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Review of Selected Documents Related to Flooding at City of Salisbury Facilities on the Yadkin River Upstream from High Rock Dam, North Carolina, September 2007

Open-File Report 2007–1314

U.S. Department of the Interior
U.S. Geological Survey

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U.S. Department of the Interior
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U.S. Geological Survey
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Contents

Figures

Tables

Conversion Factors and Datums

Inch/Pound to SI

Multiply	By	To obtain
	Length	
foot (ft)	0.3048	meter (m)
mile (mi)	1.609	kilometer (km)
	Area	
square mile (mi^2)	2.590	square kilometer (km^2)
	Volume	
cubic foot (ft^3)	0.02832	cubic meter (m^3)
	Flow rate	
cubic foot per second (ft^3/s)	0.02832	cubic meter per second (m^3/s)
	Specific capacity	
gallon per minute per foot [(gal/min)/ft)]	0.207	liter per second per meter [(L/s)/m]

Vertical coordinate information is referenced to the North American Vertical Datum of 1988 (NAVD 88).

Horizontal coordinate information (latitude/longitude) is referenced to the North American Datum of 1983 (NAD 83).

Elevation, as used in this report, refers to distance above the vertical datum.

Review of Selected Documents Related to Flooding at City of Salisbury Facilities on the Yadkin River Upstream from High Rock Dam, North Carolina, September 2007

By Jerad D. Bales

Abstract

This report documents a review of the hydraulic and sediment-transport models developed by the City of Salisbury, Alcoa Power Generating, Inc., and the Federal Energy Regulatory Commission to address issues of flooding and sedimentation in the vicinity of Salisbury's water-supply intake 19.4 miles upstream from High Rock Dam. The objective of the review was to determine if the modeling results submitted by Salisbury clearly demonstrate that the presence of High Rock Dam has led to an increase in water levels at Salisbury facilities or, conversely, if the documents of Alcoa Power Generating, Inc., demonstrate that High Rock Dam has not had an effect on water levels at Salisbury facilities. No new data were collected as a part of the review, and the models developed by involved parties were not tested during the review. Some historical discharge-measurement notes and previously published reports were checked as part of the review.

The one-dimensional hydraulic modeling results submitted by Alcoa Power Generating, Inc., did not assess the effects of changes in bathymetry on changes in flood levels at Salisbury's facilities because pre-impoundment conditions were not simulated. Hydraulic modeling performed by consultants for the City of Salisbury seems to indicate that both the presence of the dam in the absence of any post-impoundment sedimentation and changes in bathymetry between pre-impoundment and 1997 conditions have resulted in increased water levels relative to pre-impoundment conditions at Salisbury facilities on the Yadkin River for a fairly wide range of flows. The degree to which the dam and the changes in bathymetry have affected flood levels at the Salisbury facilities relative to pre-impoundment conditions is open to discussion because of uncertainty in topographic/bathymetric data and the absence of calibration and sensitivity testing of the hydraulic models. None of the three hydraulic models appears to have been calibrated to or tested against measurements, and no sensitivity testing was reported. Sediment-transport modeling results submitted by the City of Salisbury were calibrated, well documented, and provide a good understanding of the expected growth of the sediment delta in the upper end of High Rock Lake. Simulations made using this model seem to have demonstrated that the presence of the dam and the growth of the delta have resulted in increases in water-surface elevations at Salisbury's facilities over a range of flows and that these increases are expected to increase through time if current conditions remain unchanged.

Introduction

The City of Salisbury has operated a water-supply intake at the confluence of the Yadkin and South Yadkin Rivers since 1917 (fig. 1). The City maintains that the operation of High Rock Dam, completed in 1927 and currently operated by Alcoa Power Generating Inc. (APGI), has created a sediment delta in the headwaters of High Rock Reservoir and that this delta has caused (1) increased flooding of the water-supply pump station, (2) sediment deposition around the pump intake, and (3) increased flooding at a wastewater-treatment plant pump station located near the mouth of Grants Creek (fig. 1).

The APGI currently (2007) is seeking to relicense four hydroelectric stations, including High Rock Dam, on the Yadkin-Pee Dee River. The license for the hydroelectric stations and the reservoirs that support them is granted by the Federal Energy Regulatory Commission (FERC). The North Carolina Department of Environment and Natural Resources (NCDENR) is participating in the relicensing process. NCDENR has signed a Relicensing Settlement Agreement with APGI and subsequently must respond to an application by APGI for a section 401 water-quality certification for the stations.

The City of Salisbury has requested that APGI address the issue of flooding and sedimentation at the City's facilities on the Yadkin River during the FERC relicensing process settlement agreement. APGI maintains that (1) their operation is too far downstream to affect the City's pump stations, (2) the Yadkin River has a naturally high sediment load, and (3) the pump station is in the floodplain. Because of APGI's position, Salisbury retained consultants to develop hydraulic

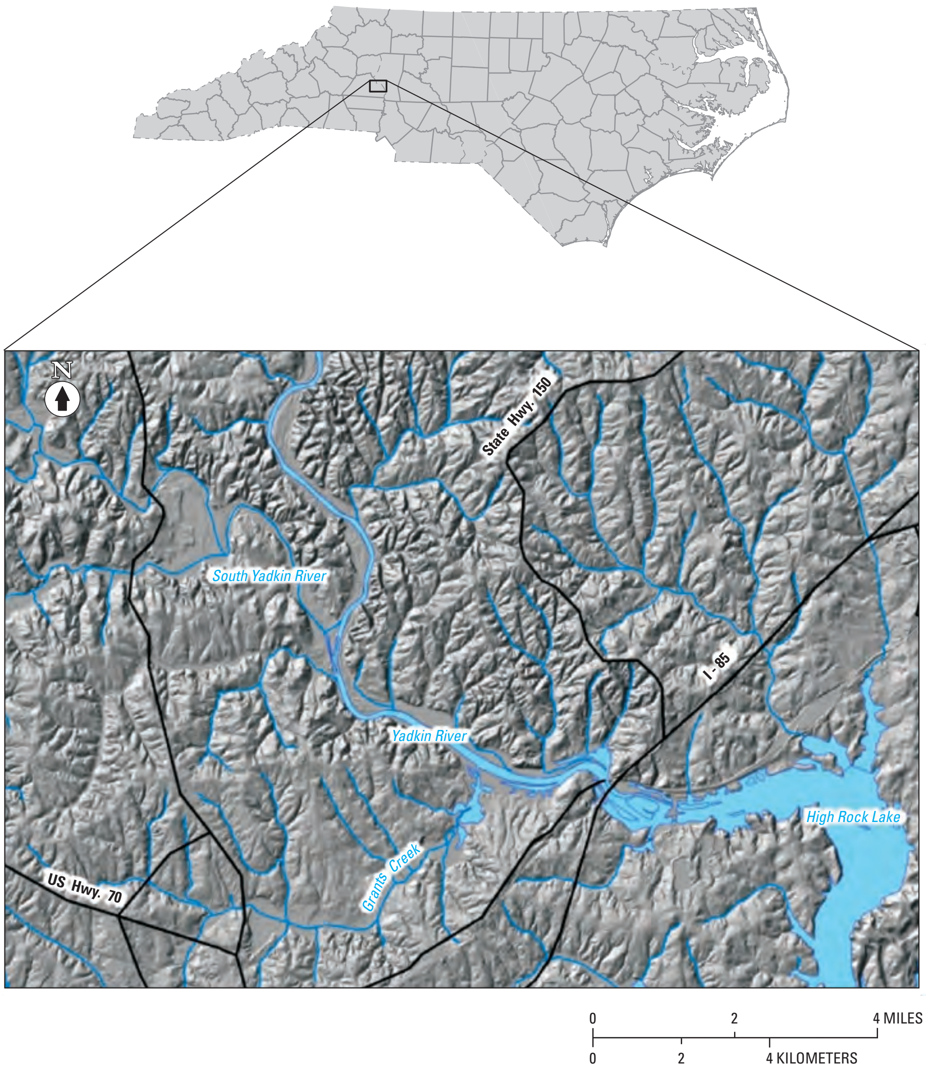

Figure 1. Yadkin River, South Yadkin River, Grants Creek, and upstream end of High Rock Lake, North Carolina.

and sediment-transport models for the reach in question. The final report was submitted to FERC on February 26, 2007, as part of Salisbury's relicensing scoping comments. APGI also has funded studies of their own, including a review of the City's documents.

Because of the complexity of the issues, NCDENR enlisted the U.S. Geological Survey (USGS) to review documents from both APGI and the City of Salisbury related to flooding at the City's facilities. The independent review is needed in order to assist NCDENR in their review of the application of APGI for a section 401 water-quality certification and subsequent renewal of the FERC license for High Rock Dam.

Purpose and Scope

The purpose of this report is to summarize a review of the hydraulic and sediment-transport models developed by the City of Salisbury, APGI, and FERC, as well as related data and information. The objective of the review was to determine if the documents submitted by Salisbury clearly demonstrate that the presence of High Rock Dam has led to an increase in water levels at Salisbury facilities, or conversely if APGI documents demonstrate that High Rock Dam has not had an effect on water levels at Salisbury facilities. Documents that were included in the review are listed in the following section. The review included a site visit to the Yadkin and South Yadkin Rivers and downstream to High Rock Lake. No new data were collected as a part of the review, and the models developed by the parties involved were not tested during the review. Some historical discharge-measurement notes and previously published reports were checked as part of the review.

This report is structured in the following manner—first, the documents that were reviewed are listed, next are the reviews of the hydraulic modeling and related documents, followed by reviews of the sediment-transport modeling conducted by the City's consultant and comments provided by APGI's consultant. A brief review of other documents provided by the City and APGI is followed by a summary and recommendations.

Materials Reviewed

The documents reviewed during this study are as follows:

Documents from the City of Salisbury

- Technical Report—"High Rock Dam and High Rock Lake sedimentation flooding effects as estimated using HEC–RAS modeling, January 2006," prepared by Hazen and Sawyer for Salisbury-Rowan Utilities (hereafter referred to as SAL–1)

- Correspondence—Letter from V. Randall Tinsley to Secretary Magalie Salas, Federal Regulatory Commission, dated February 23, 2006 (SAL–2)

- Report—"Numerical sedimentation investigation, Yadkin River, North Carolina, February 20, 2007," prepared by

R.R. Copeland, Mobile Boundary Hydraulics for the City of Salisbury (SAL–3)

- Report—"High Rock Dam and sediment delta flooding and sedimentation effects (1927–2058) on City of Salisbury critical infrastructure, February 2007," prepared by Martin Doyle for the City of Salisbury (SAL–4)
- Correspondence—Letter from R.R. Copeland and W.A. Thomas to Matt Bernhardt, Salisbury-Rowan Utilities, May 8, 2007, in response to Williams' affidavit (SAL–5)
- Correspondence—Letter from Martin Doyle to Matt Bernhardt, Salisbury-Rowan Utilities, May 9, 2007, in response to Shiers' affidavit (SAL–6)

Documents from Yadkin / Alcoa Power Generating, Inc.

- Report—"Review of January 1998 flood of Yadkin River, February 1998," prepared by Stone & Webster for Yadkin, Inc. (hereafter referred to as APGI–1)
- Report—"Yadkin Hydroelectric Project—FERC No. P–2197–073, Alcoa Power Generating, Inc., responses to Federal Energy Regulatory Commission's September 14, 2006, and November 22, 2006, additional information requests, April 6, 1998," prepared by Julian Polk, Yadkin, Inc. (APGI–2)
- Correspondence—Letter from Gene Ellis, Licensing and Property Manager, APGI, to Secretary Magalie Salas, FERC, December 13, 2006, in response to the additional information request for Yadkin Hydroelectric Project (APGI–3)
- Affidavit of David Williams, Ph.D., P.E., March 26, 2007 (APGI–4)
- Affidavit of Paul F. Shiers, P.E., March 27, 2007 (APGI–5)
- "Consolidated answer of Alcoa Power Generating, Inc., to petitions to intervene and comments in response to scoping document 1," prepared by LeBoeuf, Lamb, Greene, and MacRae, LLP, Counsel to Alcoa Power Generating, Inc., [undated] (APGI–6)
- Report—"Sediment fate and transport report, final report, November 2005," prepared by Normandeau and Associates, Inc., and PB Power (APGI–7)

Documents from FERC

- Correspondence—Letter from Jerrold Gotzmer, Director, FERC, to Julian Polk, Yadkin, Inc., dated March 11, 1998 (hereafter referred to as FERC–1)
- Correspondence—Letters from Jerrold Gotzmer, Director, FERC, to Ron Qualkenbush, dated May 6, 1998, and May 21, 1998 (FERC–2)
- Report—"Hydraulic modeling report for Yadkin Project—North Carolina, Alcoa Power Generating, Inc. (APGI), June 2003," prepared by Federal Energy Regulatory Commission (FERC), and transmittal letter from FERC to David Treme, Ron Qualkenbush, and Milton Crowther (FERC–3)

One-Dimensional Hydraulic Modeling

One-dimensional hydraulic models were developed by Stone & Webster for APGI (APGI–1), FERC (FERC–2), and Hazen and Sawyer for Salisbury-Rowan Utilities (SAL–1). Important aspects of these models are summarized in table 1.

Stone & Webster Modeling

In January 1998, a campground approximately 20 miles (mi) upstream from High Rock Dam was flooded during high flows. The Stone & Webster model was created to evaluate "the effect that the operation of High Rock Dam may have had on this flooding" (APGI–1). The model extent is from High Rock Dam to the confluence of the Yadkin and South Yadkin Rivers, 19.4 mi upstream from High Rock Dam (or river mile (RM) 19.4). An estimated inflow hydrograph at the upstream boundary and a range of downstream water-surface elevations at the dam were used for this model.

Cross sections were scaled from topographic maps and were assumed to be trapezoidal in shape. The report does not specify how the bottom and(or) top width of the cross sections were determined nor how the side slopes were determined. Apparently, more detailed cross sectional data were available (APGI–7) from 1997 surveys, but these data were not used. The channel bed slope was based on the assumption of a linear slope between the dam and RM 18.1; the slope was assumed to be zero between RM 18.1 and RM 19.4. It does not appear that the model was calibrated.

The report concluded that, for existing conditions, the water level at RM 19.4 was independent of the lake level at High Rock Dam. The report also concluded that water levels at RM 19.4 were affected by a channel constriction at the railroad bridge near the NC–150 bridge and by a narrow bend in the river at about RM 18.4.

The conclusion regarding the relation of water levels at High Rock Dam and water levels at RM 19.4 for current conditions is reasonably supported by the modeling for current conditions. The conclusions could be strengthened by conducting a sensitivity analysis of the effects of the assumed channel geometry and bed slope on simulated water levels at RM 19.4. No evidence is given in the report for the conclusion that the channel constriction and narrow bend in the river control water

Table 1. Characteristics of one-dimensional steady-flow modeling applied to High Rock Lake and the Yadkin River, North Carolina, by Stone & Webster, the Federal Energy Regulatory Commission, and Hazen and Sawyer.

[FERC, Federal Energy Regulatory Commission; mi, mile; ft, foot; NGVD 29, National Geodetic Vertical Datum of 1929; ft^3/s, cubic foot per second]

Stone & Webster	FERC	Hazen and Sawyer
	Purpose	
Evaluate effects of High Rock Dam operation on upstream flooding; at request of FERC, additional analysis was conducted to evaluate upstream flooding with no dam present.	"Determine the influence of the High Rock Reservoir elevation on the water-surface elevation at the confluence of the Yadkin and South Yadkin Rivers" (FERC–3).	"…evaluate the effects of High Rock Dam and dam-induced sediment accumulation on the frequency and magnitude of flooding…at the Yadkin-South Yadkin confluence."
	Cross-section locations	
At bends, constrictions, and contractions; although the number was not specified, based on the Hazen and Sawyer report (SAL–1), the number was probably 24 over a 19.4-mi reach.	Started with Stone & Webster model; added cross sections in reaches where needed; extended model reach upstream from confluence.	24 cross sections over the 19.4-mi reach; same locations as Stone & Webster model.
	Source of geometry data	
Scaled from 1:24,000 topographic maps with 10-ft contour intervals.	10-ft contours developed from 100-ft digital elevation model. Centerline of channel and bank elevations from 1:24,000 topographic maps.	Pre-impoundment conditions—1917 topographic map (1:4,800) with 5-ft contours above 630-ft elevation and 10-ft contours below 630-ft elevation. Post-impoundment conditions—1997 surveys.
	Channel cross sectional geometry	
Assumed to be trapezoidal; assumptions regarding top width, bottom width, and side slope were not given.	Assumed to be trapezoidal with 4:1 side slope from channel banks to the bed.	Trapezoidal cross section assumed below 1997 water surface.
	Reach length	
High Rock Dam to confluence of Yadkin-South Yadkin, or about 19.4 mi.	High Rock Dam to 10,000 ft upstream from Yadkin-South Yadkin confluence, or about 21.3 mi.	High Rock Dam to confluence of Yadkin-South Yadkin, or about 19.4 mi.
	Calibration	
No mention of calibration.	No mention of calibration.	No mention of calibration.
	Bed configuration	
Assumed that channel bottom was at 613.6-ft elevation at 7,000 ft downstream from Yadkin-South Yadkin confluence; flat upstream to confluence; linear slope to dam.	Same as Stone & Webster model from point 7,000 ft downstream from confluence to dam (linear bed with slope = 0.00062); upstream from confluence, slope was 0.0002 based on topographic maps.	Linearly interpolated between the dam and Salisbury's water-supply intake.
	Bed slope	
0.00062	0.00062 and 0.0002 (see above).	Pre-impoundment slope = 0.0005.
	Manning's n	
0.035 in channel; 0.05 in overbank.	Not reported; assumed to be the same as Stone & Webster.	Not reported; assumed to be the same as Stone & Webster.
	Expansion and contraction coefficients	
0.1 and 0.3, respectively, except at NC-150 bridge, where the values were 0.3 and 0.5, respectively.	Not reported; assumed to be the same as Stone & Webster.	Not reported; assumed to be the same as Stone & Webster.
	Conditions simulated	
1998 flood and current conditions.	2003 flood, a range of flows, and current conditions.	No dam, current conditions, and possible future conditions for a range of flows at confluence.
	Vertical datum	
Not clear whether it was NGVD 29 or other.	"…local vertical datum" (FERC–3).	NGVD 29

Table 1. Characteristics of one-dimensional steady-flow modeling applied to High Rock Lake and the Yadkin River, North Carolina, by Stone & Webster, the Federal Energy Regulatory Commission, and Hazen and Sawyer. — Continued

[FERC, Federal Energy Regulatory Commission; mi, mile; ft, foot; NGVD 29, National Geodetic Vertical Datum of 1929; ft^3/s, cubic foot per second]

Stone & Webster	FERC	Hazen and Sawyer
Important conclusions		
At flow rates greater than 30,000 ft^3/s, water level near Yadkin-South Yadkin confluence is independent of High Rock Dam operations. Reason: downstream constrictions at railway bridge and NC-150, and sharp bend in river.	Operation of High Rock Reservoir did not have a significant effect on water levels at Yadkin-South Yadkin confluence for March 2003 flood.	Pre-impoundment and current conditions were simulated, showing increases in water-surface elevations over a range of flows at Salisbury's intake as a result of changes in reservoir bathymetry.
Limitations		
No analysis of pre-dam or pre-bridge conditions; therefore, not directly relevant to evaluation of effects of delta on flooding at Salisbury's facilities. No sensitivity tests. 1997 topography was not used.	No analysis of pre-dam or pre-bridge conditions; therefore, not directly relevant to evaluation of effects of delta on flooding at Salisbury's facilities. No sensitivity tests. 1997 topography was not used.	No mention of pre-impoundment bridges. No sensitivity tests. All aspects of model not well documented.

levels at RM 19.4 during high flows. A sensitivity analysis of the effects of the expansion and contraction coefficients and simulations without the bridges in place is needed to give credibility to the conclusion regarding the effects of bridge constrictions. It is not clear how results from the one-dimensional model were used to make conclusions regarding the effects of the bend.

Doyle (SAL–4) briefly described the HEC–RAS modeling that was conducted to evaluate the effects of the bridges on water levels at the Salisbury facilities. His analysis indicated that the upstream effects of the bridges are minimal, even under high flows. Essentially no details are given in Doyle's report regarding the model, so it is impossible to assess these conclusions.

The results of the Stone & Webster modeling are not directly relevant to the issue of the effects of the presence of High Rock Dam or the delta on flooding at RM 19.4. This is because no simulations for pre-impoundment or pre-delta conditions were performed for comparison with 1998 conditions. Moreover, simulations for conditions with and without the bridges were not conducted, making it impossible to assess the effects of the bridges on water levels at the Salisbury facilities.

Federal Energy Regulatory Commission Modeling

The Federal Energy Regulatory Commission (FERC) obtained the HEC–RAS model used by Stone & Webster (APGI–1) to conduct additional one-dimensional hydraulic modeling investigations (FERC–3), and particularly to "determine the influence of the High Rock Reservoir elevation on the water surface elevation at the confluence of the Yadkin and South Yadkin Rivers" during a 2003 flood. The model domain was extended upstream to about RM 21.3, and additional cross sections were added to the model to provide greater resolution at locations where FERC concluded that the Stone & Webster cross sections were too widely spaced. The model was used to simulate water-surface profiles for the March 2003 flood for a range of water levels at High Rock Dam. FERC used a digital elevation model to develop a topographic map that perhaps provided more detailed cross sectional information than was in the Stone & Webster model, but the detailed data from the 1997 survey were not used in the model. The approach used by FERC was much the same as the approach used in the Stone & Webster study other than the source of the topography data and the flood to which the model was applied. As a result, the conclusions from this study were essentially the same as those from the Stone & Webster study—water level at RM 19.4 is essentially independent of water level at High Rock Dam for flows between 40,000 and 70,000 cubic feet per second (ft^3/s) under current conditions. As with the Stone & Webster study, no simulations were produced for pre-impoundment or for 1917 bathymetric conditions for comparison to current conditions.

Hazen and Sawyer Modeling

Hazen and Sawyer (SAL–1) constructed a HEC–RAS model for High Rock Lake and a portion of the Yadkin River to "evaluate the effects of High Rock Dam and dam-induced sediment accumulation on the frequency and magnitude of flooding . . . at the Yadkin-South Yadkin confluence." This statement presumes the conclusion that all of the sediment accumulation in the reservoir is "dam-induced." The modeling effort was unique in two ways — (1) 1997 topography was used to construct cross sections for current-conditions model input, and (2) pre-impoundment conditions were simulated.

The 1997 topographic survey was conducted by APGI contractors when the lake level was at 12 feet (ft) below full pool. The survey extended out from the full-pool elevation about 0.25 mi. A topographic map with 2-ft contour intervals was prepared (APGI–7). Hazen and Sawyer also simulated pre-impoundment conditions by using 1917 topographic data obtained from maps provided by APGI and estimating channel cross sectional shape below the 1917 water surface. Simulations were made assuming the dam was not in place and using 1917 topography.

Results indicated that the presence of the dam alone, with no sediment accumulation (that is, 1917 bathymetry), may have led to an increase in water levels at RM 19.4 for flows less than about 80,000 ft^3/s. At a flow of about 20,000 ft^3/s, the increase may be about 6 ft relative to pre-impoundment conditions. The increases relative to pre-impoundment conditions were greater when simulations were made using 1997 topography/bathymetry, with an increase of about 10 ft at a flow of about 20,000 ft^3/s. Water levels for estimated 2038 conditions were linearly extrapolated by assuming that the average annual increase in water-surface elevation for each flow rate during 1927–97 continues through 2038.

Various aspects of the Hazen and Sawyer model are poorly documented, including the Manning's n, expansion and contraction coefficients, and treatment of bridges for historic conditions (that is, did the simulations for 1917 include the bridges from 2005, the bridges from 1917, or no bridges?). In addition, as in the Stone & Webster and the FERC models, the Hazen and Sawyer model does not appear to have been calibrated or compared to observed conditions. Nevertheless, this model seems to clearly demonstrate that the presence of the dam and the changes in bathymetry likely have had an effect on water levels at the Salisbury intakes relative to the pre-impoundment conditions. The exact magnitude of the change is less certain, primarily because of uncertainties in current and historic bathymetry, because model performance has not been tested through comparison to measured conditions, and because all aspects of the model were not documented.

Doyle (SAL–4) summarized the work of Hazen and Sawyer (SAL–1) in his report. The hydraulic modeling aspects of Doyle's report were subsequently reviewed by APGI's consultant, Parsons Brinkerhoff (PB; APGI–5). The PB review identified four major areas of concern, which are listed below, along with observations regarding the concerns. It should be noted, however, that none of these criticisms by PB relates directly to the issue of the effects of High Rock Lake on possible increased water levels at Salisbury's facilities but rather to peripheral issues related to the details of the analysis by Salisbury's consultants. Doyle (SAL–6) subsequently responded to PB's criticisms (APGI–5).

- *The resolution of the topographic data used in Hazen and Sawyer's modeling, in particular the pre-dam conditions, does not justify Doyle's conclusions.*

In fact, Doyle reported water-surface elevations to the nearest 0.1 ft for future conditions. These numbers should be used with caution. Copeland (SAL–3), however, addressed the issue of uncertainty with regard to topography in the sediment-transport modeling, although the sediment-transport model did not address the effects of High Rock Dam on water levels at Salisbury's intake. Doyle (SAL–6) also noted that Stone & Webster's modeling (APGI–1) did not include an analysis of the sensitivity of model results to topographic elevations.

- *Doyle calculated the "design flow" of 121,000 ft^3/s at RM 15.2 rather than at the water-supply intake at RM 19.4.*

Doyle apparently used records collected at RM 15.2 to represent conditions at RM 19.4. The increase in drainage area between the two sites is about 90 mi^2, or less than 3 percent of the total drainage area. The at-station 100-year recurrence interval flow at RM 15.2 is 166,000 ft^3/s based on records collected during 1896–1927 (Pope and others, 2001), which is less than Doyle's "design flow." These issues, however, do not directly relate to the question of the effect of High Rock Lake on water levels at Salisbury's intake but rather to the magnitude of the effect of selected conditions (100-year flow, "design flow," etc.).

As an aside, the methods used by Doyle (SAL–4) and Copeland (SAL–3) may underestimate the 100-year flood at the confluence of the Yadkin and South Yadkin Rivers. Pope and others (2001) provide methods for estimating flood flows at ungaged sites. Greater use of at-station flood-frequency information for the Yadkin River at Salisbury and South Yadkin River at Cooleemee also may be helpful.

Doyle (SAL–6) asserts that inflows from Grants Creek would not affect peak flows measured at RM 15.2, because Grants Creek likely would peak before the Yadkin River. This argument is reasonable, although no data were provided to support this assertion for the particular case of the 1916 flood.

- *PB asserted that Doyle mischaracterized APGI's statements regarding causes for sediment accumulation in the reservoir.*

This criticism may be valid but is not relevant to the issue of effects of High Rock Dam on water levels at Salisbury's intake. APGI argued that sediment accumulation is caused, in part, by natural bends in the river and that channel constrictions from bridges contribute to flooding at Salisbury's facilities. As noted above (and by Doyle, SAL–6), however, the evidence presented by APGI to substantiate these claims is weak to nonexistent, at least in the documents available for review.

PB also indicated that Doyle did not present evidence that the river was in geomorphic equilibrium prior to 1927.

Indeed, Doyle did not present quantitative evidence for this assertion, although Copeland (SAL–3) apparently examined the stage-discharge relation for Yadkin River at Yadkin College and found the rating to be stable.

- *There is an issue related to Doyle's characterization of flooding at the Grants Creek wastewater pump station and the design of the pump station to account for possible flooding.*

This issue is unrelated to the effects of High Rock Lake on increased flooding at Salisbury's facilities.

One-Dimensional Sediment-Transport Modeling

A one-dimensional unsteady sediment-transport model was constructed "to evaluate the potential impact of continuing delta aggradation in the Yadkin River at the upstream end of High Rock Lake" (SAL–3). The objective of this study seems to presume that all of the sediment accumulation is directly attributable to the presence of High Rock Dam. The model was applied to evaluate four alternatives for reducing sedimentation at the City of Salisbury facilities near RM 19.4. The HEC–6T model, which is a proprietary version of the U.S. Army Corps of Engineers HEC–6 model, was used for the simulations.

Cross sections for the sediment-transport model were obtained from the Hazen and Sawyer HEC–RAS model, from light-detection and ranging (LiDAR) data, and from bathymetric survey data. Additional cross sections were surveyed between RMs 21.3 and 31.3, and these cross sections were assumed to be stable over the simulation period. The pre-impoundment river-bottom elevations used in the HEC–6T model were, however, adjusted upward from those used in the Hazen and Sawyer HEC–RAS model. Fairly extensive sediment inflow records were available for the inflow sediment model-boundary conditions. Sediment inflow rates for future conditions were assumed to be the same as those for historical conditions, but the sensitivity of model results to this assumption was evaluated. Assumptions regarding inflow hydrographs were required, and these assumptions seem reasonable, although a number of other approaches could have been used for estimating inflow scenarios.

The model was calibrated such that measured and simulated bed profiles for 1917 and 1997 were in general agreement. The model also was calibrated to water levels measured at RM 19.4 for selected events. The sensitivity of model results to changes in sediment inflows, the sediment-transport equation used in the model, and to variability in bottom elevation was evaluated. The model does not simulate natural adjustments in channel width; it has been noted elsewhere (APGI–7, SAL–3) that channel widths in the region of concern have changed over the last 70 years.

The model was applied to simulate the growth of the delta in the headwaters of High Rock Lake during 1928–97. Changes in water-surface elevations at the Salisbury facilities for three flow conditions as a function of changes in bed elevation are presented for the period 1920–2057.

Copeland's report (SAL–3) provides good documentation of the data and assumptions used to construct the model and provides a reasonable assessment of uncertainty in model results. The data, analyses, and simulations presented in the report add to current understanding of sediment transport and accumulation in High Rock Lake and the Yadkin River.

The report does not, however, address the issue of the relative effects of High Rock Dam on sediment accumulation, because the model was not applied to simulate conditions without the dam in place. The study also does not address the relative effects of the bridges on sediment accumulation in the upper reach of High Rock Lake. As a result, it provides much improved understanding of sediment transport and accumulation but no new information on the effects of High Rock Dam or bridges on sediment accumulation relative to what may have occurred naturally.

Copeland's report (SAL–3) was reviewed by David Williams (APGI–4). The review identified three major areas of concern regarding Copeland's sediment-transport modeling. Copeland and Thomas (SAL–5) subsequently responded to Williams' affidavit.

- *The base condition (or pre-impoundment condition) was not modeled, so the effect of High Rock Dam on sediment accumulation is not known.*

This is a valid criticism of Copeland's work, just as it is for the Stone & Webster (APGI–1) and FERC (FERC–3) hydraulic modeling. The actual increase in sediment deposition in the reach of the Yadkin River between High Rock Dam and RM 19.4 attributable to the presence of the dam cannot be determined from Copeland's original results.

As noted above, the objective of Copeland's work (SAL–3) was "to evaluate the potential impact of continuing delta aggradation in the Yadkin River at the upstream end of High Rock Lake." As a result of Williams' criticism, Copeland and Thomas (SAL–5) used their sediment-transport model to simulate sediment thalweg and water-surface elevations in the study reach for the pre-impoundment condition. Widths of the channel cross sections were set equal to original river bank widths, presumably determined from 1917 maps, and no erosion of bed or bank material was simulated in the model.

Comparison of the simulations for pre-impoundment and current (or base) conditions indicates that water-surface elevations for the 10-year flood are about 8 ft higher currently than would be expected if the dam were never constructed. Similar results are shown for other flood flows. Results also demonstrate temporal increases in water-surface elevation at RM 19.4 relative to the pre-impoundment condition as a result of the growth of the delta. Copeland and Thomas did not state whether their pre-impoundment model included bridges.

- *The sediment-transport model appears to have numerical instabilities when results are displayed for each computational time step.*

The computational time step used by Copeland was one day, except during high-flow events (SAL–3). Figures 1, 3, and 4 of Williams' report (APGI–4) show oscillations of about

6 ft in the bed elevation at RM 19.4. Similar oscillations are not evident upstream from RM 19.4. The largest oscillations (Williams' figs. 3 and 4) begin at about day 22,000 from the beginning of the simulations, which seems to correspond to sometime in the mid-1980s (although this is an estimate based on material presented in the reports). Oscillations appear to have an approximately annual frequency.

Copeland noted that his model simulated sand extraction at locations near RM 19.4 during 1965–84 and from 1988 to the end of simulation; sand was extracted in the model simulations at the end of each water year.[1] It seems likely that the oscillations in bed elevation presented by Williams are the result of the annual sand extraction in the model, particularly because the oscillations seem to be present at RM 19.4, where extraction occurred, but not at other nearby cross sections.

Copeland and Thomas (SAL–5) confirmed that the oscillations were indeed a result of dredging operations on thalweg elevation. Copeland and Thomas presented additional results to demonstrate that the model is not numerically unstable, citing guidelines from a U.S. Army Corps of Engineers training document containing guidelines for application of HEC–6.

Williams also pointed out that model results seemed unusual during the first 2 years of the simulation (Williams' fig. 2), in that there were large changes in bed elevation during this period.

Some numerical models require a "warm-up" period, because initial conditions cannot be known throughout the model domain. Therefore, this warm-up period is used to transport the estimated initial conditions out of the model domain before boundary conditions begin to affect model simulations throughout the model domain. Simulation results normally are not considered useful during this warm-up period.

Copeland did not address the issue of initial conditions, a warm-up period, or the bed-elevation changes during the first 2 years of simulation in his original report (SAL–3). Copeland and Thomas, however, confirmed in their response to Williams' affidavit that these changes were a result of model "warm-up" (SAL–5).

Other Studies

Normendeau Associates, Inc., and PB Power prepared a report on sediment fate and transport in the Yadkin-Pee Dee River basin (APGI–7). The report provides a comprehensive review of literature on sediment transport in the Yadkin River basin. Although the material in the report is quite interesting and well documented, most of the information is not directly relevant to the question of the effects of High Rock Dam on water levels at RM 19.4. The study presents a comparison of the 1917 bathymetry with 1997 topography in the upper 12 ft of the reservoir, although a full bathymetric survey of current conditions has not been completed. Sedimentation patterns also were analyzed by comparing the 1917 and 1997 topographic maps. The report notes "the deepest portion of the river has narrowed" from the I–85 bridge upstream to the confluence of the Yadkin and South Yadkin Rivers.

Doyle (SAL–4) presented an overview of reservoir sedimentation processes. A time series of aerial photographs of High Rock Lake also was provided, and Doyle discussed sedimentation patterns and the growth of the delta in the upstream end of the reservoir. The riverbed profile also was reconstructed for pre-impoundment and 2000 conditions. This discussion provides a useful documentation of sedimentation in High Rock Lake. The discussion by itself, however, does not unequivocally demonstrate that High Rock Dam is responsible for all or part of the sedimentation. Doyle's arguments, the aerial photographs, and a general understanding of river morphology could lead one to conclude that sedimentation in the portion of the Yadkin River that is now the upper end of High Rock Lake has increased as a result of High Rock Dam. The amount of increase attributable to the presence of High Rock Dam and to the bridge abutments in the reach, respectively, has not been quantified through either Doyle's presentation or Copeland's modeling.

Doyle asserted that the Yadkin River was in morphological equilibrium prior to 1917 and continues to be in equilibrium, meaning that the overall sediment deposition and erosion in the river is in general balance with the sediment supply. Doyle offered no quantitative evidence of this assertion. Cross sections measured at USGS gaging stations (Yadkin River at Salisbury at about RM 15.2 and Yadkin River at Yadkin College) could be examined to document changes in the river geometry at measurement sections for both pre-impoundment and post-impoundment periods, although the channel width at these cross sections may be constrained by bridge abutments. Given the known sediment-legacy issues in the basin (extremely high sediment loads in the past; somewhat lower loads currently), the assumption of morphological equilibrium seems to require greater support than what was offered in SAL–4.

Summary and Further Analyses

The following primary conclusions resulted from this review:

- The hydraulic models of Stone & Webster and FERC did not assess the effects of changes in bathymetry on changes in flood levels at the confluence of the Yadkin and South Yadkin Rivers. In other words, pre-impoundment conditions were not simulated, so the effect of High Rock Dam and post-impoundment sedimentation on water levels at RM 19.4 cannot be evaluated from these studies.

[1] Water year is the period October 1 through September 30 and is identified by the year in which the period ends.

- The hydraulic modeling performed by Hazen and Sawyer seems to indicate that both the presence of the dam in the absence of any post-impoundment sedimentation and changes in bathymetry between pre-impoundment and 1997 conditions have resulted in increased water levels relative to pre-impoundment conditions at Salisbury facilities on the Yadkin River for a fairly wide range of flows.

- The degree to which the dam and the changes in bathymetry have affected flood levels at the Salisbury facilities relative to pre-impoundment conditions is open to discussion because of uncertainty in topographic/bathymetric data and the absence of calibration and sensitivity testing of the hydraulic models.

- None of the three hydraulic models appears to have been calibrated to or tested against measurements, and no sensitivity testing was reported.

- Copeland's sediment-transport model was calibrated to estimated bed elevations and to water levels at RM 19.4. The model is well documented (except for issues related to initial conditions and possible numerical instabilities) and provides a good understanding of the expected growth of the sediment delta in the upper end of High Rock Lake.

- In a response to criticism from APGI, Copeland and Thomas simulated thalweg and water-surface elevations for the pre-impoundment condition and seemingly demonstrated that the presence of the dam and the growth of the delta have resulted in increases in water-surface elevations at RM 19.4 over a range of flows, and that these increases are expected to increase through time if current conditions remain unchanged.

Further analyses and studies to improve understanding of the relation of High Rock Lake to sedimentation in the lake and changes in the flood regime in the upper part of High Rock Lake include the following:

- Several elevation datums are used in the various documents, including the Yadkin datum, "USGS datum," NGVD 29 datum, and some datums that are unspecified. This leads to a good bit of confusion in interpreting results from the reports. All parties should agree that elevations will be referenced to the current standard North American Vertical Datum of 1988 (NAVD 88).

- A detailed bathymetric survey of High Rock Lake and the Yadkin River from High Rock Dam to 20 mi upstream from the dam would provide the correct information needed for hydraulic (and sediment-transport) modeling of the reach for current conditions. Detailed topographic data of the region are available from the North Carolina Floodplain Mapping Program at *http://www.ncfloodmaps.com/default_swf.asp* .

- The current bathymetry and topography could be combined to generate realistic channel cross sections for hydraulic modeling of current conditions. Pre-impoundment conditions have been simulated by Hazen and Sawyer, although some clarification and documentation of their approach is needed.

- Copeland's model could be used to simulate sediment accumulation as a result of the presence of bridges. Sediment accumulation attributable to the dam and to bridges then could be distinguished from what may have occurred for a natural condition.

- In the absence of realistic bathymetry for current conditions, a sensitivity analysis could be performed to determine the effects of changes in channel cross sections and slope on final results. A sensitivity analysis for pre-impoundment conditions, for which it is not possible to know channel cross sectional geometry, could be conducted. Likewise effects of bridges could be evaluated for current and pre-impoundment conditions.

- Cross sections measured at USGS gaging stations (Yadkin River at Salisbury at about RM 15.2, South Yadkin River at Cooleemee, and Yadkin River at Yadkin College) could be examined to document changes in the river channel for both pre-impoundment and post-impoundment periods.

- Sediment-coring and age-dating methods on both the bed and the floodplain could be investigated as a means to evaluate sediment throughout the reaches of interest for both the post- and pre-impoundment periods. It may be possible to estimate accumulation rates for both pre- and post-impoundment conditions. It also may be possible to estimate geomorphic equilibrium conditions prior to and following dam operations and the effect of the legacy sediment on current morphological conditions.

- Flood data from current and discontinued gages could be examined to determine if a change in the flood-flow regime has occurred. Improved estimates of flood-recurrence intervals could be obtained by using the methods of Pope and others (2001) and historical at-gage flood frequencies.

References

Pope, B.F., Tasker, G.D., and Robbins, J.C., 2001, Estimating the magnitude and frequency of floods in rural basins of North Carolina—Revised: U.S. Geological Survey Water-Resources Investigations Report 01–4027, 44 p.

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