on the Sentinel 2 satellite launched by the European Space Agency, and we're going to see more and more applications of that technology over time. So remote sensing is going to have a huge impact to help us understand exactly what's going on.

Our biggest investment at Monsanto was Climate Corp. We bought Climate Corp about three years ago for a billion dollars, and I think we shocked everybody. Why would a seed and herbicide company in St. Louis buy/spend a billion dollars on a bunch of software engineers in San Francisco. And it was the realization that bits and bytes were going to solve the problem of bushels. With Climate Corp we have built the data science infrastructure that we're going to need to know exactly where to put the right crop at the right time, in the right soil with the right microbes, something we're calling precision product placement. Also with Climate Corp, we're going to solve the problem of yield through math. Very often, farmers have relied on what their neighbors are doing or their favorite extension scientist at a university to help them explain what they should be doing and where they should provide

inputs. But with the algorithms that Climate Corp can develop, and the remote sensing technology, we're hoping to bring more and more precision to that. So knowing exactly how much nitrogen to put down, to prevent nitrogen runoff, to prevent contamination of waterways, and spilling in the Gulf.

Finally, let me give you a bit of hope about the private sector. When I first started in venture capital about eight years ago, there was about $200 million a year coming from VCs into the agricultural sector, mainly into first generation ag/biotech companies. Last year was $4.6 billion. The private sector has gotten very excited about agriculture and food because it's such a large market. They're making a large number of investments. If you think about the fact that we've got to feed all these people by 2050. Think back what 30 years ago looked like. In the 1980s, the five biggest companies that we know about today were barely around. Facebook and Google weren't around. Microsoft and Apple were little startup companies. There were no cell phones, there was no internet. The impact of innovation has always surprised economists around any kind of predictions that they're going to make. They can never seem to account for it. And that pace of innovation is accelerated, and I think it's going to help us with the problems that we have with water, and help us solve some of these big problems in agriculture. Thank you.

Panelist: Robert Meaney
Former Chairman-International
Valmont Industries

Thank you you for the invitation to speak. I'll be speaking with my own thoughts and not speaking for Valmont or for the other industries that I might be mentioning. I'll just frame the irrigation equipment industry globally for you. The center-pivot industry adds up to about $2.1 billion in sales per year globally. Drip is about another $3-4 billion. So we tend to think about the global irrigation equipment business being about $8 billion. That doesn't include pumps and doesn't include contracting and civil work, the well drilling. But it includes the equipment manufactured. $8 billion seems like a big number, but consider that there are 280 million irrigated acres in the world. It's not really such a big industry in some ways. The municipal water industry is multiples of the size of the irrigation equipment industry. The global center-pivot industry is about 18.3 hectares underneath center pivots in the world. That works out to about 6 percent. I don't know the exact or the best number for drip, but it's probably about half that in terms of acreage covered. In the U.S., we have 12 million hectares under center pivots, that's about 50 percent of irrigated acres. Drip is about 8 percent of irrigated acres. Flood has been declining over the last 40 years or so. It's at about 40 percent of irrigated acres.

The irrigation equipment industry in general is down this year and for the last couple of years. But over the last 30 years, it's had a growth rate globally of about 5 percent. Investments and actions to adapt to or to reduce water availability for agriculture relate to two challenges—long term availability of water, and response to drought. Most challenges have been addressed over the past four decades in North America by improved farm management, better water management and new technologies. The net result has been a dramatic increase in total food production while withdrawals of water for irrigation actually

declined. Farmers continue to implement water conserving farm management practices, and improved irrigation technologies like center pivots and drip. Government agencies and producers continue to cooperate in managing water supplies with increased sophistication and more detailed measurement of outcomes.

For irrigation technology, a few of the areas stimulating new investments—I'm sure many in the room are more familiar with it than I am—center pivot; remote management of pivot operations and pumping operations; remote sensing of soil moisture, crop temperature, weather and so forth; and more recently introducing variable rate irrigation. For decades we tried to make the watering pattern of a pivot very uniform. Now we can divide a field, a quarter section, into 6,000 sectors and water different parts of the field in different ways, stop the watering if it's going over rocks or increase the watering if it's a particularly dry place according to a prescription developed by the farmer himself. Originally, pivots were adapted as a labor saving and soil management tool, but now of course pivot irrigation is considered by some as a water management and conservation device. There are many types of developments that are going on in the field of startups at the universities and at government agencies with new applications to be combined with center pivots. Center pivots are in the field moving through the crop, so they're really a platform for any number of innovations when it comes to farm management and water application.

Drip irrigation similarly has a lot of new developments emerging, much related to improving the performance of the midders and avoiding root intrusion. Also, remote sensing is another factor, remote system management, and applications to new crops like, large field crops like alfalfa and corn.

This investment in irrigation is centered in the main irrigated areas of the western United States when we're talking about North America, but it's also increasing in areas east of the Mississippi where it is used to assure a full crop even when a drought hits. Returns on investments in center pivots and drip irrigation are good in normal times, and paybacks

are very quick in times of drought. Another important adaptation to water scarcity now under way is the improvement of agricultural water productivity in developing countries. In many of these countries, the climate permits year round cropping, and irrigation can enable farmers to triple or quadruple their output. The needed institutions, farm management practices and technologies already exist in the developing world, but they are currently available to only a few. In Africa, there are 1.5 million hectares under center pivots all in the hands of large commercial farmers. Most of the farmers in Africa are poor. There is a big opportunity ahead for farmers in these regions to use irrigation to increase production in order to supply their markets. What farmers in Brazil and Argentina have accomplished in recent decades can also be done in Africa and irrigation and improved water management will be an important part of that story. The main barriers to progress in these markets are lack of financing and lack of institutions with water management experience.

Turning to Susanne's point about the lack of excess water flows with center pivots and drip, it's true that center pivots and drip can cause problems for neighboring irrigators. Also, there could be cases of farmers using the water saved for expansion of their own irrigation. However, these technologies are tools used by farmers who are governed by water management authorities. In the Central Plains, irrigated farming is subject to water management regimes that prevent unfair or destructive actions by irrigators. In addition, university extension services and consultants educate irrigators all the time on best practices for water conservation. Over the past 40 years, there's been a dramatic expansion of acres irrigated by center pivots and drip that has contributed to a vast increase of production of food with less water removed. Underneath Nebraska which overlays two-thirds of the Ogallala aquifer water volume, the aquifer is not going down. It's at about the same level as before irrigation started. Also, Nebraska's rivers and streams are required to meet ecological goals. The 26 Natural Resources Districts which are organized by watershed and have locally elected boards impose pumping restrictions in times of drought, and they work with

the Director of Natural Resources at the state level to identify land that should no longer be irrigated. In the future, these management techniques will evolve, taking advantage of data analytics and new ideas like water markets. My point is that center pivots and drip are technical tools that can lead to great results when combined with advanced water management practices and good governance.

Center pivots and drip will be important in the developing markets around the world. They offer good controlled water, and good controlled nutrient application with lower per capita costs than flood irrigation, and they are simple to operate and monitor. I believe that in a green field situation, center private and/or drip technology combined with effective water management institutions is the approach most likely to provide positive investment returns. Compared to flood and gravity, it tends to be less costly, is compatible with no-till practices, less invasive to the environment, and it provides an open platform for high tech applications.

Susanne's point about groundwater is very important. In Africa, where we already have quite a bit of land under center pivots but all with surface water, there's a large groundwater resource yet to be fully understood and developed. It will be important to develop proper governance and new resources in areas like well construction to ensure the sustainability of Africa's water resources. Thank you.

General Discussion
Moderator: Nathan Kauffman
Assistant Vice President and Omaha Branch Executive
Federal Reserve Bank of Kansas City

Audience Question: So this is a question for Mr. Hamer about an issue that also came up yesterday in regards to plant breeding. The question I've been wondering about a lot is, for a given unit of water that's consumptively used by a crop, a lot of it is used for the non-useful part of the crop. You know, almonds, a lot of trees and branches and leaves, for example, that go into making the nut. And so you mentioned work on sort of drought tolerance issues. But I'm wondering, what do you see as, I mean, is this an area that you see potential for in terms of really getting more crop per drop from a consumptive water use perspective as part of the yield frontier?

John Hamer: I don't know, even though I'm from California, I don't know enough about almonds. I've been with Monsanto long enough to know a little bit about corn. So obviously, there's a lot of areas around the life cycle of corn that water's going to play a very important role. Again, the development of DroughtGuard gave us a real chance to sort of look at the parameters that are going to make, so where does this gene act, and how does it act, and what's the pathway it's acting in so that it's not impacting plant growth when there is sufficient water. So yields are as good as any other hybrid. And if drought hits at certain specific times over a specific period it's yield is not as impacted as if you didn't have the gene in there. So there's something like, it's not resistant, right? You get about 20 percent, you know there's numbers all over the place, but somewhere around 20 percent more yield out of the DroughtGuard crop when you get drought at anthesis in the corn. But it's given us a chance to look at things like transpiration and what role does that play, leaf architecture, plant architecture in general, all those sorts of things.

So I think there is that chance, but it's been a long haul to get to something that we can finally begin to get a thread that we can begin to pull on and unravel. What are the next genes in that pathway, and how do they impact things, what are the other homologues and other crops that look like this gene, and what are their impact? So I think we're at the beginning with DroughtGuard and some other traits that have been discovered to begin to unravel some pathways that may have some long term value in providing more opportunities to stack traits. The codex, you know concerned scientists, came out and said, "Oh, it's not doing all that much." Well, there's going to be the opportunity to stack drought genes much like we've stacked insect tolerance genes. So I think we're at the beginning of an opportunity here, not at the end of one. Your point is well taken. Research will show.

Chuck Rice, Kansas State University: John, you made an excellent point, but I guess what Robert was saying as well is that there is a lot more to worry about. Think about a system, and that's much more complex is the plant breeder is working with irrigation, working with microbiologists. But are we there? I don't think we're thinking as a systematic approach to really innovating ag and water conservation.

John Hamer: I think I would agree with you in the sense that even at Monsanto, we've been a little bit isolated. The breeders are over here, Climate Corp's in San Francisco, biotech is over there working on insect and more herbicide resistance type things. There's the opportunity to bring it together. We have some collaborations with Netafim for example around drip. We've begun to launch a system in Europe, our DeKalb brand in Europe is now packaging DeKalb along with a Hydro Bio subscription so that growers planting that seed get a subscription for irrigation specific recommendation for that seed and where they're growing it. That's a product called Aqua Tech. So there's beginning to be some integration of that. Now we're cautious because growers don't like bundling. They don't like a single company to bundle a whole lot of things in one thing, and say, "Hey, you've got to buy the bundle." So there is an integration in terms of, there's beginning to be more and more integration

in terms of thinking, and I would say that was another huge driver in the acquisition of Climate Corp was to be able to have the data handling skills and algorithmic skills to be able to even deal with our own breeding and field trial data. So I think we're at the beginning, and I would say you're right, we're not, at least I feel at Monsanto, we're not there yet with that fully integrated approach.

Audience Question: John, could you comment on what is your or Monsanto's take these days on the potential of Biologic's yield and resistance and so forth?

John Hamer: Yeah, so we think that's a huge opportunity. So for people in the audience, pesticides, we're running out of them. We haven't had a new mode of action discovered in 20 years in any major pesticide group. A lot of the big pesticides, insecticides and others are getting deregulated and taken off the market for various reasons. And so it's sent the industry looking for biological sources of crop protection and crop growth enhancement. So this is things like microbes. So think about yogurt for plants, right? So this is—understanding the plant microbiome and giving beneficial microbes to plants. So we've got a huge effort at Monsanto on that. As you know, Bayer's got a big effort, so does Syngenta. DuPont has started an effort as well. Most of us are collaborating with big microbiology companies, so we've collaborated with Novazyme; Syngenta has collaborated with DSM. And so it's those kinds of collaborations where we're combining expertise in microbiology and fermentation with expertise in understanding plants and being able to sort of decipher the plant microbiome and figure out what are the beneficial microbes, and how can we provide those to the seed in areas where they're not there? And so it's a big opportunity and there's some hints that there's going to be some great products coming out of that. So think about this. Think about the entire ag chemistry industry, researching products that can be used in organic agriculture. So essentially all of these microbiology products are going to be organically certified. So it's really an amazing step change in the ag chemistry industry that we're spending billions of dollars doing research on products that will ultimately benefit

organic growers. So it's really an exciting time.

Audience Question: A question maybe for the panel. You've all talked to some extent about the role of data, and I'd be interested in your thoughts on how you see that translating into better decision making. You know, we all have a lot of data regardless of what field we're in. But could you talk about what are the steps involved in terms of how that's leading to better decisions?

Robert Meaney: I'm not an expert, but I know that farmers who use pivots use more and more data all the time, and they get it from new sources, new ventures, some exist for a few years and disappear. But you can see that there's tremendous amount of work going on all over the place in the U.S. and Europe and other places. So the farmers are the most important people to supply with the kind of data that will help them improve their productivity, but there's also a lot going on in the regulation area. I'm not sure the farmers are always happy about the regulators becoming more and more sophisticated and collecting more and more data, but that's an issue that will work itself out.

Quiquiong Huang: More funding for data collection. So as far as the research done by our research team, I see that data can be used to advise policy makers throughout the whole process in terms for example to evaluate the situation of water scarcity. For example, we read lots of articles that say north China is one of the most water scarce areas in the whole world. And I use that sentence too. But we did a large survey, like covering seven provinces in north China, and we look at the changing water levels, and what we found is actually in 50 percent of villages, the water level actually stayed constant between 1995 and 2004. Actually in some the water level actually increased because those are shallow aquifers so they can recharge. It's only in about 10 percent of the villages we see that water level drops like one meter per year, which is an alarming rate. So even though we said we have water scarcity problem, we had to realize it's not everywhere, it's only in parts of the region. So that's an important message for the policy makers when they think about what policy to

make and where to focus the efforts.

I also see increasingly, at least in the field of economics, we used to do lots of prediction, but now I think more the focus is how to evaluate what policy works and what policy does not work, and this is particularly important in China because China likes to do pilot reforms, we're doing trial and error approach. So we need research on evaluating whether those pilot reforms has worked or not, and the government is really revising the next [inaudible] reform based on those research and we use data to evaluate this reform. So I really see this is playing a bigger and bigger role in making policies.

Jeff Peterson, University of Minnesota: So, we've heard on the panel here about both innovations in the institutional realm as well as technological innovations, and one of the observations that's often made is that some of the issues that we have now, I think this was mentioned in Susanne's talk, is that given a system of markets and policies and so on, the current institutions, recent institutions, when new technological innovations come along, the way they're adopted doesn't end up having the, we have unintended consequences from that. My question is with the new waves of innovations that are coming, both institutionally and technologically, what has to be done differently to make sure that the new technological innovations have their intended impacts?

Susanne Scheierling: One important thing is this better data collection, and when you look at the water sector, the data situation is unbelievable. Even like for countries like the U.S., if you want to have more information on, let's say, county level data, water use for different sectors; farm level data, how much is really withdrawn, applied, consumed—it's not there. You can't find it. That is the first step, data. And then the assessments should also be carried out much more closely dependent on the water related data. But hardly ever are studies being carried out with regard to what actually works to really conserve the water. And especially with irrigation water conservation, you can't find one study really if you tried to look, was water really conserved with what intervention, you can't find. And it's amazing

when you think about it. So this situation needs to be improved. There's no question about it.

John Hamer: So I think the challenge has always been making sure these policies are science-based. And you just look at the difference of regulation in the EU and the regulation in the U.S. with regards to genetic modification in crops. So I think we've got to have, I think most people in the U.S. would say we've got to have, science-based policies based on evidence and science. And therefore, the technology has to be out there for a while. So that's one comment. The second comment would be, I'm concerned about policies that are really going to end up supporting the incumbent infrastructure. And so there's a number of new technologies that are emerging. One can think about Uber and Airbnb and others, really breakthrough technologies that are changing the face of industries. Of course, the incumbents are pushing back with all kinds of "policy," but it's not policy at all. It's preserving an incumbency that doesn't want to be disrupted. So keeping those two things in mind, I think we do have to be aware that some of this new technology is going to have some very profound changes, but ensuring that it's science-based and not just there to support incumbents.

Robert Meaney: I think it really goes back to governance again. It's a common resource and you can't have every individual acting on their own. They can in 98 percent of what they do, but on the important 2 percent if it's a new technology that starts to affect a watershed, the people responsible for the management of watershed have to act.

Audience Question: A comment first, and then a question. First of all, I want to make the comment that we're not looking long enough in water. It's been 27 years for me in this industry now, and it takes 20 or 30 years to create a reform in water and we're talking about the next 35 years, 2050, it's not long enough. We need to be talking about the next 100 years if we're talking about water reforms that take 20 years. So that's a comment. The question is, if we're drawing water resources out at a faster rate than are being replenished, that's

water mining. That's mining a water resource. Does the World Bank or any other of the speakers here have any concept at the moment about the percentage of water in the world we're mining instead of sustainably using? And how will this affect farm productivity in the future?

Susanne Scheierling: I'm not aware of a global dataset with regard to water mining. I think there are data for specific regions. Like, I think in China they have some data for some regions. One could calculate based on the withdrawals when you're comparing this renewable resource, it's like the difference, like I showed it in percentages. But you can calculate the amounts and add them up. So that could be possible. But then what do you do with that number?

John Hamer: Certainly, we are mining water in some areas, and Saudi Arabia is the famous example, and they've cut way back so that it will last longer. Libya has the Nubian aquifer that will last probably 100 years, but these are more decisions about do you just leave it there, or do you use it, or do you use it fast or slow. But I think that percentage that's non-renewable is not so great because we're still ... the big irrigation areas of the world are still India, China, Pakistan, the United States, Iran. The list is about the same of the top 15, and those are all based on rivers and flows, and the melting of the snow in the mountains. In the Himalayas, I think they feed eight or nine rivers that eventually go through irrigation or they come to fertile land, and then they're used for irrigation. So all of that is still I think much more than half the irrigation in the world. You can name probably 20 different irrigation schemes that would still be half the irrigation in the world.

Steve George, Freemont Farms: I have a three part question. For Mr. Hamer. You mentioned the genomics that allow corn yields to be mentioned at a rate of increase. Were you referring to a linear increase we've seen historically, or will the genomic effects allow acceleration, a more of an exponential increase perhaps?

John Hamer: Yeah, I'm not prepared to say exponential increase because all the plant

breeders at Monsanto would shoot me. But I think it's the linear increase you're talking about. But it's continuing to build on that base. What was the world record this year for corn? 504 bushels an acre. That was the same genetics. So it's not just going to be the genetics, right? It's going to be a lot more that drives that yield. But genetics is going to be a bit part. So when you think about, imagine all the world growing 500 bushel an acre corn. We wouldn't be talking about 2050 anymore. But the potential is there. Right? It's in the genome, and it's there. And it's there today.

Steve George: And you also mentioned a big effort/movement underway from Silicon Valley. Silicon Valley has discovered agriculture in the last five years.

John Hamer: Yeah, I think it's because we spent a billion dollars. That's why they discovered it.

Steve George: Right, but there's been huge conferences, and articles from the Wall Street Journal talking about how there are all these brainiacs in Silicon Valley, and I have a son who works there, who believe they're going to revolutionize agriculture because it's a bunch of dumb, dull farmers that have never innovated in their life. The farmers are sitting over there laughing about saying, "You kids have no idea what you're in for to learn," and my question is, are some of these startups actually working with farmers directly and incorporating them as part of their user group in a more intelligent way rather than some of the condescending type of attitude that we've seen in some of the efforts to date?

John Hamer: Well, the good news is California is a $36 billion farm value state. So you don't have to drive far from Silicon Valley to run into that. So the good news is they are going to Salinas, they are going to Fresno, they are seeing the Central Valley. More and more conferences in the Bay area, and you're right, there have been tons of ag conferences, are now incorporating growers that are coming in. So big growers from the Salinas Valley or Central Valley, some of the big almond farms, some of the big pomegranate and other type big growers, are coming into Silicon Valley. And of course, these guys have the high

acre crops. So these are the crops that are $10,000-$20,000 an acre crops. This is not corn and soy. So, these farmers have the wherewithal, and they're growing perennials, so they're only making a decision a couple of times in their lifetime about what to put in the ground. So their crops are very valuable, very wealthy. You know, they've got a lot of value in that crop. So they're willing to experiment on technology. So it's actually turned out to be a very productive fit between Silicon Valley and innovative technology, and farmers growing high value perennial crops in the Central Valley, and they're only a two hour drive apart. So that's the good news. I think the challenge is when Silicon Valley guys end up in Iowa. And I think that's where you, or Nebraska or Kansas, and I think that's where some of the challenges have been. But I think they're going to get it solved.

Steve George: And then finally, do you have any comments on Monsanto's efforts to get social acceptance of these technologies? I heard your VP of Research speak a year ago and he was talking about how Monsanto has to change their strategy to gain the social acceptance, social contract among millennials and others, or certain percentages that are rejecting this technology as dangerous. And if you have any thoughts that you can share on new strategies for overcoming those attitudes. Because the greatest technology in the world, but if there's not a social contract of acceptance, we're seeing state laws in Vermont against GMO and so forth.

John Hamer: To quote our CEO, we just thought everybody would read the papers. Right? I mean, literally it was the view for 20 years that most people at Monsanto just thought, you know, the farmers love us, we're through EPA, and everybody else should just read the papers or read the toxicology reports. And suddenly over the last three or four years, finally figuring out that people vote and if Monsanto doesn't have a message, everybody will have a message about Monsanto. So they are making a very concerted effort to create more engagement, to talk openly about biotech and what it can do and what it can't do, and to think about as Chuck was saying, it's a system of genetics. We're going to need genetics

in breeding, we're going to need biotech, we're going to need data science, we're going to need advanced engineering and remote sensing. It's all those things combined. And I think someone showed the chart of increasing yields and how many of those were engineering advantages and agronomic advantages that led to those changes? So I think Monsanto's thinking much more holistically than I think it ever thought before. So thank you for those comments.

Session 4: Markets and Allocation

Speaker: Mike Young*
Professor and Chair, Water and Environmental Policy
University of Adelaide

Thank you for the chance to share a vision about what could happen in this country. I was just thinking as I was writing through my notes whether or not, in 10 or 20 years time, you would find a water utility in Mexico deciding intentionally to invest in shares in the Colorado system in Idaho, Nevada, and Colorado as an investment strategy to manage risk. In Australia that now happens.

Let me backtrack and talk about water and what I think is important in the vision that I hold. I think it's best captured when I was flying here and I was transferring from one airport to another in New York, sitting next to a young American family with a young child. They said, "Why are you going to Kansas City?" I said, "I'm going to talk to Americans about how they might build a new water management system." They looked at me and said, "Oh, I had heard that Beijing was sinking because the Chinese were taking too much groundwater out of Beijing." I said, "You don't have to go to Beijing to find that problem, you can find it in California. In fact, last year there were some areas and some towns that sank more than the height of your young son." And they were shocked and said, "How do you fix it?" I said, "It's easy. You define, first of all, you set a limit on the amount of water that can be taken so that the groundwater no longer, or the ground stops sinking. You issue shares in the amount of water that's allocated each year, and give everybody a water account that's just like your bank account, and imagine an ATM for water." And they said, "Why don't you do it? That's simple, that's obvious." And the thing I wanted to convey to you first of all is the importance of thinking very simply about what really needs to happen.

There's a famous diamond paradox that really says nothing is more useful than water, but doesn't really purchase much. And Adam Smith had made this observation back in the

*Please see the corresponding paper and/or presentation available at www.kansascityfed.org/publications/research/rscp/rscp-2016 for additional detail and referenced charts.

1700s. I wonder if somebody will say at some stage in the future that water may be the jewel in the crown held by the farmers in western USA that is awaiting discovery. I want you to think about things quite differently than the way it's talked about so far.

Paul Keating famously said back in the 1980s that he was worried, and at this stage he was our treasurer. He was in charge of what really runs the Federal Reserve here or the equivalent of it. He said he was concerned that Australia might be becoming a banana republic or at least at risk of becoming one. When he became Prime Minister, he set up a national competition policy that made some observations, which I think could be made about the United States today. If you brought him over here, he would probably be puzzled by the arrangements and the complexity of the whole regimes used to manage water. He really pointed to the fact that water trading didn't really work, and that water was used in low value industries when it could be used in much higher value industries. And this went through and was adopted by COAG, the equivalent of your Western Governors Association. The great insight that came out of that back in 1994 was that you don't talk about markets, you don't even waste your time trying to set them up. What you do is you design, you fix up your allocation entitlement arrangements so that markets emerge naturally. The more you get governance right, the more markets emerge, and the more efficient water use becomes. So the vision and the journey that Australia started in the 1980s flowed through into the 90s, through into the 2000s, and now 2016, it's still wrong, but it's on the right journey.

Let me make four I think very important observations before I go further into this talk. The focus needs to be on trading, and the language needs to improve. This conference has been about water markets; it should be about water trading. In some systems you'll get to have markets, but markets involve lots of players, lots of people acting, trading continuously, but the focus needs to be on getting to systems where water trades naturally, quickly at low cost. In Australia, as people like Tom Rooney will tell you, it's now possible to trade water from one region to another, from the start of the deal to completing the deal to

paying for it and having the water moving on to the new farm in 40 minutes. Why isn't that possible throughout most of western USA?

There needs to be two types of trades, not one, two markets if you like. One is about trading volumes of water that are available for use now, and the other is about long term investment-type things and well-defined systems have two types of trades and often many more types of trades, but at least two. As I said markets emerge naturally when the institutional conditions are right. So focus on building the institutional conditions and be thrilled and excited when suddenly you have a broking industry. The US broking industry is run by the law firms who seem to take 5 years to do a trade, not 40 minutes. There's something wrong.

Finally, language, narratives and process really matter. I think one of the greatest steps forward came in about 2003-2004 when those responsible for water reform in Australia met actually in Adelaide, and I was there at the meeting when they agreed to do it. And they agreed to write a glossary and amongst them all agreed never again, for a period of time—they now use it again—but they agreed collectively not to use the word "water right" because they found when they went into rooms that were talking about something that was totally new, it was about entitlements, new government arrangements, allocations, and compulsory meeting, statutory plans, etc., and they were using the old language to describe something that was new. When you talk about something that's new using old language, people still think you're talking about the old system. Changing the narrative, changing the paradigm, writing a glossary ended up being I think one of the most important steps in the reform process and journey that Australia went on. We discovered that some of the terms used in one state meant exactly the opposite in another state. If you're running a system like the Colorado we were talking about arrangements in Queensland and South Wales and South Australia. The word "entitlement" meant the reverse in one state to another. So a lot of things had to be cleaned up. Having consistent language and having a consistent narrative is really

important.

When I was talking yesterday, Ellen Hanak asked me to tell you about some of the things that Australia's still got wrong. Some time ago I wrote a report that really upset the Australian government that said Australia made at least 18 horrible, very expensive disastrous mistakes. When I presented talks about the list of 18 up here, and asked everybody to put up their hand if they're not making all of them, nobody put their hand up. I don't have time to give that talk. But I urge you not to make the mistakes that Australia made. The narrative which is most important I think is one that realizes that the waters are based at the moment as it's cast in the United States is really cast as a zero sum game. Everybody is very protective; everybody wants to protect their rights.

Remember though that the value of rights, whatever they are, is determined by the quality of the asset you have. If you have an old broken down car, it's not worth very much. If you have a brand new Cadillac with a GPS and all the rest in it, then people are interested in buying it and will pay a lot for it.

When I went into Nevada last year to help people in the Diamond Valley solve the mess they're in, it took me about 15 minutes to get them to say let's go to a new system. I think the thing that most underscored how bad their system was, was when we went through the process and say, "Okay, now I'm going to recommend to you that you validate who owns what," and the State Department official said, "Well, it's easy, we've got a register." I said, "Well, let's just send a letter to every registered owner to find out and let them know we're about to fix up the water rights system." A month later, 30% of the letters came back from U.S. post, "no one at this address." We went back into the room and sat down in a room like this with everybody in it and said, "Who owns this water right? Who owns this one?" It was a fascinating process. The community realized that they didn't have a clue what was going on. I can assure you that throughout much of western USA, there are some exceptions, that is the state of your knowledge of who owns what. Systems that have integrity

build good markets. When you don't know who owns what, you hit very complicated legal processes that take forever, and even after you think they're finished, you still don't know if you really own what you've paid for. There is an opportunity to fix things up, and essentially to do what I've just shown you, build a cake which is much more valuable. The narrative needs to be about increasing opportunity, increasing wealth.

The framework for this is set out in a blueprint that we released last year for all of the west. It talks about setting limits and enforcing those limits. There needs to be much more talk about enforcing limits. In most of the states that I've been looking at, and I'm now working at the moment in California, the limits haven't been set and rapid depletion is occurring in much of what's going on. The plans put in place need to be statutory, need to have standing that stops legal argument. You need unbundling structures and I'll come back and talk about them more. And you need efficient trusted governance. I can't emphasize how important it is to have trust. You in the corporate world know how important it is that, for example, the Reserve Bank speaks with solidarity. If you had members of the Reserve Bank or actually your Federal Reserve who went out and said, "We've just set the wrong interest rate," you'd have a disaster. You need systems that are not based on representative governance. You need low cost administrative processes, and you need to consider, as Australia now does, giving the environment a legal share.

Ten opportunities, and I need to be very, very quick, as I go forward because time is short. One of the first things Australia did was to build centralized water right registers of guaranteed integrity, and we took a process of, rather than doing what you do here which is adjudicating rights, it's simply validating a right, and inviting people who had an old system right to convert it into a new system right, which was recorded on a central register. And the only way you could own that right was if it as in the central register. This is done throughout most of the world now for property, and why wouldn't you do it for water. And why wouldn't you bring in a framework that says, if you want to trade, you have to have a new system

right. We'll stop trading of old system rights, so people start to convert over quickly. And why wouldn't you make those rights mortgageable, and go to the banking industry, and we're now building a water right system that you can bank on and that you can mortgage for dollars and actually execute the mortgage in ten minutes. It's not hard. When you do that, as Australia found, a lot of people become very interested in lending against the value of water, and the more they do that, the more innovation you get, and the more they become concerned about having credibility in the governance systems you put in place.

The second big opportunity, which adds to the value of the water system and grows the cake is to unbundle the water right and split it out, and to establish a long term share and manage those shares separately from the allocations that are made time by time. So you don't have complicated leasing processes, you just have a very simple structure. And this is what Australia did. In 1994, we did what America is just now starting to do, talking about setting limits, talking about making water rights, we called them licenses, or tradable, and as China is doing, getting the price right. You actually need to do the two and the architecture around that is very important. That happened back in 1993-94 in a process that went through. We then unbundled the structure further, issued people shares just like shares in a company, and we went through the difficult process of working out how you would have a fungible share structure. We required everybody to have what we now describe as a water account, just like your bank account. When allocations are made, just like dividends are made to shares in a company, the second allocations are made, they're recorded in a water account. And as you use water, it's dedicated off their account. If you want to trade water, why can't you just log into your water account and transfer the water from one account to another account. Why can't a water manager do as a bank manager does, sum up all of the accounts and see how much water is left in the system? Why don't you do these things? And as part of this process then, you issue permits to use water separately, and the beneficial use requirements which tangle up so much of what happens, are only about how you use water.

Yes, water has to be put to a beneficial use and not cause harm, but if somebody wants to save water and leave it in the account, what's wrong with doing that?

One of the big mistakes Australia made early on which cost us millions, in fact billions, was to not allow people to carry water forward from year to year. We discovered as we introduced markets and we had a use it or lose it program, you need to have a use it, lose it, or save it. We concluded that saving was often the most beneficial use you could do. So why don't you build structures that do that? And having mechanisms that separate shares from allocations from use builds opportunities for people to get development approval essentially and do an entire irrigation industry, and then buy the water down the track. In fact, we're now finding many farm businesses have very, very valuable irrigation structures but don't even own their water. They don't need to because, just like electricity, you can buy it.

The third important experience that's come out of Australia is you need to give the plans that are written statutory integrity. So what we'll do is we'll end up taking them right back up into the legislator after they've been approved and get our legislator to improve them so they have the same standing as all other legislation. This is important because it reduces all the legal contests about what's going on. The plans are short. They are legal documents that say this is how decisions must be made. If the rule of trading water from zone A to zone B is an exchange rate of 0.9, you say it's 0.9. You don't put in the plan 20 pages of documentation of the science and knowledge and the hydrology so the lawyers can have a fight about whether or not you've got the science right. You just say as your Federal Reserve does, the answer is 0.9, and if there's a third party appeal, the third party appeal can run a process to change the plan, but in the meantime the trades continue at 0.9. This is a very, very important building clause. And as part of the process, and this is difficult, and I've been working on it this last year in Nevada and have some equations to do it, and I'm now trying to do the same thing in California, you convert all of the complex rights systems

through into a simple sharing system. Most of you here know enough about the corporate world to know that you can merge companies. Think of a process where you equably work out how to convert all of the rights, which were all different in the prior appropriations system, every single right is different, through into a simple one that has several classes of shares and put it all together so that you know what's tradable, and you know the value of shares, and the markets, and you know what things are worth. Then brokers and others can report on what's happening.

And then thinking about giving the environment an entitlement just like other shareholders. We now have the environment as a significant shareholder in Australia. Every time water is allocated on the first, the day after the 1st and the 15th of each month, the first working day after the 1st and 15th of each month, allocations are announced, and the environment receives a share of those allocations. We now have environmental water managers who are selling water back into the market because I'd like to use the money to buy more shares or invest in other things. They're now part of the system, and we've had a revolution in environmental water management.

This conference has talked a lot about irrigation water use efficiency. Why haven't you talked about environmental water use efficiency? Australia is discovering when you give environmental water managers the capacity to manage environmental flows, determine when releases are made and where water is put, that they can get much more environmental gain to a drop of water allocated to them. Think about the total rather than half of the cake. Sharing systems we put in place look like this, where you have some bits managed under rules, you put conveyance systems in place, you have normally no more than three classes of shares, and three different markets, and that allows people to manage risk. If you have medium, high, and low security shares then everybody can work out what sort of supply risk they ought to take depending on the investment. Towns want high security, rice growers might want less security, this is something which can be worked out in the market. And

with shares, you can manage risk. They're called shares for good reason. They used to be volumetric entitlements. We discovered that you can't guarantee that it's going to rain; you can't guarantee water supplies. The best you can do as the corporate world worked out several hundred years ago is give people a share of what's the profit, but you cannot guarantee there's a profit, and you need incentives for every single investor to manage and understand that scarcity exists.

The next important opportunity is to build trusted governance arrangements. You need to realize if you have representative governments, you'll end up with insider trading problems. Don't do that. Instead, build independent expertise by governance structures. Have a nested planning hierarchy to pull everything together. One of the mistakes Australia made was not to manage ground and surface water resources as one; you need integrated structures to pull the plans together. Adopt simple gross accounting systems. We used to worry about return flows; we now have a system that says allocations across the whole system get reduced as water use efficiency increases. That's much more efficient and saves a lot of administrative costs. Think about tag trading arrangements, so that Mexico could invest in Colorado or Idaho with confidence, and not be worried about what's going on, rather than having to move rights from one state to another or one region to another. And lastly, make sure you allocate rights to individuals. One of the big things Australia did with a lot of controversy was to transfer the right of ownership from districts down to individuals, and require each district to allow water trade between districts. That generated probably an increase in value of 20-30 percent. The cost benefit analysis work that needs to be done on this is really important. There needs to be much better methods in place. Looking at opportunities over here has identified there's a really big opportunity to move to an Australian type system. It will have, they actually see losses from where you are now. You need to document the many things that come. Talk about innovation, talk about community resilience. Understand as people in Nevada are now realizing in the Diamond

Valley that social coherence is something that people value. It comes out of trust; it comes out of integrity; it comes out of having bankable water management systems and positive environmental outcomes.

This story I think summarizes the Australian experience better than anything else. When Australia started the journey back in the 1990s, and committed to fixing up its water allocation system, the profits, the return on investment sat around 20 percent per annum, never went under 15 percent per annum, outperformed the Australian share market for the first decade. I would like you all to think about designing a system in America and the West, which can outperform the rest of the U.S. economy for a decade. It's doable and it's feasible. At a state level, the focus to do it, this is on building institution arrangements that are robust, and transitioning to new water systems. The federal government I think they are providing assistance for pilot demonstrations, early investments, and doing things like funding the installation of meters throughout the whole system, demonstrating a willingness itself to support a transition and not having departments of reclamation, interior, whoever they are saying, "No, no, this is our water; it's not state water; it's separate." You must have one system that has integrity. And being prepared to restrict its role so that statutory plans are respected rather than having ongoing legal contests, and a lot of that comes out of the federal legislation and resolve.

If I had more time, I'd talk more, but I want the paper to draw you to a checklist that's at the back of the paper which sets out 14 checks. I think if you read through that, you'll discover that most of the systems used in the United States file the most basic of robustness tests. The vision I'd leave you is one of which says, focus on the institutional arrangements, and be excited in 20 years time when you have vibrant water markets, and irrigation in communities that are prosperous, and environments that are healthy because you focused on getting the design detail right rather than talking about markets, and talking about markets, and talking about markets, but not doing or making the changes that need to happen. Thank you very much.

Discussant: Nicholas Brozovic
Director of Policy, Water for Food Institute
University of Nebraska-Lincoln

Thank you very much. It's a pleasure to be here. Mike is a tough act to follow. Let me start by saying I greatly enjoyed his paper. I am a huge fan of the Australian water system. I think there is a lot of learning to be had there. That said, I think it's important to acknowledge that markets are part of a larger water management tool kit, they exist within a specific institutional context, and they're not the only solution to water management and allocation problems. So think, there is an enormous path dependency in water resources. A lot of the history is very localized, and so it's important to understand what the local context is, and what the applicability is. So that said, I'm going to lay out some of the key findings from Mike's paper that I think we can all agree on. I'm going to mention some points of disagreement, and then give you a little bit more context about the U.S. setting of water markets, water transfers, water transactions—there is actually a lot of work being done there formally and informally—and talk about some of the innovations that we have. I will mention that within this room we have a large proportion of U.S. expertise in water transfers and water markets. And so for those of you in the rest of the audience, it's important to understand that, and I'd encourage those of you—you know who you are—to come forward and ask questions.

So let me start by trying to frame the conversation in terms of much of our audience who represent growers and their interests, who represent agricultural lending and investing perspectives. Why should you care about water markets? Why should you care about any of this discussion that you've heard so far? First of all, it's important to recognize, and I think we all know this, across much of the U.S. and globally, access to water is critical to crop productivity and farm income. As a result, access to water translates directly into rental

rates, land market prices, and profits at the field level and farm level. Similarly, risks to water availability, whether those are physical risks from depletion, regulatory risks, legal risks, or risks from climate change, mean that there is investment risk. So if you are interested and work in agricultural investment, you need to understand water risk. Because of this, understanding the value of water in agriculture is very key. I will also argue that in general understanding the value of water in agriculture, and particularly how water is capitalized into land market prices and water rights values is generally not well understood. So those of you that work actively in water management or in investment, I would urge you to take a moment and think about how you value water risk in your enterprises. You know it's there, but I think that at least in the conversations that I've had with people about the ag lending community, sometimes those approaches are not very sophisticated. Speaking as an academic, I also know that we struggle to value water risk because of data issues.

Why do we care about water markets? Well, first of all, water markets can provide enormous clarity on the value of water. So they serve an important purpose there. They provide a different kind of risk management opportunity, and therefore a different kind of investment opportunity. They can also provide an incentive for innovation as they monetize on-farm savings. So they provide a different way for growers that are innovative, new technologies, to provide an income stream.

Now, let me then come back to what I think really comes through in Mike's paper. First of all, water markets provide strong agriculture risk management. Second of all, there is an important need to provide registries, and markets function only as well as the institutions and regulations that underlie their function. So monitoring and enforcement are incredibly important within markets and market-like systems. This is something that often gets lost in the debate. In order to have the market that functions well, the underlying institutions have to function well. I also really appreciate the focus on trust and the importance of trust in water markets. This is something that I've personally found in my work, and I think many

others that have worked on the ground will emphasize that too. Finally, the role of markets from an environmental protection, I think markets can have a very, very important role in environmental protection. That's a very controversial topic, and I would defer to Chris on that one. He's someone that works at the forefront of that field. But if done correctly, markets can provide a lot of environmental protection and that's a very worthy goal.

Now, to come to things in the paper that are perhaps debatable or contentious within the U.S. community, first of all, the paper argues that the U.S. water rights system, which is primarily based on prior appropriation, is an inefficient way to structure water markets. So I guess there are several issues to clarify here. First of all, prior appropriation is one system that exists within the U.S. There are many, many other systems operating for water rights allocation within the U.S. These include riparian rights, correlative rights, tribal rights, adjudicated rights, mining rights, and in some cases all of these coexist at the same time. Now that's perhaps an argument for simplification, but it's important to understand that it's not just a prior appropriation system.

Second of all, there is active water transfers and water trading throughout much of the U.S., and many of the highest value and volume systems are in prior appropriation systems now. Therefore, I don't think ex ante that we can say that prior appropriation does not create good market outcomes. Now, we can argue as to whether that is in itself an efficient outcome or you might do better going to another system; however, I will note that when you have an entitlement system with different classes of reliability, that doesn't look that much different theoretically from a prior appropriation system with different vintages of water rights. Third of all, there is the concept of beneficial use and that this is problematic in reallocating water. I think that we all agree that theoretically beneficial use doctrine is a problem in western water allocation. My own sense has been that people are generally very hesitant to use beneficial use doctrine to take back water rights. And so it's there on the books, but beneficial use doctrine doesn't really get applied. So we talk about use it or lose it a lot, but

the number of people that have lost it is very, very small. And again, I'd reach out to the audience here if I'm wrong on that one.

Second of all is the idea here, and I think many of us, we'd like this idea to be true, that moving to a formal water market will increase the value of water. There is a very, very important caveat here. If you start with a regulated constrained system in place, then moving to a water market will increase the value of water because it increases investment opportunities. If you start in a system like we have in California that has been unconstrained for over 100 years where you have very, very high value agriculture, no restrictions on pumping, no restrictions on drilling, then in order to move to a place where a market can exist, that will involve a very, very large reduction in pump water. That will reduce farm level profits. So markets and market-like systems are a way to blunt the impact of regulations. They're a way to provide new investment opportunities, but by themselves it's not clear that they will, they don't exist without other restrictions in place too. So it's not clear to me that in the case where you introduce both restrictions in a market at the same time, whether the value of water rights will increase or decrease.

Next, we need to acknowledge the role of transaction costs in moving to a market. Administratively, changes, monitoring, and enforcement are very, very costly. So large institutional changes cost money. Within the Australian context, I don't know the final value, but I know around $8 billion U.S. dollars was spent on environmental buy-backs. I know that cost share subsidies for technology adoption was several billion U.S. dollars. In addition, there were payments for state governments to make the changes acceptable. There were grand water buyouts and so on. These are tens of billions of dollars in a system that is in order of magnitude less than what we have in the U.S. And so I think it's important to acknowledge that moving to systems that may in the end be much, much more efficient is very costly and that requires a level of political willpower that it's important to acknowledge.

Next of all, I actually very much like the Australian system of water rights. The

pragmatic part of me says that it's going to be very, very difficult to convince people that have senior water rights to give them up. Now, within the U.S., I'm aware of two prior appropriation systems of groundwater where this has been tried. The first is the Sheridan 6 Local Enhanced Management District in Kansas that a few years ago petitioned the state to move from a prior appropriation system and flatten its water rights to a correlative system so that they could reduce everybody's pumping by 20 percent below baseline. That is a phenomenal experiment that many, many of us in this room are watching very, very carefully. Now in the last two years, it's been wet, so they haven't come anywhere near that cap. I will also say that that system has a little over 100 farmers in it. That's a very small system. The second system which has been attempted is the Diamond Valley system. They have not yet gone all the way through to changing their water rights to a shared base system. I think they're closer and I'm hopeful that it will happen. That system is about 60 farmers. So these systems are very, very small, where social bonds really matter. What I'm less clear on is when you move to a system where you have millions of acres, thousands of farmers, institutional investments, and billions or tens of billions of dollars are water rights, whether people will rely on those same social mechanisms to allow a change in water rights. I fear that there will be major legal challenges.

Let me talk a little bit about the U.S. context of irrigated agriculture now. So, the U.S. has about 54 million irrigated acres; that's roughly ten times more than Australia. Several states within the U.S. have more irrigated acreage than Australia, and several others have more irrigated acreage than the Murray-Darling Basin. So for example, Nebraska, lots of people talk about Nebraska. I love to talk about Nebraska. I'm going to try not to talk about it too much. We have 8.5 million irrigated acres. Australia has 6.4; Murray-Darling Basin is around 3.5. Within that is enormous complexity.

I now want to come to the value of water in irrigated agriculture. This is, of course, an issue of a lot of interest. First of all, right now within the U.S., in most cases, the value

of water rights is partially or fully capitalized into land values. So if you're in an area that irrigates, you're paying for the water right through your leasing contract or through your purchasing of that land. What are those values? Well, they vary enormously. California, of course, is on one end. The value of water rights in California is much, much more than it is anywhere else. Spot market prices in the drought have exceeded urban water use values for lease arrangements. I should also say, and this is something that I don't have a good answer for, but I just found out within the last few months, when you look at Australian water prices, they're about an order of magnitude less than the water prices we have in the U.S. Now, that's a mystery to me. I've been told that some of that is a result of the high regulatory costs and labor market constraints within Australia. But when for example, you look at Murray-Darling Basin spot market prices, or I guess allocation entitlement prices, you compare them to what's happening in California, there's an order of magnitude difference. Corn in Nebraska, irrigation water rights are worth two or three times more than they are in Murray-Darling Basin for similar amounts of water. So this is something that is a mystery to me, but I really want to emphasize that it's not the case that the value of water in the U.S. is underappreciated.

So when we look at the United States, there's an incredibly varied water management, water rights system across the U.S. The federal system we have puts a lot of control over water at the state level, and as a result of that, we've had a very large variety of different kinds of policies put into place. I like to think of it as a grand water management experiment. So across the United States, there's enormous innovation in groundwater management. Across Nebraska we have just about as much variation in water management as across the rest of the United States because of the local management system we have there, the Natural Resources Districts. There are many, many both formal and informal water markets operating, so Chris has talked a lot about the value of informal water markets. My suspicion is that informal water markets right now have a higher volume and value of water

transacted. They're not called water markets; they're often called pooling arrangements. There's enormous value generated for agriculture there that we don't really know about because we're not asking the right questions. So I'd say that there the key is that there is enormous local innovation, and our challenge is to collect and synthesize that information, move it from anecdote, to rigorous statistical testing, to impact stories, and then to a narrative as to how lessons learned from one area can move to another. I'm a big believer in pilot programs. I think pilot programs are a great way to kick the tires and see what works, but we need to acknowledge that pilot programs will often fail, and we need to talk about those failures and understand that that will happen, too.

So with that, I'm going to summarize in my remaining six seconds. First of all, when we talk about markets and incentives, it's important to think about things from an ag investment and grower perspective. Water is a production input, and its value is either partially or fully capitalized whether you have water markets or not. There are many markets and market-like transactions operating right now within the U.S. that represent investment opportunities. In general, I'm very optimistic. You know, I think that we will see an increase in market transactions. I think approaches like we see in Australia are very useful. I hesitate to suggest that large-scale reform of water rights is the only way to get there, but in general as I said, I'm very optimistic. Thank you very much.

Discussion with Mike Young and Nicholas Brozovic
Moderator: Troy Davig
Senior Vice President and Director of Research
Federal Reserve Bank of Kansas City

Troy Davig: Mike, why don't you take a few minutes if you have any thoughts or want to respond in any way to Nic. And while Mike is commenting, if you have any questions for either Nic or Mike, please make your way to the microphones.

Mike Young: Yeah, I think I agree with almost all of Nic's insight. So very little actually disagreement. I don't think if we really talk through we're very far apart. I could spend a lot of time talking about why actually prices in Australia are different, but I don't think that's useful. The point is that we have prices. We have systems where the price of water allocations changes with the weather forecast. So if irrigators see a forecast that says it's going to rain, they know they're not going to irrigate, and that water then can be sold to somebody else. And those sorts of systems is the sorts of systems I would expect to find. To get there, you need great simplicity.

The journey Australia started on back in the 1980s, and went through with increasing clarity was messy. We never expected to end up where we ended up. We're very lucky we got there. The main message is work on getting the structures simple. The obvious first steps, which I think you'd agree with, building a new system of registers so that people know what they've got, and can trade with confidence as a permanent thing, and then getting the short term allocation market. People in Australia are puzzled by the fact that you need fallowing programs where people are paid not to farm a whole area. If you have a proper allocation market, or temporary market whatever you call it, you don't have to pay people to fallow. They might want to use one acre-foot, two acre-foot, or three acre-foot, whatever it is, they just make that decision and it's much more efficient. I mean, importantly, when water is scarce, every single water use with exception looks for opportunities to save water.

In Australia now, virtually every single water user in the Murray-Darling Basin has traded water within the last three or four years. The trading is just part of the things you do in business. I could go on talking, but I think it's more important to have discussion. So I think I agree with all the detail and yes it is possible to go part the way through without going to the fully fledged, unbundled simple system, but its clarity and vision and the new language is very important. When you get the simple structures and you go from all the different prior appropriation type systems, all the other water systems, converting them all into a standard structure, and having one type of water right, then you have one market with clarity and tradeoffs. Whenever you have separate different systems as Australia used to have, you have an uncontrollable mess.

John Ambroson, John Deere Financial: There's a lot of lenders in the room here, Mike, and I'd just be curious of what the role or how the financial community was integrated into the process in Australia and if there were any learnings or any thoughts or advice or comments around how that worked and what we could learn from that in the financial side?

Mike Young: Engaging with the financial sector was critically important, particularly as we went through the unbundling process because a lot of banks used to have mortgages over land, which reflected the value of the water rights held with that land. When we separated the two, time had to be given for the banks to renegotiate all the mortgages. That became very interesting in ensuring the integrity of the system. We've now got to the stage where to put it bluntly banks love lending against mortgage, or mortgage water shares. Imagine somebody walks in and says, "Look, I've got half a million worth of water rights, I want to borrow $300,000." As a banker, you can look at what the value of the rights are. It's very easy to do. You can go to one of the water broker exchanges to see what it's worth, you know exactly what it's worth. If they have half a million and they want to borrow $300,000 worth against that, it's an easy do. Moreover, 12 months down the track, if somebody can't pay, you ring them up and say, "Look, you haven't made your payment. We could put you in the

courts, but alternatively you can sell five or six shares and pay us and you as the mortgagee will get the money." So the banks actually love this new system, those that understand it. There's been a real challenge in actually conveying this new system to the banks; the idea of lending against shares that are mortgageable is something that's strange to them. So there's a whole education process that's gone through. But once you get the banking industry banking on the integrity of the system, the governors, presidents, the people involved in the Federal Reserve start to understand that this system better work.

Panelist: Richard Sandor
Chairman and Chief Executive Officer
Environmental Financial Products

If we look at wealth creation in the United States in the post World War II period, if you go from ’45 to ’70, it was manufacturing. In the ’70s to 80s, it was with the Russian crops failing and the Chinese crops failing, and [inaudible] anchovies across the Peruvian coast, grain prices exploded, and wealth became, and value occurred in the commoditization. If we go to the 80s, we had a different kind of commoditization. We had a commoditization of financial markets. We created this thing called derivatives and brought in asset liability management which was held in low repute by the banking community. The regulators borrow overnight, lend for 30 years, curve will never invert, and you’ll be in terrific shape. Jump on’s-another pejorative. Or, you know, some crazy got it in Atlanta, he thought there should be a 24-hour news network. You know? Turner, and he was thrown away, and a guy came up with something called the cell phone. All of this stuff financed by junk. Basically, MCI taking on AT&T, also garbage.

Then in the 90s, we had a different kind of wealth creation. It was the commoditization of technology, information, etc. In ’86, Microsoft went public, stupid idea, a geek, young kid, dropped out of a university. In ’90, Cisco; in 1995 Mark Andreessen came up with something called Mosaic and it ultimately caused the birth of the web and it was a $10 an hour research project by a kid who didn’t use it for health, but decided to find a way to date women, and that came into the browser. And then we go into the turn of the 20th century, and it was the birth of social media—Twitter, you know, no great social cases, no academic arguments. They arose organically because they satisfied a need.

Hypothesis: The great value proposition in the 21st century will be the commoditization of air and water. That’s where value is. The question is, how do you

capitalize on that and how do you deal with it? Why do we say, all anybody has to do is look at water. There's three continents that are long water: North America, South America, Europe. The rest of the world is short—Africa, the Middle East, India, China. You know, we're blessed, 5 percent of the population of the world, if that, and 15-20 percent of the water, Great Lakes, etc. It's in the wrong places, it's in the wrong way.

What do we do in this country well? We create organized markets for the production and distribution of goods and services. No better area than agriculture. Nothing better. You don't see it, you don't hear it, you put a price for corn, and all of a sudden there's elevators that emerge and finance it; there are people who come about, great public firms, no big to do. The price is what is critical. Set the price in a fair and clear way, and you will find the proper allocation of capital.

I want to speak about having been a professional inventor, getting it wrong a lot of times, and sometimes getting it right. The first thing that you need is education. I think Mike put it right, Nic put it right. Tom and I have spoken. Whether it's governors or it's anybody like that, you have to understand water is a hot button issue. But the hot button issue is when we're talking about water trading, we are speaking about the excess, the excess beyond hydration and hygiene. We need 25 to 30 gallons of water in the world. The United States uses 150 gallons a day for hygiene and hydration, as opposed to the Europeans in 75 and the Chinese at 25. It doesn't work. Two hour recreational showers in Scottsdale isn't on. It doesn't work. Leaky bathtubs don't work. If you would try to approach it with command and control, not the way Mike said or Nic, you're going to get a legislative result, and let's talk about the legislative results. You know, the U.S. Constitution was 6 pages. Federal Reserve established in what 25 pages? Sarbanes-Oxley: 165 pages. Dodd-Frank: 2300 pages, longer than the New Testament, the Old Testament, and the Koran combined. Is that an efficient use? And what does it cost? Waxman-Markey, the climate bill, 1400 pages; greater than all of the religious testaments in the world that govern the morality. So, I'm going to come

back, and I have two minutes, so I'm going to just suggest a couple of things that might be worthwhile.

Number one, we started a climate exchange 15 years ago, and we did it on a voluntary basis, and everybody said, "That's the dumbest thing in the world. Go back to Chicago. Nobody in the United States is going to take on mandatory reductions without a law." The fact is, we ultimately signed up as pilot members: Ford, IBM, Honeywell, American Electric Power, 128 corporations with no federal law, and it was in effect the size of Germany, and it worked. It got practices, it got what Mike and Nic talked about. We had monitoring, we had verification, etc. Listen carefully. We monitored 128 corporations, which were the size of Germany, and the registry monitoring and verification cost a million and a half dollars a year. Not what Nic was saying or Mike. It's really pretty simple. It's not at all complex. So these things can be done.

So, one voice from the audience is go around the political process, engage the private sector, the users, develop a cap and trade system that has reductions, they can't be politically toyed with, and they go on like the acid rain program in the United States, and make sure they can't be fiddled with. And as an economist, you don't want the rent seekers getting a hold of it—K Street, the lobbyists. All they do is increase transaction costs.

The second bold contract is bypass, which we did in Europe, the spot market. This is totally out of the box thinking, but set up a futures market where you get twice the transparency, regulation, and make that the first step and not worry about spot water trading, because 99 percent of futures don't get settled by delivery. So you can go down a low cost regulatory path, get a buy-in from industry about how you deliver because I think as Mike said, if you put the price up, behavior changes. You don't have to swap the water. You only need to swap the water to make the market at delivery be honest. But if you want price transparency, regulation, regulatory clarity, you can bypass the existing one and design a delivery system to price a certain amount of water in a certain way which will give you

95 percent of the benefits. I'm very optimistic. We can't go on like this. We can't have 1800 gallons for a one pound steak. We can't have 500 gallons for a pound of chicken. Water trading exists today. It is called the international grain trade. And it's just inefficient to buy water and have to buy it simultaneously with food if you can unbundle it.

So I would say, what does the future look like? Stick my neck out, and I'm often wrong, but I'll stick it out here. You'll see water index trading in the United States in another year or two or three. We trade temperatures, we trade rain, all of these markets are potential and you can get through with what looks like a terribly difficult situation with inventive activity, and assembling a team of willing users. So by and large, the creativity in this room, the advocacies, behind Nic, behind Mike, saying it doesn't bite, it saved what? $370 million I think, Mike, in New South Wales. The water markets, a couple hundred million, in Australian GDP. You have them, and don't worry about adjudication, less appropriation, more appropriation. Adjudication is just like having junk bonds. They get priced if they're not adjudicated well, and they become inferior goods. So don't try to make it perfect. Use existing exchanges and I think we can solve a problem that the world needs to pay serious attention to. Thank you.

Panelist: Tom Iseman
Deputy Assistant Secretary for Water and Science
United States Department of the Interior

I appreciate the opportunity to be here. Again, I'm Tom Iseman. I'm the Deputy Assistant Secretary for Water and Science at the Department of the Interior. My introduction described a bit about what Water and Science and the Department of the Interior do, but I did want to discuss that as a starting point to explain why we have an interest and a role in water markets, and to put some sideboards on the rest of my comments this morning.

Our primary interest in water and western water is through the Bureau of Reclamation, which owns and operates water supply projects in 17 western states. We have over 300 dams, almost 250 million acre feet of storage. We provide water to one in five farmers in the western states, and irrigated water for 10 million farmland acres. So, we work with a lot of the states here in this district, and other states in the western U.S., and we work a lot generally on water management issues in the western U.S. because of this infrastructure and our responsibility to manage these assets. We also have the U.S. Geological Survey, which plays an important role in monitoring water flows, groundwater aquifers, subsidence as Mike discussed earlier. And I think they can play an important role in providing data to help track and monitor trends in water use in a way that can inform markets. And it's not a part of what Water and Science does, but we also have the Fish and Wildlife Service in the Department of the Interior. We've talked a lot about environmental flows, and certainly they play an important role in describing the need for ecosystem flows and trying to protect flows for habitat and wildlife.

So the Department has an important role in water resources, and I'm going to focus on that role today as I talk about some of the opportunities I see here along the lines of this discussion. One of the starting points I would say though is that even, notwithstanding our

important role, we've clearly acknowledged that the states control the administration of water. So, we work with our local water user partners and the states to administer water. We I think are very cautious and respectful of the state's role, and I think that helps to inform the ways that we see potential contributions from the Department of the Interior in this conversation.

So I do want to start with some points of agreement that I see with Professor Young and some of the other discussants today. First, there are clearly benefits to using markets in trading, that they can allocate water to higher value uses, and address issues of shortage or scarcity. They can help to incentivize efficiency in water use. When you put a price on the asset, it will make people value it and conserve it differently. They can provide flexibility for climate adaptation or in drought conditions. Mike talked about how in Australia they've allocated the risk for climate adaptation to private water users, and to me markets are one of the best tools that we can give to private users to help deal with this risk. And I think they're in a better position frankly than the government to make those decisions. Certainly, that's one of the things that to me is an advantage for enabling local water users to participate in markets, is that it avoids the risk of the federal government having to do, I think in Mike's paper, what it called a claw-back of water, or trying to make decisions about how to allocate water. We'd much rather see local water users in the state doing that than having to interject a federal role in those cases.

One of the points also that is not my expertise but I thought might be best suited to the people in this audience, and given that we've got a lot of farmers, and in particular, bankers and lenders. As I said, reclamation has a lot of water supply infrastructure—dams and canals, pipelines. A lot of it was built in the early to mid-1900s. We need to reinvest in those assets. To the extent we can start to treat water rights more as bankable assets, I think is a term that was used in Mike's paper, that can be used effectively in the process of reinvesting in our infrastructure, providing collateral essentially to get loans. It's certainly a

challenge right now for the federal government to make these investments. We work closely with our water user partners. One of the things we've seen is the need for some collateral. There are difficulties using our infrastructure as collateral, but to the extent that we can treat these water rights as bankable assets, it will really provide a benefit.

I agree with Mike that we need to focus on the institutional conditions, thinking about registries and monitoring. I mentioned some of the resources that we have that can help to do that both in terms of data, infrastructure, water management and governance. Also, I agree with Mike that water resource planning can help to inform markets and to drive markets, and that's something that we're doing through something we call the Basin Studies. We talked a little bit yesterday about the Colorado River Basin Study which covers seven states, and looks at water supplies and demands. We've Basin studies in 22 Basins in the western U.S. They bring people together, start to look at the challenges, and identify solutions, and that's one way that we can start to structure and incentivize markets.

So what are we currently doing, what the federal government doing? One of the points that I wanted to highlight is the Reclamation Water Smart program. We've made significant investments in water conservation and efficiency. I know there's been some debate about the merits of that. We've conserved over one million acre feet. Some of it consumptive, some of it more along the lines of water efficiency. We have limited the expansion of use in those cases, but I think there's still a question about what happens systematically to that water, and it's a question that bears further investigation. More importantly though, I think we have a long history actually of supporting water markets and exchanges and trading, really maybe trading isn't the best term for it. It was discussed by Nic and others that there are several cases. It was discussed yesterday. I did want to flag a few just to describe some of the history that we've seen at Interior. As early as 1988, Interior had principles that recognized that water transfers could be beneficial and that we should try to accommodate them and reduce the transaction costs associated with using

our infrastructure to do transactions. In the Central Valley Project, as early as the 70s, congress has given us authority to look at water banking programs and drought. In the recent drought in California, we've averaged approximately 350,000 acre-feet transferred each year, most of it being ag to ag, and I think it demonstrates Mike's point about how markets can be a tool for adaptation. The Colorado Big Thompson Project in Colorado, there's an ongoing market with functional and low cost institutions. You see a lot of year to year trading among farmers. The Idaho Snake River, we have longstanding state sanctioned rental pools for water supply. And another role for markets, and we talked a little bit about environmental protection, but there are several places where reclamation is actually a market participant. We are acquiring water for environmental protections. We see that in places like the Klamath Basin in Oregon, the middle Rio Grande in New Mexico, and the Snake River as well in Idaho. Yesterday, Les mentioned the system conservation program. I think that's a great example of an innovative model. It's not really a trading process, but we are using market mechanisms to acquire more water, to bolster this water supply system in the Colorado River Basin.

So, this time went faster than I expected, but I'm going to close with a few comments looking at what we can do going forward, and maybe some observations about what I think might be the best strategies for how we approach this. I think it's been discussed there are clear distinctions between Australia and the United States, one important one being the state/federal relationship and the leadership role of states in administering water; another one being the availability or lack of availability of federal funding that the federal government can't just come in and make or decree these markets or make significant new investments to acquire water.

With that said, there are things we can do. I mentioned the Water Smart grants. This year, we are going to carve off I think three million dollars that would be to support the development of institutions for water markets or trading. I would encourage anyone

who's interested in establishing or pursuing markets to look at that program. Again, it's Water Smart. There will be information available online that describes that program, and establishes criteria that you can see kind of what kinds of practices we're trying to promote. I think we can play a role in trust and governance, and that might sound laughable to some people when you see what's happening with the current election. But despite I think some of the concerns about the federal government, some of which may be merited, what I've seen when I've been out working with Reclamation and with our local water user partners is that they do trust their on-the-ground Reclamation staff, the people who are operating the facilities, the people that they work with day to day. And Reclamation can play an important role in governance. We can provide the incentives, in particular the use of our infrastructure and targeted investments in water. And we can also I think do more work along the lines of the cost benefit analysis; or as Nic I think described it, developing the narrative for why there's an important reason to pursue trading and markets. I think, as I said, I don't think there's enough awareness of how much activity there is in markets, and that there are real benefits to be had to the extent that we can help promote trading.

So finally, I would just say in Australia it seems like we saw wholesale reform. In America, I think we're going to see incremental change; we're going to see it locally and geographically, and I think that's the right way to do it is to support some of those local innovations. I as well as some of these other panelists, I'm an optimist about this, and the federal government, I can say confidently, will be there to support some of those local innovations in this direction.

General Discussion
Moderator: Troy Davig
Senior Vice President and Director of Research
Federal Reserve Bank of Kansas City

John Tracy, Texas Water Resources Institute: One of the discussions that struck me through this whole meeting is that we're predominately talking about water or the ag economy from sort of one part of the hydra services perspective when we're looking at managing river systems, and that is water supply either for the environment, agriculture, or communities. But when we're talking about markets, there seems to be this presumption that water will always have some positive value, and when we look at river system management, there is a hydra service where water actually has a negative value, and that is with flooding. And in many of the large regulated river systems in the western United States, when you look at the positive value associated with managing the river for water supply, you also have it run into conflict with if you do too much towards water supply you can create a negative value with increased flooding. So the question becomes, how would you price that in a water market, and is that something Australia started dealing with? And if no, thinking about this, that it's not always storing water reduces flooding risk; there's many circumstances with western reservoirs where storing water increases flooding risk, and how would that be priced into a water market that isn't just looking at a water supply market, but rather a hydra services market, looking more comprehensively at why we manage river systems?
Mike Young: The Australian approach, or the approach that I put up a sketch that looked like a tank. You won't notice, the bottom bit of the tank, the conveyance water is managed according to rules, not in a market process. Similarly, the bit at the very top of the tank, which is called flood water, actually I price under rules management. The shares bit, the bit in the middle, sorts out itself through a market process. So you're right, you need to have

clear separation, and with issues like flood, nobody wants to own flood water. Because if you own flood water, you're liable for what it does. When you have water that you own, and you start applying it to a field or whatever you do with it, you're liable for all the consequences that result from that use. Flood waters have to be managed through regulations, and the high level systems plans that are in place have to be very careful with issues like actually carry-forward, for example, when you start filling up a dam. There has to always be enough space left in the top of the dam so you can control flood risk. We in Australia made some very serious mistakes, one which was up in Brisbane where people essentially over-zealously kept too much water in the dam, concerned about the importance of having water available for use, and forgot to leave enough air space in the top and we had a big flood, actually a huge rainfall event that caused a disaster because they actually mismanagement of the dams. So you need first of all to have the rules in place to deal with all of these issues and manage that through very careful governance at the top, and then letting the market work within that overall framework. So your point is very important. You have to have the two managed separately and enough instruments to do both.

Audience Question: I guess this is the point of the question, is that we're talking about moving away from rules managing water for one segment of the hydra services and moving to market based approaches. So why wouldn't we look at creating a market based approach for all of the hydra services? Why would we separate them? This is a real situation in Idaho where there is this real discussion, I guess I'd say controversy around certain reservoirs where there is a feeling on the people using it for water supply that there's too much benefit being accrued to the people that are using it for flood prevention, and that if there was a market there that in essence allowed the water supply users to take on the risk associated with the flooding and bring it all into the market rather than just part of the hydra services.

Mike Young: You can design it. There's been work in Australia that suggested essentially you pay and trade opportunities for people who invest, [inaudible], that actually allow a

flood risk. So you can pay people to build storage, etc., that actually lower risk. Those sorts of things are being played with and explored. But essentially, what you're saying I think is there's a need for people who specialize in designing systems, and we haven't got the skills anywhere in the world nearly enough in terms of knowing how you design systems and the system data, how people who understand hydrology economics, markets, governance, the whole lot. We're into very uncharted fields. And that's the frontier in all of this. And while I'm there, I'll make a quick comment that I think you need to be very careful in thinking through the sequence of reforms; where you start and where you end up is very important. The biggest opportunity I think in America at the moment is to convert your existing water rights through into new registers, but having systems which are like a tolerance title type system. It's the only way you can own something is if your name is in the register, and you don't have complex paper trails. Designing that transition is the holy grail in terms of starting the journey. If you get that wrong, you'll lock yourself into designs that will make it impossible to step forward. That includes dealing with flood. The greatest insight that Australia did was to set up new systems that became defined as shares, not as rights to volumes.

Richard Sandor: If we take, and I think the Australian situation is terrific because it deals with all of these levels. But in theory, if you go back to the work of Ronald Koes, and deal with externalities, as long as you have unambiguous property rights, and they are transferable. It doesn't matter if you give the rights to people who are being flooded or you give them to people as rights to use. So, almost any of these systems we know can be dealt with at least theoretically, and have been dealt with, whether it's sales or auctioning of bandwidth, other sorts of things. If you get that bit right, a tradable solution is not a very hard one. The problem is if you want buy-in, then you're in a political process. And there's two things. And the second thing, keeping in mind that the allocation of these rights, be they on the polluted or the polluter, is irrelevant as long as you have low transaction costs

and unambiguous property rights. So what we know in economics and what virtually any economics class will tell you, these are all doable problems and then when you start to fiddle with them, then you increase the transaction costs, and then David Ricardo's gains from trade disappear, and you've got to carefully balance. Australia's done it, but it doesn't mean that it couldn't be done, or you could take the rights and price them negatively. Oh my God, you might say. Well, there's $40 trillion of sovereign debt out there, and $12 trillion trades below zero interest rate. So negative prices are something that we're living with right here. So none of these, I don't think there's a magic pill. If you take a look at the Coasian framework, and you follow the line of reasoning that Mike and Nic talked about, make it transparent, get registries, allocate them, set limits, and then provide a regulated market that gives you price discovery and price transparency, whether it's for spot or future prices, you'll get there. And the debate often falls down, as it's falling down with climate change, and just to make a point, which I do think is very important, it's not whether we are or are not running out of water. It's not whether the Ogallala will last for 10,000 years or 10 years. The question is, is there an institutional framework that can be designed where the benefits exceed the costs, and you will have no macro effect? And if you lower water use from 150 gallons per capita, and you don't subsidize the growth of cotton in Arizona, and do some very simple things, the problems are tenable.

Mike Young: I think you know you're getting close to a solution when you have brokers who are charging for an outcome. In things like land sales, brokers take a percentage of the final sale, and basically deliver the whole thing for that. At the moment when you do a water trade in the United States, you employ a lawyer who charges by the hour, or actually every 5-minute block. Because they don't know how long it's going to take, how complicated it's going to get. So part of the design framework is to build, as you said, unambiguous rights so that people can complete, to work out how to complete the transaction at the lowest cost. And it's getting the certainty around the right enables then you to get competition

around how you deliver brokering services and get the markets to operate. While you have such huge regulatory confusion, right confusion, you don't go forward. Convincing water users that they will profit from having meters in place is really hard. When they start to understand what happens at the moment is people are allowed to steal from each other, and they have a product that if they weren't allowed to steal from each other, they could sell, then they start to understand the benefits of going to metering. But step one is to get registries of the long term rights, and defining them as Australia did with shares, and saying, in this water system there will be no more shares ever issued, and making governments honor that is a very important step. The second building block is to have monitoring of allocations, and have water accounting systems that have the same integrity as your financial systems, where if somebody goes into negative, and if their water account goes into negative, they have to make good very, very quickly. If they don't make good, it's going to cost them so much, that it's in their interest to go back into the market to solve the problem rather than to say, "Oh, whoops, sorry, forgive me, I might fix it up next time."

Richard Sandor: I want to add one thing which I think is worth bearing in mind. We're talking abstractly about the gains from trade, and the benefits, and I think Mike, Nic, Tom have all talked about it. But we did a study for the state of New Mexico. And let me in very simple terms tell you what the gains from trade are like. If you take a square mile, take 640 acre-feet of water. In New Mexico, that produces an alfalfa crop that's worth $250,000. That same amount of water is what Intel uses in its fabrication plant, and has a local payroll of $500 million, and it can't double the plant site because the water rights can't be transferred. So you have water being used here, $250,000; use here $500 million for the exact amount of water, and the farmer would be a lot better off just turning it into a recreational property and have people out there, and that doesn't go to the subsidized gas that goes into drawing it; it doesn't speak to ag subsidies. And that's the magnitude of the problem we're talking about. Do you produce $250,000 or do you produce 6,000 jobs? One farmer who wouldn't lose

his property just by unbundling the water and making the rights separable from the land ownership will unlock 5,000 new jobs that are sustainable. And that's what you need to be thinking of, not water trading per se, but what happens when you don't allow it?

Nicholas Brozovic: I'm going to follow up quickly to Mike's observation that when you see brokers in the room that it means there's value to be made, and money to be made in water trading. I think that's very fair. I don't think it's correct to characterize the U.S. system of trading and transfers as run by lawyers. The brokerage system is what's used in Australia. That does exist very actively within the U.S., both specific water brokers and real estate brokers do trade water. But there are also a number of other institutional arrangements that are not brokered that are used in water markets. That's part of a larger discussion, but I just wanted to ... I think, I don't know. There are some water lawyers in the room perhaps. We want to speak carefully about them. But just again to clarify that.

Mike Young: I was going to observe that when we unbundled in Australia, one of the things that really delighted me was to see how many people in agriculture who were trapped in agriculture because they were poor, retired, sold their land to their sons or daughters, minus the land, and they then used their water rights as a source of income. We were amazed to see how much structural adjustment and innovation occurred and how quickly areas that were depressed became vibrant again. I used to spend a lot of time in a town, which used to be a rundown, decrepit, old, struggling community. All the shops were unpainted, dusty, struggling. You go there today and there are vibrant shops, new cars. The prosperity that came back into this area, that also had a massive salinity problem, and nobody could see the solution to, is amazing. And it came because the community had the opportunity to suddenly trade their water out of the district, the water lift, and everybody said this is going to be a disaster. The people then had cash, and they themselves found a solution to the salinity problem that government consultant after government consultant never could see. They brought the water back in again, and now it's a prosperous community without

the environmental problems that used to be there, and confidence and pride. I find it tremendous to go back there 20 years later and just see the change and the transition. And I might add while I've got the microphone, that keeping it simple is very important. There's a great game among scientists to build very complex models. At the moment, in Diamond Valley, the management plan or the draft management plan says, if the average depth of water table monitored at four wells on the first of February each year drops, then the management board must reduce allocations per share by between 3 and 6 percent. That gives everybody confidence. It's very, very simple. It takes one person on the first of February to go out and see how deep the water is in four wells, and come back and report it. There were proposals from consultants to build very, very complicated models, and what they really know is that managing its depth to groundwater, and as it goes down, pumping costs go up. So why not keep it simple? Build it approximately right, rather than comprehensively wrong, but not inordinately expensive to run.

Ellen Hanak, Public Policy Institute of California: Thanks, this has been such a great discussion all of you. A couple of quick observations on how to lower transactions costs. Mike, I agree getting the registry right is key. But I think the other thing that you mentioned, but you haven't come back to and highlighting as an essential thing for reducing the role of lawyers in the process here in the U.S. is that exchange rate thing that you guys worked out, where you figured out how much water ... my water right here is tradable locally or further along depending on kind of the environmental requirements of water that needs to stay in the river. And that's the really tough part of a lot of surface water trading in the U.S. So that's a job that we really need to do in order for guys like Tom Rooney to be able to really have a good business here. So that's one observation. And then the second one, this is a request really to Tom. You mentioned that the Bureau has a lot of infrastructure, and that is a really useful way of moving water around, not just for folks who have contracts with the Bureau, but more generally in the system. And you guys are not especially nimble at making

that easy for people. I think there are a lot of simple things that could be done like waiving some of the reviews that have to be done every year if you show that there's not a cultural significance to transferring water from point A to point B in year one; it could be the same in year five. So those are just a couple of thoughts on making this all work better, guys.

Mike Young: And certainly I would agree in terms of setting the exchange rates, and also how you manage return flow issues which is something that was talked about a lot yesterday. Most of the systems in Australia rely on what I would call a simple gross accounting system, where there's no concern about return flows on a trade by trade basis. In theory, what's supposed to happen is that as the system becomes more efficient, actually allocations per share across the system go down. So there are incentives for people to move ahead of the game, and actually costs for those who move more slowly. The transaction costs are much less because you don't have to do case by case assessments. In practice, we have a mixed approach where if you trade water out of the region or if you're using it for some urban purposes, sometimes return flows are actually managed. So it's a design issue that can be adaptively managed as you're going forward. But going to a gross rather than a net accounting system can save a lot of transaction costs.

Richard Sandor: One punctuation here which I think adds. If you take a look at costs of transaction and do it in a Coasian framework, you have legislative costs; that is to implement anything. You have regulatory costs. You have the costs of building the institution; that is the exchange. And you have the costs that come up with the designing of the contract per se. And if we take a look at trends today in America, the exchanges disintermediate the lawyers because they have rules books and conflict resolution, which is outside the court system. The exchanges are now disintermediating the brokers. So you can take transaction costs by 10-20 percent down dramatically which could make a trade worthwhile, but wouldn't in the institutional. So, we have the most efficient markets that you have. You don't even think twice about corn, and what goes on there and the world allocation price is done with

almost no transaction costs. You know, they are fractions of a tenth of a cent of a bushel. So there's lots of things that I would say, if you looked at organized exchanges, disintermediate the brokers, get rid of the lawyers, and develop a governance system which is efficient and works well where the government is not the active, but the oversight that exchanges enforce their rules, rather than having it there. All you need to look at corn, wheat, beans, crude oil, cocoa, sugar, cotton, and you'll see a system that has these low transaction costs. But you will find that brokers won't be amused by disintermediation; the lawyers won't be amused by disintermediation; K Street will not be amused by disintermediation; but you have to design a system and an exchange in an electronic platform, no voice brokerage. You have to do a lot of things that will ultimately make costs cheap and competitive. I speak from what I know because we started with an exchange, and it's not to be self promotion, which was an idea for carbon trading. We built the technology, we had no brokers allowed on the exchange, we had no lawyers, and it is the predominant system in Europe, and we started with a couple of million dollars and sold the exchange for $650 million to somebody because the design was very cost effective. So you have to really pay attention. Your question was fantastic. That is the key, and the key is if you had a blank board, you'd get rid of, and weren't subject to lobbying, you'd get rid of all of these external service providers who get rents, and you'd make it an enclosed system. And that's ended up with the most efficient food system in the world.

Conclusion

Richard Howitt
Professor Emeritus,
University of California-Davis

It's traditional of course for wrap-up speakers to scan through the abstracts of the papers, say something nice about each speaker, and then talk about their research, which is really valuable. I'm an Emeritus, so I'm not going to talk about my research. And I have 19, I sat last night and counted, 19 paper presenters, discussants, and respondents. So, I'm not going to bother to say something nice about everybody. It would take up too much time. I'm going to try and work out some themes, questions, omissions from the conference.

The themes, the overall theme is growing water scarcity under uncertainty, and remember the uncertainty is not stationary; it's non-stationary due to climate change. And what would one do about it? And I think one of the really interesting responses comes in the concept of information, and if you stand way back from agriculture and look at it, it's a process of changing the entropy of the natural ecosystem towards those species that we favor, or that generate food for us. And if anyone's tried to weed a vegetable garden with a four year old helping you, you would realize that identification of the difference between weeds and carrot seedlings is as important as pulling them out. What we've done in agriculture is we've had a vast investment of energy related inputs, started with mechanization, running through chemistry, and then also going to research. What I'm interested in, and what I think shows a path forward is something that several of the speakers, John, Rich Sandor and so on mentioned, which is the breakthrough we're getting now on information about our natural resources. And so I'm going to come back to that as information and shifts in information systems about natural resources as the thing that can lower the transaction costs and enable better management. So here's the theme—scarcity, uncertainty, and of course, commodification of water.

So, what responses have we got? We've got two responses, technical and institutional. The environment we've dealt with in the research environment is both developing countries and developed countries. For instance, this morning we had a masterly discussion on water markets, their development, their application, the theoretically best ones, the ad-hoc adjustments. Those are very applicable to economies where we have clear property rights assignable, but get more complicated and more difficult for places where the stresses are really great. So going back, if I can spend some time before we go back to information theories and so on, to talk about the developing agriculture environment where we started out. And I was sitting there, and I really enjoyed Mark's talk, and I like the impact model because it's incredibly comprehensive; it also takes into account lots of things I value. But I was left with thinking that's pretty optimistic. We had a substantial reduction in the number of people under hunger stress; we had an increase in the consumption; we had a decrease in prices. Interesting. And Mark's shaking his head, yeah. And yet, we had a rate of technological trains driving that, which in one slide he put 0.23 per annum, which is significantly lower. It's got to be higher than the agronomists rate of 1.2 percent.

We have the other thing that came up with Pat's comments about the dietary shift. And so we have the dietary shift, and you remember that curve where all those countries are clustered down there wanting to have their animal protein, but not getting it, and the question is how far up that curve are they going to go?

Finally, we have Susanne's paper which was looking at the fundamental water stocks, and in particular of course we have Tom's question, how much of our current supply is not in steady state? And the truth is, I didn't get a simple reconciliation between the food consumption question, the population question, which from Pat and Mark seem to be fairly optimistic. From Ken it was fairly pessimistic. And Susanne, I'm not quite sure whether she was pessimistic or optimistic because she showed some really heavily stressed places, the middle east serious problems, Qiuqiong tells us that China has gotten most of it under

control, but there are regions, and we have serious problems in India and other places. So, what to do?

We can't go to the Indo-Gangetic Plains, walk into a 2,000-year-old society and yell, "Markets, guys, markets!" It's not going to work. One of the missions that I heard, and we talked a lot about institutions and transactions. One of the admissions from this conference is I never heard the name Elinor Ostrom mentioned by anybody. She is the only person to get a Nobel Prize for resource economics. She actually is a political scientist, but she had some brilliant insights into self-governing systems for common properties, and that's what she got a Nobel for. And if you look at her writings, and this is coming from someone who's a real die-hard market person, she has eight principles of self-governance. But some of them have real echoes in some of the other characteristics we've heard about the Natural Resource Districts in Nebraska for instance, the one place in the Ogallala that is not mining its water down. Not that mining's bad, by the way; it's a question of are you mining at the right rate? But nobody mentioned Ostrom, and yet she has had significant influence and input into talking about self-reinforcing institutions. For instance, she has an important point that monitoring and enforcement must be done indigenously by the people who are being regulated. And so one possibility is that we will see commodification and markets in developed economies, no question about that. We've had a tremendous discussion on that this morning. But in underdeveloped countries, we have the problem of putting an institution which is not alien to the culture on systems. And so what I would think is a possibility is to utilize Ostrom's insights into collective communities managing their own natural resources, but what we can do from a policy perspective is we can give them information, and we can give them information from a scalable and hopefully unbiased source, which I get to talk about remote sensing later. So, on one side, we have markets fully developed in Australia and a mishmash in the western United States. In fact, I would argue we have lots of trades, quite a few transfers, and no markets. I define a market as something

that I get on my iPhone from Tom's organization, and he can tell me what the price right now is of water at a certain place. So if I wanted to find that in California where we have an active market, I just cannot go to a market and see a price. So we have lots of trades, quite a lot of trading, but no real markets.

So my question number one is, how do I reconcile those four, really similar, nice discussions and analyses of water, agriculture, and developing economies? I'm not sure yet quite how bad the situation is. In one way, I look at it and I think, yeah, China is not so bad, and overall we can balance it out with trade and virtual water trades. And then another way I look at some of Susanne's extreme water stress maps and think, we are in serious trouble, because on top of that, I'm adding population growth, I'm adding climate change temperature increases, I'm adding glacial melt. For instance, I spent some time in Chile where their entire storage system is in the glaciers. That's going to change. And so generally, I think I'm a bit more pessimistic. The response is to of course, I think, recognize the difference between institutions which can be adapted to prices, and institutions that have to be left to local control and local institutions. And we can see that the system can accommodate both. We can accommodate Nebraska's, and we can accommodate the tradeoffs in California.

So, technical. We've got a technical response and an institutional response. The idea of rushing in and subsidizing field level water efficiency improvement has been fairly generally discredited in this conference. I agree. I've had a look at, I had a student who was cited by Susanne on Kansas, superb Kansas data. There is no question we're going from regular center pivots to drop tubes, financed by Equip, made you grow more crop per unit of water. But there's also no question that for any water use, there is a behavioral side and there is a technical side. And if you fix the technical side, or subsidize the technical side without changing the behavioral side, the farmer's behaviors will and profit maximization wins out, and total water use and the rate of abstraction from the Kansas aquifers went up, subsidized

by the US taxpayer. It probably wasn't what they meant to happen. And so whether it comes down to quality or quantity policies, we have to take into account the behavioral side and the technical side.

So, what about the institutional side? We've had a really good discussion on market institutions and Bonnie gave us an overview of those with some disturbing pictures of what happens when the institutions don't work, and you have walls of shame and so on. What we didn't get was how to correct them. And I think the answer is that the correction factors have to be along the lines that Elinor Ostrom laid out of local self-governing institutions rather than trying to impose institutions from above. And so we do not want to fall into the trap of being the neoclassic, arrogant economist who says we can fix everything.

So what did we miss here? We've had a long water conference about quantity but not quality. It's inherent in irrigation that we have an accumulation of environmentally and physically damaging characteristics in our groundwater from irrigation—salt, nitrates, heavy metals. In fact, so much so that going back to my state of California, I am more worried about the degradation quality of the groundwater running out before the quantity runs out. And again, we have both technical fixes and behavioral fixes because if you look at attempts to minimize the salinity load going to the groundwater, first of all you see something like drip irrigation is extremely valuable because it slows down the residence time in the zone, a greater proportion of the water gets taken up, less is leaching down, and less is generating salts. But, you have to take into account the fact that farmers have incentives to modify the mix of water, the types of crops, and the rate of application that they're doing it. So water quality degradation and the sustainability of the water quality in groundwater is very significant.

The second thing we didn't hear much about was risk and supplemental irrigation. I've been working with some colleagues in Brazil where supplemental irrigation is key. And we looked at one of these national worldwide maps, and when you think about Nebraska, Kansas to a lesser extent, depends on which part, throughout China, India, for most of the

world, irrigation is supplemental irrigation. It's a function of the monsoon, it's a function of the rainfall. And it is a risk-reduction mechanism. And it's quite possible that the risk reduction from supplemental irrigation has a greater value marginal product as economists would call it than the 100 percent irrigation that we practice in fully arid areas.

The second point I want to think about risk is the possibility of going back to Ken's yield gap, and he had that 80 percent rule, and he looked at people in Nebraska and he looked at people in other places, and the farmer will run up to 80 percent and after that, it just gets too risky. One thing we could possibly do, and I have a colleague Michael Carter Davis who's doing this, is to use the concept of index insurance, which is an insurance policy, not based on what the individual does, but some overall index. And he has an active system of insuring grazing for itinerant grazers in northern Kenya, and it's reinsured by Geneva. So you've got Swiss bankers reinsuring itinerant grazers in Kenya. My point is here, that if you have insurance for the drought, you're going to treat your animal stocks differently. For irrigation, I see no reason why we shouldn't use an index insurance policy based on the water year, and essentially add a policy layer of insurance, and it could be a market insurance to encourage farmers to move beyond that 80 percent towards the 100 percent.

And finally, we come to the point that was mentioned quite a bit in the last discussions of transactions costs. This is going back to my starting theme of information. It's information about resources, about natural resources, because one of the reasons why we have these really ad-hoc rigid rules is it's so hard to measure. We need to measure consumptive use—Mike, notwithstanding your gross accounting—and we need consumptive use, and we need it measured by an impartial, trusted source. I've been working for the last few years with a system called Metric, which is a clever piece of Dutch programming implemented which can turn radiant energy measures from lands sat into measures of vapor transpiration. It's done on a 40-meter pixel, so this room we can figure that out. A bit bigger than this room. Not much. 120 foot. We can get it every week

depending on cloud cover, and we have used it in a number of experimental situations. I had an interesting experience. Last week, I was at a conference sitting next to a water district manager, and the conference was about this new law in California which is going to force people kicking and screaming to manage their groundwater. And I was talking to this manager who is a very forward-thinking person that I said, "Well, what are you going to do? How are you going to do this rapidly because we don't any meters on the wells?" He says, "Oh, well, that's not a problem, we just use the satellite." And I said, "Really, the farmers went for it?" And he said "yeah", he said, "I told them about it, and they said huh?" And we went out and we got, it was Cali Poly San Luis Obispo who have a very well respected water measurement thing. And they said, "Ground truth based on so and so's field, ground truth so and so's field, and ground truth in here." And they ground-truthed it, and the farmers have bought in. They would rather have the eye in the sky than bother with the metering. So we've got not only a quantum shift, and it's just going to go, and I noticed that John was talking about this, and he mentioned this outfit that I visited last year, Planet Labs. If you want to have pretty pictures, Google them up. They're only pictures at the minute, so we have to use land sat to get a vapor transpiration. But when the farmers accept it, we're really, really close. The other characteristic which is coming up the line, which is harder to do but it's coming on, is of course crop identification remotely.

So to summarize then, we are moving in and several people have said this, we are moving into the information age for natural resource management. As we move into that information age, transaction costs will go down, public policy, but information is of collective good, and is a highly scalable cost function on satellites. So I see that instead of subsidizing people to convert to more efficient irrigation systems, let them do that on their own dime, but tell them exactly what they're using and what their neighbor is using, and have it open access information on natural resource use and we will end up hopefully with a bunch of Nebraska natural resource management districts trading with each other. Thank you very much.

Discussion
Moderator: Nathan Kauffman
Assistant Vice President and Omaha Branch Executive
Federal Reserve Bank of Kansas City

Audience Question: A question on your last point about open information on who's using what water and where. Do you think that's a function of the federal system, a state agency, or the private sector?

Richard Howitt: Well, it's been generated by the private sector at the minute, but I'm trying to encourage a consortium of two state agencies and one federal agency in California to put together and buy this analysis from private firms. So the private firm would do it, but of course, the machine that actually, that land sat, is again like the internet. It's a collectively provided good through the US federal government. But I ceded both the agencies having a tremendous benefit of combining and scaling this information. And then just make it open, open information.

Bruce Royer, Northwest Iowa Farmer: I come from part of the country that doesn't deal with the shortages that we've been hearing about. Our crops are grown totally by rainfall. We don't irrigate. And the change that we are seeing is excess moisture and the deleterious effect that that is having on us. We have rain events now that can be as high as 8 to 10 inches in one event, in an overnight or less. And that is very devastating, creating the flooding end of things. And so we look into things like draining the excess out quickly so as to be able to have the sponge wrung out so it can catch the next one. Now that doesn't mean you don't have periods of minimal rainfall in between, but the pendulum is swinging back and forth much more rapidly and much further is the change that I am seeing in this part of the country. The other thought I have, you mentioned quality of water. We had in an attempt to clean the air, we had oxygenation of our gasoline. We had the MTBE, and we had the

ethanol. MTBE went away because of its creating carcinogens in groundwater. My concern is internationally. MTBE is still being produced at the same rate as it was when it was sold in the States, but it's all being sold overseas. And so you have developing countries that are polluting their groundwater with carcinogenic vapors from the MTBE so they're losing quality as they're trying to clean their air. So that is something I think that will need to be watched in the future. When you mentioned quality, that thought came to me. Now, no real question there, but just comments.

Richard Howitt: I take your points and I remind you on Ken's little plot of low coefficient of variation, high yields. Ideal place to grow corn. The best ever. You might just have to put in a few drains though. Other places have put up with that, but you're still going to be a great place to grow corn. And the MTBE question is a classic international externality question. It's one that we can only help by providing information and perhaps monitoring what those levels of MTBE in the groundwater are in these developing countries. It might not be their only pollutant. Sometimes arsenic is a real problem too.

Bruce Royer: Just following up on that. There's a court case in Iowa now that deals with runoff from the operations and the quality of the water in terms of nitrogens. And so there's this whole debate now in many parts of the corn belt and the Midwest are dealing with what's flowing through the Mississippi River system down to the Gulf, and causing problems down there. What do you think about the long-term consequences for some of those natural water events and how we're going to deal with that in terms of the water quality.

Richard Howitt: That is a very serious problem and it's under significant study. But again, that interestingly enough, comes down to microbe management of the agronomy on the farm. We clearly have to simultaneously have nutrient control and runoff control. One possibility that's actually starting to come in in California more is the use of winter cover crops to stabilize. I don't know whether that's a practical solution for Iowa or not. But it both stabilizes the surface and of course helps infiltration rather than direct runoff. And the

other thing of course is what you're already doing which is minimal tillage.

Cortney Cowley, Federal Reserve Bank of Kansas City: Hi, thank you so much Dr. Howitt for wrapping us up so completely. I want to go to your comments on risk, and you talked about the situation in Brazil where irrigation used as a supplement on land that got some rainfall was, did you say more valuable? Or, helped reduce risk more than in arid areas where there's less rainfall. I was kind of wondering how you came about that conclusion because my research here in the district involves farmland values, and I've seen in some research in California looking at the differences in farmland values on irrigated land compared to non-irrigated land, and a lot of the models precipitation is not significant whereas similar models in our district, precipitation is a significant variable in contributing to farmland values for irrigated crop land. And so that kind of reminded me of some of the things you discussed on Brazil, and I was wondering if you could comment on that.

Richard Howitt: Yes indeed, and that's exactly it. In Brazil, as in many Midwestern situations, summer rainfall is an important component of the vapor transpiration. And as we saw on Ken's slides, going back to them again, that one with the curve, and there was all those ones going to the western part of Nebraska which had both highly variable climate and rain, and of course lower yields overall. The question is if we could have added more supplemental irrigation to those regions, then they would have moved down, reduced their risk, and raised their average. So clearly rainfall is critical, as is soil type and micro climate. But the access to supplemental irrigation, even as a much smaller level than full irrigation, can be very valuable in reducing the risk in those peak periods, and we found the same thing in central Brazil.

Audience Question: Richard, you mentioned the work Michael Carter is doing on weather index insurance. There are a lot of other pilots out there. From what I've seen though, there still hasn't been a system designed that gets rid of the basis risk without very heavy subsidies to make it viable, and the reinsurance companies only come in when they have pretty strong

guarantees from the government. Do you see any way of designing those kinds of systems so they'd be commercially viable without subsidies? It's perfectly fine if the government decides that's a priority for public money, but so far I haven't seen any way that get away from significance, even on index insurance.

Richard Howitt: No, I take your point, and the basis risk is still there because what we're doing is we're trying to improve the productivity of people who are living in inherently low productivity, risky situations. I think the question is not that we get a free lunch, but the fact is if we're going to buy lunch, do we pour our money into one characteristic where we try and influence the day-to-day operations of individual farmers when they make decisions, or do we invest in something that's both scalable and has a public good characteristic. And then, so 'look farmer if you want to buy this risk, here's the discounted price.' Then you make your production decisions conditional on less risk. I just think it's a way if we're going, and we have to, and we have a moral obligation to transfer wellbeing from the developed to the developing countries, and I think this is perhaps a more effective way, or one effective way of doing it because it has the characteristics of not trying to substitute for the farmer's decision making. I belong to the Theodore Schultz theory that they're poor but rational.

Mike Young, University of Adelaide: Following on to that, I think that once you have a market in the sense you're talking about where prices are really transparent and rapid, the case for insurance becomes much less. When you look at what's happening now in Australia, rather than buying an insurance product, if you want security, you buy more shares, the long term entitlement, and plan in most years to sell off the water you don't need. And that is the cheapest form of insurance you can get. If you look at the market in fact, what's happening now in Australia is farmers tend to pay too much for entitlements, the long term share, rather than being prepared for being risk neutral which means you just buy water as you need it. And so you've got a market which does this, and particularly when you allow people to actually carry forward water from year to year, and use it in storage

or put it into groundwater systems, and you have actually exchange between the two, as you're starting to see occur in parts of California, essentially the market collectively and everybody's behavior probably supplies the most efficient form of insurance. So the fact you have insurance means you've got a design problem in your rights system.

Richard Howitt: And it might be that, but I think the most likely explanation goes back to something you emphasized, which was you've got your transaction costs down, right down, your 40-minute deal. And so in that situation, it becomes much more efficient as you point out. The other thing which I think is interesting following from your remarks is something that Richard Sandor said about going straight to futures markets and not worrying about the spot market. And really that's something that in the west, I've always thought we should have, and yet it just seems to be too hard to do. We have contention contracts which are a sort of futures market, but we don't have a proper futures market.

Susanne Scheierling, World Bank: You mentioned the work of Elinor Ostrom and one could comment that without, again without policing institutional arrangements, these self-governing entities may not work for a long time. And if there is small security provided by some kind of natural framework, there are usually problems except maybe in cases where people are very remote and nobody interferes with them. So I think one has to also see Elinor Ostrom in a larger framework.

Richard Howitt: I think I get your point, Susanne. I agree. We need some larger structure to keep the small structures in place, but I think that's okay. I mean, things have worked. For instance, the Spanish-Mexican systems of allocating water, not without strife, but they have been there for 600 years or thereabouts. I think I know Ostrom's study various allocation systems for water in Peru and so on. What I haven't found yet is one of groundwater because the information is not there. So I think, yes, you're absolutely right, we need an overall structure to encourage people to form these districts like Nebraska for instance. But we also need to provide information cheaply and reliably to allow them to

make their decisions. This really goes back to something that QQ was talking about in China where decisions are made within the villages. I think this is the natural format, that everybody in the small village or even a large village knows exactly what everybody else is doing, and particularly that you have satellite pictures that you can look up on your iPhone and there it is. So, add information to traditional institutions and they should go better.