Water Quality and Stream Macroinvertebrate Conditions in Reaches of the South Fork Rivanna River Downstream of the South Fork Rivanna Reservoir – Initial Findings

Prepared by StreamWatch for Rivanna Water and Sewer Authority
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1) Project background; scope of work

StreamWatch is an ecological monitoring program supported and governed by a partnership of organizations and agencies involved in the utilization, management and conservation of Rivanna River basin streams and rivers. Per StreamWatch's charter, the program's ultimate purpose is "to help maintain and improve the health of streams and rivers in the Rivanna basin. Many organizations and agencies share this goal, and a key principle of StreamWatch is the recognition that conservation is a community effort." Rivanna Water and Sewer Authority is a leading partner and funder of the program.

StreamWatch pursues its goal by providing the community with high-quality scientific data and information. StreamWatch's data collection capacity is enhanced through the contributions of trained volunteers, and StreamWatch offers its services to the community at costs well below commercial rates. StreamWatch is a public program; all StreamWatch data and information products are available to all partners and to the general public.

StreamWatch maintains a core program of biological monitoring at 32 sites throughout the Rivanna watershed. The core program generates synoptic information about the Rivanna basin, and the core program's long-term, comprehensive dataset supports better understanding of conditions at discrete sites and within limited time-frames.

In addition to the core program, StreamWatch provides by-request services to program partners. In summer 2005, Rivanna Water and Sewer Authority (RWSA) requested StreamWatch monitoring services to address water quality questions related to the anticipated restart of the hydropower facility at South Fork Rivanna Reservoir. RWSA's purpose is to assess the ecological effects of hydropower generation and to better understand the potential environmental effects. This report presents initial findings and recommendations for further monitoring should RWSA elect to extend the project.

2009 Update: Based upon the initial findings presented by StreamWatch in this paper, RWSA installed a continuous real time monitoring probe at the discharge end of the hydroplant. Parameters recorded include pH, temperature, and dissolved oxygen. RWSA water resources staff is working to design additional studies to conclusively determine the impact of hydropower generation on the benthic invertebrate community.

2) Data collection

Biological and ambient water quality samples were collected at eight sites downstream of the reservoir from late summer 2005 through spring 2006 (see accompanying data file). Six of the sites were located in an approximately 1-kilometer reach extending from the dam to a point downstream of the Route 29 Bridge. One site was located at the South Fork Soccer Park, approximately 3 kilometers downstream of the dam, and the most distant site was located near the confluence of the North and South Forks of the Rivanna, approximately 5.5 kilometers downstream of the dam.

Benthic macroinvertebrate samples were collected in riffle areas. A 1500 micron mesh kick net was used to collect a target number of 200 organisms per sample. Specimens were identified to the family level and samples were interpreted via the Adapted Stream Condition Index—a multimetric index of biological integrity developed by the Virginia Department of Environmental Quality and adapted by StreamWatch. Dissolved oxygen and temperature measurements were taken with a Yellow Springs Instruments model 58 dissolved oxygen meter owned and maintained by RWSA. The meter was calibrated before and during each field session by RWSA staff.

StreamWatch and RWSA staff worked side-by-side to collect all field data, with the exception of 1 of 11 biological samples, which were collected by StreamWatch staff or volunteers.*

**Benthic data from core program sites are included in this analysis. Core program data costs were funded from the core program, and were not charged to this specific project.*

3) Findings and discussion

3.1 – Zones

In the illustration below, the reservoir and dam are situated to the upper left, and the river flows to the lower right. Based on field observations and sampling point results to date, four water quality zones were identified: Zone A, outlined in red, is located immediately downstream of the hydropower facility. It is limited to the right side of the river and extends to approximately 100 meters downstream of the hydropower plant and 150 meters downstream of the dam. Zone B is the area immediately downstream of the dam. It parallels Zone A, but occupies the middle and left portions of the stream. Zone C commences at the terminations of Zones A and B, and extends at least 1 kilometer downstream of the dam. Zone D, not pictured, extends from the termination of Zone C downstream to the confluence with Powell Creek (about 3.5 kilometers downstream of the dam).

Figure 1. South Fork Rivanna River between reservoir and Route 29

Kilometers (approximate)

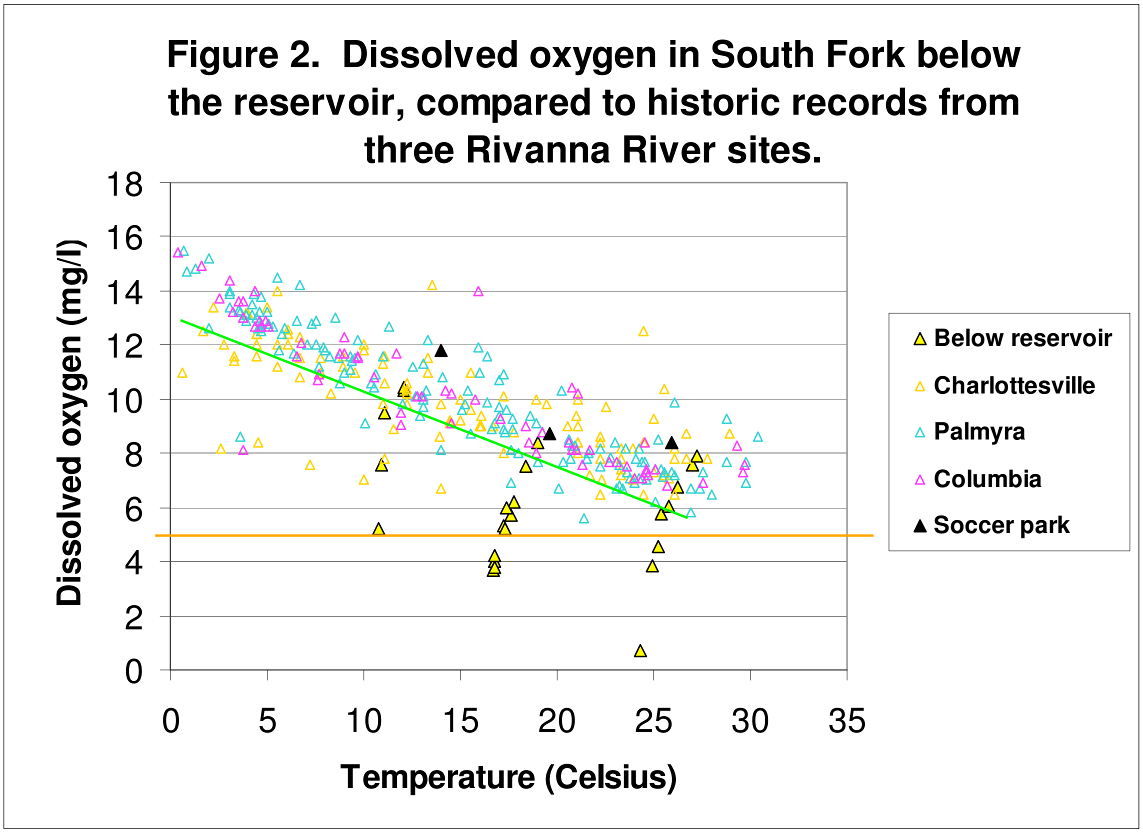
0 0.3 0.6 0.9

The zones represent approximate areas of differing water quality variously influenced by dam and hydropower operations. When data were gathered for this study, Zones A and B were dominated by flows from the hydropower plant and the dam, respectively. As discussed in section 3.3 below, Zone A waters were frequently oxygen-depleted, with dissolved oxygen measurements ranging from 3.7 to 9.5 mg/l. Waters flowing over the dam into Zone B were well oxygenated. Zone C was a mixing zone, receiving waters from Zones A and B. Zone C terminates (and Zone D begins) at an unknown point where waters become fully re-oxygenated.

All the zone boundaries are coarsely estimated. Further, inasmuch as they represent areas of differing water quality, the zones' dimensions probably vary with season and operations.

3.2 – Dissolved oxygen and temperature

Figure 2 below allows a comparison of recent dissolved oxygen/temperature (DO/TEMP) measurements in the study area against historic DO/TEMP measurements collected by Virginia Department of Environmental Quality from other sites on the Rivanna River. Absent of biochemical influences, DO concentration in wadeable Piedmont streams is largely a function of temperature. As shown in the figure, DO falls as temperature rises. Biological and chemical processes cause DO to fluctuate within ranges constrained by temperature.



The swath of clustered data points in Figure 2 indicates the normal range of variability observed at three Rivanna River sites over 38 years. The green slanted line is assumed to be the approximate lower limit of the natural range of DO in the Rivanna mainstem for given temperatures. The orange horizontal line marks the Virginia standard for 24-hour average DO (5 milligrams per liter). The historic DEQ data are indicated with unfilled yellow, blue, and red triangles, and data collected downstream of the dam for this report are indicated with solid yellow triangles. It is readily apparent that during the study period, DO in portions of the river below the reservoir fell below normal levels and below the state standard. It should be noted that the sampling point with the DO below 1 ppm was directly downstream from the hydropower plant, at the effluent outlet. The hydropower plant was not operational at the time, but data was collected at a shallow pool that was generated by the designed slow release of water through the wicket gates for flow control, and is not within the free flowing portion of the stream.

Figure 3. Dissolved oxygen in South Fork below the reservoir.

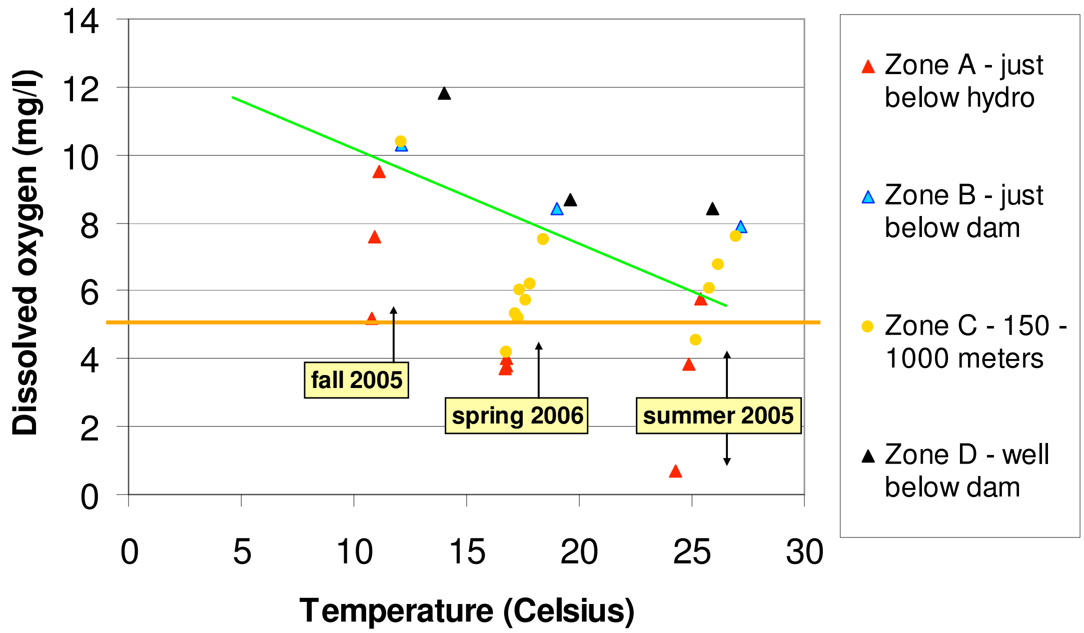


Figure 3 gives a closer view of the data collected for this inquiry. The “normal” and “standard” bars are included, as in Figure 2. The timing and location of DO levels can be discerned in the graph: data points are color-coded to indicate zones, and the data naturally segregate into vertical bands along the temperature axis according to the season during which the data were collected.

Zone A, the limited area at river right just below the hydropower plant, was frequently fed by water flowing from the south mudgate and also by the designed slow release of water through the wickets of the hydropower facility. Zone B, the limited area at midstream and river left just below the dam, is fed by water spilling over the dam. The north mudgate would deliver water to this zone if opened, but it remained closed during each of this inquiry’s field sessions.

The great majority of measurements taken in Zone A show dissolved oxygen below the Virginia 24-hour standard of 5mg/l, while all measurements taken in Zone B show dissolved oxygen within the normal range. Temperatures in Zone A were 1 to 2 degrees lower on the Celsius scale than in Zone B. In summer 2005 substrate in Zone A was thickly covered with iron oxide precipitate, a phenomenon that occurs when deoxygenated water rich in iron ions is exposed to oxygen, resulting in the formation and deposition of iron oxide. The water quality data and presence of precipitate could indicate that reservoir waters were stratified and that waters flowing from the hydropower facility and mudgate were hypolimnetic. In summer 2005 and spring 2006 the stratification was pronounced, and DO levels in Zones A and B differed sharply. In fall 2005 the differences were less dramatic.

Earlier in the inquiry—in summer and fall 2005—the hydropower plant was non-operational and the designed slow release of water through the wicket gates for flow control had low DO content (0.7 mg/l in summer, 5.2 mg/l in fall). Water flowing from the mudgate was not as severely deoxygenated. In spring 2006, the hydropower plant was operational, flow from the plant was strong, and DO was low (<4 mg/l).

In Zone C, the mixing zone, results were variable, with oxygen levels apparently affected by an interplay of seasonal conditions and operations (see discussion in Section 3.4). In summer 2005, iron oxide precipitate was evident in the "river right" portion of this zone.

Measurements were taken at only one site within Zone D. On each of three occasions, dissolved oxygen fell within the normal range.

3.3 – Benthic macroinvertebrate communities

The Adapted Stream Condition Index represents benthic community health on a 100-point scale, with higher being better. Health categories are associated with ranges of index scores as shown in the table to the left. However, formal StreamWatch health assessments are based on average and minimum scores from multiple samples. The index, borrowed from the Virginia Department of Environmental Quality, is less accurate in 6th order streams such as South Fork Rivanna than in smaller streams. Benthic results for this report are presented with moderate but not high confidence.

Ranges of biological index scores associated with health tiers. Assessments are based on average and minimum scores from multiple samples.

Adapted Stream Condition Index score	Health
61.3 and over	Very good
55.1 - 61.2	Good
40.0 - 55.0	Fair
25.1 - 39.9	Poor
0.0 - 25	Very poor

Table 1 at the end of this report provides biological condition of the sites and zones. Results were poorest immediately downstream of the hydropower facility (Zone A), with health rated as very poor. In the area immediately below the dam (Zone B), conditions were somewhat better, with health rated as poor. In Zone C, the mixing zone, biological condition was poor to fair. Variation in this zone may correspond to intra-zonal locational variation, with poorer conditions at river right—the area most influenced by flow from Zone A. Biological health in Zone D is rated as poor, based on samples taken from a site adjacent to the South Fork Soccer Park.

Particle size distributions that potentially affect biota were fair to good at all sampling locations. However, in Zone A, iron oxide precipitate formed fine particles that were sufficiently prevalent to constitute a negative habitat factor. In the author's opinion, in-stream habitat quality at all other benthic sampling locations did not significantly affect benthic scores.

For the sake of comparison, Table 1 also provides benthic results during the study time period for six Rivanna River sites downstream of the study area.

3.4 – Discussion and recommendations for future study

Along with benthic conditions, Table 1 provides summary DO conditions for the sites and zones, with DO expressed as *percent saturated*. Percent saturated is calculated by dividing measured concentration by the saturation concentration for pure water at the given temperature. This expression of DO allows quick comparison of conditions regardless of season and temperature. Consideration of data from the percent saturated perspective may also facilitate better understanding of biotic requirements: Aquatic organisms are evolutionarily adapted to a range of DO conditions that vary with season, temperature, and other factors, and a DO concentration that meets regulatory standards but falls below the natural range of saturation may be insufficient for biota.

Imprecision in field measurements contributed to error in calculations of percent saturation values. The error does not diminish the quality of DO data with respect to actual DO levels, nor does it diminish confidence in this report's conclusions about relative percent saturated values among sites and zones. As with straightforward DO concentration, low percent saturated values occur in Zone A. In Zones B and D, DO conditions appear to be normal.

Percent saturated values vary widely in Zone C, depending on whether or not the reservoir is stratified, and, if stratified, on dam and hydropower operations. When the volume of hypolimnetic water released through the mudgate or hydropower plant is small relative to dam overflow, low DO in Zone C may be limited to a few hundred meters downstream along the right side of the river. As the volume of hypolimnetic release increases, so also do the dimensions of the low DO area in Zone C. In spring 2006, the hydropower plant was operational and hypolimnetic flow appeared to constitute about 80% of total flow through and over the dam. In this setting, with the exception a small area immediately adjacent to Zone B, DO in Zone C was subnormal across most of the width of the river to a distance of at least 1 kilometer downstream of the dam.

Biological conditions in the entirety of the South Fork Rivanna River below the dam were significantly degraded. Degradation was not limited to the low DO areas, and extended through and past Zone D to the confluence with North Fork Rivanna. Over a three-year period ending in fall 2005, biological health at the terminus of South Fork was consistently poor. Though well-oxygenated on each of 3 field visits, Zone B had poor benthic health. (It is possible that Zone B received hypolimnetic water from the north mudgate during the period of inquiry; the field measurements consisted of only 3 "spot checks.")

It is likely that hypolimnetic releases contribute to some degree to benthic degradation in Zones A and C, and possibly also in Zone B. But considering that areas probably well downstream of the mixing zone are also degraded, it appears that additional significant stressors are involved in benthic degradation. Speculatively, these may include high concentrations of algae in reservoir water, and general flow perturbation associated with dam and hydropower operations. Further downstream, beyond Zone D and downstream of the South Fork Soccer Park, the river receives the waters of Powell Creek which StreamWatch and DEQ monitoring show to be significantly impacted, likely due to intensive residential and commercial development.

The biological condition of South Fork contrasted with the remainder of the Rivanna River, which was generally fair from Darden Towe Park to the James River. It is unsurprising that reaches of the South Fork Rivanna below the reservoir show biological and water quality degradation. As with many waterways downstream of dams, the degradation in the South Fork Rivanna is likely caused by water quality and flow changes related to impoundment and water supply management. Hydropower generation may or may not cause ecological changes beyond those already caused by the dam. To best determine the focus of further study, RWSA should consider both water quality goals and operational constraints. Ideally, future study should be conducted after a range of possible desired future conditions is compared with management options. This exercise would reduce the universe of possible study designs

Hypolimnetic releases are not limited to the hydropower plant; they occur also through the mudgates. The purposes of mudgate releases include reservoir sediment management, dam safety in the form of reservoir drainage prior to large storms, and maintenance of minimum flows per regulatory requirements and ecological best management practices. To the extent mudgate releases are needed for these and other purposes, options for minimizing hypolimnetic releases may be limited.

It is not yet clear whether hydropower generation produces significant increases in the frequency, duration, volume, and severity of hypolimnetic releases beyond those issuing from the mudgates. It is still unclear whether or not the hydroplant releases have benthic invertebrate impact. Finally, if it could be determined that hydropower-related biological impact was significant, managers may wish to weigh this impact against the financial and ecological benefits of local non-fossil fuel power generation.

Following are recommended elements of future study, assuming RWSA determines that sufficient options exist to warrant study:

A) Determine the downstream extent of the mixing zone in various seasons and operational settings. This would best be achieved through longitudinal surveys with a field DO meter. The surveys should be conducted under controlled conditions, with minute-by-minute communications between the field crew and dam operators. A mixing zone would only exist when the dam is spilling water.

B) Place an additional (second) in-stream DO meter after the above-described longitudinal surveys have been conducted. The most useful placement of the meter would be towards the downstream end of the mixing zone, but that location cannot be estimated until the surveys have been completed.

C) Continue to collect information on downstream conditions in order to characterize potential impacts and evaluate operational parameters.

D) To evaluate instrument precision, compare the output of RWSA’s dissolved oxygen meter against other reliable instruments.

E) High levels of algae in water spilling over the dam may be contributing to benthic degradation by supplying excess food to opportunistic filter-feeding taxa. To determine the degree to which reservoir algal levels exceed Rivanna River background levels, water samples from several stations on the South Fork Rivanna River should be compared with data from stations further downstream on the Rivanna River. The sampling should be conducted with particular focus on seasons of high algal production.

F) Pursue additional academic research using the historical record to analyze the natural range of DO saturation in the Rivanna River. Combine this analysis with modest research of scientific literature to develop percent saturated benchmarks and objectives for the impact area. The literature reviewed should include Mr. Graham Bond's undergraduate course paper on South Fork Reservoir releases.

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Table 1. Biological and dissolved oxygen conditions at sites and zones in the South Fork Rivanna River. Dissolved oxygen data are given in terms of percent of saturation value.

ZONE	Descrip-tion	DO condition of sites (percent saturated)					Biological condition of sites						DO condition of zones (percent saturated)					Biological condition of zones		
		SITE ID	n	Avg	Min	Max	StreamWatch benthic station name (provisional)	n	Avg	Min	Max	Health	ZONE	n	Avg	Min	Max	n	Avg	Health
A	just ds of hydro	D&H-A-1	3	67%	40%	90%							A	9	50%	10%	90%	2	21.0	Very poor
		D&H-A-2	3	32%	10%	50%														
		D&H-A-3	3	52%	40%	70%	South Fork immediately downstream of hydro plant	2	21.0	14.5	27.5	Very poor								
B	just ds of dam	D&H-B-1	3	97%	90%	100%	South Fork immediately downstream of dam	3	33.9	32.3	36.3	Poor	B	3	97%	90%	100%	3	33.9	Poor
C	mixing zone, ds of zones A and B, ends ~1 km ds of dam	D&H-C-1	1	61%	60%	60%							C	12	70%	40%	100%	3	44.3	Poor to fair
		D&H-C-2	2	64%	40%	80%														
		D&H-C-3	2	77%	60%	100%														
		D&H-C-4	2	89%	80%	100%	South Fork 1/4 mile downstream of dam, middle	2	48.0	44.0	52.0	Fair								
		D&H-C-5	2	66%	60%	80%	South Fork 1/4 mile downstream of dam, right	1	36.8	36.8	36.8	Poor								
		D&H-C-6	2	65%	60%	70%														
		D&H-C-7	1	55%	60%	60%														
D	ends at Powell	D&H-D-1	3	106%	100%	120%	South Fork @ soccer park	3	43.0	30.9	55.8	Poor	D	3	106%	100%	120%	3	43.0	Poor
Down-stream	main-stem Rivanna River from Powell Creek to James River						South Fork @ Forks of Rivanna	4	49.3	17.6	66.0	Poor	Down-stream					25	57.4	n/a
							Rivanna @ Darden Towe	4	59.4	38.5	72.5	Fair								
							Rivanna @ Milton	5	53.9	41.4	60.3	Fair								
							Rivanna @ Crofton - A	4	58.6	51.8	68.3	Fair								
							Rivanna @ Palmyra	4	68.3	61.8	74.3	Very good								
							Rivanna @ Rivanna Mills	4	55.9	49.7	62.5	Fair								