Total Dissolved Gas Exchange at Lower Granite Dam, 2002 Spill Season

Prepared For

U.S. Army Engineer District, Walla Walla
201 North Third Ave.
Walla Walla, Washington

by

U.S. Army Engineer Research and Development Center
3909 Halls Ferry Road
Vicksburg, MS 39180

Contents

Contents 2
Preface 3
Executive Summary...4
Background 6
Objective 7
Approach..8
Total Dissolved Gas Properties and Processes 9
TDG Properties 9
TDG Exchange Processes 9
Forebay 9
Spillway..10
Turbine passage 10
Entrainment of powerhouse releases 10
Stilling basin 11
Tailwater Channel...11
Site Characterization...12
Study Design...15
Project Operation..16
Results - TDG Exchange 17
Water Temperature 17
Barometric Pressure 18
TDG Time-History Forebay 18
TDG Time-History Transect T1 19
TDG Time-History Transect LGNW..20
TDG Variation During Constant Spill 21
TDG Summary at All Stations 22
TDG Response Function...23
Spillway Capacity Limited by TDG Variance..23
Tailwater Fixed Monitoring Station Response 24
TDG Exchange for RSW and Non-RSW Spill 25
Model of TDG Exchange 25
Event based analyses of TDG exchange 26
Unaggregated data analyses..31
Conclusions 32
Recommendations...34
Appendix A..35
Water Quality Instrument Calibration and Maintenance 35
Calibration of TDG 35
Calibration of Dissolved Oxygen 36
Water Quality Calibration Data from COE DGAS Field Studies 36
Appendix B Tables 38

Preface

The U.S. Army Engineer District, Walla Walla sponsored this study conducted by the Engineer Research and Development Center (ERDC). The following document represents a total dissolved gas exchange study conducted at Lower Granite Dam and the Snake River during April 3 through July 20 of 2002. Several of the figures referenced in this report are moving pictures containing video footage of flow conditions taken during the spill season and a data animation of project operations and total dissolved gas saturation. Separate files and computer resources are required to view these supporting images.

Any questions or comments regarding this document can be addressed to Mike Schneider 541-298-6872.

E-mail: Michael.L.Schneider@nwp01.usace.army.mil

Executive Summary

An understanding of the total dissolved gas (TDG) exchange characteristics of the Lower Snake River projects is necessary to efficiently manage spillway operations for the benefit of fish passage. In particular, the TDG exchange characteristics associated with the newly configured removable spillway weir (RSW) and test spill management policy at Lower Granite Dam was of interest during the 2002 spill season. This document contains the results from a field investigation of the TDG exchange characteristics at Lower Granite Dam during the 2002 spill season.

The influence of spill at Lower Granite Dam on the TDG properties in the Snake River were found to be a function of the spill discharge, spill pattern, and powerhouse discharge. Reducing the magnitude and frequency of spill at Lower Granite Dam will result in a general lowering of the TDG supersaturation in the Snake River.

The TDG saturation associated with three different spill management policies at Lower Granite Dam were investigated during the 2002 spill season. The three operating scenarios involved spill over the raised spillway crest with accompanying training spill of 8 kcfs and 16 kcfs, and uniform spill over bays 2-8 at the spillway capacity dictated by the Washington State waiver criteria of 120 percent at the tailwater fixed monitoring station. The TDG characteristics of RSW spill with 8-and 16-kcfs training spill resulted in significantly smaller average TDG pressures in the Snake River when compared with spilling to capacity as limited by the TDG waiver standard. The average TDG saturation generated during operation of the RSW with 8 kcfs training spill, the RSW with 16-kcfs training spill, and spilling to capacity over bays 2-8 was 107.6 percent, 109.9 percent, and 117.0 percent, respectively.

The average cross-sectional TDG saturation downstream from Lower Granite Dam during active spill was 113.8 percent as compared to the TDG saturation in the forebay of 103.7 percent. The average increase in TDG saturation in the Snake River caused by spillway operation at Lower Granite Dam was 10.1 percent during the 2002 spill season. This average increase in TDG saturation in the Snake River caused by operations at Lower Granite Dam was significantly higher than conditions observed at other U.S. Army Corps of Engineers' projects in the Snake and Lower Columbia River due to the low background levels.

Observed TDG levels at the tailwater fixed monitoring station frequently exceeded the Washington State waiver criteria of 120 percent saturation even for total spillway discharges as low as 40-45 kcfs. This spillway discharge is considerably lower than the 60 kcfs spill capacity cited in the Water Management Plan draft for the 2003 spill season.

A strong lateral interaction of project releases was apparent at Lower Granite Dam during much of the 2002 spill season. Powerhouse releases were entrained into the highly aerated stilling basin flow and exposed to the TDG exchange processes resulting in elevated TDG loading of the Snake River. The transport of powerhouse flow into the stilling basin was indicated by surface circulation patterns and the frequent presence of elevated TDG saturation downstream of the powerhouse near the left descending bank. In many instances, the entire powerhouse release was redirected into the aerated spillway flows contributing to the resultant TDG pressure in the Snake River. The entrainment discharge was estimated to be equal to the spillway discharge.

The TDG saturation was found to be an exponential function of the unit spill discharge. A spill pattern broadly distributing spill over all eight bays will result in the lowest generation of TDG saturation. The highest TDG saturation observed during the study was 129.4 percent during a spillway discharge of 115.4 kcfs on June 5.

Background

The influence a dam has on the TDG conditions in the Snake River will depend upon the magnitude and frequency of spill and the TDG exchange properties at a given structure. The background TDG characteristic are a critical component in determining the change to the TDG loading in a river caused by a given spill operation. However, the background TDG characteristics have not proven to be an important determinant of the resultant TDG exchange properties in spillway releases. The TDG conditions approaching Lower Granite Dam are generally below 105 percent of saturation. Typical operations calling for spill to aid fish passage at Lower Granite Dam have resulted in the largest increase in average TDG saturation of the four Lower Snake River projects.

Spillway flow deflectors have been installed on all eight spill bays at Lower Granite Dam significantly reducing TDG exchange associated with spill compared to a standard spillway design. Prior to the 2002 season, spill was distributed across all eight bays during voluntary spill for fish operations. A RSW was installed at Lower Granite Dam prior to the 2002 fish spill season. A series of test conditions were scheduled throughout the 2002 season to help evaluate the effectiveness of alternative spill patterns on fish guidance and survival. A companion study was devised to quantify the impact of spill operations on the TDG exchange and near field transport and mixing at Lower Granite Dam.

Objective

The purpose of this field study was to define and quantify processes that contribute to dissolved gas transfer during spill at Lower Granite Dam. In general, the transfer of dissolved gas has been found to be a function of the unit spillway discharge, spill pattern, spillway geometry, stilling basin and tailwater depth and flow conditions, forebay TDG concentration, project head, and water temperature. This study focused on resolving questions regarding the change in TDG saturation in the Snake River cause by project operations at Lower Granite Dam. TDG time history information across the fixed-station sampling array as related to specific project operations was of particular interest. The data were analyzed to provide estimates of the gas transfer throughout the tailwater area and to provide guidance on the relative importance of gas exchange processes within the stilling basin and in the downstream tailrace channel. The specific objectives of the field investigations were as follows:

a. Describe dissolved gas exchange processes (exchange, mixing, transport) in the Lower Granite Dam tailwater for various spillway/powerhouse operational scenarios

b. Provide recommendations for future water quality (WQ) monitoring as needed

c. Provide recommendations for minimizing TDG resulting from Lower Granite Dam project operations

The conclusions drawn from this effort should aid in the identification of operational measures that may reduce TDG supersaturation in the Snake River in the event of spill.

Approach

The spatial and temporal patterns of TDG gas pressures were investigated in the region upstream and downstream of Lower Granite Dam during the period of April 4 – July 19, 2002 using an array of automated water quality logging instruments. The study employed 8 TDG in combination with the existing forebay and tailwater fixed monitoring stations (FMS). The main transect of five TDG pressure logging instruments was located downstream of the highly aerated flow conditions associated with spillway flows and adjacent to the tailwater fixed water quality station. Two additional instruments were located downstream of the spillway and adjacent to the end of the navigation lock guide wall. One last sampling station was positioned near the south shore approximately 400 ft downstream of the powerhouse draft tube deck to detect the frequency of eddy formation below the powerhouse. The spill pattern and total spill discharge were systematically varied during the test with spillway releases ranging from 0 kcfs to 115.4 kcfs. The water quality instruments were deployed along a series of lateral transects and recorded the time history of TDG pressures as operational changes were implemented. Hence, lateral and longitudinal gradients in TDG pressures were investigated both upstream and downstream of the dam.

The real-time operational requirements of Lower Granite Dam provided some limitations to the proposed testing protocol. The duration of most of the scheduled spill events allowed steady TDG conditions to develop at the downstream sampling stations. However, the power production demands at Lower Granite Dam resulted in frequent changes to powerhouse output introducing changes to the flow conditions and the TDG saturation response.

The structural characteristics of Lower Granite Dam are unique among mainstem dams on the Snake River. The operation of the raised spillway weir was cycled on and off throughout the spill season in combination with a wide range of spill patterns and total spill flows. On several occasions, the power production was terminated and 100 percent of the river was spilled. The distribution of powerhouse releases relative to aerated flow changed regularly during the spill season providing an opportunity to quantify the fate of these flows in terms of TDG exchange.

Total Dissolved Gas Properties and Processes

TDG Properties

The TDG pressure in water is composed of the sum of the partial pressures of atmospheric gases dissolved in the water. The primary gases making up TDG pressure in water are oxygen, nitrogen, argon, and carbon dioxide, and the atmospheric composition of these gases are 20.95, 78.087, 0.93, and 0.03 percent, respectively. Henry's Law relates the solubility of a given gas to the partial pressure at equilibrium. The constant of proportionality is called Henry's constant or the Bunsen coefficient that is a function of barometric pressure, temperature, and salinity. The mass of dissolved gases in water can be determined from estimates of the TDG pressure, water temperature, and barometric pressure assuming atmospheric composition of gases in solution. For constant temperature and pressure conditions, the TDG can be represented as either a concentration or pressure in conservation statements.

The solubility of a gas in water is dependent on the total pressure, water temperature, and salinity. The total pressure in the water column is composed of the barometric pressure and hydrostatic pressure. The solubility of gas in water doubles at a depth of about 33 ft. The compensation depth is where the saturation concentration is equal to the ambient concentration in the water. The solubility of water is inversely proportional to the temperature. If the total concentration of dissolved gases is 30 mg/, an increase in temperature of 1^{o} C will result in a reduction in the saturation concentration and an increase in the TDG saturation of 2.2 percent.

TDG Exchange Processes

The TDG exchange characteristics at a hydraulic structure are closely coupled to the system hydrodynamics. As the flow conditions are altered by structural or operation means, the TDG exchange is also modified. The following general description of processes governing TDG exchange at hydropower dams has been formulated based in part upon the theory of mass exchange, laboratory studies, and near field TDG studies conducted as part of the Dissolved Gas Abatement Study (USACE 1997[1]). This discussion focuses upon the hydrodynamic and mass exchange characteristics in four regions: forebay, spillway/turbine passage, stilling basin, and tailwater channel.

Forebay

The TDG properties in the immediate forebay of a dam have generally been found to be well mixed when no thermal stratification is present. Thermal stratification can limit the influence of air/water exchange of gasses to the near surface layers of a pool. The heating or cooling of an impoundment can cause total gas pressure responses that result in supersaturated conditions. Biological activity involving the production or consumption of oxygen will influence the TDG pressure. Therefore, under stratified conditions, the initial TDG pressure of spillway releases may be different from those associated with hydropower releases. TDG levels in the

[1] USACE. (1997). "Dissolved gas abatement study, Phase II," 30 percent draft, U.S. Army Corps Engineer Districts, Portland and Walla Walla, North Pacific Region, Portland, OR.

forebay can change rapidly in response to operations of upstream projects, tributary inflows, and meteorological conditions. The flow under a spillway gate or into a turbine intake may spawn air-entraining vortices that provide a vehicle for air entrainment. In general, the TDG concentrations are not significantly altered by near field flow conditions in the forebay.

Spillway

The depth of flow and water velocities change rapidly as flow passes under the spillway gate onto the face of the spillway. The roughness of the spillway piers and gates may generate sufficient surface turbulence and water spray to entrain air. Flow on the spillway may become aerated for smaller specific discharges as a consequence of the development of the turbulent boundary layer. However, the short time of travel down the spillway will limit the exposure of water to entrained air bubbles to only a few seconds and thereby limit the amount of gas exchange. The entrained air and shallow flow on the spillway may cause desorption of dissolved gases, if forebay levels are elevated.

Turbine passage

There is little opportunity for entrained air to be introduced into the confined flow path through a turbine, except during turbine startup or shutdown, when air may be aspirated into the turbine. Under some conditions it may be advantageous to introduce air into a turbine to prevent cavitation or to smooth operation. When air is introduced into a turbine, the opportunity exists for mass transfer to occur resulting in TDG super-saturation. The extent of TDG transfer in a turbine will be dependent upon the amount of air introduced and the total pressures encountered. In most cases where no air is introduced, there is no appreciable change in TDG pressure as flow passes through the penstock, turbine, and draft tube. The powerhouse simply conveys the TDG properties withdrawn from the forebay pool to the tailwater and does not directly contribute to higher TDG loading.

Powerhouse discharge may either be entrained into spillway flows in the stilling basin or mixed with spillway releases in the river channel downstream from the region of bubbly flow. In many cases, the lateral mixing of powerhouse and spillway releases is complete by the time the combined-release water arrives at the next dam. However, for short pools, the mixing may be incomplete prior to arrival at the downstream dam and thus, complete mixing is not achieved.

Entrainment of powerhouse releases

The high energy content and dissipation rate of spillway flows has the potential to entrain large volumes of water into highly aerated flow contributing to the TDG loading of project releases. When the spillway is adjacent to the powerhouse, a portion of this entrainment flow is supplied directly from powerhouse releases. This entrained flow is exposed to entrapped air bubbles causing some degree of uptake of dissolved gas. The fate of powerhouse discharges varies from project to project and depends upon operating conditions, structural features such as training walls and energy dissipation features, and tailwater channel properties. The findings from the Little Goose spillway performance test (Schneider and Wilhelms 1998[2]) showed that nearly all of the powerhouse flow was entrained into spillway releases and gassed to comparable pressures.

Stilling basin

The flow conditions in the stilling basin are often highly three-dimensional (3-D) and are shaped by the presence of spillway flow deflectors, spill pattern, spillway piers, training walls, baffle blocks, end sill, tailwater pool elevation, project head, and spillway geometry. In general, however, the flow conditions downstream of a spillway are characterized by highly aerated flow transporting air throughout various depths in the stilling basin. The baffle blocks and end sill redistribute the bottom-oriented discharge jet throughout the water column. Because of the high air entrainment and the transport of air to depth, a rapid and substantial absorption of atmospheric gases takes place in the stilling basin below the spillway. These flow conditions result in maximum TDG pressures experienced below the dam. The TDG levels monitored downstream of Ice Harbor Dam stilling basin prior to flow deflector installation, reached as high as 170 percent saturation during a standard spill pattern with an average discharge of 6,000 cfs per spillbay.

Tailwater Channel

A rapid and substantial desorption of supersaturated dissolved gas takes place in the tailwater channel immediately downstream of the stilling basin. As the entrained air bubbles are transported downstream, they rise above the compensation depth in the shallow tailwater channel. While above the compensation depth, the air bubbles strip dissolved gas from the water column. The entrained air content decreases as the flow moves downstream and as the air bubbles rise and escape to the atmosphere. The desorption of dissolved gas appears to be quickly arrested by the loss of entrained air within 200-500 ft of the stilling basin. The reduction of TDG pressures downstream from the aerated flow regime are generally the result of dilution, temperature change, surface exchange, and chemical/biological processes.

The depth of the tailwater channel appears to be a key parameter in determining TDG levels entering the downstream pool. If a large volume of air is entrained for a sufficient time period, the TDG saturation will approach equilibrium conditions dictated primarily by the average depth of entrained air. Thus, mass exchange in the tailwater channel can have a significant influence on TDG levels delivered to the downstream pool during high spill discharges. This process may account for the upper limit on TDG observed at many Corps projects at high spillway discharges.

---

[2] Schneider, M.L. and Wilhelms, S.C. (1998). "Total dissolved gas exchange during spillway releases at Little Goose Dam, February 20-22, 1998," CEWES-HS-L Memorandum for Record, December 10, 1998, U.S. Army Engineer Waterways Experiment Station, Vicksburg, MS.

Site Characterization

Lower Granite Lock and Dam is the upstream-most project on the Lower Snake River, located 107.5 miles above the Snake River confluence with the Columbia River. The main structure includes the powerhouse, spillway and stilling basin, navigation lock, fish facilities, concrete nonoverflow sections, and a rock-filled embankment adjacent to the north shore. The dam spans 3,200 ft including the earthen nonoverflow embankment. An aerial photograph showing the general layout of Lower Granite Lock and Dam is shown in Figure 1.

The powerhouse is located near the south shore with the spillway and navigation lock to the north. The powerhouse consists of six generator bays with a maximum total discharge capacity of 130,000-cfs. The hydraulic capacity of Lower Monumental Dam is similar to Little Goose and Lower Granite. The powerhouse capacity is only 123 kcfs when all units are operated within 1 percent of peak efficiency. The turbine units are numbered from 1 to 6 starting at the south bank.

The Lower Granite spillway is 512 ft long. It has eight 50-ft-wide spillway bays separated by seven 14-ft-wide piers. The spill bays are numbered consecutively from north to south. The spillway crest elevation is 681.0[3]. The spillway discharge is controlled by eight radial (tainter) gates that are 50 ft wide by 60 ft high. The spillway will pass the project design flood of 850,000 cfs, with the maximum pool elevation of 746.5 and the standard project flow of 678,000 cfs with the normal full pool elevation 738.0. A raised spillway crest was added to spillbay 1 during the winter of 2002. The RSW is operated in a full open or closed mode with an average discharge of about 6.8 kcfs.

The energy of flow released through the spillway is dissipated by a hydraulic jump contained within a horizontal apron-type stilling basin. The stilling basin is 188.0 ft long, the floor is set at elevation 580.0 and it has a sloped end sill as shown in Figure 2. A short training wall separates the powerhouse and spillway sections of the dam.

The Lower Granite spillway has deflectors on all eight spillway bays. The deflectors are each set at elevation 630 fmsl, are 12.5-ft long and have a 15-ft radius transition from the slope of the spillway to the horizontal deflector surface. The average submergence of flow over the spillway deflectors at Lower Granite Dam is similar to Little Goose Dam and averages about 7 ft. The deflector design was based upon spillway discharges much greater than typical voluntary spill flow and for higher pool conditions in Lake Bryan.

The tailrace channel below Lower Granite Dam spillway becomes increasingly shallower with distance below the spillway end sill. A section below the north end of the spillway does contain elevations less than 580 ft as shown in Figure 3. The channel bed elevation below the powerhouse quickly increases and diminishes the conveyance channel below the south side of the project. A training wall extending over 100 ft from the north end of the powerhouse separates the south side of the stilling basin from the powerhouse. The elevation of the tailwater channel downstream of the stilling basin generally approached 600 ft at a distance of 800 ft below the

[3] All elevations (el) referenced to the National Geodetic Vertical Datum (NGVD). To convert feet to meters, multiply by 0.3048.

stilling basin. The thalweg of the Snake River channel runs along the north bank of the tailwater channel below the earthen embankment section of Lower Granite Dam. The channel narrows considerably within 1 mile of the dam resulting in a channel width of about 1,000 ft at the location of the fixed monitoring station.

The circulation patterns below Lower Granite Dam are characterized by the strong lateral interaction of spillway and powerhouse discharges. The interaction between spillway and powerhouse releases is prompted by the tailwater channel topography and high entrainment demand generated from spillway flow deflectors. The entrainment of powerhouse flows can be large enough to stall downstream transport along the south bank and result in a counterclockwise eddy forming below the powerhouse. The shallow channel elevations below the powerhouse and deeper channel elevations along the north-channel bank also promote the lateral transport of project releases. The spillway flow deflectors are generally submerged less than 7 ft resulting in a highly turbulent surface jet that entrains large volumes of both air and water. A region of recirculating flow resides beneath the surface jet in the stilling basin drawing flow into the stilling basin. The lock wall bounds project flows from the north and further enhances the entrainment of powerhouse flows. A recirculation cell also forms during spillway releases below the earthen embankment along the northern portion of the tailwater channel. The non uniform spill pattern also results in focusing of flow downstream of bays with higher unit discharge.

The total head at Lower Granite Dam is about 96 ft. The forebay pool elevation is maintained near the lower end of the operating range at 733 ft during the spill season. The tailwater elevation varies as a function of storage in Lake Bryan and total river flow. The 90 percent confidence interval for tailwater elevation ranged only 5 ft from 633.3 to 638.3 ft during the 1994 - 2000 spill season. The 10-year, 7-day average flow through Lower Granite Dam is 228,000-cfs; the peak average mean daily discharge is approximately 120,000-cfs, and the average discharge throughout the spring juvenile fish out-migration period of April 3 to June 21 is approximately 90,000-cfs.

The TDG exchange at Lower Granite Dam has been found to be a function of the unit spill bay discharge, powerhouse discharge, and tailwater elevation. The in-pool TDG exchange associated with the standard spill patterns at Lower Granite Dam were investigated during June 6-14, 1997 (60 percent Dissolved Gas Abatement Study (DGAS) Report). The standard spill pattern using all eight bays was found to produce average TDG saturations of 115, 120, and 125 percent for spillway discharges of 45, 64, and 90 kcfs, respectively. The powerhouse discharges were found to significantly contribute to the TDG load delivered to the Snake River downstream of Lower Granite Dam. The historic TDG observations indicate the largest increase in TDG saturations on the Lower Snake River occur at Lower Granite Dam due to the lower background levels. The entrainment discharge was estimated to be as large as 75 percent of the spillway discharge. The evaluation of TDG saturations at the fixed monitoring station has shown that TDG exchange is a function of the unit spillway discharge and the tailwater elevation. Higher tailwater elevations have been found to be directly related to TDG generation. This description of TDG exchange was based upon the data observed at the tailwater fixed monitoring station and the conditions observed in the forebay of Little Goose Dam.

The TDG pressure is monitored in the Lower Granite forebay at the end of the lock guide wall in the tailwater about 0.65 miles downstream of the spillway on the north bank. The tailwater FMS generally reflects the conditions in spillway releases based upon lateral observations of TDG pressures at the tailwater sampling station. The TDG saturations arriving at Lower Granite Dam rarely exceed 110 percent saturation during the spill season. The TDG saturation approaching Lower Granite Dam is influenced by the TDG and water temperature conditions entering Lower Granite pool. The frequency of exceeding the TDG waiver standard of 120 percent at the tailwater FMS has varied widely during the past 7 years, ranging from 0 percent in April-June during 1994 and 1995 to 57.9 percent during the high flow conditions in 1996. The frequency of TDG waiver violations at the tailwater FMS during 1998 - 2000 ranged from 3.0 percent to 24.4 percent. In two of these three years, the frequency of violations of the TDG waiver standards downstream at the Little Goose forebay has exceeded the frequency of violations at the Lower Granite tailwater FMS. Under many conditions, the high TDG levels arriving at Little Goose Dam can constrain operations at Lower Granite Dam.

Study Design

An array of eight TDG instruments was deployed in the Snake River in addition to the forebay and tailwater FMS, to measure the TDG pressures approaching and exiting Lower Granite Dam. The TDG pressures above and below Lower Granite Dam were sampled from April 1 through July 20. The sampling frequency varied from 15-, 30-, and 60-min intervals, depending upon sampling location. The TDG pressure, water temperature, instrument depth, and instrument voltages were measured at the sampling stations during the study period. The auxiliary sampling stations were deployed on the bottom of the channel in heavy steel housings. The general locations of all TDG sampling stations and transects are shown in Figure 4. The general objective of the sampling array was to determine the change in TDG saturation in the Snake River caused by Lower Granite Dam operations.

The forebay TDG pressure was recorded on an hourly interval from the fixed monitoring station (LWG) maintained by the Walla Walla District. A TDG instrument was deployed from the floating lock guide wall in the forebay (FB) of Lower Granite Dam at a depth of about 15 ft. The depth of this instrument was fixed but the elevation changed as the forebay elevation fluctuated during the study. The sampling location of this forebay station is shown in Figure 4. A vertical array of thermistors was deployed in the forebay of Lower Granite Dam during the summer months of 2002. This data provided additional insight into thermally induced TDG fluctuations in the forebay during periods of stratification.

The first downstream transect composed of three sampling stations, was sited below the highly aerated flow conditions generated during spillway operations at Lower Granite Dam. Two stations were located on the channel bottom near the end of the downstream lock guide wall about 1,145 ft downstream from the stilling basin as shown in Figure 4. The station T1P3 was located adjacent to the lock guide wall while station T1P2 was directly downstream from spill bays 7 and 8. The third sampling station (T1P1) was deployed from the left channel bank about 460 ft downstream of the powerhouse. The purpose of this sampling transect was to capture the TDG saturation of waters immediately downstream from the powerhouse and spillway prior to further mixing of these two sources. The water quality data was recorded at 30-min intervals for these sampling stations.

The second downstream sampling transect was designed to measure the TDG loading or cross-sectional average TDG pressure throughout the study period. A series of six instruments were located about 1 mile below the dam near the tailwater fixed monitoring station (LGNW). Five stations were deployed on the channel bottom and distributed across the channel near the tailwater fixed monitoring station as shown in Figure 4. These instruments recorded water quality data on a 30-min interval during the period from April 4-May 21 and on a 15-min interval from May 21 to July 20. The tailwater fixed monitoring station (LGNW), was located in a steel conduit deployed from the right channel bank, and completed the sampling stations on this transect.

This array of automated logging TDG instruments provided a nearly continuous record of the change in TDG saturation in the Snake River associated with Lower Granite Dam operations during the 2002 spill season. The project operations were not altered from standard conditions to accommodate the TDG sampling during the 2002 season.

Project Operation

The average Snake River flow at Lower Granite Dam during the 2002 spill season was 83.2 kcfs with a maximum river discharge of 144.9 kcfs. The spillway discharge averaged 34.7 kcfs at Lower Granite Dam during the 2002 spill season, which began on April 3 and was completed on July 16. The average percent of river spilled was 43.3 percent during active spill events as listed in Table 1. The tailwater elevation averaged 634.3 ft resulting in an average deflector submergence of only 4.3 ft and an average stilling basin depth of 54.3 ft. The total project head remained relatively constant during the sampling period at about 100.3 ft.

The Snake River experienced a dual peaked hydrograph during the 2002 spill season with the initial peak flows occurring during April 14 with a longer duration peak runoff during the first week in June. The time-history of project operations and tailwater elevation are shown in Figure 5. The detailed operations at Lower Granite Dam detailing the individual turbine and spill bay flows on a 5-min interval was available from April 18 through July 20. These records were used to identify when the raised spillway weir was in operation and the characteristics of alternative spill patterns. The line labeled Q_{rsw} in Figure 5 shows when spill bay 1 (RSW) was active. During the period from April 1 through July 31, spill using Bay 1 (RSW) occurred during 41.3 days compared to only 28.9 days of spill over bays 2-8. About three-quarters of the spill occurred during discharges less then 50 kcfs and only 5.3 percent of the spill was greater than 60 kcfs as listed in Table 2.

There were several periods when the powerhouse was shut down and 100 percent of the river was spilled. On June 5 and again on June 10, the entire river was diverted through the spillway for a portion of the day. These events provided a short glimpse of exchange conditions without the influence of powerhouse flows.

The daily schedule of spillway releases varied widely over the spill season. One spill policy called for spilling to the TDG wavier condition during the nighttime hours followed by no spill during the daylight hours. The spill conditions during April closely adhered to this policy. A second spill policy called for long duration moderate spill using the RSW in conjunction with a training spill discharge. The month of May was dominated by this alternative spill policy. The high flow events in June dictated forced spill typically with discharges greater than 50 kcfs scheduled during the nighttime hours. The spillway releases were grouped into discreet events to help summarized study findings. A spill event was defined by a duration of spill 1 hour or longer. A total of 205 spill events were identified during the 2002 spill season at Lower Granite Dam as summarized in Table 3.

Results - TDG Exchange

A total of auxiliary TDG instruments were deployed on April 1 below Lower Granite Dam to compliment the existing forebay and tailwater fixed monitoring stations. The instruments, with the exception of T1P2 and T1P3, were serviced on May 21 and removed on July 16. All of the water quality instruments were successfully recovered from this investigation. However, not all of the water quality instruments functioned properly throughout the entire study period. The instrument at station T1P1 failed to function from April 3-May 21. The instruments deployed at station LGNWP5 also failed during the study period from May 22 to June 29 and again from July 9 to July 16. A pre- and post calibration of all the instruments was performed as documented in Appendix A. There was no need to adjust any of the TDG pressures collected during the study based upon the data quality assurance evaluation.

The TDG saturation was calculated using the atmospheric pressures collected at the forebay and tailwater fixed monitoring stations. The delta TDG pressure was also determined by taking the difference between the TDG pressure and the atmospheric pressure. These data were then integrated into a relational Microsoft Access database for processing.

A general statistical summary of the TDG saturation determined from the 10 sampling stations are listed in Table 4. The TDG saturation in the forebay averaged about 103.7 percent but experienced a maximum TDG saturation of 113.5 percent. The forebay TDG saturation exceeded 110 percent only 1.1 percent of the time. The TDG saturation immediately downstream of the spillway on stations T1P2 and T1P3 averaged about 115 percent saturation with maximum TDG saturations of 128.3 and 125.8 percent, respectively. The TDG pressures exceeded 115 percent saturation at these sampling stations over 50 percent of the time. The TDG saturation at station T1P2 exceeded 120 percent saturation over 25.8 percent of the time. The average TDG saturation for the complete time-history at the tailwater fixed monitoring station LGNW and LGNWP4 were nearly identical to conditions on Transect T1 below the spillway (T1P2 and T1P4). The TDG saturation at the tailwater fixed monitoring station exceeded 120 percent about 19.1 percent of the time.

Water Temperature

The water temperatures in the Snake River are an important component of the TDG concentrations generated during spillway operations. The water temperatures ranged from 6^o C in April, to 23^o C in July. The influence of weather systems generated a cyclical rise and fall of water temperatures throughout this study period. Daily temperature changes as high as 1^o C were observed at the tailwater FMS and 2-3^o C at the forebay FMS. The presence of warmer water temperatures at the forebay FMS in comparison to the tailwater temperatures was a periodic condition during April and May, but a persistent condition during the summer months. The warmer temperatures in the forebay were caused by thermal stratification of the Snake River and resulted in a corresponding rise in TDG pressures. The thermally induced rise in TDG pressure resulted in observed TDG pressures that were not representative of average conditions in the forebay of Lower Granite Dam. Cold water inflow from the Clearwater River also contributed to the development of thermal stratification in the forebay of Lower Granite Dam. The time-history of water temperatures at the fixed monitoring stations is shown in Figure 6. The forebay water temperatures exceeded the tailwater temperatures by almost 1^o C in early April. On July 13, the forebay water temperature approached 23^{o} C while the tailwater temperatures remained at or below 19^{o} C. The instantaneous water temperature at the forebay station remained warmer than the tailwater temperature beginning in July of 2002.

Barometric Pressure

The barometric pressure (BP) below Lower Granite Dam at station LGNW ranged from 735 mm Hg to 758 mm Hg during the study period of 4 April through 19 July, 2002, as shown in Figure 7. BP data were collected at both the forebay and tailwater TDG fixed monitoring stations (LWG, LGNW), which were maintained by the Walla Walla District. The TDG saturation at the forebay FMS were calculated using BP values reported at the forebay fixed monitor. Barometric pressure data from the tailwater fixed monitor was used to calculate TDG percent saturations and delta pressures at all sampling stations located below the dam. The variation in barometric pressure influences the calculated TDG saturation as well as the total pressure exerted on entrained air during spillway releases.

TDG Time-History Forebay

The TDG saturation in the forebay of Lower Granite Dam can be characterized by reviewing both the TDG saturation at the forebay station (LWG) and the TDG saturation at the tailwater stations during periods of no spill. The TDG saturation observed at the forebay station generally agreed with observations at the tailwater stations during periods when no thermal stratification existed in the forebay and no spill was scheduled. The comparison of forebay and tailwater TDG saturation during April was instructive because of the infrequent occurrence of thermal stratification and frequent occurrence of no spill. The time-history of project operations and TDG saturation at all monitoring stations are shown in Figures 8-15. The variation in the forebay TDG saturation in April (Figures 9-10) ranging from 100-105 percent was closely reflected in the TDG observations in the tailwater during periods of no spill. These data support the hypothesis that water passage through a powerhouse and adjoining tailrace channel do not change the TDG saturation. The exception to this statement occurs when air is aspirated into a turbine during rough operating conditions typically occurring during start-up or shutdown sequences. These data also support the conclusion that the TDG saturation in the forebay can be inferred by tailwater observations when no water is being spilled.

As the season progressed, the likelihood of thermal stratification in the forebay increased until a continuous period of stratification developed in late June and July. The frequency of the TDG saturation observed at the forebay station (LWG) exceeding 105 percent increased significantly during the first 2 weeks in July and reached a maximum level of about 117 percent on July 13 (Figure 15). The TDG saturation at forebay station (LWG) was consistently greater than observations in the tailwater during periods of no spill in July, as shown in Figure 15. These data at the forebay station (LWG) reflect the elevated TDG saturation in the warmer surface waters of Lower Granite pool during July. However, these forebay TDG pressures were not representative of waters located below the surface that make up the bulk of waters released by powerhouse operation. A review of all the TDG saturation data during the entire spill season supports the conclusion that the average TDG saturation above Lower Granite Dam ranged from 100 to 107 percent. There were lengthy periods when the average TDG saturation in the forebay could not be determined from the data because of thermal stratification in the forebay and spill related operations influencing the tailwater TDG levels. The observations of forebay TDG saturation exceeding the water quality criteria of 110 percent were localized to surface waters and were not representative of average river conditions during the 2002 spill season. These warmer forebay surface waters do contribute to conditions in fish passageways and ladders. The stratified flow conditions in the forebay of Lower Granite Dam will also influence water movement into the RSW and turbine intakes. A number of ongoing studies are designed to characterize the near field thermal characteristics at Lower Granite Dam and the related impacts to fish guidance.

TDG Time-History Transect T1

The TDG saturation observed on Transect T1 frequently reflected the extreme conditions discharged by Lower Granite Dam during a given operation. The station T1P2, located below the spillway, generally experienced the highest TDG pressures observed below the dam. The proximity of station T1P2 to spill bays with the highest specific discharge (kcfs/bay) is likely the cause of the frequent occurrence of the greatest TDG saturation at this station. Station T1P1, located against the left channel bank below the powerhouse, frequently recorded the lowest TDG saturation observed below the dam. Elevated TDG pressures above forebay conditions on station T1P1 indicated the presence of a recirculation cell downstream of the powerhouse. The general circulation patterns below Lower Granite Dam were recorded during May 30 during a spill discharge of 59.6 kcfs and a total river flow of 134.9 kcfs, as shown in Figure 16. A strong return current was present below the powerhouse with powerhouse releases directed into the aerated flow conditions in the stilling basin. Downstream transport of TDG saturations similar to forebay levels was observed at station T1P1 during low percent spill events (Figures 12-15).

The correlation between elevated TDG saturation on Transect T1 and spill operations is clearly illustrated in Figures 8 to 15. The TDG saturation on Transect T1 drops to background levels during periods of no spill and quickly rises to elevated TDG pressures during spillway releases. About 90 percent of the average increase in TDG saturation is achieved during the first 30 min of a spill event and equilibrium conditions are reached after about 1 hr of constant operation.

The TDG saturation time-history at stations T1P2 and T1P3 were similar throughout the study period. The TDG saturations at these stations were generally within 2 percent saturation of each other. The spill discharges greater than 50 kcfs resulted in a slightly higher TDG saturation on station T1P2 when compared to T1P3. The TDG saturation on station T1P2 averaged 115.3 percent and ranged from 101.2 to 128.3 percent saturation, as shown in Table 4. The TDG saturation at station T1P2 exceeded 110, 115, 120, and 125 percent saturation about 75, 56.3, 25.8, and 3.8 percent of the time respectively, during the sampling period.

The TDG saturation remains nearly constant during periods of constant project operation as shown during events 162 or 183 in Figure 14. The TDG saturation at stations T1P2 and T1P3 also appear to be directly related to the magnitude of spill discharge with higher spill rates resulting in higher TDG saturation. An increase in spill discharge was almost always associated with an increase in TDG saturation at stations T1P2 and T1P3. The change in spill pattern can also result in changes to the TDG saturation observed at these stations. The total spill discharge was held constant during events 149-151 on June 18-19 while the spill pattern was modified as shown in Figure 17. The increase in the TDG saturation in the Snake River at stations T1P2 and T1P3 between events 145 and 146 was likely caused by the increase in the specific discharge resulting from a spill pattern change from 8 to 7 bays.

The change in powerhouse discharge was also found to change the TDG saturation observed at stations T1P2 and T1P3. On June 17 and 18, the spill discharge was held constant during event 141 at 34.9 kcfs while the powerhouse discharge varied from 25 to 75 kcfs, as shown in Figure 18. The TDG saturation was observed to range from 116 percent during the high river flow conditions, to a peak value of 119 percent during the low river flow conditions. The variation in TDG content of spillway releases resulting from changes in powerhouse flow may be related to changes in the skimming flow conditions generated by different deflector submergences, the ratio of bubble surface area to water volume, and the transport of water from specific spill bays.

The TDG saturation below the powerhouse at station T1P1 can be used as an indicator of the degree of entrainment of powerhouse releases into the stilling basin at Lower Granite Dam. The presence of elevated TDG pressures at this station indicates the transport of waters exposed to elevated rates of TDG exchange associated with the highly aerated flow conditions in the stilling basin and tailwater channel. The appearance of waters with TDG pressures similar to forebay conditions indicates a predominant downstream transport of powerhouse flows independent from waters associated with spillway releases.

The TDG saturation at station T1P1 was first available during May 21, as shown in Figure 12. The TDG saturation was highly variable at this station for some flow conditions, which may be a consequence of transient flow conditions and changing operations. The occurrence of TDG pressures in excess of background conditions at station T1P1 was a function of the percent of river spilled, with higher ratios of spill to total flow resulting in an increased likelihood of elevated TDG pressures. The spillway discharge was held constant at about 40 kcfs during May 21-22 with the total river flow ranging from 95 to 120 kcfs during event 70. The appearance of elevated TDG saturation at station T1P1 was observed when the total river flow dropped below 100 kcfs or when at least 40 percent of the river was spilled. The entire river was spilled on June 10 resulting in the maximum TDG saturation located at station T1P1.

TDG Time-History Transect LGNW

The TDG saturation observed in the Snake River adjacent to the tailwater fixed monitoring station on Transect LGNW were consistent with observations from Transect T1. The TDG saturation generally increased from left to right bank in accordance with a diminished influence from powerhouse releases. The TDG saturation at the tailwater FMS were similar to the data collected near the right channel bank at station LGNWP5. The peak TDG saturation observed in Transect T1 was similar to the TDG saturation observed at the tailwater fixed monitoring station for prolonged duration spill events. The presence of TDG pressures similar to forebay conditions on Transect LGNW was limited to events with no spill. The elevation of TDG saturation across the entire river implies a significant interaction of powerhouse and spillway flows in the short river reach below the project.

The TDG exchange response to project operations in the Snake River was clearly apparent in the data on Transect LGNW. The influence of spill pattern, spill discharge, and powerhouse discharge were clearly reflected in the TDG conditions on this transect, as shown in Figures 19-26. The TDG saturation on Transect LGNW drops to background levels during periods of no spill and quickly rises to elevated TDG pressures during spillway releases. The time of travel to Transect LGNW resulted in a slightly slower response to operational changes compared to conditions on Transect T1. The TDG saturation on stations LGNWP3 and LGNWP2 approached equilibrium conditions within 1 hr of an operational change. The nearshore stations required a little longer time to reach these steady conditions due to the lower velocities associated with this flow path.

The TDG saturation time-history at stations LGNW and LGNWP5 were similar throughout the study period. The TDG saturation at these stations was generally within 1 percent saturation of each other. The TDG saturation on station LGNW averaged 115.2 percent and ranged from 99.9 to 124.7 percent saturation as shown in Table 4. The TDG saturation at station LGNW exceeded 110, 115, 120, and 125 percent saturation about 81.8, 56.5, 19.1, and 0.0 percent of the time respectively, during the sampling period. The statistical summary of TDG saturation over the entire sampling period at station LGNW was similar to conditions observed at stations T1P3 and LGNWP4.

The peak TDG saturation on Transect LGNW was often observed at the fixed monitoring station for low to moderate percent spill conditions. The peak TDG saturation during high percent spill conditions was often located near midchannel at station LGNWP3. During spill events 102 and 105 shown in Figure 24, the TDG saturation on station LGNWP3 was 2-4 percent saturation higher than observed at the tailwater fixed monitoring station. There were a limited number of events where the peak TDG saturation was located closer to the left bank at station LGNWP2. During event 45, the peak TDG saturation was consistently located at station LGNWP2, which was 3-4 percent higher than recorded at the FMS (LGNW).

Another noteworthy feature of the TDG saturation observed across the LGNW transect was the similarity in response across the entire river. The background TDG conditions were not found on Transect LGNW during spill, even when most of the river was passing through the powerhouse. The elevation of TDG saturation across the entire transect implies a significant interaction of powerhouse and spillway flows in the short river reach below the project either through entrainment directly into the stilling basin or mixing with spillway releases after the bubbles were vented from the flow.

TDG Variation During Constant Spill

The spill events on June 18-19, 2002 reflect many of the prominent operational characteristics influencing the TDG characteristics in the Snake River downstream of Lower Granite Dam. This series of events was unique in that the spill discharge was held constant while the spill pattern and powerhouse discharge was varied. The time-history of project operations and the TDG saturation at the tailwater fixed monitoring station are shown in Figure 17.

On June 18 at 3 p.m., spill event 144 was initiated where the spillway discharge was set to 42 kcfs distributed over bays 4-8 for a unit discharge of 8.6 kcfs/bay. The TDG saturation approached equilibrium conditions at the tailwater fixed monitoring station that ranged from 117 percent to 123.5 percent with an average of 120.5 percent. Spill event 145 distributed the same flow rate over all eight bays resulting in a net reduction in the unit discharge to 5.4 kcfs/bay. The powerhouse flows were altered during the first half of this event but were returned to nearly the same rate as event 144 during the second half of this event. The average TDG saturation during the second half of event 145 of 116.5 percent was about 4 percent less than generated for the same spill and powerhouse discharge as event 144. Reducing the unit spill discharge from 8.6 to 5.4 was likely the cause for the reduction in the TDG saturation for these two conditions. This difference represents a net reduction in the TDG loading of the Snake River and demonstrates the gas abatement benefits of broadly distributing spillway discharge across all eight spill bays at Lower Granite Dam.

The spill pattern was changed again during event 146 while the total spill discharge was held constant. The RSW was shut down during event 146 and the flow over bays 2-8 was increased to 5.8 kcfs/bay to make up the difference in total spill flow. Although small changes in TDG saturation were observed at individual stations, the average cross-sectional TDG saturation remained nearly the same at 116.5 percent. The spill discharge and pattern for event 149 was identical to event 144 (42 kcfs @ 5 bays) and the resultant TDG distribution and average was also reproduced. The spill discharge and pattern for event 150 was identical to event 146 (42 kcfs @ 7 bays) and also produced similar TDG conditions. All throughout this period when spillway discharge was held constant, an increase in powerhouse flow resulted in a reduction in TDG saturation across the entire river. The TDG saturation at the fixed monitoring station ranged from 117 percent to 122 percent for a constant spillway discharge of about 42 kcfs in response to changes in spill pattern and powerhouse discharge. Therefore, the ability to predict the outcome of a given spill discharge can be improved by knowledge of the spill pattern and powerhouse flow.

TDG Summary at All Stations

The TDG saturation and operational pattern were summarized on a 15-min interval for the entire study period. The lateral position in the river channel of each station was normalized by the channel width at each transect. The distance used to present these findings ranged from 0 (left bank) to 1 (right bank). The lateral distribution of TDG saturation at all sampling transects on May 30 at 1100 hours is shown in Figure 27. The bar chart in the lower left hand corner of this figure shows the instantaneous turbine and spill bay discharge. The lateral distribution of TDG saturation at each sampling station is shown in the upper left-hand quadrant of this figure. The legend of the TDG lateral distribution contains the date and time of the data presented along with the total river flow and spill discharge. A 6-hr time-history window (previous 3 hr and next 3 hr) of project operation and TDG saturation at selected stations is displayed in the right hand side of this figure.

The lateral distribution of TDG saturation varied widely during the study period as a function of spill pattern, spill discharge, and powerhouse flow. Notable features of the lateral TDG distribution was the uniformity in elevated TDG saturation across the channel during low percent spill conditions. The highest TDG pressures were often present at station T1P2 and the lowest TDG pressures were located on the left channel bank at station T1P1. A data animation of project operations and TDG saturation can be viewed in Figure 27 by clicking on the figure in the digital version of this document (requires file lwgtdg02.avi). The change in spill pattern, spill discharge, and powerhouse discharge can be seen in the distribution of TDG saturation on Transect LWGN.

Data Analyses - TDG Exchange

TDG Response Function

The TDG saturation observed in spillway releases were influenced by the spill rate, spill pattern, and powerhouse flow. The TDG saturation was found to be an exponential function of the unit spill discharge or discharge per foot of active spillway width. The rate of increase in TDG saturation decreases for increasing unit spillway discharge reaching an upper limit during high spillway discharges. The highest TDG saturation observed during the study was 129.4 percent during a spillway discharge of 115.4 kcfs on June 5. An inverse relationship was often observed during nonforced spill conditions between powerhouse flow and the TDG saturation associated with spillway flows. Increasing powerhouse releases frequently caused a moderate reduction in the TDG saturation in spill waters.

Spillway Capacity Limited by TDG Variance

The spillway discharge resulting in TDG saturation at the tailwater fixed monitoring station of 120 percent is an important characteristic when developing and implementing a spill management policy. A spill event generating TDG saturation greater than 120 percent based on the highest 12-hr average of daily observations will constitute a violation of the Washington State TDG wavier criteria. The daily averaging of TDG observations allows for TDG levels to exceed 120 percent for limited time periods. A second criteria specified in the Washington State waiver standard requires no hourly observation to exceed 125 percent of saturation at the tailwater fixed monitoring station.

An attempt to quantify the likelihood of exceeding these TDG waiver standard criteria was conducted using the TDG observations at Lower Granite Dam during the 2002 spill season. The hourly observations at the tailwater fixed monitoring stations were first filtered to include only those observations associated with spill events of 1-hr duration or longer. This filtering removed observations where equilibrium conditions were not established at the tailwater fixed monitoring station. The remaining observations were then grouped in 5 kcfs spill increments from 5-10 kcfs to 110-115 kcfs and a statistical summary by spill discharge grouping was conducted, as found in Table 5.

The first series of statistical operations on each data cluster summarizes the number of hourly observations (N), the average TDG saturation (Avg), the maximum (Max) and minimum (Min) TDG saturation. The average TDG saturation generally increases as the spillway discharge increases with spill discharges in the range of 15-20 kcfs averaging 108.6 percent, 45-50 kcfs averaging 119.7 percent, and 85-90 kcfs averaging 122.3 percent. The increase in TDG saturation follows an exponential function of spillway discharge where the rate of increase in TDG saturation continually declines until an upper threshold is reached. The number of observations defining this upper threshold is limited for spillway discharges greater than 70 kcfs using the 2002 TDG data, but generally was on the order of 123-124 percent.

A large variance in TDG saturation was determined for each spillway discharge range using observed hourly data from the tailwater fixed monitoring station downstream of Lower

Granite Dam. The second set of statistics characterizing the variability of TDG observations within each spillway discharge range was determined from the 2002 spill data. The TDG saturation associated with the 5th, 25th, 50th, 75th, and 95th percentile were determined for each spillway discharge range, as listed in Table 5. The median (50th percentile) TDG saturation is generally similar to the average TDG saturation for a spillway discharge range. One-half of the TDG observations within a spillway discharge range are defined by the 25th and 75th percentiles. Similarly, 90 percent of the observations fall within the range of TDG saturations defined by the 5th and 95th percentiles. For the spillway discharge range of 40-45 kcfs, the 50 percent confidence interval ranged from 117.9 to 119.9 percent saturation and the 90 percent confidence interval ranged from 115.8 to 121.6 percent. The wide range in TDG saturation suggests that there is some likelihood that spillway discharges of 40-45 kcfs will result in a TDG saturation greater than 120 percent at the tailwater fixed monitoring station. The source of variability in TDG saturation within a narrow range of spill discharge is associated with variability in spill pattern, spill magnitude, powerhouse load, and barometric pressure.

The occurrence of exceeding TDG saturation levels of 110, 115, 120, and 125 percent were summarized for each spill discharge range, as listed in Table 5. For spill discharges ranging from 40-45 kcfs, the probability of exceeding 120 percent was 24.6 percent during the 2002 spill season. The probability of exceeding 120 percent at the tailwater FMS increased to 48.9 percent for spillway flows ranging from 50-55 kcfs and 71.0 percent for spillway flows ranging from 55-60 percent. This spillway capacity of 60 kcfs spill capacity was listed in the Water Management Plan draft for the 2003 spill season for Lower Granite Dam. A spill discharge of 60 kcfs has a high chance of exceeding 120 percent at the tailwater fixed monitoring station based on TDG data collected during the 2002 spill season. The likelihood of exceeding the water quality waiver must also take into consideration the hourly schedule of spillway releases during any given day.

Tailwater Fixed Monitoring Station Response

The tailwater fixed monitoring station (LGNW) located about 0.65 mile below the spillway on the right bank is used to determine compliance with the Washington TDG variance. The instantaneous TDG criteria is 125 percent while the average of the highest 12-hr observations in a day is not to exceed 120 percent of saturation. The array of TDG stations across the river from the tailwater FMS allowed the characterization of the tailwater FMS in terms of average and maximum TDG saturation in the Snake River. The event average TDG properties were used to summarize conditions at the tailwater FMS transect, as listed in Table 6. In about one-half of the 205 spill events (51.4 percent), the maximum TDG saturation was observed at the FMS station LGNW. In about 79 percent of the spill events monitored during the 2002 spill season, the average TDG saturation at the tailwater FMS (LGNW) was within 1 percent saturation of the maximum observed level. The maximum TDG saturation in the Snake River at the tailwater monitoring station exceeded the conditions at the tailwater FMS by 1, 2, and 3 percent saturation for 21.3, 13.2, and 3.4 percent of the events. The maximum TDG saturation occurred away from the channel bank during events with a high percentage of the river spilled. A summary of the difference between the FMS saturation and the maximum observed TDG saturation at the LGNW Transect is listed in Table 6.

Lateral gradients in TDG saturation were frequently observed in the Snake River below Lower Granite Dam at the tailwater FMS transect. A comparison between the weighted average TDG pressures at the tailwater FMS transect and at station LWGN was conducted using the event-averaged conditions. The TDG saturation was less than the event based cross-sectional average about 23 percent of the time and greater than the cross-sectional average in 77 percent of the cases. The TDG saturation at the tailwater FMS was within ±1 percent of the average cross-sectional average TDG saturation in only about 29.2 percent of the events. The tailwater FMS infrequently reflects the cross-sectional average TDG saturation conditions in the Snake River.

The TDG saturation at the tailwater fixed monitoring station was compared to the TDG exiting the spillway as observed at station T1P3 for event-averaged conditions during the 2002 spill season. The event-averaged conditions observed at station T1P3 were highly correlated with conditions observed downstream at station LWGN, as shown in Figure 28. A simple linear regression between these two stations for events of 2 hr duration and longer resulted in a correlation coefficient of 0.98. This comparison clearly shows that water exiting the spillway on the north side is very similar to the conditions monitored downstream at the tailwater fixed monitoring station (LWGN). Lateral gradients in TDG saturation below Lower Granite Dam are caused by heterogeneities in TDG produced in the stilling basin and the entrainment and mixing associated with powerhouse releases.

TDG Exchange for RSW and Non-RSW Spill

The TDG saturation associated with three different spill management policies at Lower Granite Dam were investigated during the 2002 spill season. The three operating scenarios involved spill over the raised spillway crest with accompanying training spill of 8 kcfs and 16 kcfs and uniform spill over bays 2-8 at the spillway capacity dictated by the Washington State waiver criteria of 120 percent at the tailwater fixed monitoring station. The TDG characteristics associated with RSW spill with 8 kcfs training spill resulted in a significantly smaller increase in the average TDG loading of the Snake River when compared with the other two spill events.

The three spill patterns evaluated during the 2002 spill season consisted of spill through the raised spillway weir crest located in spill bay 1, with 8 kcfs (RSW+8) and 16 kcfs (RSW+16) training spill flow, and uniform spill over spill bays 2-8 (U2-8) up to the Washington State waiver criteria of 120 percent at the tailwater fixed monitoring station. The capacity spill discharge associated with 120 percent at the tailwater FMS was selected to range from 40-45 kcfs for this comparison. Spill using the RSW with 8 kcfs training flow resulted in the average TDG saturation in the Snake River of 107.6 percent, as listed in Table 7. The net increase in the TDG saturation in the Snake River averaged 4.5 percent during the RSW+8 events. Spill using the RSW with 16 kcfs training flow resulted in an average TDG saturation in the Snake River of 109.9 percent. The net increase in the TDG saturation in the Snake River averaged 7.1 percent for the RSW+16 events. Uniform spill of 40-45 kcfs over bays 2-8 resulted in an average TDG saturation in the Snake River of 117.0 percent with a net increase in the TDG saturation in the Snake River of 13.7 percent.

Model of TDG Exchange

The estimation of TDG exchange at Lower Granite Dam will aid in the management of spill as limited by the Washington State TDG variance and provide guidance for TDG abatement alternatives. The ability to estimate the peak TDG levels associated with spillway releases will help develop an understanding of the TDG conditions observed at the tailwater fixed monitoring station (LWGN). The TDG loading released from Lower Granite Dam as represented by the average cross-sectional TDG saturation is important for characterizing the project's operational impacts on TDG level in the Snake River and providing a means of estimating the TDG levels delivered to Little Goose Dam. The TDG data collected during the 2002 spill season was used to develop predictive equations for the TDG saturation associated with spillway releases. This relationship was then used to develop a model for determining the TDG loading produced during project operations. The strong lateral interaction of powerhouse and spillway flows was central to the formulation for estimating the release of TDG loading from Lower Granite Dam.

Two different sets of data were used to evaluate the TDG exchange from Lower Granite Dam. The first data set involved the event averaged TDG pressure on Transect T1 and LWGN. The event-based averaging of TDG data is intended to help simplify the summary of TDG response to project operations, by pairing project operations with the TDG response across the downstream sampling array. This aggregation of data suffers from the variation of other factors such as powerhouse discharge and tailwater elevation within a given event.

The second approach to developing an empirical model of TDG exchange enlists the raw observations of TDG pressure on a subhourly interval as coupled with project operating conditions. The benefits of the unaggregated data analysis are the large number of observations collected during the 2002 spill season. The challenge of this approach is to pair up project conditions with the appropriate TDG response. The change in project operation is separated from the response at a downstream sampling station by both the time of travel and response time of the instrument. It may take from 30 to 60 min for the change in spill operations at Lower Granite Dam to reach a steady-state response at the tailwater sampling transect.

Event based analyses of TDG exchange

A total of 205 events with a spill duration of 60 min or longer was identified during the 2002 spill season, as listed in Table 3. The spill discharge ranged from 6 kcfs on event 197 to 103.9 kcfs during event 102. The operating conditions including total river flow, spillway discharge, specific spillway discharge, forebay elevation, and tailwater elevation were averaged over each event. The specific spill discharge was weighted by the flow from each bay, as shown in Equation 1. The flow weighted specific discharge was calculated for the entire spillway and for spill bays 6-8. The flow weighted specific discharge has been found to be a better causal estimator of TDG exchange in cases where the spill pattern is nonuniform such as is the case for RSW spill with 8 or 16 kcfs training spill. The events were also grouped by the spill pattern applied (STD-standard pattern bay 2-8, RSW- bay 1 active, NSTD – nonstandard pattern, UNKN-unknown missing records).

$$q_s = \frac{\sum_{i=1}^{n} q_i^2}{\sum_{i=1}^{n} q_i} \qquad (1)$$

Where

q_s = weighted unit spillway discharge (kcfs/bay)
q_i = discharge for spill bay i (kcfs)
N = number of spill bays

The station and transect average TDG saturation for each event is summarized in Table 6. The Transect T1 average TDG level was estimated using the average condition observed at stations T1P2 and T1P3. The stations T1P2 and T1P3 were located below the north half of the spillway and were likely to be representative of conditions in spillway flows. The cross-sectional average conditions at the tailwater FMS was estimated by weighting the observations at stations LGNWP1-P5 with the following coefficients: 0.125, 0.25, 0.25, 0.25, and 0.125. The stations near the shore were assigned lesser weight because of the smaller flow conveyance near the channel banks. Alternative approaches to weighting the observations across Transect LWGN, such as using the observed flow distribution, should improve upon the analysis used in this summary. The use of the simplified approach of weighting coefficients used to estimate the cross-sectional average conditions in the Snake River can be justified in cases where the lateral gradients in TDG saturation are weak. The range in average TDG saturation below the spillway on Transect 1 ranged from a low of 105.9 percent observed during a 10 kcfs spill to 126.6 percent during a spill of 88.8 kcfs. The range in average TDG conditions at the LWGN Transect were nearly identical to conditions observed on Transect 1. In most cases, the average TDG saturation observed below the spillway was higher than the average conditions on Transect LWGN due to the influence of the lower TDG conditions contributed from powerhouse flows.

The approach taken to quantify TDG exchange at Lower Granite Dam involved first determining the TDG response in spillway flows, and secondly, estimating the cross-sectional average TDG saturation observed at Transect LWGN which must take into account all project releases. The regression analyses for the event averaged TDG conditions in spillway flows used the average delta TDG pressure at stations T1P2 and T1P3, as determined from the difference in TDG pressure and the local barometric pressure. The determination of the TDG saturation as a function of delta pressure is shown in Equation 2. The delta TDG pressure below the spillway on Transect T1 is shown as a function of total spill discharge in Figure 29. The different types of spill patterns resulted in slightly different trends in the relationship between delta pressure and spill discharge. The nonstandard spill pattern resulted in the highest TDG pressure for a given discharge while the RSW pattern resulted in the lowest TDG exchange rate for a given discharge.

$$TDG_{sat} = \frac{\Delta P + BP}{BP} x\ 100 \qquad (2)$$

where:

TDG_{sat} = Total Dissolved Gas Saturation (%)
BP = Barometric Pressure (mm Hg)
ΔP=Delta Total Dissolved Gas Pressure (mm Hg)

The average event response of delta TDG pressure on Transect T1 to the flow weighted specific spillway discharge for the entire spillway reduced some of the variance in this relationship. The TDG responses for the higher discharges were much more closely grouped when expressed in terms of specific discharge, as shown in Figure 30. The range in TDG response for some of the RSW patterns for small spill levels did not follow the trend indicated by most of the events.

The flow-weighted specific discharge over spill bays 6-8 was determined for each event and plotted against the delta TDG pressure, as shown in Figure 31. The TDG response for all three types of spill patterns tended to collapse onto a single response curve. The delta TDG pressure appears to be exponential functions of the specific discharge of spill bays 6-8. The spill bays 6-8 were generally aligned with the stations T1P2 and T1P3 and reflect a more consistent response with the delta TDG pressure observed on these stations.

An nonlinear multivariate regression analysis was conducted relating the event averaged delta TDG pressure on Transect T1 as an exponential function of the specific discharge over bays 6-8, as shown in Equation 3. A total of 166 events were used in this evaluation pooling all the conditions from the different spill patterns. The delta TDG pressure on Transect T1 averaged 120 mm Hg and ranged from 43.5 mm Hg to 198.3 mm Hg. The specific discharge ranged from 1.9 kcfs/bay for Event 118 to 15 kcfs/bay during event 102 while the total spill discharge ranged from 14.3 kcfs to 115.4 kcfs.

$$\Delta P = C_1(1 - e^{-C_2 q_s}) \qquad (3)$$

where:

ΔP=Delta TDG Pressure, TP-BP Total Pressure minus Barometric Pressure (mm Hg)
C_1= Régression Coefficient
C_2= Regression Coefficient
q_s = unit spillway discharge (kcfs/bay) on spill bays 6-8

A nonlinear optimization solver was used to determine the two coefficients in Equation 3 based on the observed conditions for the 166 events with complete data. The results from this analysis are summarized in Table 8. The least squares nonlinear regression using Equation 3 with coefficients of C_1= 255.5 and C_2 = -0.128 resulted in a standard error of 11.9 mm Hg and a R-squared coefficient of 0.921. The calculated delta TDG pressure for Equation 3 is shown in Figure 32 along with the observed TDG response on Transect T1. The calculated response is a function of only the specific discharge over bays 6-8 and has a singular response surface. The large overestimation of TDG pressure associated with event 102 with a specific discharge of 15 kcfs may have resulted from the unusual flow condition of 100 percent of the river being spilled.

An alternative formulation relates the delta TDG pressure on Transect T1 to the specific discharge over spill bays 6-8 and tailwater depth. This functional formulation allows the upper delta TDG pressure threshold to increase as the tailwater elevation increases for higher river flows. The effective tailwater depth is determined from the difference between the event averaged tailwater elevation and the elevation of the tailwater channel below the spillway. The functional form of this relationship is shown in Equation 4 with only two coefficients to be determined from nonlinear least-squared regression techniques.

$$\Delta P = C_1(TWE - 585)(1 - e^{-C_2 q_s}) \qquad (4)$$

where:

ΔP=Delta TDG Pressure, TP-BP Total Pressure minus Barometric Pressure (mm Hg)
C_1= Regression Coefficient
C_2= Regression Coefficient

TWE=Tailwater Elevation (ft)
q_s = unit spillway discharge (kcfs/bay) over spill bays 6-8

A nonlinear optimization solver was used to determine the two coefficients in Equation 4 based on the observed conditions for the 166 events identified during the study period. The results from this analysis are summarized in Table 9. The least squared nonlinear regression using Equation 4 with coefficients of C_1=5.20 and C_2=0.123 resulted in a standard error of 12.2 mm Hg and a R-squared coefficient of 0.92. The calculated delta TDG pressure for each event is shown in Figure 33 as estimated by Equation 4. The estimated TDG pressure is a function of two parameters in this formulation causing a small variation in estimated response for a given specific discharge. The observed range in TDG pressure for similar spill discharge was much larger than accounted for by Equation 4.

The data were further reviewed to identify any other determinant of the observed TDG exchange during spillway operations. Other parameters considered were forebay TDG pressure, water temperature, and powerhouse discharge. Upon further examination, the degree of powerhouse discharge was found often to be correlated with the change in TDG saturation in spillway flows. During event 56, a spill of 43.1 kcfs was maintained for 11 hr on May 4 and 5 as shown in Figure 11. The powerhouse discharge was changed from 65 kcfs to only 25 kcfs during this event prompting an increase in the TDG saturation at station T1P2 from 119 to 122 percent. The cause for the observed change in TDG pressure during this operational sequence ranges from improved skimming flow associated with lower deflector submergence, higher ratio of bubble surface area to water volume, to the variation in transport of water containing different TDG properties.

The influence of the powerhouse discharge on TDG exchange on Transect 1 was investigated using the event-averaged data. A nonlinear optimization solver was used to determine the three coefficients in Equation 5 based on the observed conditions for the 166 events identified during the study period. The results from this analysis are summarized in Table 10. The least squares nonlinear regression using Equation 5 with coefficients of C_1=243.7, C_2=-.145, C_3=-0.093, resulted in a standard error of 11.7 mm Hg and an R-squared coefficient of 0.93. The calculated delta TDG pressure for each event is shown in Figure 34, as estimated by Equation 5. The estimated TDG pressure is a function of two parameters in this formulation causing a small variation in estimated response for a given specific discharge. The influence of the size of powerhouse generation on TDG saturation in spillway flow was small with a 10-kcfs increase in powerhouse discharge resulting in only a 0.9 mm Hg decrease in spill-related TDG saturation. The introduction of both the depth of the tailwater and powerhouse discharge in the description of TDG exchange at Lower Granite Dam is not warranted based on the results from these analyses.

$$\Delta P = C_1 (1 - e^{-C_2 q_s}) + C_3\, Q_{gen} \qquad (5)$$

The second step in the evaluation of event averaged TDG exchange involved the estimation of the cross-sectional average TDG pressure in the Snake River, as observed on Transect LWGN. The mass conservation principles for atmospheric gasses can be stated in terms of saturation if water temperatures remain constant over the study reach. If the TDG content of spillway flows can be represented by the average TDG saturation at stations T1P2 and T1P3, then a simple conservation statement can be applied to calculate the average cross-sectional TDG saturation below Lower Granite Dam. This estimate can then be compared to the observed average TDG saturation as measured in the Snake River at the LGNW transect. The following Equation 6 was used to estimate the average TDG saturation below Lower Granite Dam assuming the observed average TDG saturation on Transect T1 was representative of spill flows and the entrainment discharge Q_{ent} was negligible. This formulation also assumes that the entrainment flow from the powerhouse experiences the same level of TDG exchange as does spillway flow.

$$TDG_{avg} = \frac{(Q_{sp} + Q_{ent})TDG_{sp} + (Q_{gen} - Q_{ent})TDG_{gen}}{Q_{tot}} \qquad (6)$$

where:

Q_{tot}= Total River Flow (kcfs)
Q_{sp}= Spillway Discharge (kcfs)
Q_{gen}=Generation Discharge (kcfs)
Q_{ent}=Entrainment Discharge (kcfs)
TDG_{gen} = Total Dissolved Gas Saturation of Generation Discharges (%)
TDG_{avg} = Average TDG Saturation on Transect LWGN (%)
TDG_{sp}= Total Dissolved Gas Saturation of Spillway Discharges (%)

The calculated average TDG saturation for Transect LWGN consistently underestimated the observed TDG saturation of all but nine of the 167 spill events. The observed and calculated average TDG saturations for the LWGN transect are listed in Table 11. The predictive error defined as the observed minus calculated average TDG saturation ranged from –1.40 to 9.5 percent with an average error of 4.3 percent. The r^2 correlation between the observed and calculated average TDG saturation at the LWGN transect was only 0.24. This large error (underestimation in TDG saturation) in the estimated average TDG below Lower Granite Dam further supports the hypothesis that powerhouse flows interact with aerated flow from the spillway resulting in an increase in the resultant TDG loading of the Snake River below Lower Granite Dam. A least-squares evaluation of the predictive errors was used to estimate an event-specific entrainment discharge Q_{ent}, as defined in Equation 7. The entrainment discharge was assumed to be a function of the spill discharge and was bounded by the available powerhouse flow. An entrainment coefficient of 1.01 was found to reduce the mean predictive error (observed TDG_{lwgn} minus calculated TDG_{lwgn}) to almost zero (0.1 percent). The r^2 correlation between the observed and calculated average TDG saturation at the LWGN transect was 0.92 with the entrainment contribution included. The entrainment coefficient of slightly greater than unity implies that the amount of water experiencing the high rates of TDG exchange can be roughly twice the spill discharge given the powerhouse flow does not limit the entrainment discharge. The large entrainment coefficient is also consistent with the frequent pattern of flow recirculation downstream of the powerhouse accompanied by a strong lateral current transporting powerhouse flow into the stilling basin (Figure 16).

The estimation of entrainment flow also has implications regarding TDG abatement alternatives at Lower Granite Dam. The construction of a training wall between the powerhouse and spillway that completely eliminates the entrainment of powerhouse flow into highly aerated spillway releases will result in a substantial reduction in the average TDG introduced into the

Snake River. The average reduction in the TDG saturation caused by eliminating the entrainment of powerhouse flows based on 2002 spill conditions would be about 4.3 percent saturation.

$$Q_{ent} = C_{ent}\, Q_{sp} \quad \text{if } Q_{ent} < Q_{gen} \qquad (7)$$
$$Q_{ent} = Q_{gen} \quad \text{if } C_{ent} Q_{sp} > Q_{gen}$$

Unaggregated data analyses

The evaluation of individual observations of TDG saturation or unaggregated data was conducted in a similar two-phased approach as outlined in the events based analyses. The TDG saturation associated with spillway flows was first evaluated using Equation 3 using the average instantaneous observations at stations T1P2 and T1P3 and the specific discharge on spill bays 6-8. The second phase involved the estimation of an entrainment discharge required to achieve the cross-sectional average TDG saturation on Transect LWGN. The data used to estimate the three exchange coefficients included observations during spill events with a duration of 60 min or longer. This subset of data excludes transitional periods following the change in spill.

A nonlinear optimization solver was used to determine the two coefficients used to define the TDG pressure associated with spillway flows. A total of 2,707 observations were used to estimate the unknown exchange coefficients in Equation 3. The results from this analysis are summarized in Table 12. The least squares nonlinear regression using Equations 3 produced exchange coefficients of C_1=245.8, C_2=-0.141 with a corresponding standard error of 10.2 mm Hg and an R-squared coefficient of 0.94. The mean coefficient estimates determined from the instantaneous data analyses fell within the 95 percent confidence interval of estimates generated from the events based evaluation.

The conservation statement (Equation 6) applying the results in Table 12 to describe the TDG exchange associated with spillway flows, was used to estimate the entrainment discharge required to predict the observed cross-sectional average TDG saturation in the Snake River on Transect LWGN. A least-squares evaluation based on Equation 6 was used to estimate the entrainment discharge Q_{ent} as defined in equation 7. The entrainment discharge was assumed to be a function of the spill discharge and was bounded by the available powerhouse flow. A total of 4,317 observations were used to estimate the entrainment coefficient. An entrainment coefficient of 0.98 was found to produce the best fit to the observed data. The r^2 correlation between the observed and calculated average TDG saturation at the LWGN transect was 0.96 with an average predictive error of –2.1 mm Hg and a standard error of 7.4 mm Hg (1.0 percent).

A hindcast of TDG exchange was calculated using the exchange coefficients generated in the analyses of instantaneous TDG observations below Lower Granite Dam. The hourly project operations are shown in Figure 35 for May 24-June 6, 2002 along with the observed and calculated TDG saturation in spillway flows (T1avg) and average cross-sectional TDG saturation at the tailwater fixed monitoring station (LGNWavg). The empirical model of TDG exchange closely reproduced both the peak and average TDG saturation over a wide range of project operations and spill patterns. This approach overestimated the exchange during the highest discharge event on June 6 and caution should be used in applying this relationship for unit spillway discharges greater than 12 kcfs/bay.

Conclusions

A thorough understanding of the TDG exchange characteristics of the lower Snake River projects is necessary to efficiently manage spillway operations for the benefit of fish passage. In particular, a more thorough understanding of both the TDG exchange characteristics and project hydrodynamics related to mass absorption and dilution is needed at Lower Granite Dam in light of the structural and operational changes made for the most recent fish passage season. The Walla Walla District operated the removable spillway weir (RSW) at Lower Granite Dam during the 2002 fish spill season. ERDC conducted a field study that was designed to quantify TDG exchange and near-field transport and mixing at Lower Granite Dam.

A total of eight TDG pressure logging instruments were deployed in addition to the forebay and tailwater fixed monitoring station throughout the spill season at Lower Granite Dam. The TDG pressure logging instruments were all located at various distances downstream of the highly aerated flow conditions generated by spillway flows. The TDG exchange associated with RSW and standard spill events were monitored on a 15-min interval throughout the sampling period.

The spillway discharge averaged 34.7 kcfs at Lower Granite Dam during the 2002 spill season, which began on April 3 and was completed on June 16. The average percent of river spilled was 43.3 percent during active spill events. The cross-sectional average TDG saturation downstream from Lower Granite Dam during active spill was 113.8 percent as compared to the TDG saturation in the forebay of 103.7 percent. Therefore, the average increase in TDG saturation in the Snake River caused by spillway operation at Lower Granite Dam was 10.1 percent. This average increase in TDG saturation in the Snake River caused by operations at Lower Granite Dam was significantly higher than conditions observed at other Corps of Engineer's projects in the Snake and Lower Columbia River.

Observed TDG levels at the tailwater fixed monitoring station frequently exceeded the Washington State waiver criteria of 120 percent saturation even for total spillway discharges as low as 40-45 kcfs. This spillway discharge is considerably lower than the 60 kcfs spill capacity cited in the Water Management Plan draft for the 2003 spill season.

The TDG saturation associated with three different spill management policies at Lower Granite Dam were investigated during the 2002 spill season. The three operating scenarios involved spill over the raised spillway crest with accompanying training spill of 8 kcfs and 16 kcfs and uniform spill over bays 2-8 at the spillway capacity dictated by the Washington State waiver criteria of 120 percent at the tailwater fixed monitoring station. The TDG characteristics associated with RSW spill with 8 kcfs training spill resulted in a cross-sectional average TDG saturation of 107.6 percent which is below the Washington State water quality standard of 110 percent. Spill using the RSW with 16 kcfs training flow resulted in an average TDG saturation in the Snake River of 109.9 percent. Uniform spill of 40-45 kcfs over bays 2-8 resulted in an average TDG saturation in the Snake River of 117.0 percent.

A strong lateral interaction of project releases was apparent at Lower Granite Dam during much of the 2002 spill season. Powerhouse releases were entrained into the highly aerated stilling basin flow and exposed to the TDG exchange processes resulting in elevated TDG loading of the Snake River. The transport of powerhouse flow into the stilling basin was indicated by surface circulation patterns and the frequent presence of elevated TDG saturation downstream of the powerhouse near the left descending bank. In many instances, the entire powerhouse release can be redirected into the aerated spillway flows and contribute to the resultant TDG pressure in the Snake River. The entrainment discharge was estimated to be equal to the spillway discharge when it is not limited by the powerhouse discharge. The entrainment discharge effectively doubles the amount of water exposed to high TDG exchange processes below the spillway and reduces the amount of low TDG water available for dilution in the mixing zone.

The TDG saturation observed in spillway releases were influenced by the spill rate, spill pattern, and powerhouse flow. The TDG saturation was found to be an exponential function of the specific spill discharge or discharge per foot of active spillway width. The rate of increase in TDG saturation decreases for increasing specific spillway discharge that eventually reaches an upper limit during high spillway discharges. The highest TDG saturation observed during the study was 129.4 percent during a spillway discharge of 115.4 kcfs on June 5.

An inverse relationship was often observed during nonforced spill conditions between powerhouse flow and the TDG saturation associated with spillway flows. Increasing powerhouse releases frequently caused a moderate reduction in the TDG saturation in spill waters. The influence of powerhouse flow on the TDG content of spillway releases was not found to be statically significant in the development of empirical equations of TDG exchange.

The empirically derived relationships between project operations and TDG exchange will provide reliable estimates of peak and average TDG exchange at Lower Granite Dam for the range of project operations sampled during 2002.

The tailwater fixed monitoring station often reflects the highest TDG saturation generated in spillway releases from Lower Granite Dam. The TDG saturation observed directly below the spillway near the end of the lock guide wall was highly correlated to the TDG saturation observed at the tailwater fixed monitoring station LWGN.

Recommendations

The TDG saturation observed at the forebay fixed monitoring station is frequently influenced by thermal stratification. The elevation of surface-water temperatures results in a corresponding increase in the local TDG pressure that is not representative of average conditions in the Snake River. The forebay FMS should be relocated to avoid the thermally induced gain in TDG pressure.

The relationships between the TDG saturation observed at the tailwater fixed monitoring station and the peak and average TDG conditions generated in the Snake River below Lower Granite Dam were established for 2002 project operations. The information collected at the tailwater fixed monitoring station is well suited to describe project impacts on TDG conditions in the Snake River for the range of operations sampled. Care should be taken when extending TDG exchange relationships to operations outside of this operating range.

The influence of the entrainment of powerhouse flows into the stilling basin on the net TDG exchange at Lower Granite Dam was estimated from simple conservation statements and not measured directly. A more rigorous evaluation of the fate of powerhouse releases should be conducted to assess the TDG abatement benefits of extending a training wall between the powerhouse and spillway exit channel.

Appendix A

Water Quality Instrument Calibration and Maintenance

The Hydrolab Corp. model DS4® was used exclusively for water quality monitoring in the Rocky Reach Dam field studies. The model DS4® instruments are wireless and capable of remotely logging temperature, depth, specific conductance, dissolved oxygen (DO), and TDG for a 1-2-week deployment period depending on logging rates and water temperature. Battery life can be shortened considerably in colder waters (4 – 10°C). Programming, calibration, and maintenance procedures of these instruments followed manufacturers' recommendations per instrument manuals. Any changes or modifications in instrument handling were implemented only after consulting with factory technicians. Adjustments and calibrations were performed on all instruments within 2 days prior to each deployment. Postdeployment checks on calibration were completed as soon after retrieval as possible for evaluation of instrument drift and accuracy. An evaluation of instrument performance based on calibration drift was conducted to verify proper equipment operation and define the confidence limits for collected data.

Calibration of TDG

The Hydrolab tensionometers used for measuring TDG pressures employ semipermeable membranes connected to pressure transducers with associated electronics to directly measure in-situ TDG pressure. Air calibrations for TDG were performed using either a certified mercury column barometer or a portable field barometer that had been calibrated to a certified mercury column barometer. TDG was calibrated by comparing the instrument readings (in mm Hg) to those of the standard barometer at atmospheric conditions. Slope checks were performed by adding known amounts of pressure, usually 100 and 300 mm Hg, directly to the transducer, and then adjusting the instrument reading accordingly. The membrane is bypassed during these calibrations so that the probe itself is calibrated, rather than the probe/membrane combination. The condition of the membrane and any condensation trapped inside it could influence readings and result in a false calibration.

An inspection for leaks was performed on the membrane itself before completing the calibration routine. One of the checks employed involves immersing the membrane in seltzer water. The expected result of a properly functioning membrane is an immediate jump in the TDG reading of at least 300mm Hg. Membranes are also visually inspected for leaks and condensation moisture trapped inside the membrane. The leaks will usually appear as large darker spots in the membrane and indicate that water has entered the silastic tubing through a tear. Defective membranes were replaced before use.

Calibration of Dissolved Oxygen

DO calibration followed procedures developed in the CE DGAS field-sampling program. A water bath was employed so that more than one instrument could be rapidly calibrated at a time. The water bath serves as a calibration chamber. After equilibration in this water bath, multiple instruments can then be calibrated to a standardized instrument. By adding a motor-driven propeller sleeved in a ported cylinder to the 50-gal batch tank, it is possible to achieve a steady state, homogeneous mixture of water approximately 97 percent saturated with air at a constant temperature. One instrument is designated as the standard for comparison and calibrated for specific conductance, depth, and DO (in air). Once the standard instrument and tank are prepared, several Winkler titration analyses are run to further verify the DO concentration in mg/L of the calibration tank. Adjustments are made to agree with the Winkler titration of DO at this point. The remaining instruments are then adjusted to read the same as the standard instrument for DO, specific conductance, and depth. Several additional Winkler titrations are performed throughout the calibration procedure for the rest of the instruments to ensure consistency.

Water Quality Calibration Data from COE DGAS Field Studies

Calibration checks and necessary adjustments performed on the Hydrolab DS4 instruments have been documented during the 1996, 1997, 1998, and 1999 field sampling for the CE DGAS program on the Lower Columbia and Lower Snake Rivers. The status of each of the parameters before and after each calibration check and adjustment was kept in a calibration log. Data gathered from logs kept on calibration activities were examined as a group, reflecting a pooled data set of all DS4s and all deployments. The data assessed in this evaluation reflect only the calibrations performed on instruments before and after deployments that resulted in readings that were included in the study database. Logs for instruments requiring large-scale adjustments exceeding factory recommendations were excluded from the data set. In addition, data logs resulting from instruments determined to be malfunctioning based on normal quality assurance criteria established by the manufacturer were not incorporated into the study database.

An analysis was completed to provide summary statistics defining the variability about the mean of the instrument drift and calibration error (Table A1). The individual data points comprising the population analyzed were the difference between the postdeployment reading of the parameter and its expected calibration value. DO and TDG were the only parameters evaluated in this assessment because they were the primary parameters in this study.

The mean (±2 standard deviations) post operation calibration shift in DO over all years and instrument types was 0.07 mg/l ±1.08 mg/l. The mean (±2 standard deviations) post deployment calibration shift in TDG pressure over all years and instrument types was 0.44 mm Hg ± 7.4 mm Hg.

Table A1. DGAS Postdeployment Calibration Check for Drift in DO (mg/l) and TDG (mm Hg)						
Year	Parameter	N	Minimum	Maximum	Mean	Std. Deviation
1996	DO	253	-2.2	2.1	0.13	0.56
	TDG	235	-21.0	19.0	0.14	5.8
1997	DO	459	-2.4	1.5	0.04	0.42
	TDG	494	-16.0	18.0	0.43	3.5
1998	DO	296	-2.3	2.1	0.06	0.68
	TDG	316	-7.0	8.0	0.67	2.1
1999	DO	25	-0.7	0.9	0.06	0.38
	TDG	24	0.0	6.0	0.67	1.6
Combined Years	DO	1033	-2.4	2.1	0.07	0.54
	TDG	1069	-21.00	19.0	0.44	3.7

Of the approximately 1,100 TDG and DO predeployment calibrations performed over the four DGAS sampling seasons, only a small percentage have resulted in “out of tolerance” readings or other errors during calibration. Though these numbers do not necessarily reflect the number of times the instruments were serviced by field personnel or by factory technicians, they do suggest that there is a very low frequency of deployments resulting in erroneous measurements. Barring any unforeseen complications or errors associated with deployment and postcalibration handling, the instruments used in DGAS field sampling produced accurate data. Most calibrations revealed that the instruments’ measurement error generally fell within what could be considered an acceptable range of drift. The observed range was wider than that defined by the manufacturers (± 0.2 mg/L DO and ± 1 mm Hg TDG pressure). It should be noted, however, that manufacturer-defined expected error is based on optimal lab conditions, not the field conditions and time intervals in which the instruments were required to function. An additional consideration is the fact that calibration conditions and methods were constantly being modified and refined during the DGAS program so that the most accurate and efficient calibrations possible were maintained. It is likely that more experience resulted in the culmination of techniques that could afford tighter calibration data.

Appendix B Tables

Table 1. Statistical Summary of Project Operations During Spill at Lower Granite Dam, 2002

	Qtotal (kcfs)	Qgen (kcfs)	Qspill (kcfs)	Qspill/Qtotal (%)	TWE (ft)	FBE (ft)
Average	83.2	49.1	34.7	43.3	634.3	734.6
Max	144.9	88.9	115.4	100.0	636.3	737.0
Min	17.0	0.0	0.3	0.3	631.3	733.0

Table 2. Statistical Summary of Spill at Lower Granite Dam, April 1-July 31, 2002

Spillway Flow Range (kcfs)	Raised Weir Crest bays 1-8 (days)	Uniform Spill Pattern bays 2-8 (days)	Unknown Spill Pattern (days)	Total (days)	Cumulative Time (days)	Frequency of Occurrence (%)	Cumulative Frequency of Occurrence (%)
0				41.0	41.0	33.6	33.6
0-10	0.1	0.2	0.4	0.7	41.7	0.6	34.2
10-20	11.3	5.6	0.5	17.4	59.1	14.3	48.5
20-30	13.9	1.9	1.2	17.0	76.1	13.9	62.4
30-40	4.6	7.9	1.8	14.3	90.4	11.8	74.2
40-50	4.4	10.8	4.6	19.8	110.2	16.3	90.5
50-60	2.0	1.8	2.1	5.9	116.2	4.9	95.3
60-70	3.5	0.0	0.1	3.7	119.8	3.0	98.3
70-80	0.2	0.0		0.2	120.1	0.2	98.5
80-90	0.6	0.2	0.0	0.8	120.9	0.7	99.2
90-100	0.5	0.3		0.8	121.7	0.7	99.9
100-110	0.0			0.0	121.7	0.0	99.9
110-120	0.2			0.2	121.9	0.1	100.0
Grand Total	41.3	28.9	10.7	121.9	121.9		

Table 3. Statistical Summary of Project Operations by Event at Lower Granite Dam, 2002

Event	Starting Time	Ending Time	Duration (hr)	Q_{total} (kcfs)	$Q_{total\ Max}$ (kcfs)	$Q_{total\ Min}$ (kcfs)	Q_{SPILL} (kcfs)	Active Spill Bays	q_s ((kcfs/bay)	Q_{RSW} (kcfs)	Q_{spill}/Q_{total}	TWE (ft)	FBE (ft)
1	4/3/02 20:00	4/3/02 22:00	3	54.9	55.4	53.7	54.4				99.1	632.2	734.8
2	4/4/02 0:00	4/4/02 5:00	6	58.2	59.0	57.5	57.7				99.2	632.6	734.8
3	4/4/02 20:00	4/4/02 23:30	4.5	50.5	51.1	49.8	50.2				99.4	632.1	734.5
4	4/5/02 1:00	4/5/02 5:30	5.5	56.3	57.3	55.5	55.7				99.0	632.6	734.6
5	4/5/02 20:00	4/6/02 5:30	10.5	67.7	79.3	59.1	59.3				88.9	632.7	734.5
6	4/6/02 19:00	4/6/02 22:30	4.5	63.6	63.8	49.6	49.9				78.4	632.5	734.1
7	4/7/02 0:00	4/7/02 1:30	2.5	67.4	73.2	44.2	44.6				66.7	633.1	734.4
8	4/7/02 4:00	4/7/02 5:30	2.5	87.8	88.1	40.3	40.4				46.0	633.9	734.2
9	4/7/02 9:00	4/7/02 14:30	6.5	78.0	78.3	40.6	40.8				52.2	633.4	734.7
10	4/7/02 16:00	4/8/02 8:30	17.5	69.6	77.9	34.7	35.0				50.5	633.2	734.8
11	4/8/02 11:00	4/8/02 12:30	2.5	76.8	78.0	23.6	23.8				31.0	633.7	734.8
12	4/8/02 20:00	4/9/02 4:30	9.5	74.4	77.6	36.8	36.9				49.7	633.3	734.8
13	4/9/02 11:00	4/9/02 13:30	3.5	77.5	81.6	15.6	15.7				20.3	634.0	734.3
14	4/9/02 20:00	4/10/02 5:30	10.5	68.6	76.3	42.6	43.6				63.9	632.8	734.8
15	4/10/02 11:00	4/10/02 13:30	3.5	79.1	79.1	15.6	15.7				19.9	634.1	734.6
16	4/10/02 20:00	4/11/02 5:30	10.5	73.5	84.6	48.0	48.3				66.0	632.7	734.6
17	4/11/02 11:00	4/11/02 13:30	3.5	81.9	83.2	15.8	15.9				19.4	634.1	734.3
18	4/11/02 20:00	4/12/02 5:30	10.5	70.1	80.4	43.4	43.6				63.0	632.9	734.6
19	4/12/02 11:00	4/12/02 13:30	3.5	69.6	72.1	16.5	16.5				23.7	633.6	734.3
20	4/12/02 21:00	4/13/02 5:30	9.5	71.9	85.8	47.1	47.4				66.9	633.0	734.7
21	4/13/02 20:00	4/14/02 5:30	10.5	83.8	89.8	50.9	51.1				61.3	633.3	734.5
22	4/14/02 20:00	4/15/02 5:30	10.5	116.0	134.1	44.2	44.5				38.7	635.1	734.8
23	4/15/02 7:00	4/15/02 13:30	7.5	136.2	139.9	39.3	39.6				29.1	635.9	734.0
24	4/15/02 16:00	4/15/02 17:30	2.5	106.6	106.6	45.0	45.0				42.2	634.3	733.8
25	4/15/02 19:00	4/16/02 6:30	12.5	116.6	129.8	43.2	43.6				37.5	635.1	734.4
26	4/16/02 8:00	4/16/02 23:30	16.5	107.7	112.7	24.2	24.4				22.6	634.8	734.2
27	4/17/02 4:00	4/17/02 10:30	7.5	101.9	112.6	24.3	24.4				24.0	634.5	734.3
28	4/17/02 14:00	4/17/02 14:30	1.5	92.4	92.4	47.2	47.2				51.1	633.4	734.5

(Continued)

Table 3. Statistical Summary of Project Operations by Event at Lower Granite Dam, 2002

Event	Starting Time	Ending Time	Duration (hr)	Q_{total} (kcfs)	$Q_{total\ Max}$ (kcfs)	$Q_{total\ Min}$ (kcfs)	Q_{SPILL} (kcfs)	Active Spill Bays	q_s ((kcfs/bay)	Q_{RSW} (kcfs)	Q_{spill}/Q_{total}	TWE (ft)	FBE (ft)
29	4/17/02 17:00	4/18/02 6:30	14.5	100.1	120.8	24.3	24.5	8	3.9	6.7	24.8	634.4	734.3
30	4/18/02 8:00	4/18/02 8:00	1	88.8	88.8	22.6	22.6	8	3.7	6.7	25.5	634.3	734.0
31	4/18/02 9:30	4/18/02 15:00	6.5	84.5	88.5	16.7	16.7	6	3.9	6.7	19.8	633.9	734.4
32	4/18/02 17:30	4/18/02 17:30	1	86.5	86.5	30.2	30.2	8	4.3	6.7	34.9	634.1	734.4
33	4/18/02 19:00	4/19/02 5:30	11.5	88.3	94.4	47.3	47.4	8	6.2	6.8	53.9	633.6	734.6
34	4/19/02 19:00	4/20/02 6:00	12	83.5	97.0	53.9	53.9	7	7.7	0.0	65.4	633.2	734.6
35	4/20/02 19:30	4/21/02 4:30	10	76.9	88.4	49.9	50.1	7	7.3	0.0	70.7	632.9	734.5
36	4/21/02 7:00	4/23/02 6:00	48	67.8	86.9	24.2	24.5	8	3.9	6.7	37.1	633.4	734.3
37	4/23/02 7:30	4/24/02 8:30	26	75.8	88.3	16.7	16.7	6	3.9	6.7	22.3	633.9	734.4
38	4/24/02 10:30	4/24/02 15:30	6	63.4	70.4	16.7	16.7	6	3.9	6.7	26.4	633.4	734.3
39	4/24/02 19:00	4/25/02 6:00	12	63.6	75.6	16.7	16.7	6	3.9	6.7	26.6	633.4	734.4
40	4/25/02 19:30	4/26/02 6:00	11.5	64.4	89.7	42.5	42.5	7	6.1	0.0	66.9	632.8	734.7
41	4/26/02 19:00	4/27/02 5:30	11.5	59.6	69.8	34.9	34.9	7	5.2	0.0	59.0	632.8	734.7
42	4/27/02 19:00	4/28/02 5:30	11.5	58.3	65.8	38.7	38.7	7	5.6	0.0	66.6	632.4	734.6
43	4/28/02 19:00	4/29/02 5:30	11.5	60.7	65.0	38.7	38.7	7	5.6	0.0	64.1	632.6	734.7
44	4/29/02 7:00	4/30/02 13:30	31.5	58.3	74.2	16.7	16.7	6	3.9	6.7	30.2	633.2	734.4
45	5/1/02 1:00	5/1/02 22:30	22.5	61.8	63.3	42.5	42.5	8	5.5	6.9	68.8	632.9	736.3
46	5/2/02 0:00	5/2/02 0:30	1.5	69.3	69.3	52.0	52.1	8	6.6	6.9	75.2	633.0	736.6
47	5/2/02 2:00	5/2/02 4:30	3.5	76.5	76.7	55.8	55.8	8	7.1	6.9	73.0	633.4	736.4
48	5/2/02 6:00	5/2/02 7:00	2	72.7	72.8	52.0	52.0	8	6.6	6.9	71.5	633.3	736.1
49	5/2/02 8:30	5/2/02 8:30	1	73.0	73.0	52.7	52.7	7	7.6	0.0	72.2	633.1	736.1
50	5/2/02 10:00	5/2/02 10:30	1.5	72.5	72.5	52.0	52.0	8	6.6	6.9	71.7	633.3	736.0
51	5/2/02 12:00	5/2/02 16:00	5	68.6	68.8	48.1	48.2	8	6.3	6.9	70.2	633.1	736.0
52	5/2/02 17:30	5/3/02 11:00	18.5	70.6	78.7	57.3	57.7	8	7.3	6.8	77.3	633.1	735.7
53	5/3/02 12:30	5/3/02 18:30	7	64.7	65.0	63.7	63.9	8	8.3	6.9	98.7	633.0	736.7
54	5/4/02 1:00	5/4/02 6:00	6	93.8	94.4	37.5	37.5	7	5.5	0.0	40.0	634.3	736.6
55	5/4/02 12:30	5/4/02 12:30	1	72.6	72.6	16.0	16.0	7	2.5	0.0	22.0	633.8	736.6
56	5/4/02 19:30	5/5/02 5:30	11	82.4	112.4	42.5	43.1	7	6.2	0.0	54.2	633.7	735.4
57	5/5/02 7:00	5/7/02 5:30	47.5	72.2	89.3	17.1	17.2	6	4.2	7.2	24.3	633.8	734.5
58	5/7/02 7:00	5/11/02 6:00	96	64.8	99.5	24.5	24.8	8	4.0	7.0	39.0	633.8	734.4

(Continued)

Table 3. Statistical Summary of Project Operations by Event at Lower Granite Dam, 2002

Event	Starting Time	Ending Time	Duration (hr)	Q_{total} (kcfs)	$Q_{total\ Max}$ (kcfs)	$Q_{total\ Min}$ (kcfs)	Q_{SPILL} (kcfs)	Active Spill Bays	q_s ((kcfs/bay)	Q_{RSW} (kcfs)	Q_{spill}/Q_{total}	TWE (ft)	FBE (ft)
59	5/11/02 19:30	5/12/02 5:30	11	55.8	66.8	46.3	46.3	7	6.7	0.0	84.3	633.4	734.6
60	5/12/02 19:30	5/12/02 20:30	2	58.5	58.7	46.3	46.3	7	6.7	0.0	79.1	633.2	734.2
61	5/12/02 22:00	5/13/02 6:00	9	53.9	67.7	38.7	38.7	7	5.6	0.0	72.1	633.3	734.5
62	5/13/02 7:30	5/15/02 5:30	47	59.4	78.0	16.9	17.1	6	4.1	7.1	29.6	634.4	734.5
63	5/15/02 7:00	5/15/02 16:00	10	74.0	88.2	24.7	24.7	8	4.0	6.9	33.9	634.8	734.4
64	5/15/02 17:30	5/17/02 5:30	37	65.9	81.0	24.7	24.7	8	4.0	6.9	38.4	634.4	734.5
65	5/17/02 19:00	5/18/02 5:30	11.5	67.6	75.3	36.8	36.8	7	5.4	0.0	55.0	634.2	734.7
66	5/18/02 19:00	5/19/02 5:30	11.5	72.2	77.5	40.6	40.6	7	5.8	0.0	56.5	634.1	734.6
67	5/19/02 7:00	5/20/02 10:00	28	82.1	92.6	16.9	17.0		4.1	7.1	20.9	635.0	734.6
68	5/20/02 11:30	5/20/02 14:30	4	103.1	103.8	28.4	28.4	8	4.2	6.8	27.5	635.5	734.8
69	5/20/02 16:00	5/20/02 16:30	1.5	110.5	110.6	36.0	36.0	8	4.8	6.8	32.6	635.7	734.8
70	5/20/02 18:00	5/22/02 15:15	46	109.3	116.2	39.7	39.8	8	5.2	6.8	36.6	635.7	734.4
71	5/22/02 16:30	5/23/02 11:00	19.5	109.9	120.7	45.6	45.6	8	6.0	6.9	41.7	635.5	734.3
72	5/23/02 12:15	5/25/02 7:45	44.5	97.7	100.6	24.9	24.9	8	4.0	7.1	25.5	635.0	734.4
73	5/25/02 9:00	5/25/02 9:00	1	94.4	94.4	19.7	19.7	7	3.1	0.0	20.9	634.8	734.0
74	5/25/02 10:15	5/25/02 11:45	2.5	91.1	91.5	15.9	15.9	7	2.5	0.0	17.5	634.7	734.1
75	5/25/02 17:15	5/25/02 18:00	1.75	88.2	90.7	15.9	15.9	7	2.5	0.0	18.1	634.7	734.7
76	5/25/02 19:15	5/26/02 5:45	11.5	93.1	100.0	40.6	40.6	7	5.8	0.0	43.7	634.2	734.3
77	5/26/02 11:30	5/26/02 11:45	1.25	90.6	90.6	15.8	15.8	6	2.9	0.0	17.4	634.7	734.1
78	5/26/02 17:15	5/26/02 18:00	1.75	82.4	85.3	10.0	10.0	5	2.0	0.0	12.2	634.7	734.3
79	5/26/02 19:15	5/27/02 5:45	11.5	90.8	95.8	44.4	44.4	7	6.5	0.0	49.0	633.8	734.5
80	5/27/02 7:00	5/28/02 3:30	21.5	84.1	92.0	16.7	16.7	6	3.9	6.7	20.1	634.2	734.3
81	5/28/02 4:45	5/29/02 5:00	25.25	99.1	100.3	24.5	24.5	8	3.9	6.7	24.8	634.6	734.5
82	5/29/02 6:15	5/29/02 6:45	1.5	109.3	109.4	34.9	34.9	7	5.2	0.0	31.9	634.7	734.9
83	5/29/02 8:00	5/29/02 12:00	5	115.4	116.2	40.6	40.6	7	5.8	0.0	35.2	634.9	734.7
84	5/29/02 12:15	5/29/02 14:00	5.25	119.4	119.9	44.4	44.4	7	6.5	0.0	37.2	635.0	734.5
85	5/29/02 15:15	5/30/02 9:00	18.75	113.3	118.3	42.5	42.5	7	6.1	0.0	37.6	634.8	734.5
86	5/30/02 10:15	5/30/02 18:15	9	130.9	131.7	55.8	55.8	7	8.0	0.0	42.6	635.6	735.0
87	5/30/02 19:30	5/31/02 6:00	11.5	134.9	135.6	59.6	59.6	7	8.6	0.0	44.2	635.7	734.9
88	5/31/02 7:30	5/31/02 15:30	9	136.6	137.0	60.8	60.8	8	7.6	6.9	44.5	636.0	734.6

(Continued)

Table 3. Statistical Summary of Project Operations by Event at Lower Granite Dam, 2002

Event	Starting Time	Ending Time	Duration (hr)	Q_{total} (kcfs)	$Q_{total\ Max}$ (kcfs)	$Q_{total\ Min}$ (kcfs)	Q_{SPILL} (kcfs)	Active Spill Bays	q_s ((kcfs/bay)	Q_{RSW} (kcfs)	Q_{spill}/Q_{total}	TWE (ft)	FBE (ft)
89	5/31/02 16:45	6/2/02 10:30	42.75	136.0	137.1	60.3	61.0	8	7.6	7.1	44.8	635.6	734.7
90	6/2/02 11:45	6/2/02 17:00	6.25	125.0	125.5	50.8	51.0	8	6.6	6.7	40.8	635.2	734.2
91	6/2/02 18:15	6/2/02 23:00	5.75	130.0	131.1	56.8	56.8	8	7.2	6.7	43.7	635.5	734.6
92	6/3/02 0:15	6/3/02 11:30	12.25	134.6	135.3	60.7	60.7	8	7.6	6.8	45.1	635.5	734.7
93	6/3/02 12:45	6/3/02 14:15	2.5	144.2	145.0	69.6	69.9	8	8.9	6.7	48.5	635.8	734.4
94	6/3/02 15:30	6/3/02 17:30	3	134.5	135.2	60.6	60.6	8	7.6	6.7	45.1	635.5	734.2
95	6/3/02 18:45	6/3/02 22:45	5	126.3	129.3	41.6	52.3	8	6.8	6.7	41.3	635.2	734.1
96	6/4/02 1:00	6/4/02 8:30	8.5	123.2	142.7	84.6	84.7	8	11.1	6.8	69.2	634.6	734.6
97	6/4/02 9:45	6/4/02 10:15	1.5	135.9	136.1	60.6	60.6	8	7.6	6.7	44.6	635.7	734.3
98	6/4/02 11:30	6/4/02 12:45	2.25	120.2	120.7	45.4	45.4	8	5.9	6.7	37.8	635.0	734.3
99	6/4/02 14:00	6/4/02 17:45	4.75	114.4	115.0	39.7	39.7	8	5.2	6.7	34.7	634.8	734.5
100	6/4/02 19:00	6/4/02 22:45	4.75	115.9	116.9	41.7	41.7	8	5.4	6.8	36.0	634.8	734.7
101	6/5/02 0:00	6/5/02 1:00	2	119.9	137.5	84.7	90.2	8	11.8	6.8	75.0	634.1	734.7
102	6/5/02 2:15	6/5/02 6:00	4.75	113.7	116.2	37.9	103.9	8	13.6	6.8	90.7	634.5	734.7
103	6/5/02 7:15	6/5/02 13:45	7.5	116.8	117.3	41.6	41.6	8	5.4	6.7	35.7	635.3	734.6
104	6/5/02 15:00	6/5/02 17:45	3.75	109.4	111.5	35.9	35.9	8	4.7	6.7	32.9	634.9	734.4
105	6/5/02 19:00	6/6/02 7:00	13	112.0	125.3	40.6	85.4	8	11.2	6.2	76.7	634.0	734.5
106	6/6/02 8:15	6/6/02 16:45	9.5	109.7	110.5	34.9	34.9	7	5.2	0.0	31.8	635.0	734.5
107	6/6/02 18:00	6/6/02 18:00	1	95.9	95.9	40.6	40.6	7	5.8	0.0	42.3	634.7	734.5
108	6/6/02 19:30	6/6/02 21:45	3.25	110.1	114.6	88.8	88.8	7	12.8	0.0	80.7	633.5	734.6
109	6/7/02 0:15	6/7/02 0:30	1.25	100.6	100.6	81.6	81.6	7	11.7	0.0	81.2	633.3	734.7
110	6/7/02 1:45	6/7/02 6:00	5.25	110.3	123.2	90.6	90.6	7	13.1	0.0	82.2	633.4	734.6
111	6/7/02 7:15	6/7/02 9:15	3	104.5	116.4	42.5	42.5	7	6.1	0.0	40.8	634.6	734.9
112	6/7/02 10:30	6/7/02 17:45	8.25	113.1	114.7	38.7	38.7	7	5.6	0.0	34.2	635.2	734.6
113	6/7/02 19:00	6/8/02 0:45	6.75	98.0	104.2	42.5	42.5	7	6.1	0.0	43.4	634.3	734.4
114	6/8/02 2:00	6/8/02 3:45	2.75	106.4	107.6	90.6	90.6	7	13.1	0.0	85.2	633.4	734.7
115	6/8/02 5:00	6/8/02 10:45	6.75	114.1	118.6	42.4	42.5	7	6.1	0.0	37.3	635.4	734.5
116	6/8/02 12:00	6/8/02 18:00	7	91.4	92.0	16.7	16.7	6	3.9	6.7	18.3	634.3	734.2
117	6/8/02 19:15	6/9/02 8:45	14.5	100.4	117.9	41.1	41.2	8	5.3	6.7	41.3	634.5	733.3
118	6/9/02 10:00	6/9/02 14:45	5.75	89.4	90.3	14.3	14.3	5	4.1	6.7	16.0	634.5	733.3

(Continued)

Table 3. Statistical Summary of Project Operations by Event at Lower Granite Dam, 2002													
Event	Starting Time	Ending Time	Duration (hr)	Q_{total} (kcfs)	$Q_{total\ Max}$ (kcfs)	$Q_{total\ Min}$ (kcfs)	Q_{SPILL} (kcfs)	Active Spill Bays	q_s ((kcfs/bay)	Q_{RSW} (kcfs)	Q_{spill}/Q_{total}	TWE (ft)	FBE (ft)
119	6/9/02 19:15	6/10/02 4:00	9.75	88.0	96.9	41.1	41.2	8	5.3	6.7	47.6	634.2	733.2
120	6/10/02 6:00	6/10/02 6:15	1.25	60.7	60.7	59.9	59.9	8	7.7	6.7	98.7	633.1	733.5
121	6/10/02 7:30	6/10/02 9:45	3.25	51.7	51.9	50.7	51.0	8	6.8	6.7	98.6	632.5	734.3
122	6/10/02 12:00	6/10/02 12:00	1	74.8	74.8	74.0	74.0	8	9.5	6.8	98.9	633.6	734.9
123	6/10/02 13:15	6/10/02 13:45	1.5	65.2	65.2	64.5	64.5	8	8.3	6.8	98.9	632.9	735.2
124	6/10/02 15:00	6/10/02 15:00	1	75.2	75.2	74.5	74.5	8	9.6	6.8	99.1	633.0	735.4
125	6/10/02 17:15	6/10/02 19:15	3	76.3	110.7	65.2	65.2	8	8.5	6.8	89.1	633.0	735.8
126	6/10/02 20:45	6/10/02 21:15	1.5	98.0	98.3	41.3	41.3	7	6.1	0.0	42.1	634.2	735.7
127	6/10/02 23:45	6/11/02 5:15	6.5	94.2	98.6	40.6	40.6	7	5.8	0.0	43.3	634.3	734.7
128	6/11/02 6:30	6/11/02 7:30	2	79.0	87.0	19.7	19.7	7	3.1	0.0	25.0	634.1	734.6
129	6/11/02 10:00	6/11/02 17:45	8.75	86.5	91.2	15.8	15.8	6	2.9	0.0	18.4	634.7	734.7
130	6/11/02 19:00	6/12/02 5:45	11.75	72.0	86.0	42.5	42.5	7	6.1	0.0	59.9	634.0	734.7
131	6/12/02 7:00	6/12/02 8:45	2.75	91.1	91.5	15.9	15.9	7	2.5	0.0	17.5	635.7	734.7
132	6/12/02 19:15	6/13/02 5:45	11.5	71.4	73.7	42.5	42.5	7	6.1	0.0	59.6	634.1	734.5
133	6/13/02 7:15	6/13/02 11:15	5	85.2	86.0	10.0	10.0	5	2.0	0.0	11.7	635.7	734.7
134	6/13/02 19:15	6/14/02 5:45	11.5	70.7	82.1	38.7	38.7	7	5.6	0.0	55.1	634.1	734.6
135	6/14/02 19:15	6/15/02 10:00	15.75	79.5	97.0	33.0	33.0	7	4.9	0.0	42.2	634.7	734.4
136	6/15/02 11:15	6/15/02 12:00	1.75	85.7	86.0	10.7	10.7	3	4.9	6.7	12.5	635.3	734.3
137	6/15/02 19:00	6/16/02 6:00	12	79.1	93.9	32.1	32.2	8	4.4	6.8	41.3	634.7	734.6
138	6/16/02 7:15	6/16/02 14:00	7.75	85.8	86.4	10.6	10.6	2	5.7	6.7	12.4	635.5	734.6
139	6/16/02 19:15	6/17/02 6:45	12.5	86.6	99.0	15.9	31.2	8	4.3	6.7	36.2	635.2	734.8
140	6/17/02 8:00	6/17/02 16:45	9.75	95.0	95.4	19.7	19.7	7	3.1	0.0	20.7	635.8	734.7
141	6/17/02 18:15	6/18/02 6:00	12.75	92.5	110.8	34.9	34.9	7	5.2	0.0	39.4	635.2	734.6
142	6/18/02 7:30	6/18/02 9:30	3	107.1	107.3	49.8	49.9	5	10.0	0.0	46.6	634.5	734.8
143	6/18/02 10:45	6/18/02 14:45	5	91.2	92.0	34.7	34.7	5	7.1	0.0	38.0	634.5	734.8
144	6/18/02 16:00	6/18/02 16:45	1.75	99.1	99.5	42.3	42.3	5	8.6	0.0	42.7	634.4	734.8
145	6/18/02 18:00	6/18/02 21:15	4.25	103.2	117.2	41.6	41.6	8	5.4	6.7	40.6	635.9	734.3
146	6/18/02 22:45	6/19/02 6:00	8.25	92.3	108.7	40.6	40.6	7	5.8	0.0	44.1	635.3	734.3
147	6/19/02 7:15	6/19/02 7:30	1.25	93.7	94.1	19.5	19.5	5	4.6	0.0	20.8	635.7	734.7
148	6/19/02 8:45	6/19/02 9:00	1.25	100.3	100.4	42.3	42.3	5	8.7	0.0	42.2	635.5	734.6

(Continued)

Table 3. Statistical Summary of Project Operations by Event at Lower Granite Dam, 2002

Event	Starting Time	Ending Time	Duration (hr)	Q_{total} (kcfs)	$Q_{total\ Max}$ (kcfs)	$Q_{total\ Min}$ (kcfs)	Q_{SPILL} (kcfs)	Active Spill Bays	q_s ((kcfs/bay)	Q_{RSW} (kcfs)	Q_{spill}/Q_{total}	TWE (ft)	FBE (ft)
149	6/19/02 10:15	6/19/02 18:00	8.75	99.6	102.4	42.3	42.3	5	8.6	0.0	42.5	634.3	734.7
150	6/19/02 19:15	6/20/02 6:00	11.75	97.8	115.0	42.4	42.5	7	6.1	0.0	43.8	635.0	734.3
151	6/20/02 7:15	6/20/02 8:45	2.5	94.2	100.0	42.3	42.3	5	8.6	0.0	45.0	634.5	734.5
152	6/20/02 10:00	6/20/02 17:00	8	88.3	89.1	30.9	30.9	5	6.3	0.0	35.0	634.3	734.5
153	6/20/02 19:00	6/20/02 21:15	3.25	91.2	91.5	15.9	15.9	7	2.5	0.0	17.4	635.5	734.2
154	6/21/02 7:00	6/21/02 8:15	2.25	87.1	99.0	42.3	42.3	5	8.6	0.0	48.8	634.1	734.6
155	6/21/02 11:15	6/21/02 13:30	3.25	91.3	91.7	34.7	34.7	5	7.1	0.0	38.0	634.2	734.7
156	6/21/02 14:45	6/21/02 17:30	3.75	97.9	105.2	40.3	40.4	5	8.1	0.0	41.2	634.2	734.4
157	6/21/02 18:45	6/21/02 20:15	2.5	91.2	91.7	15.9	15.9	7	2.5	0.0	17.4	635.3	734.1
158	6/22/02 12:30	6/22/02 14:00	2.5	71.0	82.0	6.8	6.8	1	6.8	6.8	9.7	634.8	734.8
159	6/22/02 15:15	6/22/02 16:30	2.25	85.2	85.7	10.0	10.0	5	2.0	0.0	11.7	635.7	734.8
160	6/22/02 17:45	6/22/02 19:45	3	95.0	95.8	19.7	19.7	7	3.1	0.0	20.7	635.7	734.5
161	6/22/02 21:00	6/22/02 21:30	1.5	80.8	81.3	6.0	6.0	3	2.0	0.0	7.4	635.2	734.3
162	6/23/02 8:00	6/23/02 23:45	16.75	91.2	91.9	15.9	15.9	7	2.5	0.0	17.4	635.5	734.6
163	6/24/02 1:00	6/24/02 8:00	8	85.0	85.8	10.0	10.0	5	2.0	0.0	11.8	635.6	734.5
164	6/24/02 9:15	6/24/02 11:45	3.5	86.7	87.0	29.1	29.1	6	5.0	0.0	33.6	634.8	734.7
165	6/24/02 13:15	6/24/02 15:45	3.5	92.1	92.6	34.8	34.8	6	5.8	0.0	37.8	634.5	734.7
166	6/24/02 17:15	6/24/02 21:45	5.5	98.0	98.3	40.2	40.4	6	6.9	0.0	41.3	634.4	734.3
167	6/24/02 23:00	6/25/02 4:30	6.5	77.2	77.8	19.6	19.6	6	3.5	0.0	25.4	634.7	734.5
168	6/25/02 5:45	6/25/02 6:45	2	92.2	92.4	34.8	34.8	6	5.8	0.0	37.7	634.9	734.9
169	6/25/02 8:00	6/25/02 13:00	6	98.0	103.0	40.5	40.5	6	6.9	0.0	41.3	634.8	734.7
170	6/25/02 14:15	6/25/02 16:45	3.5	100.5	101.1	25.3	25.3	6	4.3	0.0	25.2	635.3	734.4
171	6/25/02 18:00	6/25/02 21:45	4.75	91.2	91.6	15.8	15.8	6	2.9	0.0	17.3	635.2	734.2
172	6/25/02 23:00	6/25/02 23:30	1.5	81.3	81.4	6.0	6.0	3	2.0	0.0	7.4	634.9	734.2
173	6/26/02 8:15	6/26/02 13:30	6.25	90.9	91.3	15.8	15.8	6	2.9	0.0	17.4	635.3	734.7
174	6/26/02 14:45	6/26/02 17:00	3.25	100.3	100.9	25.3	25.3	6	4.3	0.0	25.2	635.0	734.3
175	6/27/02 3:15	6/27/02 9:45	7.5	88.9	97.7	42.4	42.4	6	7.2	0.0	47.9	634.8	734.8
176	6/27/02 11:00	6/27/02 11:45	1.75	94.4	95.1	19.6	19.6	6	3.5	0.0	20.8	635.6	734.5
177	6/27/02 13:00	6/27/02 14:00	2	92.4	96.4	29.1	29.1	6	5.0	0.0	31.5	635.3	734.4
178	6/27/02 15:30	6/27/02 18:45	4.25	85.7	87.0	29.1	29.1	6	5.0	0.0	34.0	634.7	734.2

(Continued)

Table 3. Statistical Summary of Project Operations by Event at Lower Granite Dam, 2002

Event	Starting Time	Ending Time	Duration (hr)	Q_{total} (kcfs)	$Q_{total\ Max}$ (kcfs)	$Q_{total\ Min}$ (kcfs)	Q_{SPILL} (kcfs)	Active Spill Bays	q_s ((kcfs/bay)	Q_{RSW} (kcfs)	Q_{spill}/Q_{total}	TWE (ft)	FBE (ft)
179	6/27/02 20:00	6/27/02 22:45	3.75	76.8	77.4	19.6	19.6	6	3.5	0.0	25.5	634.5	734.1
180	6/28/02 0:00	6/28/02 9:15	10.25	79.6	97.2	42.4	42.4	6	7.1	0.0	54.0	634.1	734.6
181	6/28/02 10:30	6/28/02 13:00	3.5	85.0	89.5	19.7	19.7	7	3.1	0.0	23.3	635.2	734.5
182	6/28/02 14:15	6/28/02 15:45	2.5	79.5	80.7	29.2	29.2	7	4.3	0.0	36.7	634.8	734.6
183	6/28/02 17:00	6/29/02 9:00	17	88.7	93.1	38.7	38.7	7	5.6	0.0	43.7	635.0	734.5
184	6/29/02 10:15	6/29/02 13:15	4	82.1	92.2	19.7	19.7	7	3.1	0.0	24.0	635.2	734.6
185	6/29/02 14:30	6/29/02 16:45	3.25	84.9	85.4	10.0	10.0	5	2.0	0.0	11.8	635.6	734.4
186	6/30/02 9:00	6/30/02 9:45	1.75	84.3	84.6	36.8	36.8	7	5.4	0.0	43.7	635.0	734.9
187	6/30/02 11:00	6/30/02 17:45	7.75	84.5	86.7	29.2	29.2	7	4.3	0.0	34.6	635.0	734.7
188	6/30/02 19:00	6/30/02 19:45	1.75	82.9	83.3	19.7	19.7	7	3.1	0.0	23.8	635.2	734.5
189	6/30/02 21:00	6/30/02 23:00	3	83.3	83.9	29.2	29.8	7	4.4	0.0	35.8	634.9	734.3
190	7/1/02 0:15	7/1/02 13:45	14.5	73.9	95.7	40.6	40.6	7	5.8	0.0	56.2	634.2	734.5
191	7/1/02 16:00	7/1/02 18:15	3.25	63.7	101.7	40.6	40.6	7	5.8	0.0	66.7	633.5	734.4
192	7/1/02 20:15	7/1/02 22:45	3.5	58.6	60.2	29.2	29.2	7	4.3	0.0	49.8	634.0	734.5
193	7/2/02 0:00	7/2/02 11:15	12.25	62.9	86.0	38.7	38.7	7	5.6	0.0	62.1	634.1	734.7
194	7/3/02 0:15	7/3/02 7:45	8.5	53.4	55.2	38.2	38.2	8	5.1	7.1	71.6	633.7	734.7
195	7/4/02 0:15	7/4/02 11:00	11.75	56.3	82.6	40.6	40.6	7	5.8	0.0	75.2	633.9	734.8
196	7/9/02 9:15	7/10/02 6:30	22.25	42.8	62.0	20.9	20.9	8	3.6	6.9	50.0	634.0	734.4
197	7/10/02 8:00	7/10/02 8:15	1.25	54.6	54.8	6.0	6.0	3	2.0	0.0	11.0	634.6	734.6
198	7/10/02 23:15	7/11/02 7:00	8.75	35.2	40.7	19.7	19.7	7	3.1	0.0	56.3	633.6	734.7
199	7/11/02 19:15	7/12/02 7:00	12.75	35.8	47.3	20.7	20.8	8	3.5	6.8	62.6	633.7	734.5
200	7/12/02 8:15	7/13/02 0:30	17.25	46.2	61.1	30.2	30.2	8	4.3	6.7	68.1	633.7	734.4
201	7/13/02 1:45	7/13/02 11:00	10.25	39.2	59.4	20.8	20.8	8	3.6	6.8	54.9	633.8	734.8
202	7/15/02 2:00	7/15/02 2:00	1	29.2	29.2	29.2	29.2	7	4.3	0.0	100.0	633.7	734.7
203	7/15/02 3:15	7/15/02 9:45	7.5	43.2	48.1	31.1	31.1	7	4.6	0.0	73.0	633.9	734.8
204	7/15/02 11:15	7/15/02 11:15	1	63.9	63.9	19.7	19.7	7	3.1	0.0	30.8	634.5	734.5
205	7/16/02 0:15	7/16/02 5:45	6.5	34.4	51.5	21.6	21.6	7	3.4	0.0	68.8	633.9	734.8
Grand Total				86.3					4.9	3.6	42.9	634.4	734.5

Table 4. Statistical Summary of TDG Saturation by Sampling Station at Lower Granite Dam, April 1 – July 16, 2002

Station	Number	TDG Saturation (%)				Percent Exceedance of TDG Saturation Level					
		Average	Maximum	Minimum	Standard Deviation	100	105	110	115	120	125
LWG	5881	103.7	113.5	99.9	2.0	99.8	20.4	1.1	0.0	0.0	0.0
T1P1	4041	108.1	125.7	95.5	5.1	99.5	61.7	33.7	9.2	3.2	0.2
T1P2	3626	115.3	128.3	101.2	6.0	100.0	98.9	75.8	56.3	25.8	3.8
T1P3	3669	115.0	125.8	101.5	5.2	100.0	99.0	79.1	56.1	18.5	0.2
T1avg[1]	3669	115.2	127.0	101.3	5.6	100.0	99.0	77.7	56.4	21.3	2.3
LGNWP1	5862	111.5	127.7	99.0	5.2	100.0	84.4	61.3	25.5	5.1	1.0
LGNWP2	5862	112.2	128.8	99.9	5.2	100.0	89.9	66.5	32.0	6.7	1.1
LGNWP3	5864	114.5	129.4	99.9	5.5	100.0	97.4	75.1	51.1	16.5	2.9
LGNWP4	5864	115.1	126.5	99.8	5.4	100.0	98.8	78.9	55.8	19.6	1.3
LGNWP5	2129	113.6	124.5	101.6	4.9	100.0	97.8	71.8	47.7	7.3	0.0
LGNW	5878	115.2	124.7	99.9	5.0	100.0	99.1	81.8	56.5	19.1	0.0
LGNWavg[2]	5855	113.8	127.0	99.8	5.1	100.0	97.7	70.9	47.1	10.1	1.2
LGNWmax[3]	5855	115.8	129.4	99.9	5.3	100.0	99.3	83.2	58.7	23.3	2.9
LGNWavg-LWG[4]	5851	10.0	23.7	-5.2	5.5	97.6	79.9	52.4	20.0	2.0	0.0

[1]Average TDG saturation of stations T1P2 and T1P3 in spill water.

[2] Weighted average TDG saturation of stations LGNWP1-P5.

[3] Maximum TDG saturation on stations LGNW, LGNWP1-P5.

[4] Difference in TDG saturation between LGNWavg and LWG. Percent exceedance is associated with 0, 5, 10, 15, 20, and 25 levels.

Table 5. Statistical Summary of Total Dissolved Gas Saturation at the Tailwater Fixed Monitoring Station as a Function of Spill Discharge at Lower Granite Dam, 2002

Spill Range (kcfs)	TDG Saturation (%)				TDG Saturation Percentile (%)					Occurrence of Exceeding TDG Criteria (%)			
	N	Avg	Max	Min	.05	.25	.5	.75	.95	110%	115%	120%	125%
5-10	16	106.8	116.7	101.5	103.8	105.7	106.2	107.1	111.2	6.2	1.6	0	0
10-15	23	108.0	109.4	105.9	106.5	107.6	108.2	108.5	109.4	0	0	0	0
15-20	305	108.6	115.8	105.3	107.1	107.7	108.3	109.1	111.5	11.9	0.3	0	0
20-25	324	111.3	114.0	103.7	110.1	110.8	111.4	111.8	112.4	96.3	0	0	0
25-30	56	112.9	116.6	103.3	110.6	111.6	112.5	114.6	115.7	98.2	11.0	0	0
30-35	102	115.5	119.5	110.5	112.9	114.0	115.5	117.0	118.1	1	59.2	0	0
35-40	191	117.1	119.8	112.7	115.3	115.9	117.3	118.2	119.3	1	97.0	0	0
40-45	323	118.6	122.3	113.7	115.8	117.1	118.9	119.9	121.6	1	99.4	24.6	0
45-50	82	118.3	123.7	115.3	116.5	116.8	117.1	120.3	121.4	1	1	29.7	0
50-55	46	119.7	122.1	117.0	117.8	118.4	120.0	121.1	121.6	1	1	48.9	0
55-60	62	121.5	124.6	117.6	118.1	119.0	121.7	123.7	124.5	1	1	71.0	0
60-65	75	122.5	124.6	119.6	119.9	122.3	122.6	122.7	124.3	1	1	91.3	0
65-70	2	121.4	123.1	119.6	119.8	120.5	121.4	122.2	122.9	1	1	88.6	0
70-75	0												
75-80	0												
80-85	7	122.9	124.2	122.1	122.2	122.5	122.8	123.2	123.9	1	1	1	0
85-90	10	122.3	123.3	121.7	121.7	122.0	122.2	122.5	123.1	1	1	1	0
90-95	8	123.6	124.6	121.5	121.6	123.2	124.2	124.4	124.6	1	1	1	0
110-115	1	124.0	124.0	124.0	124.0	124.0	124.0	124.0	124.0	1	1	1	0

Table 6. Statistical Summary of TDG Saturation by Station, Transect, and Spill event

Event	Q_{total} (kcfs)	Q_{spill} (kcfs)	Q_{rsw} (kcfs)	LWG (%)	Transect T1 Total Dissolved Gas Saturation (%) P1 (%)	P2 (%)	P3 (%)	Avg P2 & P3	Tailwater FMS Transect LGNW Total Dissolved Gas Saturation (%) P1	P2	P3	P4	P5	LWGN	AVG	Max	Diff (FMS-Max)	TW FB
1	54.9	54.4		102.9										118.1		118.1		
2	58.2	57.7		102.0										121.4		121.4		
3	50.5	50.2		103.5		123.4	122.1	122.8	120.9	122.6	123.1	121.2	120.0	120.3	121.8	123.1	2.8	18.3
4	56.3	55.7		102.7		124.4	122.4	123.4	121.0	123.1	124.2	122.7	122.1	121.5	122.9	124.2	2.7	20.2
5	67.7	59.3		103.3		126.4	124.0	125.2	120.9	123.6	126.1	124.3	123.2	123.5	124.0	126.1	2.7	20.7
6	63.6	49.9		104.2		121.7	120.3	121.0	115.7	117.8	120.1	118.5	117.0	120.6	118.2	120.6	0.0	14.0
7	67.4	44.6		103.6		123.3	122.1	122.7	117.8	119.6	122.3	121.9	121.7	121.7	120.9	122.3	0.6	17.3
8	87.8	40.4		103.2		119.7	119.0	119.4	114.5	114.4	116.1	118.8	118.9	119.1	116.5	119.1	0.0	13.3
9	78.0	40.8		102.9		120.1	119.9	120.0	113.9	114.3	117.2	119.2	119.2	119.2	116.8	119.2	0.1	13.9
10	69.6	35.0		102.3		117.9	118.0	118.0	112.1	112.9	115.5	117.3	117.6	117.8	115.2	117.8	0.0	12.9
11	76.8	23.8		102.2		110.2	111.5	110.9	104.7	105.7	108.7	110.5	111.4	111.9	108.2	111.9	0.0	6.0
12	74.4	36.9		102.2		118.3	118.5	118.4	111.3	112.2	115.2	117.7	117.8	118.0	114.9	118.0	0.0	12.7
13	77.5	15.7		101.9		107.6	107.5	107.5	104.9	105.5	107.1	107.5	107.6	107.8	106.6	107.8	0.0	4.7
14	68.6	43.6		101.3		119.2	117.0	118.1	117.0	117.4	117.7	118.8	118.6	118.7	117.9	118.8	0.1	16.6
15	79.1	15.7		101.3		107.7	107.5	107.6	104.4	105.1	107.1	107.4	107.5	107.7	106.4	107.7	0.0	5.1
16	73.5	48.3		102.0		121.4	119.7	120.6	117.6	117.9	119.4	120.5	120.1	120.1	119.2	120.5	0.4	17.2
17	81.9	15.9		102.6		107.3	107.5	107.4	104.6	105.4	106.5	107.0	107.3	107.4	106.2	107.4	0.0	3.6
18	70.1	43.6		102.3		116.6	115.0	115.8	117.6	117.9	117.7	116.7	116.1	116.0	117.3	117.9	1.9	15.0
19	69.6	16.5		101.5		107.1	107.2	107.1	106.9	107.4	107.3	107.1	107.1	107.2	107.2	107.4	0.2	5.7
20	71.9	47.4		102.8		117.8	116.1	116.9	118.1	118.4	118.9	117.9	117.1	116.9	118.2	118.9	2.0	15.4
21	83.8	51.1		104.0		118.5	116.7	117.6	118.8	119.3	120.6	119.3	118.5	118.4	119.4	120.6	2.2	15.4
22	116.0	44.5		103.0		120.2	120.1	120.1	113.3	113.4	115.5	119.1	119.4	119.4	116.1	119.4	0.0	13.0
23	136.2	39.6		102.7		115.6	116.0	115.8	103.9	106.7	113.0	115.3	115.7	116.0	111.2	116.0	0.0	8.5
24	106.6	45.0		102.7		117.3	116.5	116.9	114.7	115.6	117.7	117.5	117.1	117.1	116.7	117.7	0.6	14.0
25	116.6	43.6		101.7		117.4	116.6	117.0	112.3	113.8	116.6	117.2	116.9	116.9	115.5	117.2	0.3	13.9
26	107.7	24.4		101.0		109.5	110.4	110.0	102.2	103.9	107.5	109.1	109.9	110.4	106.6	110.4	0.0	5.6
27	101.9	24.4		100.9		109.7	110.5	110.1	103.2	104.4	107.9	109.3	109.9	110.5	107.0	110.5	0.0	6.2
28	92.4	47.2		100.8		117.8	115.9	116.9	116.1	117.0	118.7	117.6	116.7	116.6	117.4	118.7	2.1	16.6

(Continued)

Table 6. Statistical Summary of TDG Saturation by Station, Transect, and Spill event

Event	Q_{total} (kcfs)	Q_{spill} (kcfs)	Q_{rsw} (kcfs)	LWG (%)	Transect T1 Total Dissolved Gas Saturation (%)				Tailwater FMS Transect LGNW Total Dissolved Gas Saturation (%)								Diff (FMS-Max)	TW FB
					P1 (%)	P2 (%)	P3 (%)	Avg P2 & P3	P1	P2	P3	P4	P5	LWGN	AVG	Max		
29	100.1	24.5	6.7	100.4		109.6	110.2	109.9	103.6	104.7	107.6	109.0	109.7	110.1	107.0	110.1	0.0	6.6
30	88.8	22.6	6.7	99.9		108.7	108.3	108.5	101.9	103.1	106.6	107.9	108.3	108.4	105.7	108.4	0.0	5.8
31	84.5	16.7	6.7	100.1		106.8	107.1	106.9	102.6	103.6	106.0	106.5	106.8	110.2	105.2	110.2	0.0	5.1
32	86.5	30.2	6.7	100.9		112.8	112.3	112.5	109.3	110.4	111.5	111.7	112.0	112.1	111.1	112.1	0.0	10.2
33	88.3	47.4	6.8	100.5		117.4	115.5	116.5	116.9	117.4	118.9	117.7	116.9	116.9	117.7	118.9	2.0	17.2
34	83.5	53.9	0.0	102.2		124.5	121.9	123.2	117.4	118.5	121.8	122.5	121.7	121.5	120.6	122.5	1.0	18.4
35	76.9	50.1	0.0	103.1		123.8	121.3	122.6	117.2	117.7	120.9	121.8	121.3	121.1	119.9	121.8	0.7	16.9
36	67.8	24.5	6.7	103.0		111.5	111.9	111.7	110.9	111.4	111.6	111.4	111.4	111.6	111.4	111.6	0.0	8.4
37	75.8	16.7	6.7	101.1		107.4	107.4	107.4	105.2	105.8	107.3	107.3	107.3	107.4	106.7	107.4	0.0	5.5
38	63.4	16.7	6.7	102.5		107.2	107.4	107.3	107.6	107.9	107.5	107.3	107.2	107.4	107.5	107.9	0.5	5.1
39	63.6	16.7	6.7	101.8		107.5	107.5	107.5	107.6	107.9	108.0	107.7	107.6	107.4	107.8	108.0	0.6	6.0
40	64.4	42.5	0.0	102.4		121.9	120.6	121.3	116.7	117.5	120.5	120.1	119.8	119.4	119.1	120.5	1.2	16.7
41	59.6	34.9	0.0	103.4		117.4	116.2	116.8	115.9	116.5	117.0	116.2	115.9	115.6	116.4	117.0	1.5	13.0
42	58.3	38.7	0.0	103.2		120.1	118.8	119.5	117.6	117.9	119.1	118.4	117.9	117.6	118.3	119.1	1.6	15.1
43	60.7	38.7	0.0	103.7		120.2	119.0	119.6	116.3	116.8	118.8	118.6	118.2	117.8	117.9	118.8	1.0	14.2
44	58.3	16.7	6.7	103.3		108.2	108.8	108.5	109.1	109.3	108.8	108.4	108.3	108.7	108.8	109.3	0.6	5.5
45	61.8	42.5	6.9	102.7		116.1	115.5	115.8	118.2	118.8	117.4	116.3	115.7	116.1	117.4	118.8	2.8	14.7
46	69.3	52.1	6.9	103.6		117.7	116.7	117.2	119.4	120.6	118.2	117.5	116.9	117.0	118.6	120.6	3.6	15.0
47	76.5	55.8	6.9	104.8		118.0	117.1	117.5	120.0	121.1	119.5	118.2	117.5	117.7	119.4	121.1	3.4	14.6
48	72.7	52.0	6.9	104.3		118.0	117.2	117.6	119.6	120.7	118.5	117.7	117.2	117.9	118.8	120.7	2.8	14.5
49	73.0	52.7	0.0	104.3		123.3	121.3	122.3	118.3	119.0	122.6	121.5	120.4	120.2	120.6	122.6	2.4	16.3
50	72.5	52.0	6.9	104.8		118.0	118.0	118.0	120.1	120.6	118.5	118.0	118.4	118.8	119.1	120.6	1.8	14.3
51	68.6	48.2	6.9	104.5		116.9	117.3	117.1	120.1	120.9	119.1	118.0	117.4	118.5	119.2	120.9	2.4	14.7
52	70.6	57.7	5.3	103.3		118.9	117.5	118.2	120.2	120.6	120.3	118.9	118.2	119.0	119.8	120.6	1.6	16.4
53	64.7	63.9	6.9	102.1		119.9	118.2	119.1	120.5	120.5	122.0	120.1	119.6	119.9	120.7	122.0	2.1	18.6
54	93.8	37.5	0.0	101.8		116.3	115.0	115.6	113.0	112.9	115.4	115.2	115.0	115.5	114.4	115.5	0.0	12.6
55	72.6	16.0	0.0	102.1		108.2	107.3	107.7	102.3	102.4	105.3	106.8	106.9	107.6	104.8	107.6	0.0	2.7
56	82.4	43.1	0.0	102.0		121.1	120.3	120.7	114.2	114.7	118.5	119.7	119.4	119.9	117.4	119.9	0.0	15.5
57	72.2	17.2	7.2	101.3		107.4	107.5	107.5	105.9	106.3	107.4	107.4	107.4	107.9	106.9	107.9	0.0	5.6

(Continued)

Table 6. Statistical Summary of TDG Saturation by Station, Transect, and Spill event

Event	Q_{total} (kcfs)	Q_{spill} (kcfs)	Q_{rsw} (kcfs)	LWG (%)	Transect T1 Total Dissolved Gas Saturation (%)				Tailwater FMS Transect LGNW Total Dissolved Gas Saturation (%)								Diff (FMS-Max)	TW FB
					P1 (%)	P2 (%)	P3 (%)	Avg P2 & P3	P1	P2	P3	P4	P5	LWGN	AVG	Max		
58	64.8	24.8	7.0	101.8		110.9	110.6	110.7	110.0	110.5	111.0	110.8	110.8	111.4	110.7	111.4	0.0	8.9
59	55.8	46.3	0.0	103.3		122.9	121.3	122.1	118.8	120.0	121.2	120.0	119.6	120.8	120.1	121.2	0.5	16.8
60	58.5	46.3	0.0	106.2		123.3	121.4	122.3	118.2	119.6	121.6	118.6	117.8	119.6	119.4	121.6	2.0	13.2
61	53.9	38.7	0.0	105.1		120.4	119.3	119.9	116.7	117.6	118.9	118.6	118.4	119.6	118.2	119.6	0.0	13.1
62	59.4	17.1	7.1	103.7		108.5	108.9	108.7	108.2	108.6	108.9	108.6	108.5	109.6	108.6	109.6	0.0	4.9
63	74.0	24.7	6.9	103.8		111.0	110.5	110.8	109.2	109.9	110.6	110.7	110.6	111.4	110.2	111.4	0.0	6.5
64	65.9	24.7	6.9	104.4		111.1	111.0	111.0	110.3	110.8	110.7	110.7	110.7	111.8	110.7	111.8	0.0	6.3
65	67.6	36.8	0.0	103.9		118.3	117.6	117.9	113.2	113.5	116.3	116.4	116.5	117.0	115.2	117.0	0.0	11.3
66	72.2	40.6	0.0	104.0		120.1	119.2	119.7	113.6	114.7	117.9	118.3	118.3	118.6	116.7	118.6	0.0	12.7
67	82.1	17.0	7.1	104.1		108.2	108.2	108.2	105.7	106.3	108.0	107.9	108.2	108.3	107.3	108.3	0.0	3.2
68	103.1	28.4	6.8	103.2		112.4	113.2	112.8	104.9	106.4	111.3	111.8	112.2	112.4	109.5	112.4	0.0	6.3
69	110.5	36.0	6.8	103.3		116.4	116.0	116.2	107.0	110.0	115.8	115.3	115.6	115.7	113.1	115.8	0.1	9.8
70	109.3	39.8	6.8	101.6	103.4	116.2	116.2	116.2	109.7	111.2	115.5	116.0	116.0	115.9	113.9	116.0	0.1	12.3
71	109.9	45.6	6.9	100.7	105.2	117.1	116.4	116.8	112.6	113.9	117.5	117.2		116.7	115.8	117.5	0.8	15.2
72	97.7	24.9	7.1	103.0	102.7	111.3	112.4	111.8	105.1	106.2	110.1	111.6		112.0	109.1	112.0	0.0	6.1
73	94.4	19.7	0.0	104.4	103.9	109.4	109.8	109.6	105.2	106.0	109.0	109.5		109.9	108.0	109.9	0.0	3.6
74	91.1	15.9	0.0	104.8	103.9	108.1	108.3	108.2	104.0	103.8	106.2	108.2		108.5	106.1	108.5	0.0	1.3
75	88.2	15.9	0.0	104.8	104.8	106.8	107.5	107.2	104.9	104.6	105.7	107.2		107.1	105.9	107.2	0.1	1.1
76	93.1	40.6	0.0	104.4	111.0	118.7	118.7	118.7	114.2	114.1	116.6	118.3		118.0	116.3	118.3	0.3	11.9
77	90.6	15.8	0.0	104.6	104.2	107.3	108.5	107.9	104.3	104.2	106.4	108.1		108.4	106.2	108.4	0.0	1.6
78	82.4	10.0	0.0	106.0	104.9	106.3	106.8	106.5	105.0	104.8	105.6	106.6		106.7	105.7	106.7	0.0	-0.3
79	90.8	44.4	0.0	105.0	113.5	121.2	120.3	120.7	115.3	115.4	118.6	120.3		119.9	117.9	120.3	0.3	12.9
80	84.1	16.7	6.7	105.4	104.5	108.3	108.1	108.2	105.8	106.5	108.4	108.6		108.4	107.7	108.6	0.2	2.3
81	99.1	24.5	6.7	103.4	103.2	110.7	111.1	110.9	104.8	106.0	110.3	110.9		111.0	108.8	111.0	0.0	5.4
82	109.3	34.9	0.0	102.9	102.8	114.9	115.1	115.0	107.3	109.2	113.3	114.6		114.5	112.0	114.6	0.1	9.1
83	115.4	40.6	0.0	103.2	105.9	117.4	117.8	117.6	111.4	111.8	114.4	117.0		117.1	114.4	117.1	0.0	11.2
84	119.4	44.4	0.0	103.6	107.1	119.4	119.6	119.5	112.3	112.6	115.1	118.3		118.7	115.4	118.7	0.0	11.8
85	113.3	42.5	0.0	102.9	107.3	119.4	119.5	119.5	112.4	112.6	115.8	118.8		119.1	115.7	119.1	0.0	12.8
86	130.9	55.8	0.0	103.6	112.3	125.1	123.8	124.4	116.0	116.3	120.7	123.5		123.5	120.1	123.5	0.0	16.4

(Continued)

Table 6. Statistical Summary of TDG Saturation by Station, Transect, and Spill event

Event	Q_{total} (kcfs)	Q_{spill} (kcfs)	Q_{rsw} (kcfs)	LWG (%)	Transect T1 Total Dissolved Gas Saturation (%)				Tailwater FMS Transect LGNW Total Dissolved Gas Saturation (%)								Diff (FMS-Max)	TW FB
					P1 (%)	P2 (%)	P3 (%)	Avg P2 & P3	P1	P2	P3	P4	P5	LWGN	AVG	Max		
87	134.9	59.6	0.0	103.3	113.7	126.2	124.5	125.4	116.6	116.7	121.7	124.5		124.4	120.9	124.5	0.0	17.5
88	136.6	60.8	6.9	103.6	104.1	125.0	124.5	124.8	115.7	116.5	120.7	123.9		124.3	120.3	124.3	0.0	16.7
89	136.0	61.0	7.1	104.5	105.8	123.4	122.7	123.0	115.3	116.3	120.1	122.3		122.6	119.4	122.6	0.0	14.9
90	125.0	51.0	6.7	104.6	106.3	120.5	120.0	120.2	113.6	114.8	118.8	119.8		120.1	117.6	120.1	0.0	13.0
91	130.0	56.8	6.7	104.7	108.7	120.9	120.3	120.6	114.6	115.8	119.4	120.3		120.4	118.2	120.4	0.0	13.6
92	134.6	60.7	6.8	103.6	106.0	123.2	122.5	122.8	115.0	116.0	119.8	122.1		122.3	119.1	122.3	0.0	15.5
93	144.2	69.9	6.7	104.6	109.9	124.2	123.1	123.7	115.6	116.8	121.5	123.1		123.0	120.2	123.1	0.0	15.6
94	134.5	60.6	6.7	105.4	108.2	122.9	122.1	122.5	114.9	115.9	119.9	121.9		122.1	119.1	122.1	0.0	13.6
95	126.3	52.3	6.7	105.5	106.5	120.2	119.2	119.7	113.4	114.7	118.8	119.5		119.7	117.4	119.7	0.0	11.9
96	123.2	84.7	6.8	104.8	115.5	124.3	122.3	123.3	121.2	121.8	124.7	123.6		122.7	123.0	124.7	2.0	18.2
97	135.9	60.6	6.7	104.4	107.5	123.2	122.5	122.8	114.9	115.9	119.8	122.1		122.2	119.1	122.2	0.0	14.7
98	120.2	45.4	6.7	104.5	104.4	118.4	117.3	117.8	111.8	113.3	118.0	118.1		118.3	116.1	118.3	0.0	11.6
99	114.4	39.7	6.7	104.6	104.5	117.2	116.7	116.9	109.8	111.6	116.3	117.0		117.2	114.6	117.2	0.0	10.1
100	115.9	41.7	6.8	105.7	104.6	118.2	117.6	117.9	110.4	112.1	116.8	117.8		118.0	115.2	118.0	0.0	9.6
101	119.9	90.2	6.8	105.3	116.3	123.9	121.7	122.8	121.1	121.7	124.6	123.1		121.9	122.7	124.6	2.7	17.5
102	113.7	103.9	6.8	105.0	123.9	126.4	123.1	124.7	124.5	125.6	127.2	125.2		123.8	125.5	127.2	3.4	20.5
103	116.8	41.6	6.7	104.9	104.9	117.9	117.2	117.5	110.5	112.3	117.3	117.6		117.6	115.3	117.6	0.0	10.4
104	109.4	35.9	6.7	105.0	105.0	115.9	115.8	115.8	109.1	110.8	114.9	115.8		116.4	113.5	116.4	0.0	8.6
105	112.0	85.4	6.7	104.5	118.3	123.9	121.7	122.8	121.6	122.1	125.1	123.2		122.2	123.1	125.1	2.9	18.6
106	109.7	34.9	0.0	104.2	104.3	115.2	115.3	115.3	109.2	110.0	113.6	115.0		115.5	112.7	115.5	0.0	8.6
107	95.9	40.6	0.0	104.2	109.2	118.0	118.1	118.1	112.9	113.0	115.3	117.6		117.7	115.3	117.7	0.0	11.1
108	110.1	88.8	0.0	104.1	120.1	128.1	125.0	126.6	126.4	127.0	128.2	125.5		124.2	126.5	128.2	4.0	22.4
109	100.6	81.6	0.0	103.8	120.8	127.5	124.1	125.8	124.4	125.1	127.3	125.7		124.0	125.6	127.3	3.2	21.7
110	110.3	90.6	0.0	103.7	119.9	127.8	124.6	126.2	126.9	127.2	127.8	125.5		124.4	126.5	127.8	3.4	22.9
111	104.5	42.5	0.0	103.6	110.8	120.6	119.3	120.0	114.8	114.9	117.8	119.5		119.5	117.3	119.5	0.0	13.7
112	113.1	38.7	0.0	103.7	105.9	117.5	118.0	117.7	111.0	111.3	114.6	117.2		117.9	114.4	117.9	0.0	10.6
113	98.0	42.5	0.0	103.5	111.0	120.5	119.9	120.2	114.3	114.2	117.6	119.8		119.9	117.2	119.9	0.0	13.7
114	106.4	90.6	0.0	103.3	121.7	127.1	124.3	125.7	127.6	128.4	127.4	125.1		124.1	126.7	128.4	4.2	23.4
115	114.1	42.5	0.0	103.2	108.8	119.5	119.2	119.4	113.1	113.1	115.8	118.7		119.3	115.9	119.3	0.0	12.8

(Continued)

Table 6. Statistical Summary of TDG Saturation by Station, Transect, and Spill event

Event	Q_{total} (kcfs)	Q_{spill} (kcfs)	Q_{rsw} (kcfs)	LWG (%)	Transect T1 Total Dissolved Gas Saturation (%)				Tailwater FMS Transect LGNW Total Dissolved Gas Saturation (%)								Diff (FMS-Max)	TW FB
					P1 (%)	P2 (%)	P3 (%)	Avg P2 & P3	P1	P2	P3	P4	P5	LWGN	AVG	Max		
116	91.4	16.7	6.7	103.2	103.3	107.9	108.2	108.0	104.1	104.9	107.2	108.0		108.9	106.6	108.9	0.0	3.4
117	100.4	41.2	6.7	102.6	108.0	116.8	116.3	116.5	112.4	113.6	116.9	116.8		116.4	115.5	116.9	0.5	12.8
118	89.4	14.3	6.7	102.7	102.8	107.2	107.8	107.5	102.9	103.7	105.7	107.2		108.3	105.5	108.3	0.0	2.9
119	88.0	41.2	6.7	102.3	109.8	116.5	116.0	116.3	114.6	115.4	117.6	116.8		116.2	116.3	117.6	1.4	14.0
120	60.7	59.9	6.7	101.8	120.7	119.7	117.6	118.7	119.6	119.7	121.4	119.5		118.6	119.9	121.4	2.8	18.2
121	51.7	51.0	6.7	101.7	120.6	117.2	116.0	116.6	119.2	119.2	119.6	118.5		117.9	118.9	119.6	1.7	17.2
122	74.8	74.0	6.8	101.7	123.8	121.1	119.9	120.5	120.7	121.4	122.9	121.5		120.7	121.6	122.9	2.1	19.9
123	65.2	64.5	6.8	101.9	120.7	120.6	119.0	119.8	120.0	120.6	122.5	120.8		120.3	121.0	122.5	2.2	19.1
124	75.2	74.5	6.8	102.0	122.1	120.7	119.3	120.0	120.9	121.1	123.1	121.3		120.7	121.6	123.1	2.4	19.5
125	76.3	65.2	6.8	102.6	121.5	119.3	117.9	118.6	120.6	120.5	122.0	120.4		119.6	120.8	122.0	2.4	18.1
126	98.0	41.3	0.0	102.7	109.7	118.7	116.6	117.7	114.8	114.7	117.4	117.5		117.8	116.5	117.8	0.0	13.8
127	94.2	40.6	0.0	102.1	107.8	119.1	118.0	118.5	113.2	113.1	116.6	118.3		118.3	115.9	118.3	0.0	13.8
128	79.0	19.7	0.0	101.9	102.4	108.5	110.5	109.5	105.0	104.6	107.2	109.4		110.9	107.3	110.9	0.0	5.4
129	86.5	15.8	0.0	102.9	102.3	106.8	108.3	107.6	102.7	102.8	105.3	107.3		108.1	105.2	108.1	0.0	2.3
130	72.0	42.5	0.0	103.7	113.0	120.5	120.0	120.3	114.0	114.9	118.8	119.6		119.4	117.5	119.6	0.2	13.8
131	91.1	15.9	0.0	103.0	102.5	107.0	108.1	107.5	102.9	102.5	104.8	107.2		108.6	105.1	108.6	0.0	2.0
132	71.4	42.5	0.0	104.5	113.6	121.8	120.9	121.3	114.4	115.1	119.9	120.3		120.1	118.2	120.3	0.2	13.7
133	85.2	10.0	0.0	104.4	103.1	105.2	106.6	105.9	103.4	103.1	104.1	105.9		107.1	104.6	107.1	0.0	0.2
134	70.7	38.7	0.0	107.1	114.2	120.5	119.5	120.0	115.0	115.6	118.8	119.2		119.0	117.6	119.2	0.2	10.6
135	79.5	33.0	0.0	105.6	109.5	116.4	116.6	116.5	111.1	111.4	114.5	116.0		116.2	113.9	116.2	0.0	8.3
136	85.7	10.7	6.7	106.0	104.3	107.2	107.8	107.5	104.8	105.2	107.1	107.7		108.3	106.6	108.3	0.0	0.6
137	79.1	32.2	6.8	106.0	110.9	113.3	112.8	113.0	113.5	114.3	114.3	113.9		113.7	114.0	114.3	0.6	8.0
138	85.8	10.6	6.7	105.0	104.1	107.6	108.3	108.0	104.8	105.4	107.2	107.9		108.4	106.8	108.4	0.0	1.8
139	86.6	31.2	6.7	103.4	107.7	113.0	111.7	112.4	111.3	112.3	113.5	113.4		113.1	112.8	113.5	0.5	9.4
140	95.0	19.7	0.0	102.8	102.9	110.8	111.8	111.3	103.1	103.0	108.1	111.1		111.7	107.4	111.7	0.0	4.6
141	92.5	34.9	0.0	102.9	107.8	116.8	116.5	116.7	110.2	111.2	115.1	116.2		116.2	113.9	116.2	0.0	11.1
142	107.1	49.9	0.0	102.6	104.0	127.8	124.2	126.0	119.3	121.0	125.4	124.3		123.6	123.0	125.4	1.8	20.4
143	91.2	34.7	0.0	102.5	102.8	120.2	119.4	119.8	114.1	115.1	118.8	119.0		119.2	117.4	119.2	0.0	14.9
144	99.1	42.3	0.0	102.4	103.1	124.6	122.1	123.4	116.9	118.0	122.6	122.0		120.9	120.4	122.6	1.7	18.0

(Continued)

Table 6. Statistical Summary of TDG Saturation by Station, Transect, and Spill event

Event	Q_{total} (kcfs)	Q_{spill} (kcfs)	Q_{rsw} (kcfs)	LWG (%)	Transect T1 Total Dissolved Gas Saturation (%)				Tailwater FMS Transect LGNW Total Dissolved Gas Saturation (%)								Diff (FMS-Max)	TW FB
					P1 (%)	P2 (%)	P3 (%)	Avg P2 & P3	P1	P2	P3	P4	P5	LWGN	AVG	Max		
145	103.2	41.6	6.7	102.5	105.8	117.5	116.8	117.1	111.9	113.6	117.7	117.4		117.4	115.9	117.7	0.4	13.4
146	92.3	40.6	0.0	101.5	111.6	119.2	118.1	118.7	113.9	113.8	116.7	118.2		118.3	116.2	118.3	0.0	14.7
147	93.7	19.5	0.0	101.0	101.5	108.8	112.0	110.4	102.0	103.3	107.0	110.1		114.9	107.2	114.9	0.0	6.2
148	100.3	42.3	0.0	101.1	104.9	123.6	122.2	122.9	112.3	113.7	120.1	121.9		121.5	118.1	121.9	0.4	17.0
149	99.6	42.3	0.0	102.2	102.6	124.4	121.9	123.2	116.7	117.8	122.3	122.0		121.8	120.3	122.3	0.5	18.2
150	97.8	42.5	0.0	102.4	110.2	120.7	119.7	120.2	113.7	113.8	117.5	119.6		119.9	116.9	119.9	0.0	14.5
151	94.2	42.3	0.0	102.2	104.0	124.3	121.9	123.1	117.0	118.3	122.4	122.0		121.6	120.5	122.4	0.8	18.3
152	88.3	30.9	0.0	103.2	102.2	117.5	117.1	117.3	111.9	112.8	116.5	117.0		117.3	115.2	117.3	0.0	12.0
153	91.2	15.9	0.0	103.8	102.7	106.8	108.3	107.5	102.7	102.7	104.8	107.0		108.1	105.0	108.1	0.0	1.1
154	87.1	42.3	0.0	103.5	105.4	123.7	120.6	122.1	119.0	120.3	122.1	120.7		119.7	120.6	122.1	2.5	17.1
155	91.3	34.7	0.0	104.1	103.8	120.4	119.2	119.8	114.1	115.0	118.7	118.7		118.6	117.2	118.7	0.1	13.1
156	97.9	40.4	0.0	104.8	104.6	123.1	120.9	122.0	116.6	117.2	121.4	121.2		120.5	119.6	121.4	0.9	14.8
157	91.2	15.9	0.0	105.6	104.3	107.8	109.1	108.4	104.4	104.3	106.1	108.1		109.2	106.3	109.2	0.0	0.7
158	71.0	6.8	6.8	105.5	104.5	107.9	107.8	107.9	105.2	106.1	108.1	108.2		108.8	107.4	108.8	0.0	1.9
159	85.2	10.0	0.0	107.4	105.0	106.6	107.2	106.9	105.1	105.1	105.9	106.7		107.5	106.0	107.5	0.0	-1.4
160	95.0	19.7	0.0	107.5	105.3	109.8	111.2	110.5	105.3	105.3	108.1	110.0		110.5	107.8	110.5	0.0	0.3
161	80.8	6.0	0.0	106.9	105.2	105.7	106.9	106.3	105.1	105.0	105.4	106.2		106.8	105.6	106.8	0.0	-1.3
162	91.2	15.9	0.0	104.7	104.3	107.5	108.4	108.0	104.4	104.2	105.9	107.5		107.9	105.9	107.9	0.0	1.3
163	85.0	10.0	0.0	104.1	103.9	105.2	106.5	105.8	103.9	103.8	104.3	105.6		106.2	104.7	106.2	0.0	0.6
164	86.7	29.1	0.0	104.3	103.2	115.4	115.8	115.6	109.3	109.6	113.8	115.0		114.8	112.6	115.0	0.2	8.3
165	92.1	34.8	0.0	104.6	103.8	118.5	117.8	118.2	113.0	113.5	116.8	117.3		117.2	115.7	117.3	0.1	11.1
166	98.0	40.4	0.0	106.2	104.3	122.4	121.0	121.7	114.6	115.4	120.3	120.6		120.4	118.5	120.6	0.3	12.3
167	77.2	19.6	0.0	105.1	103.8	109.7	110.8	110.2	105.5	105.9	108.8	110.3		111.1	108.3	111.1	0.0	3.2
168	92.2	34.8	0.0	104.2	103.5	118.2	117.6	117.9	112.6	113.3	116.7	117.0		116.6	115.4	117.0	0.4	11.2
169	98.0	40.5	0.0	105.1	103.5	122.1	120.9	121.5	114.7	115.4	120.2	120.4		120.4	118.4	120.4	0.0	13.3
170	100.5	25.3	0.0	106.4	104.7	113.0	114.6	113.8	104.9	105.9	110.7	113.6		114.5	110.0	114.5	0.0	3.5
171	91.2	15.8	0.0	106.9	104.9	108.6	109.5	109.0	105.0	104.9	107.2	108.8		109.5	107.0	109.5	0.0	0.1
172	81.3	6.0	0.0	106.0	104.8	105.5	106.5	106.0	104.7	104.7	105.0	106.0		106.6	105.4	106.6	0.0	-0.6
173	90.9	15.8	0.0	106.5	105.2	108.4	110.0	109.2	105.2	105.1	107.2	108.6		109.4	107.1	109.4	0.0	0.6

(Continued)

Table 6. Statistical Summary of TDG Saturation by Station, Transect, and Spill event

Event	Q_{total} (kcfs)	Q_{spill} (kcfs)	Q_{rsw} (kcfs)	LWG (%)	Transect T1 Total Dissolved Gas Saturation (%)				Tailwater FMS Transect LGNW Total Dissolved Gas Saturation (%)								Diff (FMS-Max)	TW FB
					P1 (%)	P2 (%)	P3 (%)	Avg P2 & P3	P1	P2	P3	P4	P5	LWGN	AVG	Max		
174	100.3	25.3	0.0	109.6	106.0	113.4	114.8	114.1	106.1	106.9	111.1	113.7		114.1	110.5	114.1	0.0	0.9
175	88.9	42.4	0.0	106.7	112.9	124.1	122.0	123.0	117.8	118.4	121.7	121.7		121.2	120.3	121.7	0.5	13.6
176	94.4	19.6	0.0	106.4	106.0	110.6	111.7	111.1	106.5	106.2	109.1	110.9		112.5	108.9	112.5	0.0	2.5
177	92.4	29.1	0.0	106.7	109.0	115.6	115.4	115.5	110.6	110.7	113.1	115.1		115.5	113.0	115.5	0.0	6.3
178	85.7	29.1	0.0	107.0	106.1	116.3	116.9	116.6	110.1	110.6	114.8	116.2		116.5	113.7	116.5	0.0	6.7
179	76.8	19.6	0.0	107.1	106.2	110.7	111.6	111.2	107.5	107.8	110.0	111.2		111.8	109.7	111.8	0.0	2.6
180	79.6	42.4	0.0	105.6	115.1	124.7	122.2	123.5	118.6	119.3	122.4	122.2		121.7	121.0	122.4	0.6	15.4
181	85.0	19.7	0.0	105.7	105.7	109.4	111.1	110.3	106.1	106.1	108.3	110.3		111.5	108.4	111.5	0.0	2.6
182	79.5	29.2	0.0	106.6	107.5	115.1	115.3	115.2	110.1	110.0	112.9	114.8		115.4	112.6	115.4	0.0	6.0
183	88.7	38.7	0.0	105.9	111.4	118.9	118.0	118.5	113.4	113.2	116.5	118.0		118.1	115.9	118.1	0.0	9.9
184	82.1	19.7	0.0	104.3	104.7	109.1	111.0	110.1	104.9	105.2	108.0	109.8		111.2	107.8	111.2	0.0	3.4
185	84.9	10.0	0.0	104.2	104.6	105.6	106.8	106.2	104.5	104.3	104.9	106.0		107.2	105.2	107.2	0.0	1.0
186	84.3	36.8	0.0	102.6	109.7	118.2	117.8	118.0	111.4	111.9	116.2	117.2	117.1	116.5	114.9	117.2	0.7	12.3
187	84.5	29.2	0.0	102.4	104.1	114.5	115.1	114.8	108.3	108.4	112.8	113.8	114.5	114.6	111.6	114.6	0.0	9.2
188	82.9	19.7	0.0	102.5	103.7	108.8	110.7	109.8	104.0	103.9	108.1	108.9	110.1	110.6	107.0	110.6	0.0	4.5
189	83.3	29.8	0.0	102.4	105.7	114.4	114.8	114.6	108.8	108.9	112.5	113.7	114.4	114.4	111.7	114.4	0.0	9.2
190	73.9	40.6	0.0	102.0	113.2	120.8	119.5	120.1	114.0	114.7	119.0	119.4	119.4	119.3	117.4	119.4	0.1	15.4
191	63.7	40.6	0.0	102.3	113.6	121.4	120.2	120.8	115.9	117.0	120.1	119.9	119.9	119.4	118.7	120.1	0.6	16.4
192	58.6	29.2	0.0	102.5	108.7	115.6	115.9	115.8	109.3	110.3	115.1	115.2	115.4	115.4	113.3	115.4	0.0	10.7
193	62.9	38.7	0.0	102.9	114.1	120.2	119.2	119.7	114.4	115.4	119.1	119.0	119.0	118.9	117.5	119.1	0.2	14.7
194	53.4	38.2	7.1	104.9	118.4		115.0	115.0	117.0	117.4	116.4	115.9	115.7	115.2	116.5	117.4	2.2	11.6
195	56.3	40.6	0.0	104.2	115.5		119.8	119.8	116.9	117.6	119.3	118.9	118.7	118.7	118.4	119.3	0.6	14.2
196	42.8	20.9	6.9	106.8	109.1				109.8	110.7	111.1	110.7		110.6	110.6	111.1	0.5	3.9
197	54.6	6.0	0.0	105.2	103.1				106.2	104.7	103.5	103.6		104.3	104.3	106.2	2.0	-0.9
198	35.2	19.7	0.0	105.3	108.0				108.5	109.1	110.7	110.1		100.0	100.0	110.7	0.0	-5.3
199	35.8	20.8	6.8	106.7	111.7				110.1	111.2	111.9	111.4		111.7	111.4	111.9	0.2	4.6
200	46.2	30.2	6.7	108.4	114.7				114.8	115.0	114.5	114.0		114.4	114.5	115.0	0.6	6.1
201	39.2	20.8	6.8	112.1	112.5				111.9	112.2	112.3	112.0		112.0	112.1	112.3	0.3	0.0
202	29.2	29.2	0.0	106.3	114.2				111.5	113.3	109.2	107.0		110.5	110.1	113.3	2.8	3.8

(Continued)

Table 6. Statistical Summary of TDG Saturation by Station, Transect, and Spill event

Event	Q_{total} (kcfs)	Q_{spill} (kcfs)	Q_{rsw} (kcfs)	LWG (%)	Transect T1 Total Dissolved Gas Saturation (%)				Tailwater FMS Transect LGNW Total Dissolved Gas Saturation (%)								Diff (FMS-Max)	TW FB
					P1 (%)	P2 (%)	P3 (%)	Avg P2 & P3	P1	P2	P3	P4	P5	LWGN	AVG	Max		
203	43.2	31.1	0.0	106.7	113.8				114.5	115.2	115.3	114.6		115.6	115.1	115.6	0.0	8.4
204	63.9	19.7	0.0	108.6	106.2				110.9	110.1	111.9	111.9		111.1	111.2	111.9	0.8	2.6
205	34.4	21.6	0.0	107.5	109.9				110.1	110.7	110.1	108.7		109.8	109.9	110.7	0.9	2.4

Table 7. Statistical Summary of Total Dissolved Gas Saturation during Spill at Lower Granite Dam (With and Without RSW Operation)													
Row		RSW with 8 kcfs Training Flow (%)				RSW with 16 kcfs Training Flow (%)				Uniform Spill Bays 2-8 40-45 kcfs Spill (%)			
		LWG	T1avg	LGNW	LGNWavg	LWG	T1avg	LGNW	LGNWavg	LWG	T1avg	LGNW	LGNWavg
1	N	509	456	509	509	679	542	679	679	605	332	605	605
2	Avg	103.1	108.0	108.3	107.6	102.8	111.1	111.5	109.9	103.3	119.9	119.2	1170
3	Max	108.8	110.8	111.7	110.6	107.5	113.1	112.8	112.9	106.7	121.7	122.0	120.8
4	Min	99.9	106.6	105.3	104.9	100.0	109.4	109.3	105.2	101.1	117.6	115.0	114.3
5	Stdev	1.7	0.8	0.9	1.1	1.3	0.7	0.6	1.3	1.1	1.0	0.9	1.2
6	0.05	100.8	107.0	107.1	105.9	100.5	110.0	110.5	108.4	101.8	118.3	117.3	115.3
7	0.25	104.3	108.3	107.8	108.3	103.6	110.8	111.0	108.5	102.3	119.3	118.6	116.1
8	0.5	103.1	107.9	108.4	107.5	102.9	111.0	111.6	109.7	103.2	119.9	119.2	117.0
9	0.75	104.3	108.3	108.7	108.3	103.6	111.5	111.9	111.0	104.1	120.7	119.9	118.0
10	0.95	105.7	109.7	109.8	109.6	104.8	112.2	112.4	112.0	105.1	121.4	120.5	118.9
11	110	0	3.7	3.6	1.7	0	94.4	99.1	46.5	0	100	100	100
12	115	0	0	0	0	0	0	0	0	0	100	100	96.7
13	120	0	0	0	0	0	0	0	0	0	43.9	20.4	0.3
14	125	0	0	0	0	0	0	0	0	0	0	0	0

Statistical summary of TDG saturation (%) Rows 1-5, N-Number of observations, Avg-Average, Max-Maximum, Min-Minimum, Stdev-Standard deviation.
TDG Saturation by percentile in Rows 6-10.
Percent Exceedance in Rows 11-14

Table 8. Nonlinear Regression Summary Statistics, Events Averaged Analyses

$$\Delta P = C^1 (1 - \exp(C_2 q_s))$$

qs = flow weighted specific discharge, bays 6-8 (kcfs/bay)
P = Delta total dissolved gas pressure, total pressure minus barometric pressure (mm Hg)

N = 166
R^2 = 0.921
Standard error = 11.9

Parameter	Estimate	Asymptotic Standard Error	Asymptotic 95% Confidence Interval	
C1	255.466	10.756	234.228	276.706
C2	-0.1275	0.00832	-0.1439	-0.1111

Table 9. Nonlinear Regression Summary Statistics, Events Averaged Analyses

$$\Delta P = C_1 (TWE-585)(1-\exp(C_2\, q_s))$$

qs = flow weighted specific discharge, bays 6-8 (kcfs/bay)
ΔP = Delta total dissolved gas pressure, total pressure minus barometric pressure (mm Hg)
TWE = Tailwater channel elevation (ft)

N = 166
R^2 = 0.919
Standard error = 12.15

Parameter	Estimate	Asymptotic Standard Error	Asymptotic 95% Confidence Interval	
C_1	5.2991	0.2364	4.8323	5.7659
C_2	-0.12286	.008363	-0.13937	-0.10635

Table 10. Nonlinear Regression Summary Statistics, Events Averaged Analyses

$$\Delta P = C_1 (1 - \exp(C_2 q_s)) + C_3 Q_{gen}$$

qs = flow weighted specific discharge, bays 6-8 (kcfs/bay)
ΔP = Delta total dissolved gas pressure, total pressure minus barometric pressure (mm Hg)
Qgen = Powerhouse Discharge (cfs)

N = 166
$R^2 = 0.92$
Standard error = 11.7 mm Hg

Parameter	Estimate	Asymptotic Standard Error	Asymptotic 95% Confidence Interval	
C_1	243.7	9.976	224.0	263.4
C_2	-0.145	.0119	-0.1687	-0.1217
C3	-0.092	0.040	-0.1709	-0.0131

Table 11. Event Summary of TDG Exchange at Lower Granite Dam with Calculated Average TDG Pressure With and Without Powerhouse Flow Entrainment

Event	Qtotal (kcfs)	Qspill (kcfs)	Qgen (kcfs)	Qsp/Qtot (%)	DTP_{fb}* (mm Hg)	DTP_{t1avg} (mm Hg)	$DTP_{LWGNavg}$ (mm Hg)	Calculated Average Delta Total Dissolved Gas Pressure with no Entrainment				Calculated Average Delta Total Dissolved Gas Pressure with Entrainment			
								Q_{ent} (kcfs)	$DTP_{LWGNavg}$ (mm Hg)	TP[&] Error (mm Hg)	PS[#] Error (%)	Q_{ent} (kcfs)	$DTP_{LWGNavg}$ (mm Hg)	TP Error (mm Hg)	PS Error (%)
1	54.9	54.4	0.5	99.1	22.0										
2	58.2	57.7	0.5	99.2	15.2										
3	50.5	50.2	0.3	99.4	26.4	169.5	162.5	0.0	168.7	-6.2	-0.8	0.3	169.5	-7.0	-0.9
4	56.3	55.7	0.6	99.0	20.3	173.9	162.5	0.0	172.3	-2.2	-0.3	0.6	173.9	-3.8	-0.5
5	67.7	59.3	8.4	88.9	24.4	187.0	178.4	0.0	166.9	11.5	1.5	8.4	187.0	-8.7	-1.2
6	63.6	49.9	13.7	78.4	31.0	155.5	135.0	0.0	128.6	6.3	0.9	13.7	155.5	-20.5	-2.8
7	67.4	44.6	22.8	66.7	26.7	168.7	155.2	0.0	120.7	34.5	4.6	22.8	168.7	-13.5	-1.8
8	87.8	40.4	47.5	46.0	23.6	143.9	122.3	0.0	78.9	43.5	5.9	41.2	135.3	-13.0	-1.8
9	78.0	40.8	37.3	52.2	21.3	148.7	125.0	0.0	87.9	37.1	5.0	37.3	148.7	-23.7	-3.2
10	69.6	35.0	34.7	50.5	16.9	133.9	113.0	0.0	75.6	37.3	5.0	34.7	133.9	-20.9	-2.8
11	76.8	23.8	53.0	31.0	16.7	81.1	61.3	0.0	36.7	24.6	3.3	24.3	57.1	4.2	0.6
12	74.4	36.9	37.5	49.7	16.3	136.6	110.7	0.0	76.0	34.8	4.7	37.5	136.6	-25.9	-3.5
13	77.5	15.7	61.8	20.3	14.1	56.1	48.9	0.0	22.6	26.4	3.6	16.0	31.2	17.7	2.4
14	68.6	43.6	25.1	63.9	10.0	135.1	133.6	0.0	89.4	44.1	5.9	25.1	135.1	-1.5	-0.2
15	79.1	15.7	63.4	19.9	9.5	56.6	47.8	0.0	18.9	29.0	3.9	16.0	28.4	19.4	2.6
16	73.5	48.3	25.2	66.0	14.8	153.6	143.3	0.0	106.0	37.3	5.0	25.2	153.6	-10.3	-1.4
17	81.9	15.9	66.0	19.4	19.7	55.4	46.5	0.0	26.6	19.9	2.7	16.2	33.7	12.8	1.7
18	70.1	43.6	26.5	63.0	17.1	117.9	129.0	0.0	79.8	49.2	6.6	26.5	117.9	11.1	1.5
19	69.6	16.5	53.1	23.7	10.9	53.4	54.0	0.0	21.0	33.0	4.4	16.9	31.3	22.7	3.0
20	71.9	47.4	24.5	66.9	20.8	126.2	135.6	0.0	90.3	45.3	6.1	24.5	126.2	9.4	1.3
21	83.8	51.1	32.6	61.3	29.6	129.9	143.3	0.0	90.8	52.5	7.1	32.6	129.9	13.4	1.8
22	116.0	44.5	71.5	38.7	22.4	148.9	118.9	0.0	71.0	47.9	6.5	45.5	120.6	-1.7	-0.2
23	136.2	39.6	96.6	29.1	20.1	116.8	82.8	0.0	48.2	34.5	4.7	40.5	77.0	5.8	0.8
24	106.6	45.0	61.6	42.2	19.7	124.8	122.9	0.0	64.0	58.9	8.0	46.0	109.4	13.5	1.8
25	116.6	43.6	73.0	37.5	12.4	125.6	114.7	0.0	54.7	60.1	8.1	44.5	97.9	16.8	2.3
26	107.7	24.4	83.3	22.6	7.6	73.6	49.0	0.0	22.6	26.5	3.6	24.9	37.8	11.2	1.5
27	101.9	24.5	77.4	24.0	6.3	74.8	52.2	0.0	22.8	29.5	4.0	25.0	39.6	12.6	1.7

(Continued)

Table 11. Continued

Event	Qtotal (kcfs)	Qspill (kcfs)	Qgen (kcfs)	Qsp/Qtot (%)	DTP_{fb}* (mm Hg)	DTP_{t1avg} (mm Hg)	$DTP_{LWGNavg}$ (mm Hg)	Calculated Average Delta Total Dissolved Gas Pressure with no Entrainment				Calculated Average Delta Total Dissolved Gas Pressure with Entrainment			
								Q_{ent} (kcfs)	$DTP_{LWGNavg}$ (mm Hg)	TP[&] Error (mm Hg)	PS[#] Error (%)	Q_{ent} (kcfs)	$DTP_{LWGNavg}$ (mm Hg)	TP Error (mm Hg)	PS Error (%)
28	92.4	47.2	45.2	51.1	6.1	125.4	129.5	0.0	67.0	62.5	8.4	45.2	125.4	4.2	0.6
29	100.1	24.5	75.6	24.8	2.8	74.0	52.4	0.0	20.2	32.2	4.3	25.1	38.0	14.4	1.9
30	88.8	22.6	66.2	25.5	-0.6	63.9	42.7	0.0	15.8	26.8	3.6	23.1	32.6	10.1	1.3
31	84.5	16.7	67.8	19.8	1.0	52.1	39.2	0.0	11.1	28.2	3.7	17.1	21.4	17.8	2.4
32	86.5	30.2	56.3	34.9	6.6	94.1	83.1	0.0	37.1	46.0	6.1	30.9	68.4	14.7	2.0
33	88.3	47.4	40.9	53.9	3.6	123.8	133.1	0.0	68.1	65.1	8.7	40.9	123.8	9.4	1.2
34	83.5	53.9	29.6	65.4	16.3	173.5	153.9	0.0	117.7	36.2	4.8	29.6	173.5	-19.6	-2.6
35	76.9	50.1	26.8	70.7	22.8	167.8	148.1	0.0	117.3	30.9	4.2	26.8	167.8	-19.6	-2.6
36	67.8	24.5	43.3	24.5	22.5	87.0	84.8	0.0	45.8	39.0	5.2	25.0	69.6	15.2	2.0
37	75.8	16.7	59.1	22.3	8.5	55.8	50.2	0.0	18.9	31.2	4.1	17.1	29.6	20.6	2.7
38	63.4	16.7	46.7	26.4	18.5	55.2	56.8	0.0	28.2	28.7	3.8	17.1	38.1	18.8	2.5
39	63.6	16.7	46.9	26.6	13.5	56.2	58.6	0.0	24.7	33.9	4.5	17.1	36.2	22.4	3.0
40	64.4	42.5	21.9	66.9	18.0	157.9	141.8	0.0	110.3	31.5	4.2	21.9	157.9	-16.1	-2.2
41	59.6	34.9	24.7	59.0	25.2	123.8	120.9	0.0	83.0	37.9	5.1	24.7	123.8	-3.0	-0.4
42	58.3	38.7	19.6	66.6	24.1	145.1	136.5	0.0	104.4	32.1	4.3	19.6	145.1	-8.6	-1.2
43	60.7	38.7	22.0	64.1	27.4	146.7	133.8	0.0	103.4	30.4	4.1	22.0	146.7	-12.9	-1.7
44	58.3	16.7	41.6	30.2	24.7	63.3	65.5	0.0	35.8	29.7	4.0	17.1	47.1	18.4	2.5
45	61.8	42.5	19.3	68.8	19.8	117.4	129.2	0.0	86.9	42.4	5.7	19.3	117.4	11.8	1.6
46	69.3	52.2	17.1	75.2	26.9	127.9	138.1	0.0	103.0	35.1	4.7	17.1	127.9	10.3	1.4
47	76.5	55.8	20.7	73.0	35.4	129.9	143.7	0.0	104.3	39.4	5.3	20.7	129.9	13.9	1.9
48	72.7	52.0	20.7	71.5	32.2	130.5	139.4	0.0	102.5	36.9	5.0	20.7	130.5	8.9	1.2
49	73.0	52.7	20.3	72.2	31.9	164.9	152.7	0.0	127.9	24.7	3.3	20.3	164.9	-12.3	-1.7
50	72.5	52.0	20.5	71.7	35.3	133.1	141.1	0.0	105.4	35.6	4.8	20.5	133.1	8.0	1.1
51	68.6	48.2	20.5	70.2	33.1	126.0	141.5	0.0	98.3	43.1	5.8	20.5	126.0	15.4	2.1
52	70.6	57.6	13.0	77.3	24.7	135.0	146.6	0.0	114.6	31.9	4.3	13.0	135.0	11.6	1.6
53	64.7	63.9	0.8	98.7	15.9	142.6	154.6	0.0	141.0	13.6	1.8	0.8	142.6	12.0	1.6
54	93.8	37.5	56.3	40.0	13.2	117.0	107.8	0.0	54.7	53.1	7.1	38.3	97.1	10.6	1.4
55	72.6	16.0	56.6	22.0	15.9	57.9	35.8	0.0	25.2	10.6	1.4	16.3	34.6	1.2	0.2

(Continued)

Table 11. (Continued)															
Event	Qtotal (kcfs)	Qspill (kcfs)	Qgen (kcfs)	Qsp/Qtot (%)	DTP_{fb}* (mm Hg)	DTP_{t1avg} (mm Hg)	$DTP_{LWGNavg}$ (mm Hg)	Calculated Average Delta Total Dissolved Gas Pressure with no Entrainment				Calculated Average Delta Total Dissolved Gas Pressure with Entrainment			
								Q_{ent} (kcfs)	$DTP_{LWGNavg}$ (mm Hg)	TP[&] Error (mm Hg)	PS[#] Error (%)	Q_{ent} (kcfs)	$DTP_{LWGNavg}$ (mm Hg)	TP Error (mm Hg)	PS Error (%)
56	82.4	43.0	39.3	54.2	14.6	153.9	129.8	0.0	87.4	42.4	5.7	39.3	153.9	-24.1	-3.2
57	72.2	17.2	55.0	24.3	9.9	55.7	51.8	0.0	20.8	31.0	4.1	17.6	32.0	19.8	2.7
58	64.8	24.8	40.0	39.0	13.3	80.5	79.8	0.0	39.0	40.8	5.5	25.3	65.2	14.6	1.9
59	55.8	46.3	9.5	84.3	24.9	165.9	150.9	0.0	141.9	9.0	1.2	9.5	165.9	-15.0	-2.0
60	58.5	46.3	12.2	79.1	46.4	166.9	145.3	0.0	141.8	3.5	0.5	12.2	166.9	-21.7	-2.9
61	53.9	38.7	15.2	72.1	38.0	148.3	135.7	0.0	117.2	18.5	2.5	15.2	148.3	-12.6	-1.7
62	59.4	17.1	42.3	29.6	27.9	65.2	64.2	0.0	38.7	25.6	3.4	17.5	49.6	14.6	2.0
63	74.0	24.7	49.3	33.9	28.1	80.4	76.5	0.0	45.6	30.9	4.1	25.2	63.4	13.1	1.8
64	65.9	24.7	41.2	38.4	32.6	82.3	79.8	0.0	51.2	28.5	3.8	25.3	70.3	9.5	1.3
65	67.6	36.8	30.8	55.0	29.1	133.2	113.1	0.0	85.8	27.4	3.7	30.8	133.2	-20.0	-2.7
66	72.2	40.6	31.6	56.5	29.6	145.4	123.6	0.0	94.8	28.9	3.9	31.6	145.4	-21.8	-2.9
67	82.1	17.1	65.0	20.9	30.0	60.5	53.6	0.0	36.3	17.3	2.3	17.4	42.8	10.8	1.5
68	103.1	28.4	74.7	27.5	23.6	94.6	70.5	0.0	43.1	27.4	3.7	29.0	63.1	7.4	1.0
69	110.5	36.0	74.5	32.6	24.7	119.9	97.0	0.0	55.7	41.3	5.6	36.8	87.4	9.5	1.3
70	109.3	39.8	69.5	36.6	11.7	120.4	103.0	0.0	51.3	51.7	7.0	40.7	91.7	11.3	1.5
71	109.9	45.6	64.3	41.7	4.9	125.3	118.3	0.0	54.8	63.4	8.5	46.6	105.9	12.4	1.7
72	97.7	24.9	72.8	25.5	22.1	88.2	67.8	0.0	38.9	28.9	3.9	25.4	56.1	11.7	1.6
73	94.4	19.7	74.7	20.9	33.0	71.5	59.9	0.0	41.0	18.8	2.5	20.1	49.2	10.6	1.4
74	91.1	15.9	75.2	17.5	35.5	61.0	45.5	0.0	40.0	5.6	0.8	16.2	44.5	1.0	0.1
75	88.2	15.9	72.3	18.1	35.3	53.3	43.4	0.0	38.5	4.9	0.7	16.2	41.9	1.6	0.2
76	93.1	40.6	52.5	43.7	32.8	138.8	121.1	0.0	79.0	42.1	5.7	41.5	126.3	-5.2	-0.7
77	90.6	15.8	74.8	17.4	34.3	58.4	46.3	0.0	38.5	7.8	1.1	16.1	42.8	3.5	0.5
78	82.4	10.0	72.4	12.2	44.7	48.5	42.2	0.0	45.1	-3.0	-0.4	10.2	45.6	-3.4	-0.5
79	90.8	44.4	46.4	49.0	37.4	153.7	133.1	0.0	94.2	38.8	5.2	45.4	152.3	-19.2	-2.6
80	84.1	16.7	67.4	20.1	39.8	60.7	56.7	0.0	44.0	12.8	1.7	17.1	48.2	8.6	1.2
81	99.1	24.5	74.5	24.8	25.2	81.0	65.1	0.0	39.0	26.1	3.5	25.1	53.1	12.0	1.6
82	109.3	34.9	74.4	31.9	21.6	111.6	89.1	0.0	50.3	38.7	5.2	35.7	79.7	9.4	1.3
83	115.4	40.6	74.8	35.2	23.9	131.1	106.9	0.0	61.6	45.3	6.1	41.5	100.2	6.8	0.9

(Continued)

Table 11. (Continued)

Event	Qtotal (kcfs)	Qspill (kcfs)	Qgen (kcfs)	Qsp/Qtot (%)	DTP_{fb}* (mm Hg)	DTP_{11avg} (mm Hg)	$DTP_{LWGNavg}$ (mm Hg)	Calculated Average Delta Total Dissolved Gas Pressure with no Entrainment				Calculated Average Delta Total Dissolved Gas Pressure with Entrainment			
								Q_{ent} (kcfs)	$DTP_{LWGNavg}$ (mm Hg)	TP[&] Error (mm Hg)	PS[#] Error (%)	Q_{ent} (kcfs)	$DTP_{LWGNavg}$ (mm Hg)	TP Error (mm Hg)	PS Error (%)
84	119.4	44.4	75.0	37.2	26.6	145.1	114.6	0.0	70.6	44.0	5.9	45.4	115.6	-1.0	-0.1
85	113.3	42.5	70.8	37.6	21.7	145.0	117.2	0.0	67.9	49.2	6.6	43.4	115.2	2.0	0.3
86	130.9	55.8	75.1	42.6	27.0	182.0	149.5	0.0	93.1	56.4	7.6	57.0	160.6	-11.2	-1.5
87	134.9	59.6	75.3	44.2	24.7	189.0	155.4	0.0	97.3	58.1	7.8	60.9	171.5	-16.1	-2.2
88	136.6	60.8	75.8	44.5	26.5	184.6	151.2	0.0	96.9	54.3	7.3	62.1	168.8	-17.6	-2.4
89	136.0	60.9	75.1	44.8	33.7	170.8	144.0	0.0	95.1	48.8	6.6	62.3	157.9	-14.0	-1.9
90	125.0	51.0	74.0	40.8	33.8	150.3	130.5	0.0	81.4	49.1	6.6	52.2	130.0	0.5	0.1
91	130.0	56.8	73.2	43.7	34.8	152.8	135.4	0.0	86.4	49.0	6.6	58.1	139.1	-3.7	-0.5
92	134.6	60.7	73.9	45.1	27.1	170.0	142.6	0.0	91.5	51.1	6.9	62.0	157.4	-14.8	-2.0
93	144.2	69.9	74.3	48.5	34.2	176.1	150.2	0.0	103.0	47.2	6.3	71.4	173.3	-23.1	-3.1
94	134.5	60.6	73.9	45.1	40.5	167.2	141.6	0.0	97.6	44.0	5.9	61.9	156.0	-14.3	-1.9
95	126.3	54.5	71.8	41.3	41.0	146.2	129.5	0.0	86.4	43.1	5.8	55.7	132.8	-3.3	-0.4
96	123.2	84.7	38.5	69.2	35.7	173.9	171.7	0.0	130.7	41.0	5.5	38.5	173.9	-2.2	-0.3
97	135.9	60.6	75.3	44.6	33.0	170.5	142.5	0.0	94.3	48.2	6.5	61.9	157.0	-14.4	-1.9
98	120.2	45.4	74.8	37.8	33.2	133.1	120.1	0.0	70.9	49.2	6.6	46.4	109.5	10.7	1.4
99	114.4	39.7	74.7	34.7	34.0	126.3	108.9	0.0	66.1	42.9	5.8	40.6	98.8	10.1	1.4
100	115.9	41.7	74.2	36.0	42.2	133.3	113.3	0.0	75.0	38.4	5.2	42.6	108.5	4.8	0.7
101	119.9	84.8	35.1	75.0	39.1	170.0	169.3	0.0	131.7	37.6	5.0	35.1	170.0	-0.7	-0.1
102	115.4	115.4	0.0	90.7	37.4	184.5	190.5	0.0	184.5	6.0	0.8	0.0	184.5	6.0	0.8
103	116.8	41.6	75.1	35.7	36.8	130.7	114.2	0.0	70.3	43.9	5.9	42.5	104.5	9.7	1.3
104	109.4	35.9	73.5	32.9	37.1	117.9	100.9	0.0	63.6	37.3	5.0	36.7	90.7	10.2	1.4
105	112.0	90.1	21.9	76.7	33.8	170.6	172.5	0.0	143.9	28.6	3.8	21.9	170.6	1.9	0.3
106	109.7	34.9	74.8	31.8	31.1	114.3	95.4	0.0	57.6	37.9	5.1	35.7	84.6	10.9	1.4
107	95.9	40.6	55.3	42.3	31.4	134.9	114.4	0.0	75.2	39.2	5.2	41.5	120.0	-5.6	-0.7
108	110.1	88.8	21.3	80.7	30.9	198.3	197.9	0.0	166.0	31.9	4.3	21.3	198.3	-0.5	-0.1
109	100.6	81.6	19.0	81.2	28.7	192.6	191.0	0.0	161.7	29.2	3.9	19.0	192.6	-1.6	-0.2
110	110.3	90.6	19.7	82.2	27.6	195.7	198.4	0.0	165.7	32.7	4.4	19.7	195.7	2.7	0.4
111	104.5	42.5	62.0	40.8	27.1	149.3	129.5	0.0	76.8	52.7	7.1	43.4	127.6	2.0	0.3

(Continued)

Table 11. (Continued)

Event	Qtotal (kcfs)	Qspill (kcfs)	Qgen (kcfs)	Qsp/Qtot (%)	DTP_{fb}* (mm Hg)	DTP_{t1avg} (mm Hg)	$DTP_{LWGNavg}$ (mm Hg)	Calculated Average Delta Total Dissolved Gas Pressure with no Entrainment				Calculated Average Delta Total Dissolved Gas Pressure with Entrainment			
								Q_{ent} (kcfs)	$DTP_{LWGNavg}$ (mm Hg)	TP[&] Error (mm Hg)	PS[#] Error (%)	Q_{ent} (kcfs)	$DTP_{LWGNavg}$ (mm Hg)	TP Error (mm Hg)	PS Error (%)
112	113.1	38.7	74.4	34.2	27.9	132.2	107.2	0.0	63.6	43.7	5.9	39.5	100.0	7.2	1.0
113	98.0	42.5	55.5	43.4	26.1	150.4	127.9	0.0	80.0	47.9	6.4	43.4	135.1	-7.2	-1.0
114	106.4	90.6	15.8	85.2	24.5	191.9	198.9	0.0	167.1	31.8	4.3	15.8	191.9	7.0	0.9
115	114.1	42.5	71.6	37.3	23.9	144.4	119.0	0.0	68.7	50.3	6.7	43.4	114.6	4.4	0.6
116	91.4	16.7	74.7	18.3	23.9	59.9	49.5	0.0	30.5	19.0	2.6	17.1	37.2	12.3	1.6
117	100.4	41.2	59.3	41.3	19.6	123.4	115.4	0.0	62.2	53.2	7.1	42.1	105.7	9.7	1.3
118	89.4	14.3	75.1	16.0	19.8	55.9	41.3	0.0	25.6	15.7	2.1	14.6	31.4	9.8	1.3
119	88.0	41.2	46.9	47.6	17.0	121.4	121.7	0.0	65.8	55.9	7.5	42.1	115.7	6.0	0.8
120	60.7	59.9	0.8	98.7	13.3	139.3	148.9	0.0	137.6	11.3	1.5	0.8	139.3	9.6	1.3
121	51.7	51.0	0.7	98.6	12.7	124.1	141.5	0.0	122.6	18.9	2.5	0.7	124.1	17.4	2.3
122	74.8	74.0	0.8	98.9	12.9	153.4	161.7	0.0	151.9	9.8	1.3	0.8	153.4	8.3	1.1
123	65.2	64.5	0.7	98.9	14.1	148.1	156.8	0.0	146.7	10.1	1.4	0.7	148.1	8.7	1.2
124	75.2	74.5	0.7	99.1	15.1	149.1	160.9	0.0	147.9	13.0	1.7	0.7	149.1	11.8	1.6
125	76.3	65.2	11.1	89.1	19.6	139.2	155.0	0.0	121.8	33.2	4.4	11.1	139.2	15.8	2.1
126	98.0	41.3	56.7	42.1	20.0	132.0	123.1	0.0	67.2	56.0	7.5	42.2	115.4	7.7	1.0
127	94.2	40.6	53.6	43.3	15.8	138.5	118.9	0.0	68.7	50.2	6.7	41.5	122.7	-3.8	-0.5
128	79.0	19.7	59.3	25.0	13.9	71.2	54.4	0.0	28.2	26.2	3.5	20.1	42.8	11.6	1.6
129	86.5	15.8	70.7	18.4	21.8	56.5	38.9	0.0	28.2	10.7	1.4	16.1	34.6	4.3	0.6
130	72.0	42.5	29.5	59.9	27.7	151.1	130.7	0.0	100.6	30.1	4.0	29.5	151.1	-20.4	-2.7
131	91.1	15.9	75.2	17.5	22.6	56.4	37.8	0.0	28.5	9.3	1.2	16.2	34.5	3.3	0.4
132	71.4	42.5	28.9	59.6	33.6	159.4	135.6	0.0	108.5	27.1	3.6	28.9	159.4	-23.8	-3.2
133	85.2	10.0	75.2	11.7	32.7	43.9	34.3	0.0	34.1	0.2	0.0	10.2	35.4	-1.1	-0.1
134	70.7	38.7	32.0	55.1	52.5	148.7	131.1	0.0	105.2	26.0	3.5	32.0	148.7	-17.6	-2.4
135	79.5	33.0	46.5	42.2	41.4	122.4	103.0	0.0	75.0	27.9	3.8	33.7	109.4	-6.4	-0.9
136	85.7	10.7	75.0	12.5	44.9	55.8	49.2	0.0	46.3	2.9	0.4	10.9	47.7	1.5	0.2
137	79.1	32.2	47.0	41.3	44.4	96.5	104.0	0.0	65.6	38.4	5.2	32.9	87.2	16.8	2.3
138	85.8	10.6	75.1	12.4	37.4	59.2	50.5	0.0	40.1	10.4	1.4	10.9	42.8	7.6	1.0
139	86.6	32.2	54.4	36.2	25.3	91.8	95.5	0.0	50.0	45.5	6.1	32.9	75.3	20.2	2.7

(Continued)

Table 11. (Continued)

Event	Qtotal (kcfs)	Qspill (kcfs)	Qgen (kcfs)	Qsp/Qtot (%)	DTP_{fb}* (mm Hg)	DTP_{t1avg} (mm Hg)	$DTP_{LWGNavg}$ (mm Hg)	Calculated Average Delta Total Dissolved Gas Pressure with no Entrainment				Calculated Average Delta Total Dissolved Gas Pressure with Entrainment			
								Q_{ent} (kcfs)	$DTP_{LWGNavg}$ (mm Hg)	TP[&] Error (mm Hg)	PS[#] Error (%)	Q_{ent} (kcfs)	$DTP_{LWGNavg}$ (mm Hg)	TP Error (mm Hg)	PS Error (%)
140	95.0	19.7	75.3	20.7	20.9	84.0	55.2	0.0	34.0	21.2	2.9	20.1	47.4	7.9	1.1
141	92.5	34.9	57.6	39.4	21.2	123.7	103.3	0.0	59.9	43.4	5.8	35.7	99.4	3.9	0.5
142	107.1	49.9	57.2	46.6	19.5	192.9	170.6	0.0	100.2	70.4	9.5	51.0	182.7	-12.1	-1.6
143	91.2	34.7	56.5	38.0	18.9	147.0	129.1	0.0	67.6	61.5	8.3	35.5	117.4	11.7	1.6
144	99.1	42.3	56.8	42.7	17.6	173.7	151.5	0.0	84.2	67.3	9.0	43.2	152.3	-0.8	-0.1
145	103.2	41.6	61.6	40.6	18.5	127.5	117.9	0.0	62.5	55.4	7.5	42.5	107.4	10.5	1.4
146	92.3	40.6	51.7	44.1	11.2	139.4	121.0	0.0	67.7	53.4	7.1	41.5	125.3	-4.3	-0.6
147	93.7	19.5	74.2	20.8	7.6	78.2	54.0	0.0	22.3	31.7	4.2	19.9	37.3	16.7	2.2
148	100.3	42.3	58.0	42.2	8.4	171.4	135.8	0.0	77.2	58.6	7.8	43.2	147.5	-11.7	-1.6
149	99.6	42.3	57.3	42.5	16.1	173.2	151.8	0.0	82.8	69.0	9.2	43.2	151.0	0.8	0.1
150	97.8	42.5	55.3	43.8	17.9	150.4	126.1	0.0	75.5	50.6	6.8	43.4	134.3	-8.2	-1.1
151	94.2	42.3	51.9	45.0	16.0	172.4	152.8	0.0	86.2	66.6	8.9	43.2	158.0	-5.1	-0.7
152	88.3	30.9	57.4	35.0	24.0	128.9	113.2	0.0	60.7	52.5	7.1	31.6	98.2	15.0	2.0
153	91.2	15.9	75.3	17.4	28.5	55.9	37.0	0.0	33.3	3.7	0.5	16.2	38.1	-1.2	-0.2
154	87.1	42.3	44.8	48.8	25.9	164.8	153.4	0.0	93.4	60.0	8.1	43.2	162.3	-8.9	-1.2
155	91.3	34.7	56.6	38.0	30.7	147.1	127.8	0.0	74.9	52.9	7.1	35.5	120.1	7.7	1.0
156	97.9	40.4	57.5	41.2	35.3	163.1	145.2	0.0	88.0	57.2	7.7	41.3	141.9	3.3	0.4
157	91.2	15.9	75.3	17.4	41.8	62.5	46.9	0.0	45.4	1.5	0.2	16.2	49.1	-2.2	-0.3
158	71.0	6.8	64.2	9.7	40.7	58.5	54.6	0.0	42.4	12.3	1.7	6.9	44.1	10.5	1.4
159	85.2	10.0	75.2	11.7	54.9	51.2	44.4	0.0	54.5	-10.0	-1.4	10.2	54.0	-9.6	-1.3
160	95.0	19.7	75.3	20.7	55.5	77.7	58.0	0.0	60.1	-2.1	-0.3	20.1	64.8	-6.8	-0.9
161	80.8	6.0	74.8	7.4	51.3	46.8	41.7	0.0	51.0	-9.3	-1.3	6.1	50.6	-9.0	-1.2
162	91.2	15.9	75.3	17.4	34.7	59.2	44.2	0.0	39.0	5.3	0.7	16.2	43.3	0.9	0.1
163	85.0	10.0	75.0	11.8	30.5	43.5	34.8	0.0	32.0	2.8	0.4	10.2	33.6	1.2	0.2
164	86.7	29.1	57.6	33.6	32.2	116.3	94.1	0.0	60.4	33.7	4.5	29.7	89.3	4.8	0.6
165	92.1	34.8	57.3	37.8	33.9	135.6	116.9	0.0	72.4	44.5	6.0	35.6	111.6	5.3	0.7
166	98.0	40.4	57.6	41.3	46.1	161.9	137.4	0.0	93.9	43.5	5.8	41.3	142.7	-5.3	-0.7
167	77.2	19.6	57.6	25.4	38.2	76.4	62.0	0.0	47.9	14.1	1.9	20.0	57.8	4.2	0.6

(Continued)

Table 11. (Continued)

Event	Qtotal (kcfs)	Qspill (kcfs)	Qgen (kcfs)	Qsp/Qtot (%)	DTP_{fb}* (mm Hg)	DTP_{t1avg} (mm Hg)	$DTP_{LWGNavg}$ (mm Hg)	Calculated Average Delta Total Dissolved Gas Pressure with no Entrainment				Calculated Average Delta Total Dissolved Gas Pressure with Entrainment			
								Q_{ent} (kcfs)	$DTP_{LWGNavg}$ (mm Hg)	TP[&] Error (mm Hg)	PS[#] Error (%)	Q_{ent} (kcfs)	$DTP_{LWGNavg}$ (mm Hg)	TP Error (mm Hg)	PS Error (%)
168	92.2	34.8	57.4	37.7	31.1	133.7	114.9	0.0	69.8	45.1	6.0	35.6	109.4	5.6	0.7
169	98.0	40.5	57.5	41.3	38.1	160.5	137.3	0.0	88.6	48.7	6.5	41.4	140.3	-3.0	-0.4
170	100.5	25.3	75.2	25.2	48.0	102.6	74.2	0.0	61.7	12.5	1.7	25.9	75.8	-1.6	-0.2
171	91.2	15.8	75.4	17.3	51.4	67.3	52.3	0.0	54.1	-1.8	-0.2	16.1	56.9	-4.6	-0.6
172	81.3	6.0	75.3	7.4	44.7	44.7	39.8	0.0	44.7	-4.8	-0.6	6.1	44.7	-4.8	-0.6
173	90.9	15.8	75.1	17.4	48.0	68.3	52.5	0.0	51.5	1.0	0.1	16.1	55.1	-2.6	-0.4
174	100.3	25.3	75.0	25.2	70.8	104.5	77.3	0.0	79.3	-2.1	-0.3	25.9	88.0	-10.7	-1.5
175	88.9	42.4	46.5	47.9	49.7	170.5	150.3	0.0	107.4	42.9	5.8	43.3	166.2	-15.9	-2.2
176	94.4	19.6	74.8	20.8	47.3	82.6	66.1	0.0	54.6	11.5	1.6	20.0	62.1	4.0	0.5
177	92.4	29.1	63.3	31.5	49.4	114.6	96.1	0.0	70.0	26.2	3.5	29.7	90.9	5.2	0.7
178	85.7	29.1	56.6	34.0	51.9	122.6	101.3	0.0	75.9	25.5	3.4	29.7	100.4	0.9	0.1
179	76.8	19.6	57.2	25.5	52.4	82.7	71.4	0.0	60.1	11.3	1.5	20.0	68.0	3.4	0.5
180	79.6	42.4	37.2	54.0	41.3	174.2	155.8	0.0	112.1	43.7	5.9	37.2	174.2	-18.4	-2.5
181	85.0	19.7	65.3	23.3	42.6	76.2	62.0	0.0	50.4	11.6	1.6	20.1	58.3	3.7	0.5
182	79.5	29.2	50.3	36.7	49.0	112.5	93.5	0.0	72.3	21.1	2.9	29.8	96.2	-2.7	-0.4
183	88.7	38.7	50.0	43.7	44.0	136.7	117.4	0.0	84.5	33.0	4.5	39.5	125.8	-8.4	-1.1
184	82.1	19.7	62.4	24.0	32.2	74.7	57.8	0.0	42.4	15.4	2.1	20.1	52.8	5.0	0.7
185	84.9	10.0	74.9	11.8	31.5	46.2	39.0	0.0	33.3	5.7	0.8	10.2	35.0	4.0	0.5
186	84.3	36.8	47.5	43.7	19.2	134.5	111.3	0.0	69.5	41.7	5.6	37.6	120.9	-9.7	-1.3
187	84.5	29.2	55.3	34.6	17.6	110.4	86.7	0.0	49.7	37.0	5.0	29.8	82.5	4.2	0.6
188	82.9	19.7	63.2	23.8	18.5	72.8	52.0	0.0	31.4	20.6	2.8	20.1	44.6	7.5	1.0
189	83.3	29.2	54.1	35.8	18.2	108.7	87.0	0.0	49.9	37.1	5.0	29.8	82.3	4.7	0.6
190	73.9	40.6	33.3	56.2	15.1	150.6	130.6	0.0	89.6	41.0	5.5	33.3	150.6	-20.0	-2.7
191	63.7	40.6	23.1	66.7	17.5	155.8	139.9	0.0	105.6	34.3	4.6	23.1	155.8	-15.9	-2.1
192	58.6	29.2	29.4	49.8	18.9	117.8	99.1	0.0	68.1	31.0	4.1	29.4	117.8	-18.7	-2.5
193	62.9	38.7	24.2	62.1	21.5	147.4	131.1	0.0	99.0	32.1	4.3	24.2	147.4	-16.3	-2.2
194	53.4	38.2	15.2	71.6	36.2	111.6	122.5	0.0	90.1	32.4	4.4	15.2	111.6	10.9	1.5
195	56.3	40.6	15.7	75.2	31.5	147.5	137.3	0.0	115.1	22.2	3.0	15.7	147.5	-10.3	-1.4

(Continued)

Table 11. Concluded

Event	Qtotal (kcfs)	Qspill (kcfs)	Qgen (kcfs)	Qsp/Qtot (%)	DTP_{fb}* (mm Hg)	DTP_{t1avg} (mm Hg)	$DTP_{LWGNavg}$ (mm Hg)	Calculated Average Delta Total Dissolved Gas Pressure with no Entrainment				Calculated Average Delta Total Dissolved Gas Pressure with Entrainment			
								Q_{ent} (kcfs)	$DTP_{LWGNavg}$ (mm Hg)	TP[&] Error (mm Hg)	PS[#] Error (%)	Q_{ent} (kcfs)	$DTP_{LWGNavg}$ (mm Hg)	TP Error (mm Hg)	PS Error (%)
196	42.8	20.9	21.9	50.0	50.9		79.8	0.0							
197	54.6	6.0	48.6	11.0	38.7		31.9	0.0							
198	35.2	19.7	15.5	56.3	39.3										
199	35.8	20.8	15.1	62.6	50.0		84.2								
200	46.2	30.2	15.9	68.1	62.2		107.6								
201	39.2	20.8	18.4	54.9	89.1		89.4								
202	29.2	29.2	0.0	100.0	47.0		75.1								
203	43.2	31.1	12.1	73.0	49.5		111.9								
204	63.9	19.7	44.2	30.8	63.9		83.2								
205	34.4	21.6	12.8	68.8	55.5		73.1								

* DTP – Delta Total Pressure = Total Dissolved Gas Pressure minus Atmospheric Pressure (mm Hg)
fb – forebay, t1avg-Transect T1 average, LWGNavg-Transect LWGN average
&TP – Total Dissolved Gas Pressure
#PS – Total Dissolved Gas Saturation (%)

Table 12. Nonlinear Regression Summary Statistics, Instantaneous Data Analyses

$$\Delta P = C_1 \; (1 - \exp(C_2 \; q_s))$$

qs = flow weighted specific discharge, bays 6-8 (kcfs/bay)
P = Delta total dissolved gas pressure, total pressure minus barometric pressure (mm Hg)

N = 2707
$R^2 = 0.94$
Standard error = 10.2 mm Hg

Parameter	Estimate	Asymptotic Standard Error	Asymptotic 95% Confidence Interval	
C_1	245.8			
C_2	-0.141			

Figure 1. Aerial Photo of Lower Granite Lock and Dam

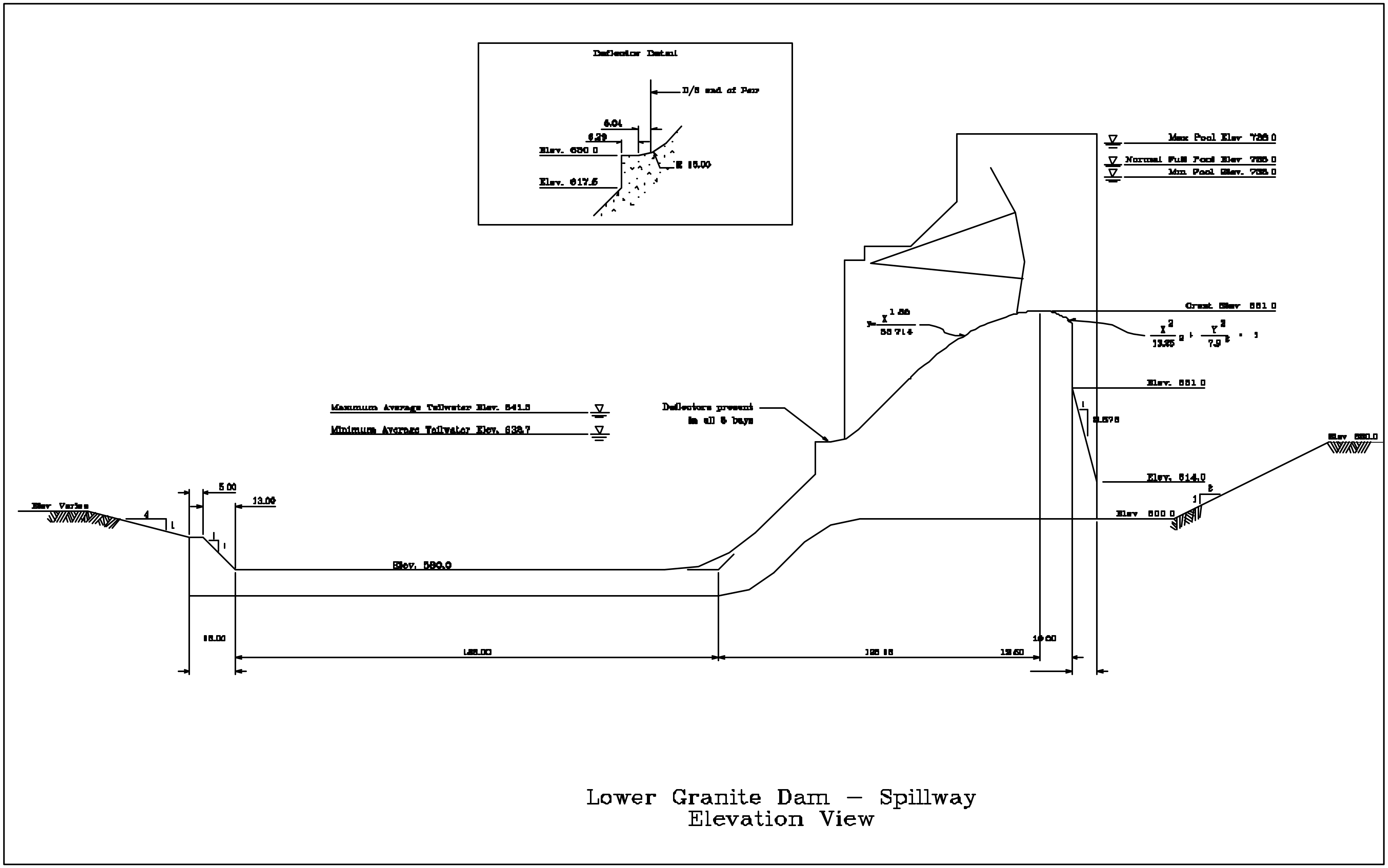

Figure 2. Profile view of Lower Granite Spillway and Stilling Basin

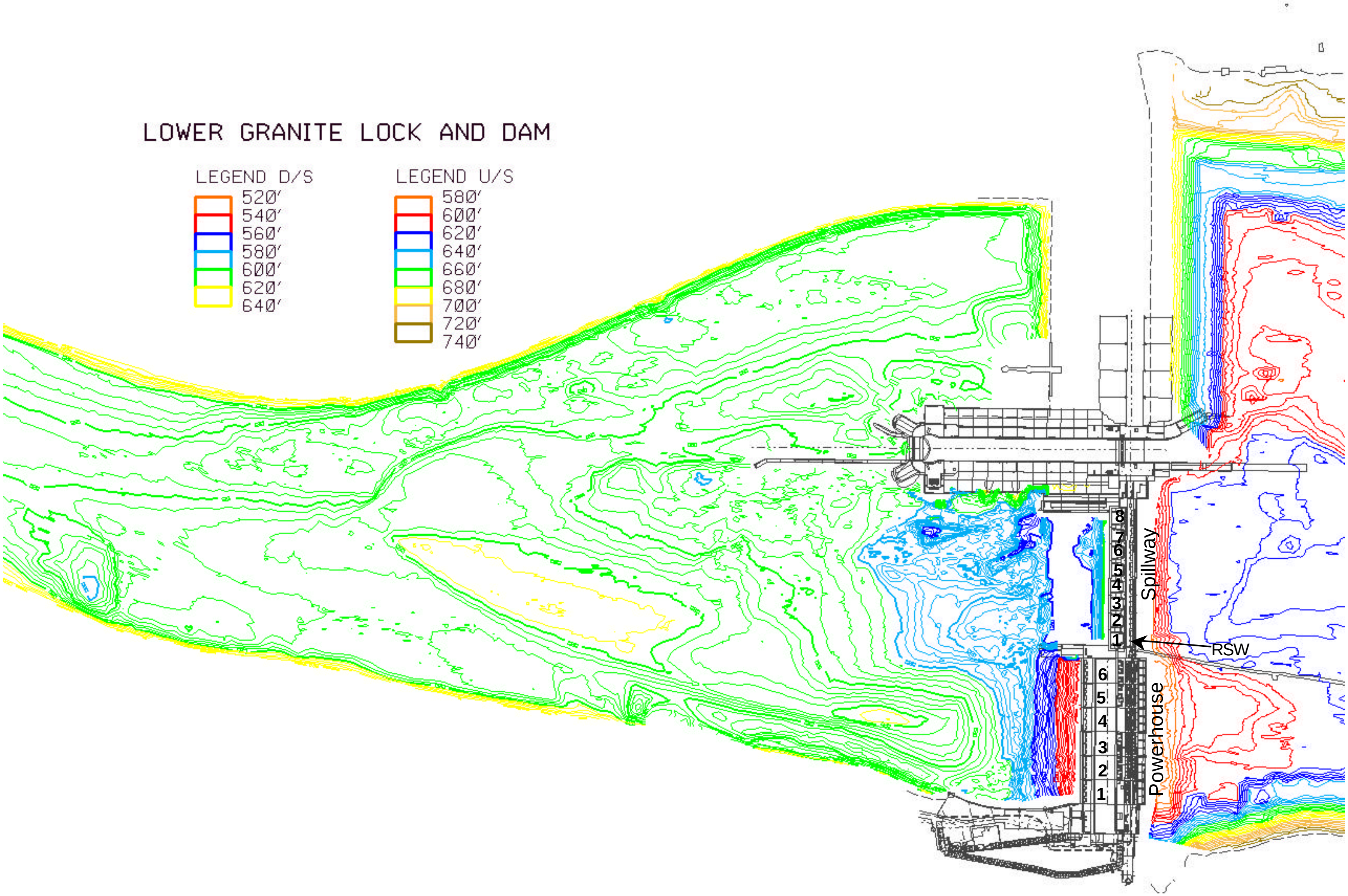

Figure 3. Tailwater channel bathymetry downstream of the Lower Granite Spillway

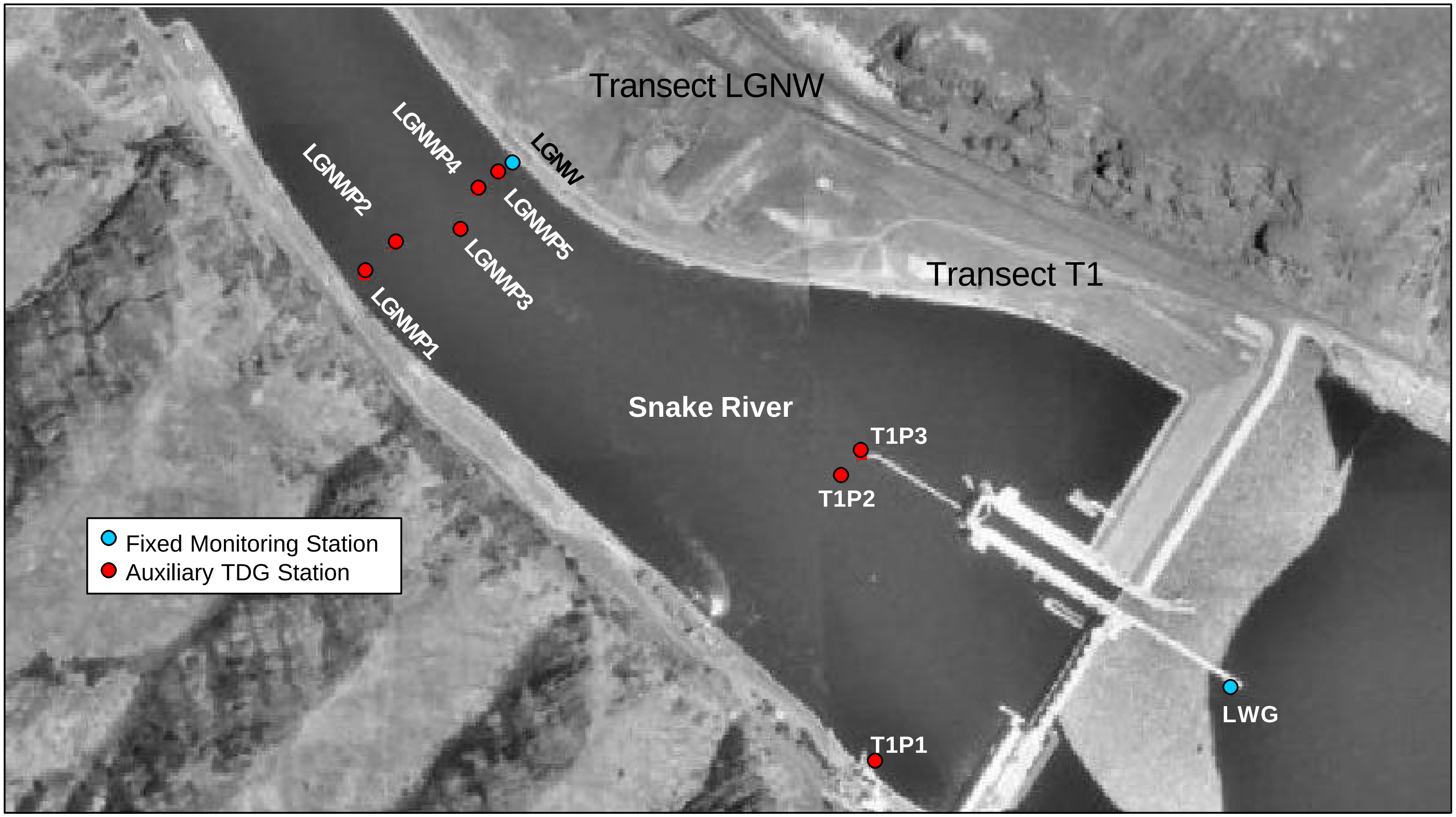

Figure 4. Deployment sites and fixed monitoring stations, Lower Granite Dam, April 04, 2002

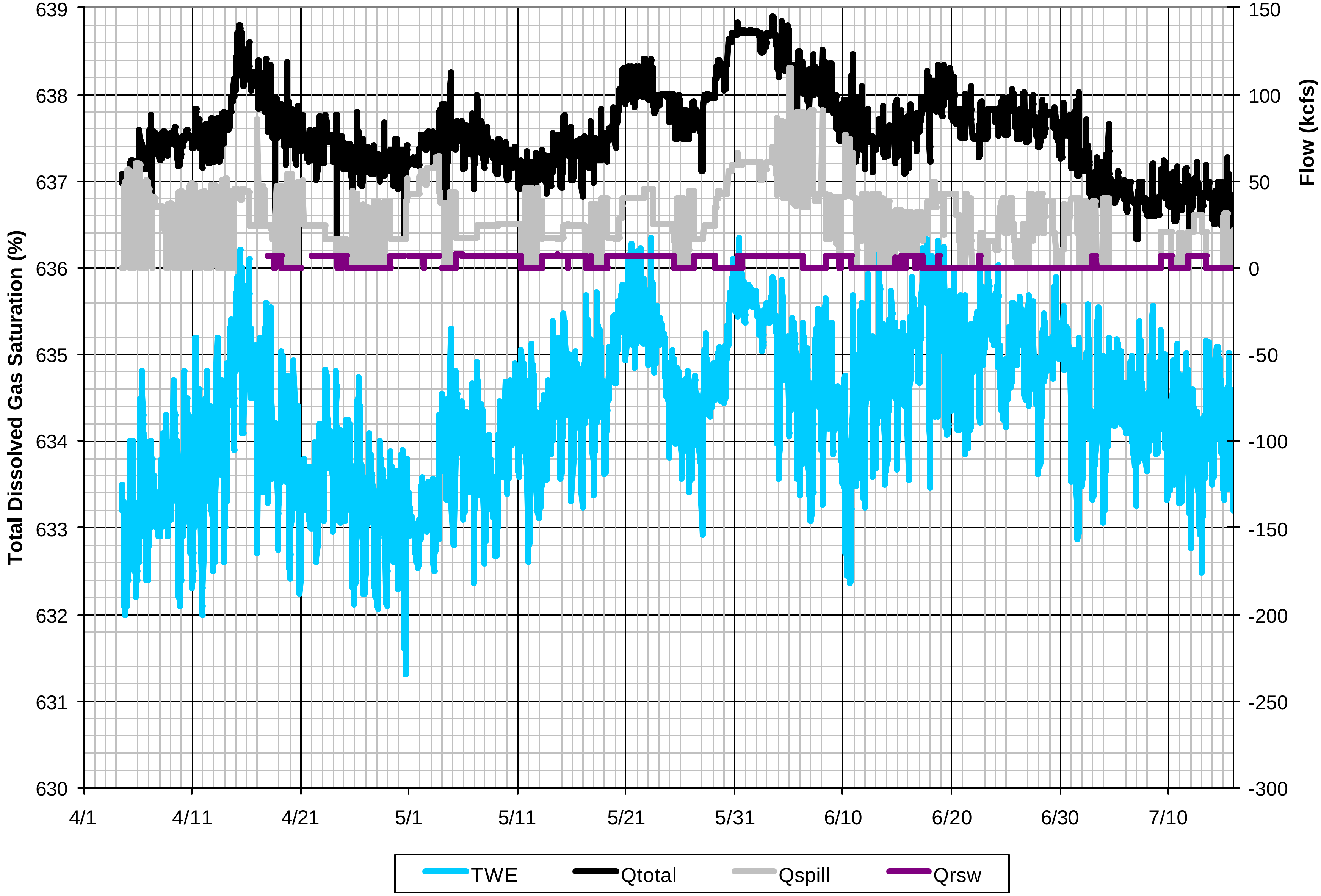

Figure 5. Project operation and tailwater elevation at Lower Granite Dam, April 1 – July 16, 2002

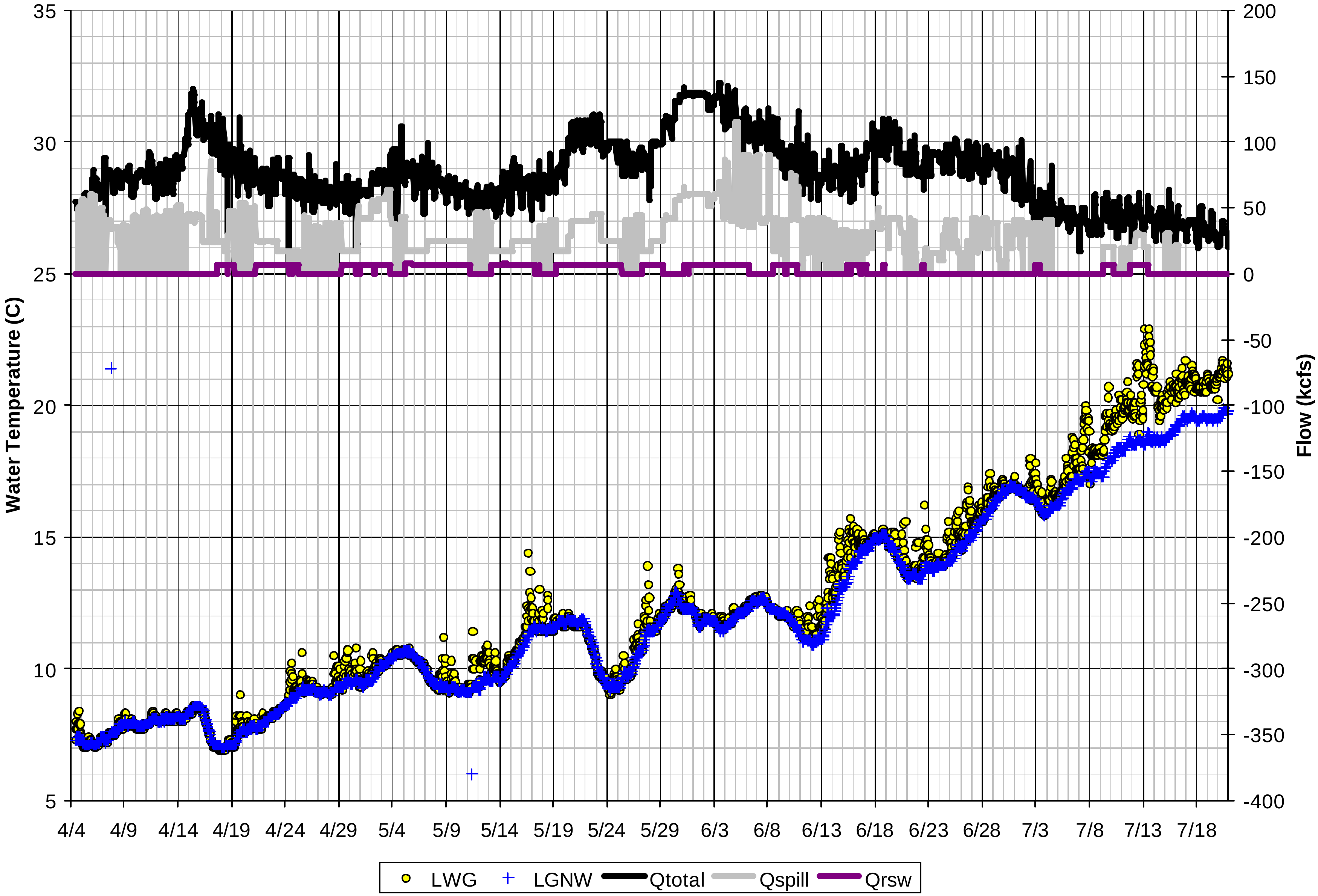

Figure 6. Lower Granite operations and Snake River water temperature at the forebay (LWG) and tailwater (LGNW) fixed monitoring stations, April 4 – July 20, 2002

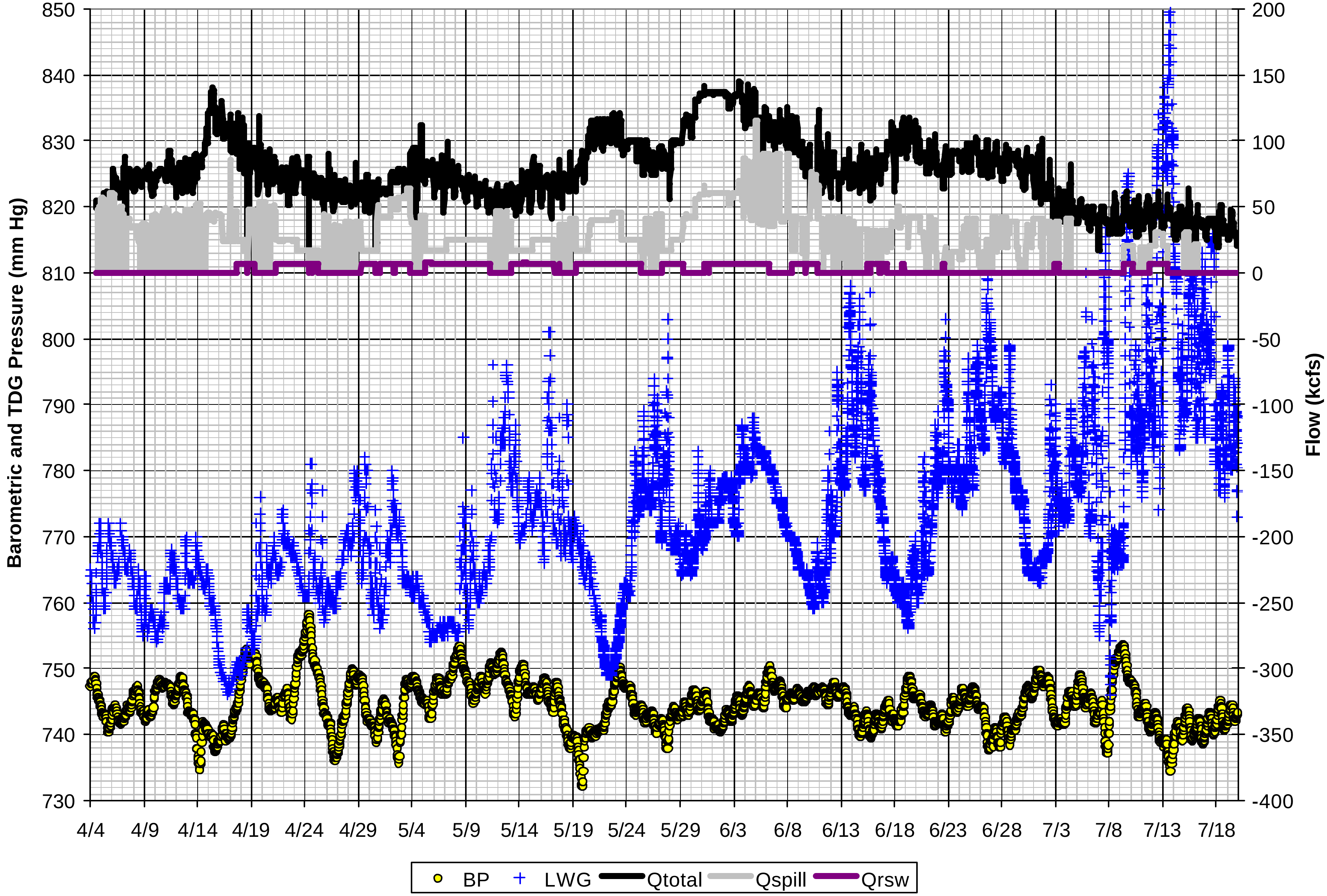

Figure 7. Lower Granite operations, barometric pressure, and total dissolved gas pressure at the forebay fixed monitoring station (LWG), April 4-July 19, 2002

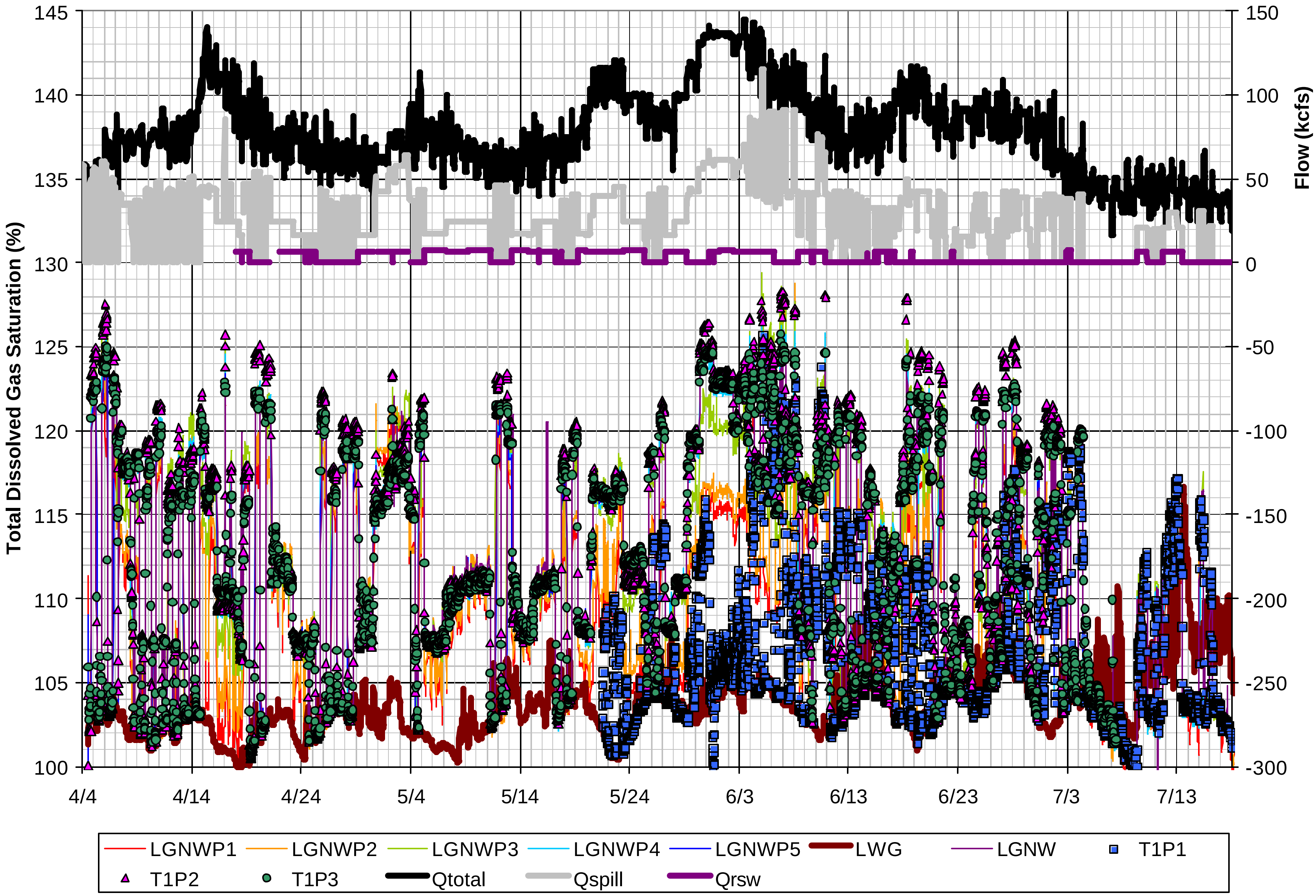

Figure 8. Lower Granite project operations and total dissolved gas saturation in the Snake River at the forebay, Transect T1, and tailwater fixed monitoring station, April 4-July 16, 2002

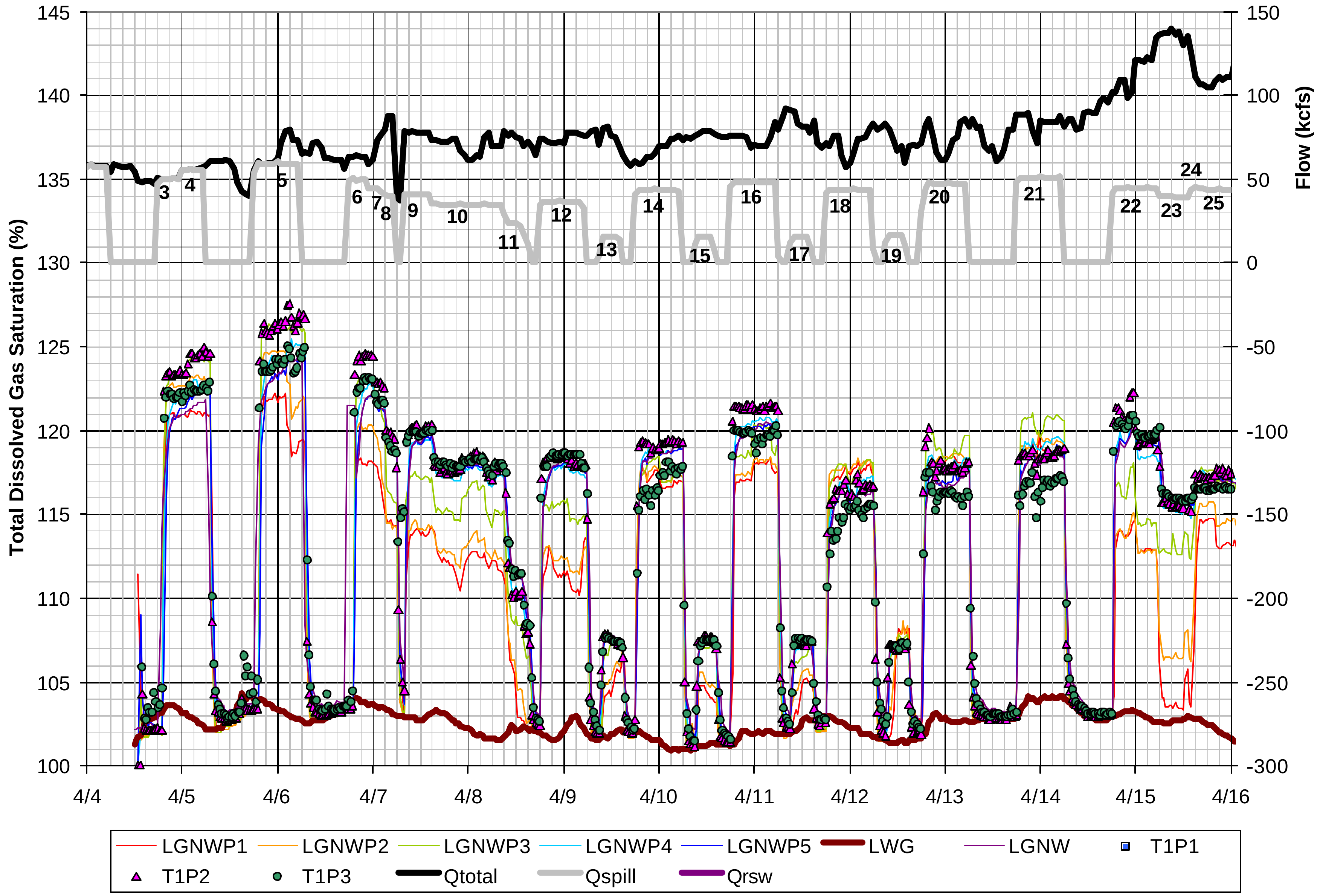

Figure 9. Lower Granite project operations and total dissolved gas saturation in the Snake River at the forebay, Transect T1, and tailwater fixed monitoring station, April 4-15, 2002

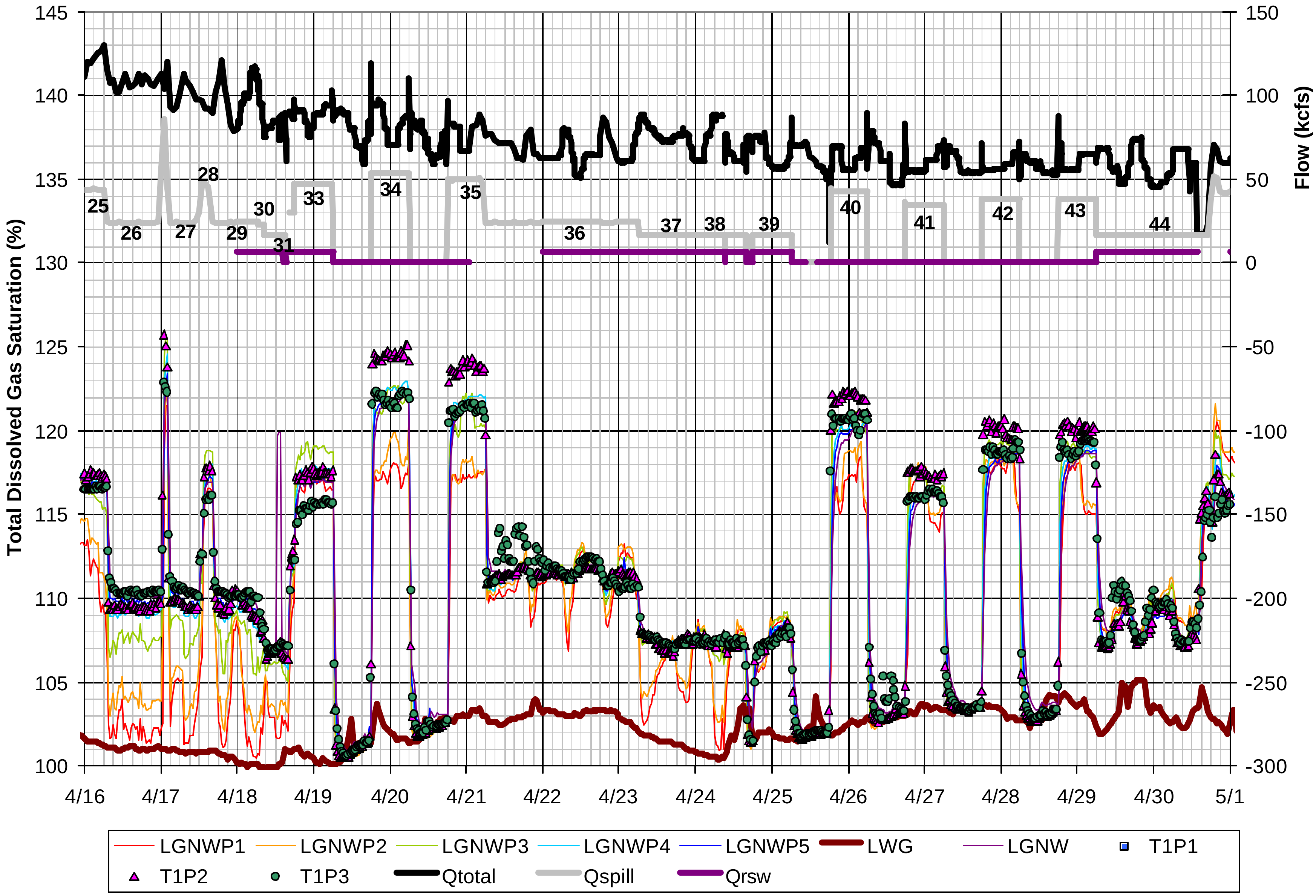

Figure 10. Lower Granite project operations and total dissolved gas saturation in the Snake River at the forebay, Transect T1, and tailwater fixed monitoring station, April 16-30, 2002

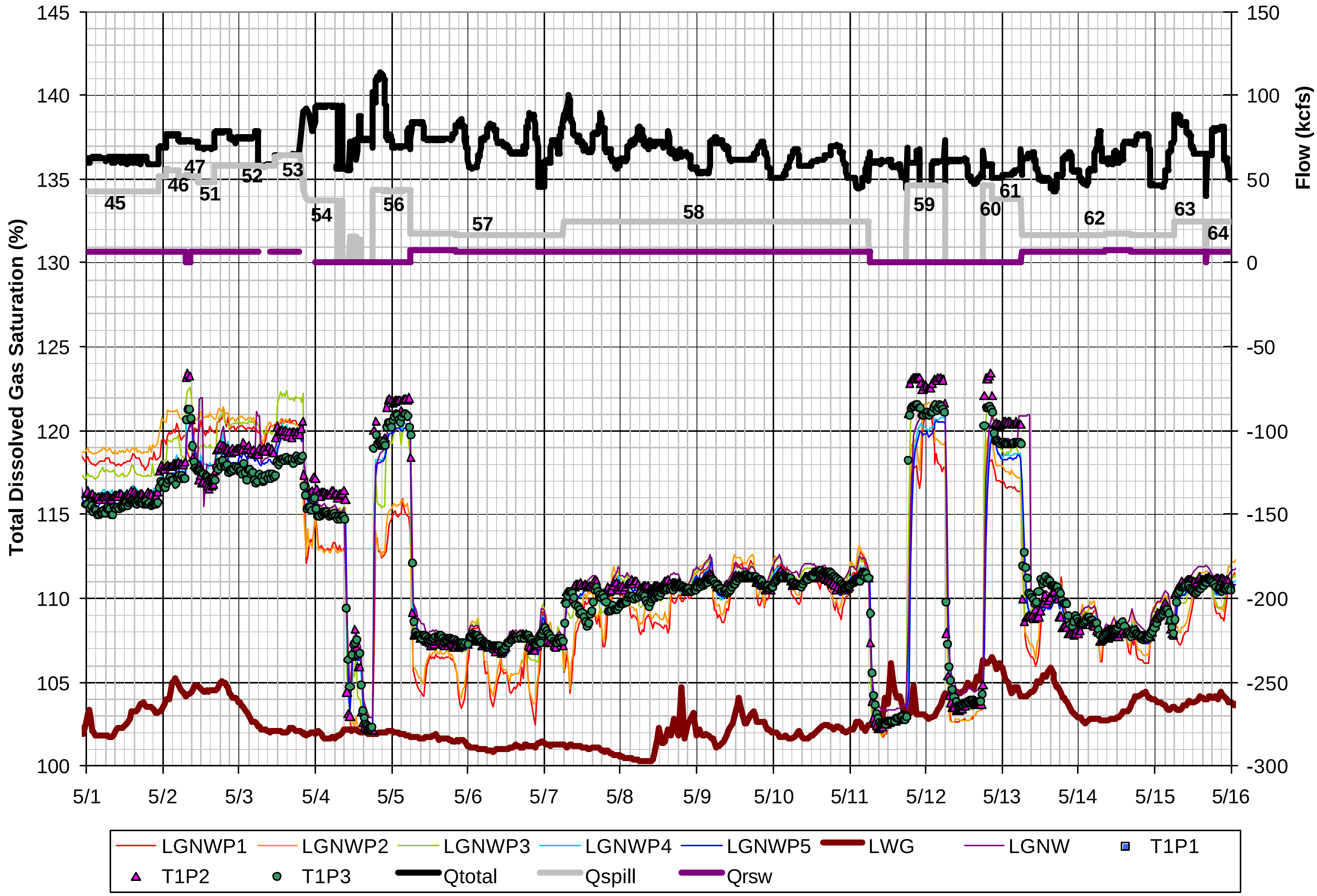

Figure 11. Lower Granite project operations and total dissolved gas saturation in the Snake River at the forebay, Transect T1, and tailwater fixed monitoring station, May 1-15, 2002

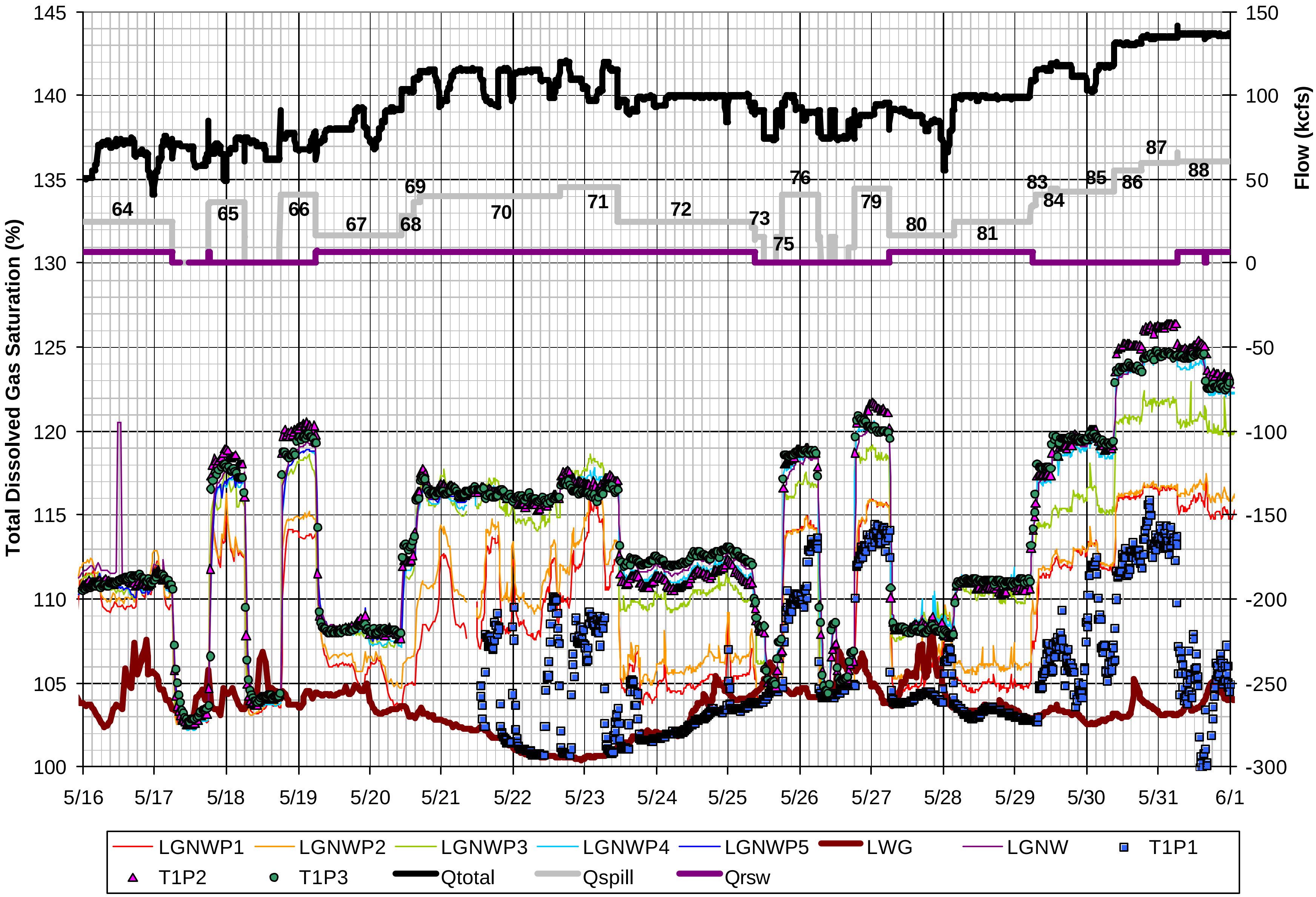

Figure 12. Lower Granite project operations and total dissolved gas saturation in the Snake River at the forebay, Transect T1, and tailwater fixed monitoring station, May 16-31, 2002

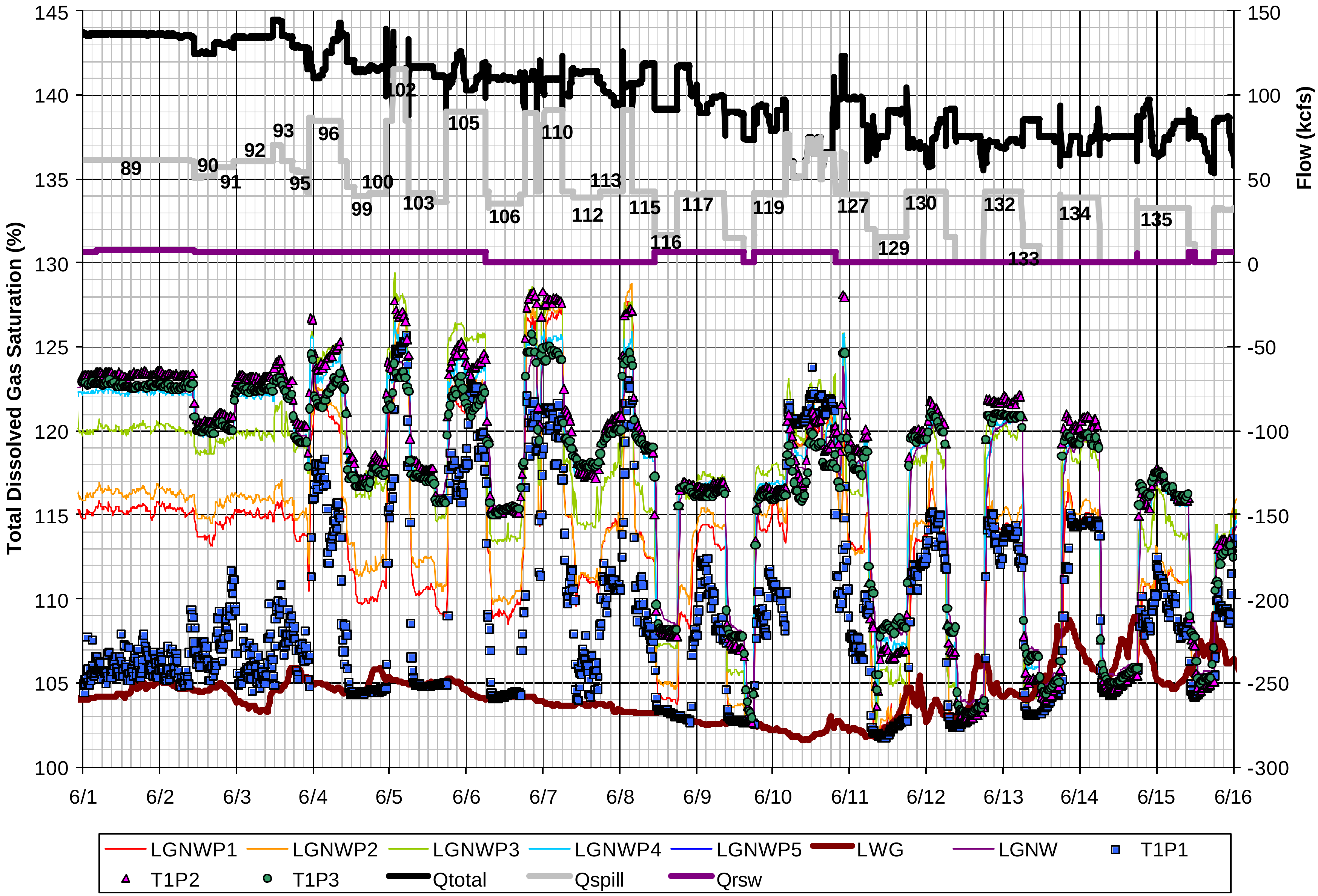

Figure 13. Lower Granite project operations and total dissolved gas saturation in the Snake River at the forebay, Transect T1, and tailwater fixed monitoring station, June 1-15, 2002

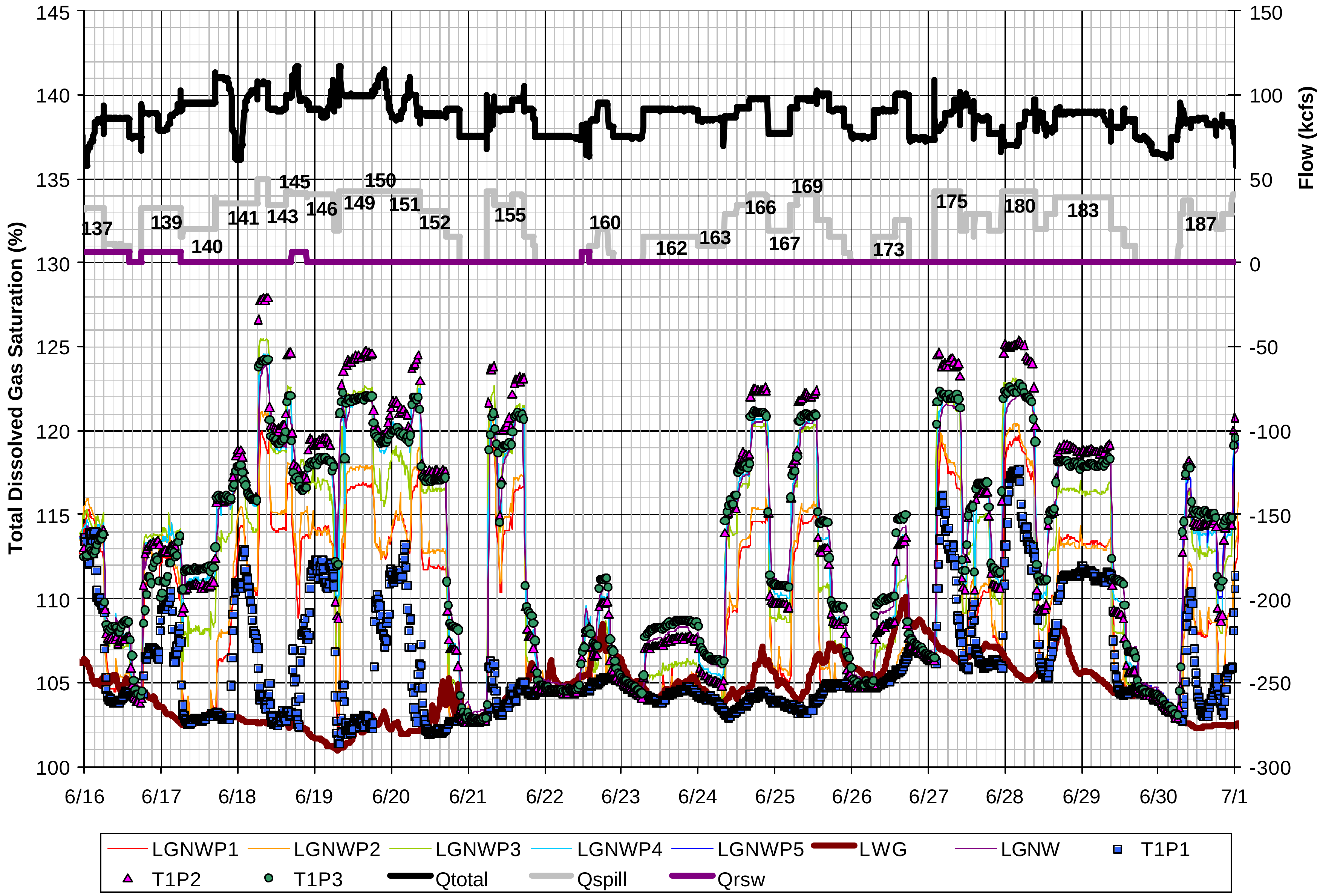

Figure 14. Lower Granite project operations and total dissolved gas saturation in the Snake River at the forebay,Transect T1, and tailwater fixed monitoring station, June 16-30, 2002

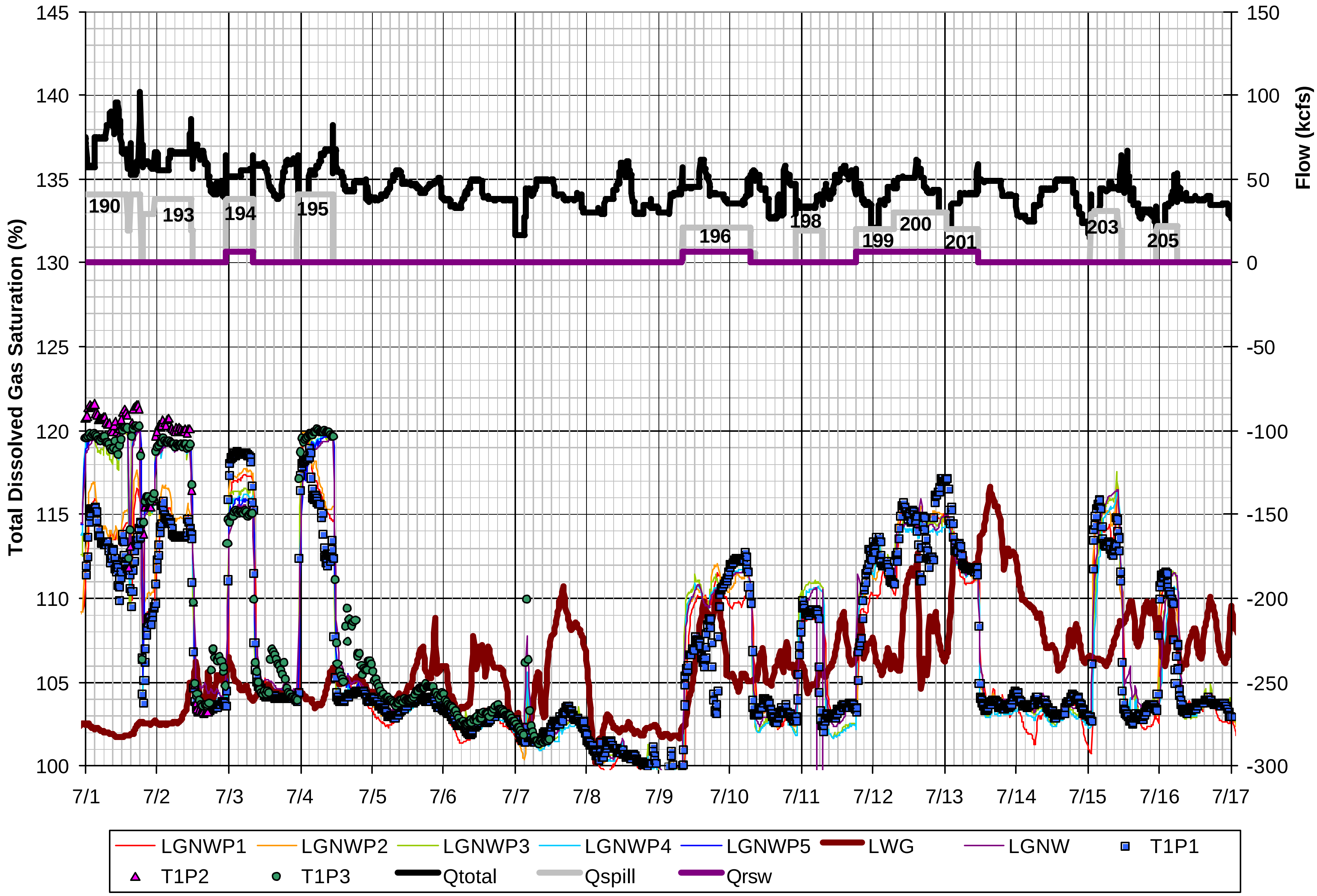

Figure 15. Lower Granite project operations and total dissolved gas saturation in the Snake River at the forebay, Transect T1, and tailwater fixed monitoring station, July 1-16, 2002

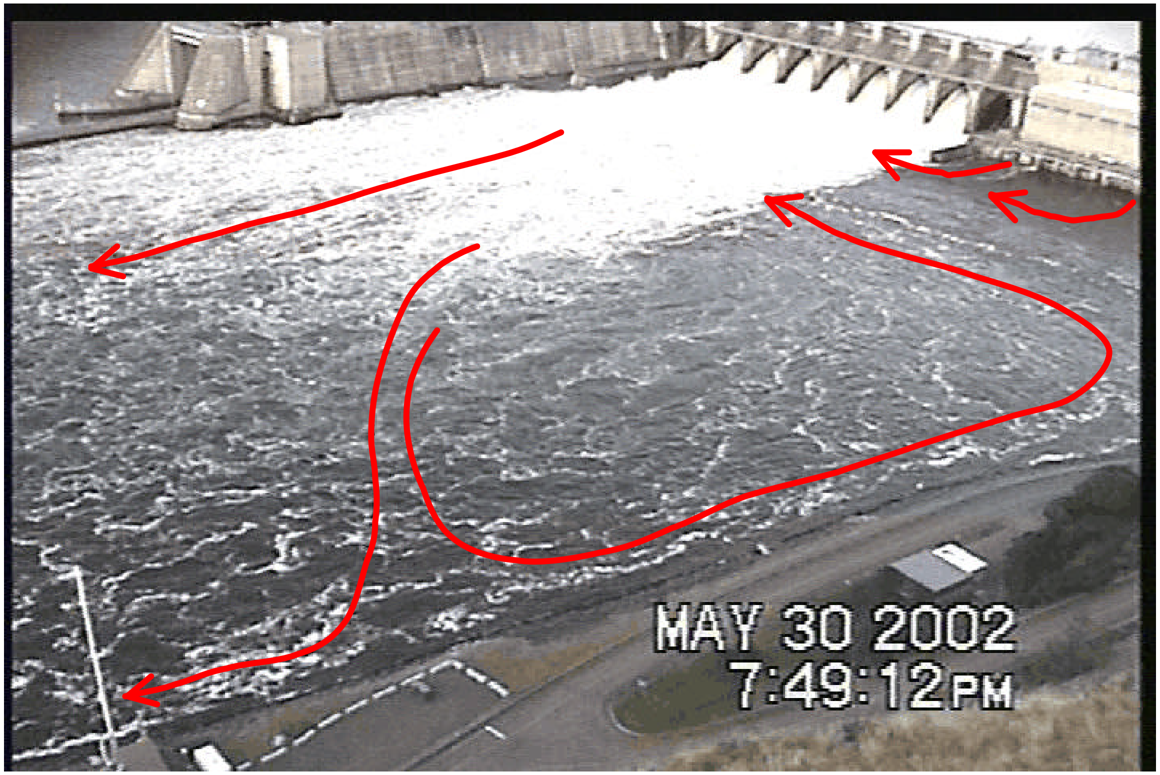

Figure 16. Video of surface circulation patterns downstream of Lower Granite Dam, May 30, 2002
(Qtot=134.9 kcfs, Qsp=59.6 kcfs, TWE= 635.7 ft, spill pattern bays 2-8)
(requires file “lwg1proc.Avi, click on figure to start)

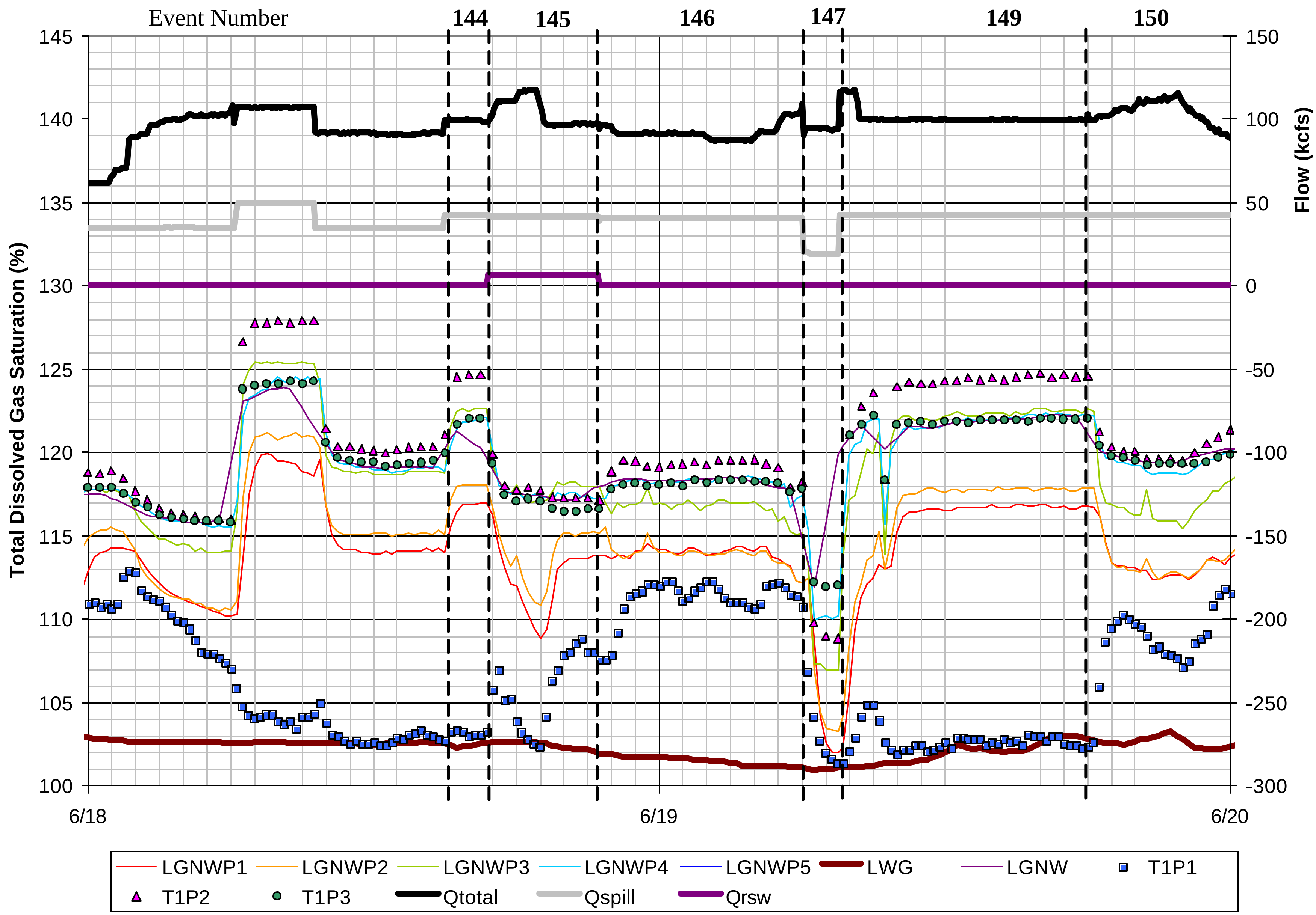

Figure 17. Total dissolved gas saturation in the Snake River and project operations at Lower Granite Dam, June 18-19, 2002

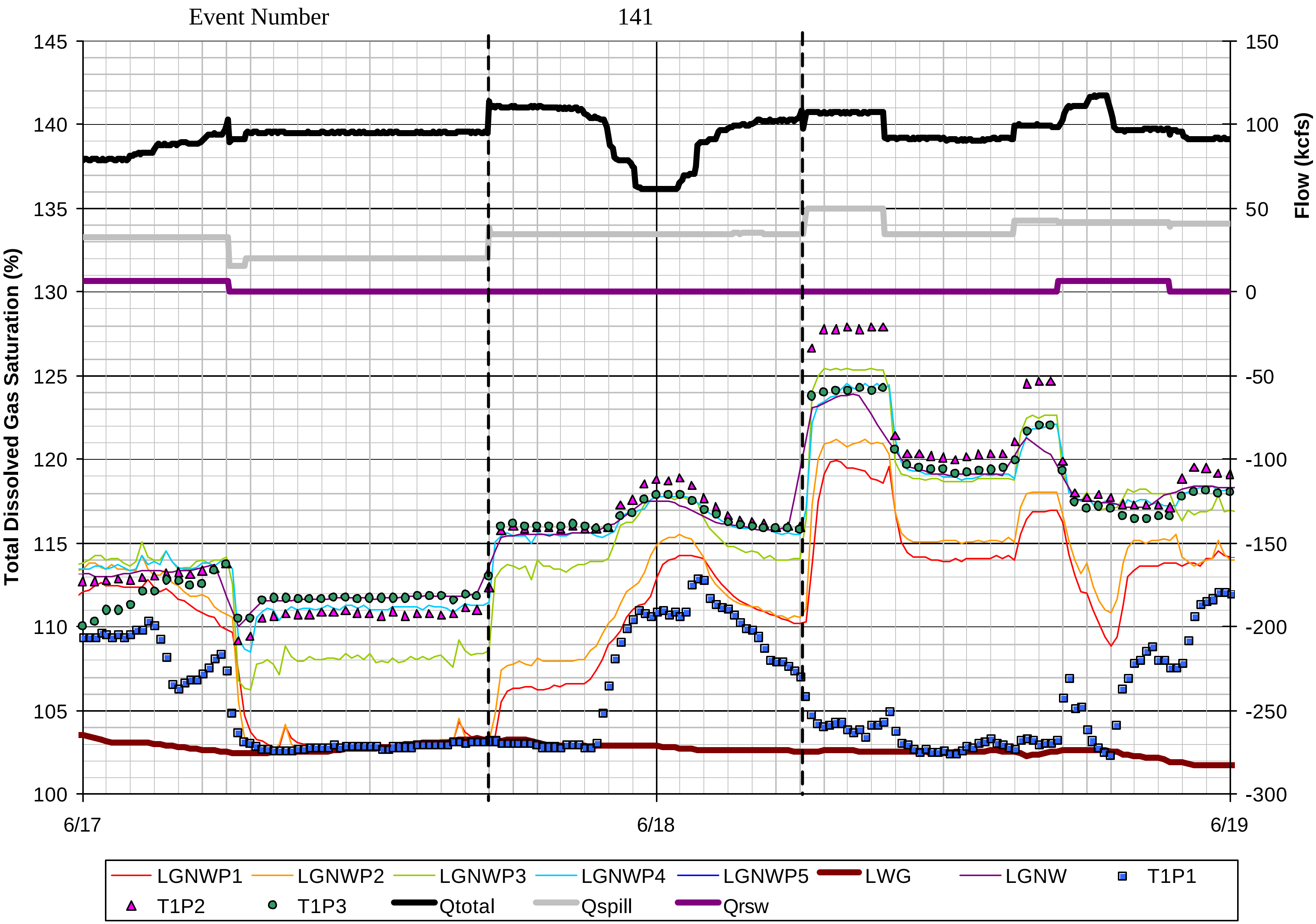

Figure 18. Total dissolved gas saturation in the Snake River and project operations at Lower Granite Dam, June 17-18, 2002

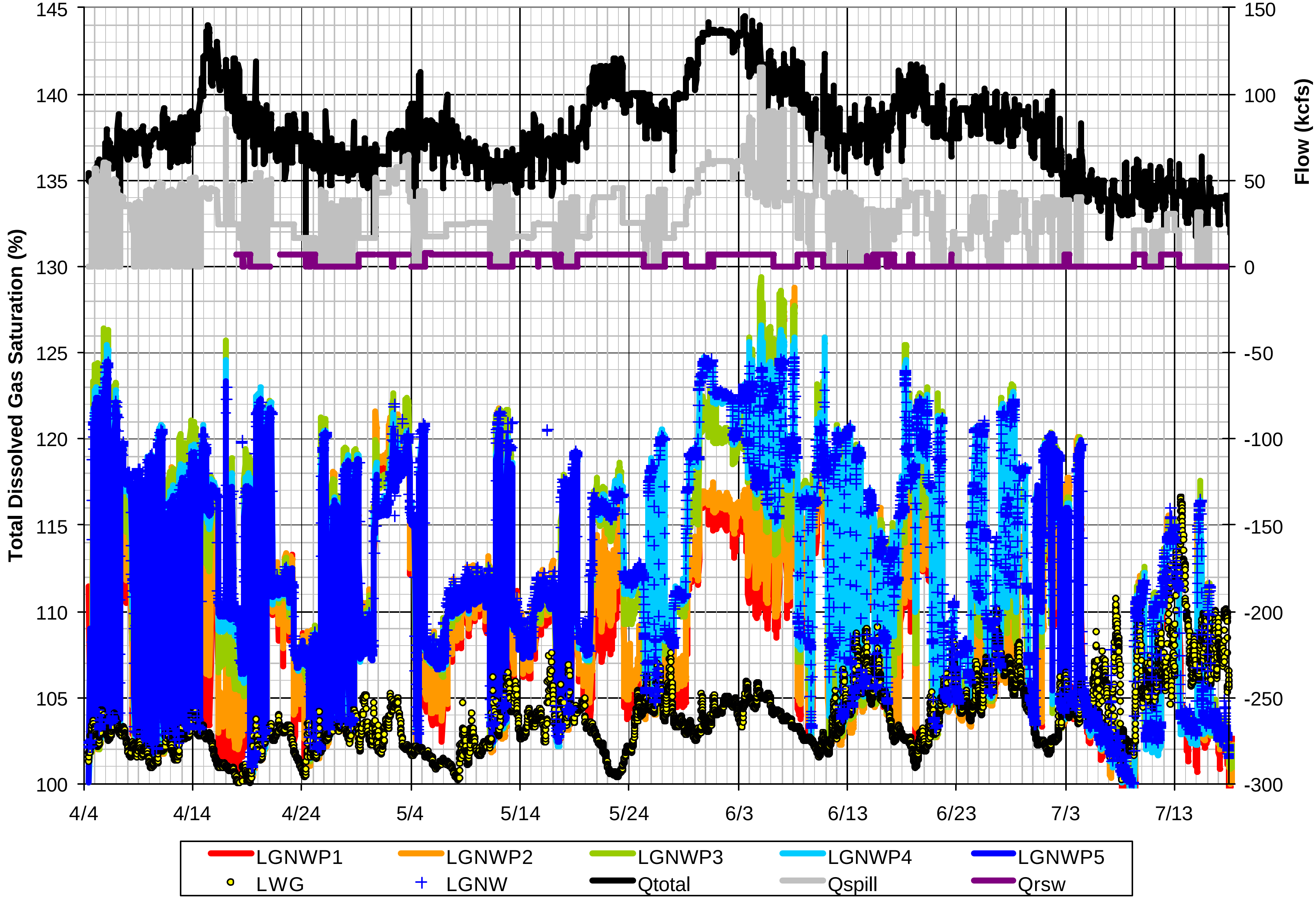

Figure 19. Lower Granite project perations and total dissolved gas saturation in the Snake River at the forebay and tailwater fixed monitoring station, April 4-July 16, 2002

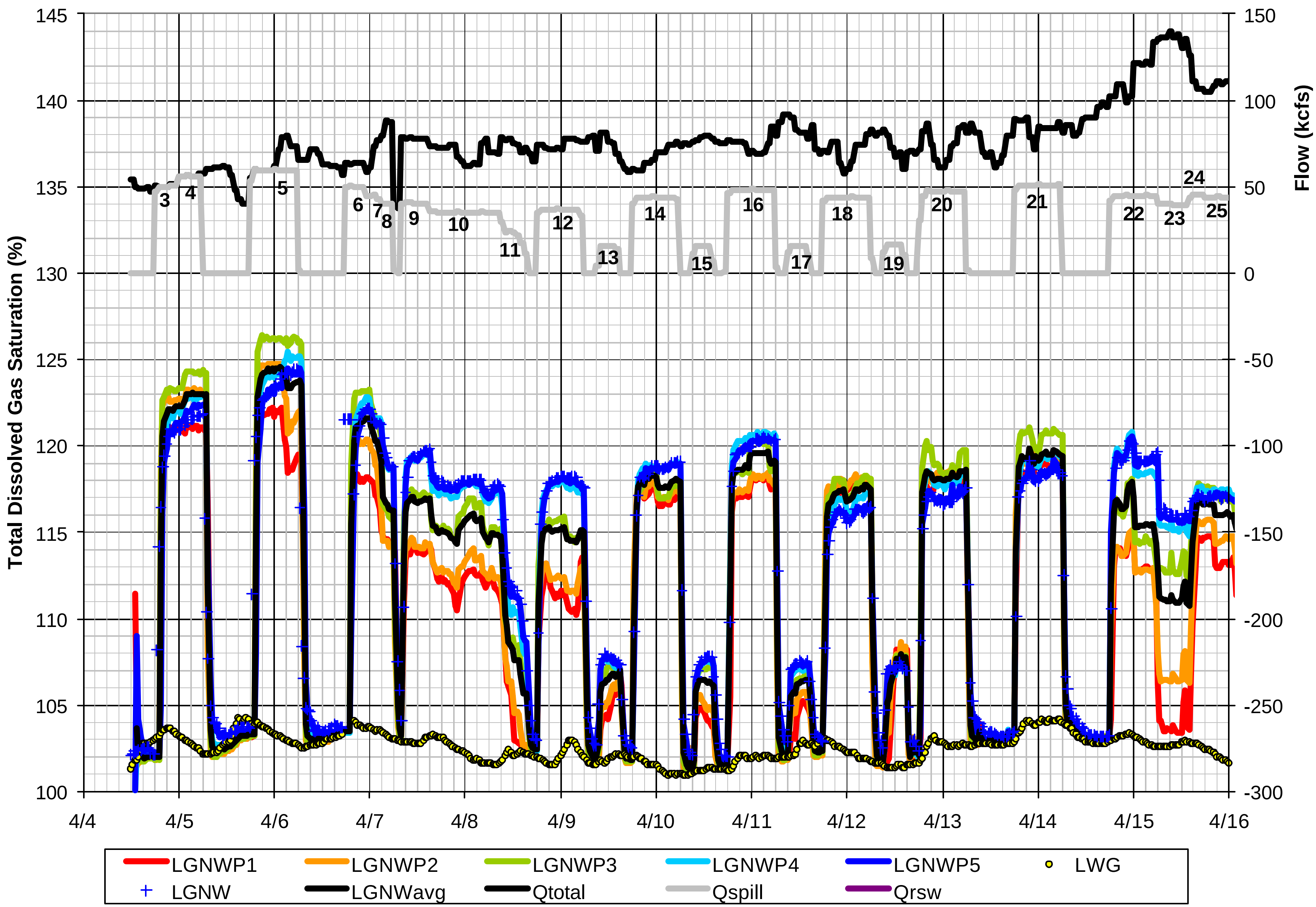

Figure 20. Lower Granite project operations and total dissolved gas saturation in the Snake River at the forebay and tailwater fixed monitoring station, April 4-14, 2002

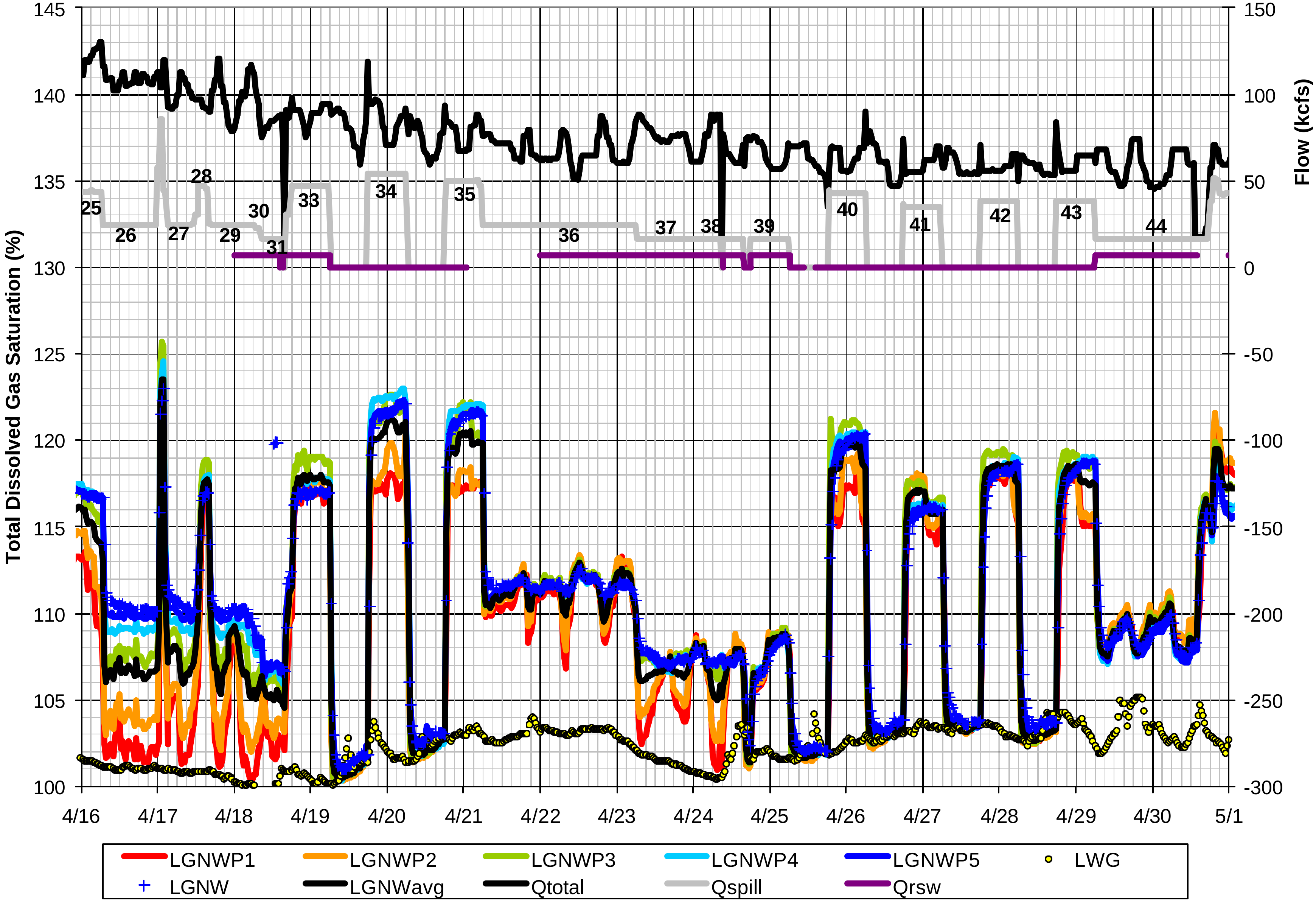

Figure 21. Lower Granite project operations and total dissolved gas saturation in the Snake River at the forebay and tailwater fixed monitoring station, April 16-30, 2002

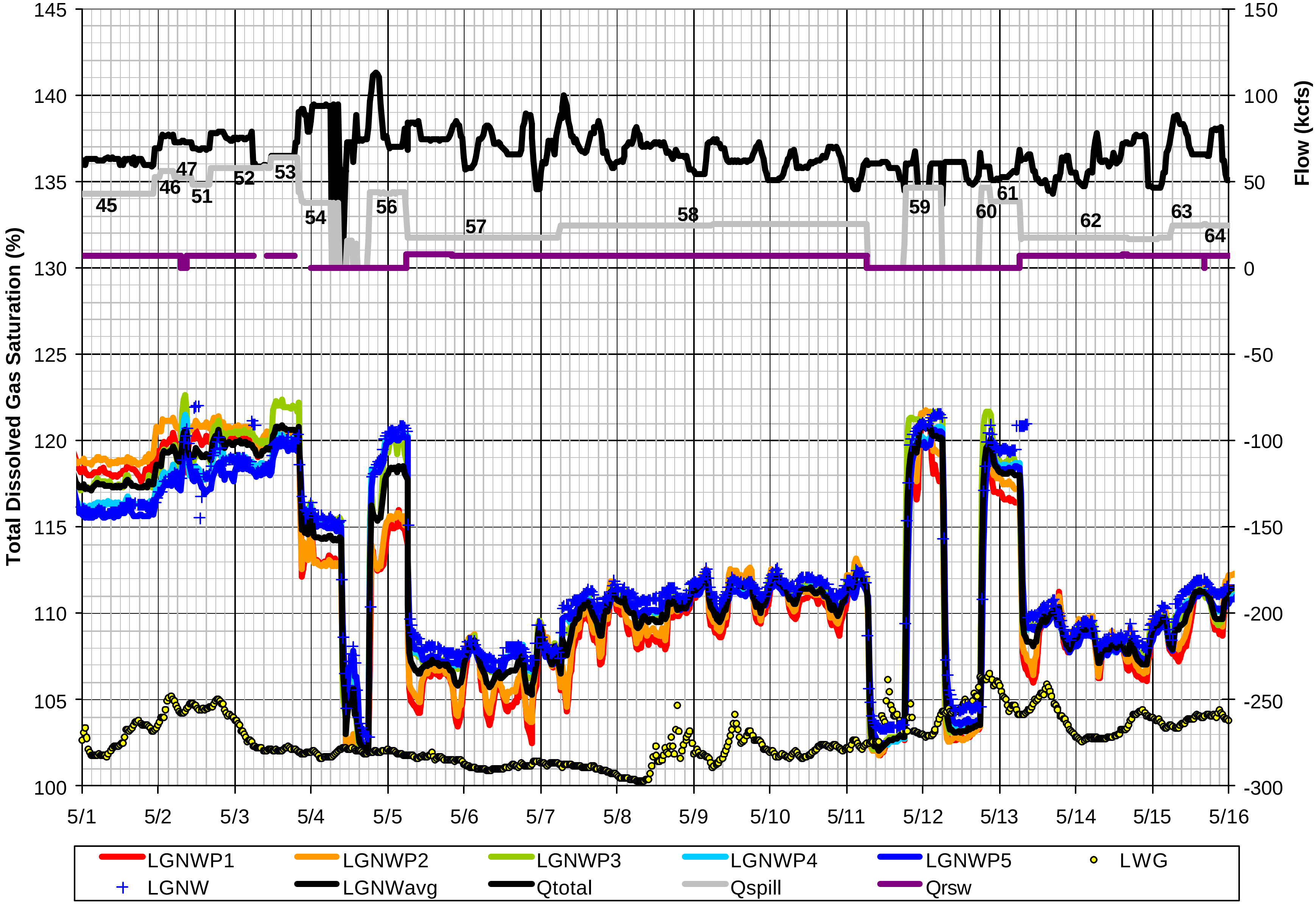

Figure 22. Lower Granite project operations and total dissolved gas saturation in the Snake River at the forebay and tailwater fixed monitoring station, May 1-15, 2002

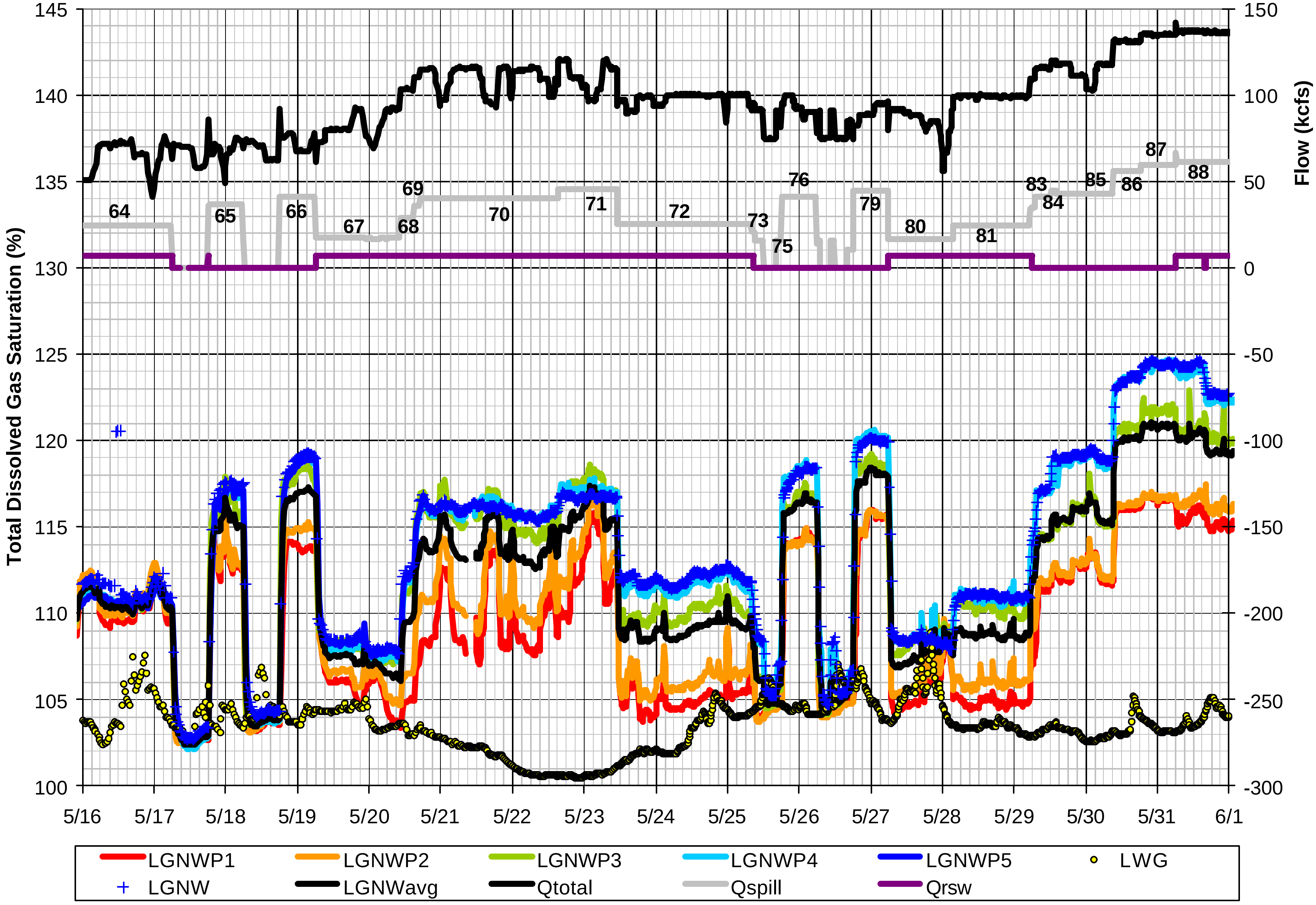

Figure 23. Lower Granite project operations and total dissolved gas saturation in the Snake River at the forebay and tailwater fixed monitoring station, May 16-31, 2002

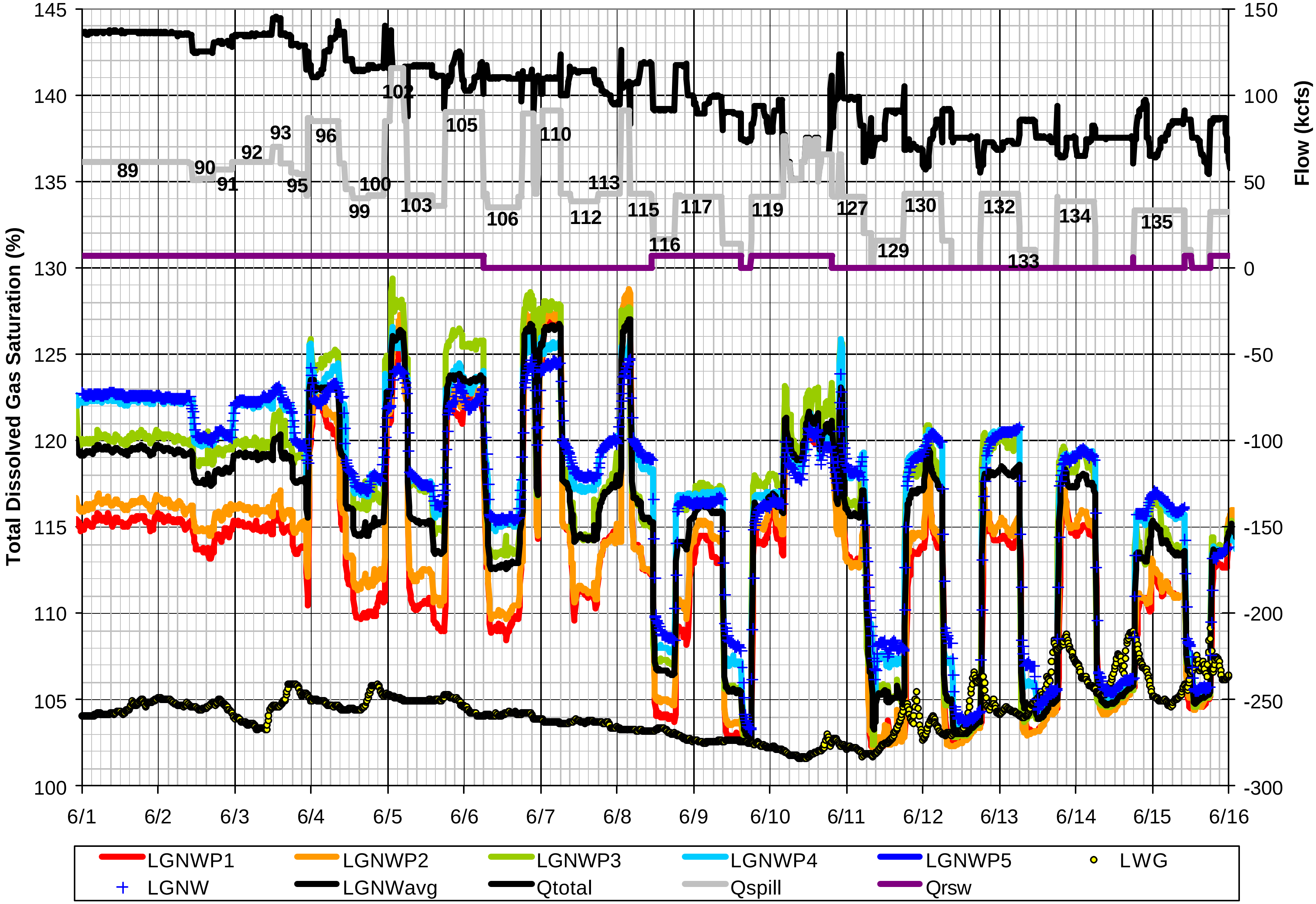

Figure 24. Lower Granite project operations and total dissolved gas saturation in the Snake River at the forebay and tailwater fixed monitoring station, June 1-15, 2002

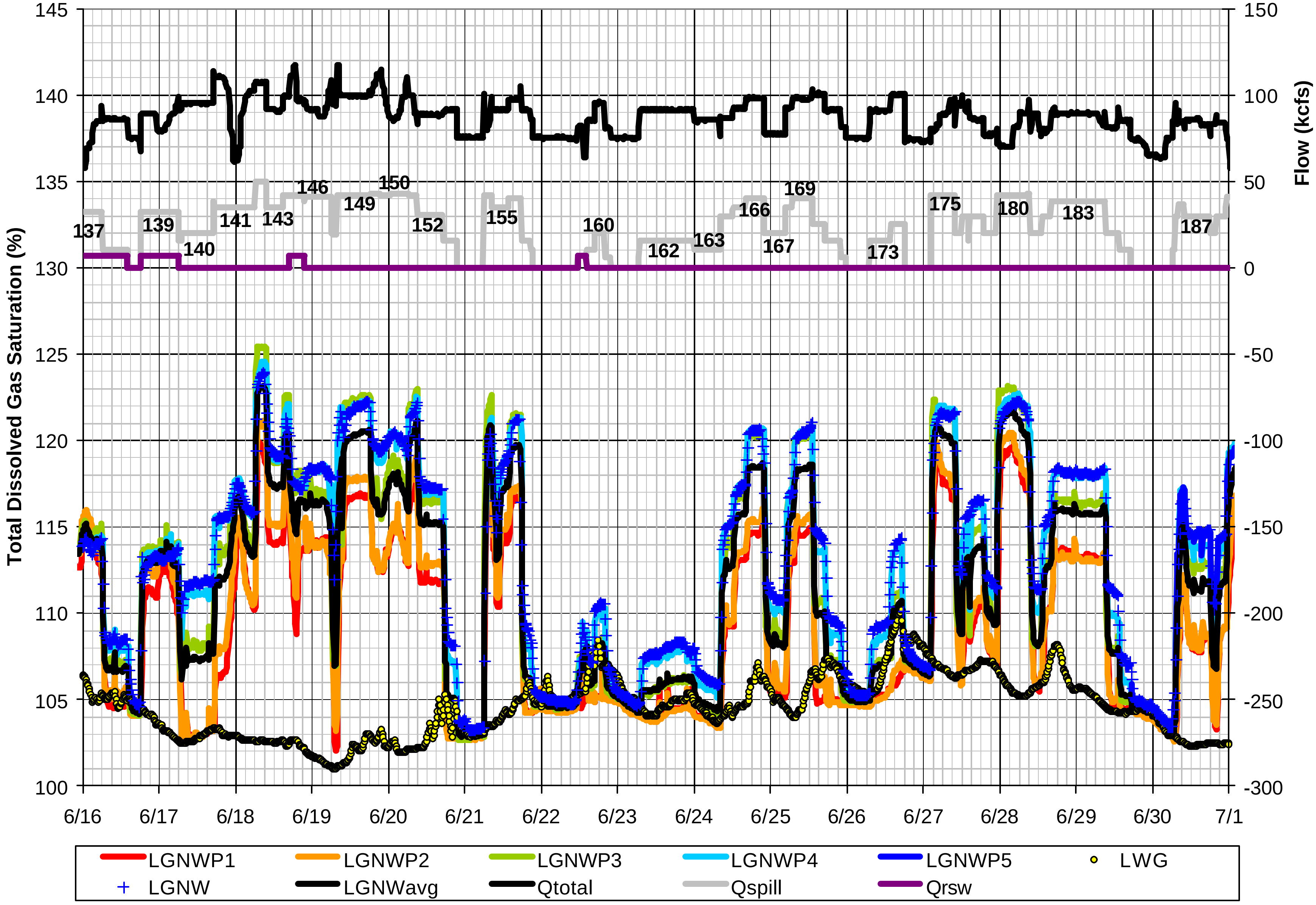

Figure 25. Lower Granite project operations and total dissolved gas saturation in the Snake River at the forebay and tailwater fixed monitoring station, June 16-30, 2002

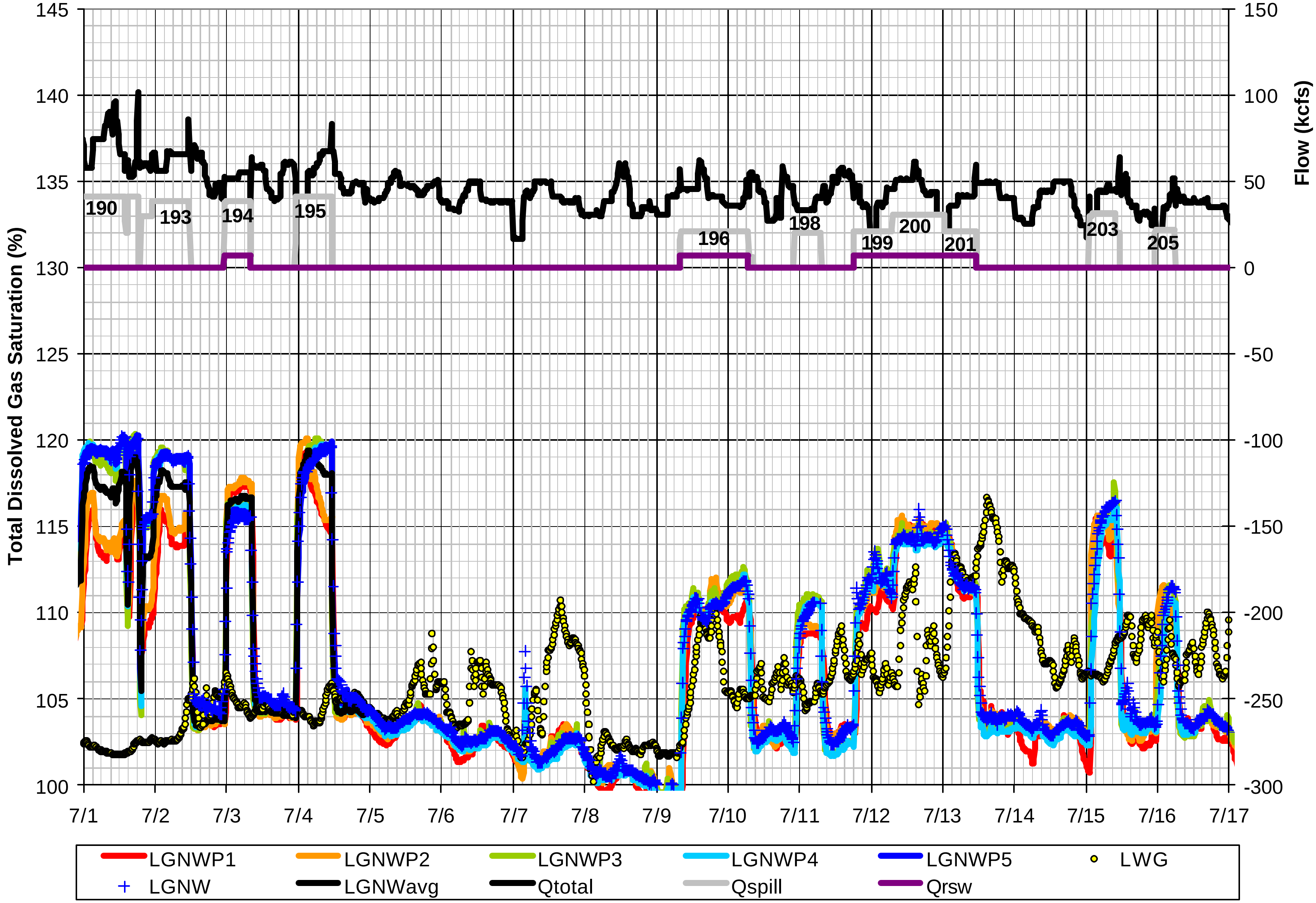

Figure 26. Lower Granite project operations and total dissolved gas saturation in the Snake River at the forebay and tailwater fixed monitoring station, July 1-16, 2002

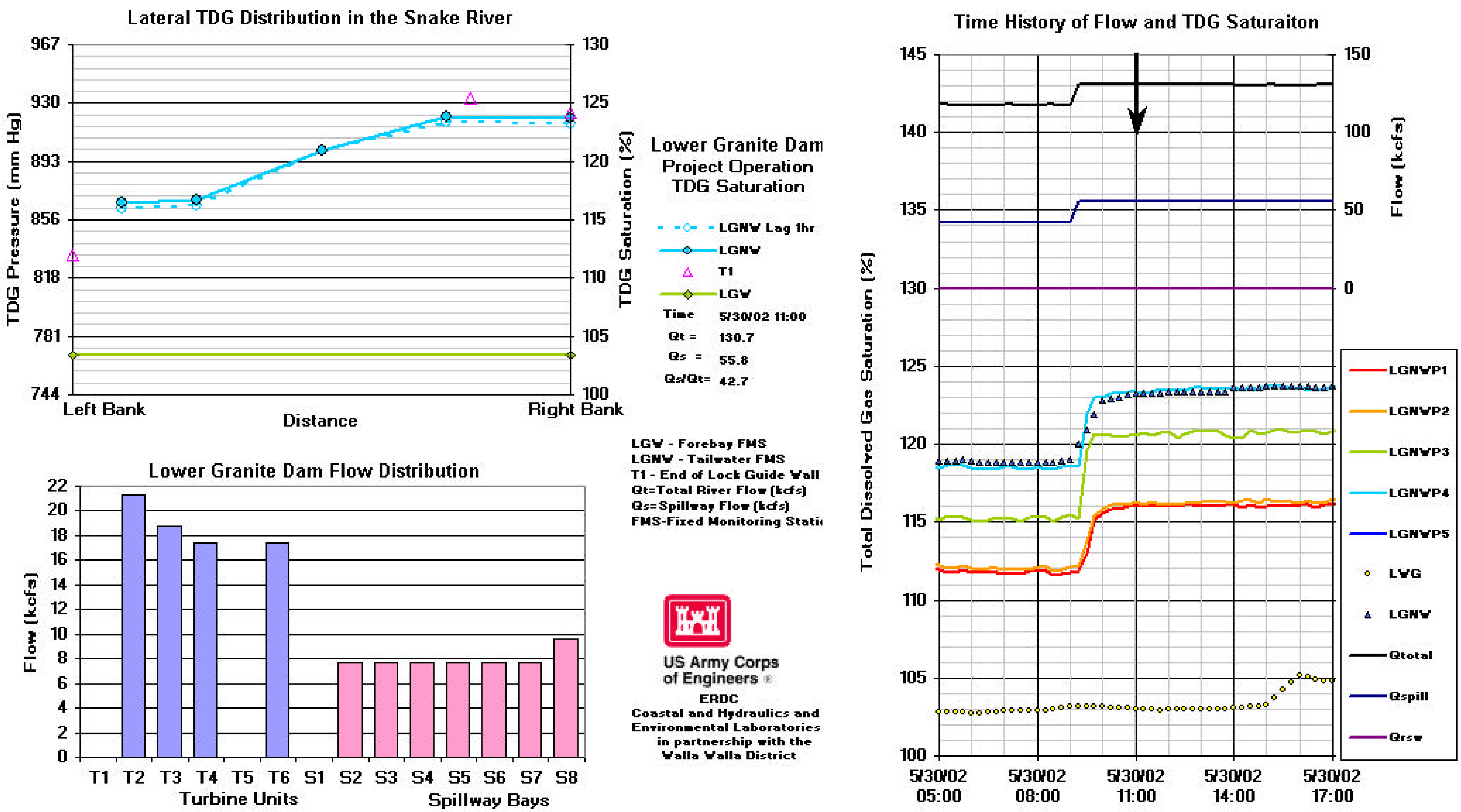

Figure 27. Lower Granite project operation by turbine unit and spill bay and the corresponding TDG saturation on April 18 – July 16, 2002
(Note: start data animation by clicking on figure above, requires file entitled lwgtdg02.Avi)

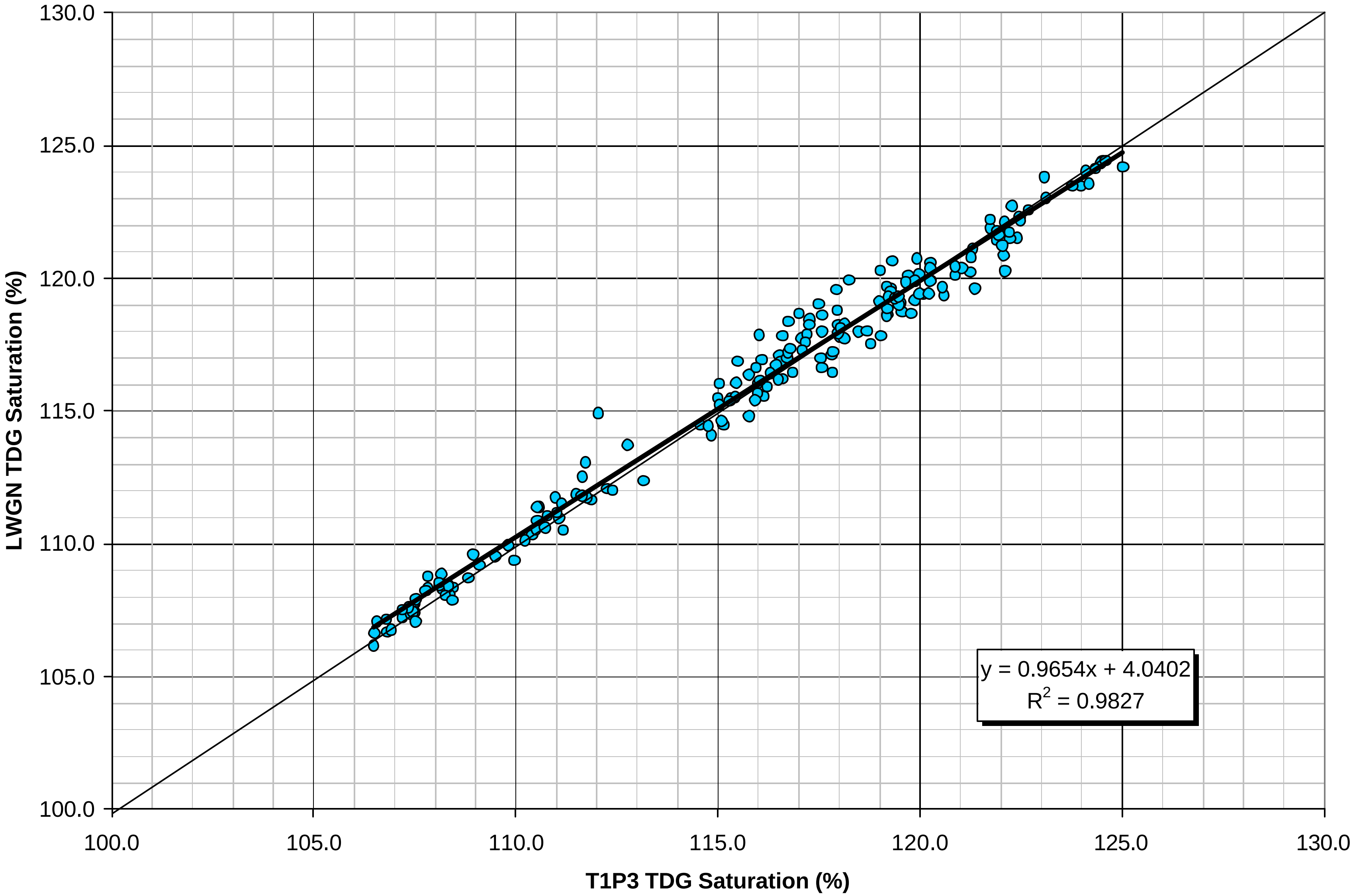

Figure 28. Event averaged TDG saturation at stations T1P3 and LGNW below Lower Granite Dam, 2002

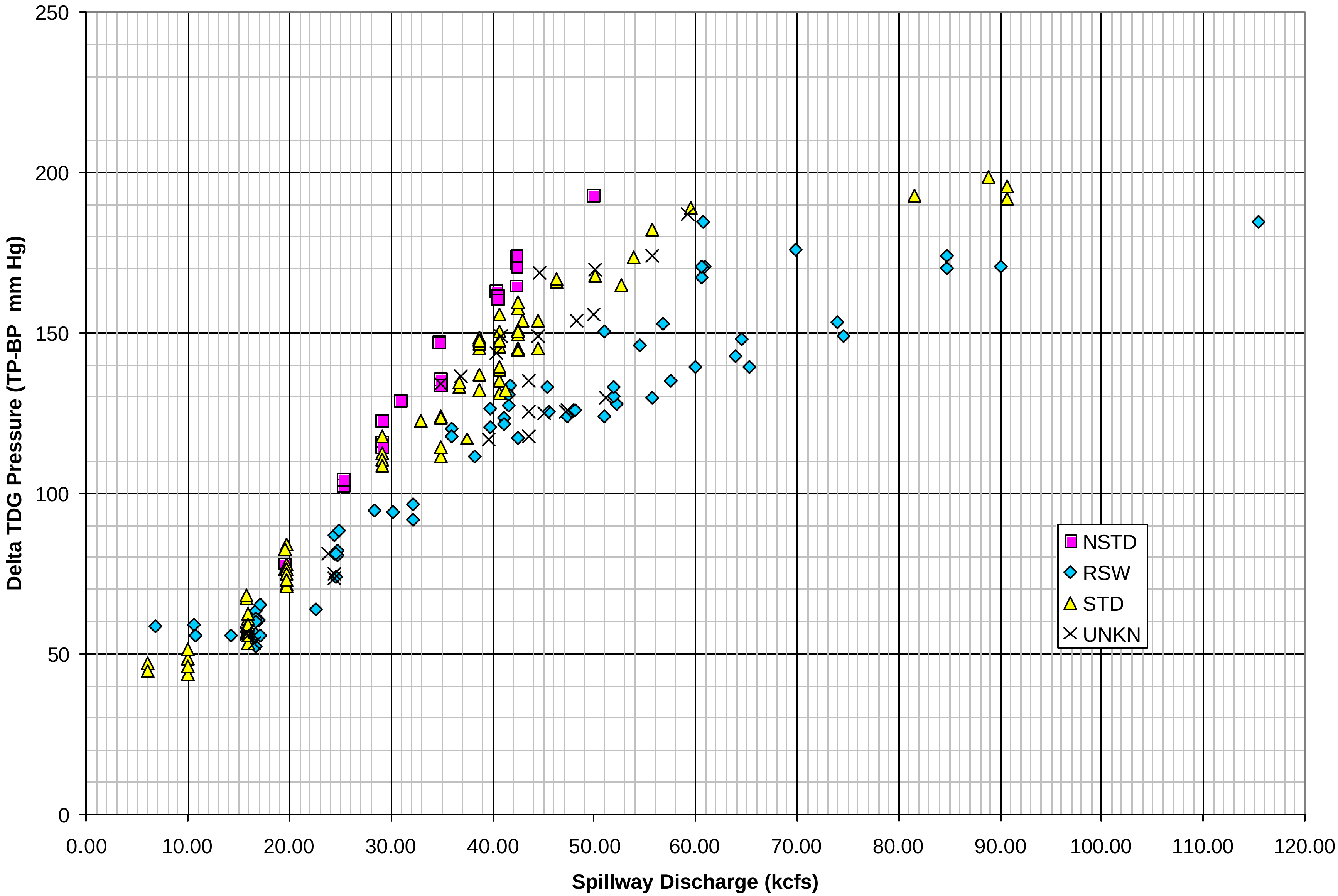

Figure 29. Event averaged delta TDG pressure on Transect T1 as a function of total spillway discharge below Lower Granite Dam

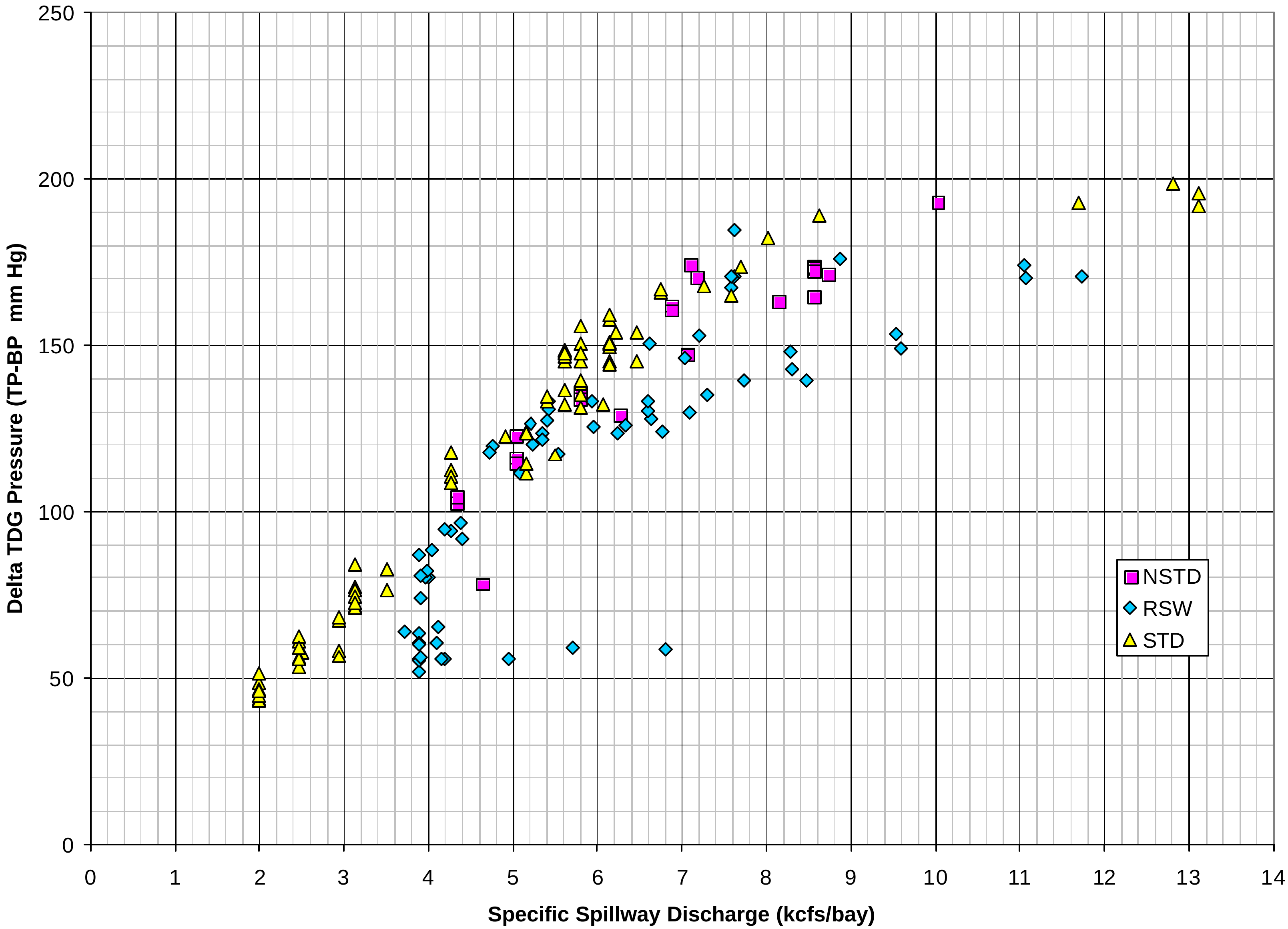

Figure 30. Event averaged delta TDG pressure on Transect T1 as a function of specific spillway discharge (bays 1-8) below Lower Granite Dam

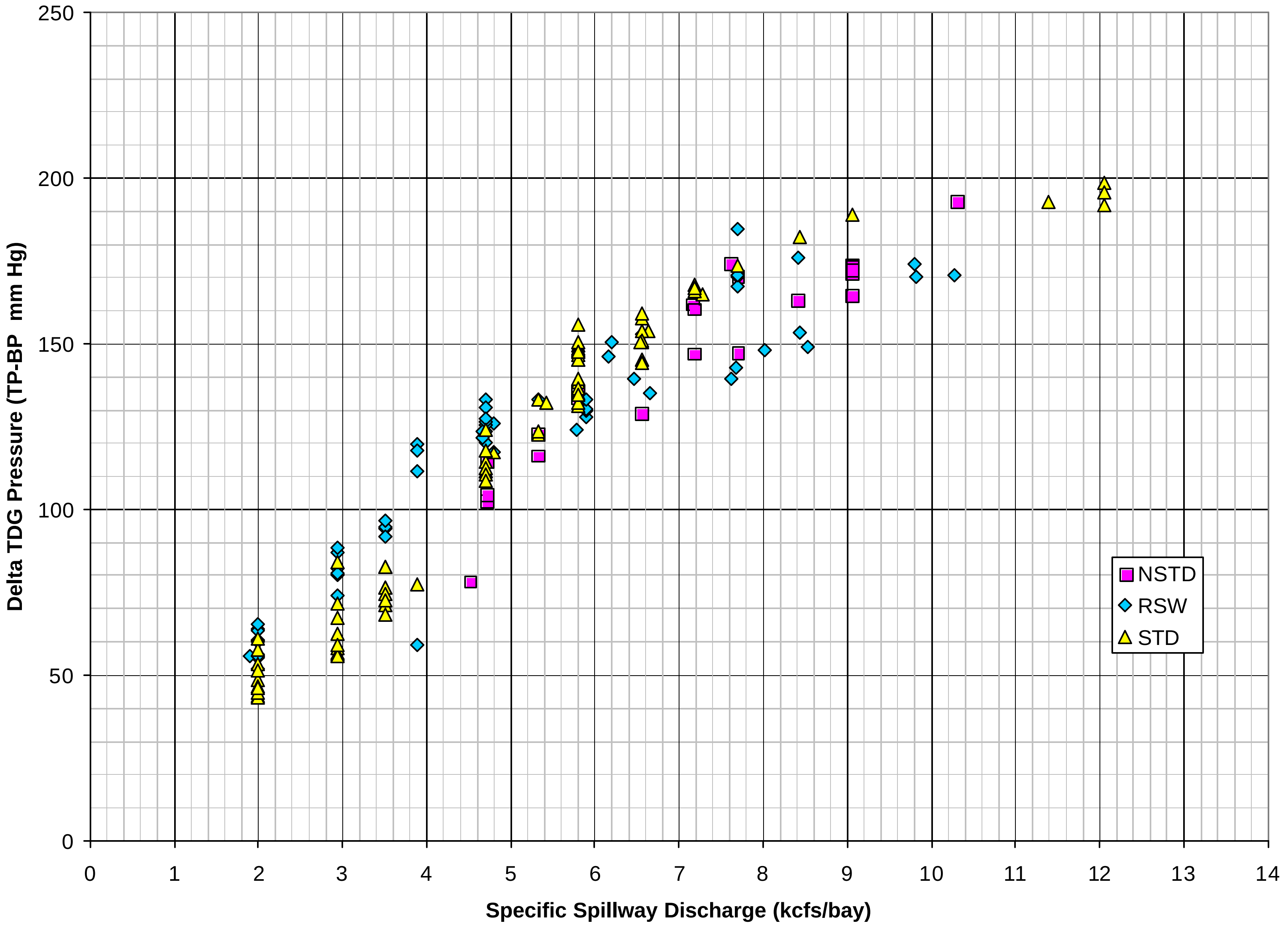

Figure 31. Event averaged delta TDG pressure on Transect T1 as a function of specific spillway discharge (bays 6-8) below Lower Granite Dam

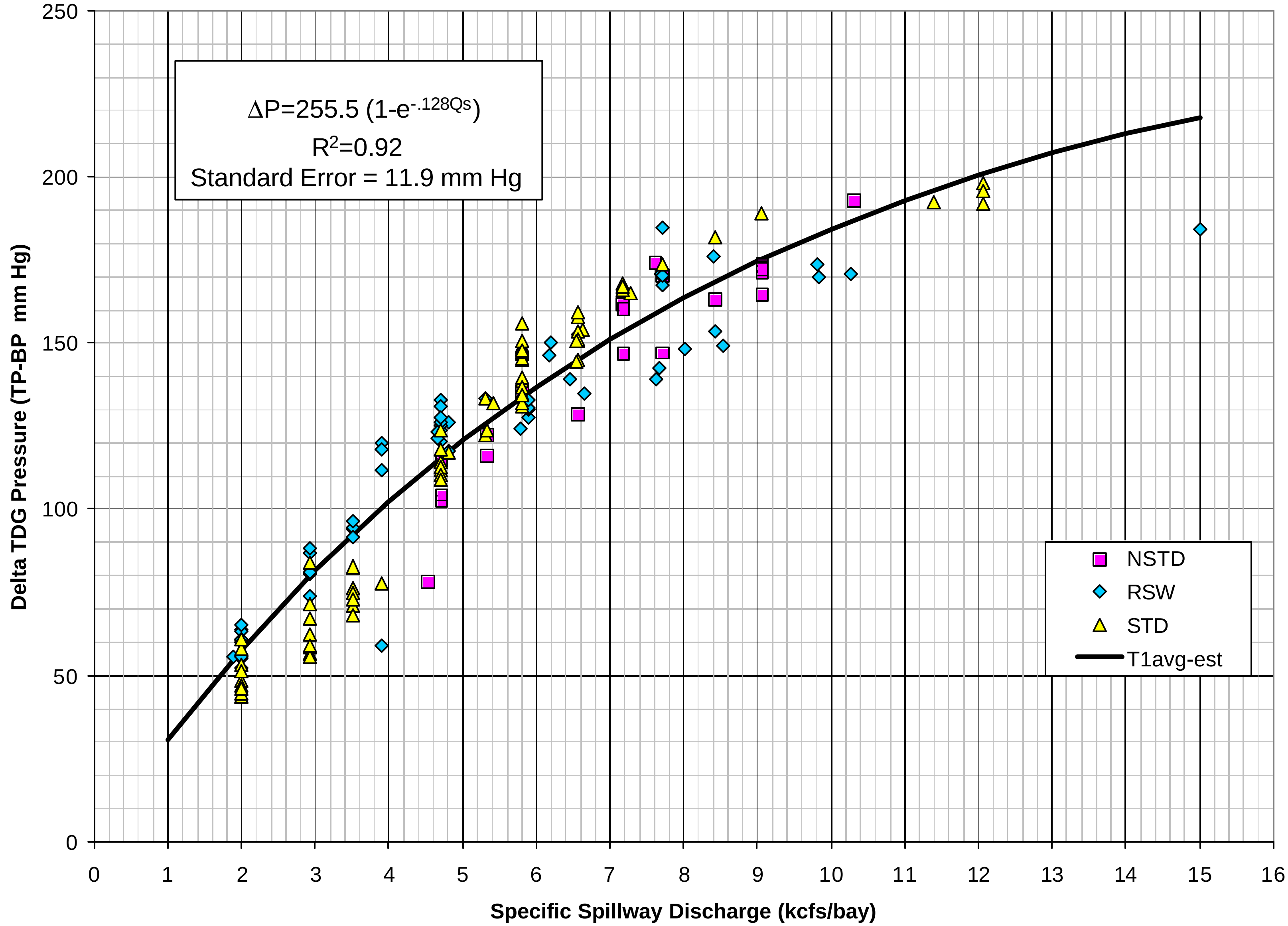

Figure 32. Observed and calculated event averaged delta TDG pressure on Transect T1 as a function of specific spillway discharge (bays 6-8) below Lower Granite Dam

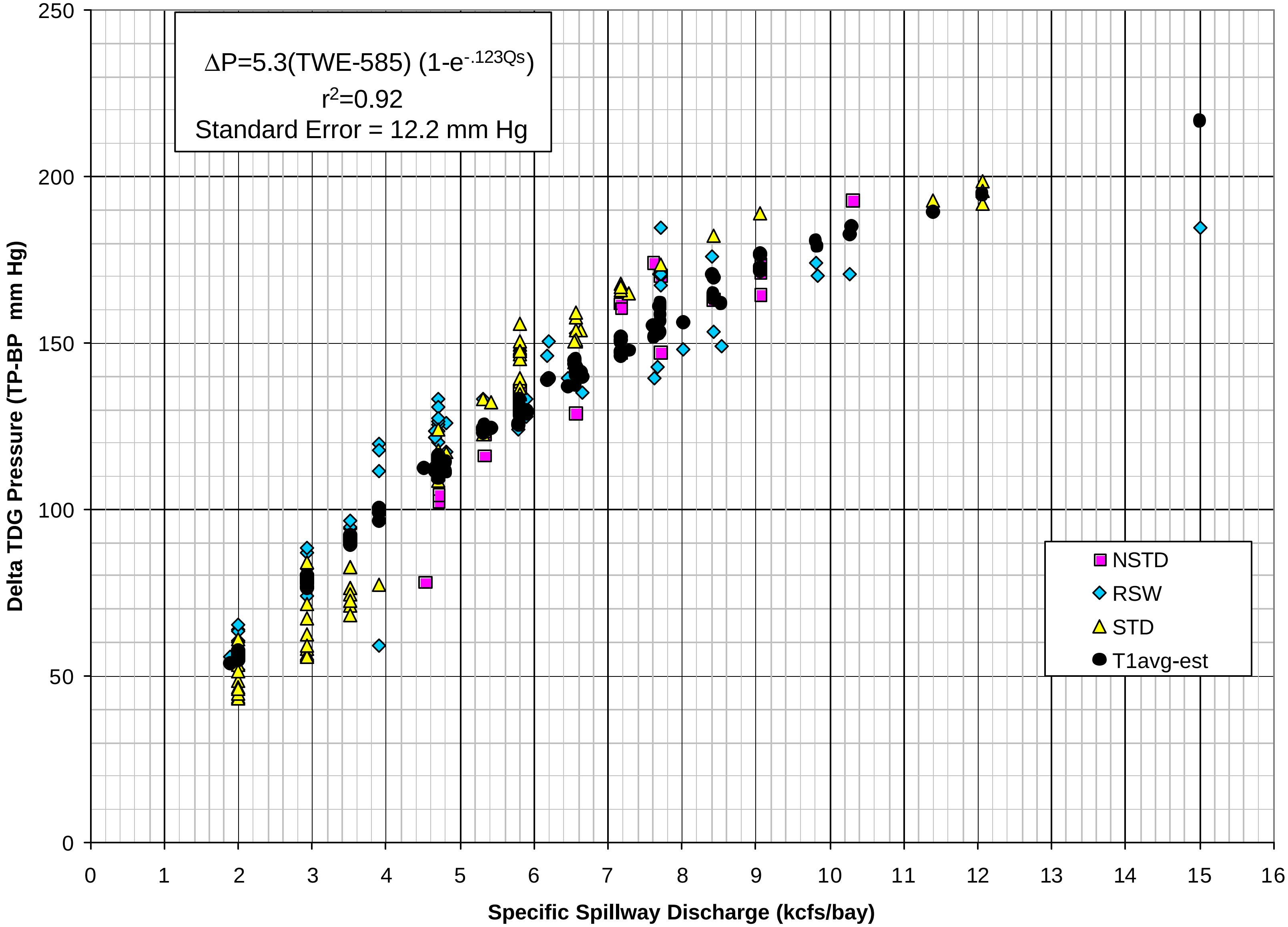

Figure 33. Observed and calculated event averaged delta TDG pressure on Transect T1 as a function of specific spillway discharge (bays 6-8) and tailwater elevation below Lower Granite Dam

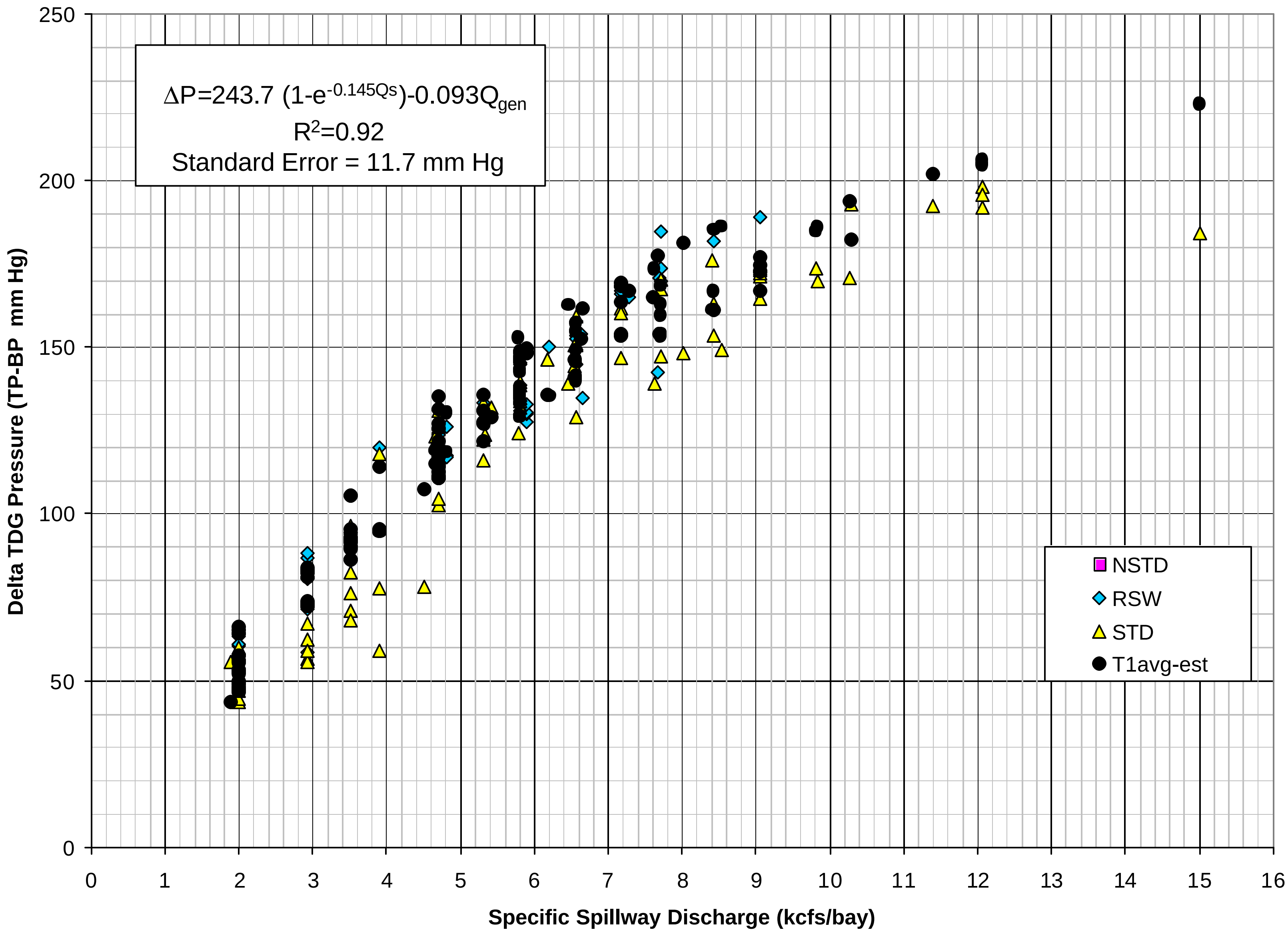

Figure 34. Observed and calculated event averaged delta TDG pressure on Transect T1 as a function of specific spillway discharge (bays 6-8) and powerhouse flow below Lower Granite Dam

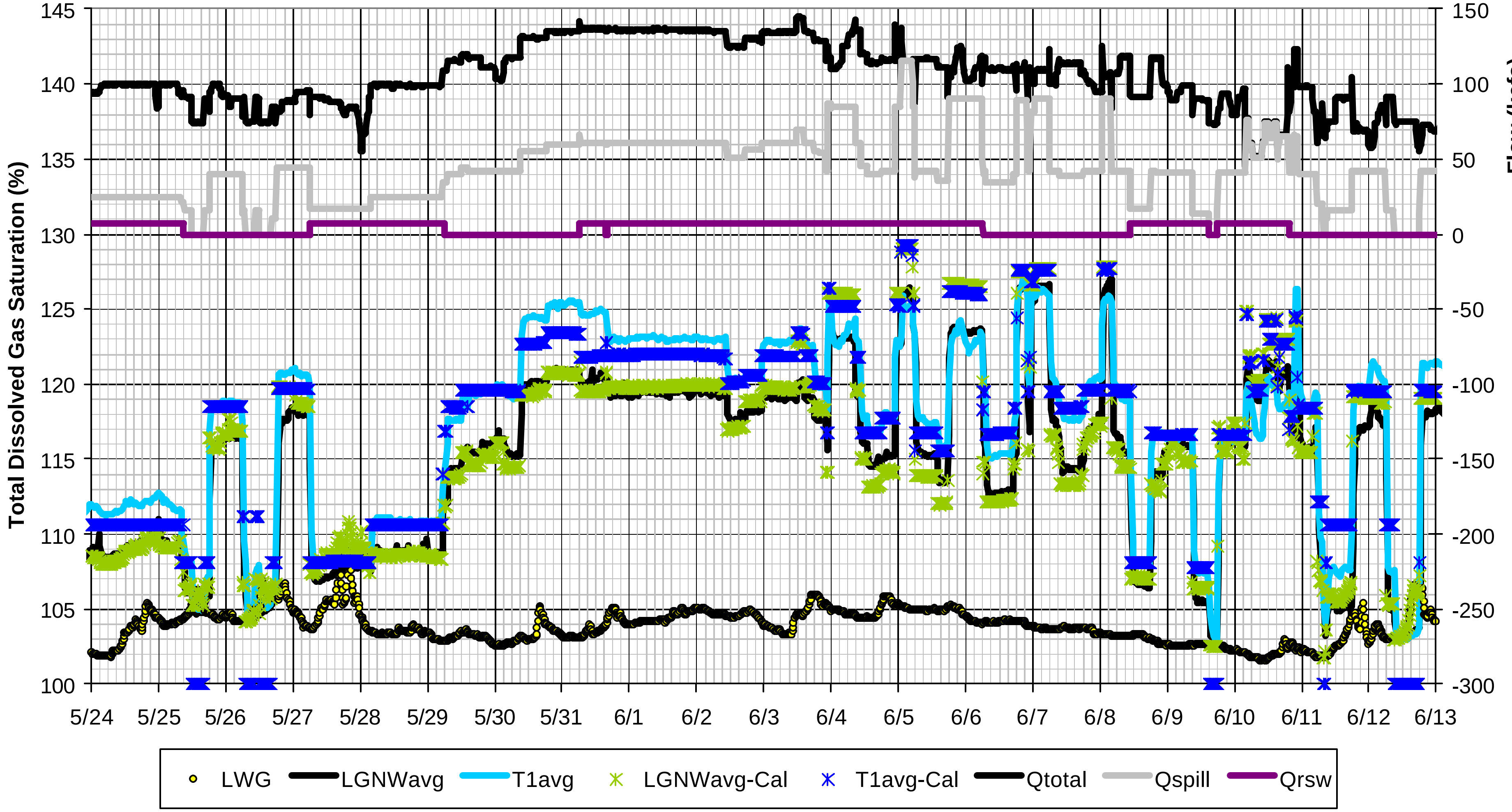

Figure 35. Calculated and observed TDG saturation below Lower Granite Dam, May 24-June 13, 2002
(T1avg = spillway flows and LGNW= average cross-sectional)