Dissolved Gas and Fishery Investigations at Ridgway Dam – Phases 1, 2 and 3 Report

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Dissolved Gas and Fishery Investigations at Ridgway Dam – Phases 1, 2 and 3 Report

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TABLE OF CONTENTS

EXECUTIVE SUMMARY

A brief summary is presented of the report "Dissolved Gas and Fishery Investigations at Ridgway Dam – Phases 1, 2 and 3 Report." Gas bubble trauma (GBT) in fish has been documented in the river below Ridgway reservoir for many years. Nitrogen gas levels have also been documented in the river since 1998. A dissolved gas survey in the reservoir was conducted as a part of this research project in June 2003. This report provides a compilation and analysis of historical and recent dissolved gas and temperature data with recommendations for possible solutions and is the final product of phases 1, 2 and 3 of the Science and Technology Research Project No. 581.

The investigations regarding gas bubble disease in the fish are included in the fisheries section of the report. The fisheries information includes background of the historical fisheries data collection and stocking in the tailrace below Ridgway reservoir and results of the survey conducted in March 2003. The collecting of the historical information on the fisheries of the Uncompahgre River is an ongoing process, with further data expected from the Colorado Division of Wildlife records in the future.

The fisheries survey conducted in March 2003 showed a percent occurrence of GBT (based on external examination of the species present) to range from 48% (Snake River Cutthroat) to 21% (Colorado River Cutthroat). Detailed gas measurements taken within the electrofishing survey transect showed a drop in saturation levels immediately below all but one of the habitat improvement structures.

The dissolved nitrogen levels in the river are a function of both the reservoir gas levels and potential production by releases. The levels are high immediately downstream from the structures then decrease to potentially acceptable levels downstream with the installed habitat improvement structures and the normal river gradient. The one reservoir dissolved gas survey shows that the dissolved gas level in the reservoir at the level of the release intake and the level measured below the outlet works was similar. This could mean that the outlets are simply passing the reservoir gas level or that the highest dissolved gas measurement was missed. The one set of reservoir dissolved gas profiles taken in June show that the levels entering the reservoir are somewhat high and that the reservoir is stratified with gas levels worse near the bottom at the intake elevation.

Possible solutions for reducing the supersaturated dissolved nitrogen gas levels:

- Construct a gas stripping rock weir across a river section downstream from the bypass and outlet works release area to reduce gas levels to 110 percent when either structure is operating.
- Modify the outlet works and bypass structures separately by:
    - Preventing the outlet works releases from plunging by raising the floor or adding deflectors to force skimming flow.
    - Modify the bypass pipe to discharge into a rock cascade on the bank adjacent to the current release point to strip gas before the flow enters the river.
- Construct a gas stripping weir in the river upstream from the reservoir to decrease the gas levels entering the lake to near saturation.

- Construct a power plant to pass reservoir gas levels downstream without further increasing gas production with an upstream modification or a reservoir selective withdrawal system to ensure year-round gas level compliance.
- Install a selective withdrawal system in the reservoir to withdraw from a layer with reduced gas level in the lake. Selective withdrawal may create other temperature or dissolved oxygen issues that would need studying. This would need to be coupled with an upstream or downstream modification to ensure compliance.

If further data are desired to continue monitoring the problem or verifying the effectiveness of a modification then the following is recommended:

- Investigate installing a permanent TDG monitor at the USGS site. Prior to installing a monitor at this site, or any other site, the river cross section should be checked to determine if the velocity and TDG levels are uniform across the width.
- Perform a test program over a wide range of flows while carefully measuring upstream and downstream TDG levels.
- If continuing to monitor with hand-held devices;
    - Be consistent with depth and measurement locations. Ensure the measurement is taken where the flow is fully mixed or find the maximum reading downstream from the bypass and outlet works, probably by performing a transect of the cross sections where measurements are taken. Make sure instrument is calibrated and submerged when taking the readings.
- Understand GBT downstream distribution (longitudinal extent and severity) by expanding sampling effort downstream through cooperative effort with the CDOW.
- Monitor variance between years by species, size, reach, and operations.
- Develop methodology to quantify internal manifestations of GBT in fish.
- Plan mitigation or rehabilitation strategy for fish if problem persists.

ACKNOWLEGMENTS

This report was prepared for Reclamation's Western Colorado Area Office (WCAO) under a Service Agreement that was funded by Reclamation's Science and Technology Program. Glenn Stone and others in his office provided guidance of the scope of work and review comments. Rocky Dial, Civil Engineering Technician, from the Western Colorado Area Office, Northern Division, has collected and provided the dissolved gas data and assisted with coordination. Dan Kwolski of the Colorado Division of Wildlife (CDOW) and Trout Unlimited has collected fisheries data and is continuing to provide assistance with collecting fisheries data. In addition, the Tri-County Water Irrigation District has provided assistance on site.

Juddsen Sechrist, Research Associate, in the Fisheries Application Research Group of the TSC is assisting Steve Hiebert in fisheries data collection, analysis and reporting. This document was peer reviewed by a consultant, Mr. Perry Johnson, retired Reclamation employee from the Water Resources Research Laboratory.

BACKGROUND

An ongoing program of spot checking the levels of dissolved gas below Ridgway reservoir has been performed since 1998 in order to understand the cause of possible elevated levels of dissolved gas below the outlet of Ridgway Dam. Levels of dissolved gas (specifically the nitrogen portion) above the EPA standard of 110 percent are documented as detrimental to fish. An initial examination of the dissolved gas data collected since 1998 by Dr. Robert White of Montana State University (White 2000) indicated variation in dissolved gas levels over time downstream from the outlet works. In addition, a fisheries survey conducted below the dam in April 2000 indicated some evidence of gas bubble trauma in a few fish. The significance of the incidence of gas bubble trauma was not determined by White and he recommended that a series of flow tests be performed to determine a relationship between discharge from the outlet works, the outlet works bypass, spillway, and reservoir dissolved gas levels. This report is provided as the product for the first three phases of the service agreement between the Western Colorado Area Office and the TSC to accomplish work funded by Reclamation's Science and Technology Program.

OBJECTIVE

The objective of this research is to define, recommend, and investigate solutions to the dissolved gas and fishery issues below Ridgway Dam on the Uncompahgre River. There were five phases defined to perform the work:

- Gather information and assess the problem.
- Perform flow tests.
- Analyze data and make recommendations for possible operational or structural modifications in a progress report.
- Perform hydraulic modeling to investigate structural modifications, if necessary.
- Provide results of modeling and perform post-structural modification verification testing and reporting.

The tasks under these work phases will be performed jointly by WCAO staff and Steve Hiebert and Kathy Frizell from the TSC.

RIDGWAY DAM

The dam construction began in 1978, was completed in 1987, and filled in 1990. Ridgway Dam is a 227-ft-tall embankment dam with an outlet structure intake at El. 6741 (1) and a morning glory spillway (2). Each structure discharges into a separate hydraulic jump stilling basin downstream from the dam, figure 1. The maximum reservoir water surface is 6879.9 under which the outlets have a capacity of 1380 ft^3/s and the spillway a capacity of 9028 ft^3/s. There is also a small flow bypass pipe with a 20 in jet-flow gate with a discharge capacity of 100 ft^3/s. The bypass originally exited along the left side of the outlet works stilling basin wall. The bypass structure is the primary method used for releases during the winter. The outlet works are generally used during the spring runoff period and throughout the irrigation season. The spillway is rarely used and an informal agreement exists between Reclamation and the Colorado

Division of Wildlife (CDOW) to keep the reservoir below the spillway crest level to prevent entrainment of fingerling kokanee into the spillway inlet.

Figure 1. – Downstream view of Ridgway Dam outlet works and spillway stilling basins and a short section of the river. The bypass pipe has been relocated into the left side of the narrow channel just downstream from the outlet works stilling basin.

The geometry of the bypass, figure 2, shows that an air vent is present downstream from the jet flow gate. Air is drawn into the pipeline downstream of the gate by the high velocity flow and is needed to prevent cavitation damage to the steel pipe. The aerated flow travels a short distance along the invert until meeting with the tailwater and plunging.

In 1996, recommendations were made to clean out and repair the basin. To prevent reoccurring problems of material moving upstream into the basin, the riprap slope downstream from the basin was removed and clean material was reinstalled (3). The bypass pipe was modified at that time to meet downstream flow requirements while the riprap was cleaned and the while the damage to the outlet works was being repaired. The 30-inch-diameter pipe was angled to the left shore downstream from the jet flow gate and extended about 150 ft downstream from the basin to discharge at the top of the stilling basin exit channel slope, figure 3. A standpipe was installed just upstream from the bypass exit to release some of the air in the pipe. Releasing air would prevent violent surging which could cause damage to the bypass pipe and reduce icing problems that had been experienced in the past. It was also hoped that less air would be introduced to the flow potentially causing gas transfer to the downstream river. Figure 4 shows a discharge of about 45 ft^3/s from the bypass near the surface of the outlet works exit channel and that highly aerated flow is still present.

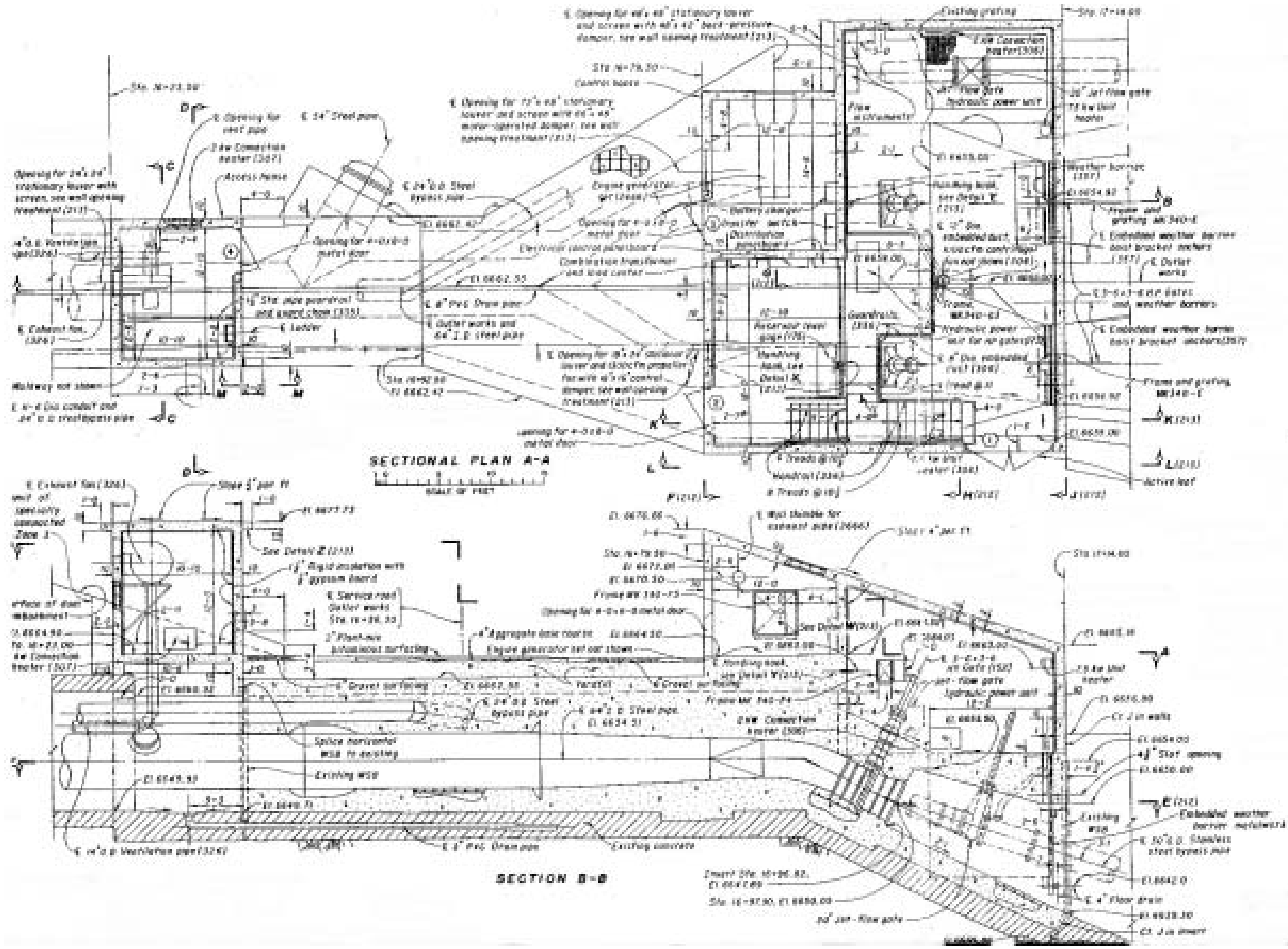

Figure 2. - Sectional plan and section of the bypass pipe geometry for the Ridgway outlet works. The bypass is frequently used for all discharges up to 100 ft^3/s and discharges to the left and downstream from the outlet works stilling basin.

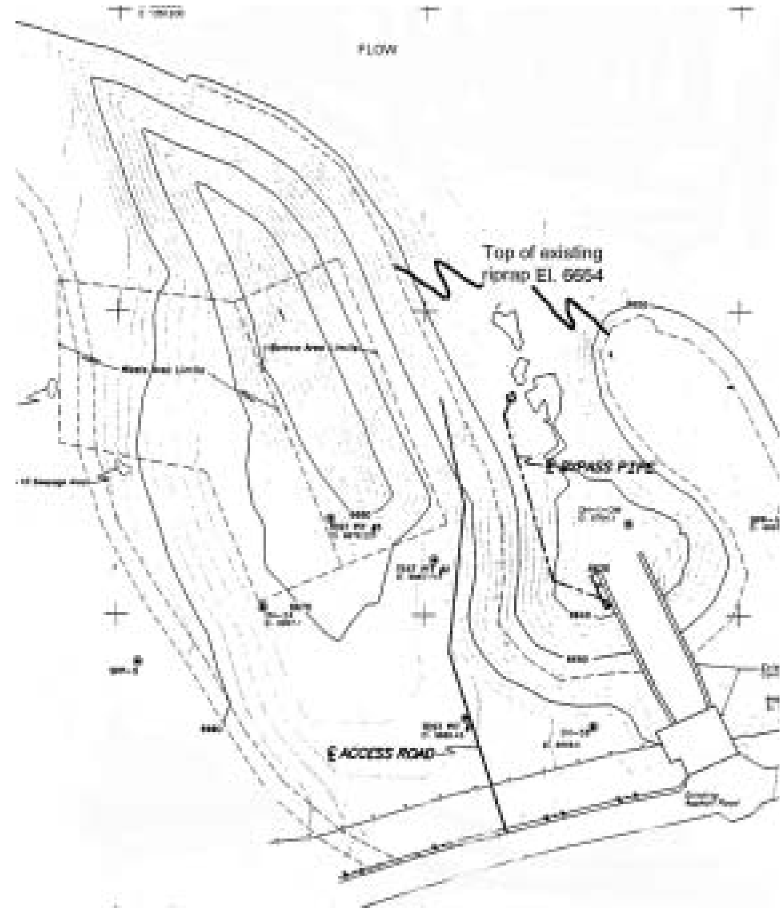

Figure 3. - Plan view of the modified bypass alignment that was constructed in 1996.

Figure 4. - Close up view of the bypass pipe exit. A standpipe is located on the very left side of the picture. The standpipe was installed to allow air to escape from the flow.

DISSOLVED GAS INVESTIGATIONS

The following sections discuss the dissolved gas data from the river and reservoir. In addition, reservoir water quality and temperature is discussed in relation to their affect on dissolved gas levels. Finally, predicted gas levels for the outlet works are presented.

Analysis of Existing Dissolved Gas Data

Dissolved gas data have been gathered using handheld saturometers downstream from the dam for many years. Ken Weston transmitted approximately monthly gas data from November 3, 1998 to March 28, 2002 for evaluation (4). Also included in the package was a map of the river section for about 1 mile below the dam and photographs of the river sections where the data were gathered. Figure 5 shows photographs of measurements being taken at the bypass, USGS, Big Rock, and Kiva stations. These were typical of the measurement stations and the shallow flow in the river for a discharge of 45 ft^3/s. However, it should be noted that the measurement taken at Big Rock is in swift-moving water and at Kiva in a pool. This could have an influence on the resulting dissolved gas level. Figure 6 shows the eight historic and eight additional sites in March 2003 where river sampling has occurred. In addition, figure 6 shows the reservoir sites that were used for data collection in June 2003. The percent dissolved nitrogen saturation data shown on figure 6 is; however, for the specific date in March and will change with releases.

Signs of gas bubble disease have been reported by White (5) in 2000 and were observed by Colorado Division of Wildlife (CDOW) fish survey crews following a high spill discharge in 1996 (Hebein *pers. comm.*). White stated that external signs of gas bubble disease would be observed when the dissolved gas levels in the river are above 110 percent. White also stated that a series of flow tests for the bypass and outlet works should be performed to further investigate the cause of the fairly high dissolved gas levels measured.

Table 1 is a comprehensive table of past data from 1998-2000 as reported by Weston and the recent data gathered approximately monthly throughout the 2001, 2002, and 2003 years. The intake for both the outlet works and the bypass is at El. 6741 or about 140 ft below the maximum reservoir water surface. The spillway withdraws from near the surface with a morning-glory intake. Data were gathered when the bypass or outlet works were operated with the exception of one release from the spillway on May 4, 2000 with a discharge of 245 ft^3/s as indicated in the table. In general, all the outlet flows were small and do not provide a comprehensive range of flow for investigation. With only one spillway release, really no conclusions can be drawn about its potential for gas production.

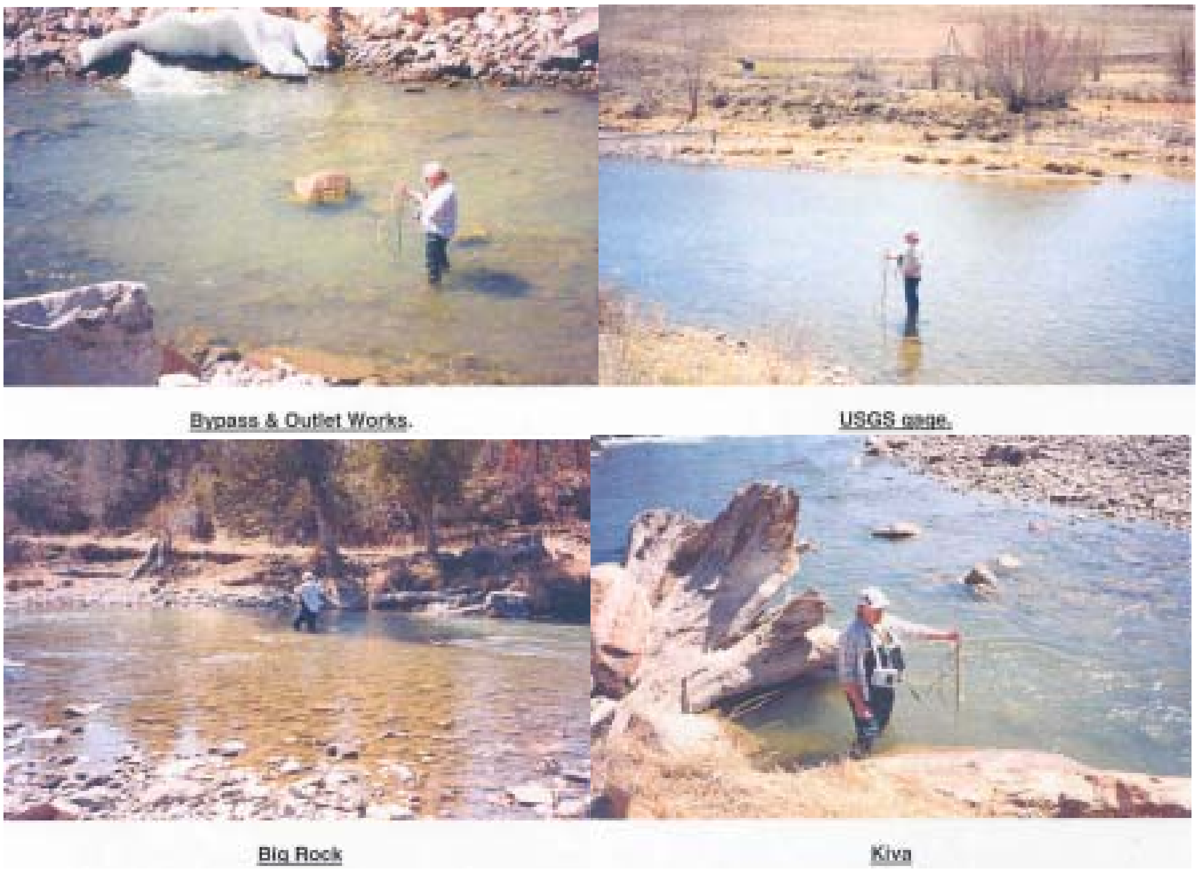

Figure 5. – The bypass, USGS, Big Rock, and Kiva station locations are shown with the dissolved gas measurements being gathered in March 2002. Note the generally shallow water for the flow rate of 45 ft^3/s.

Table 2 shows sixteen sites (8 historic or the same as in table 1 and 8 new) that were sampled on 3/27/03 to determine percent nitrogen saturation. The sample sites ranged from the Uncompahgre River entering the reservoir to below the Uncompahgre River/Cow Creek confluence (figure 6). Data gathering methodologies were consistent with those presented in Clesceri et al.(6) . A WTW Multiline P4 and a Sweeny saturometer were used for data collection by the TSC biologists. Readings were also taken for comparison at all historic sites on 3/25/03 (Table 1) by Grand Junction personnel using a Sweeney saturometer, and a YSI 85 dissolved oxygen meter. Figure 6 indicates the nitrogen saturation level by river site for the 3/27/03 data and the stations where reservoir gas data were later collected.

First of all, a quick explanation of the data in the table is needed. The barometric pressure, water temperature, depth, dissolved oxygen concentration, pressure differential between total and barometric pressure, and the percent total dissolved gas saturation were measured and recorded. Bunsen coefficients for oxygen and vapor pressure recorded are based on individual site temperatures (6). Often, the presentation of dissolved gas is given as total dissolved gas (TDG).

The percent nitrogen gas saturation reported is not to be confused with percent total dissolved gas. Total dissolved gas is made up of approximately 78 percent nitrogen, 21 percent oxygen, and 1 percent argon and carbon dioxide. The percent saturation presented in tables 1 and 2 is percent nitrogen and argon saturation. The percent nitrogen and argon elements are usually reported together after computations. The project personnel have chosen to report their findings in percent nitrogen saturation because it is the greater percentage and it is more stable than the oxygen factor of the total dissolved gases. It is also the factor that affects the fishery when it is established that there is not an oxygen deficit problem.

The percent nitrogen and argon saturation (N+Ar(%)) was correctly computed by the equation:

$$N + Ar(\%) = \left[\frac{BP + \Delta p - \left[\frac{C_{O_2}}{\beta_{O_2}} (0.5318) \right] - P_{H_2O}}{(BP - P_{H_2O})0.7902} \right] 100$$

Where:

BP = barometric pressure (mmHg)
Δp = pressure differential (mmHg)
C_{O2} = dissolved oxygen concentration (mg/l)
β_{O2} = Bunsen coefficient (from tables)
P_{H2O} = vapor pressure of water (mmHg) from tables

The nitrogen saturation values were entered in the table either below the outlet works or the bypass column (the column 2 or 3) depending upon which was releasing at the time. The measurements were taken at the same point in the river downstream from the exit channel regardless of which structure was releasing the flow. The velocity was too strong for personnel to wade in the narrow exit channel under higher discharges from the outlet works. It is possible that the measurement location did not capture the supersaturated jet issuing from the bypass structure, but obtained a measurement from stagnant water with a different level. Figure 5 shows the technician gathering data adjacent to the bypass but not in the flow stream directly issuing from the bypass structure.

The column entitled "CFS dam" in table 1 shows the release associated with the percent nitrogen saturation listed in either the outlet or bypass column. Bypass flows are under 100 ft^3/s. The percent nitrogen saturation at the named river sections downstream from the dam are then given with the distance downstream from the toe of the dam shown. Also indicated in the table is whether the data were gathered near the surface or the bottom of the river.

Examining the data table, a couple of initial anomalies appear with the elevated dissolved gas levels recorded from bypass releases in November 1999 and October 2000. These high fall levels were unexpected because fall dissolved gas levels are typically declining. Data were not taken in October of 2001 and 2002, but the September levels seem consistent with the August levels. Usually, high TDG levels are associated with spring runoffs and higher levels entering the system as the outlet works reading in May of 1999 shows for a discharge of 345 ft^3/s. In addition, on July 2, 2002, data were taken with both the usual saturometer and a saturometer from a Hydrolab instrument. These data show a remarkable difference that will be discussed further in this section.

The data were plotted several ways and trends or anomalies were examined. First, all of the data in table 1 were plotted as percent nitrogen saturation versus discharge for the station directly below the outlet works or bypass release, figure 7. These data are the average of the top and bottom readings when both were gathered.

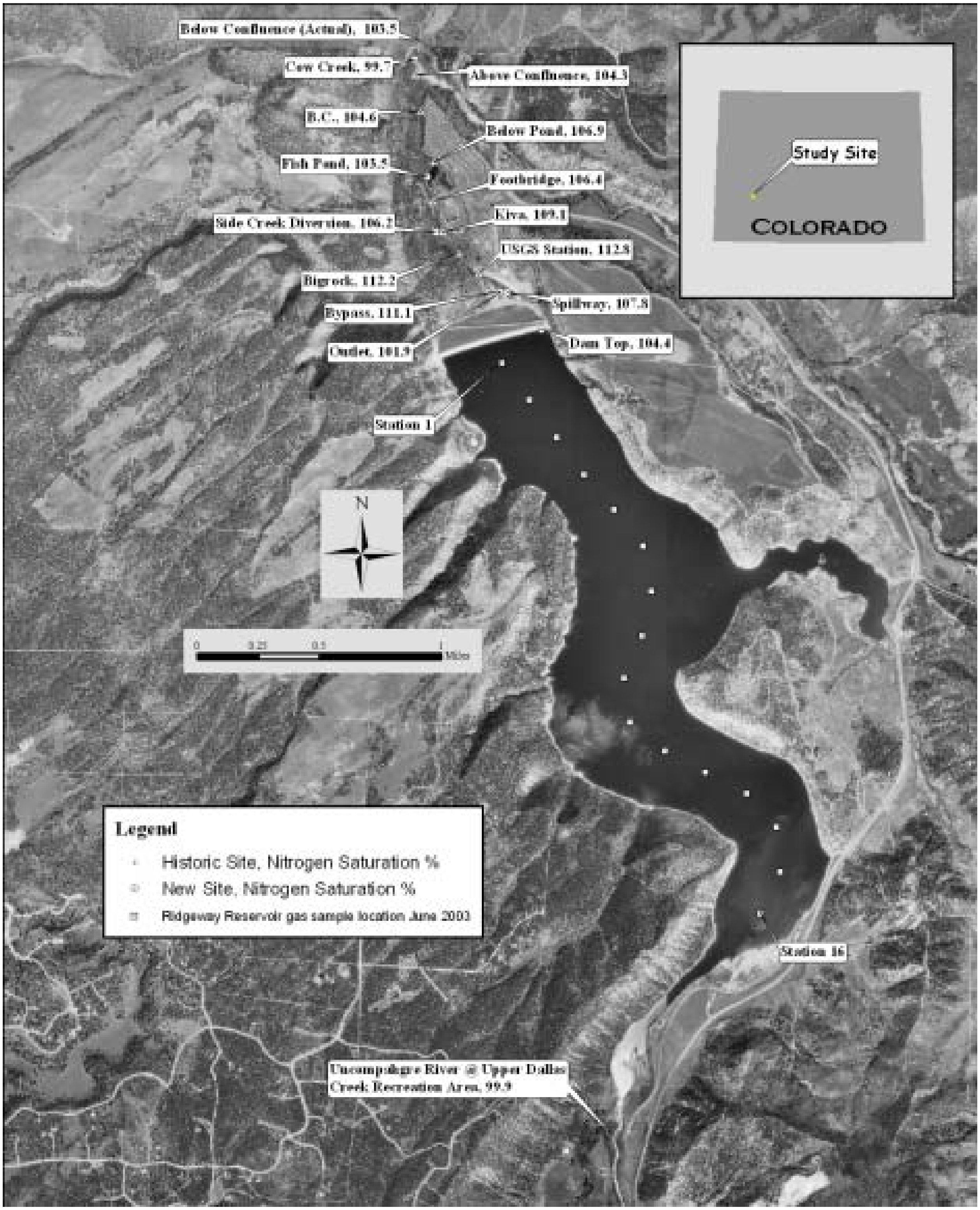

Figure 6. - Digital orthographic quarter quadrangle of Ridgway Reservoir and river nitrogen supersaturation measurement sites for the data taken on 3/27/03 by TSC personnel. Ridgway reservoir gas sampling locations were used in June 2003 by field personnel. (The Uncompahgre River is entering the lake at the bottom.)

Table 1. – Percent nitrogen saturation data gathered monthly below Ridgway Dam for the 1998-2003 seasons. The "CFS d/s dam" flow refers back to column 2 or 3 where the $\%N_2$ is given under the structure that was operating.

			UNCOMPAHGRE RIVER near RIDGWAY RESERVOIR											
River distance (ft)	0	0	750	1100	1840	2920	3720	5350	5930					
Samples	% N_2 Sat.	% N_2 Sat.	% N_2 Sat.	% N_2 Sat.	% N_2 Sat.	% N_2 Sat.	% N_2 Sat.	% N_2 Sat.	% N_2 Sat.	% N_2 Sat.	% N_2 Sat.	CFS	CFS	CFS
Date/Station	Outlet	Bypass	USGS	Big Rock	Kiva	Bridge	Pond	B.C.	Confluence	Dallas Cr	u/s River	d/s dam	u/s River	Dallas Cr
11/03/98		114.86	113.71		103.57									
11/04/98		115.80	116.64											
11/04/98	110.54		111.13											
03/16/99		112.68	112.65	114.84	114.07	112.53	111.41					81		
04/14/99		105.67	109.51	108.07	107.27	104.50	104.19					73		
05/21/99	126.45		125.54	126.44	130.80	134.68	132.28					345		
09/16/99	116.77		118.09	118.47	116.92	119.55	114.33					496		
10/18/99	119.55		121.06	119.42	117.15	108.10	108.28					149		
11/23/99		125.57	125.76	121.12	121.86	117.36	117.32					46		
01/06/00		112.98	113.08	114.91	112.73	111.01	109.28					45		
02/15/00		118.32	118.33	118.07	116.89	114.85	112.76	110.72	109.92			55		
04/03/00		112.64	116.53	115.48	114.63	111.84	110.20	109.03	107.50			45		
05/01/00	117.21		119.92	119.95	117.60	115.85	114.80	114.30	114.02			100		
05/04/00	108.17		109.18	109.01	108.69	107.68	107.41	106.08	105.84			254	Spillway flow	
06/14/00	114.63		117.24	117.79	117.69	115.22	115.09	112.60	112.12			400		
07/12/00	116.61		119.93	116.97	116.61	116.53	114.59	112.00	111.97			320		
08/10/00	114.26		118.33	117.09	116.28	114.39	113.82	110.82	106.19			285		
09/12/00	113.17		116.32	114.93	112.36	111.11	110.43	108.07	106.92			106		
10/12/00		126.78	124.11	121.55	116.15	116.81	114.86	112.75	112.07			68		
12/01/00	bottom	115.92	112.65	119.43	114.58	114.99	113.59	112.41	109.45			50		
12/01/00	Top	108.88		115.04	114.93	114.42	113.17	108.58				50		

Table 1. – Percent nitrogen saturation data gathered monthly below Ridgway Dam for the 1998-2003 seasons. The “CFS d/s dam” flow refers back to column 2 or 3 where the $\%N_2$ is given under the structure that was operating.

			UNCOMPAHGRE RIVER near RIDGWAY RESERVOIR											
River distance (ft)	0	0	750	1100	1840	2920	3720	5350	5930					
Samples	% N_2 Sat.	% N_2 Sat.	% N_2 Sat.	% N_2 Sat.	% N_2 Sat.	% N_2 Sat.	% N_2 Sat.	% N_2 Sat.	% N_2 Sat.	% N_2 Sat.	% N_2 Sat.	CFS	CFS	CFS
Date/Station	Outlet	Bypass	USGS	Big Rock	Kiva	Bridge	Pond	B.C.	Confluence	Dallas Cr	u/s River	d/s dam	u/s River	Dallas Cr
12/19/00	bottom	115.79	112.38	118.08	113.82	104.4	110.43	108.12	107			50		
01/19/01	bottom	120.05	120.13	124.08	120.96	116.51	117.92	114.94	112.71			52		
02/16/01	bottom	118.72	114.23	113.24	113.2	110.57	112.59	110.24	108.89			52		
05/30/01	116.58	Bottom	116.14	115.84	115.91	114.59	114.05	111.17	111.99			300		
05/30/01	117.15	Top				114.11	112.52	111.31	111.69			300		
06/21/01	115.57	Bottom	113.28	116.33	114.45	114.5	112.96	110.73				350		
06/21/01	115.33	Top		116.57		113.98	112.92	110.4				350		
9/6/2001	116.66	Bottom	109.98	114.5		112.41	112.16	110.04	109.01			235		
9/6/2001	115.43	Top	115.46	113.88	113.11	111.28	110.46	108.97	108.28			235		
1/22/2002	bottom	117.53	101.93	115.83	111.81	113.84	113.25	108.16	107.61			45		
1/22/2002	top				112.47		111.92					45		
2/22/2002	bottom	116.98	104.51	119.31	118.36	115.66	114.91	109.94	112.79			45		
2/22/2002	top	105.26			108.26		114.36					45		
3/28/2002	bottom	112.19	111.58	115.04	106.81	110.03	111.26	106.03	108.91			45		
3/28/2002	top				105.93		109.79					45		
04/24/02	115.13	Bottom	105.28	110.86	110.50	108.58	107.93	106.02	105.28	105.79	105.79	250	109.9	2.44
04/24/02	113.77	Top			110.17		106.25	103.57	105.15					
05/22/02	120.63	Bottom	117.70	121.25	115.22	112.10	112.84	108.57	108.42			250		
05/22/02	120.04	Top		120.71	113.97		111.06							
07/02/02	118.97	Bottom	123.15	121.87	121.11	117.88	117.02	113.51	112.42			162		
07/02/02	118.73	Top			119.37	117.67	116.28					162		

Table 1. – Percent nitrogen saturation data gathered monthly below Ridgway Dam for the 1998-2003 seasons. The "CFS d/s dam" flow refers back to column 2 or 3 where the $\%N_2$ is given under the structure that was operating.

			UNCOMPAHGRE RIVER near RIDGWAY RESERVOIR												
River distance (ft)	0	0	750	1100	1840	2920	3720	5350	5930						
Samples	% N_2 Sat.	% N_2 Sat.	% N_2 Sat.	% N_2 Sat.	% N_2 Sat.	% N_2 Sat.	% N_2 Sat.	% N_2 Sat.	% N_2 Sat.	% N_2 Sat.	% N_2 Sat.	CFS	CFS	CFS	
Date/Station	Outlet	Bypass	USGS	Big Rock	Kiva	Bridge	Pond	B.C.	Confluence	Dallas Cr	u/s River	d/s dam	u/s River	Dallas Cr	
07/02/02	98.51	Hydrolab	97.60	103.22	102.66	104.60	104.32	97.44	96.49			162			
09/05/02	116.61	Bottom	117.94	114.68	116.04	110.98	110.90	108.05	107.32			120			
09/05/02	116.58	Top			107.49		110.92					120			
01/09/03	bottom	111.62	113.31	104.82	114.21	110.04	109.18	108.01	105.62			30			
02/12/03	bottom	107.45	96.38	115.90	111.98	109.05	109.28	104.69	102.34			30			
03/25/03	bottom	123.17	103.09	117.25	119.65	117.21	116.89	108.88	113.67			30			
05/13/03	115.18	Bottom	116.94	113.71	114.91	111.91	110.38	107.86	107.89			120			
05/13/03	115.2	Top			112.6		108.96	106.53				120			
06/25/03	116.83	Bottom	114.72	116.54	114.78	113.17	112.69	110.11	109.28			300			
06/25/03	116.3	Top			114.94	112.99	112.22	109.5				300			

Table 2. - Percent nitrogen saturation data taken on 03/27/03 by TSC personnel at additional sites under a bypass flow of 30 ft^3/s. Data are plotted on figure 6.

Site Name	Upper Dallas Creek	Dam Top	Spill-way	Outlet	Bypass	USGS Site	Big Rock	Kiva	Side Creek Diversion	Bridge	Fish Pond	Below Pond	B. C. (old)	Above Conflu-ence	Cow Creek	Below Conflu-ence (actual)
Comments	New Site	New Site	New Site	New Site	Historic Site	Hist. Site	Hist. Site	Hist. Site	New Site	Hist. Site	New Site	Hist. Site	Hist. Site	Historic Site	New Site	New Site
Nitrogen Sat.	99.9	104.4	107.8	101.9	111.1	112.8	112.2	109.1	106.2	106.4	103.5	106.9	104.6	104.3	99.7	103.5

The EPA standard for total dissolved gas in a system is 110 percent. Given this standard, most of the releases exceed the accepted gas level just looking at the percent nitrogen saturation. The dissolved gas data measured immediately below the outlet works and bypass didn't seem to show any particular relationship between dissolved gas and discharge. In addition, a regression analysis performed for the nitrogen saturation data at the USGS station versus discharge also indicated no statistically significant correlation. Unfortunately, the discharge range under which data have been gathered is narrow because it corresponds to the typical system operation.

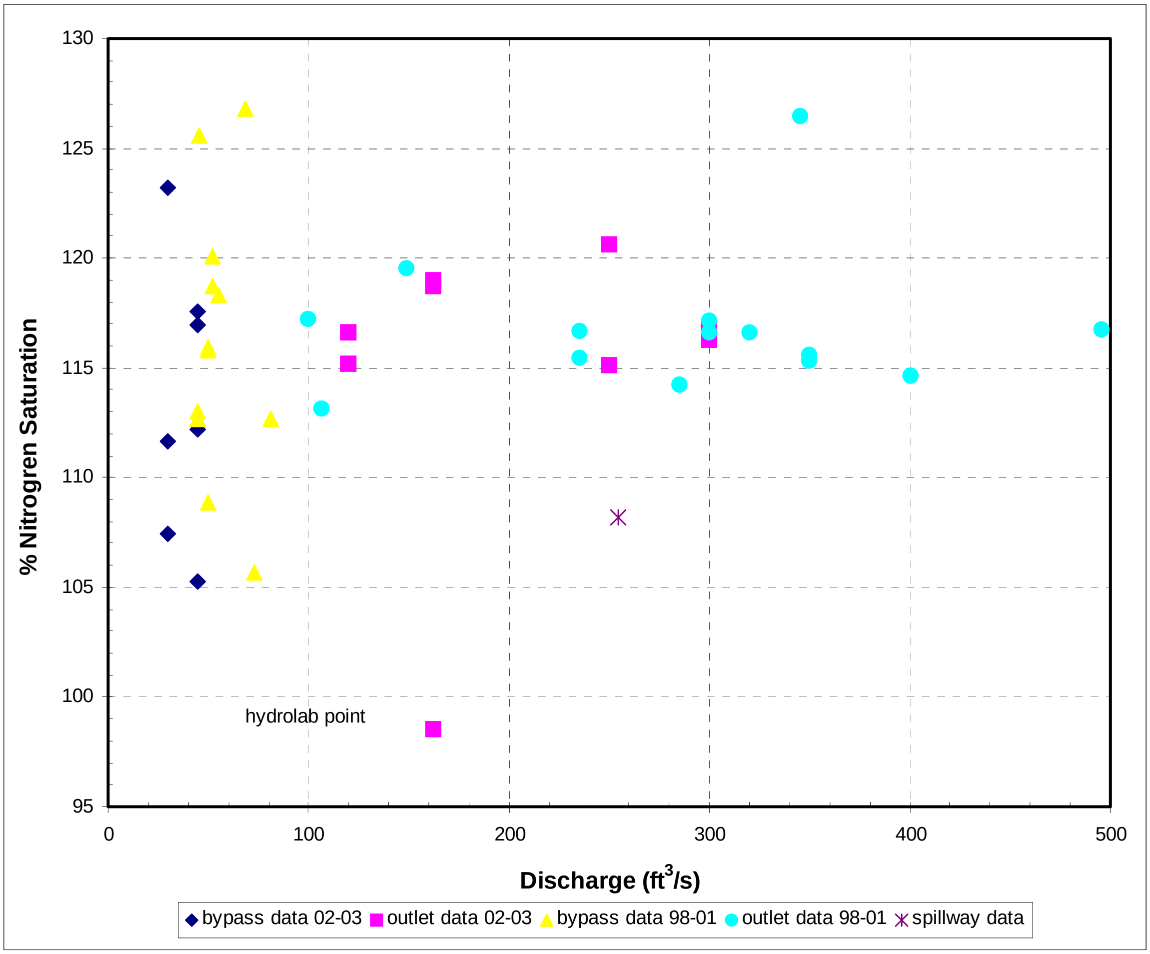

Figure 7. - Dissolved gas data for 1998-2003 collected in the field as measured immediately downstream from the release points of the bypass, outlet works, and spillway. The data plotted are the average of the top and bottom measurements.

Normally it would be expected that dissolved gas levels would increase with discharge as the jet plunges deeper into the stilling basin or river. The bypass flow range, between 45 and 100 ft^3/s, is probably not great enough to show this, but more consistent dissolved gas values would be expected unless seasonal variation of water quality in the reservoir is affecting the results. The data from table 1 do not, however, show expected seasonal variation either. The outlet works is used during the spring and summer where the discharge usually varies from about 100 to 500 ft^3/s. This is a fairly small range, given the design discharge value for the outlet works of 1380 ft^3/s; however, it is the normal flow range and should have shown some trend of increasing dissolved gas with discharge. The outlet works releases did show a better correlation though because the outlet works basin gas transfer characteristics would probably dominate over the initial reservoir levels.

The one data point for a spillway release indicated a low level of dissolved nitrogen, figure 7. The spillway reading is probably low because this was a very small discharge for the basin size. Larger spillway flows would produce more dissolved gas as the spillway stilling basin floor is lower than the outlet works floor or the original or modified bypass elevation and there would be flow plunging to greater depths forcing more dissolved gas into the water. Under an informal agreement with the CDOW the reservoir is not operated at a high enough elevation to spill using the uncontrolled spillway crest to prevent suction of kokanee fingerlings.

The historical data were then plotted as percent nitrogen saturation versus distance downstream or data station by the Western Colorado Area Office. A typical plot is shown on figure 8 for a bypass release of 45 ft^3/s in April of 2000.

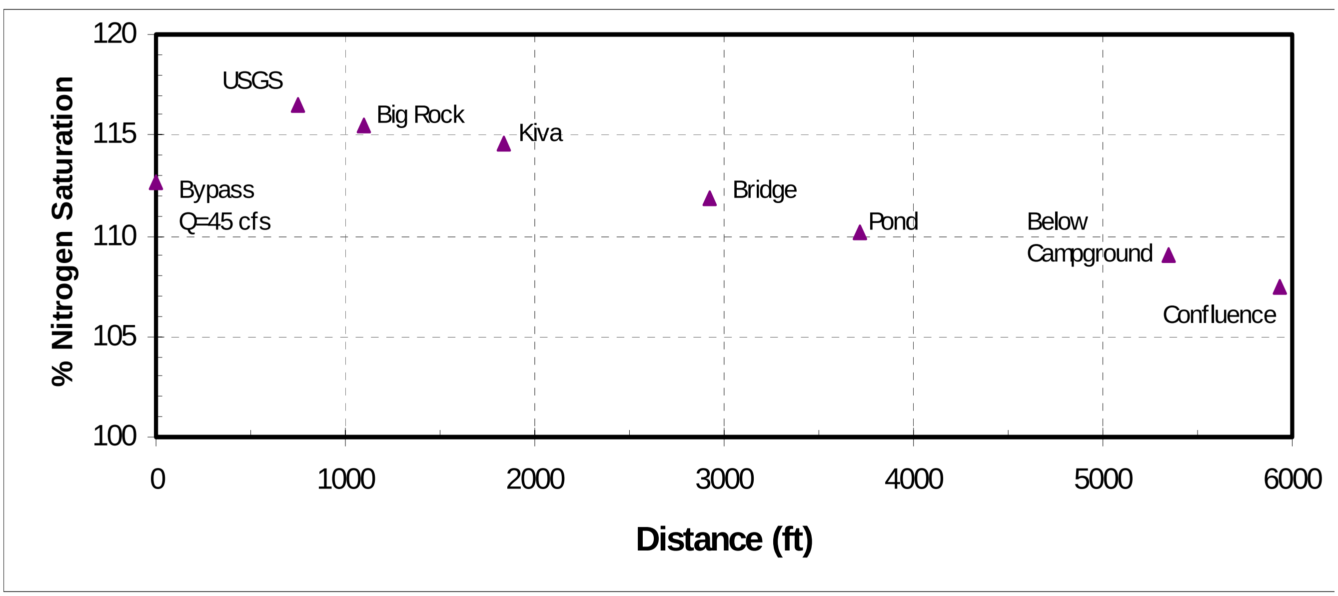

Figure 8. - Gas data for April 3, 2000 with the bypass operating. Note that the gas level increases between the bypass and the USGS gage site then decreases down river. This was typical for either bypass or outlet operation. (Below Campground is B.C. in the tables.)

The plots provide a view of how the gas level changes as releases flow downstream. Inspection of the all the plots tracing the dissolved gas levels downstream showed:

- The highest measured percent nitrogen saturation consistently occurred at either the USGS or Big Rock stations.
- Gas levels typically decreased down river from the USGS or Big Rock stations.

The trend in figure 8 shows that the river gradient and geometry also is important when evaluating the percent nitrogen gas production.

A view of the river between the dam and the USGS station is shown on figure 9. The USGS station is about 750 ft downstream from the toe of the dam. The area upstream from the USGS station is restricted to public access. The river is very shallow and has gone through a significant bend prior to reaching this measurement point. The topographic map also showed some minor tributaries that could provide additional elevated dissolved gas levels between the dam and this station. However, tributary flows causing the problem are highly unlikely. A more likely concern at the USGS station is whether or not the gas distribution is uniform across this section.

Figure 9. - The USGS river gage station about 750 ft downstream from the dam. Note the walls of the spillway stilling basin can be seen in the background. Also notice the shallow water at this site. This is typical of the small bypass releases that occur.

The higher readings at the USGS or Big Rock stations are most likely a result of missing the highest reading immediately downstream from the respective structures with the hand-held field instruments and inadequate mixing of the gas at the measurement locations. The close proximity of the USGS and Big Rock stations to the release point would mean that there should not be significant warming of the water. Warming of the water also would cause an increase in percent saturation with a constant concentration but a significant increase in temperature does not occur in the data between the dam and these two stations.

Figures 5, 9 and 10 show the variability of the river sections and measurement locations downstream from the dam. Figure 5 shows the measurement locations in the natural river with riffles, and pools, but generally shallow flow conditions. Figure 10 shows typical "natural" stream restoration structures in the form of rock weirs that were designed by Dave Rosgen and constructed in the river in 1994 below the USGS station to promote improved fish habitat. The success of these structures to promote fish habitat is discussed in a later section.

Figure 10. - Example of two rock weirs or Rosgen habitat structures that have been installed in the stream below Ridgway Dam to provide habitat and help improve water quality.

Gas measurements were taken both immediately above and below four of the habitat improvement structures in the river within a river section that was electrofished by CDOW and Reclamation personnel on 3/27/03 (figure 11). Site #1 on figure 11 corresponds to the Big Rock site of the historical data. The Big Rock site (#1) is actually below three other constructed rock weirs that are below the USGS site and are also seen on figure 11. Measurements were taken by the TSC staff to investigate benefit the structures may provide in decreasing the amount of nitrogen saturation across the structures, figure 11. Other measurements were taken by field personnel and are given in Table 1 for March 2003. The structures and the river itself are effective in decreasing nitrogen supersaturation. Some data showed a reduction in dissolved gas between the USGS site and the Big Rock site which may be due to these other three rock weirs. Examining the available data from this date in March, most of the benefit is gained at the first rock structure with a decrease in gas of about 1.7 percent. The next largest drop in gas levels occurs in the river section itself between stations #2 and #3 and is about 0.7 percent. In fact, these two reaches seem to account for almost the entire gas reduction of about 2.6 percent through the relatively short distance where the four structures are located.

In the pools several mechanisms can be at work to change the saturation concentrations. If there are highly windy conditions, gas exchange rates increase and degassing or a reduction in saturation may occur. If conditions are still and dissolved gas concentrations are constant, the percent saturation may increase if the water temperature increases or barometric pressure drops. Also, periods of algal growth can increase dissolved oxygen levels, which results in a higher TDG percent saturation. However, because oxygen is metabolized by the aquatic life, the physical effects of supersaturated oxygen are minor compared to nitrogen and can be neglected.

Again, figures 7 and 8 were plotted using the average of the top and bottom measurements taken in a shallow river. Weston (4) provided separate plots of the top and bottom readings, but with these shallow flow conditions it is probably not appropriate to assume much difference between the surface and depth for the flow conditions that existed during the measurement period. The trend of decreasing nitrogen saturation with distance downstream in the river does appear logical given the shallow, often turbulent river downstream including the sections with rock weirs. The data did not show a significant change in temperature with travel downstream.

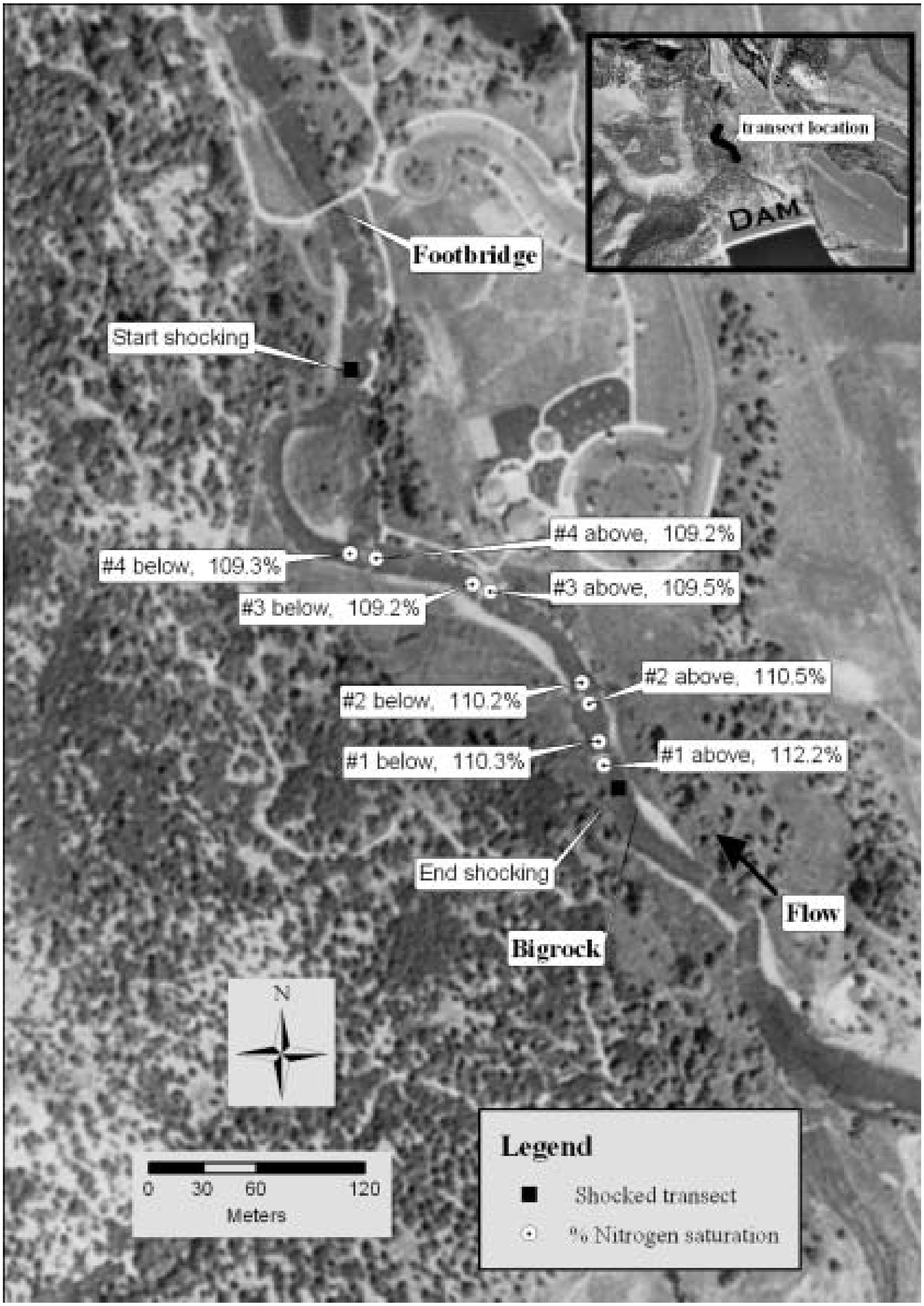

Figure 11. - Digital orthographic quarter quadrangle of Pa-Co-Chu-Pak Public Access Area, featuring nitrogen saturation measurements from 03/27/03 on Rosgen habitat structures and area of electrofishing transect. Site #1 above is the Big Rock site.

Figure 12 shows the dissolved gas data gathered with two different instruments. The data trends are similar but not identical, and the magnitudes of the gas values are very different. These data, taken in July 2002 for a discharge of 162 ft^3/s from the outlet works were the only reported historical data when measurements were taken with different meters. Unfortunately, the saturometer data shows dissolved gas data that exceeds the 110 percent standards, while the Hydrolab data shows gas levels that are below the standard and would not indicate that a problem exists. To determine which instrument was correct, data from July 2000 with an outlet release of 320 ft^3/s was plotted. The July 2000 and 2002 data measured with the standard saturometer showed similar magnitudes and trends. The data taken with the standard saturometer showed consistent results over the years and fish stress, which implies gas levels over 110 percent, has been noted over the years so perhaps the saturometer measurements are valid. The magnitudes of the hydrolab data are questionable and may be due to the small instrument measurement surface and longer equilibrium time required.

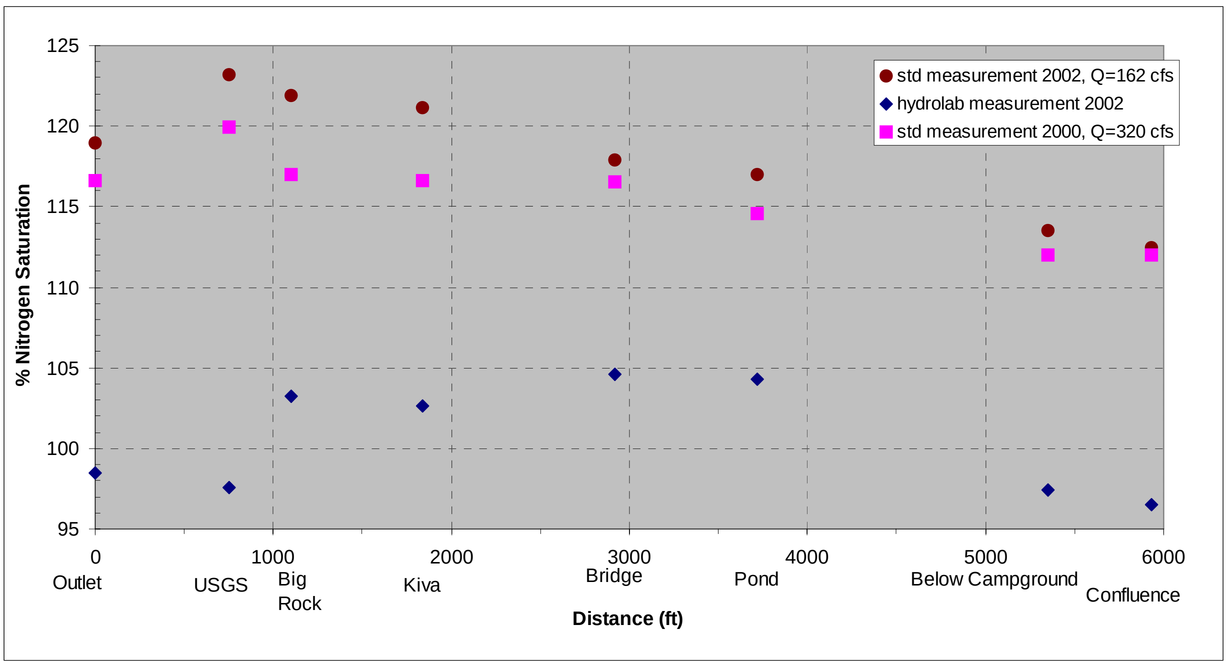

Figure 12. – Dissolved gas data gathered at the same stations with the standard hand-held saturometer and the Hydrolab instrument on July 2, 2002 with an outlet works flow of 162 ft^3/s. The data trend is somewhat different as are the data magnitudes with the different instruments. The standard saturometer was used to also measure dissolved gas on July 12, 2000 with an outlet works flow of 320 ft^3/s and compared favorably with the other saturometer data.

There is no question that the dissolved nitrogen levels are high in the river downstream from the dam. The outlet works and bypass releases are highly aerated with the presences of air vents downstream from the gates and aerated jets entering the river. The variability of the measurements is somewhat disturbing though. There are several potential reasons why the dissolved gas data shown in figures 7, 8 and 12 do not indicate expected results:

- Seasonal stratification of the reservoir with respect to temperature and/or gas

- Seasonal variation of inflow dissolved gas to the reservoir
- Poor mixing at the measurement locations whether near the structures or at the first downstream station such as the USGS site.
    - Transects across the measurement stations should probably be performed to ensure that the introduced gas level is fully mixed with the surrounding water.
- Poor maintenance or calibration of the instruments
    - Calibration is performed on instruments that provide for calibration. All maintenance instructions are followed, but instrumentation may need to be updated.
- Expected accuracy of metered TDG data is ±2.3 percent

The reservoir water quality and the predicted gas levels were investigated to try to ascertain the reason behind the variable nitrogen saturation measurements.

Reservoir Water Quality

The reservoir water quality could also directly affect the water quality in the river. Projects that make releases with power plants simply pass the dissolved gas levels in the reservoir to the river downstream. When spills or releases through hydraulic structures such as spillways and outlet works are made, often the dissolved gas levels downstream are increased depending upon the geometry of the structures and the hydraulic parameters. The small releases from Ridgway dam through the bypass and outlet works that seem to be causing the problem make exploring the possibility of the problem originating in the reservoir worthwhile.

During the construction of the dam in 1981, Johnson performed a study to determine if reaeration of the reservoir would be necessary (7). Apparently, low dissolved oxygen and poor water quality due to the presence of heavy metals in the reservoir was a concern early in the design process for Ridgway Dam, not supersaturated levels. Several numerical reservoir studies were performed to predict temperature and dissolved oxygen profiles for the reservoir for a single low level and a dual level outlet that was under consideration at the time. The possibility of installing an artificial aeration device was also investigated if poor dissolved oxygen levels deep in the reservoir were anticipated. Developed temperature and dissolved oxygen profiles showed the reservoir would stratify with respect to both elements. Using a dual level outlet and releasing from the upper outlet keeps the lower water cooler longer for use later in the year. Higher withdrawal will also produce lower, and possibly, unacceptable dissolved oxygen levels in the lower level of the reservoir particularly through late June into late August. If low level releases are made then the overall reservoir temperature will increase and dissolved oxygen levels will be adequate throughout the depth.

A decision was made to not construct the multiple level withdrawal outlets or the reaeration device based upon these studies and the temperature and dissolved oxygen data available from other reservoirs within the region. As a result, only one low level outlet was installed at El. 6741.

Reservoir Dissolved Gas and Temperature Measurements

Since construction and operation of the reservoir, supersaturated nitrogen levels have become a concern in the river downstream from the dam. The questions to answer are whether the entire problem is from the releases made from the dam or does the reservoir water temperature and quality contribute to the problem.

Many years of dissolved gas measurements have been taken in the river downstream from the dam, however, no data had been gathered in the reservoir until the 2003 season. The water quality in the reservoir may greatly influence the water quality downstream if high nitrogen or low oxygen levels exist in the reservoir. Gas bubble disease is a function of high dissolved nitrogen levels and the reservoir water quality might be contributing to the problem.

A reservoir dissolved gas survey was performed in June of 2003. The reservoir data were requested in an effort to better understand the dissolved gas data in the river. Data were taken up the centerline of the reservoir at 16 stations starting near the face of the dam at station 1. The sampling locations were about 1000 ft apart with increasing station numbers upstream to 16 plus the inlet of the Uncompahgre River, figure 6. The reservoir is about 3.2 miles long and about 225 ft deep at the dam.

Data were taken for the first 8 stations on June 11th and then an entire set, stations 1-16 plus the river, taken on June 26-27, 2003. Figures 13 and 14 show the measured reservoir dissolved nitrogen saturation data plotted versus depth below the reservoir water surface. The reservoir water surface elevation was 6868.59 on June 11th and 6869.17 on June 26-27th. The zero depth on the y-axis corresponds to these values on figures 13 and 14. The surface readings were always taken 1 ft below the water surface with the maximum depth varying with the reservoir depth. Station 1 on both plots represents the measured gas level closest to the intake. The elevation of the outlet works and bypass intake is 6741 and is shown by the horizontal line on the plot. The percent nitrogen saturation at the elevation of the intake is where the water is withdrawn and can influence the initial percent saturation of the water in the river.

Examining both nitrogen saturation data sets from the June surveys revealed that the data from station 1 for the June 11th survey has a percent nitrogen saturation value of about 104 percent and from the June 26-27th survey of about 117 percent. At the elevation of the intake the percent nitrogen saturation varies between 104 to 114 percent throughout the reservoir on June 11th and between 110 to 117 percent on June 26-27th. These disparate values in gas levels show a significant difference that is worthy of further investigation. The percent nitrogen saturation of the river flowing into the reservoir on June 27th was about 104-105 percent or just over saturation. Spring inflow values could be significantly higher.

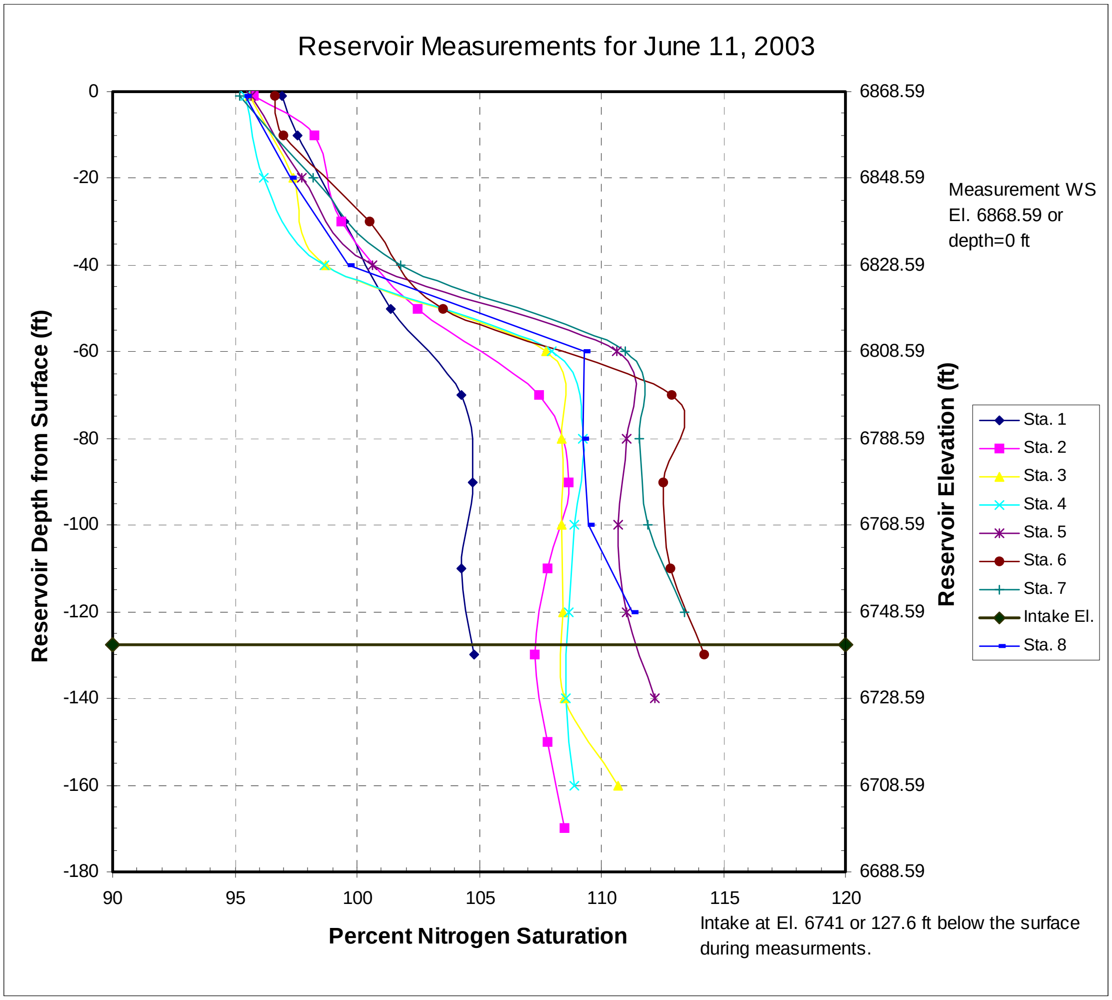

Figure 13. - Ridgway reservoir dissolved nitrogen gas profiles recorded June 11, 2003. The profiles are shown with zero depth at the surface of the reservoir and show increasing percent nitrogen saturation with depth. The flow through the reservoir at this time was between 120 to 300 ft^3/s. Station 1 is at the dam and would be the percent saturation level seen by the outlet works or bypass intake.

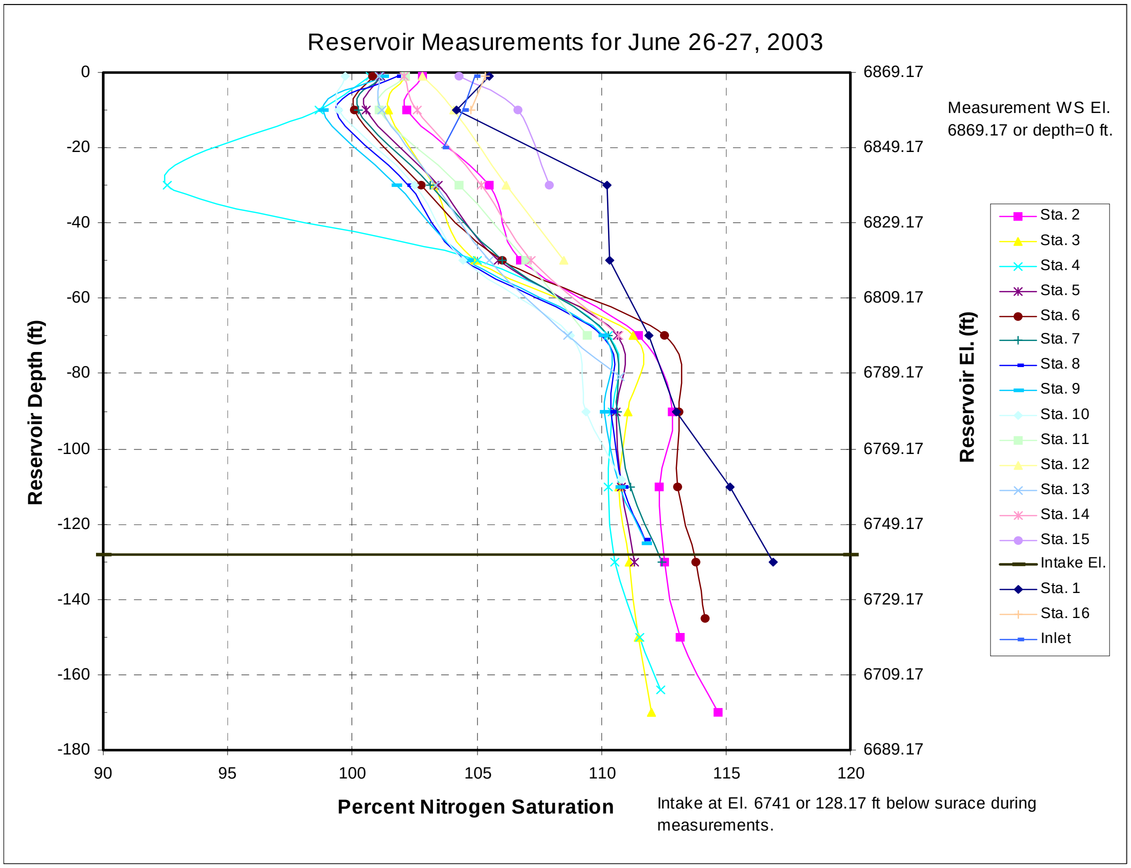

Figure 14. - Ridgway reservoir dissolved nitrogen gas profiles recorded June 26-27, 2003. The profiles are shown with zero depth at the surface of the reservoir and show increasing percent nitrogen saturation with depth. The flow through the reservoir at this time was 300 ft^3/s. Station 1 is at the dam and would be the percent saturation level seen by the outlet works or bypass intake.

Both June reservoir data sets show that the surface gas levels are lower than those at depth. This is the expected general tendency as the system seeks equilibrium by gas exchange from the water surface to the air. Wind can increase gas exchange by causing mixing in the surface layers. The gas levels in the surface layer are also influenced by temperature.

The data set for June 26-27 was selected for further analysis because it was a full data set, the flow rate was known, and there was also a data set taken in the river. The dissolved gas level in the river was about 116.5 percent which also matches well with that in the reservoir, although additional gas could have been produced with the outlet discharge above the level transferred from the reservoir.

There was quite a bit of scatter in both sets of gas profiles. Additional information is provided by plotting temperature profiles from the June 26-27th survey data, figure 15. The percent nitrogen saturation and temperature profiles show that Ridgway reservoir is stratified with respect to both elements. The surface layer of the reservoir is called the epilimnion and overlays the thermocline of a lake. The surface temperature is between

17 and 18°C. The warmer lighter oxygen-rich zone is separated from the lower colder heavier oxygen-poor zone by the thermocline layer. In the thermocline, the temperature typically declines at least one degree centigrade with each meter increase in depth. The bottom layer of the lake is called the hypolimnion and is the part of a lake below the thermocline made up of water that is isolated from atmospheric interaction and of essentially uniform temperature except during the period of overturn. The temperature profiles, figure 15, show this trend and mean that Ridgway reservoir is stratified with respect to temperature in June.

The temperature profiles throughout the reservoir show that the profiles are consistent with about a 9°C difference between the warmer surface and colder bottom of the reservoir. As is typical of mountain reservoirs, it will destratify or turn over in the fall, then stratify again starting in the spring and continue through the summer months. The temperature at the intake El. 6741 at station 1 is about 8.5°C. The temperature of the river water entering the reservoir is quiet a bit colder at depth than the surface and will tend to plunge. The intake temperature profile shows that the cold water is plunging at the point where this reading was taken. This plume will remain near the reservoir bottom as it travels toward the dam. The weak gradient shows very small bottom withdrawal influences and the temperature in the reservoir is fairly constant from a depth of about 50 ft down. The constant temperature profiles throughout the reservoir in the hypolimnion would infer that the gas profiles should also be fairly constant which is not really indicated by the data sets.

Total dissolved gas is composed of both oxygen and nitrogen. The flow into the reservoir will carry a certain amount of TDG. Naturally occurring levels of TDG often exceed 100 percent saturation. The reservoir is about 3.2 miles long. The reservoir body of water may be influenced by ambient or environmental conditions such as turbulence and mixing, changes in water temperature, barometric pressure, and wind. The gas levels of the Uncompahgre River entering the lake should be gathered throughout the year to determine the levels entering the lake.

An ideal target for TDG entering the reservoir would be somewhat less than 110 percent saturation to allow a margin of safety for gas levels to increase due to changes in ambient conditions. The choice of presentation of gas levels in terms of nitrogen is a good one, because nitrogen levels are more stable than oxygen levels in the reservoir. All gas values reported are based upon atmospheric pressure and there is likely no gas transfer occurring in the hypolimnion.

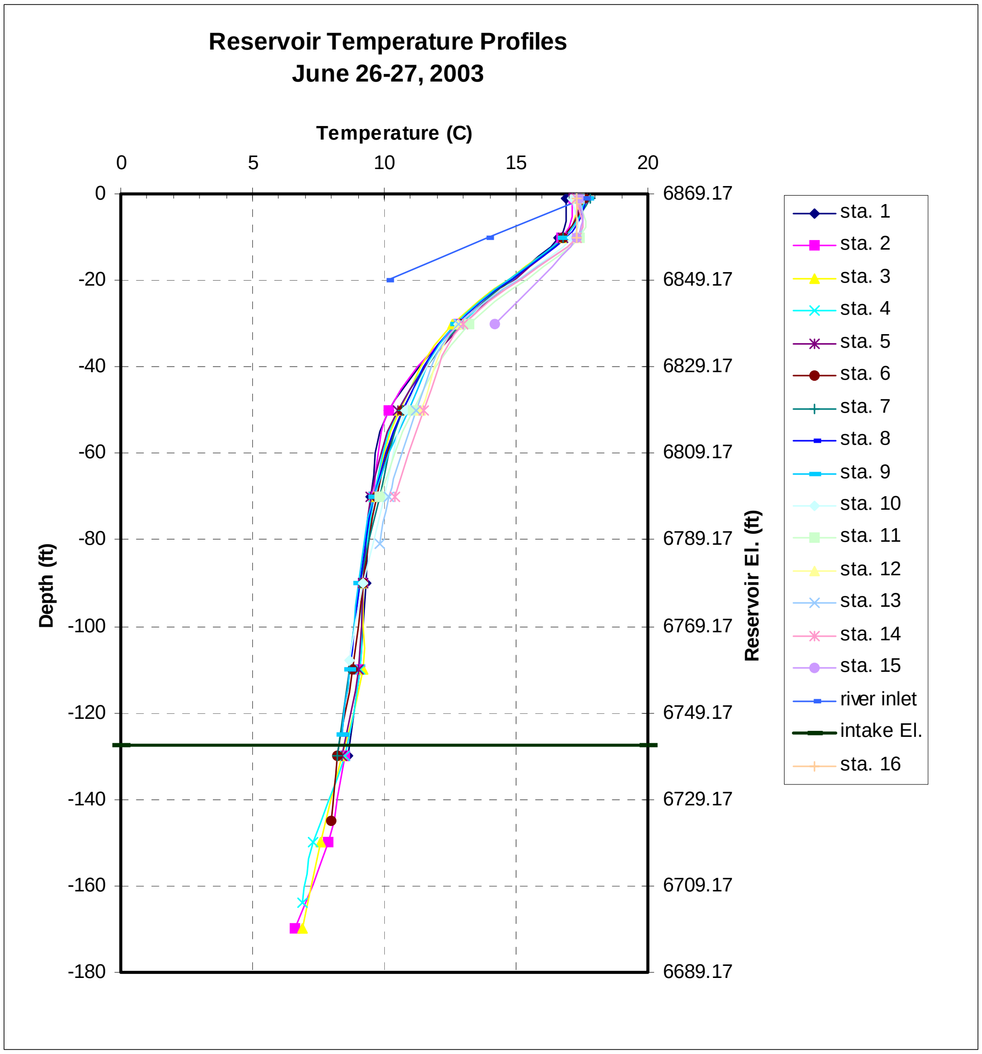

Figure 15. The entire set of temperature profiles gathered through Ridgway reservoir in June 2003 shows very consistent temperatures with travel time and depth. The river inlet shows that cold water enters the reservoir. The reservoir is temperature stratified which will influence the dissolved gas saturation levels at various depths. The epilimnion shows surface warming, the thermocline shows the changing temperature to the hypolimnion at depth with colder water.

The residence time for flow to move through Ridgway Reservoir and the complexity and variability of interactions between these parameters make it very difficult to predict the magnitude and frequency of TDG increases from changing ambient conditions, but the gas and temperature profiles collected in June show fairly typical levels and provide insight into the system.

These profiles show that the reservoir is supersaturated with respect to nitrogen at the level of the intake, at least during this time of year, and even if the flow were released from the reservoir without further gas production, the river downstream would exceed standards and cause symptoms of gas bubble disease in fish.

Predicted Dissolved Gas Levels for the Outlet Works

Theoretical calculations were made to predict the dissolved gas levels for the outlet works to determine what levels could be expected (8). This method uses the geometry of the structure with the discharge and tailwater values, elevation, barometric pressure, temperature and initial saturation concentrations of the gases. It was also assumed that the reservoir was saturated to 100 to 115 percent with a water temperature of 8 °C. Figure 16 shows the result of these calculations for a flow range of 100 to 1380 ft^3/s when using head losses measured from previous hydraulic modeling (1) and assuming no head losses. If an upstream weir were constructed in the Uncompahgre River above the reservoir, then perhaps the gas levels expected in the river below the reservoir could be bounded by the 105 percentile computations for outlet works releases, assuming no increase in gas transfer caused by the release.

The expected gas levels for these two cases of head loss were computed to hopefully verify or at least bracket the expected dissolved gas levels that have been measured in the field. The theoretical predictions indicate that the percent saturation should increase with releases from the outlet works over the full range of outlet flows. With no head loss the gas levels increase quicker since the computation is directly related to velocity and plunge depths.

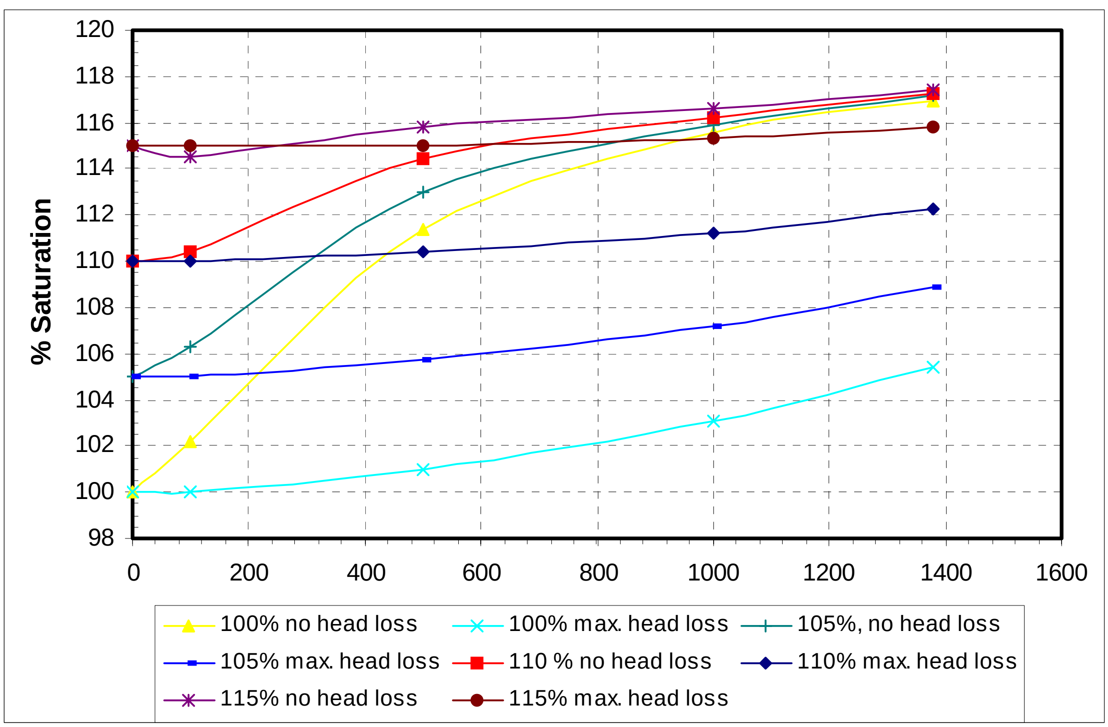

Figure 16. - Percent total dissolved gas levels predicted for the outlet works operation determined with no head loss and maximum head loss for the system. The reservoir gas level used was 100 to 115 percent with a water temperature of 8 degrees Centigrade.

The reservoir gas saturation levels of 110 to 115 percent were used for comparison to field data after receiving the gas profile data from the field survey performed in the summer of 2003. Figure 17 shows the predicted total dissolved gas levels with the measured nitrogen gas levels measured in the field for the range of flow under which the field data were gathered. The nitrogen saturation component may be higher than the total dissolved gas level with the difference being a lower oxygen level. This will account for some of the difference when making comparisons. Another factor is that the instrumentation generally only measures within an accuracy of ±2.3 percent. The low flow range under which the outlets have operated may also not be well predicted. Given these factors, the field data are quite similar to the predicted gas levels with the reservoir at 115 percent saturation with a few outliers.

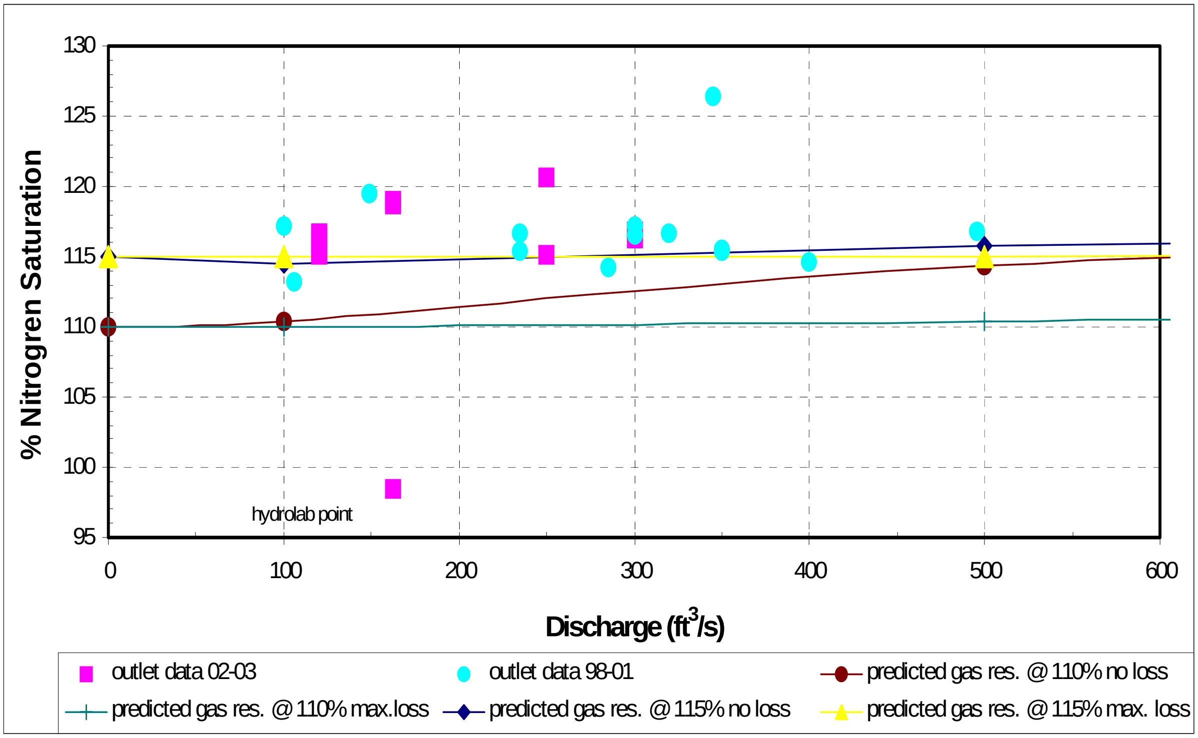

Figure 17. - All the outlet works field dissolved gas data presented with the computed theoretical calculation based upon reservoir gas level of 110 and 115 percent and a water temperature of 8°C.

FISHERIES BACKGROUND BELOW RIDGWAY DAM

The Uncompahgre River is known to have water quality issues associated with heavy metals and/or toxic chemicals resulting from anthropogenic activities upstream of Ridgway Reservoir (9). A trace metals monitoring program was started in 1987-1996 by various state and Department of Interior agencies, which began collecting samples from fish, invertebrates, plants and sediments (9). Reclamation data suggests that sedimentation within the reservoir may be trapping or slowing migrating contaminants;

however, bioaccumulation of cadmium and mercury in older resident fish within the reservoir is a concern.

Dissolved oxygen levels are not considered limiting to fish and invertebrates in the tailrace below the reservoir, but low temperatures are. Periodic drought conditions and the informal agreement to not use the spillway to withdraw from the surface at Ridgway Reservoir have resulted in lower than optimal tailrace temperatures due to lack of surface water spills.

The Ridgway Reservoir tailrace (prior to 1994) was considered lacking in low velocity refugia, and characterized as predominantly laminar flow well past Cow Creek. Figure 18 shows retention of stocked salmonids was extremely variable based on electrofishing records (Appendix. A). The CDOW found fish habitat decreasing with increasing flows past 100 ft^3/s. Lack of habitat and variable flows were attributed to downstream flushing of stocked fish.

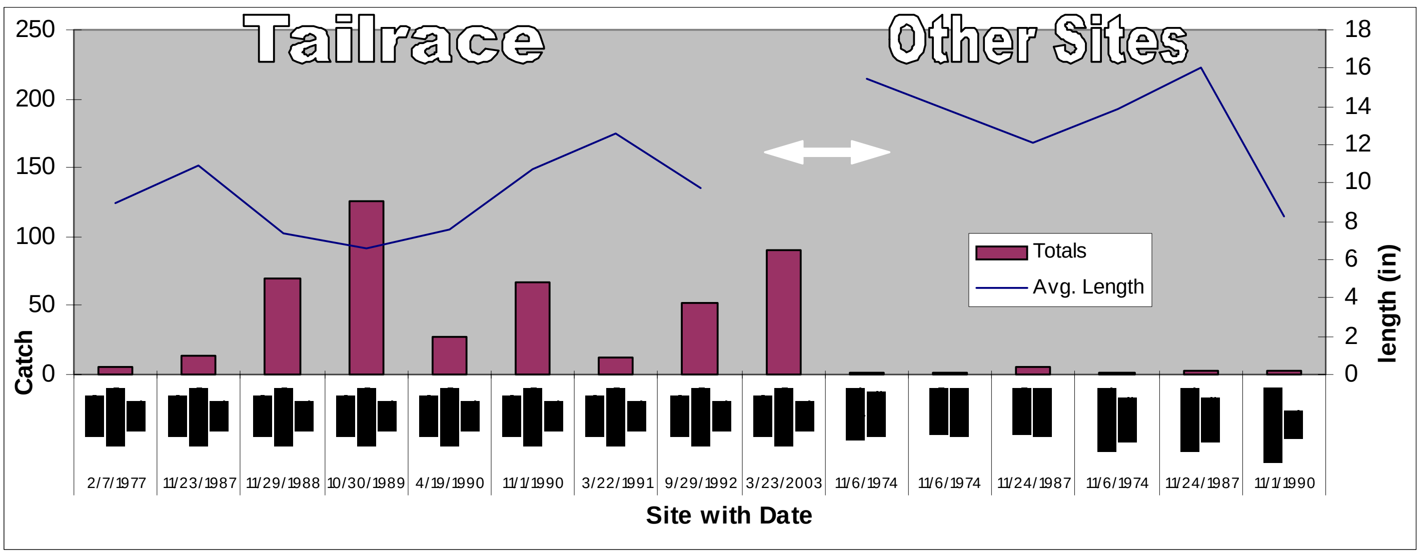

Figure 18. - Brown trout catch per unit effort and average length by sample site (1974-2003), Uncompahgre River.

A stream improvement project was initiated in 1994 to provide 1) stabilized bed loads, 2) salmonids spawning habitat, and 3) low velocity refugia and increased in-stream useable area to fish in Pa-Co-Chu-Pak Public Access Area of Ridgway State Park. The discussion and photographs, figures 10 and 11, of the habitat improvement structures that also provide reduction of the dissolved gas levels was given in a previous section of this report. The Rosgen structures provided improved habitat for the fishery in addition to reducing the dissolved gas levels. Post-improvement analysis conducted by the CDOW indicted the project was successful in achieving stated objectives. The river is heavily stocked with a variety of salmonids (Table 3). Complete stocking records for 1993-2003 are presented in Appendix A.

Table 3. - Summation of stocking data (1993 – 2003) from Highway 90 to the South Canal, Uncompahgre River.	
Species	Number Stocked since 1993
Brown Trout	77465
Colorado River Cutthroat	1081
Colorado River Rainbow	21998
Rainbow Trout*	75838
Snake River Native	602
Tasmanian Rainbows	15004
Total	**191988**

The tailrace below Ridgway Reservoir is known to have supersaturated levels of dissolved atmospheric gas. Atmospheric nitrogen, forced into solution, is known to cause Gas Bubble Trauma (GBT) in salmonids and other species inhabiting tailraces and hatcheries (10). GBT is an acute / chronic condition involving various forms of bubble growth, both internal and external to the fish. GBT in fish was first noticed by CDOW biologists after modifications to the stilling basin occurred in 1996 (Hebein *pers. comm.*), although it is not known if symptoms were prevalent prior to that date. Previous attempts to quantify supersaturation by White (5) have indicated that the bypass line may be responsible for high dissolved gas supersaturation found in the tailrace.

2003 Fish Survey Results and Incidence of Gas Bubble Trauma

Personnel from the CDOW, Reclamation, and Trout Unlimited volunteers completed a two-pass electrofishing effort at the Pa-Co-Chu-Pak Public Access Area of Ridgway State Park on 3/26/03 (figure 11). Species, length (mm), and weight (g) were recorded, as was information pertinent to GBT detection such as sub-dermal blisters and their location (buccal, opercula, fins, body, inner mouth, gill lamella and eyes) and severity (rated 1 – 4: 1 = 1 – 25%, 2 = 26 – 50% etc; (10)). GBT was assessed externally for all fish. No effort was made to measure blood chemistry, or internal manifestations or disease associated with GBT. Data for the electrofishing efforts on 3/26/03 is summarized in table 4. Raw data from this effort is compiled in Appendix B.

Table 4. - Summary of results of 2 pass electrofishing effort at Pa-Co-Chu-Pak Public Access Area of Ridgway State Park (below Ridgway Reservoir) on 3/26/03.		
Species	**Number Collected**	**Percent Occurrence of GBT**
Brown Trout *Salmo trutta*	88	33
Rainbow Trout *Onchorhynchus mykiss*	4	25
Colorado River Cutthroat *Onchorhynchus clarki sp.*	200	21
Snake River Cutthroat *Onchorhynchus clarki sp.*	23	48
Yellowstone River Cutthroat *Onchorhynchus clarki sp.*	1	0
Mottled Sculpin* *Cottus bairdi*	81	5

*GBT data from this species from first pass only.

External manifestation of GBT in the tailrace was most common on one or more fins. Other affected sites included inner and outer opercula, eye (exophthalmia), ventral head, and some unspecified sub-dermal bubbles to the fish's bodies. Photos of fish experiencing various symptoms of GBT are presented in Appendix C. Effects of GBT are thought to be cumulative with more severe effects manifesting after repeated exposure (10, 11).

Brown trout, rainbow trout, Colorado River native cutthroats, Snake River native cutthroats, Yellowstone River native cutthroats, and mottled sculpins were collected (Table 4). Only Yellowstone River natives (n = 1) did not show an incidence of GBT. Snake River natives had the highest incidence of GBT (n = 11, or 48%). Rainbow trout were the most abundant fish sampled, but had the lowest overall incidence of GBT of the salmonids (21 %). Mottled Sculpins were abundant (n = 183) but only sculpins from the second pass were analyzed for GBT; the incidence was 5%. Mottled sculpins have been found to be tolerant of high nitrogen saturation levels in laboratory experiments (10).

Fish in the tailrace without external symptoms may still suffer from acute internal GBT symptoms, such as gas bladder over inflation, circulatory complication and infection. Under some conditions, such as rapid shifts in total gas pressure, fish may experience mortality from these GBT complications without any external symptoms, especially in larger fish (10).

Larger fish are more likely to develop symptoms associated with and perish from GBT in situations where it occurs (10, 11). Minimum sizes of brown and rainbow trout with GBT on the Uncompahgre were always larger than non – GBT fish for both passes (Appendix B). Brown trout may be more susceptible to GBT than rainbow trout (based on percent incidence) in the tailrace. White et al. (10) reports similar findings on the Bighorn River, MT. Minimum sizes of Snake River natives without GBT were greater than those where GBT was apparent; however, stocking records indicate that the only brood fish >14 in. were being stocked in the tailrace. Over 800 Colorado River natives were stocked in the Uncompahgre in 2001 and 2002 (< 10 in), but the small sample size (n = 4) and GBT occurrence (25%) may not be an accurate representation of these fish overall.

Natural spawning of both brown and rainbow trout has been documented in the tailrace and spawning channel (Hebein *pers. comm.*). It is unknown how GBT affects spawning success of fish on the Uncompahgre River, or if infected fish spawn at all. Gas bubble trauma has not been shown to affect eggs of salmonids, though alevin and fry may suffer gas bladder over inflation in supersaturated water (11). White et al. (10) speculate that tolerance for nitrogen saturation levels on the Bighorn River, MT, in spawning adults may allow selection for this tolerance in offspring; however, this situation may be improbable in the tailrace due to the use of a variety of hatchery brood fish provided to supplement any wild reproduction.

RECOMMENDATIONS FOR 2004 PROGRAM

Phase IV investigations should build on stated objectives of reservoir saturation monitoring prior to different release configurations and collection of biological data in the following manner:

- Understand GBT downstream distribution (longitudinal extent and severity) by expanding the fish sampling effort downstream through cooperative effort with the CDOW.
- Check for variance between years by species, size, reach, and operations.
- Continue nitrogen saturation monitoring including the downstream river, reservoir, and inflow.
- Develop methodology to quantify internal manifestations of GBT.
- Plan mitigation or rehabilitation strategy for fish if problem persists.

If further data are desired to continue monitoring the problem or verifying the effectiveness of a modification then the following is recommended:

- Investigate installing a permanent TDG monitor at the USGS site. Prior to installing a monitor at this site, or any other site, the river cross section should be checked to determine if the velocity and TDG levels are uniform across the width.
- Perform a test program over a wide range of flows while carefully measuring upstream and downstream TDG levels.
- If continuing to monitor with hand-held devices;
    - Be consistent with depth and locations. Perform transect measurements to ensure that the measurement location is valid. Make sure instruments are calibrated and submerged when taking the readings.
- Perform additional reservoir modeling calibrated with the June 2003 profiles to estimate the gas and temperature levels throughout the year.

POSSIBLE SOLUTIONS

The dissolved nitrogen levels in the river are a function of both the reservoir gas levels and gas production by releases. The levels are high immediately downstream from the structures, then decrease to potentially acceptable levels downstream with the river gradient structures that have been installed. The dissolved gas levels entering the reservoir in June are somewhat high and are a potential source of the problem. The reservoir gas and temperature profiles show that the reservoir is stratified with gas levels worse near the bottom at the intake elevation. The nitrogen gas levels at the intake, if directly transferred may often exceed the water quality standard. Direct transfer of the nitrogen-supersaturated water is therefore not the solution by itself.

Possible solutions for reducing the supersaturated dissolved nitrogen gas levels:

- Construct a gas stripping rock weir across a river section downstream from the bypass and outlet works release area to reduce gas levels to 110 percent when either structure is operating. The weir could be constructed of sheet pile and rocks for a normal flow range up to 500 ft^3/s or a flow range selected by the project personnel. The weir would need to produce about a 5 ft drop to reduce TDG levels to 110%. The location for the weir would depend upon the slope and cross section of the river.
- Modify the outlet works and bypass structures separately by:
    - Preventing the outlet works releases from plunging by raising the floor or adding deflectors to force skimming flow.
    - Modify the bypass pipe to discharge into a rock cascade on the bank adjacent to the current release point to strip gas before the flow enters the river. The cascade could be located parallel to the road on figure 2 with a drop of about 5 ft. Because the bypass operates only up to 100 ft^3/s the tailwater elevation would be about 6643 ft. Replunging of the flow after it travels over the cascade must be prevented.
- Construct a gas stripping weir in the river upstream from the reservoir to decrease the gas levels entering the reservoir to a target of 105 percent.
- Construct a power plant to pass reservoir gas levels downstream without further increasing gas production with an upstream modification or a reservoir selective withdrawal system to ensure year-round gas level compliance. Providing a selective withdrawal system would require investigation of dissolved oxygen influences.
- Install a selective withdrawal system in the reservoir to withdraw from a layer with reduced gas level in the lake. This would need to be coupled with an upstream or downstream modification to ensure compliance.
- Operationally, perhaps the spillway could be used for low flow releases when the reservoir elevation is above 6671.3 and the temperature is not expected to be a problem.

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APPENDIX A

CDOW Electrofishing Data And 10 Year Stocking Information

ELECTROFISHING DATA IS COMPILED INTO LENGTH FREQUENCY DISTRIBUTIONS FOR A SELECTION OF SPECIES SAMPLED FROM 1974 – 2003 AT DIFFERENT AREAS ABOVE AND BELOW THE RIDGWAY RESERVOIR.

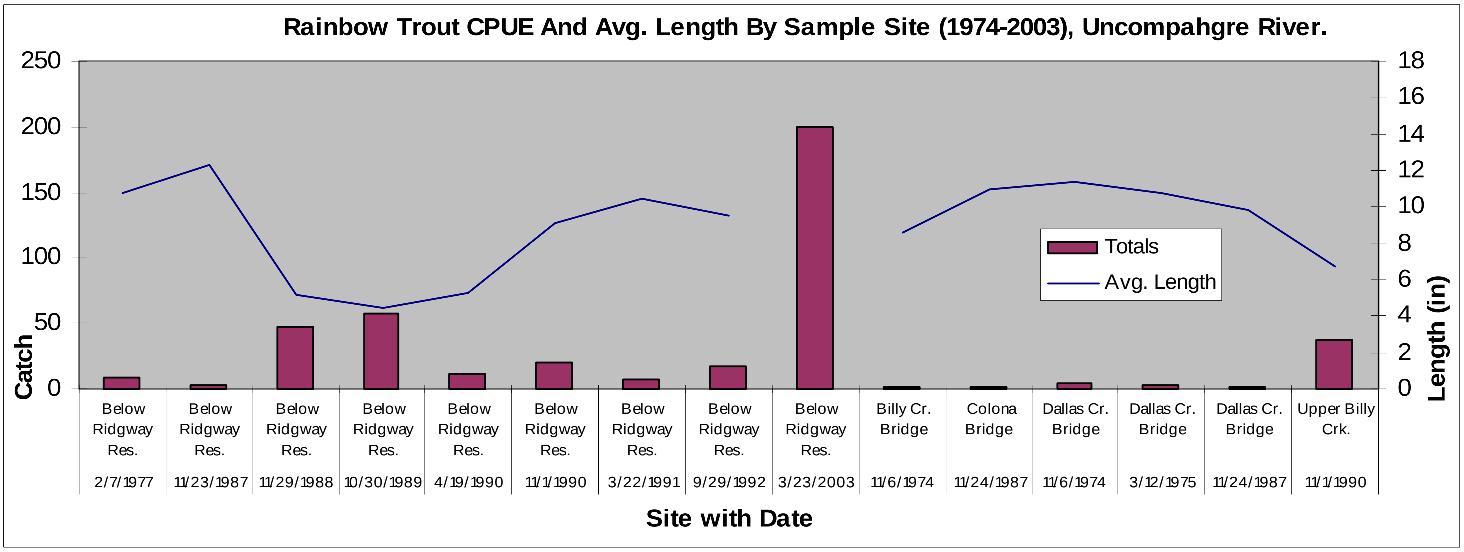

Figure B1. Rainbow trout catch per unit effort and average length by sample site (1974 – 2003), Uncompahgre River.

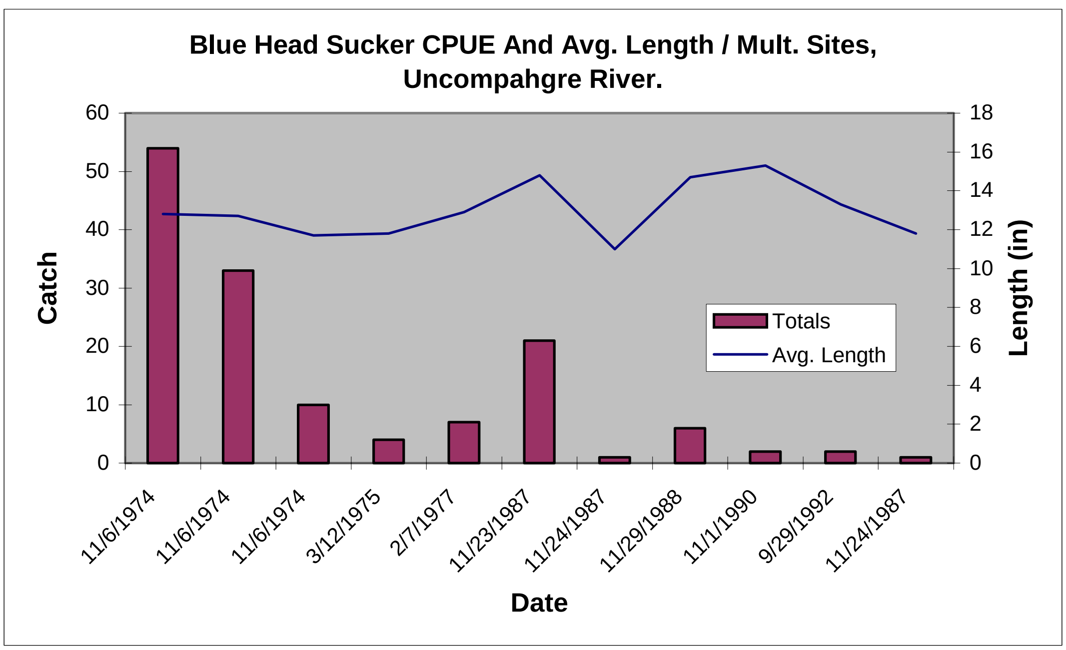

Figure B2. Blue head sucker (*Catostomus discobolus*) catch per unit effort and average length at multiple sites, Uncompahgre River.

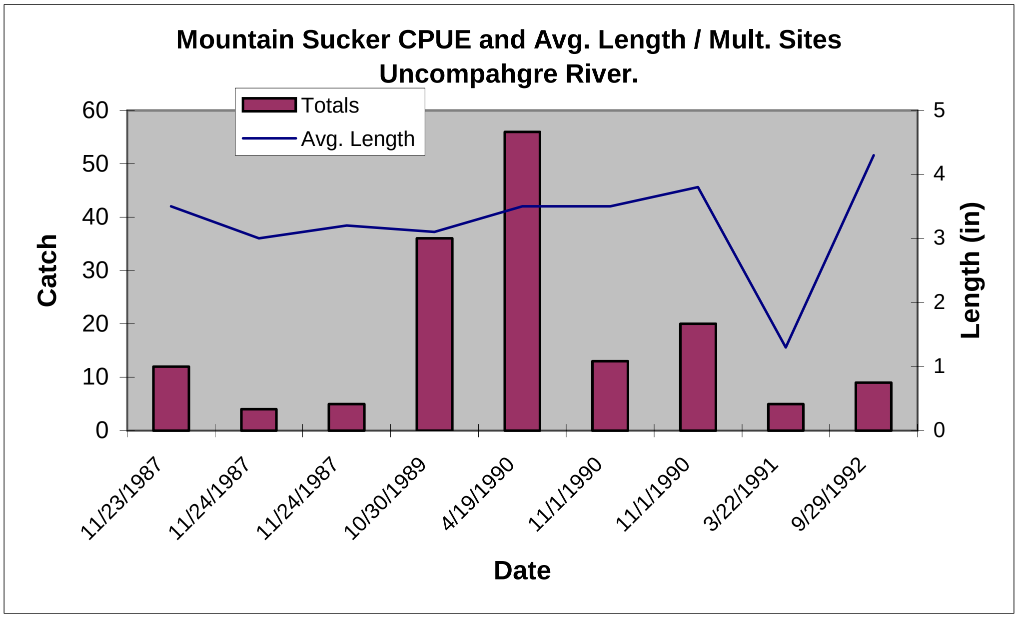

Figure B3. Mountain Sucker (*Catostomus platyrhynchus*) catch per unit effort and average length at multiple sites, Uncompahgre River.

COMPILATION OF STOCKING RECORDS FOR THE UNCOMPAHGRE RIVER, HIGHWAY 90 BRIDGE TO SOUTH CANAL, 1993-2003. THE RECORDS INCLUDE OFFICIAL STOCKING RECORDS KEPT BY THE CDOW AND ANCILLARY INFORMATION TAKEN FROM CDOW RECORDS. DATA IS SORTED BY SPECIES, THEN BY STOCKING DATE.

Date	Species	Number Planted	Average Size (in)	Biomass (lbs)
5/16/94	BRT	33	11.54	20.3
11/18/94	BRT	2	8	
6/9/99	BRT	10000	2.87	95
7/8/99	BRT	20124	3.18	258
8/9/00	BRT	10000	3.31	145.2
7/19/01	BRT	11200	2.72	90.285
8/30/01	BRT	4800	4.21	143.94
7/9/02	BRT	8000	3.51	139.32
6/26/03	BRT	13306	3.56	241.81
6/20/01	CRC	400	10.28	173.91
9/6/02	CRC	475	5.89	39
7/15/03	CRC	206	15.35	298.55
9/8/93	CRR	10000	2.92	100
9/23/96	CRR	11998	2.06	41.66
7/16/93	RBT	690	9.97	273.8
7/29/93	RBT	353	9.23	111
5/16/94	RBT	133	13.27	124.3
6/23/94	RBT	494	10.78	248
7/14/94	RBT	598	10.09	246.09

Date	Species	Number Planted	Average Size (in)	Biomass (lbs)
8/11/94	RBT	378	10.23	162.2
8/31/94	RBT	407	10.59	193.72
9/20/94	RBT	4000	5	
10/7/94	RBT	900	20	
11/18/94	RBT	28	16	
11/18/94	RBT	2	9	
12/14/94	RBT	4000	6	
8/24/95	RBT	48	23.21	240
11/8/95	RBT	400	20.05	1290.32
4/2/96	RBT	879	18.97	2400.55
9/18/96	RBT	1215	13.6	1215
10/17/96	RBT	600	17.84	1363.64
9/14/98	RBT	3020	3.54	56
9/25/98	RBT	300	14.94	400
8/5/99	RBT	9999	5.74	757.5
9/19/99	RBT	5092	4.04	134
7/5/00	RBT	2247	2.46	13.37
6/26/01	RBT	10002	5.27	587
8/8/01	RBT	5037	3.06	58
7/17/02	RBT	10017	3.96	249
8/4/03	RBT	9999	2.87	95.45
8/4/03	RBT	5000	2.87	47.73
4/9/02	SRN	200	16.27	344.82
3/20/03	SRN	402	14.32	472.94
7/24/01	TAS	15004	4.38	505

APPENDIX B

Ridgway Gas Supersaturation: Summary of Fisheries Data for a Two Pass Electrofishing Effort on the Uncompahgre River, 3/26/03

Pass #1 (4 fish excluded due to incomplete data)
<u>Brown Trout:</u>
n = 62
Gas Bubble Trauma (GBT) n = 20
32% Occurrence

Minimum TL (mm) and Weight (g) Non GBT Brown Trout = 61, 5 *
Maximum TL (mm) and Weight (g) Non GBT Brown Trout = 538, 1800
Minimum TL (mm) and Weight (g) GBT Brown Trout = 122, 20
Maximum TL (mm) and Weight (g) GBT Brown Trout = 425, 815
* Min weight on scale was 5 g

Summary:
19 of 20 fish had GBT one or a combination of the following Fins: Caudal, Dorsal, Anal, or Pectoral. GBT was almost always apparent on left and right or dorsal and ventral for fins affected.
1 of 20 showed GBT on operculum only (1 other fish showed a combination of operculum and dorsal fin GBT.
1 of 20 had GBT on left eye, in combination with GBT to dorsal fin (see photos).

<u>Colorado River Cutthroat</u>
n = 3
Gas Bubble Trauma (GBT) n = 0

Minimum TL (mm) and Weight (g) Non GBT Cutthroat = 70, 5*
Maximum TL (mm) and Weight (g) Non GBT Cutthroat = 256, 160
* Min weight on scale was 5 g

<u>Rainbow Trout</u>
n = 159
Gas Bubble Trauma (GBT) n = 34
21% Occurrence

Minimum TL (mm) and Weight (g) Non GBT Rainbows = 70, 5*
Maximum TL (mm) and Weight (g) Non GBT Rainbows = 490, 1125
Minimum TL (mm) and Weight (g) GBT Rainbows = 123, 15
Maximum TL (mm) and Weight (g) GBT Rainbows = 457, 950
* Min weight on scale was 5 g

Summary:
33 of 34 fish one or a combination of the following Fins: Caudal, Dorsal, Anal, or Pectoral. GBT was almost always apparent on left and right or dorsal and ventral for fins affected.
1 of 34 showed GBT on operculum only. Other occurrences included inner opercula and top of head with some combination of GBT to fins.

Mottled Sculpins
Tallied only, this Pass = 102

Snake River Cutthroat
n = 22
Gas Bubble Trauma (GBT) n = 11
50% Occurrence

Minimum TL (mm) and Weight (g) Non GBT Cutthroat = 363, 370
Maximum TL (mm) and Weight (g) Non GBT Cutthroat = 484, 540
Minimum TL (mm) and Weight (g) GBT Cutthroat = 362, 500
Maximum TL (mm) and Weight (g) GBT Cutthroat = 463, 910

Summary:
11 of 11 fish had GBT on one or a combination of the following Fins: Caudal, Dorsal, Anal, or Pectoral. GBT was almost always apparent on left and right or dorsal and ventral for fins affected.
4 of 11 also had GBT on opercula with some combination of GBT on fins.

Yellowstone River Cutthroat
n = 1
Gas Bubble Trauma (GBT) n = 0

Minimum / Maximum TL (mm) and Weight (g) Non GBT Cutthroat = 305, 260

Pass # 2 (1 fish excluded due to incomplete data)
<u>Brown Trout:</u>
n = 26
Gas Bubble Trauma (GBT) n = 9
35% Occurrence

Minimum TL (mm) and Weight (g) Non GBT Brown Trout = 85, 5 *
Maximum TL (mm) and Weight (g) Non GBT Brown Trout = 228, 125
Minimum TL (mm) and Weight (g) GBT Brown Trout = 100, 5*
Maximum TL (mm) and Weight (g) GBT Brown Trout = 378, 520
* Min weight on scale was 5 g

Summary:
5 of 9 fish had GBT to fins (some damage was unspecified).
1 of 9 had GBT to operculum only.
1 of 9 had GBT to eye only.
2 of 9 had GBT to body (damage was unspecified).

<u>Colorado River Cutthroat</u>
n = 1
Gas Bubble Trauma (GBT) n = 1

Minimum / Maximum TL (mm) and Weight (g) GBT Cutthroat = 198, 80

Summary:
This fish had damage to operculum, and unspecified GBT to fins

<u>Rainbow Trout</u>
n = 41
Gas Bubble Trauma (GBT) n = 8
20% Occurrence

Minimum TL (mm) and Weight (g) Non GBT Rainbows = 64, 5*
Maximum TL (mm) and Weight (g) Non GBT Rainbows = 292, 225
Minimum TL (mm) and Weight (g) GBT Rainbows = 120, 15
Maximum TL (mm) and Weight (g) GBT Rainbows = 190, 45
* Min weight on scale was 5 g

Summary
6 of 8 fish had GBT to fins (some damage unspecified).
2 of 8 fish had unspecified GBT to the Body.
1 of 8 had GBT to the eye, with some combination of unspecified GBT to fins.
1 of 8 had GBT to the operculum, with some combination of unspecified GBT to fins.

Mottled Sculpins
n = 81
Gas Bubble Trauma (GBT) N = 4
5% Occurrence

Minimum TL (mm) and Weight (g) Non GBT Sculpins = 41, 5*
Maximum TL (mm) and Weight (g) Non GBT Sculpins = 146, 50
Minimum TL (mm) and Weight (g) GBT Sculpins = 75, 5*
Maximum TL (mm) and Weight (g) GBT Sculpins = 113, 20
* Min weight on scale was 5 g

Summary:
3 of 4 fish had unspecified GBT to the head.
1 of 4 fish had unspecified GBT to the body.

Snake River Cutthroat
n = 1
Gas Bubble Trauma (GBT) n = 0

Minimum/Maximum TL (mm) and Weight (g) Non GBT Cutthroat = 364, 515

Summary: 2 pass effort

Brown trout
n = 88
Gas Bubble Trauma (GBT) n = 29
33% Occurrence

Colorado River Cutthroat
n = 4
Gas Bubble Trauma (GBT) n = 1
25% Occurrence

Rainbow Trout
n = 200
Gas Bubble Trauma (GBT) n = 42
21% Occurrence

Mottled Sculpins (2nd pass only)
n = 81
Gas Bubble Trauma (GBT) n = 4
5% Occurrence
102 sculpins tallied from first pass

Snake River Cutthroat
n = 23
Gas Bubble Trauma (GBT) n = 11
48% Occurrence

Yellowstone River Cutthroat
n = 1
Gas Bubble Trauma (GBT) n = 0

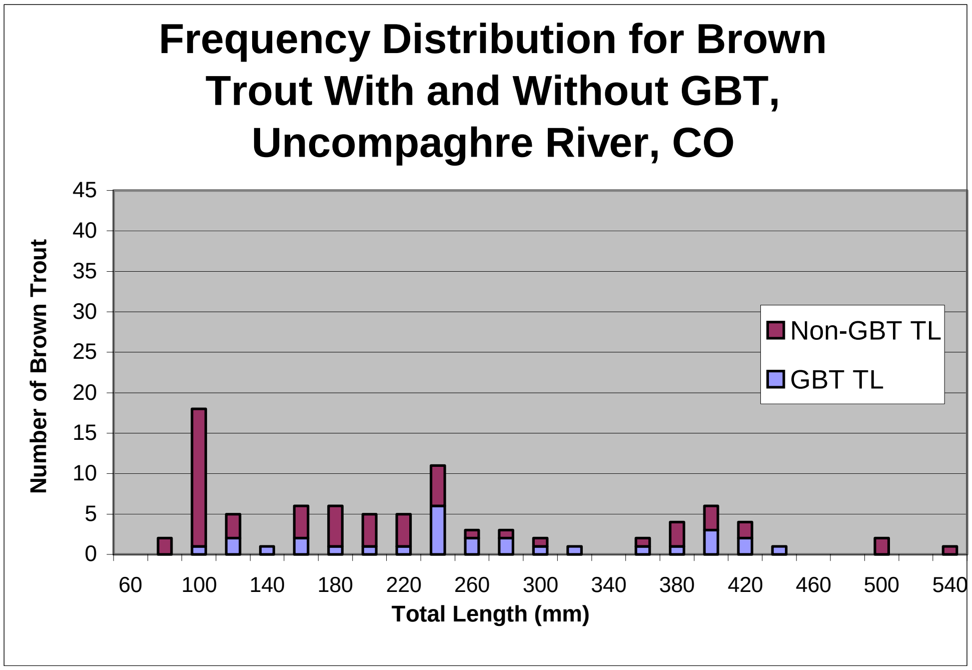

Figure A1. Frequency distribution by 20 mm bin for Brown Trout with and without GBT, two-pass electrofishing effort on 3/26/03 below Ridgway Reservoir, Uncompahgre River, CO.

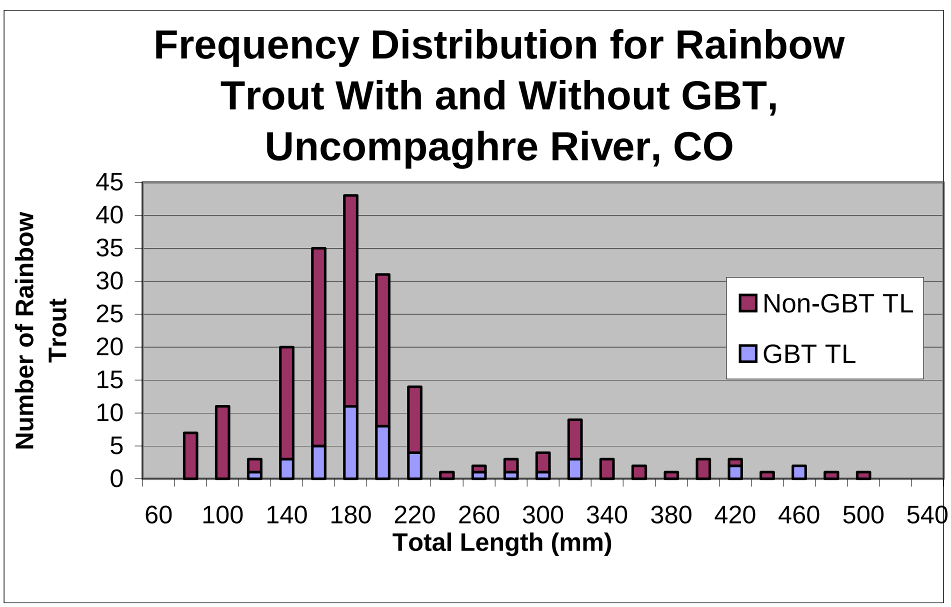

Figure A2. Frequency distribution by 20 mm bin for Rainbow Trout with and without GBT, two-pass electrofishing effort on 3/26/03 below Ridgway Reservoir, Uncompahgre River, CO.

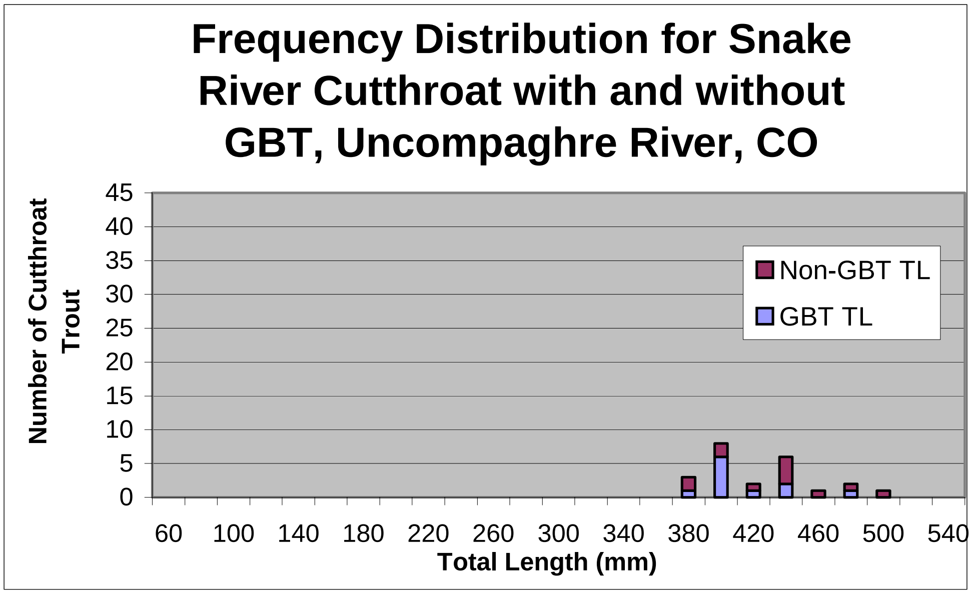

Figure A3. Frequency distribution by 20 mm bin for Snake River Natives with and without GBT, two-pass electrofishing effort on 3/26/03 below Ridgway Reservoir, Uncompahgre River, CO.

APPENDIX C
Photographs

Figure C1. Rainbow trout with severe GBT visible on opercula. White lesions are scar-tissue associated with GBT.

Figure C2. Sub-dermal GBT on dorsal fin.

Figure C3. Mottled sculpin with GBT. Ventral GBT was typical in this species.

Figure C4. Inner opercula bubble formation on a rainbow trout.

Figure C5. Juvenile rainbow trout exhibiting exophthalmia (popeye) due to GBT within the choroid rete mirable

Figure C6. Healthy brown trout with a small lesion on opercula.