The Relationship Between Water and Energy: Run-of-River Hydro and the Electrical Grid

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Scott Backhaus received his PhD in physics in 1997 from the University of California at Berkeley in the area of macroscopic quantum behavior of superfluid 3He and 4He. He came to Los Alamos in 1998 as a Director's Funded Postdoc from 1998 to 2000, a Reines Postdoctoral Fellow from 2001 to 2003, and a Technical Staff Member from 2003 to the present. While at Los Alamos, Backhaus has performed both experimental and theoretical research in the area of thermoacoustic energy conversion including fundamental topics such as several thermoacoustic streaming instabilities, streaming assisted heat transfer, and acoustic power manipulation. He holds seven patents in the area of thermoacoustics, and his work has been recognized with several awards including an R&D 100 award in 1999, a Technology Review's "Top 100 Innovators Under 35" award in 2003, and a "Best Paper of the Year" award in 2011 from the journal Cyrogenics. Recently, his attention has shifted to other energy-related topics including the fundamental science of grid-integration of renewable generation, geologic carbon sequestration, and thermal fluids problems related to energy and climate.

Editor's Note: The following paper represents a transcription of the speaker's remarks made at the conference. Remarks were edited for publication by the editor. The speaker did not review this version of his presentation and the editor is responsible for any errors.

I think that the relationship between energy and water is way too broad a topic for fifteen minutes, or even fifteen months. Given the focus here, I am excited to narrow that down by a lot and talk about our work on the low-head hydro and the electrical grid.

Kris Polly spoke this morning and motivated me to say some things. I am from a scientific organization, Los Alamos National Laboratory, but like Kris, I grew up in Nebraska. My family has been growing corn and soybeans for 80 years there. I am now a New Mexican transplant and I am actually involved with water in many ways both from the electrical grid, but also from the water side. Some of you from northern New Mexico may recognize the name Richard Cook. I heard a couple laughs out there, so some of you may know about the legal wrangling that has been going on. I am one of the land owners that is involved in that wrangling, so I have a stake in water in northern New Mexico. Although I have a white shirt and tie on today, tonight I will go home and take care of the animals and fend for them. I am a stakeholder and I am concerned with the availability and reliability of water that it will be delivered down the Chama River through the Abiquiu dam. That is what I am here to talk about today. How can we use the existing water resources that we have to make the asset owners increase their revenue, and beyond that, also provide some useful services back to the electrical grid?

I picked up a copy of Kris Polly's journal, *Irrigation Leader*, this morning. It is a great journal, and if you haven't seen it yet you should pick up a copy. In the issue I just paged through, there is an article about in-house hydro power in irrigation districts called Common Sense Hydro Power: Small Hydro Power as a Solution, Traditional Hydro Power in the West. Clearly there is a focus here on hydro power, but everything that I have seen so far is from the water direction looking back at the grid. Why can't I have this hydro power and just hook it up to the grid? Well, there are issues with that. You can't just hook anything up to the grid. As you all know, water systems are large engineered networks, and so is the electrical grid. We have to be careful how we do this. Looking at this problem from the grid into the water system, I see the same thing. I see a huge resource in Abiquiu. Why can't I use that the way I want to for the benefit of the grid? Clearly, there are downstream stakeholders. How do we get these two sides to talk to each other for mutual benefit? That is what I would like to focus on today.

Part of this talk was to present a "proposal for meaningful change." My meaningful change would be to change one word in the Flood Control Act of 1960:

Public Law 86-645
86th Congress, H. R. 7623
July 14, 1960

> Cochiti Reservoir, Galisteo Reservoir, and all other reservoirs constructed by the Corps of Engineers as a part of the Middle
>
> Rio Grande project will be operated solely for flood control and sediment control, as described below:…

The one word from Public Law 86-645 that I would like to change is "solely." That is a tough word when it comes to lawyers. Let's modify the rules and regulations governing the sole purpose of the dams of the Rio Grande basin to allow a small degree of flexibility in water flows that will enable hydro-electric owners to provide services to the area that will: increase the economic value of those hydro stations to the owner and operator; provide services to the grid; reduce CO2 emissions and cooling water consumption at other locations; and also ease the integration of some other carbon free resources into the grid, while having minimal impact to stakeholders. If that one word, "solely," were changed, it would provide a lot of flexibility.

What specific installations are we actually talking about? Figure 1 shows the hydro stations owned and operated by Los Alamos County Department of Public Utilities. Abiquiu is run by the Army Corps of Engineers with 17 megawatts of max generation. El Vado Dam, also owned by Los Alamos County Department of Public Utilities provides 8 megawatts of max generation.

Figure 1. Hydro stations owned and operated by Los Alamos County Department of Public Utilities

What are we proposing to do? You all know about water, but let me give you two figures on the important features of the electrical grid that I am going to talk about today. Figure 2 is the U.S. grid and the area of concern is the Four Corners region with its big coal stations. You all now understand what I am talking about when I say the electrical transmission grid. It is the bunch of big wires that you see running down the side of I-25 and it is meshed so there are many ways that you can get from BPA down to PNM. It is primarily supplied by large synchronous generators: big chunks of spinning steel hooked to steam turbines that are connected to generators on the other side. The rate of rotation is what determines grid frequency, which is sixty hertz coming out of the wall. Generation and load are rebalanced every two seconds, while balancing water is done every 24 hours. It is a much harder job rebalancing every two seconds and to a fine degree of accuracy. You can think of it this way: if you flip the light on in the back of the room, it increases the load on the system. If you don't have the power to meet that requirement, the power has to come from somewhere–it starts sucking it out of those big spinning chunks of steel, and that is why it has to be rebalanced every two seconds or the frequency starts to fall. Large deviations can cause imbalances that are disruptive to the grid. By large, I mean large enough that a big generator trips off line. It would be like the big generator in the Four Corners area tripping off line. Throughout the entire West, this happens about twice a week. Sometimes these disruptions lead to large cascading blackouts. If you think that delivery of water is important, recall the 2003 Northeast blackout. It cost the country billions of dollars in just over a couple of days. Reliability of the grid is important, and I think that hydro power can play a role by providing lower cost reliability.

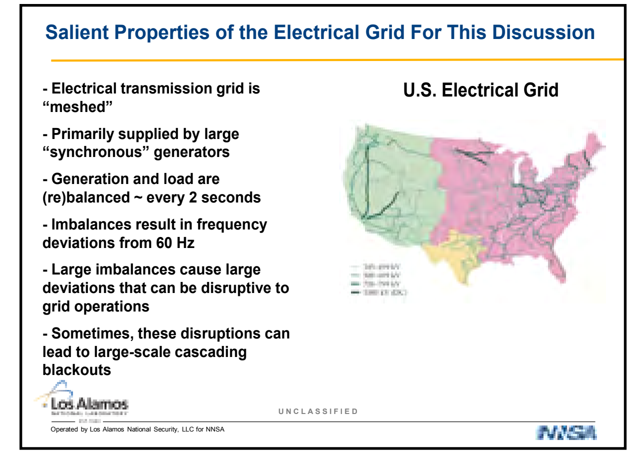

Figure 2. U.S. grid with the Four Corners region electrical transmission grid

How do we take care of the reliability? We procure spinning reserves (Fig. 3). What are spinning reserves? Imbalances are created by failures of the largest generators. It isn't the generator's fault, something disturbed it, and it tripped off line. Grid operators plan for such contingencies by buying large sections of spinning reserves, basically a fossil plant such as a big coal plant sitting on standby ready to generate power on a moment's notice to replace a generator that has been tripped off line. It must be available within five minutes, and typically used for one hour. Generally in the West, we have two such events every week, and we would need such reserves for that one hour twice a week.

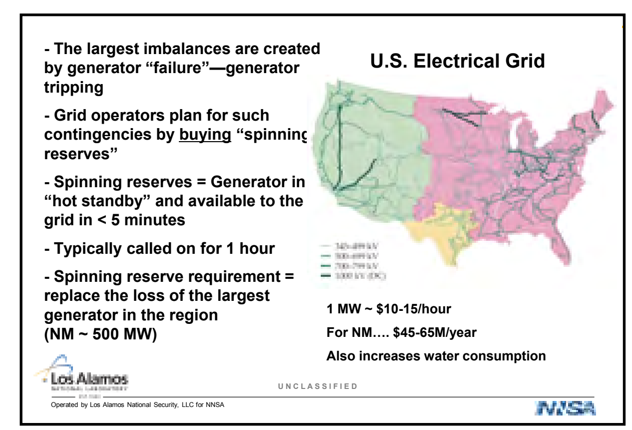

Figure 3. Spinning Reserves—Properties and Costs

To give you a sense of the economics here, the FERC requires that you be able to replace the largest generator in your area. In New Mexico, that is about a 500 megawatt generator. One megawatt costs about $10-15 an hour to have as a spinning reserve. In New Mexico, that means about $50 million a year in costs to provide this reliability service. Providing that service doesn't just produce CO2 emissions, it also increases water consumption, because those coal plants that are sitting in hot standby need cooling, while they are not providing any energy to the grid.

Kris Polly also mentioned today about other people's perception compared to reality. What really goes on compared to what people think goes on? We have done our homework from both sides to try to show that the services provided by the water won't impact stakeholders and beyond that, they can even earn extra revenue while providing services to the grid. We worked with the Department of Public Utilities to identify the available resources, focusing on Abiquiu, and how much flexibility in megawatts that dam can provide without impacting their revenue profile. We have looked at the impact of modifying U.S. Army Corps of Engineers steady-state operations on water flows. We have compared them with existing operations and talked to the Corps about the feasibility of these windows. We have looked at the impact of a spinning reserve event on downstream stakeholders, and we have performed simulations of real-time operations on those dams to get a better idea of impacts to the grid.

The next part of this talk is that part I love because I am a science guy. We have identified the available resource (Fig. 4). Abiquiu consists of three turbines including two 7-megawatt units and one 3-megawatt unit. These units have different flow regimes and different efficiencies, which can be characterized by efficiency curves. You want to maximize revenue for energy from any flow given to you by the Corps. You don't want to disturb that because it is your main resource. You can see in Figure 4 that for a typical flow rate, which is 300 cfs through that dam, you are generating $200-250 an hour. Remember, I want to provide a service that is will generate an extra $15-30 an hour. That means we would be increasing the value of that dam by 10% by effectively doing nothing, just sitting by and being prepared to provide that energy to the grid. That entails only providing service for two hours a week.

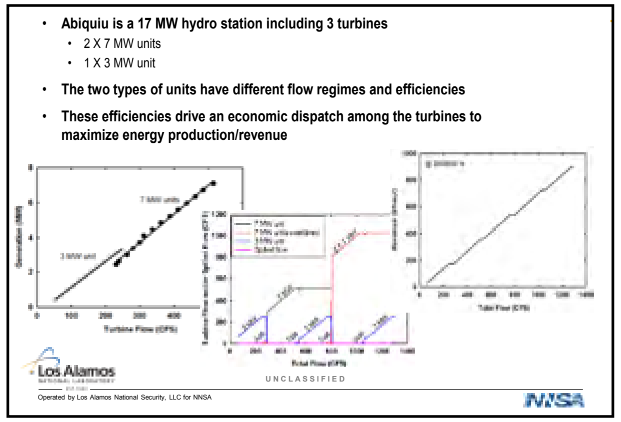

Figure 4. Abiquiu's Available Resource—Base Revenue

There is math behind this right? Yes, of course, but I won't go through all the math on Figure 5. We have done the optimizations to show that you can maximize revenue, maybe constrain water operations by a little bit, but provide extra value. Having spinning reserves requires that units be online and synchronized, which means that for a given amount of water that the Corps provides us, we would figure out how to dispatch all of our units. If we dispatch our units, what we find is that to keep our revenue at a maximum, and to provide this extra revenue to ourselves while providing this service to the grid, we have to constrain the water operations to be within certain windows. Depending on the size of the resource that we want to tap into, those windows get more and more narrow.

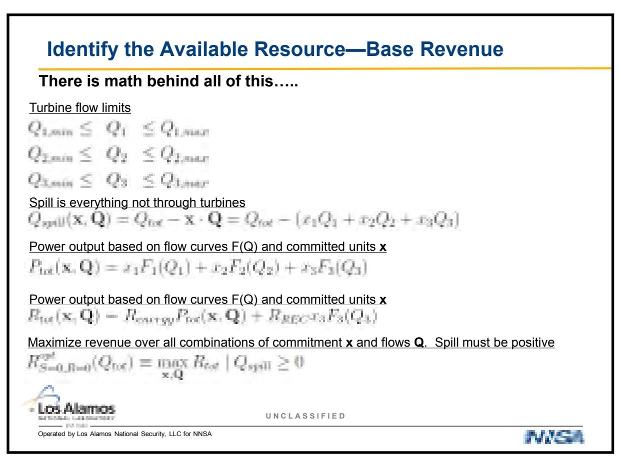

Figure 5. Identifying the available resource

Figure 6 shows the outcome of increasing the revenue of that dam by 5-10% a year. This shows normal operations for that dam in February with flow rate through the dam as a probability density. Usually in February we are normally well below 100 cfs, while in May you have spring runoff and peaks around 1500 cfs, although I think those operations have changed a bit and pushed that peak down. In August we are in irrigation season, and by November we shut down again. You can take these historical operations and force them into these little black bands as shown in Figure 6. If we constrain the steady-state operations to fall within those bands, we can do two things: continue to maximize revenue in terms of energy from those dams; and still provide 10% more revenue with the services we provide. It is pretty simple and straightforward. However, we do have to constrain the water operations. Remember, I'm a grid guy mostly looking at this from the grid size. I'm saying, that's no problem, can't you just keep the water flow within these bands? No, not exactly. What is the impact to the downstream stakeholders? If we could keep operations within those bands, with those flexibilities as I like to call them, depending on how much service we ask for, operations for one megawatt are already within that band a bit more than 50% of the time. We wouldn't actually be moving operations around that much. The revenue obtained sent back to the land asset owner is $87,000 a year. That is about a 5% increase in value of the asset over and above what it already is today. If we constrain operations a bit more and go up to a two megawatt capability from that dam, we are almost up to $200,000 a year increase in value.

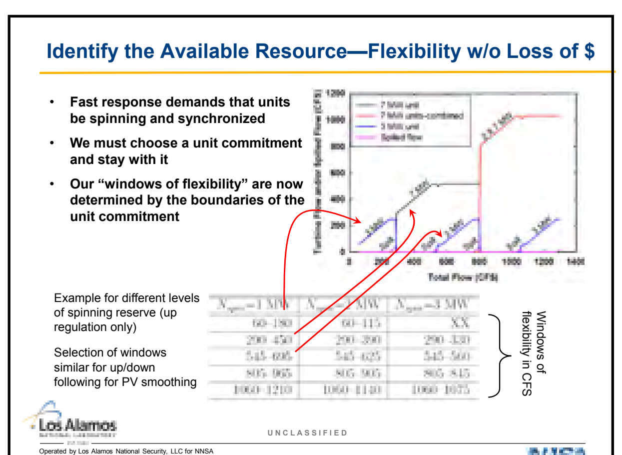

Figure 6. Outcome of increasing the revenue at Abiquiu

Kris Polly mentioned this morning that there are 18 small hydro projects that are going to cost around $12 million to implement. The cost of doing this monetarily is zero. There is no cost. The only cost is the sweat to get that one word in the legislation changed. We need the wording changed from the "sole" purpose to the "primary" purpose for flood and sediment control as well as other beneficial uses. Again though, I am an electrical grid guy looking at this from my side. I am trying to cross over enough that I understand what is going on. You might think that if I start tweaking with the water operations in the Chama River that the irrigators might be very upset, and that I might be somehow affecting the flows coming into their ditches or affecting the availability and reliability of the resource. That is the perception; the first thing they hear is that we are going to play with the water and they say, no you aren't.

We are scientists, so let's do some experiments. Look at Figure 7 for the effects. We used the commissioning of a three megawatt low-flow turbine a couple years ago to conduct a spinning reserve experiment. Part of the acceptance testing was to take the turbine from zero and ramp it up to a couple megawatts, hold it there for a couple hours, and then bring it back down again. We replicated what that would look like.

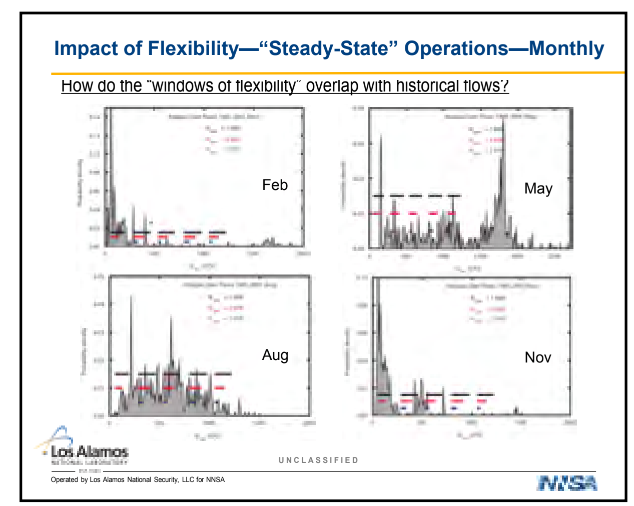

Figure 7. "Windows of flexibility" and overlap with historical flows

I want to point out a couple of things on Figure 8. The figure shows hours since midnight in May 2011, so this test is a bit old, but you can see the flow rate. These are typical operations from the U.S. Army Corps of Engineers. At 10 a.m. every day they appear to change the flow through the dam. This is a typical change you might see. Sometimes you might see nothing, but this is fairly typical. So that is already a pretty big change. You can see the commissioning test with the spinning reserve pulse that we sent down to the gauging station right below the dam. This pulse has an effect if you go maybe 40 or 50 miles downstream to the gauging station at Chamita. The effect on the water isn't that significant. This isn't perception, this is the data. This is the effect, and this would happen twice a week perhaps on average at Chamita far downstream. What if there is a stakeholder right down below the dam? What is the effect to them? They will be the ones who complains the most. We had people from the Corps go out and put gauges at the first two diversions to get an actual measure of impact to those stakeholders. The river stage during that spinning reserve pulse changed by a few inches. The anecdotal evidence from those studies was that it didn't actually affect the flow into those ditches much at all.

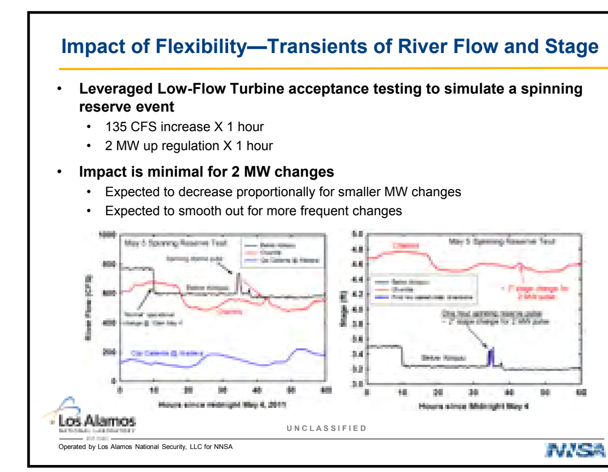

Figure 8. Transients of River Flow and Stage

What I would claim is that this simple service would increase the value of that asset by 10% with revenue on the order of a $200,000 a year. It may not seem like that much, but you start pushing that out into other resources in New Mexico and in the U.S. and it starts to add up to some reasonable dollars–dollars that could be reinvested in other hydro-power projects.

Also, we looked at the spinning reserve calls in this area for a year, and on average it is called on about twice a week (Fig. 9). So it would, in fact, be calling on the system about twice a week.

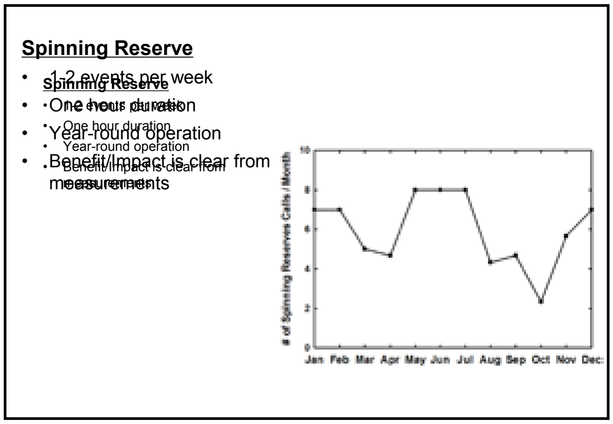

Figure 9. Frequency of transients

To wrap up here, run-of-river hydro is an underutilized electrical grid asset that can provide services while meeting other water stakeholder needs. We have done our homework both through simulations and experiments/observations to look at impacts on daily flow scheduling following services delivered and transient impacts on stakeholders.

Again, my meaningful change is to change that word “solely” in the law to “primary” and to allow a small bit of flexibility with the appropriate studies to provide additional services for run-of-river hydro.

Thank you.