

**From:** Parenti, David F.  
**Sent:** Wednesday, May 23, 2007 5:42 PM  
**To:** Tran, Paul  
**Subject:** FW: DO Memo  
**Attach:** D0EnhancementEquipmentConclusions~0516072.doc

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**From:** Parenti, David F.  
**Sent:** Monday, May 21, 2007 12:58 PM  
**To:** Ellis, H. Gene; Polk, B. Julian; 'Shiers, Paul'  
**Cc:** Tran, Paul  
**Subject:** FW: DO Memo

A couple of comments

Dave

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**From:** Ellis, H. Gene  
**Sent:** Monday, May 21, 2007 12:03 PM  
**To:** Bunker, William M.; Parenti, David F.; Paul Shiers (E-mail); 'Wendy Bley (E-mail)'; Julian Polk (E-mail); Gill, Lydia S.  
**Cc:** Ellis, H. Gene  
**Subject:** DO Memo

The attached is background for our discussion on Thursday.

Yadkin Project  
Tailwater Dissolved Oxygen Enhancement Program Status  
May 21, 2007

Background

As part of the Relicensing Settlement Agreement (RSA), APGI negotiated a schedule for undertaking enhancement measures at the Yadkin Project developments designed to improve tailwater dissolved oxygen (DO) concentrations and over time meet NC water quality standards for DO in these areas.

The schedule negotiated by APGI was designed to make best use of APGI's plans to refurbish/upgrade the generating units at the various developments. DO enhancements planned for High Rock and Narrows will be done in conjunction with the unit upgrades. A determination as to whether DO enhancements for Falls and Tuckertown will ultimately be needed will be made by NCDWQ only after DO enhancements at High Rock and Narrows have been completed, and monitoring and studies have shown a clearly demonstrated need.

Since the RSA is now complete, signed and filed with FERC, it is an appropriate time to review the DO enhancement plans in the context of the final RSA schedule. Specifically, APGI asked PB Power to work with Voith Siemens Hydro Power Generation (Voith) to review the DO enhancement needs at each of the Yadkin developments and to provide an update regarding the recommended DO enhancement technology to be used, and the cost of installing and operating that technology. In addition, PB Power was asked to consider whether installation of a "low flow" unit at each development, would be an economical fix, in the event that at some point in the future, NCDWQ would require APGI to operate the Yadkin Project developments on a continuous basis, so as to ensure that tailwater DO was at or above standards at all times. The North Carolina standard is DO concentrations of not less than a daily average of 5 mg/l with a minimum instantaneous value of not less than 4 mg/l.

Dissolved Oxygen Enhancement Equipment Study

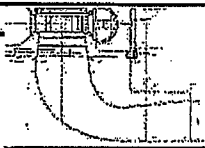
Voith has completed a study of equipment modifications that may be installed during refurbishment/upgrade of the Yadkin hydro units. Voith based this study on the available data, their experience with DO improvement, and dimensional calculations for air intake. Voith believes their conclusions to be accurate, but provides no warranty.

We note that it is not unusual in these cases that the actual field conditions do not produce the results initially expected. For example, the dimensional calculations for air intake show that at Narrows air injection is higher at flows below the design point when, in fact, it has not been verified that it is able to operate the air equipment in this range. Supplemental equipment is now being recommended for consideration in this operating range if the existing equipment cannot be operated at the lower generation levels. This demonstrates the difficulty of predicting output and performance based on technical studies alone.

High Rock

The RSA requires APGI to complete unit upgrades and install aerating runners at High Rock in 2010 (Unit 3), 2011 (Unit 2), and 2012 (Unit 1). Voith believes aerating runners currently planned for installation at High Rock will provide adequate levels of DO uptake. Their technical evaluation indicates APGI should be able to meet NC DO standards with through the runner air injection during most periods of unit operation. The cost of aerating runners is included in the refurbishment/upgrade cost estimates. There are times, however, when the DO may be as low as 1 mg/l, indicating the daily average value would be difficult to meet. Voith also evaluated the addition of central aeration to the High Rock units. They concluded that this would be a "belt and suspenders" approach and that it would not be necessary to operate both systems in parallel. They did not recommend pursuing this methodology further. Voith's estimate of DO uptake with the aerating runners is in Table 1. The DO uptake is estimated for 1 mg/l and 3 mg/l DO in the water flowing into the turbines at two incoming

water temperatures and three turbine flow conditions. Qfull is the maximum turbine flow 3430 cfs, Qopt is the design flow 3270 cfs, and Q0.8opt is 80% of design flow 2620 cfs. Minimum continuous flow for the High Rock turbine is 1960 cfs.

High Rock					Table 1
Head (ft)	52				
Unit CL (ft)	607				
Air location	600.4				
TWE (ft)	596.15				
DO uptake (mg/L)					
Qfull	3.24	3.86	2.66	3.34	
Qopt	3.26	3.88	2.68	3.35	
Q0.8opt	3.56	4.24	2.92	3.67	
Temp (°C)	27.8	16	27.8	16	
DOinitial	1mg/L		3mg/L		

#### Tuckertown

The RSA does not require DO enhancement at Tuckertown until after 2015, and then only if studies have demonstrated that the DO enhancement completed at High Rock is insufficient to allow the Tuckertown tailwater to meet state DO standards. Voith indicates that analysis of data obtained in 2006 and investigation of the tailwater levels and unit geometry do not indicate a reasonable possibility for natural aspiration. Therefore, unit upgrades cannot be used to improve DO. Voith concluded that if aeration is required by NCDWQ at the Tuckertown site (after 2015), then forced aeration methods including, but not limited to compressed air injection and oxygen bubbler systems, would have to be investigated. The estimated cost for an oxygen bubbler system in the Tuckertown forebay is \$2.3MM capital and \$800K annually for 12 hour per day, seven month operation. This cost estimate is very preliminary and is based on TVA technical papers, but could, if necessary, be used as placeholder until the impact of High Rock DO improvements are evaluated at Tuckertown. As noted above, there may be periods at High Rock where we just meet standards, even during periods of operation. The ROM cost estimates for a compressed air injection system at Tuckertown would be

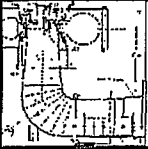
The minimum flow for the upgraded units at Tuckertown would be 1700 cfs.

Per the RSA, if it is determined by NCDWQ to be needed, DO enhancement work at Tuckertown needs to be completed by the end of 2016. Assuming the installation work could be completed in one year, a decision on need would be necessary by early 2015 to allow for approval of funds. As currently scheduled, refurbishment/upgrade, including the addition of aerating runners on the third unit at HR will be completed in 2012 and the first year of follow on DO testing would be completed at the end of 2013. A second year of DO testing and study would occur in 2014. Since the capital investment is significant and the information needed for the decision may not be available as soon as desired, appropriate allowances would need to be included in the long term capital budget process.

Initially, a \$300K allowance for Tuckertown was included in license implementation costs based on releasing water through a spillway gate for DO enhancement. This \$300K represents releasing 1000 cfs 10 hours per day May through November. Additionally, for this method to be effective the output of turbine discharge at Tuckertown would have to be limited to about 7000 cfs, about 75% capacity. This would impact the generating capacity of the entire Yadkin system, particularly the downstream development at Narrows, as well as limiting the generating capacity at Tuckertown. Since these limitations may not be acceptable or economical to APGI, further consideration of the forced air/oxygen injection is suggested.

**Narrows**

The RSA requires APGI to complete unit upgrades and install aeration technology at Narrows in 2009 (Unit 1) and 2010 (Unit 3).<sup>1</sup> Narrows Unit 4 has a peripheral aeration system installed on its draft tube cone. With the addition of this system on the other three units, Voith estimates the DO uptake in Table 2. The DO uptake is estimated for 1 mg/l and 3 mg/l DO in the water flowing into the turbines at two incoming water temperatures and three turbine flow conditions. Qfull is the maximum turbine flow 2300 cfs [30MW], Qopt is the design flow 2000 cfs [26MW], and Q0.8opt is 80% of design flow 1600 cfs [~20MW]. The minimum operating flow for the upgraded units is 1100 cfs.

Narrows		Table 2			
Head (ft)	174.5				
Unit CL (ft)	376				
Air location	371.63				
TWE (ft)	364.14				
DO uptake (mg/L)					
Qfull	4.16	5.05	3.3	4.24	
Qopt	4.41	5.36	3.51	4.51	
Q0.8opt	5.34	6.52	4.23	5.48	
Temp (°C)	27.8	16	27.8	16	
DOinitial	1mg/L		3mg/L		

However, below 20 MW the peripheral aeration system does not draw air well which is not indicated by the data in Table 2, which shows that it should be working better at this point, not worse as it does. Currently the air valves on unit 4 are closed when the load is less than 20 MW because of concerns that water will flow out of the draft tube air valves and cause flood damage. This condition would indicate units have to always be operated above 20 MW to allow for DO enhancement. In fact, the units may need to be operated above ~ 23MW to inject enough air to improve the tailwater DO significantly. This is a constraint on operations since 23 MW is about 1800 cfs and the units can be operated as low as 1100 cfs. This limit also has an impact on DO conditions since the units would be operated less time in a given day, increasing the periods of non generating time when DO conditions may be lower and possibly below standards. For reference the design output is 26 MW at 2000 cfs (Qopt in Table 2), the maximum output is 30 MW at 2300 cfs (Qfull in Table 2). Voith believes that the peripheral aeration should operate without concern for backflow at lower flows and has suggested that additional study of Narrows is needed to determine the reason for the current 20 MW limitation and provide options for correction.

Voith has also suggested that a central aeration scheme could be provided but that additional analysis is needed to provide cost, feasibility and performance data. Voith recommends pursuit of both methods of air injection at this time to allow units to draw air at lower than 20 MW. Voith has been requested to provide a proposal and cost to pursue both methods. Bottom line, the cost of DO provisions may increase at Narrows.

It is recommended that Voith be authorized to proceed on this work in 2007, pending receipt of their proposal and pricing and approval of the Narrows Unit 1-2 Upgrade funding request.

Voith has determined that installing aerating runners is not technically feasible with Narrows upgraded units.

**Falls**

The RSA does not require DO enhancement at Falls until after 2013, and then only if studies have demonstrated that the DO enhancement completed at Narrows is insufficient to allow the Falls tailwater to meet NC DO standards. Voith believes that the Falls units could have DO enhancement

<sup>1</sup> The RSA DO enhancement schedule assumes upgrades and the installation of aeration technology at Narrows Unit 2 will be completed in 2008.

equipment installed as part of turbine refurbishment. The Francis Unit 1 could receive an aerating runner. The propeller Units 2 and 3 could be outfitted with either or both peripheral and central aeration. The Voith estimate of DO uptake associated with the aeration technology described above is shown in Table 3. The DO uptake is estimated for DO in the water flowing into the turbines at two incoming water temperatures (27.8 °C and 16 °C) and DO concentrations (1 mg/l and 3 mg/l) and three turbine flow conditions. Qfull is the maximum turbine flow 2660 cfs, Qopt is the design flow 2450 cfs, and Q0.8opt is 80% of design flow 1960 cfs. Minimum flow for the Falls turbine is 1470 cfs.

Falls		Table 3			
Head (ft)	54				
Unit CL (ft)	330				
Air location	324.8				
TWE (ft)	306.5				
DO uptake (mg/L)					
Qfull	5.17	6.35	3.83	5.1	
Qopt	5.46	6.74	4.03	5.4	
Q0.8opt	6.34	7.22	4.57	6.31	
Temp (°C)	27.8	16	27.8	16	
DOinitial	1mg/L		3mg/L		

Because it is anticipated that the DO enhancements at Narrows will have a significant impact on the Falls DO, and that NCDWQ may not require additional aeration at Falls, the cost of DO enhancement equipment for Falls is not currently in the license implementation estimate. Per the RSA, the need for additional DO enhancement must be determined by the end of 2013 at Falls. Based on this schedule, two years would be available for engineering, design and fabrication of a through the runner air injection system. We recommend that Unit 1 instead of Unit 3 be upgraded last to allow this unit to be upgraded with through the runner air injection if need is determined. The preliminary additional cost estimated to install an aerating runner in Unit 1 is \$700K and central/peripheral aeration in Units 2 and 3 is total cost \$600K. These costs are in addition to the budgeted refurbishment costs for these generation units.

#### Low Flow Unit Analysis

The aeration enhancements described above and currently being considered are all designed to operate when APGI is generating. According to the RSA, APGI will be required to operate with air injection provisions on all units during all periods of generation from May 1 through November 30. However, at this time it is unknown whether the tailwater areas will meet State DO standards when units are not operating. It is possible, even after all the aeration technology has been installed per the RSA that DO concentrations in the tailwaters may fall below NC DO standards during periods of non-operation. In this case, it is possible that NCDWQ may eventually require APGI to take steps to ensure that DO standards are met at all times. Continuous operation or pulsing operations are two possibilities for "fixing" this problem. Other options could include, spilling water through special aeration valves with or without adding compressed air or oxygen .... Or other technologies .... that would need to be evaluated

PB worked with Voith to investigate whether a single low-flow unit provided at each development in place of one of the planned unit upgrades would be more economical if continuous operation is eventually required by NCDWQ to meet DO standards. A low-flow unit would release less water during periods of off peak generation if 24/7 operation is required and would generate at a higher unit efficiency during these periods.

OASIS model runs using technical data provided by Voith for smaller units have not shown an overall positive benefit of providing one smaller unit at each development. The results show the smaller units increase efficiency marginally and reduce generation transferred to off peak during continuous high

flow operations, but the smaller capacity units result in increased spills that negate this potential benefit. A summary of results is below.

TABLE 4. Cost of RSA with DO Enhancement Under Different Scenarios

	Ave Annual ENERGY (MWh)	Ave Annual REVENUE (\$1000)	Ave Annual COST (\$1000)
<u>Base Case with Upgrades</u>	994,559	\$43,595	
<u>Cost of DO Enhancement relative to the Base Case with Upgrades:</u>			
RSA w/Upgrades - All units the same:			
air on May thru Oct; no continuous ops	994,061	\$42,560	\$1,035
air on and continuous ops May thru Oct	977,911	\$41,176	\$2,419
RSA w/Upgrades - 1 small unit at each development:			
air on May thru Oct; no continuous ops	967,308	\$41,050	\$2,545
air on and continuous ops May thru Oct	962,335	\$40,637	\$2,958

Risk Issues

The possibility that at some future point continuous operation of DO enhancement will be required to ensure that DO standards are met on a 24/7 basis remains a significant concern. The estimated cost of operating the four developments continuously so as to provide DO enhancement on a continuous basis is \$1,384,000, annually. Again, however, pulsing units may be an option to continuous operation that has the potential to reduce these costs and should be explored at that time.

DO monitoring is also an area of concern. Under the current agreement, APGI is expected to operate DO enhancement continuously on all units (where it is available) whenever those units are operating during the period May 1 through November 30. In association with that APGI is required to monitor DO in the four tailwater areas, but only needs to download the DO results weekly, and provide those results to NCDWQ at the end of each year. In the future, APGI may want to have the opportunity to modulate the operation of the DO enhancement equipment to meet State DO standards. To do this would require that APGI undertake continuous, real-time DO monitoring. The data from continuous DO monitoring could also be used to help reduce losses if generating units need to run more continuously during previously planned periods of non-generation to meet NC DO standards. Real time DO monitoring will have both a higher capital and annual cost impact than the values included in the RSA losses. However, if peaking or pulsing generating units can be used instead of continuous operation to meet NC DO standards the cost to operations will be less. To have the ability to operate generation only when DO enhancement is necessary will require continuous real time DO monitoring data to support operations decisions.

Conclusions and Recommendations

High Rock

- Planned aerating runners should be capable of achieving levels of DO uptake required to meet DO standards most of the time when units are operating.
- Possible central aeration should not be pursued any further.

### Tuckertown

- Natural aspiration methods are not feasible (valves, runners, etc), and forced air or oxygen injection will be required if DO enhancement is needed. High Rock numbers for uptake based on the technical evaluation by Voith indicate there are times when meeting DO standards even in upstream High Rock tailrace will be difficult.
- If it is determined that DO enhancement is required at Tuckertown, it will have to be completed by December 31, 2016 in accordance with the RSA, so a decision would be needed in early 2015 to allow for approval of project funding.
- Estimated cost of a forebay oxygen bubbler system is \$2.3 MM capital and \$800 K annually for operation. Planning budgets may need to be updated to reflect these costs. Estimated cost for a compressed air system may be .....

### Narrows

- Planned aeration valves should be capable of achieving levels of DO uptake required to meet DO standards when units are operating above 23 MW.
- Additional investigation should be conducted by Voith to understand and develop an alternative system to allow unit operation at lower flows between 1800 and 1100 cfs (between 15 and 23 MW).

### Falls

- A combination of through the runner (Unit 1) and central/peripheral aeration (Units 2 and 3) methods should be capable of achieving DO standards, if it is determined necessary by NCDWQ. The through the runner improvement would be the most effective to consider first.
- The estimated cost is an additional \$700K for the Unit 1 through the runner aeration and \$600K for the Unit 2 and 3 central/peripheral aeration above the budgeted refurbishment cost. It is not recommended to include this cost in the planning budget.

### Low Flow Units

- It does not appear that installation of low flow units at the Project development is a cost-effective solution to the possibility of having to meet DO standards continuously.
- If continuous operation becomes an issue in the future, pulsing operations and other aeration technologies should be evaluated as an alternatives.