TOTAL DISSOLVED GAS FOREBAY FIXED MONITORING STATION REVIEW AND EVALUATION FOR LOWER SNAKE RIVER PROJECTS AND MCNARY DAM, 2003-2004

(BI-OP MEASURE 132)

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Executive Summary

Action 132 of the 2000 Biological Opinion requests that a systematic review and evaluation be conducted of the total dissolved gas (TDG) fixed monitoring system (FMS) stations in the forebays of all the mainstem Columbia and Snake River dams. This report will make recommendations on improvements to the monitoring system regarding relocation and/or repositioning of the stations, as warranted to meet design purposes. This study was conducted during the 2003 and 2004 fish-spill season at McNary Dam and the four Lower Snake River projects - Ice Harbor Dam, Lower Monumental Dam, Little Goose Dam, and Lower Granite Dam. The study's objectives were to evaluate the general representativeness of the six forebay TDG fixed monitors, two at McNary and one at each of the other four projects. In addition, alternative monitor locations were evaluated and compared to the existing FMS stations. The study included four alternative station positions during 2003 and was narrowed down to one alternative station during the 2004 effort. During the 2003 sampling, one alternative station was positioned near to, but deeper than, the existing FMS station (10-m versus 5-m depth). Additional alternative sites included the upstream navigation lock guide wall, the project releases on the draft tube deck, and suspended from buoys upstream of the projects. Of the sites tested during 2003, the upstream navigation lock guide wall location was selected for further testing in 2004.

All of the project forebay FMS stations were problematic in that each experienced thermally induced TDG pressure spikes during the test periods. Some stations experienced spikes exceeding 5% saturation fluctuation on a daily basis. This phenomenon was due to near field hydrodynamics coupled with vertical thermal gradients in the water column. The monitors located on or near the upstream face of the powerhouse can be impacted by down welling of the warm surface waters, resulting in the ambiguous and non-representative spiking of the TDG. The more significant occurrences were identified in the forebays of McNary (Oregon side) and Lower Granite Dams. The Ice Harbor and Lower Monumental sites resulted in the highest percent of exceedance days of the waivered TDG water quality standard for the study period during 2003. However, the McNary produced the highest exceedances during 2004 probably due to the higher spill record for Ice Harbor Dam during that year than at the other Lower Snake River projects. The data suggests that the fixed monitor instruments can often report TDG values that are not representative of the forebay waters and may not meet the requirements or purpose for the water quality station as described in the introduction.

The primary recommendations for improving the forebay FMS operation and representativeness are twofold. The first recommendation is to permanently relocate each instrument to an area just upstream of the project in a location not affected by down welling surface waters. In general the upstream tip of the navigation lock guide wall, which does not impact flows near the instrument, meets this criterion. Note that the Lower Granite FMS station is already positioned on the upstream navigation lock guide wall. The second recommendation is to position each instrument at a depth of 12-15 m. This should be adequate to avoid most thermal responses in the TDG pressure readings

brought about by a general deepening of the warm surface layer. The water temperature for the selected depth strata should approximate the average water column.

The recommendations from this study are consistent across all stations and should result in minor impacts on future operation. They will result in more representative data that should improve uses such as project management for TDG as well as water quality compliance evaluations. These changes will improve the stations' ability to achieve all design purposes mentioned in the introduction of this report.

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TDG Forebay Fixed Monitoring Station Review and Evaluation for Lower Snake River Projects and McNary Dam

Introduction

The U. S. Army Corps of Engineers (COE) operates several hydropower projects as part of the water resources infrastructure in the Columbia River Basin. These dams, reservoirs and associated modifications to the water resources in the basin impact aquatic habitat and fisheries resources across the entire basin. Of particular concern is hyper-aeration of the water flowing through the dam spillways, which can lead to gas bubble trauma in fish and other biota (USACE 2002 Volumes I and II). Extensive water quality monitoring conducted to better understand the fundamental nature of dissolved gas loading and dynamics as a function of hydropower system operation has been ongoing since 1984 by the COE.

The management of Columbia and Snake River total dissolved gas pressures associated with project operation relies upon information from the fixed water quality monitoring system. However, management is often unevenly applied at Corps of Engineer mainstem dams. The monitor measures are usually discrete in time and space (normally on hour intervals) but are at only one depth and lateral location. These monitors can be non-representative of water quality conditions due to spatial and temporal gradients in quality conditions and near-project hydrodynamic phenomenon.

In general, the water quality fixed monitoring stations, which measure and report TDG, water temperature, barometric pressure, and instrument depth, are designed for the following purposes.

- To provide river operations and fisheries managers with assimilated and relevant information needed to control dissolved gas supersaturation in the river system on a real-time basis
- To determine how project releases affect downstream water quality and aquatic habitat relative to Endangered Species Act (ESA) Biological Opinion measures and Clean Water Act (CWA) related state and tribal dissolved gas and water temperature standards
- To identify long-term changes in basin-wide dissolved gas saturation levels and water temperatures resulting from water management decisions (structural and operational) and/or natural processes (*i.e.*, trend monitoring)
- To provide data of known quality to enhance the analytical and predictive capability of existing models/tools used to evaluate management objectives

Since 1994, two different types of stations, forebay and tailwater, have been used to achieve the system purposes, often with inconsistencies. The forebay instruments are located downstream of the dams and generally in the forebay of the receiving pool project. The downstream distance varies from approximately 24 to 75 miles for the Lower Columbia River stations and between 30 and 40 miles for the Lower Snake River

stations. The project forebay TDG monitors are intended to represent a mixed cross section in the river just upstream of the dam and provide a fair approximation of aquatic habitat as defined by TDG and water temperature in that area of the pool. This information is often applied to spill management practices for the upstream project, as well as water quality compliance monitoring. The tailwater instruments are located nearer to the project, often in spillway releases downstream of aerated flow, and prior to complete mixing with powerhouse releases. These distances range from 0.5 to 6 miles for the eight projects on the Lower Columbia and Lower Snake rivers. The tailwater location will often capture spill water average-to-peak TDG concentration.

Action 132 of the 2000 Biological Opinion (NOAA 2000) states: "The action agencies shall develop a plan to conduct a systematic review and evaluation of the TDG fixed monitoring stations in the forebays of all the mainstem Columbia and Snake River dams (including the Camas/Washougal monitor). The evaluation plan shall be developed by February 2001 and included as part of the first annual water quality improvement plan. The Action Agencies shall conduct the evaluation and make changes in the location of fixed monitoring sites, as warranted, and in coordination with the Water Quality Team. It should be possible to make some modifications by the start of the 2001 spill season."

The McNary Dam and the four Lower Snake River project forebay fixed monitor readings are often characterized by apparent thermally induced spikes in TDG pressures as presented in Figures 1-6. These thermal spikes result from apparent daily cycles in near-field hydrodynamics associated with generator unit operation which induces warm surface water down welling and may be coupled with significant vertical thermal gradients in the water column. This phenomenon can introduce considerable daily variability in the reported forebay TDG pressures and hence TDG management practices as related to upstream project operation and water quality compliance evaluations. Plus, these thermal spikes create a non-representative record of river water temperatures. The more extreme thermal-related TDG spikes are shown in Figures 1, 2, 3, and 6 for McNary (Oregon side), McNary (Washington side), Ice Harbor, and Lower Granite forebay measures. The largest pressure spikes of 5-6% saturation (35-40 mm Hg) occurred routinely in the McNary forebay at station MCQO during 2003. This phenomenon occurred only rarely at Lower Monumental and Little Goose Dams. Similar characteristics were observed from the 2004 data.

Study Design

A multi-year plan to conduct a review and evaluation of the COE forebay FMS stations within the Walla Walla District was initiated in 2003 and completed during 2004. Locations included one site at each of the Lower Snake River dams - Lower Granite, Little Goose, Lower Monumental, Ice Harbor and two forebay monitors at McNary dam. The primary objective was to determine the representativeness of the existing and potential alternative FMS station locations to that of the forebay water conditions for the projects of interest. These station locations must be capable of achieving the purposes as

outlined in the introduction for the forebay FMS. Recommendations were made on alternative locations that will provide significant improvements to meet the FMS purposes. The following tasks were conducted during the multi-year plan.

1. Review and analysis of existing data from the forebay fixed monitors for representativeness and anomalies in TDG and temperature
2. Evaluation and comparison of auxiliary sites at each project for performance and representativeness during 2003. Candidate sites were:
    a. One site in the powerhouse release located on the after deck or draft tube deck for each project,
    b. One site located approximately 1,000 to 2,500-ft upstream of each powerhouse and in the deepest part of the river cross-section for each project,
    c. One site adjacent to the current fixed monitor in the forebay of each project but at an alternate depth, and
    d. One site on the upstream end of the navigation lock guide wall for each project, when available.
3. During 2004, evaluation and comparison of auxiliary sites were as follows:
    a. One site on the upstream end of the navigation lock guide wall for each of the five projects, and
    b. One additional station located on the upstream boats restricted zone line (BRZ) buoy B on the south side of the McNary Dam forebay (to compare to the Oregon side FMS, MCQO).

Tasks 2 and 3 required the investigation, planning, and placement of self-contained automated logging water quality instruments at each location. These instruments were operated intermittently during the period from May to August during 2003 and 2004. Measurements for TDG, water temperature, barometric pressure and depth were taken on 15-minute intervals for the duration of the field study. Sixteen auxiliary instruments were needed for completion of the study. Calibration and maintenance of the equipment was conducted on a 2-4 week interval using regionally accepted methods (USCE, 2002, Volume II).

Additional data utilized in this study include project operations and FMS data taken from the COE Columbia River Operational Hydromet Management System (CROHMS) database:

http://www.nwd-wc.usace.army.mil/tmt/wcd/tdg/months.html.

Thermal profile data for each project was taken from the "Lower Snake River Temperature/Water Quality Studies 2002-2003" (CENWW 2003, McKenzie *et. al*. 2004). The project operations data included total discharge, spill discharge, and pool elevation recorded on 1-hour intervals. The FMS station data included station location, TDG, water temperature, and depth collected on hourly intervals and then stored on the COE CROHMS database. Temperature profiles were collected on 15-minute intervals using remote automated logging instruments spaced at appropriate depth intervals throughout the water column in the deepest part of the forebay cross-section of each project.

The alternate sampling station locations varied at each project. Figures 7-10 depict the sampling sites by project. These diagrams include both the added research sites as well as the existing FMS stations. During the 2003 testing, the alternate stations were at 10-m depth except for the draft tube instruments, which were at 5 m. The alternate station sampling depth was 15 m during 2004. McNary Dam sample stations are presented in Figure 7. In addition to the FMS stations at MCPW, MCQO, and MCQW, there were two TDG logging instruments, MCNFBFMSP1 and MCNFBFMSP2, located adjacent to the MCQO and MCQW respectively during 2003. The 2004 sampling added the station MCNFBNL. Station MCNFBBRZP1 was located approximately 700-m upstream of the southern end of the powerhouse suspended from a Boats Restricted Zone (BRZ) buoy on the Oregon side of the river. Station MCNFBBRZP2, located 700-m upstream of the northern end of the project, was only profiling and logging water temperature and not TDG. The draft tube deck instrument (MCNDTD) was located between units 5 and 6 releases at 5-m deep. Station MCNFBNL was located on the end of the navigation lock forebay wing wall 450-m upstream of the north end of the spillway structure.

The alternate TDG sampling station locations for Ice Harbor Dam are depicted in Figure 8. Station IHRFBFMS was located on the powerhouse upper deck adjacent to IHR. Station IHRFBNL (thermal profile only) was located on the end of the navigation lock forebay wing wall 180-m upstream of the northern end of the spillway structure. Station IHRFBBRZ was suspended from a BRZ buoy 700-m upstream of the powerhouse. The IHRDTD station was positioned at the middle of the draft tube deck.

The alternate TDG sampling station locations for Lower Monumental Dam are depicted in Figure 9. Station LMNFBFMS was located on the powerhouse upper deck adjacent to LMN. Station LMNFBNL was located 225-m upstream of the structure on the end of the navigation lock guide wall. Station LMNFBBRZ was located on a BRZ buoy 530-m upstream of the spillway. LMNDTD was positioned in the middle of the draft tube deck.

The alternate sampling station locations for Little Goose Dam are depicted in Figure 10. Station LGSFBFMS was located on the powerhouse upper deck adjacent to LGS. Station LGSFBNL was 125-m upstream of the powerhouse on the end of the navigation lock guide wall. Station LGSFBBRZ was positioned 560-m upstream of the middle of the powerhouse on a BRZ buoy. LGSDTD was positioned in the middle of the draft tube deck.

Figure 11 depicts the alternate TDG sampling station locations for Lower Granite Dam. Station LWGFBNL was positioned adjacent to the forebay routine monitor, LWG, on the end of the navigation lock guide wall. Station LWGFBBRZ was positioned 740-m upstream of the project and suspended from a BRZ buoy. LWGDTD was positioned in the middle of the draft tube deck.

Study Results

The study results are presented by project in the following sections of this report.

McNary Dam. Water temperature as monitored at the alternative TDG monitor stations during 2003 is depicted in Figure 12. The McNary forebay temperature ranged from 10 °C in early May to 20-24 °C by July. Two stations, MCNDTD and MCNFBRZP1, had only a slight diel trend on the order of 0.1-0.2 °C as contrasted to the 2-4 °C spikes for the other two alternative stations, as well as for the forebay monitors shown in Figures 1 and 2. Figure 13 depicts the thermal profile from surface to bottom for the McNary forebay as measured at MCNFBRZP2 during 2003. Surface warming is shown to intermittently extend down to between 5 and 10 meters deep in this area. During the 2004 sampling period, daily spikes of 4-6 °C occurred regularly at the MCQO FMS whereas minimal daily cycling occurred at the BRZ station MCNFBBRZP1 (Figure 14). The relationship was similar on the northern end of the project with daily swings of 2-3 °C occurring at MCQW, but relatively flat responses noted for the navigation lock wall station MCNFBNL (Figure 15). The temperatures across the entire forebay ranged from 11 °C to 22-26 °C during the 2004 sampling period.

The McNary Dam forebay TDG time history plots for the alternative sampling station data as compared to the established forebay station data is presented in Figures 16 through 21. The TDG saturation ranged from 105% up to 122% across most of the stations. As with the temperature patterns, the FMS station MCQO had the most extreme fluctuations with daily TDG spikes as high as 124 % during 2004 (Figure 18). The MCNDTD and MCNFBBRZP1 data, Figures 16 and 17, tracked consistently with the lower TDG pressures for the forebay monitors, MCQO and MCQW. The routine fixed monitor data for both MCQO and MCQW are characterized by wide diel fluctuations in TDG, 5-8 percent saturation, during 2003, whereas the draft tube instrument, MCNDTD, and the upstream BRZ instrument showed much smaller daily fluctuation on the order of 1-2% saturation. Time histories for MCNFBFMSP1 and MCNFBFMSP2, Figures 19 and 21 respectively, followed the corresponding FMS TDG closely and were similarly characterized by the wide diel fluctuations in pressure (2- 5% saturation), indicating that lowering the TDG instruments to 10 m did not remove the diel variability due to water temperature variability. The station MCNFBNL positioned further out from the structure and at 15-m deep during 2004 was characterized by considerably dampened daily TDG spikes (Figure 20).

Ice Harbor Dam. Water temperatures as recorded at the alternative TDG monitor stations during 2003 and 2004 are depicted in Figures 22 and 23, respectively. The Ice Harbor forebay temperature varied from 10 °C in late April up to 17 °C in late June during 2003, and ranged from 8.5 °C to 23 °C by late July during 2004. Diel cycles were

limited to 1 °C for the alternative TDG monitors versus the 2-3 °C apparent for the IHR forebay fixed monitor for both years. Figure 24 depicts the thermal profile from surface to bottom for the Ice Harbor Dam forebay as measured at IHRFBNL during 2003. Surface warming is shown to extend intermittently to a depth of 3 to 5 m deep in this area. The diel variability at the 5 m depth was generally less than 1 °C.

The Ice Harbor Dam forebay TDG time history plots for the alternative sampling station data as compared to the established forebay station IHR is presented in Figures 25 through 29. The TDG concentration ranged from 107% up to 124% of saturation across all stations during 2003. The IHRDTD TDG data was characterized by frequent decreases in concentrations as seen in Figure 25. The IHRFBFMS, IHRFBNL, and IHRFBBRZ data shown in Figures 26, 27, and 28, respectively, tracked consistently with the lower TDG pressures for the forebay monitor IHR and demonstrated only minor diel fluctuations in concentration for the 2003 sampling period. Figure 29 depicts a similar trend for IHRFBNL TDG saturations during 2004, but the range was limited to a maximum of 118%. The FMS IHR data is characterized by thermally induced pressure diel variation resulting in wide diel fluctuations of 5-6 percent saturation in TDG for both years.

Lower Monumental Dam. The Lower Monumental forebay FMS and alternative TDG monitoring stations' water temperature data time histories are depicted in Figures 30 and 31. The forebay temperature varied from 10 °C in late April to 18 °C by late June in 2003, but increased to 22 °C by early August 2004. Diel cycles were limited to less than 0.5 °C for stations LMNDTD, LMNFBBRZ, and LMNFBNL versus a 2 °C swing noted for both the fixed monitor, LMN, and the LMNFBFMS station during both 2003 and 2004. Figure 32 depicts the thermal profile from surface to bottom for the Lower Monumental Dam forebay. Surface warming is shown to extend intermittently to a depth of 3 to 5 m in this area. The diel variability at the 5 m depth was generally less than 1 °C.

The Lower Monumental forebay TDG time history plots for the alternative sampling data as compared to the forebay fixed monitor LMN are presented in Figures 33 through 37. The TDG saturation ranged from approximately 105% up to a high of 129% during the 2003 spill season across all stations. The diel variations noted at LMN were most likely due to the Little Goose project operation day/night daily spill cycles. The daily cycles due to upstream operation were also well represented by the alternative monitors. However, there were four temperature spikes with associated TDG spikes of 2% saturation present on June 4th through June 7th. These thermal spikes were minimal for all of the alternative monitors. The alternative monitor TDG data were consistent with the lower baseline TDG pressures for the LMN fixed monitor data on days where thermal spikes were apparent. The 2004 sampling period extended well beyond the spill season for the upstream project but still demonstrated frequent daily TDG spikes greater than 5% saturation attributable to the solar warming cycles (Figure 37).

Little Goose Dam. The Little Goose forebay water temperature time histories are depicted in Figures 38 and 39. These water temperatures varied from 10 °C in late April to near 18 °C by late June for 2003. The 2004 data showed increases up to 22-24 °C by

mid-July. Diel temperature cycles were limited to less than 1 °C for stations LGSDTD, LGSFBFMS, LGSFBBRZ, and LGSFBNL versus the 2-3 °C swings noted for the forebay fixed monitor, LGS, during 2003. For 2004, LGS showed daily spikes as much as 4 °C. Figure 40 depicts the thermal profile from surface to bottom for the Little Goose Dam forebay. As at Ice Harbor and Lower Monumental Dam, the surface warming is shown to extend intermittently to a depth of 3 to 5 m in this area. The diel variability at the 5-m depth was generally less than 1 °C.

The Little Goose forebay TDG time history plots for the alternative sampling station data as compared to the forebay fixed monitor, LGS, is presented in Figures 41 through 45. The TDG saturation ranged from approximately 100 % up to a high of 127% during the 2003 spill season across all stations. As was reported for Lower Monumental Dam, there were a limited number of thermal spikes resulting in noticeable TDG spikes of 3-4% at the LGS fixed monitor during early June. Both LGSFBFMS and LGSFBBRZ TDG data tracked well with the LGS station, differing only on the days when significant thermal spikes occurred during early June. The LGSFBNL pressure data for TDG was consistent with the lower baseline TDG pressures for LGS throughout the sample period and showed minimal daily cycling. Station LGSDTD was characterized by frequent increases of 3-5% pressure TDG saturation, likely due to noticeable entrainment of spill waters into the powerhouse releases downstream of the draft tube deck for this project during 2003. As for Lower Monumental, the 2004 sampling period for Little Goose extended well beyond the spill season for the upstream project but continued to demonstrate frequent daily TDG spikes greater than 5% saturation attributable to the solar warming cycles (Figure 45).

Lower Granite Dam. The Lower Granite forebay water temperature time histories are depicted in Figures 46, 47, and 48. These water temperatures varied from 9 °C in late April to near 18 °C by late June in 2003 and increased to 20-22 °C by late July of 2004. Diel temperature cycles were limited to less than 0.5 °C for stations LWGDTD, LWGFBNL, and LGSFBBRZP2 versus the 2-3 °C swings noted for the forebay fixed monitor, LWG. The forebay thermal profile time history for Lower Granite Dam is shown in Figure 48. Of the projects included in this review, Lower Granite pool displayed the largest vertical thermal gradient. This vertical difference is likely due to the cold bottom waters from the Clearwater River and not from any increased warming at the air water interface. By late June for both 2003 and 2004, the vertical temperature gradients remained with continued warming from day to day as the season progressed. The warming eventually extended down to a depth of 15 m.

The Lower Granite Dam forebay TDG time history plots for the alternative sampling station TDG data as compared to data from the established forebay station LWG are presented in Figures 49 through 52. The TDG concentration ranged from approximately 100% up to 110% across all stations during 2003. The navigation lock wall instrument LWGFBNL seldom exceeded 105 % saturation TDG during 2004. The LWGDTD TDG data was characterized by frequent increases in concentration of 5-10% as seen in Figure 38. As was seen at Little Goose, these excursions were likely due to

spill jet entrainment into the powerhouse releases as measured by the draft tube instrument. The LWGFBBRZ, LWGFBNL (2003), and LWGFBNL (2004) data shown in Figures 50, 51, and 52, respectively, tracked consistently with the lower TDG pressures for the forebay monitor LWG, and demonstrated only minor diel fluctuations in pressure. The LWG routine fixed monitor data are characterized by thermally induced pressure diel variations resulting in diel fluctuations in TDG of 3-5 percent saturation during each year.

Study Analysis

The initial 2003 data analysis and review was limited to the environmental conditions and weather associated with the April to June 2003 period. To expand the database, it was decided that an additional year of data be collected during 2004 prior to final analysis and recommendations regarding permanent relocations of stations. The 2004 sampling was limited to the navigation lock wall location and each instrument was placed deeper at 15 m rather than the 10-m depths used during 2003. The 2004 testing was continued until the August-September time period to coincide with an entire season of FMS operation. 2004 testing at McNary continued at the upstream BRZ site with the addition of a guide wall station further towards the upstream tip of the wall. The following analysis will be divided into two sections, the first for the 2003 data and the second to cover the additional 2004 data sampling

2003

A water quality compliance parameter was calculated for each fixed monitor and alternative monitor site used in the 2003 sampling. The parameter is based on the state water quality standard for TDG and the fish spill season waiver. This parameter is the average of the highest twelve hourly readings in each calendar day and is compared to the water quality waiver of 120% saturation for tailwater monitors and 115% saturation for downstream forebay monitors. Average values greater than the waiver are considered to be out of compliance. A summary of the calculated compliance parameter values are listed in Tables 1 – 5 by project. Comparisons can be made between the current FMS station and the alternative sites for each dam using only data from days common to all stations (all stations reported data for each day in the summary). However, in some cases, such as IHRFBNL in Table 2 and LGSDTD in Table 3, there were insufficient data available to make the comparison. The highest percent of days out of compliance was calculated for the forebay FMS sites at Ice Harbor (60-65%) and Lower Monumental Dams (60-65%). Little Goose and McNary Dams followed with 40-50 %. Lower Granite stations reported no exceedances for the sampling period. It was hypothesized that those stations recording more prominent daily spikes in TDG, namely the routine fixed monitors, would have the highest number of exceedances. This apparently was not the case since differences in compliance between stations were minimal at all projects for the 20 days evaluated during the test.

Statistical comparisons were completed for the calculated compliance parameter at each alternative monitor location versus the FMS at each project. This data presented in Table 6 shows the paired sample statistics, and Table 7 lists the paired sample test statistics. The two forebay fixed monitors at McNary showed no statistical difference (alpha = 0.05) in TDG values; this implies that during the April 25 thru June 18, 2003 sampling season of 55 days there were minimal differences between the northern side (MCQW) and the southern side (MCQO) in the McNary forebay. These same two stations showed little difference with the alternate monitors located 5-m deeper and adjacent to them. The McNary monitors both averaged about 1% saturation higher than the BRZ instrument and about 1.6% higher than the draft tube deck instrument. This bias or difference is likely due to the elevated pressures related to the thermal spikes at the fixed monitors.

The average concentration of TDG at all the Ice Harbor alternative forebay stations were significantly lower (approximately 0.3 – 0.5% saturation) than those recorded by the fixed monitor (IHR) for the same 55 day period. Similar differences are depicted in Table 7 for both Lower Monumental and Little Goose dams. The one exception was for LMNFBNL, which recorded a slightly higher average (0.43% saturation) than LMN.

The Lower Granite Dam forebay stations showed lower average TDG for both LWGFBBRZ and LWGFBNL by 1.0 and 0.7% saturation, respectively, than the LWG station. In the case of Lower Granite, the fixed monitor LWG is located on the upstream tip of the navigation lock guide wall and LWGFBNL was located at the same location but at 10 m rather than 5-m deep.

2004

It is worth noting again the main differences between the 2003 and 2004 sampling was the placement of the alternate station instruments and sampling duration. Each instrument was positioned on the upstream tip of each navigation lock at 15-m deep vs. the 10-m alternate depth for 2003. The sampling season was extended to near the end of August at all projects to cover periods outside of the normal fish spill seasons. The initial analysis was completed using the same compliance parameter as calculated for the 2003 data (fish spill waiver value). Since much of the sampling season was outside of normal fish spill, an additional comparison was completed between measured values to the US, Oregon, and Washington TDG water quality standard of 110% at any time for all projects, except McNary Dam. Since fish spill continued throughout the entire sampling period at Ice Harbor Dam the 2004 McNary Dam data analysis was limited to the initial comparison with the fish spill waiver parameter.

A summary of the calculated fish spill compliance parameter values are listed in Table 8 by project. Comparisons can be made between the fixed monitor station and the alternative sites for each dam using only data from days common to both stations. The highest percent of days out of compliance was calculated for the forebay FMS sites at McNary Dam. FMS station MCQO had 18.8% exceedances vs. 0 % for the alternate

station MCNFBBRZ. McNary FMS station MCQW had 13.7 % exceedances vs. 4.1% for the alternate station MCNFBNL. The FMS station IHR followed with 3.2% exceedances vs. 2.4% shown for the alternate station IHRFBNL. Little Goose and Lower Monumental Dams fixed monitoring stations had only 1.43 % and 1.31 % exceedances, respectively, vs. 0% for each of the alternate stations. As during 2003, Lower Granite stations reported no exceedances for the sampling period. The FMS, located at 5-m deep and often near the project dam face exhibited the highest average TDG saturation for each project. This relationship was more prominent with the 2004 analysis, likely due to the deeper depths of the alternate stations.

The comparisons depicted in Table 9 for the water quality standard of 110% saturation are similar in trend but have higher occurrences of exceedances, partially due to the comparisons done on hourly data rather than daily calculations. Only the Lower Snake River projects are presented in Table 9 due to the extended spill season for Ice Harbor, which in turn impacts McNary Dam. Again, the FMS TDG averages were higher than the alternate stations averages. Ice Harbor station IHR was highest with 357 exceedances for 11.74% of the total number. However, the alternate IHRFBNL was relatively similar with 333 exceedances and 10.95%. Little Goose had the second highest with 6.59% exceedances at LGS, but only 0.98% at LGSFBNL. LMN and LWG followed with 3.08% and 1.05% exceedances, respectively. The alternate stations had minimal exceedances at 0.68% and 0% for LMNFBNL and LWGFBNL, respectively. As with the TDG averages, the exceedance numbers were higher for the FMS stations than for the alternate stations.

Statistical comparisons were also completed for the calculated fish spill compliance parameter at each alternative monitor location versus the FMS for the 2004 data. This comparison is presented in Table 10, which lists the paired sample test statistics. The McNary forebay MCNFBBRZ - MCNFBNL pair was the only station pair that showed no statistical difference (alpha = 0.05) in TDG values; this implies that during the limited portion of the 2004 sampling season there were minimal differences between the northern and the southern sides of the McNary forebay. The largest difference, 3.42% TDG saturation, was found between McNary FMS MCQO and its alternate station MCNFBBRZ. All FMS stations tested were significantly higher with respect to the TDG waiver than the alternate stations. Again, this bias or difference was likely due to the elevated pressures related to the thermal spikes at the fixed monitors.

The comparisons depicted in Table 11 are based on the hourly data collected from 2004. The findings are nearly identical to the trends shown in Table 10 with all of the FMS stations averaging higher than the alternate station for each project.

Conclusions

Thermally induced pressure spikes in TDG were observed at the forebay fixed monitors for all of the Lower Snake River projects and McNary Dam during the test periods for 2003 and 2004 with some exceeding 6% saturation on a daily basis. This

phenomenon is coupled with near-field hydrodynamics (surface down-welling) coupled with vertical thermal gradients in the water columns. The more significant occurrences were identified at McNary and Lower Granite Dams. Values collected at the forebay fixed monitors also resulted in a relatively high number of exceedances of the water quality standard for TDG for the study period. The data suggests that the fixed monitor instruments can often report TDG values that are not representative of the forebay waters and are biased by down-welling surface waters. Because of this bias, these stations may not meet the requirements or purpose for the water quality station as described in the introduction.

Monitors that are located on or near the upstream face of the powerhouse can be impacted by the down-welling of the warm surface waters, resulting in the ambiguous and non-representative spiking of the TDG. This down-welling results from nearby flow patterns to turbine intakes during project generation unit operation. The spiking is associated with the daily surface warming that typically occurs in the river. Note that this will increase gas partial pressures and will decrease the solubility but does not affect the concentration of the gases. The monitors that fall into the area of potential impact are MCQO, IHR, LMN, and LGS. The alternate stations that were placed at the same locations but deeper in the water column were often equally affected by down welling of the warmer surface waters. The one exception was IHRFBFMS, which showed improvements similar to those seen at other stations away from the project face.

MCQW and LWG were both positioned upstream of the project face with no vertical walls to interfere or redirect surface flows. However, in each of these cases, significant surface warming to depth by mid to late season occurs on a routine basis. This warming routinely extends to a depth between 5 and 10 m at McNary and down to 15 m at Lower Granite forebay. This warming was sufficient to impact the monitor measures at these stations. In both cases, the deeper (10 m) alternative stations (LWGFBNL and MCNFBFMSP2) gave more representative measures for the entire water column than the fixed monitors at the 5-m depth during 2003. During 2004, the alternate stations were positioned at a 15-m depth and appeared to be better at avoiding the daily surface warming phenomenon.

The draft tube deck instruments produced mixed results in relation to the forebay fixed monitors. Both MCNDTD and LMNDTD produce rather smooth TDG time histories with little indication of thermal spikes or TDG increases associated with entrainment of spill waters. On the other hand, IHRDTD, LGSDTD, and LWGDTD all displayed somewhat erratic data likely due to contamination from spill jet entrainment.

The instruments located adjacent to the fixed monitors and at a 10-m depth on the upstream face of the powerhouse during 2003 also produced mixed results. Both MCNFBFMSP1 and MCNFBFMSP2 TDG data tracked well with the somewhat erratic MCQO and MCQW instrument data, respectively. The other FMS alternate stations produced TDG data that appeared representative with only intermittent pressure spikes related to temperature fluctuations.

Alternate TDG instruments positioned upstream of the dam face, either suspended from buoys or hanging from floating navigation lock wing walls, were consistent in being the least effected by the thermal related pressure spikes and tracked well with the baseline data from the fixed monitor stations. These stations produced lower average TDG percent saturation during the test along with fewer days of exceedances for the state water quality standard (using both the fish spill season waiver value and the water quality standard of 110%).

The alternate stations located in McNary Dam forebay, MCNFBBRZP1 and MCNFBNL gave comparable data that was minimally different for the study (0.3%) average TDG during 2004. This implies that one instrument would possibly be adequate to address the needs for this project. The alternative stations at MCNFBBRZP1 and MCNFBFMSP2 also gave comparable data for 2003.

Recommendations for Forebay Instrument Locations

The criteria to be used in the decision making regarding the FMS stations are as follows.

- The recommendations will result in more representative data that should improve uses such as project management for TDG as well as water quality compliance evaluations.
- These changes will improve each station's ability to achieve all design purposes mentioned in the introduction of this report.
- The recommendations regarding the forebay FMS station location will be consistent across all projects.
- The changes will result in minimal impact on operation and maintenance of each station if each new station can be accessed in a similar fashion as used for the existing stations.

The primary recommendation for improving the ability of the forebay fixed monitors to achieve the stated purposes is to relocate each instrument to an area just upstream of the main project. The location should not be affected by down-welling of the warmer surface waters, and should be at a depth adequate to avoid thermal responses in the TDG pressure brought about by the general deepening of the warm surface layers. The tip of the upstream navigation lock guide wall, similar to those stations used in the study, would meet these criteria for each project.

One additional recommendation is that each forebay FMS instrument should be positioned at a 15-m depth. The water temperature for the selected depth strata should approximate the average temperature of the water column. The TDG instruments are capable of functioning properly at depths of 20 to 30-m (based on past experience and manufacturer recommendations) so it should work well to position the proposed instrument at depths deeper than the previous 5-m. This would avoid most problems associated with the deepening surface layer seen at Lower Granite and McNary dams.

Recommendations by instrument location are as follows:

- Ice Harbor Dam – relocate the fixed monitor to near the upstream tip of the navigation lock guide wall at a 15 m depth
- Lower Monumental Dam – relocate the fixed monitor to near the upstream tip of the navigation lock guide wall at a 15 m depth
- Little Goose Dam – relocate the fixed monitor to near the upstream tip of the navigation lock guide wall at a 15 m depth
- Lower Granite Dam – reposition the existing instrument which is already located on the navigation lock guide wall to a depth of 15 m
- McNary Dam MCQW – relocate the existing instrument to a site near the upstream tip of the navigation lock guide wall at a 15 m depth
- McNary Dam MCQO – relocate to an upstream BRZ water quality float at a depth of 15 m, and consider the further comparisons and review with the north side FMS for future considerations such as elimination of this instrument altogether to reduce the number of stations at the McNary forebay to the one on the north side

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TDG FOREBAY FIXED MONITORING STATION REVIEW AND EVALUATION FOR LOWER SNAKE RIVER PROJECTS AND MCNARY DAM, 2003-2004

Figures

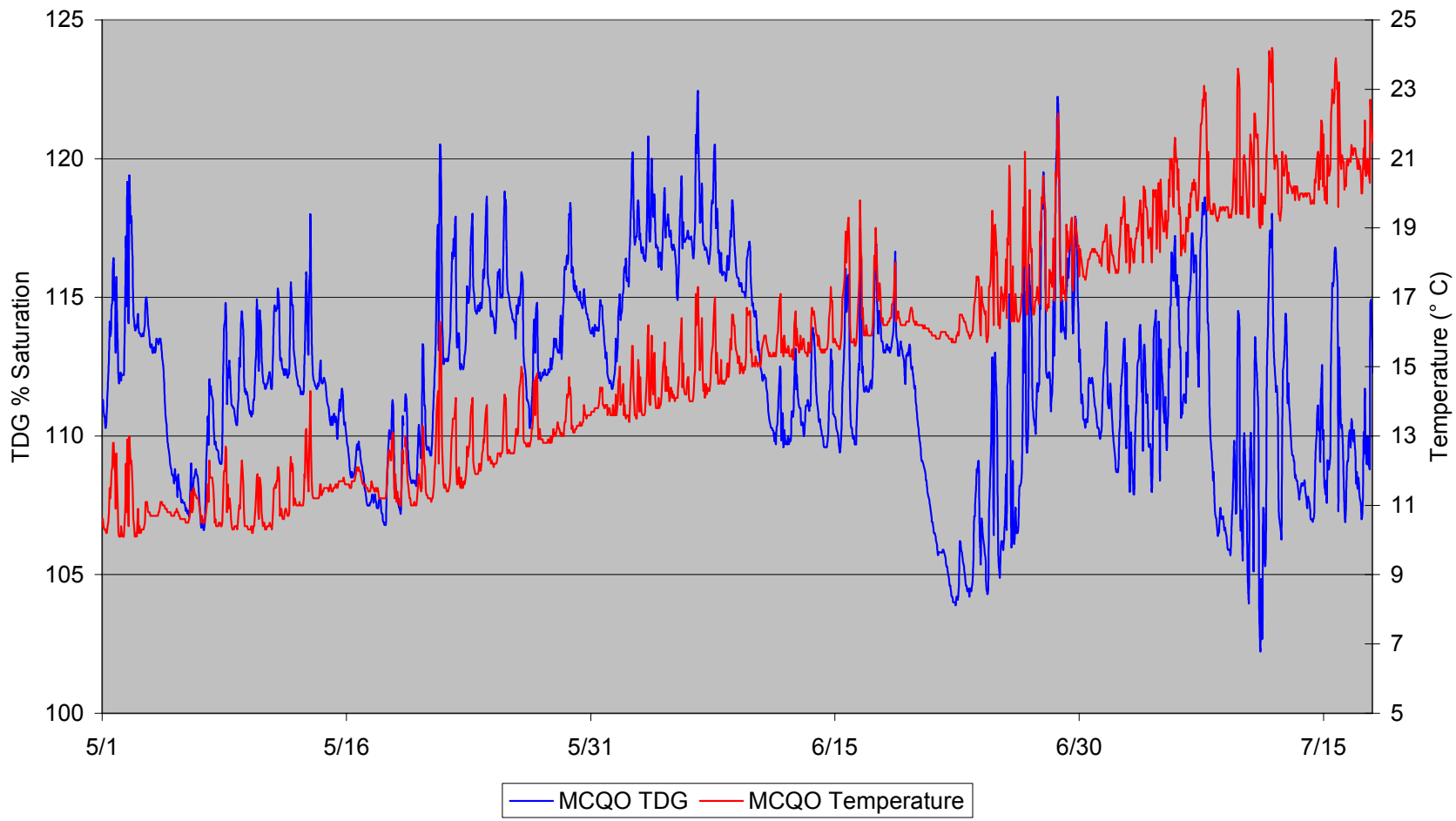


Figure 1. McNary Dam MCQO TDG and Water Temperature, 2003.

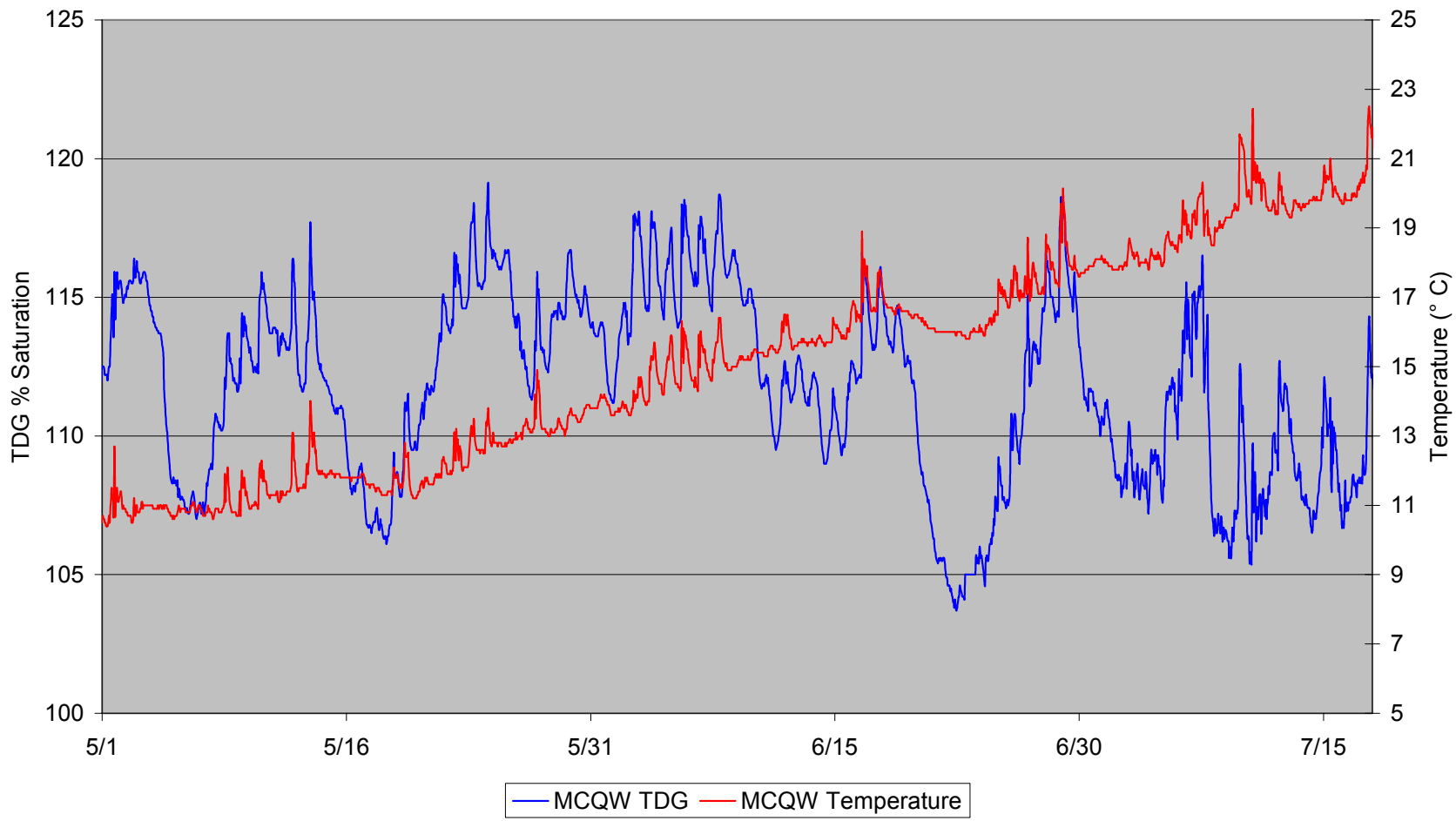


Figure 2. McNary Dam MCQW TDG and Water Temperature, 2003.

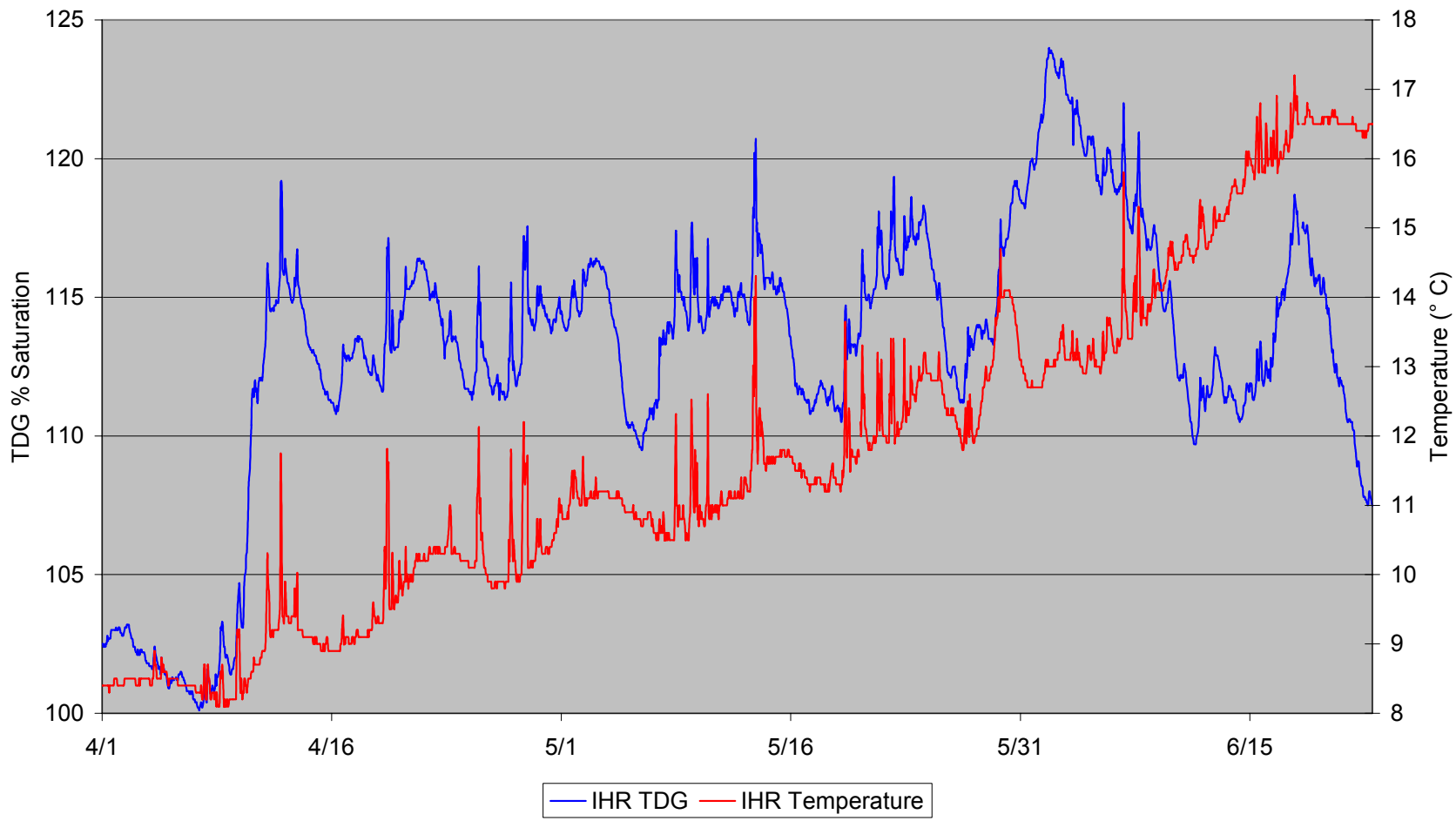


Figure 3. Ice Harbor Dam Forebay TDG and Water Temperature, 2003.

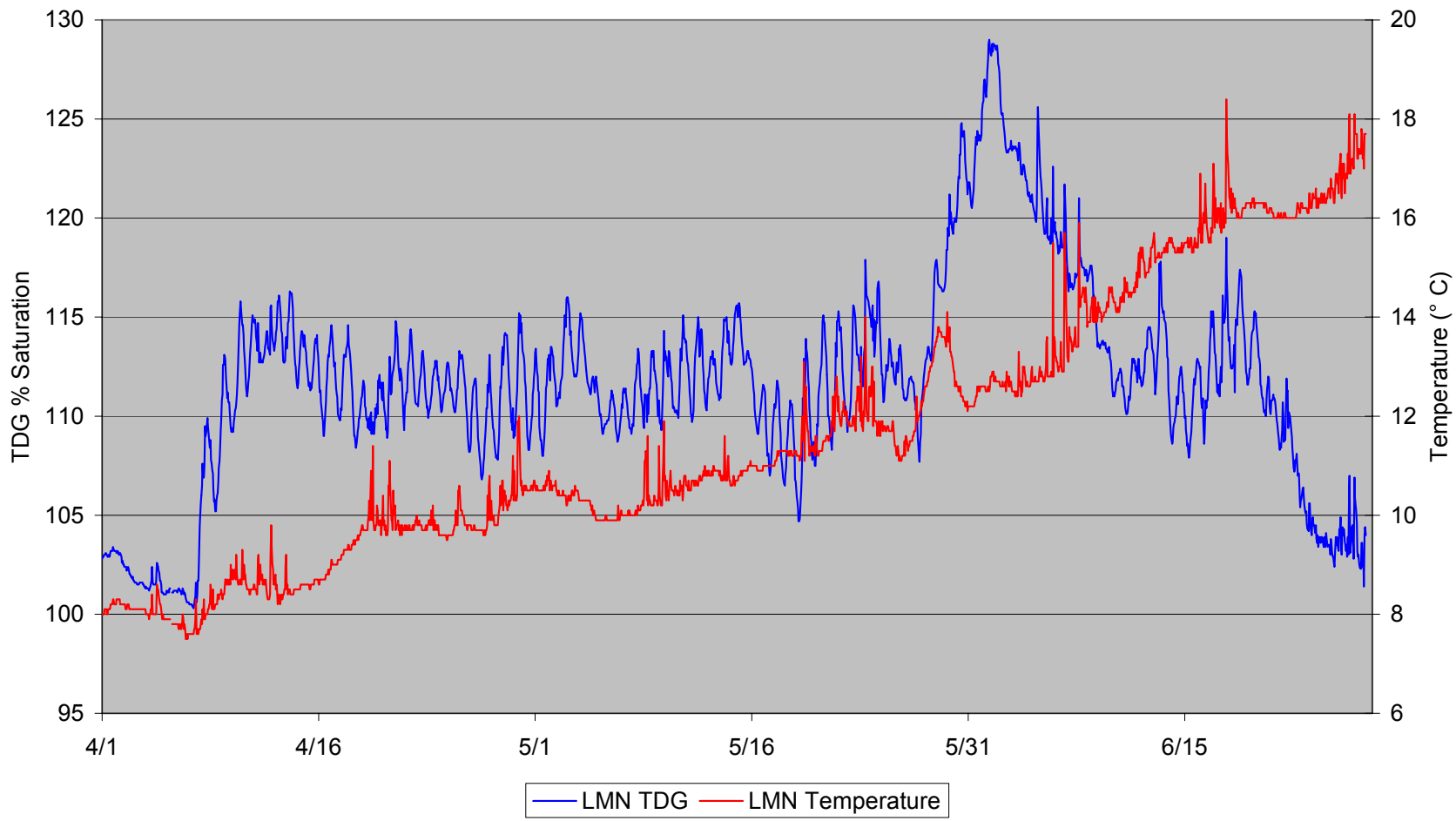


Figure 4. Lower Monumental Dam Forebay TDG and Water Temperature, 2003.

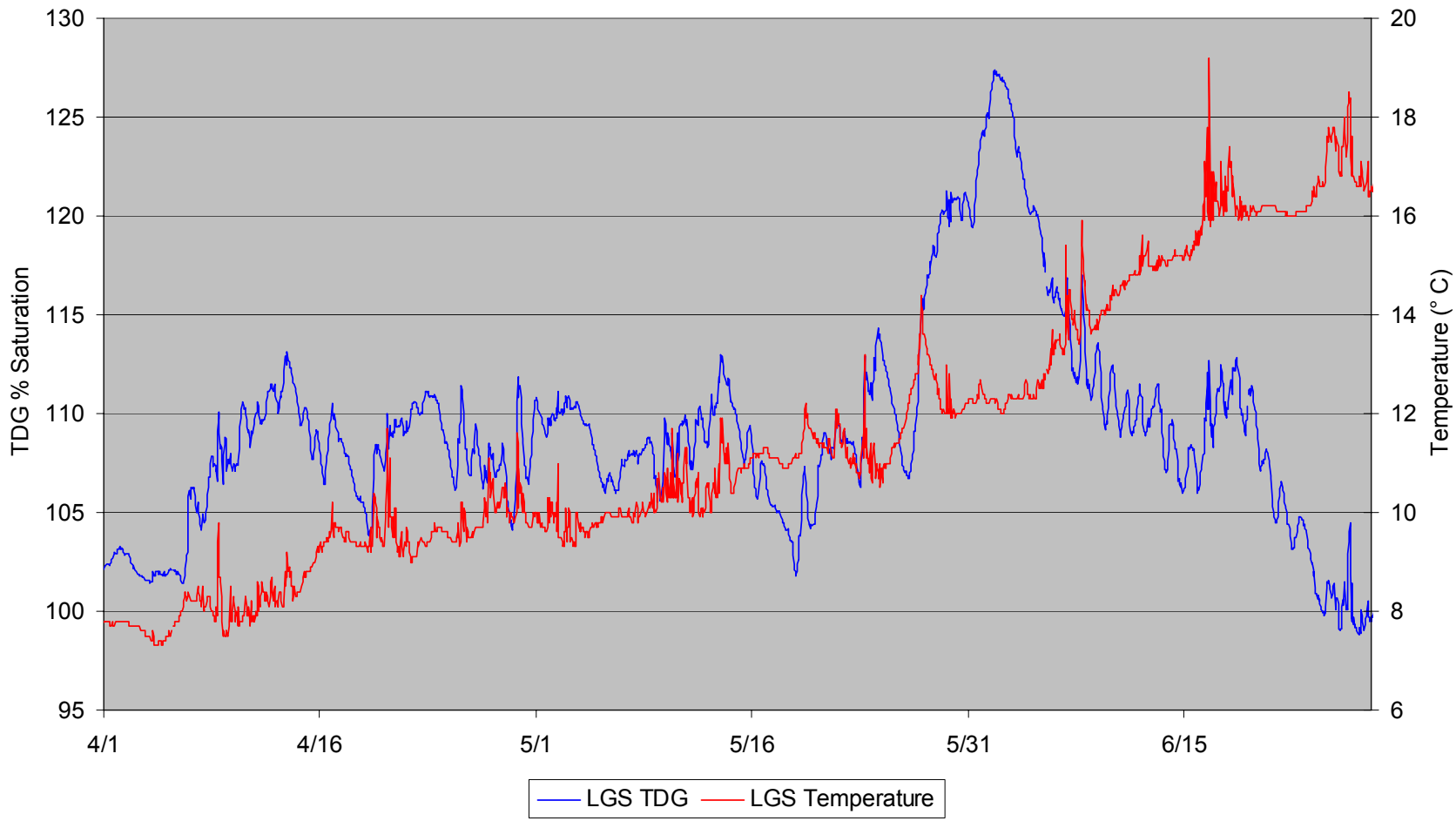


Figure 5 Little Goose Dam Forebay TDG and Water Temperature, 2003.

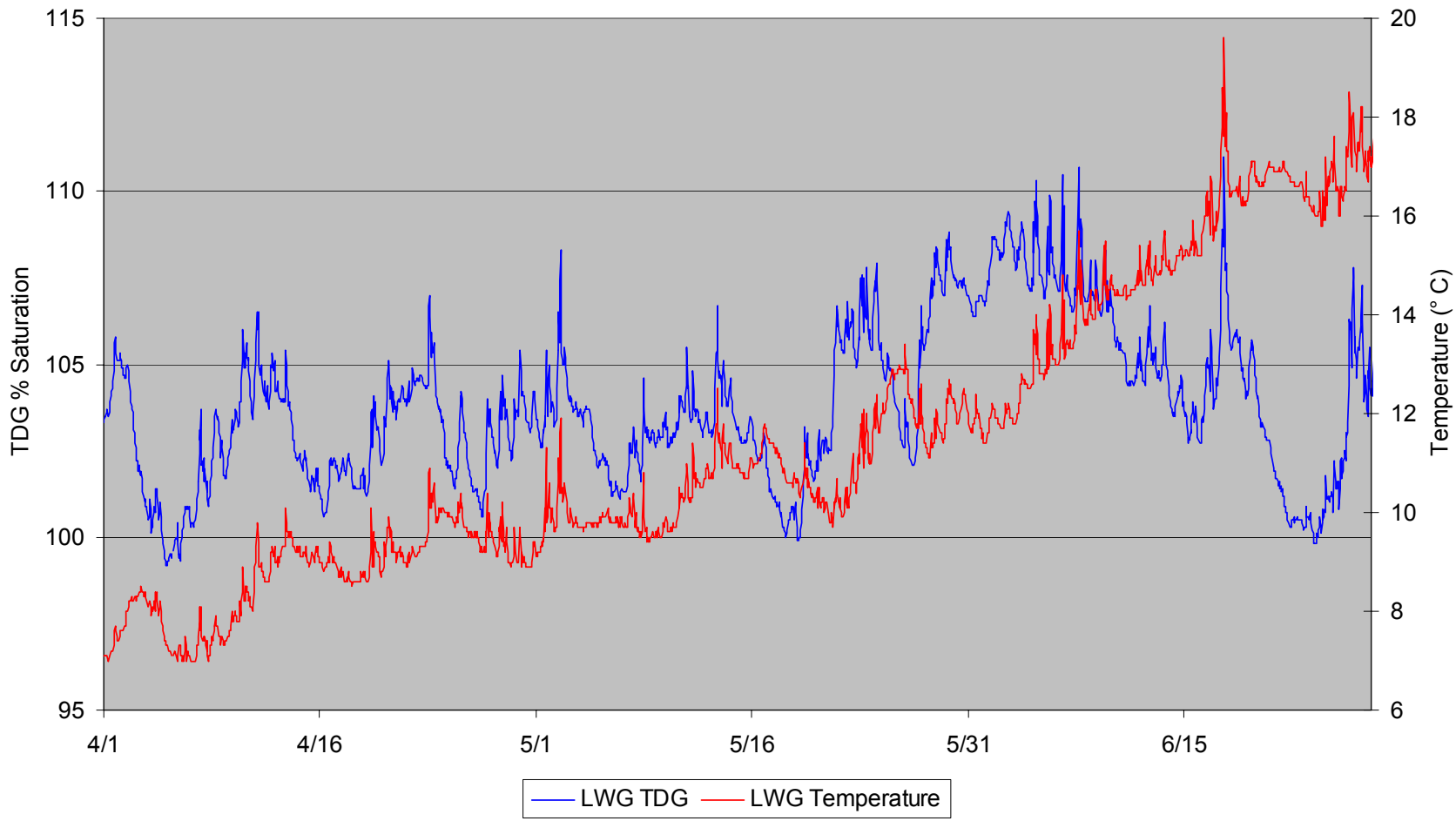


Figure 6. Lower Granite Dam Forebay TDG and Water Temperature, 2003.

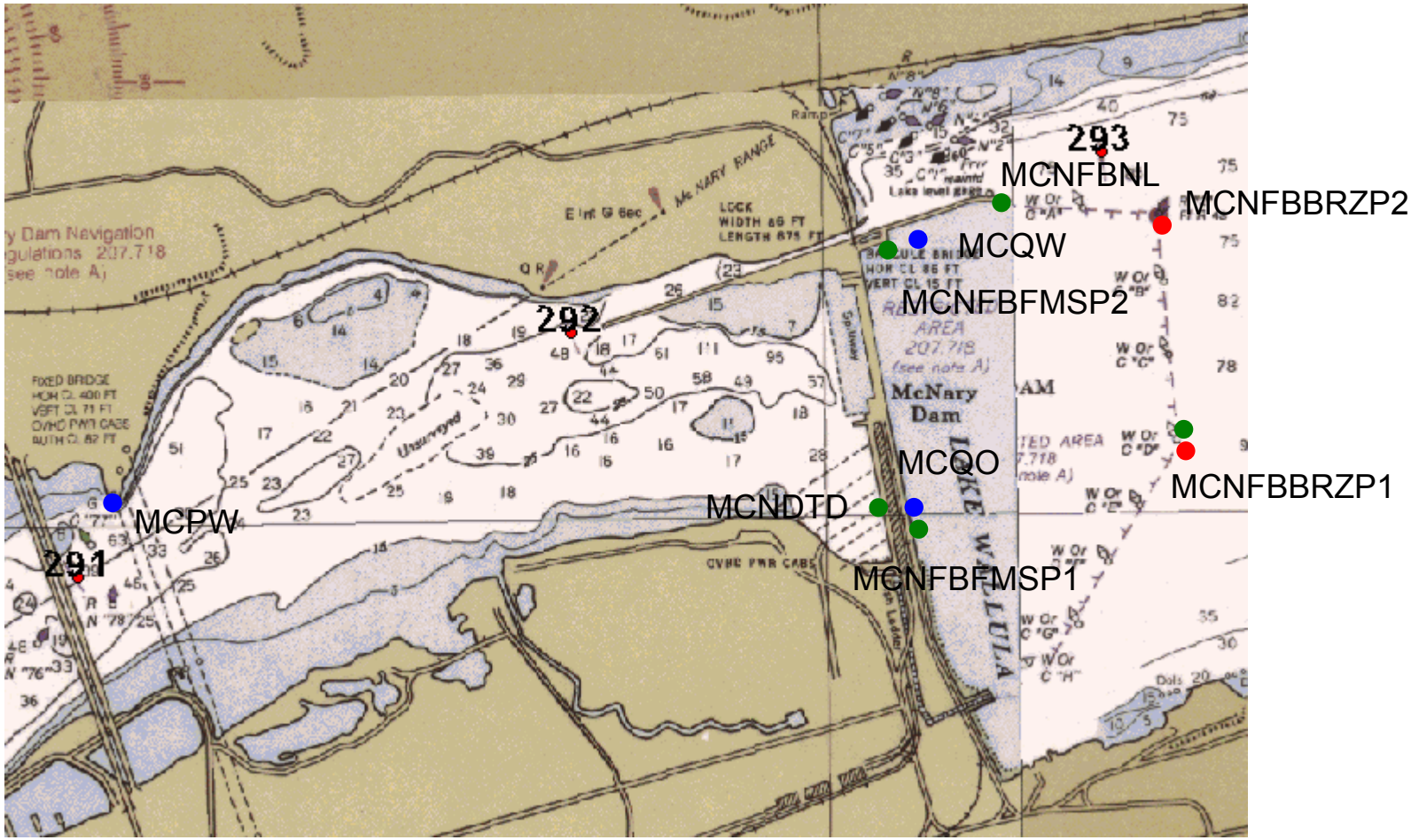
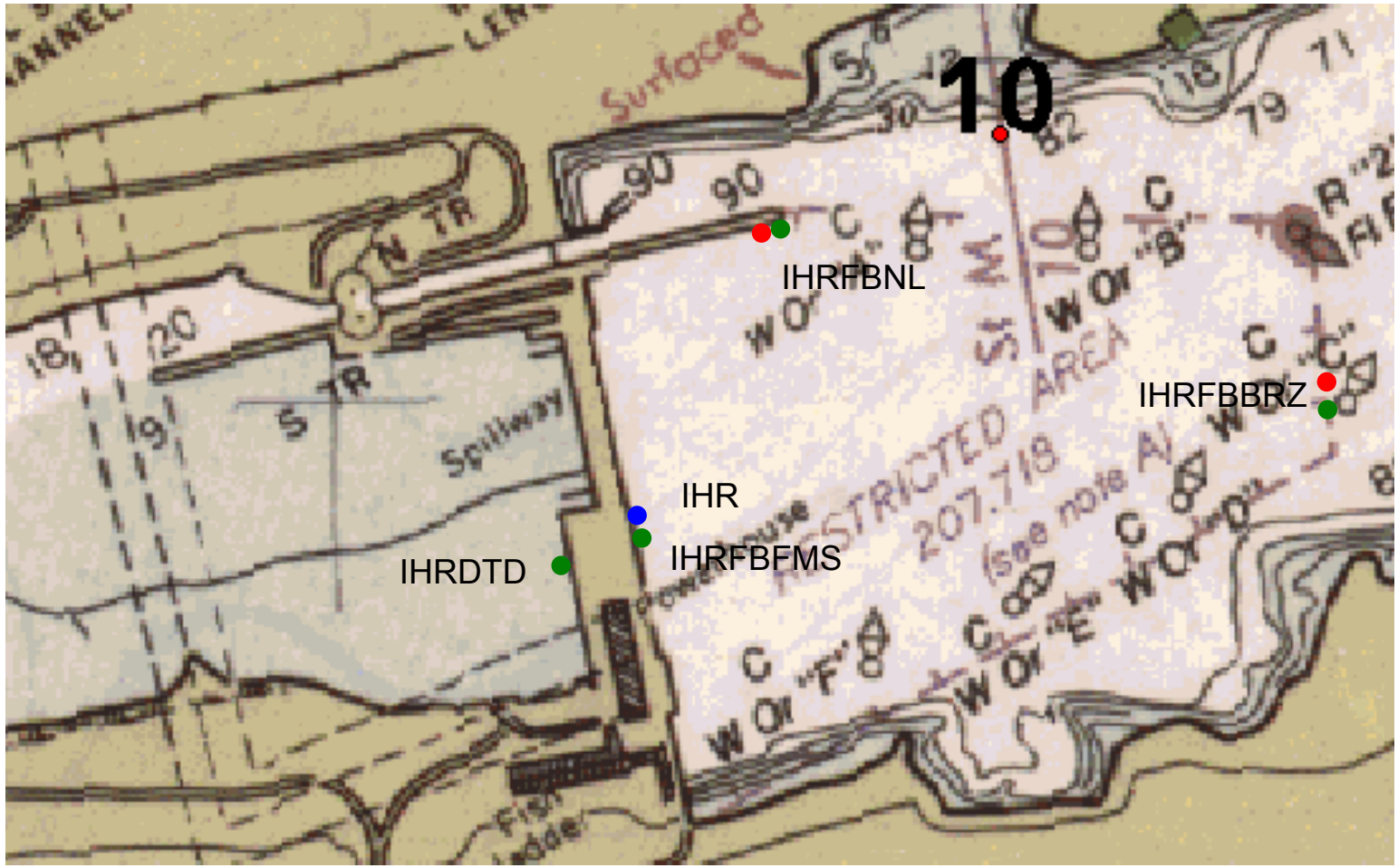
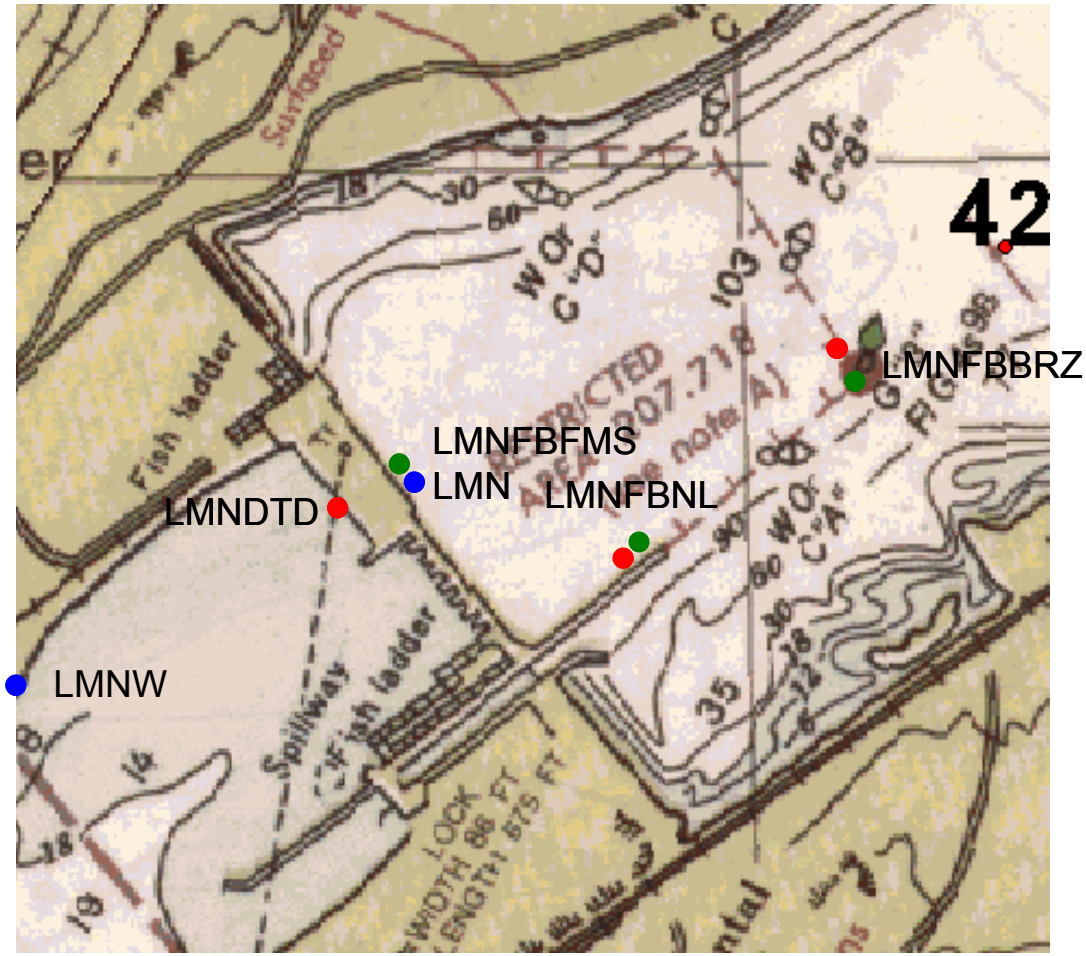


Figure 7. McNary Dam TDG FMS and RPA 132 alternative TDG stations.



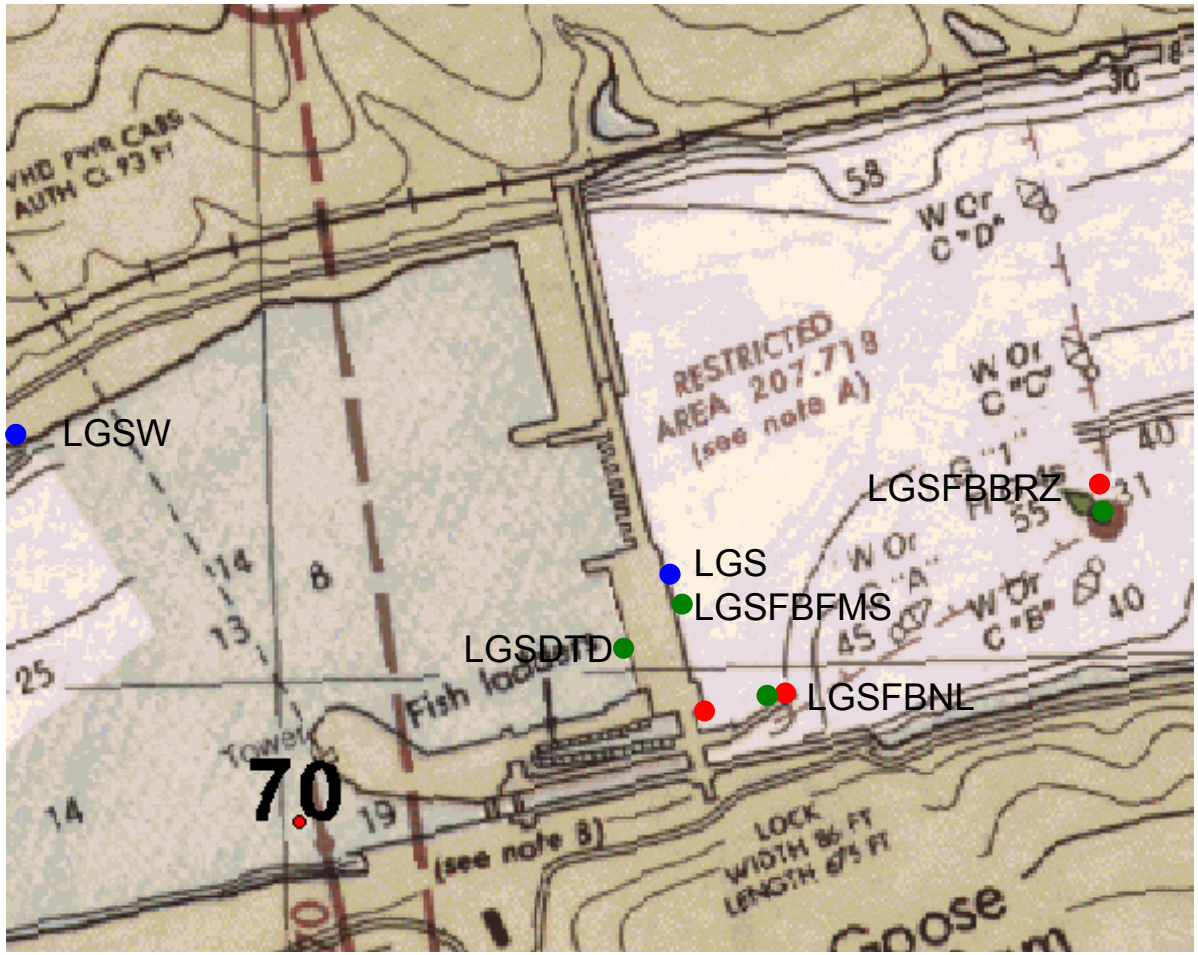
● - Alternate TDG Stations ● -Temp Strings ● -FMS Stations

Figure 8. Ice Harbor Dam TDG FMS and RPA 132 alternative TDG stations.



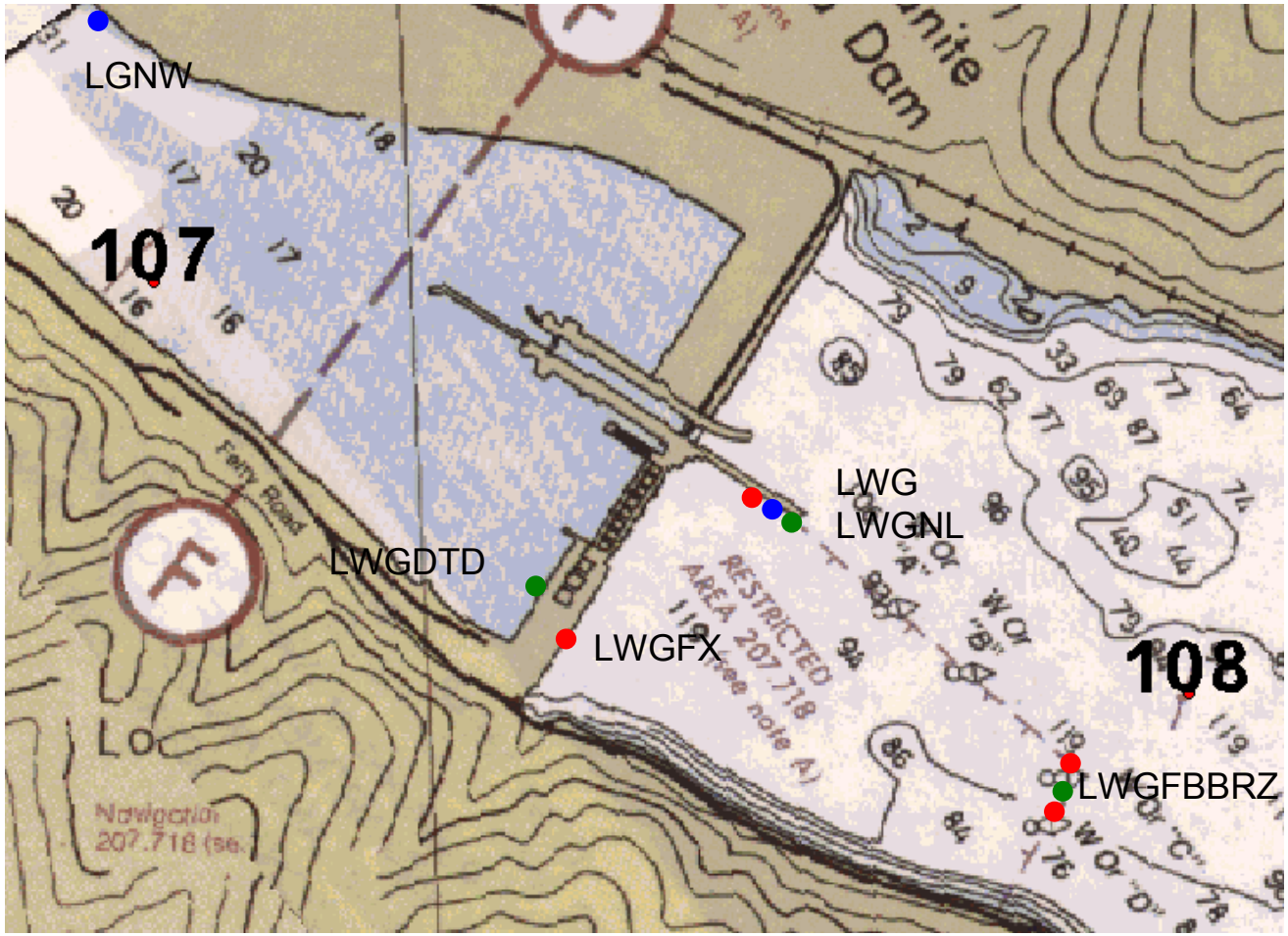
- Alternate TDG Stations -Temp Strings -FMS Stations

Figure 9. Lower Monumental Dam TDG FMS and RPA 132 alternative TDG stations.



● - Alternate TDG Stations ● -Temp Strings ● -FMS Stations

Figure 10. Little Goose Dam TDG FMS and RPA 132 alternative TDG stations.



- Alternate TDG Stations -Temp Strings -FMS Stations

Figure 11. Lower Granite Dam TDG FMS and RPA 132 alternative TDG stations.

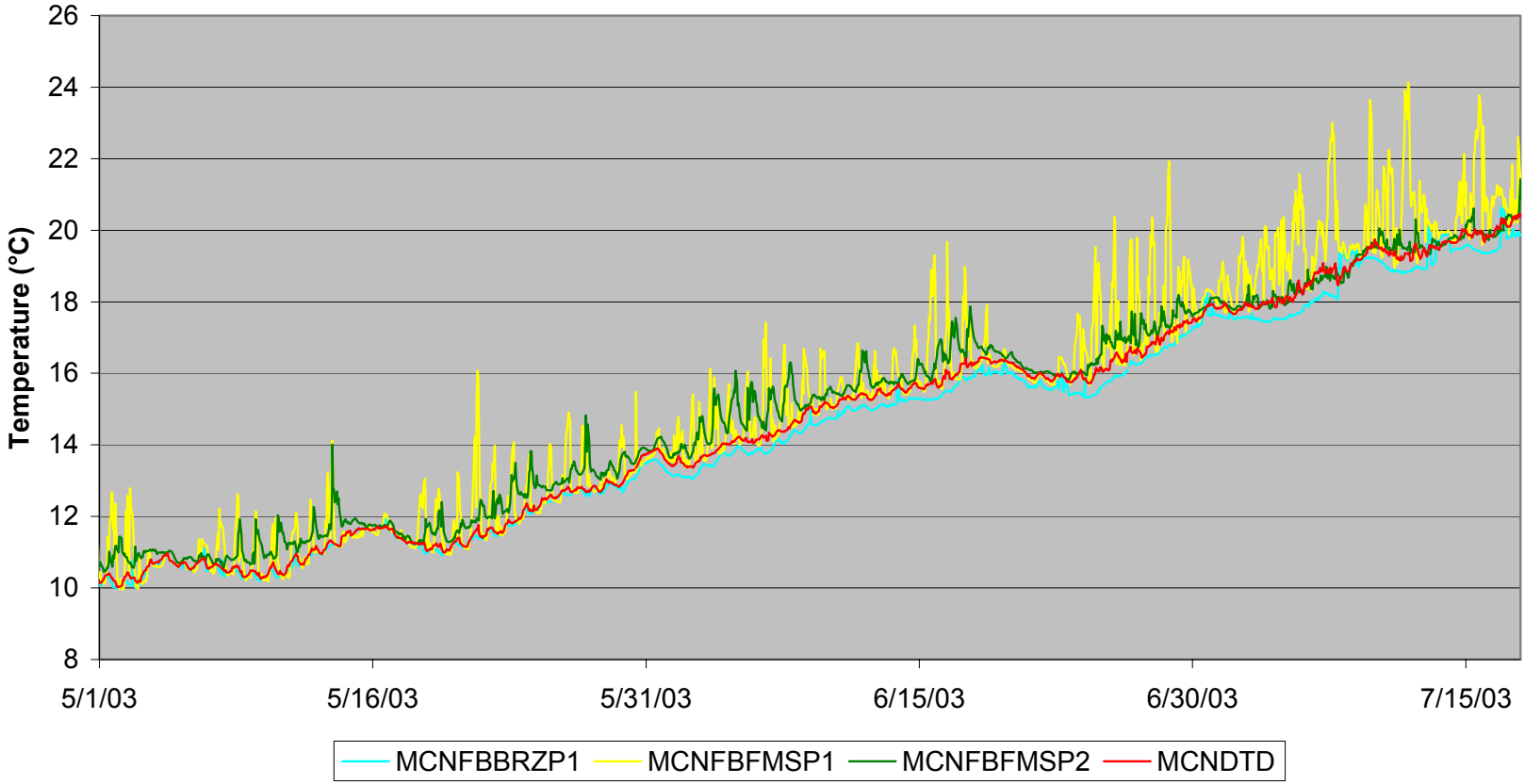


Figure 12. McNary Dam Alternate Monitor Station Temperature, 2003.

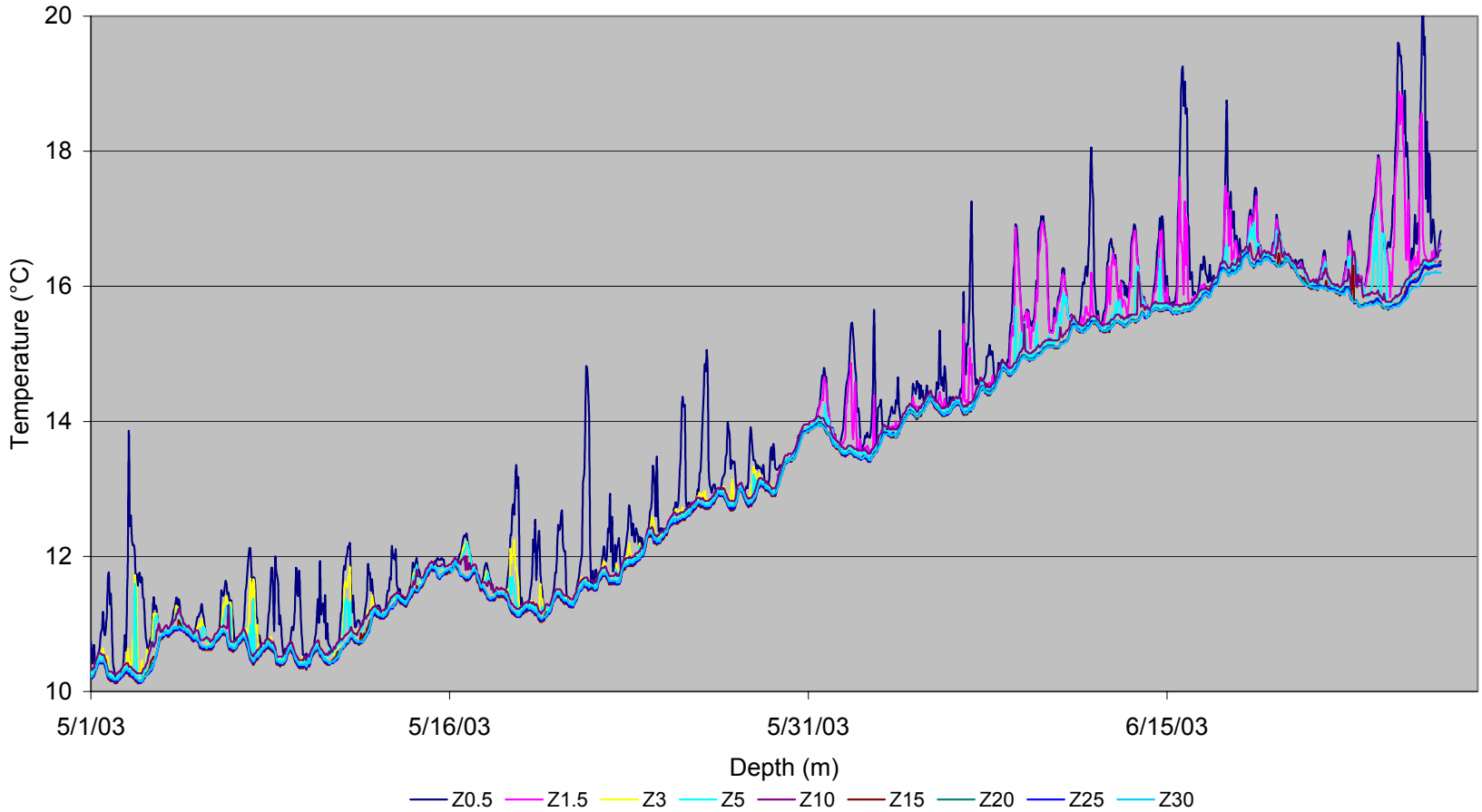


Figure 13. McNary Dam Forebay Thermal Profile, 2003.

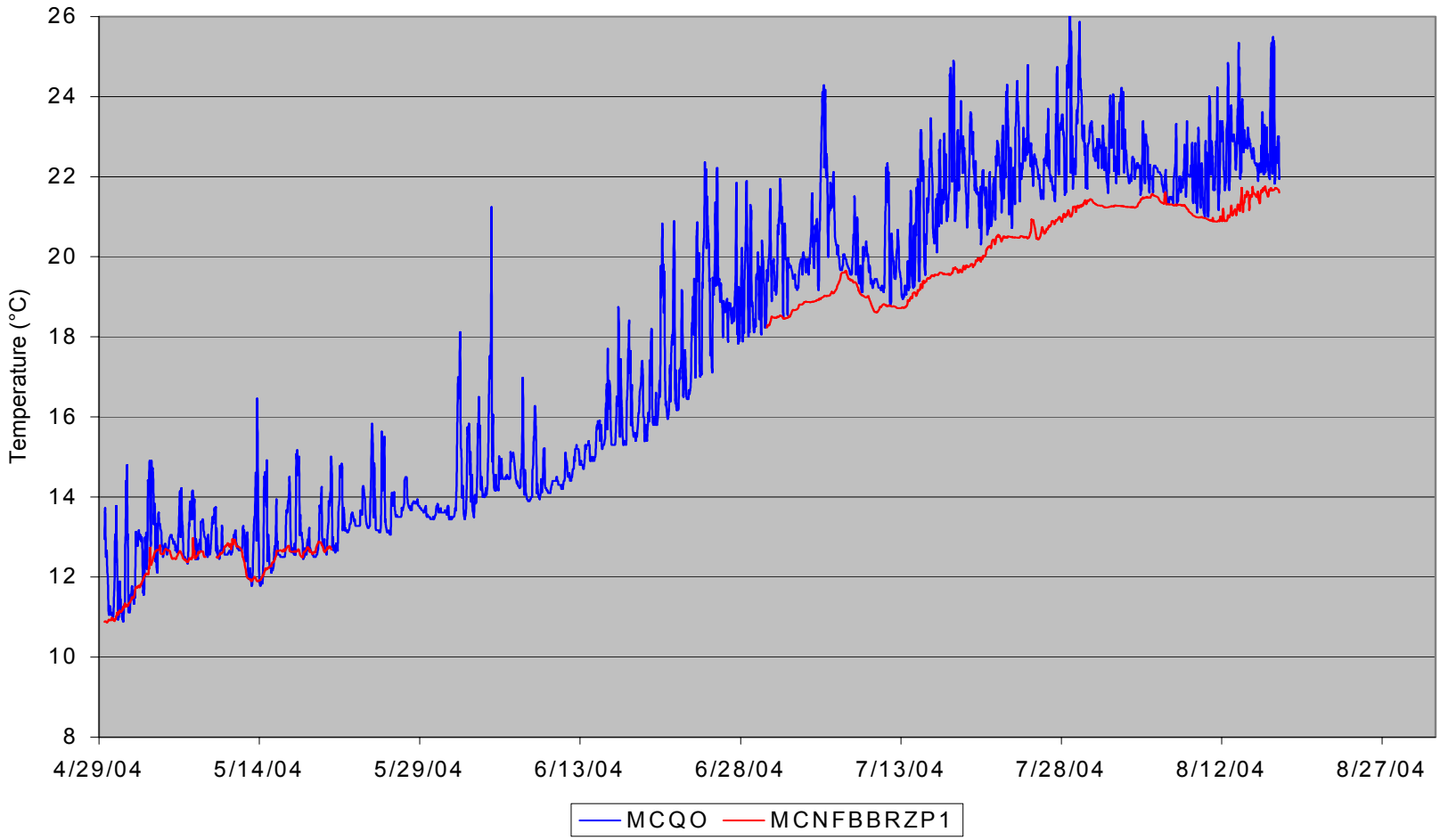


Figure 14. McNary Dam South Side Station Temperatures, 2004.

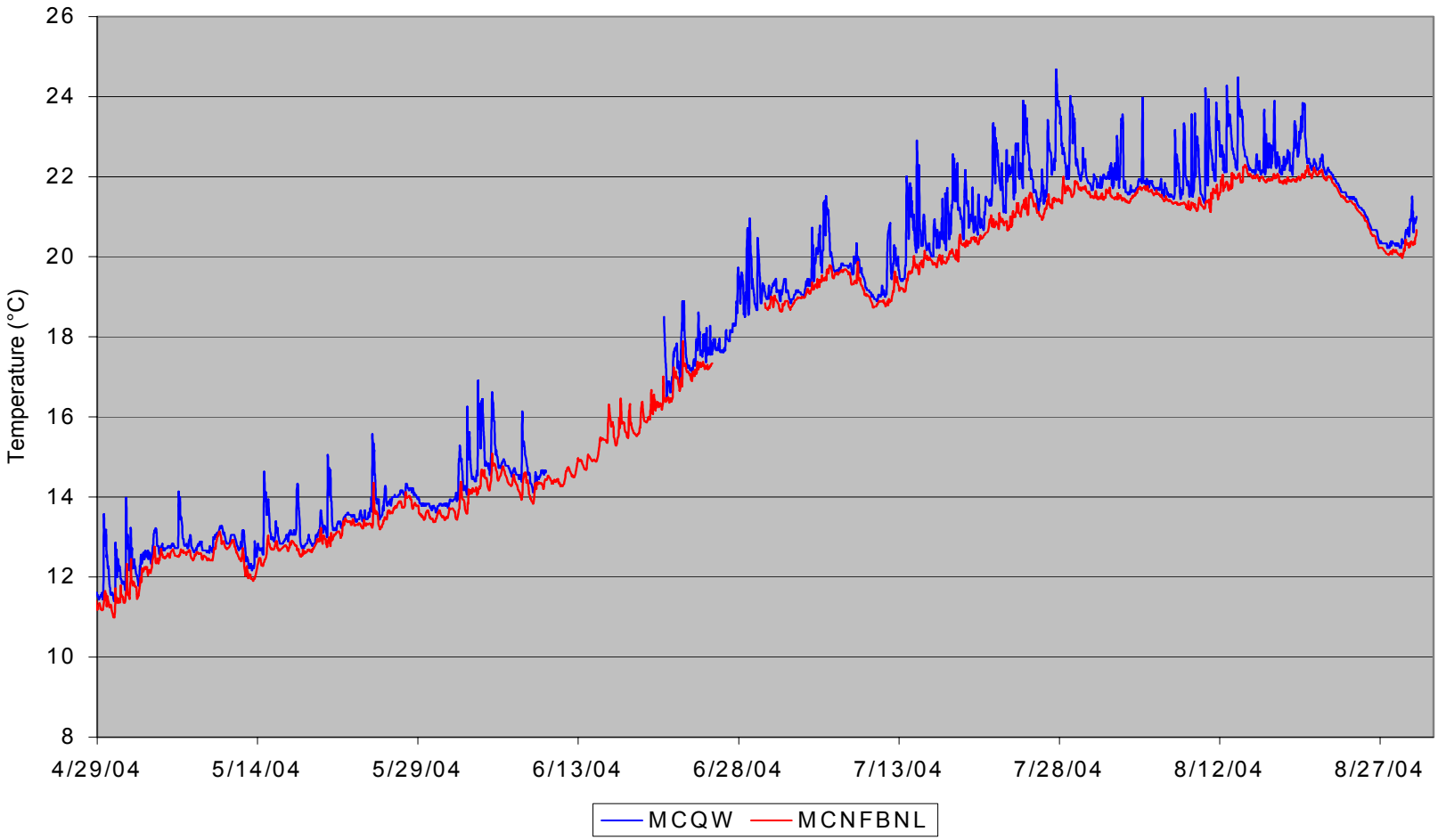


Figure 15. McNary Dam North Side Station Temperatures, 2004.

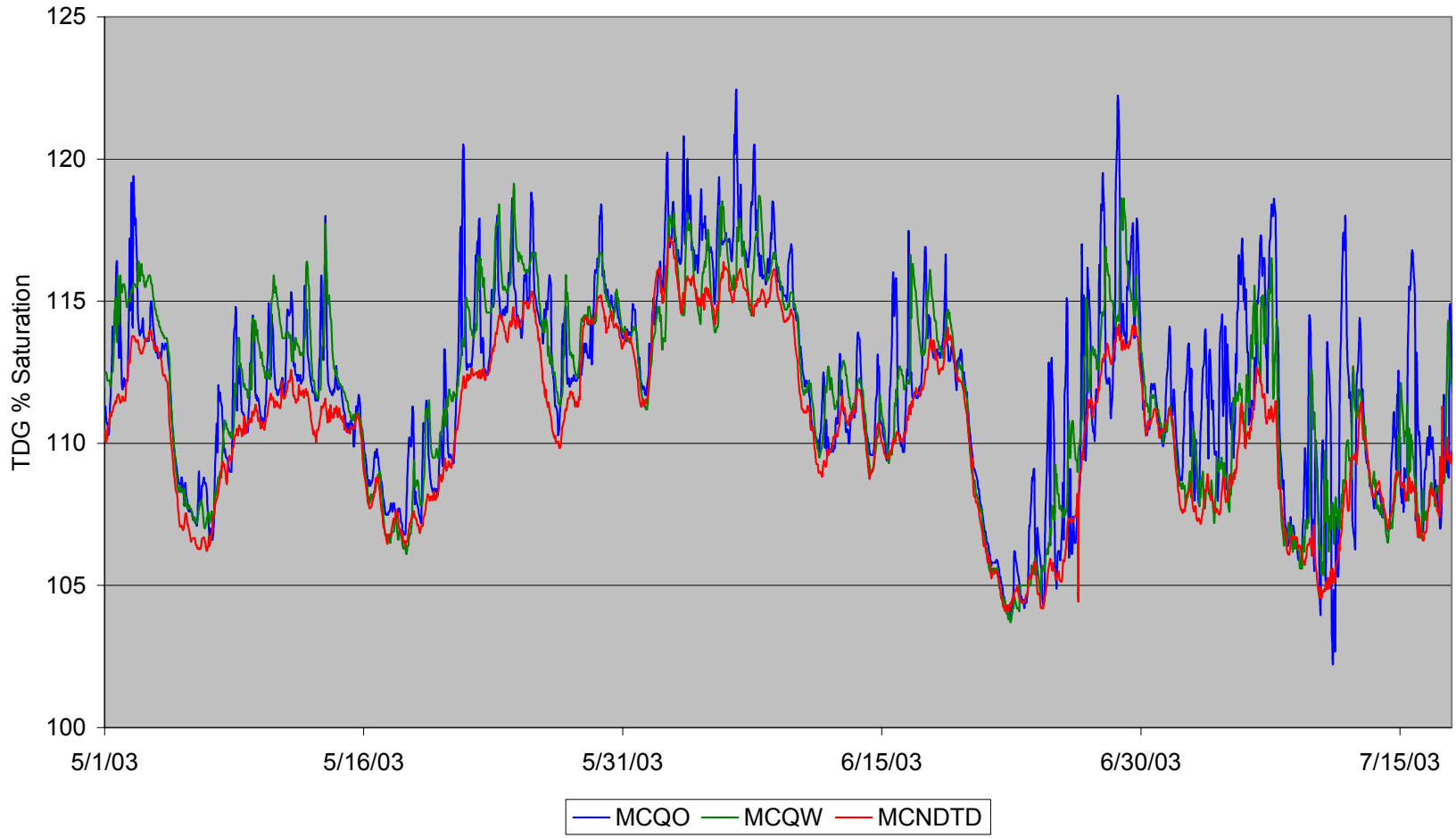


Figure 16. McNary Dam TDG Saturation MCQO, MCQW, and MCNDTD, 2003.

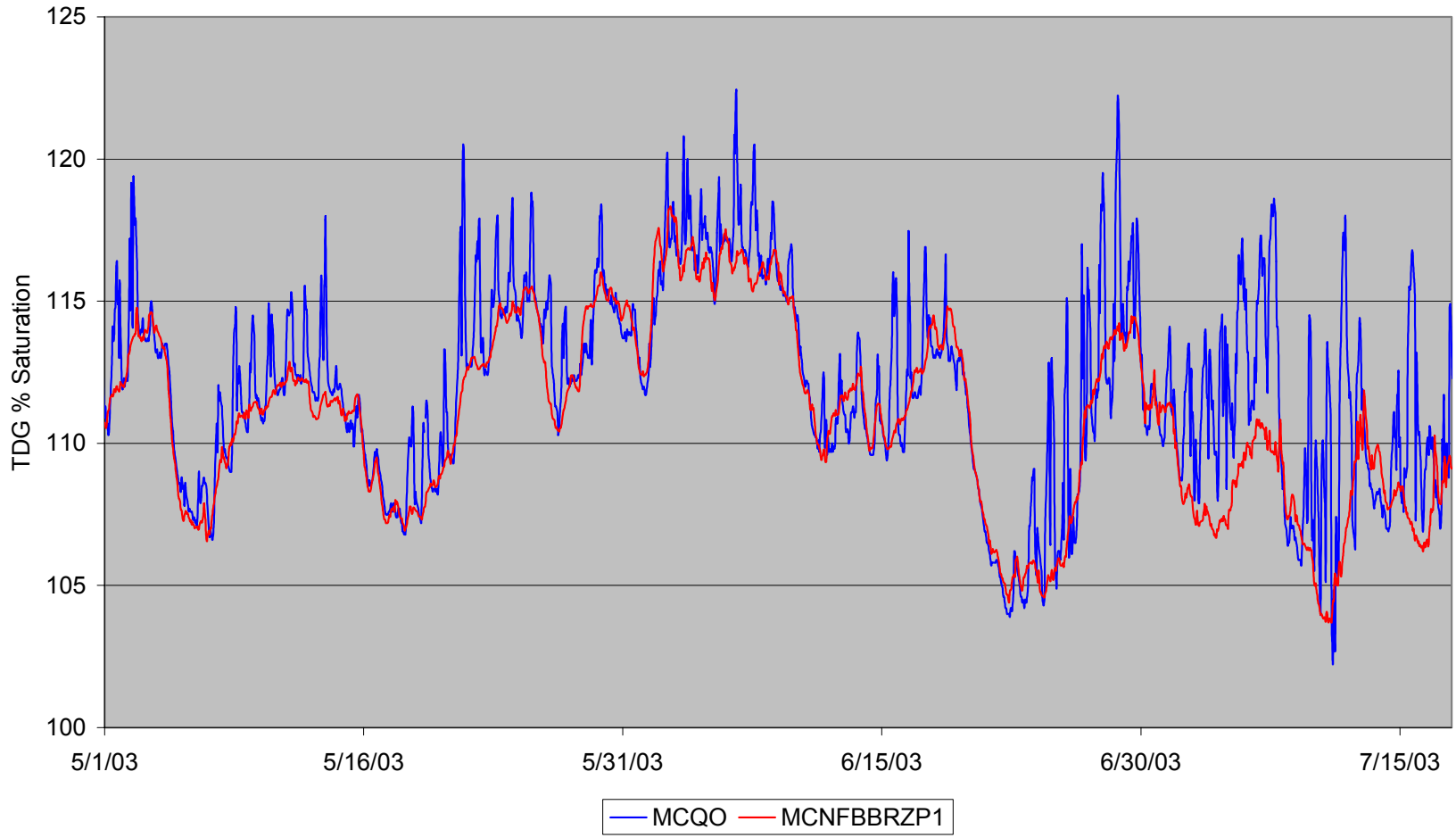


Figure 17. McNary Dam TDG Saturation MCQO and MCNFBBRZP1, 2003.

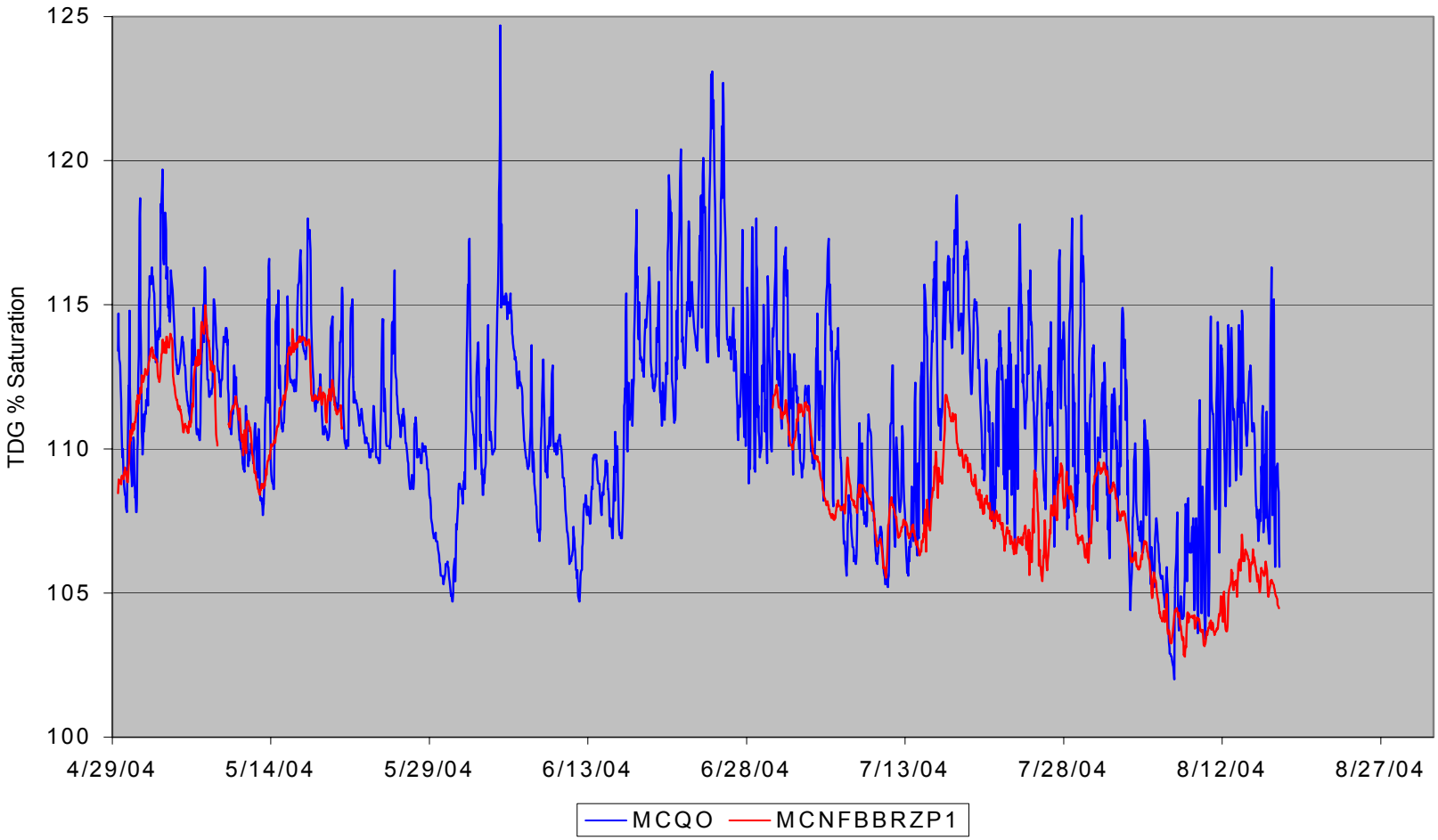


Figure 18. McNary Dam TDG Saturation MCQO and MCNFBBRZP1, 2004.

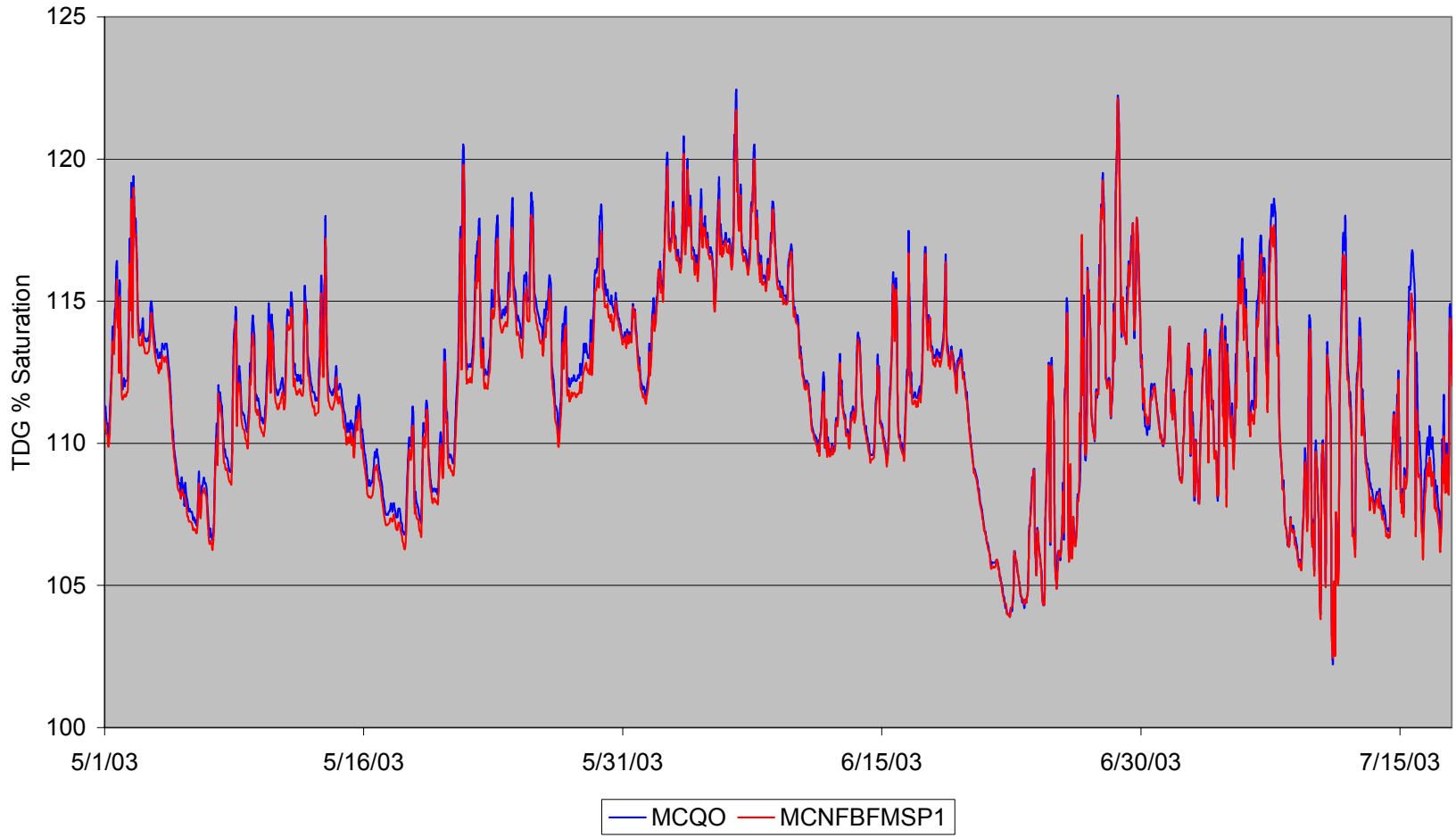


Figure 19. McNary Dam TDG Saturation MCQO and MCNFBFMSP1, 2003.

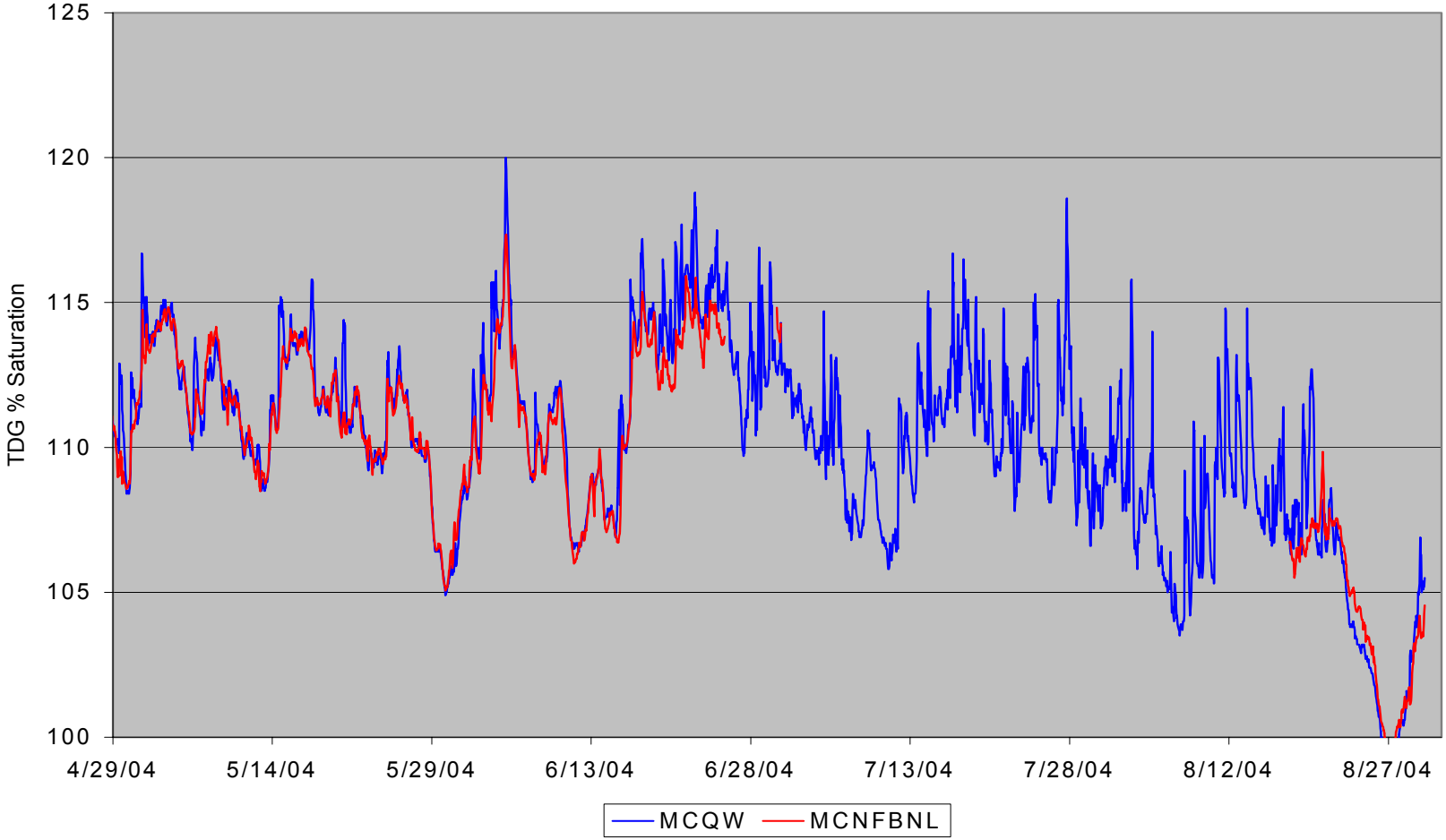


Figure 20. McNary Dam TDG Saturation MCQW and MCNFBNL, 2004.

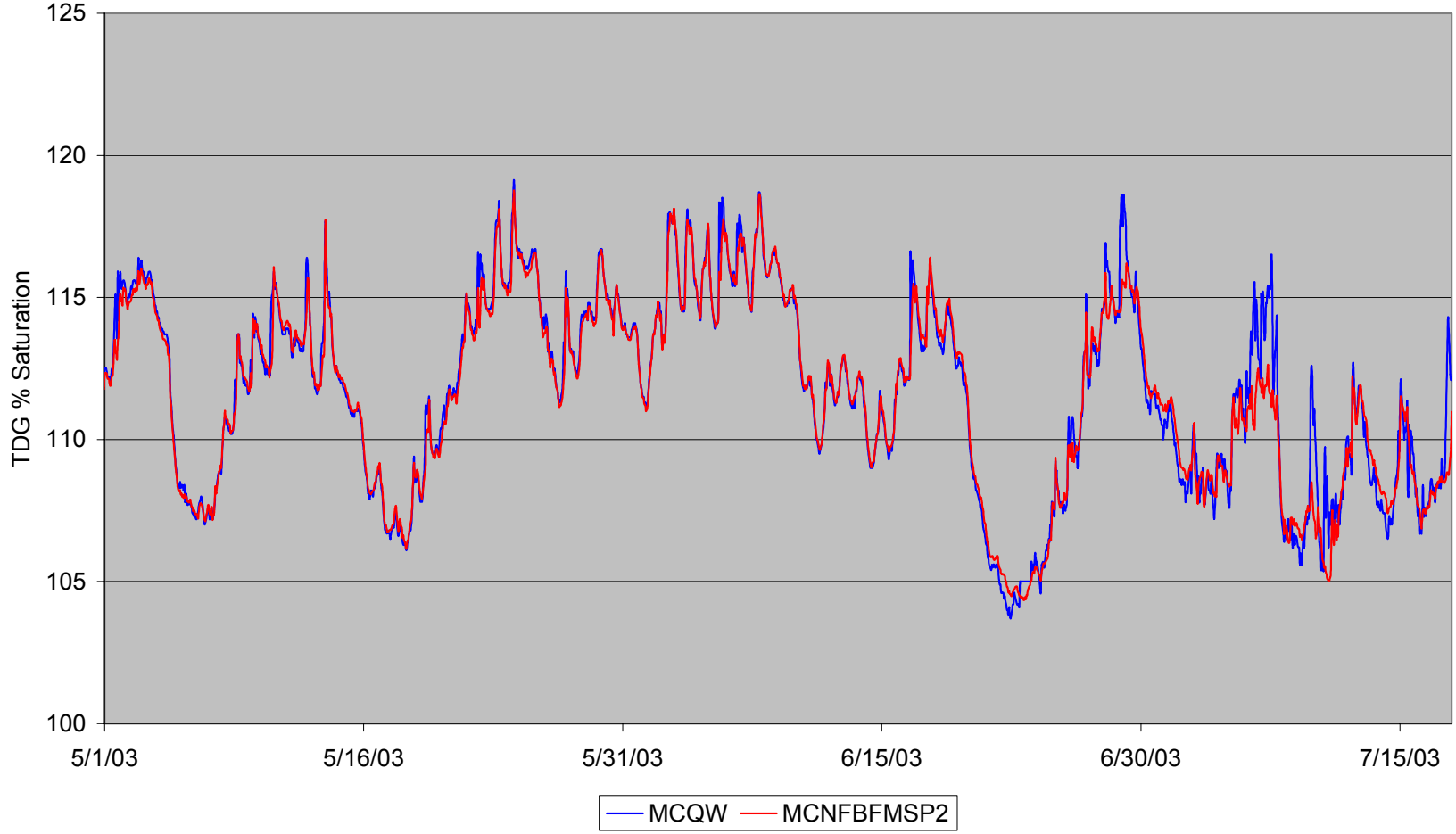


Figure 21. McNary Dam TDG Saturation MCQW and MCNFBFMSP2,2003.

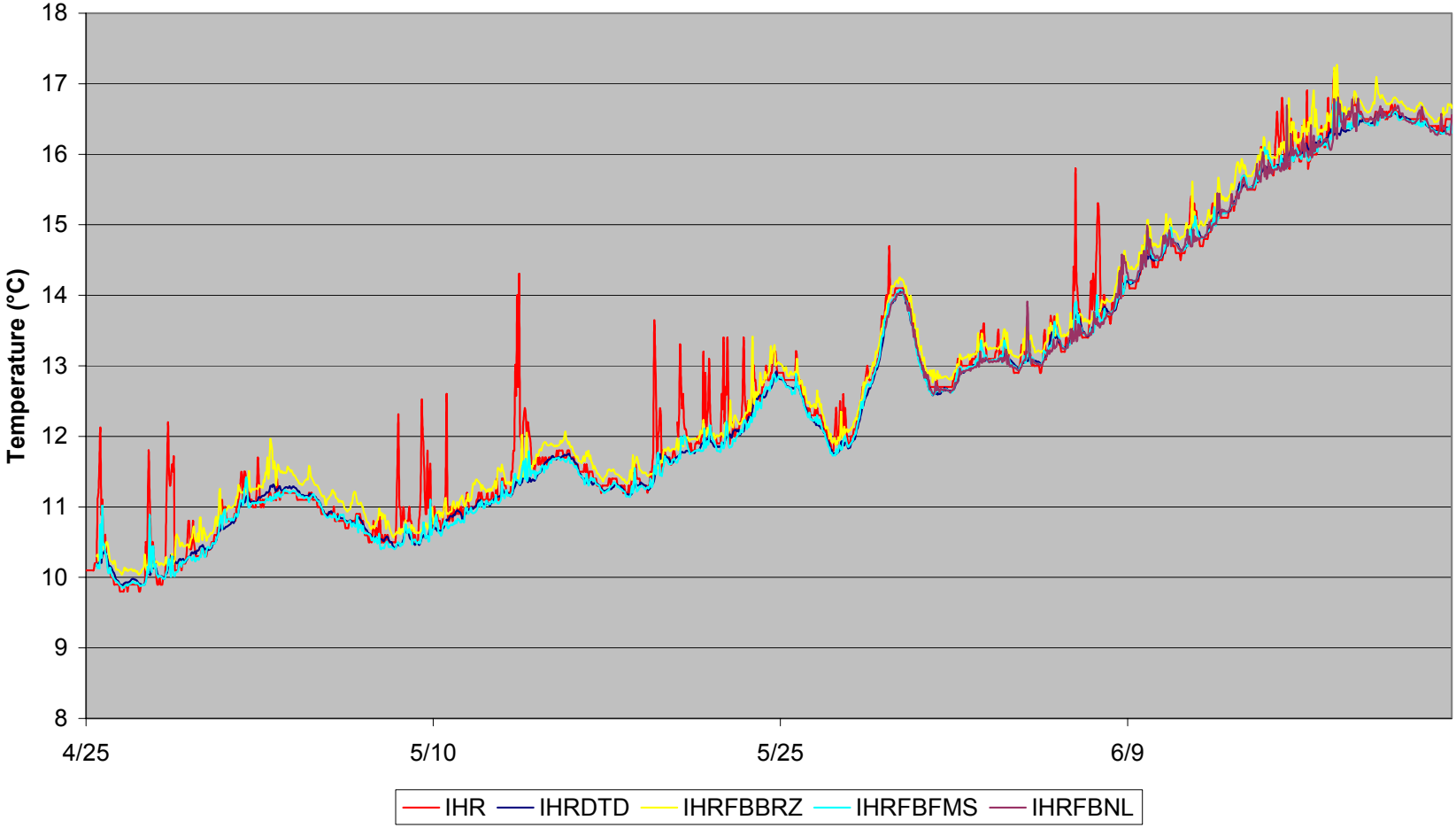


Figure 22. Ice Harbor Dam alternate TDG monitor station temperature, 2003.

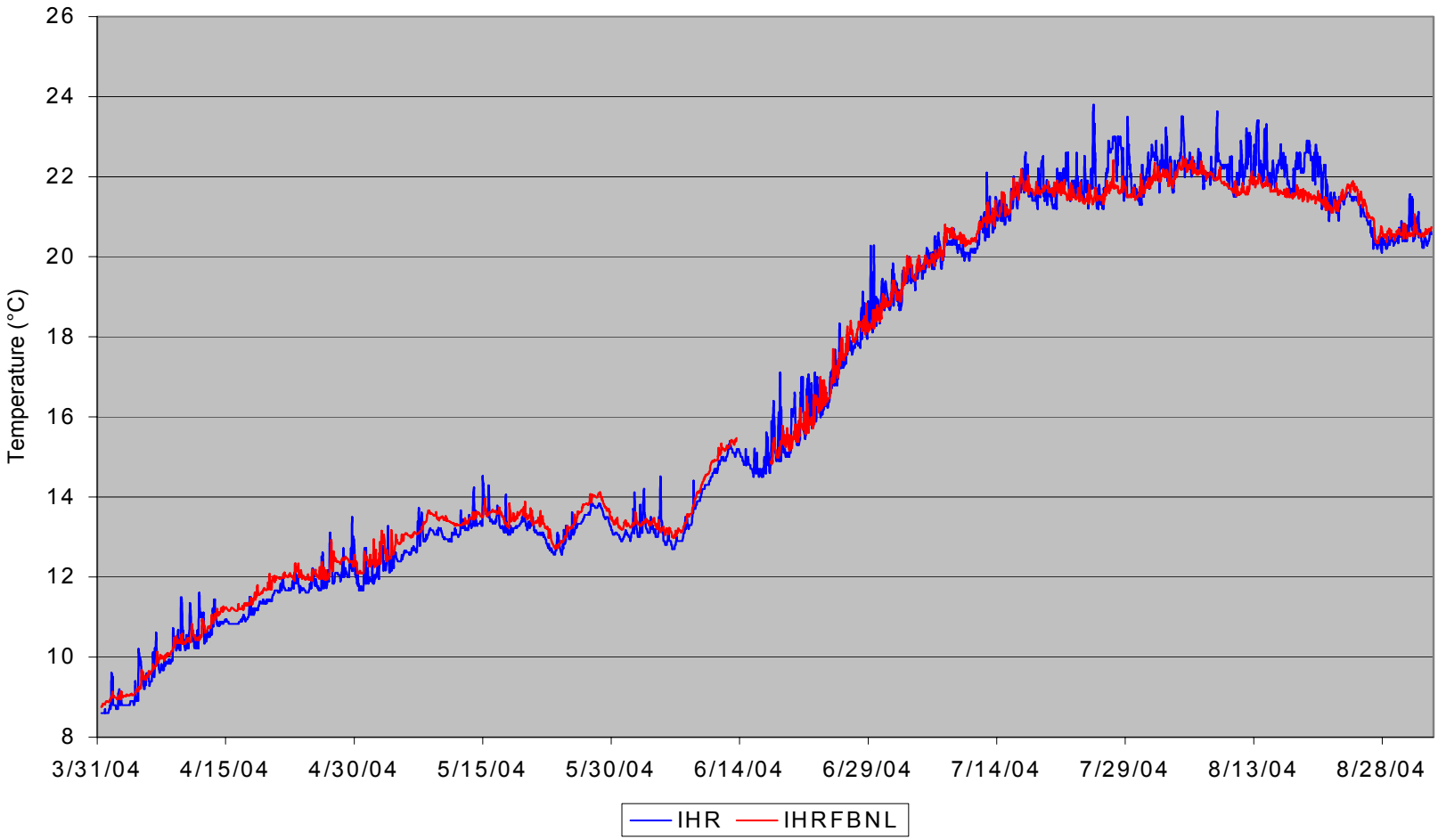


Figure 23. Ice Harbor Dam Forebay temperature, 2004.

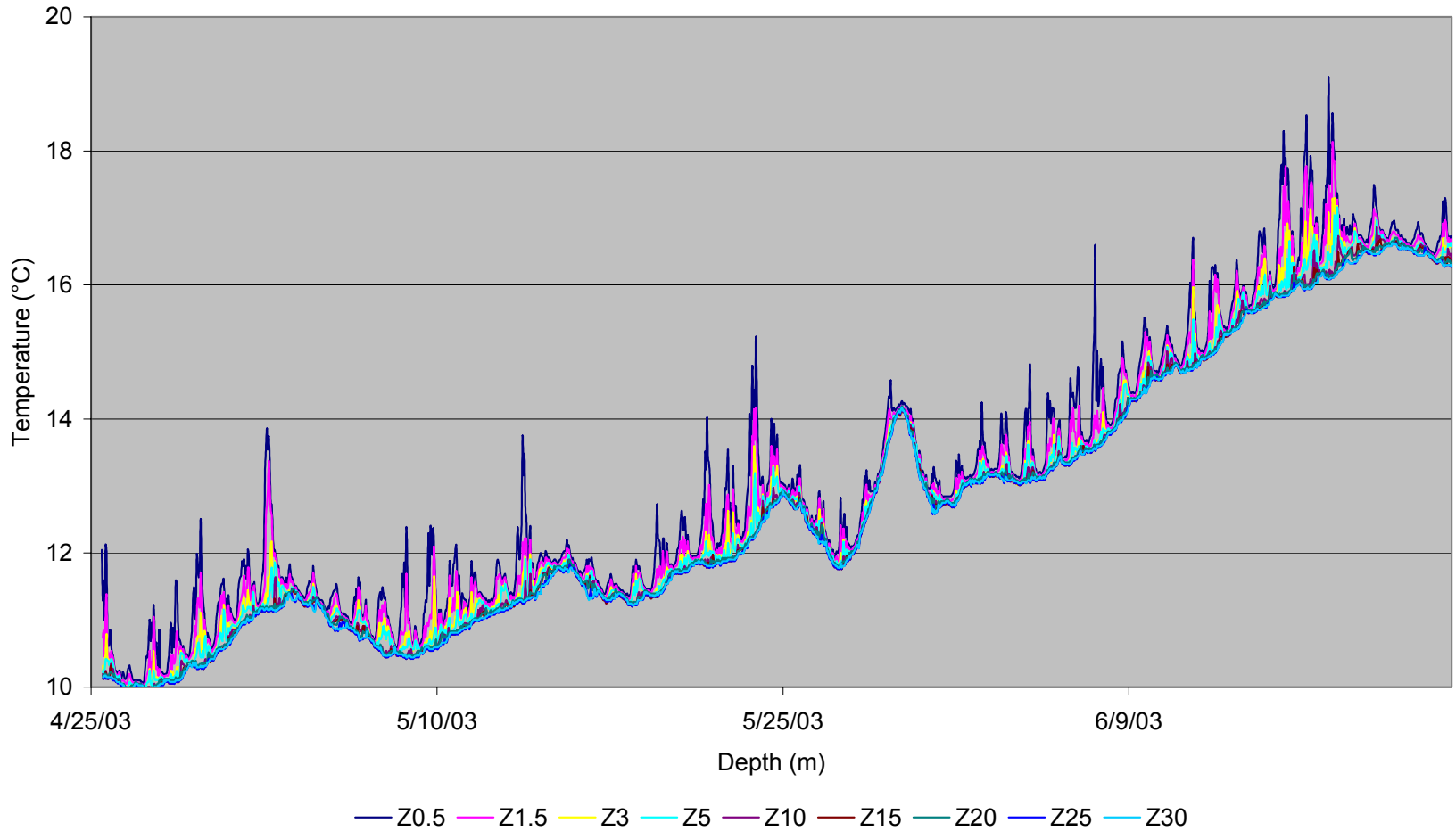


Figure 24. Ice Harbor Dam Forebay Thermal Profile, 2004.

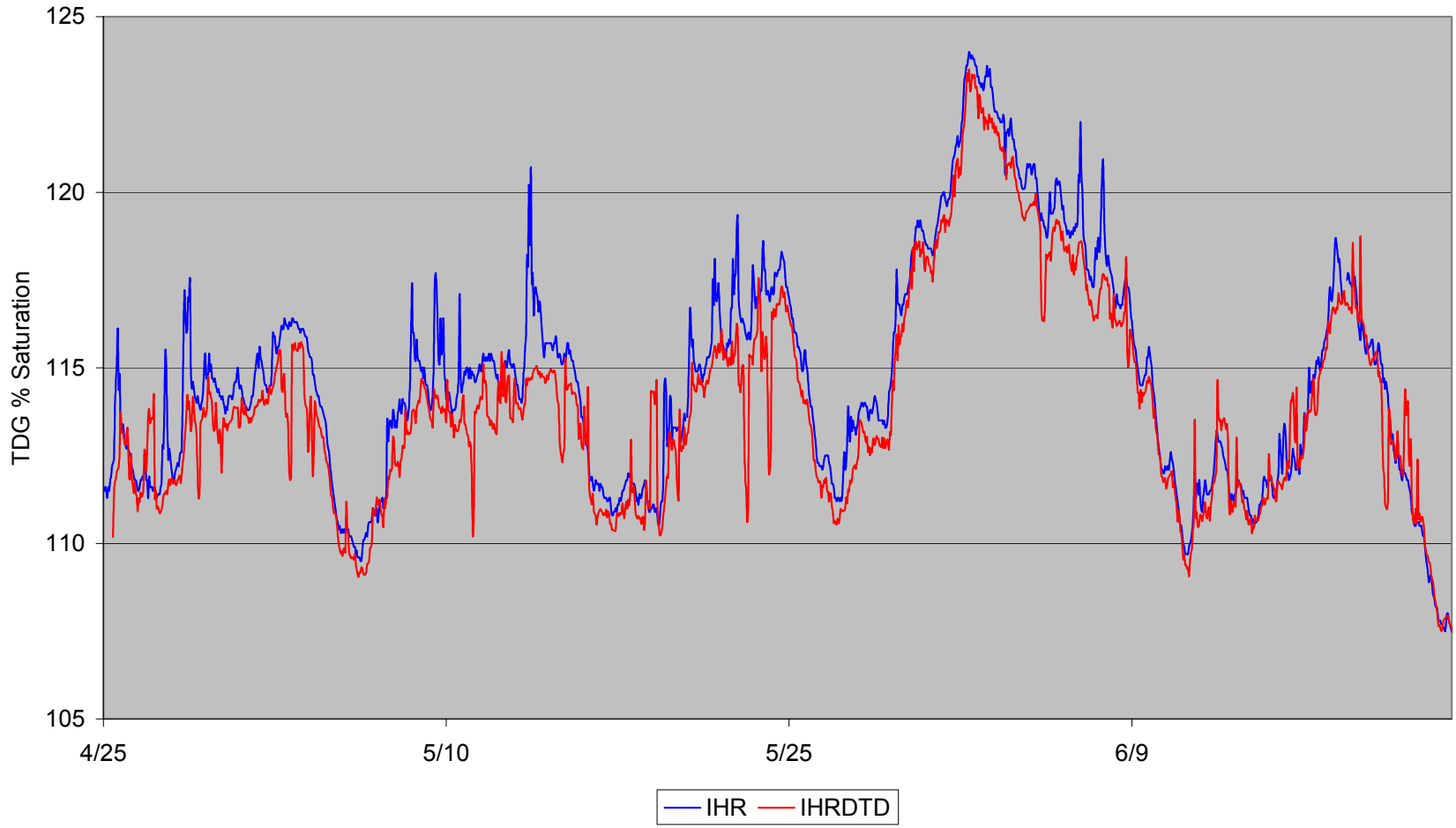


Figure 25. Ice Harbor Dam TDG Saturation IHR and IHRDTD, 2003.

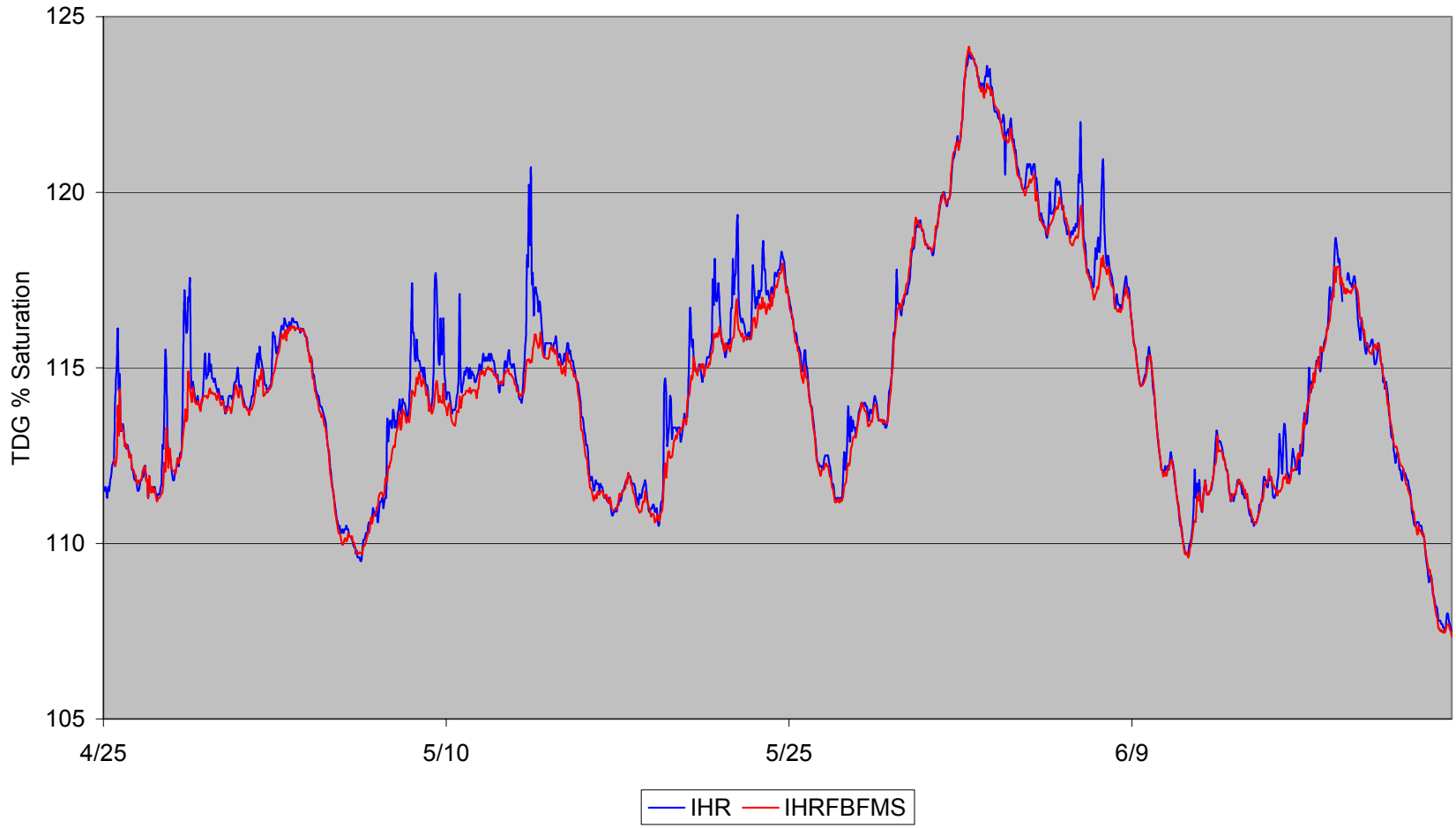


Figure 26. Ice Harbor Dam TDG Saturation IHR and IHRFBFMS, 2003.

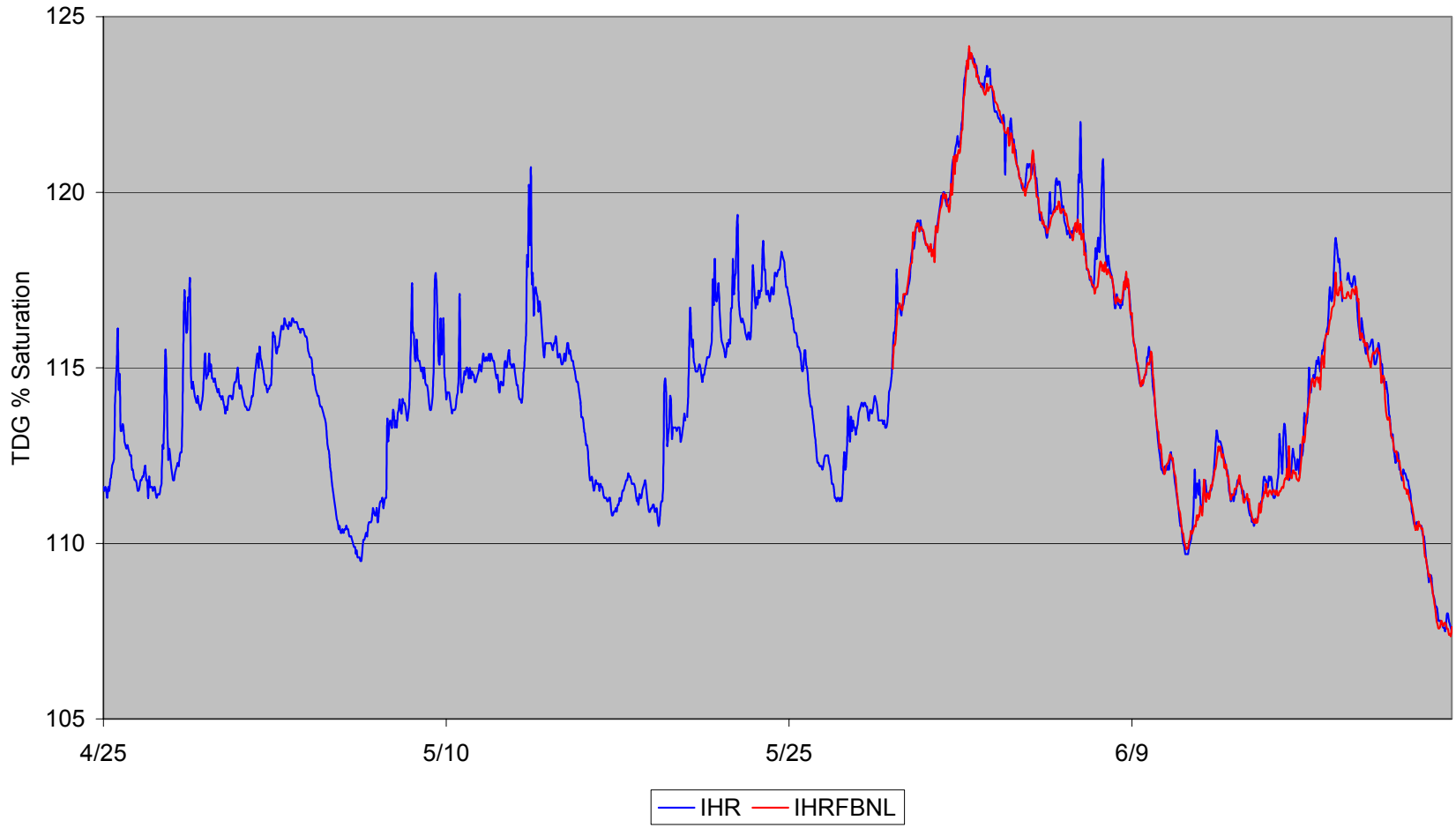


Figure 27. Ice Harbor Dam TDG Saturation IHR and IHRFBNL, 2003.

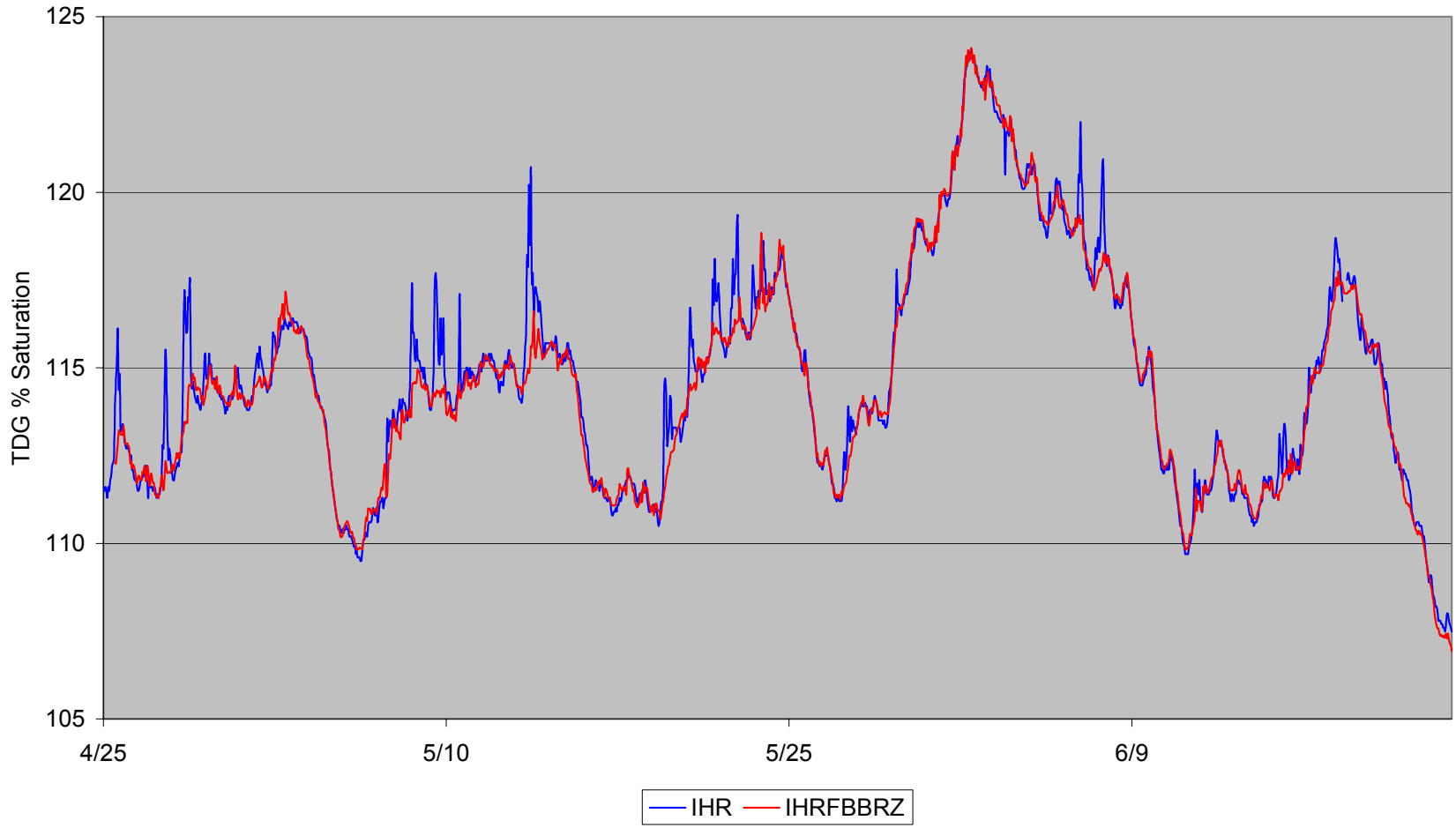


Figure 28. Ice Harbor Dam TDG Saturation IHR and IHRFBBRZ, 2003.

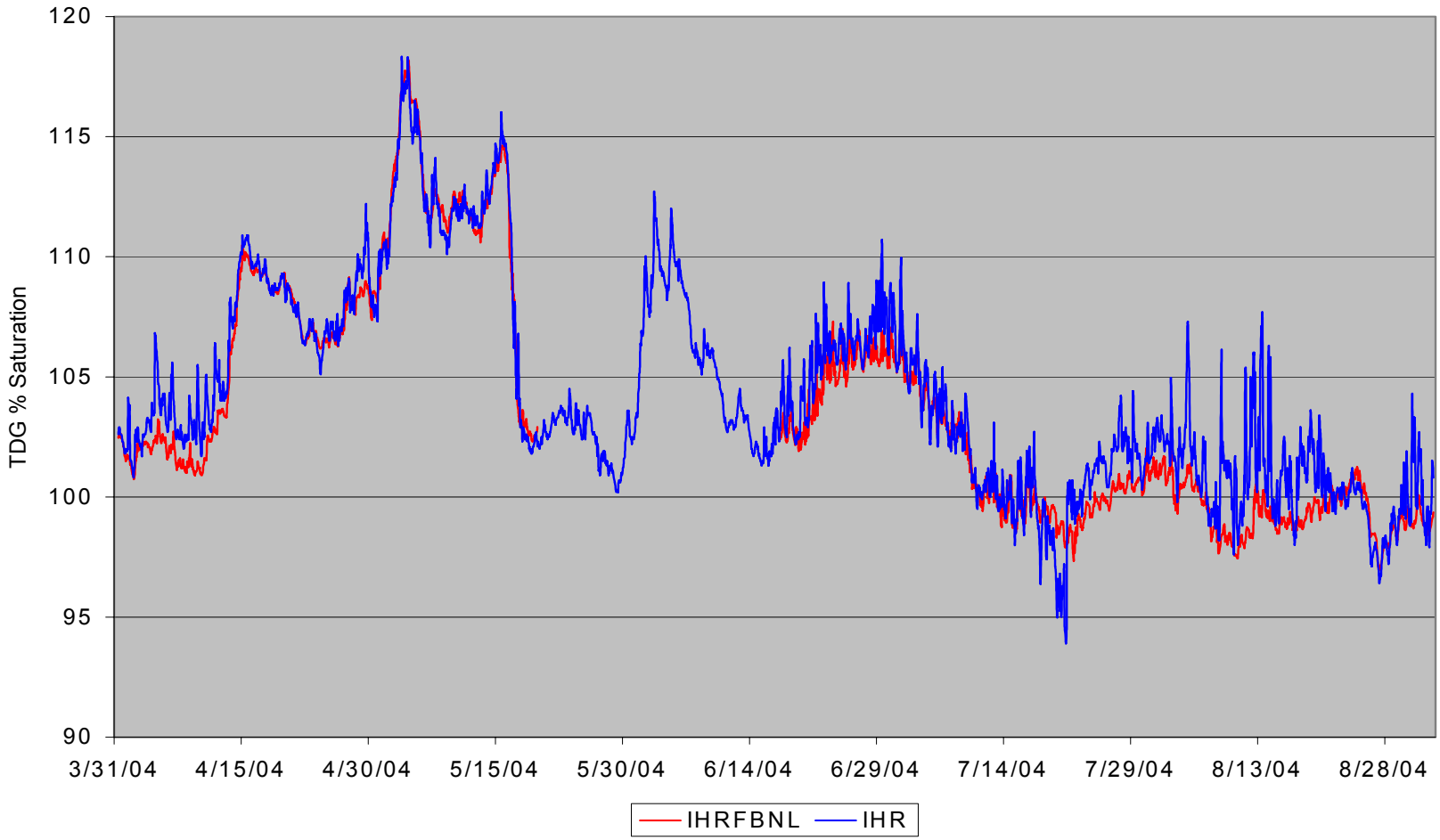


Figure 29. Ice Harbor Dam TDG Saturation IHR and IHRFBNL, 2004.

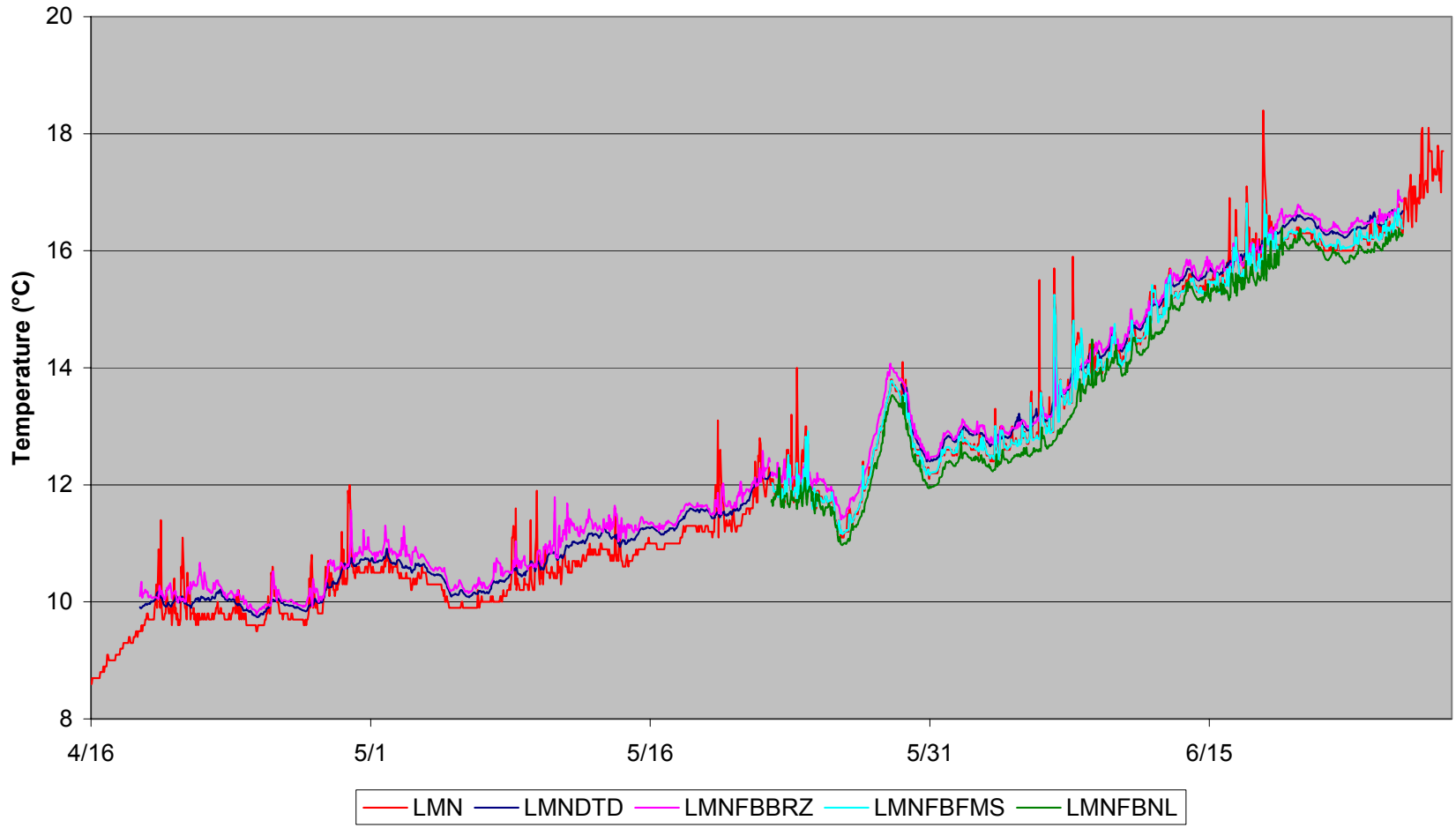


Figure 30. Lower Monumental Dam alternate TDG monitor station temperature, 2003.

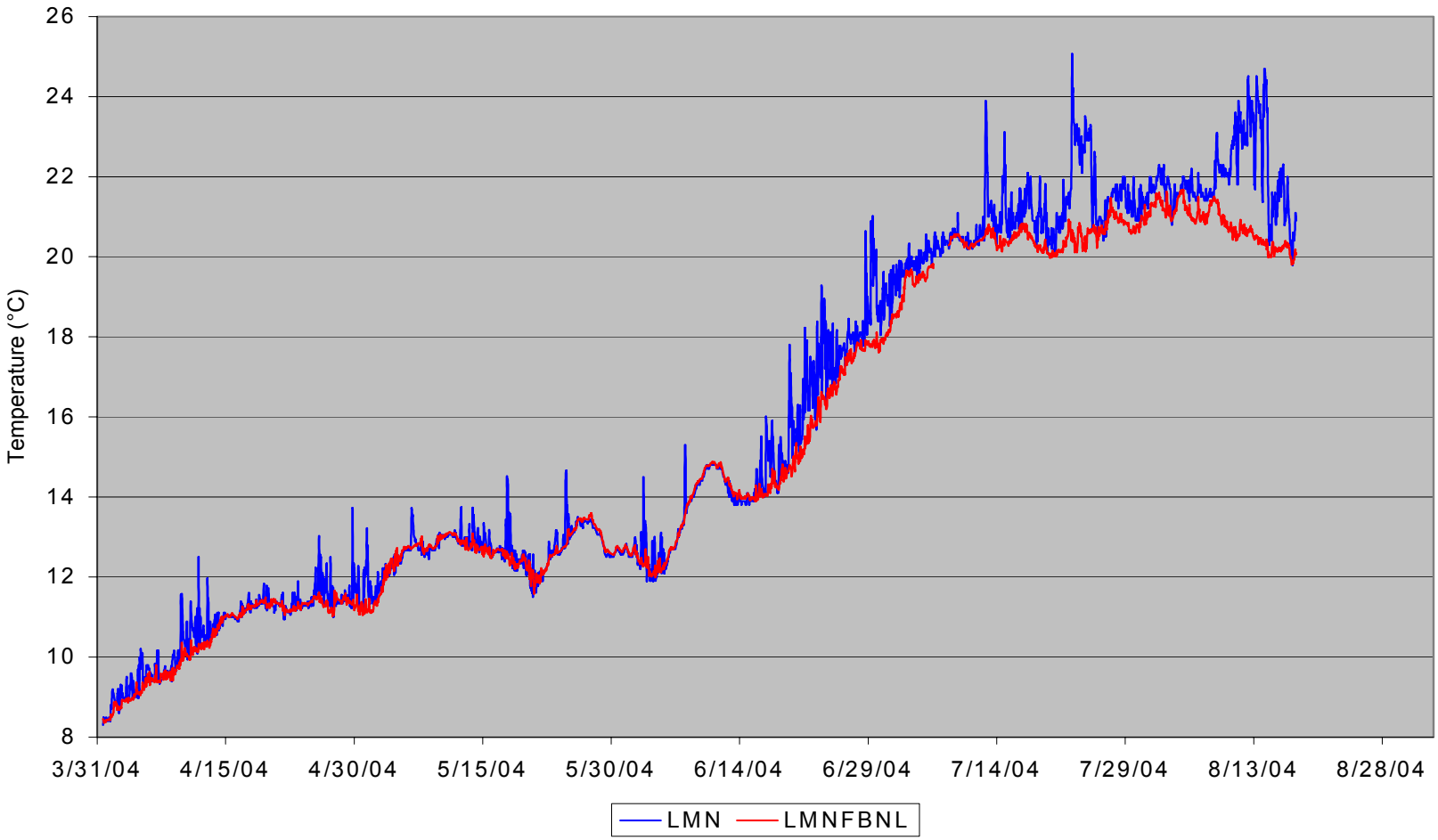


Figure 31. Lower Monumental Dam Forebay temperature, 2004.

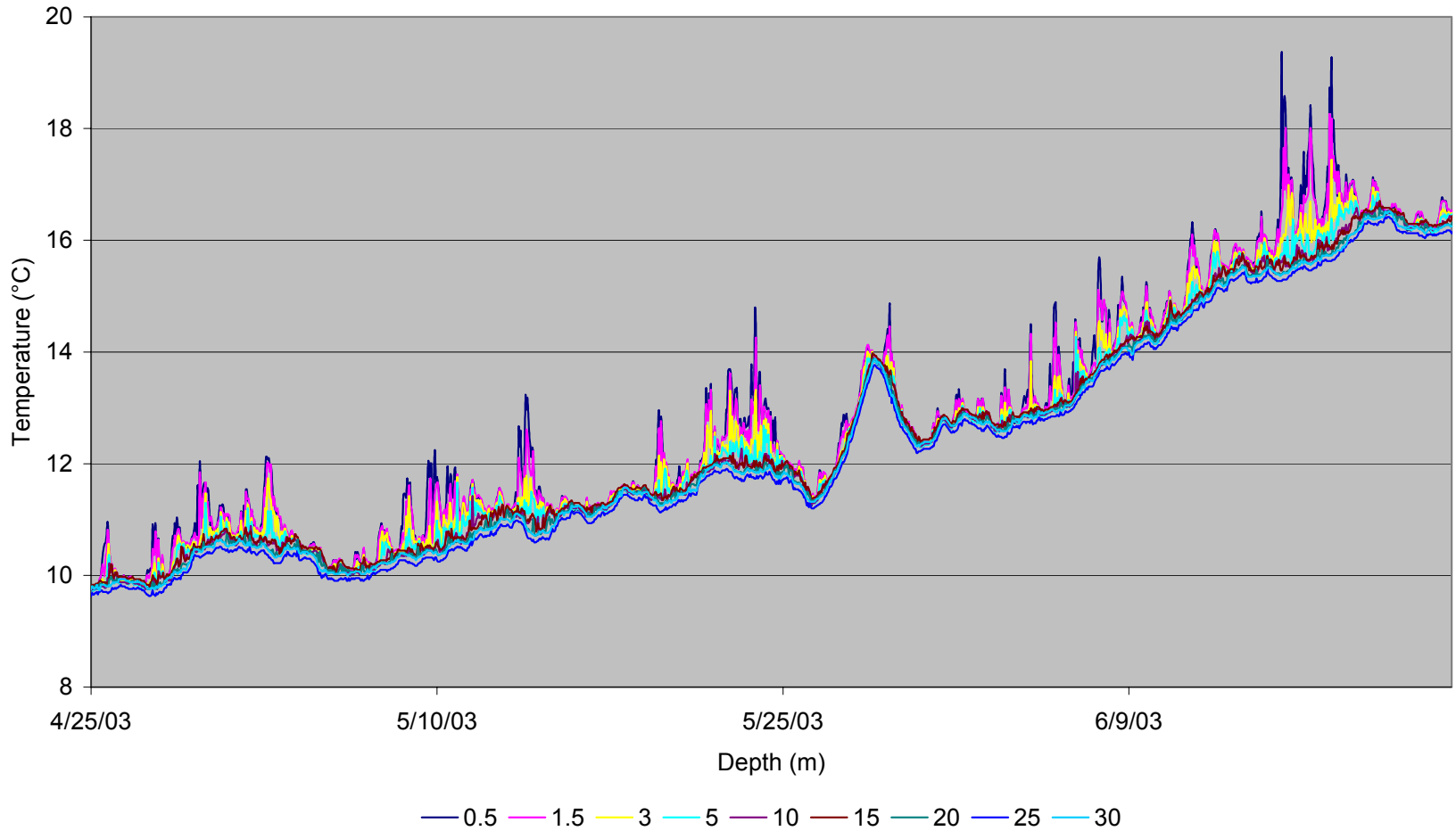


Figure 32. Lower Monumental Dam forebay thermal profile, 2003.

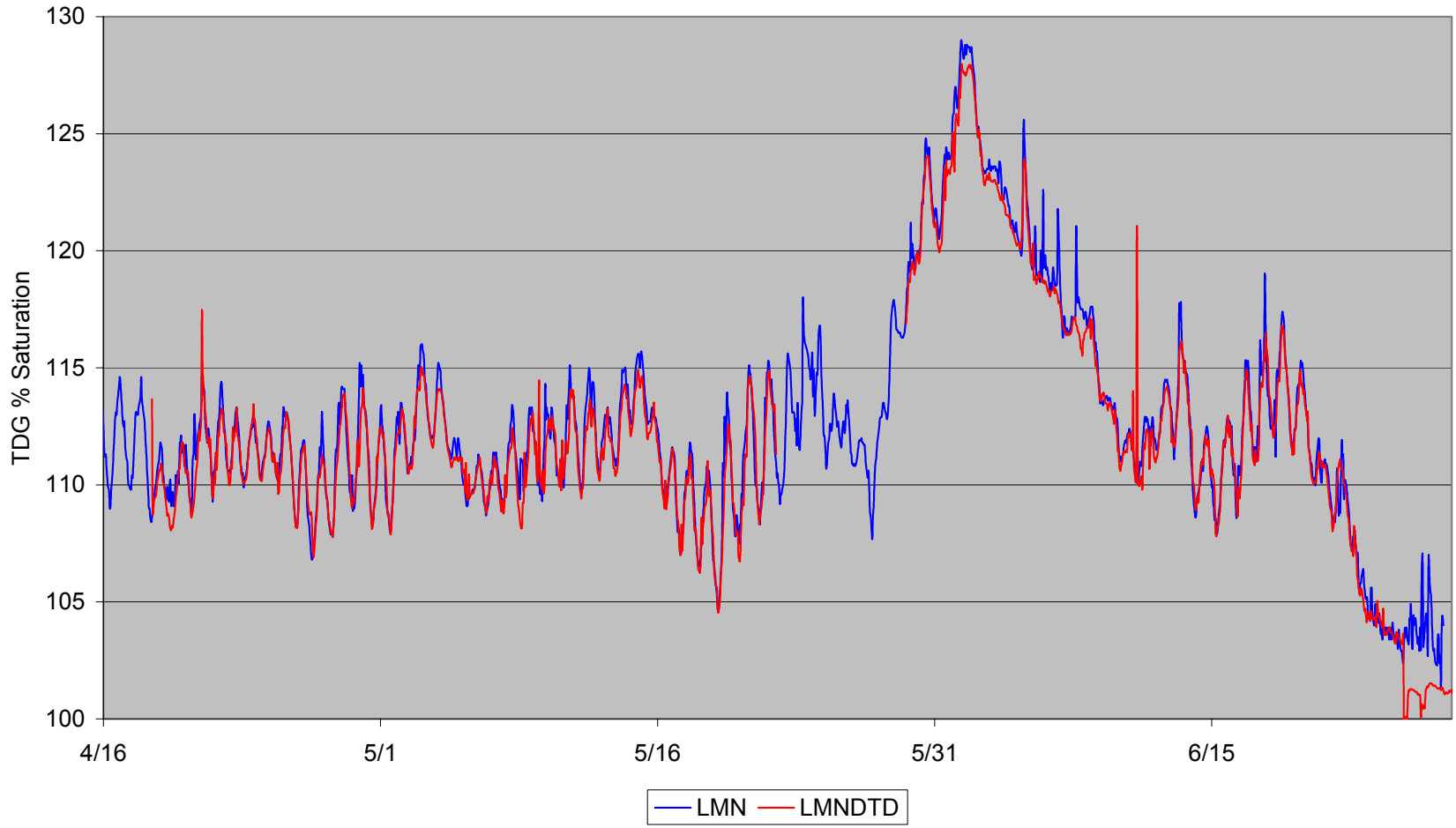


Figure 33. Lower Monumental Dam TDG Saturation LMN and LMNDTD, 2003.

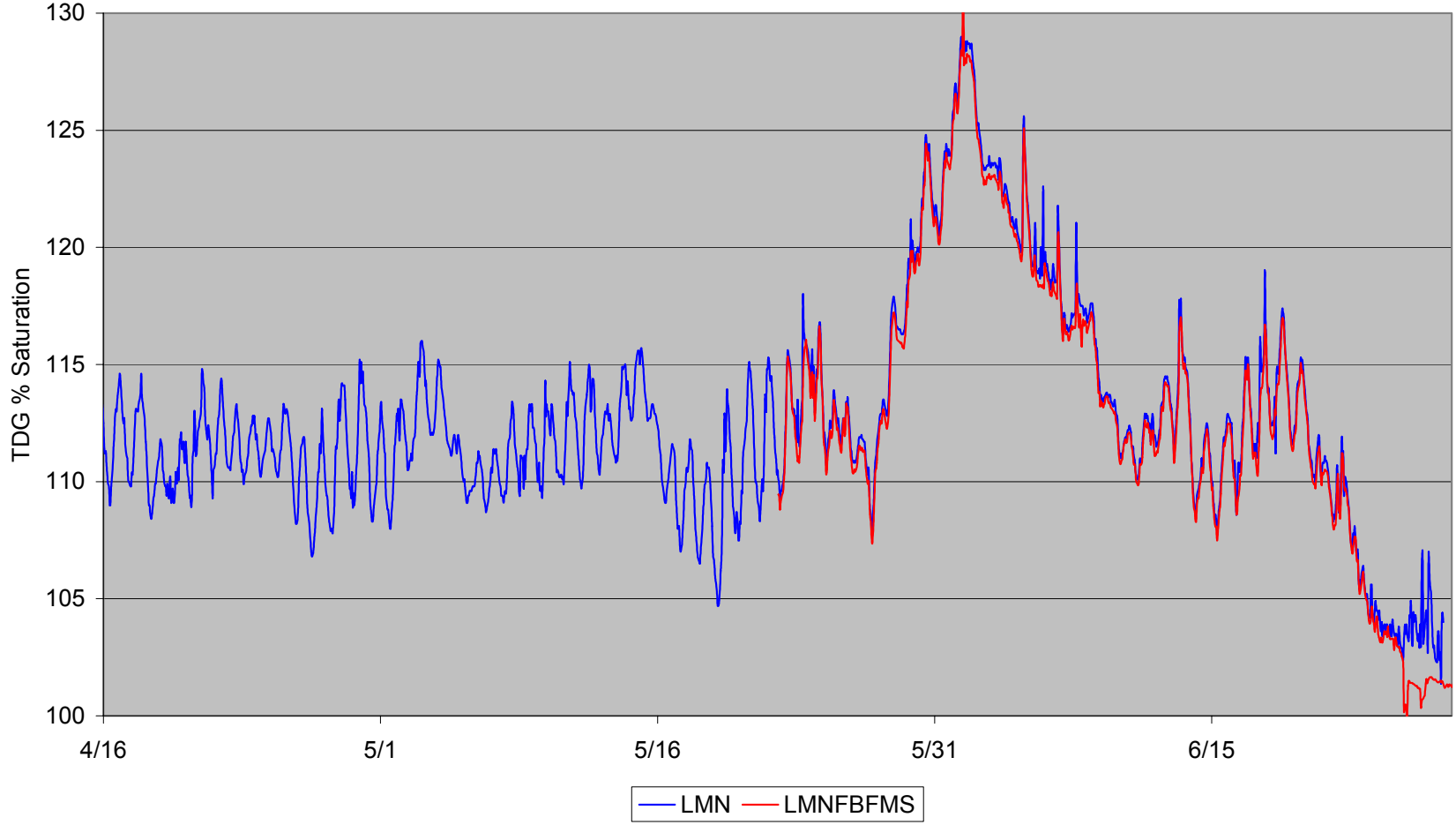


Figure 34. Lower Monumental Dam TDG Saturation LMN and LMNFBFMS, 2003.

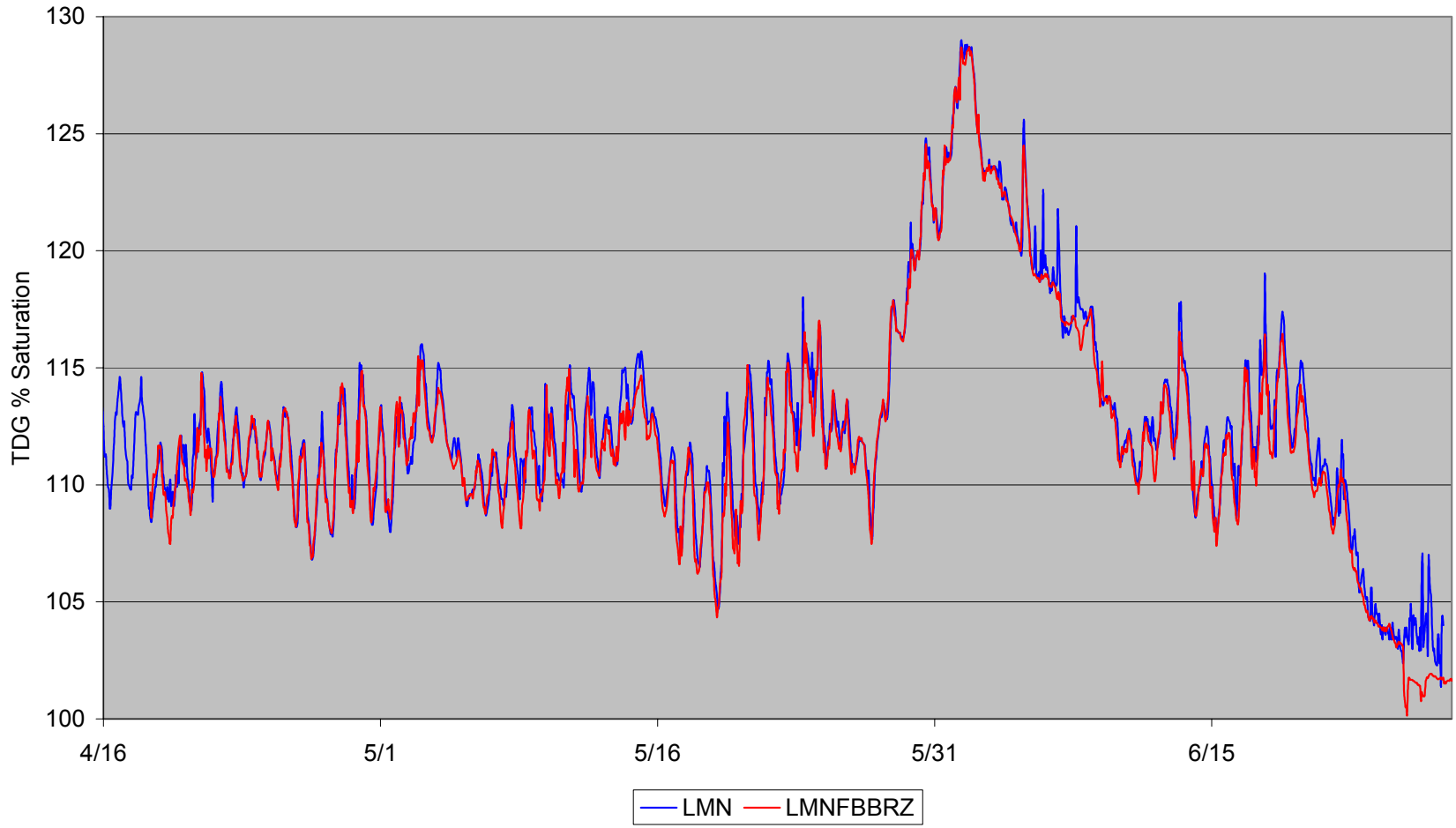


Figure 35. Lower Monumental Dam TDG Saturation LMN and LMNFBBRZ, 2003.

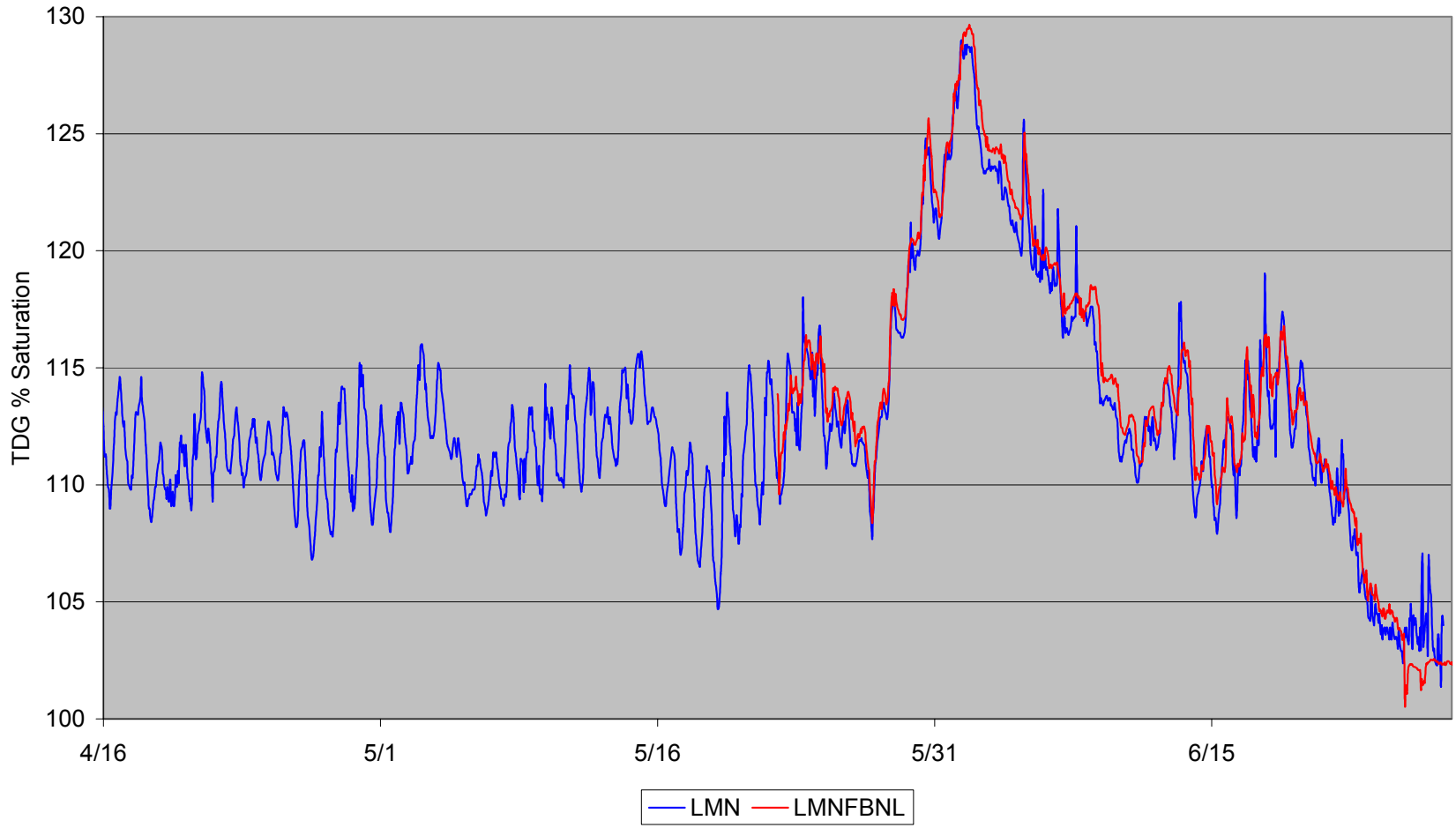


Figure 36. Lower Monumental Dam TDG Saturation LMN and LMNFBNL, 2003.

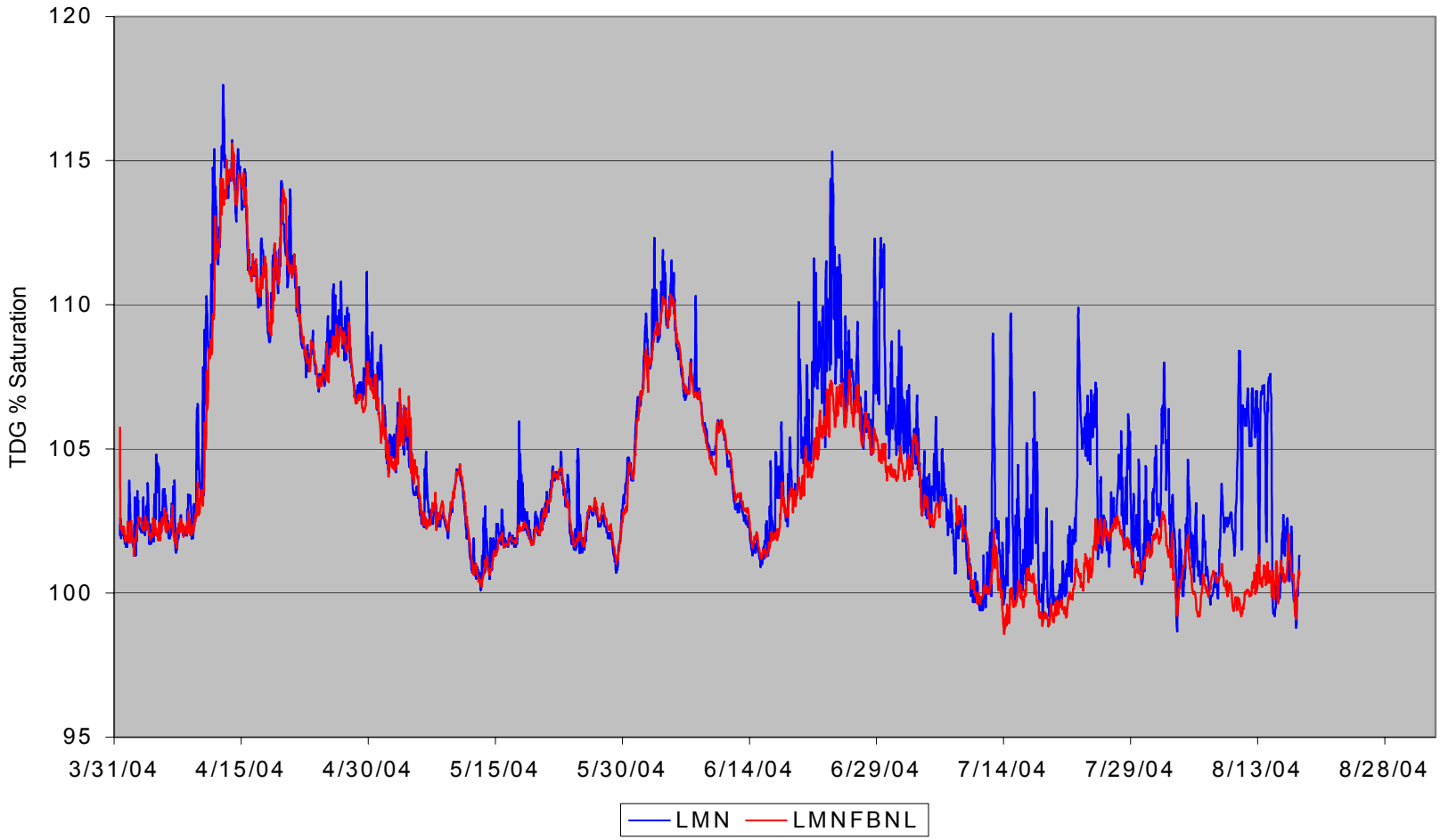


Figure 37. Lower Monumental Dam TDG Saturation LMN and LMNFBNL, 2004.

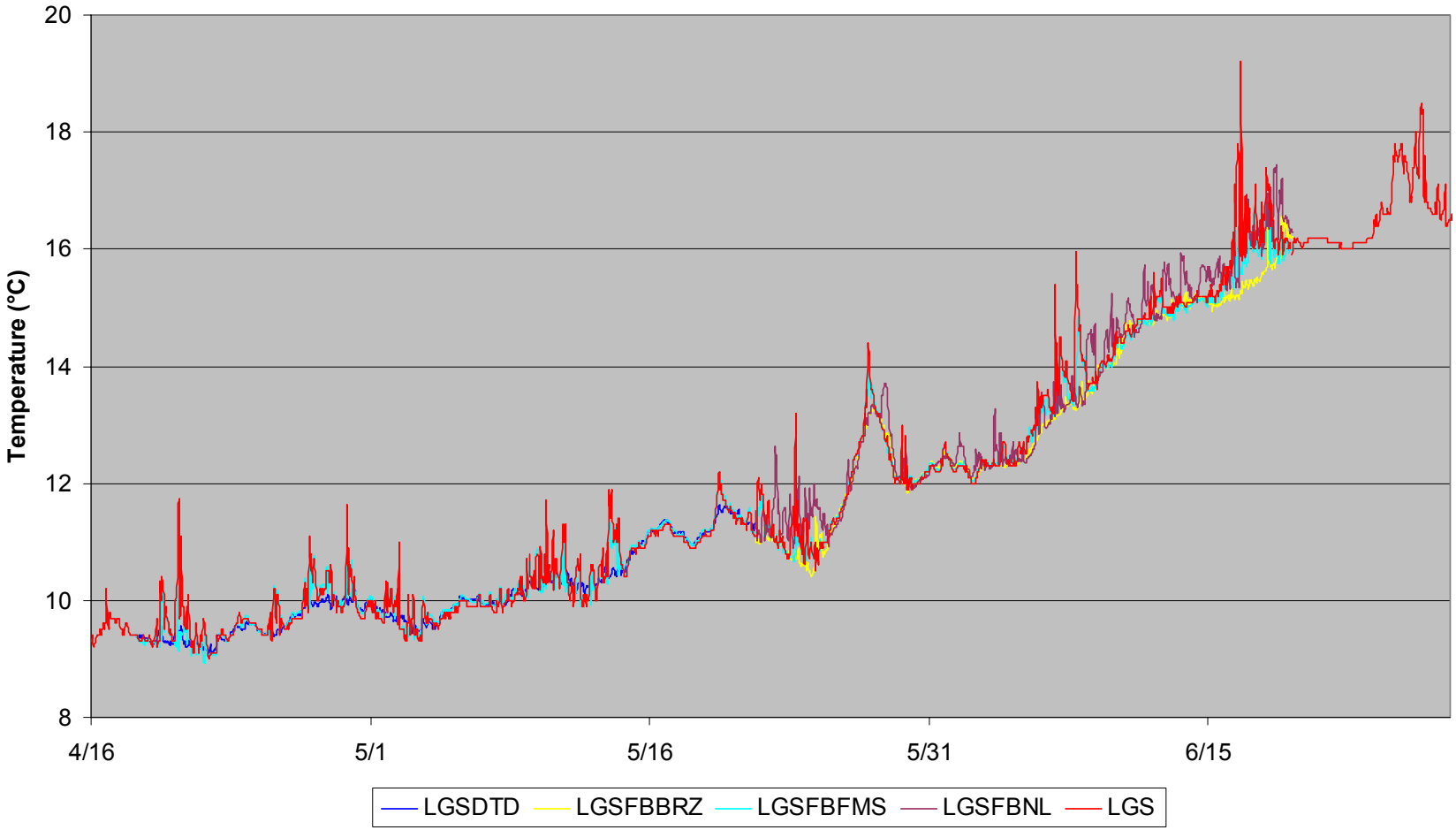


Figure 38. Little Goose Dam alternate TDG monitor station temperature, 2003.

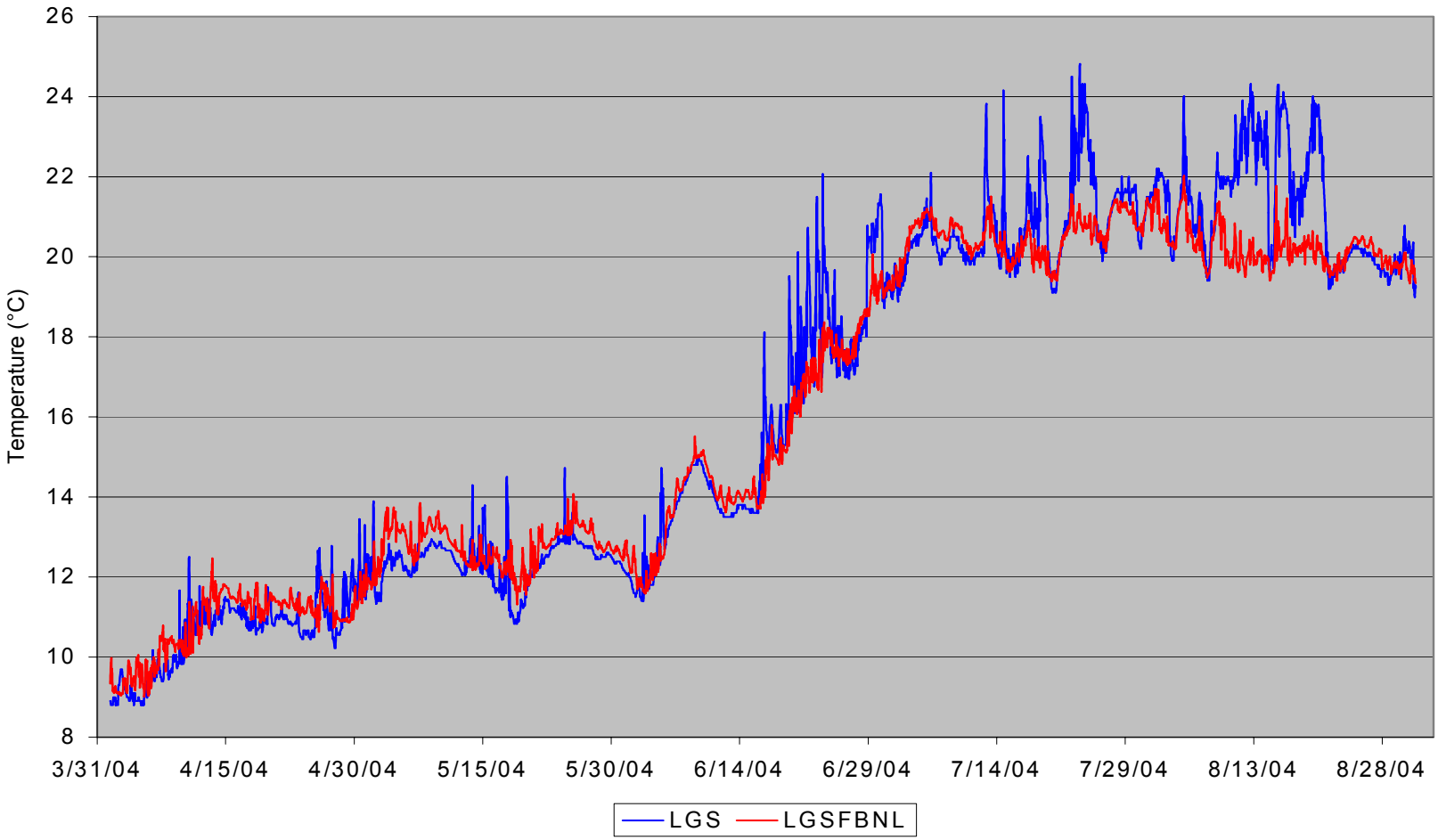


Figure 39. Little Goose Dam Forebay Temperature, 2004.

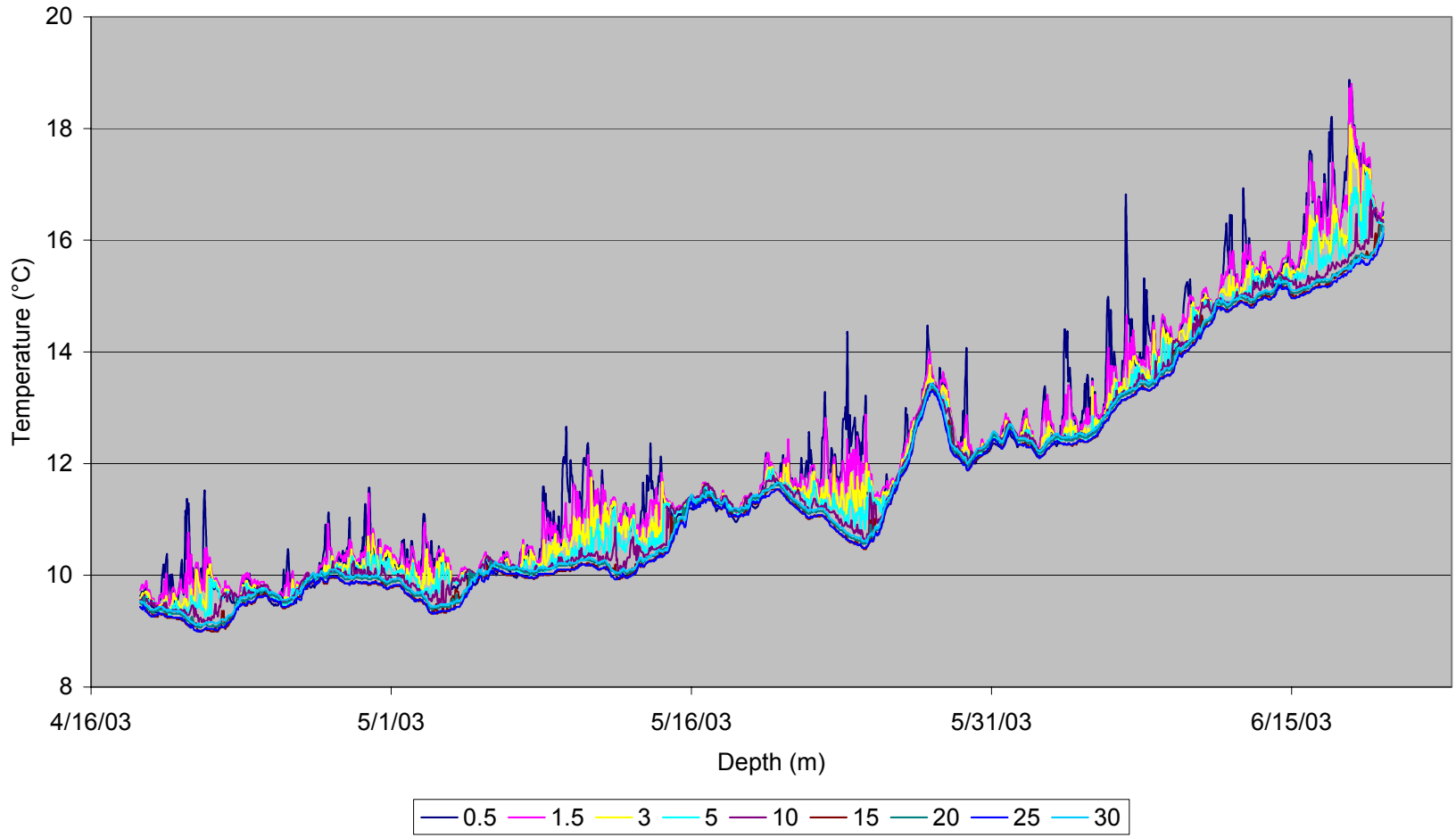


Figure 40. Little Goose Dam forebay thermal profile, 2003.

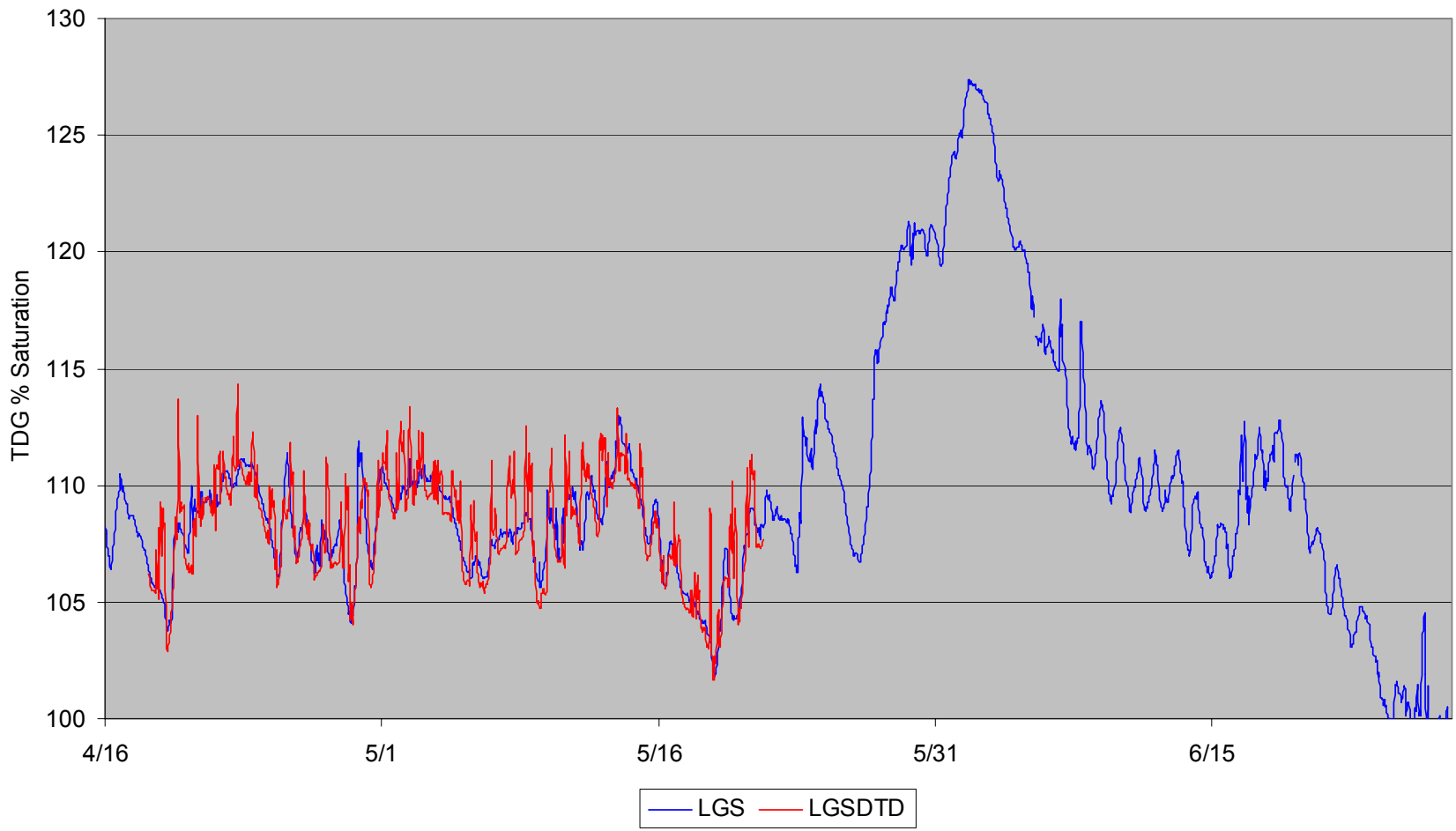


Figure 41. Little Goose Dam TDG Saturation LGS and LGSDTD, 2003.

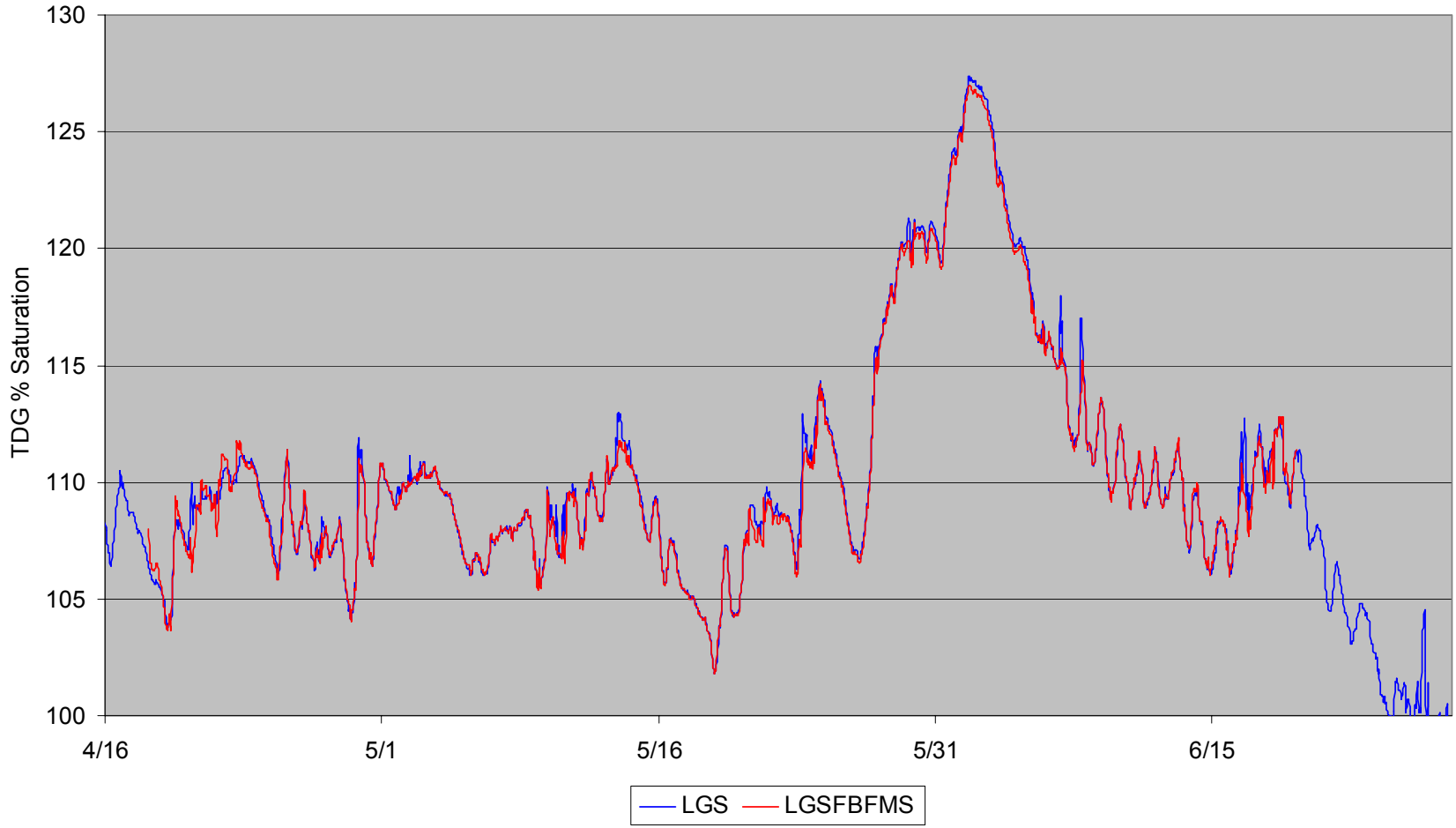


Figure 42. Little Goose Dam TDG Saturation LGS and LGSFBFMS, 2003.

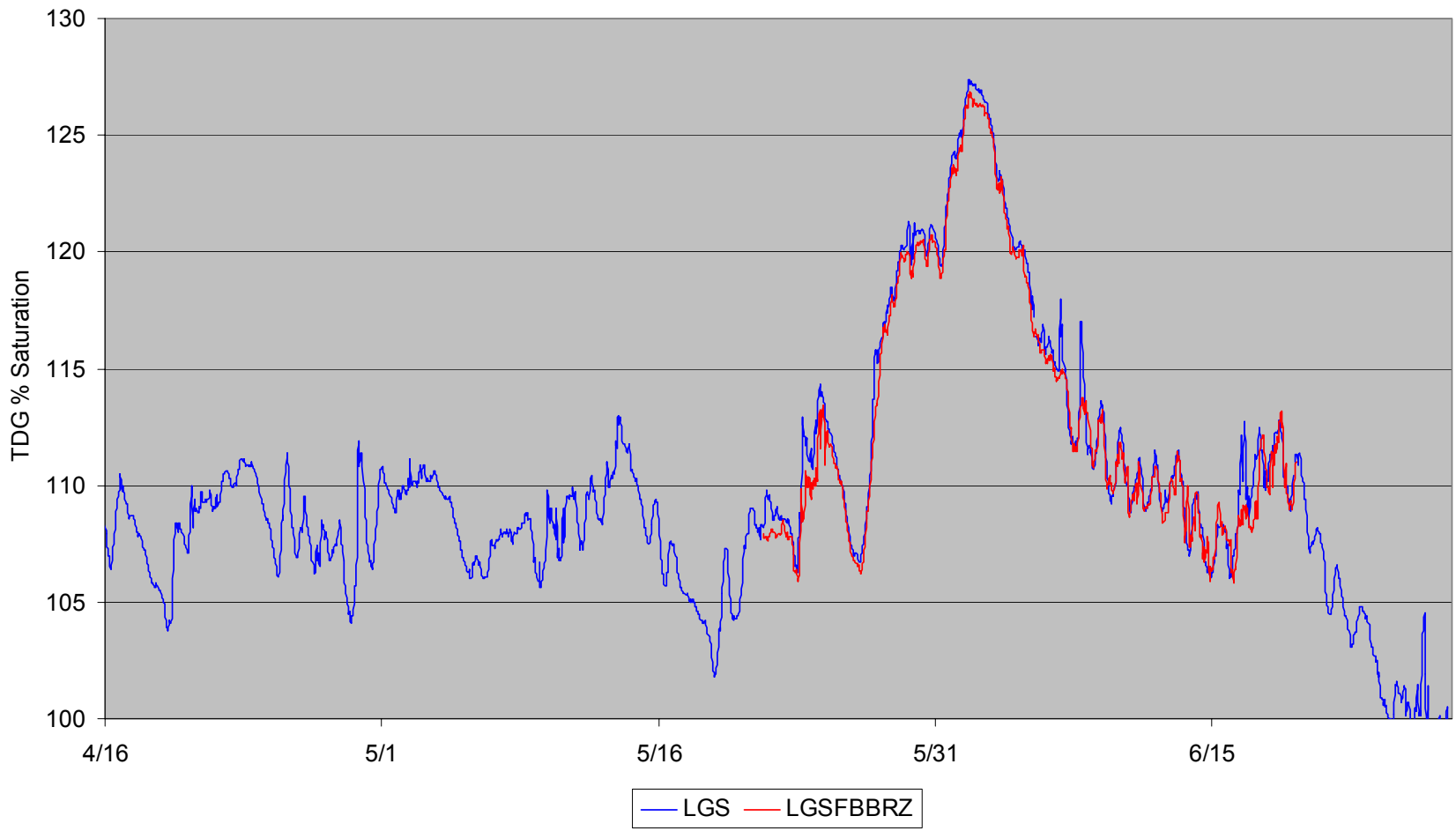


Figure 43. Little Goose Dam TDG Saturation LGS and LGSFBBRZ, 2003.

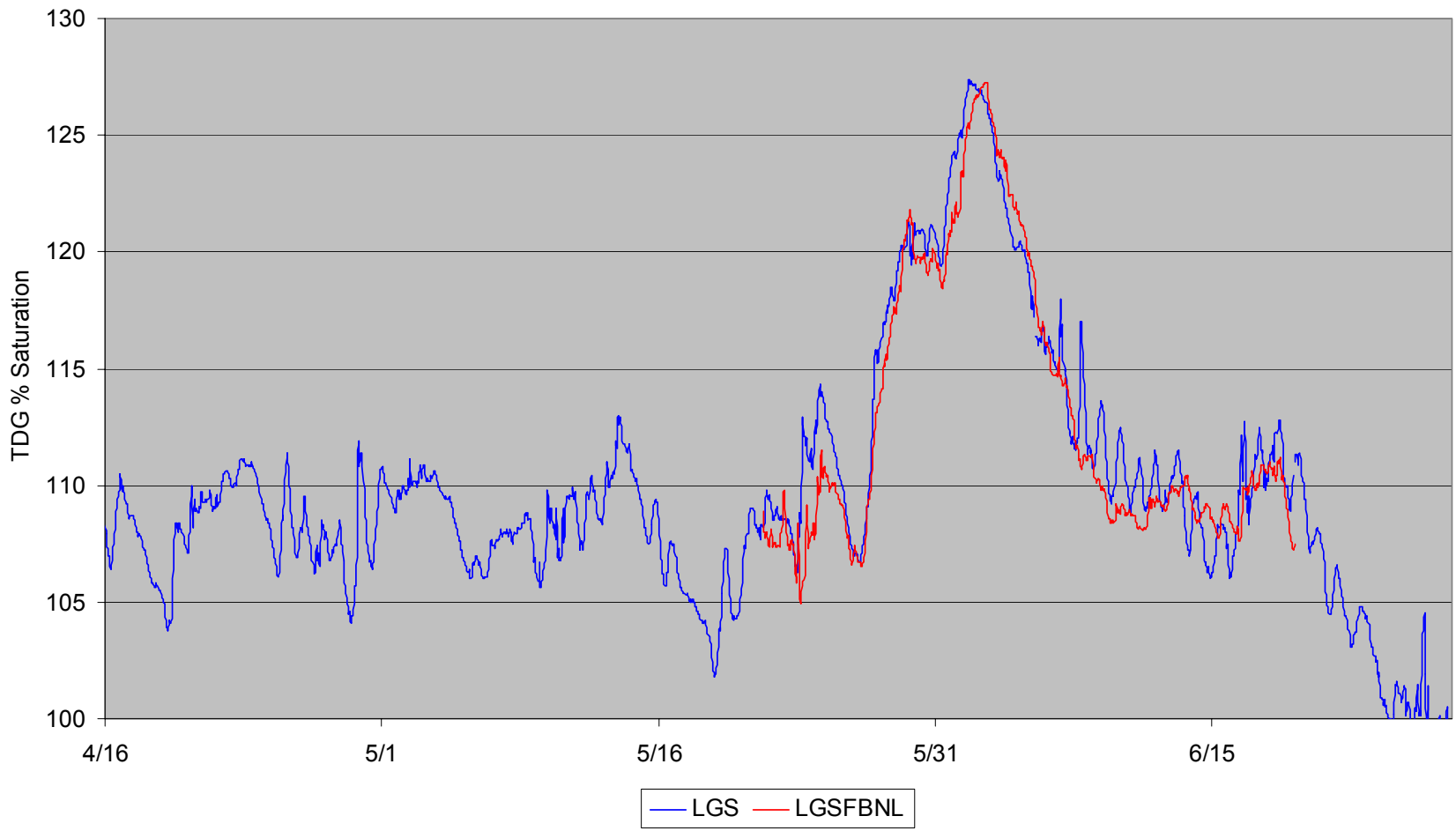


Figure 44. Little Goose Dam TDG Saturation LGS and LGSFBNL, 2003.

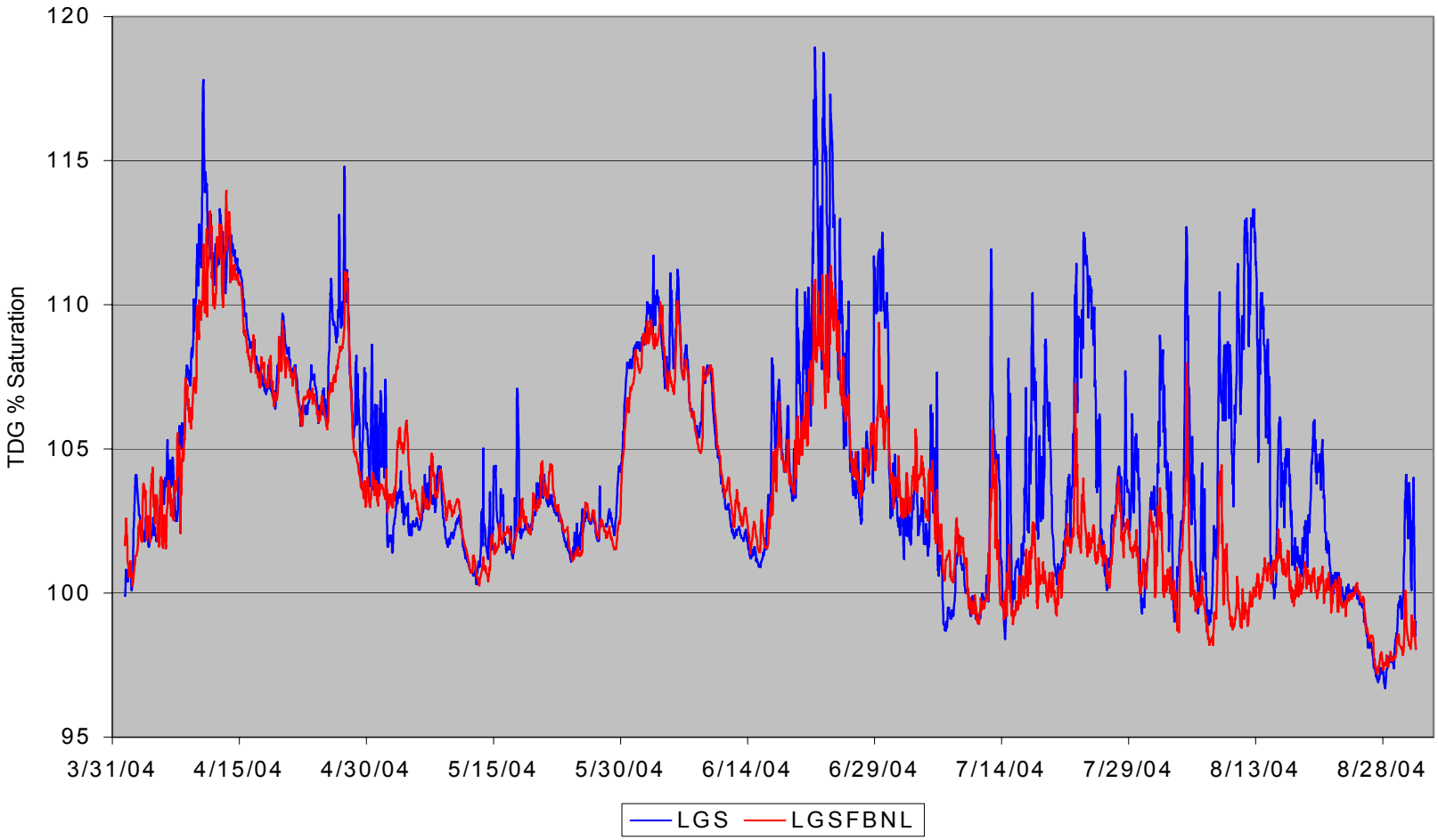


Figure 45. Little Goose Dam TDG Saturation LGS and LGSFBNL, 2004.

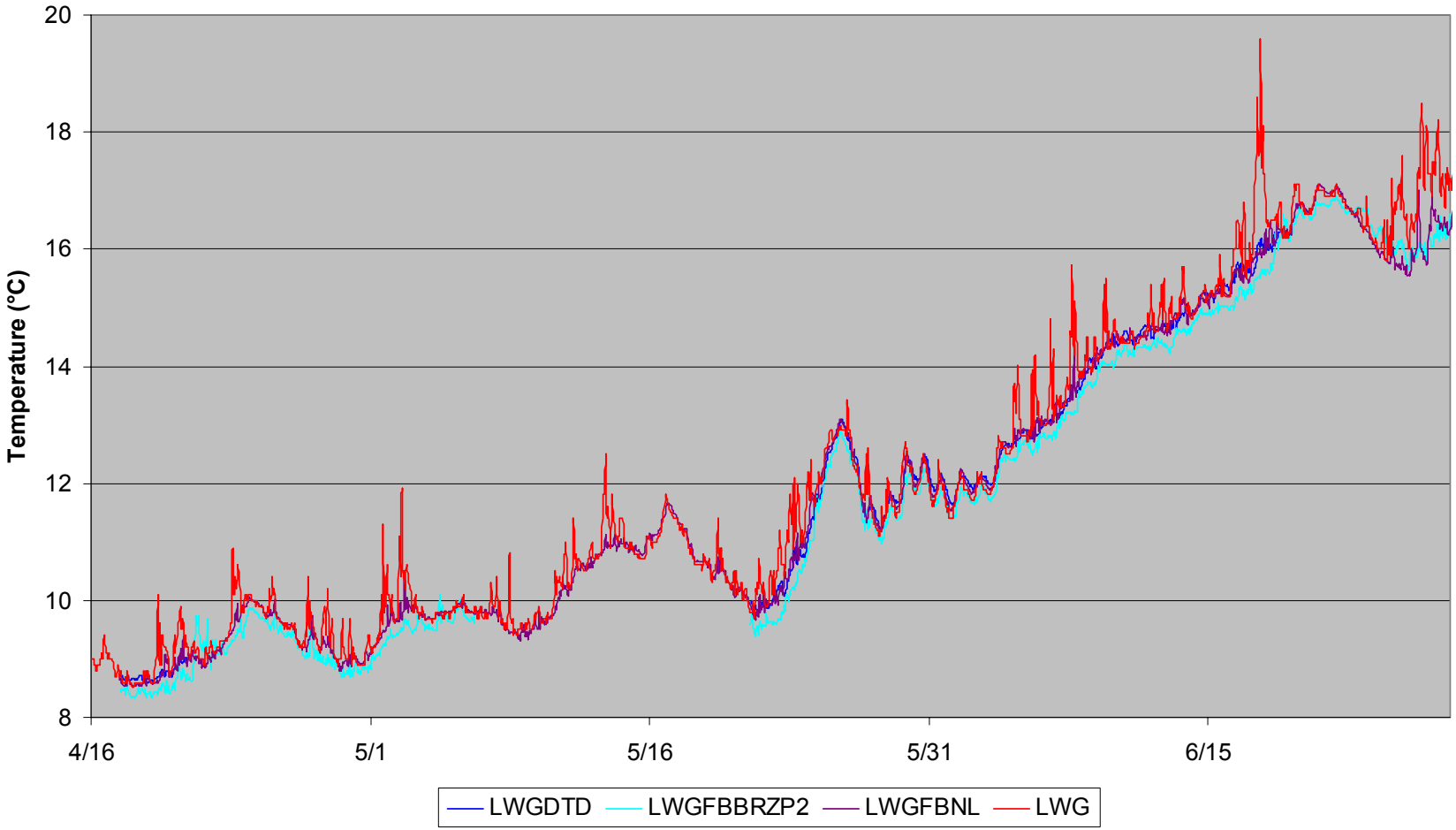


Figure 46. Lower Granite Dam alternate TDG monitor station temperature, 2003.

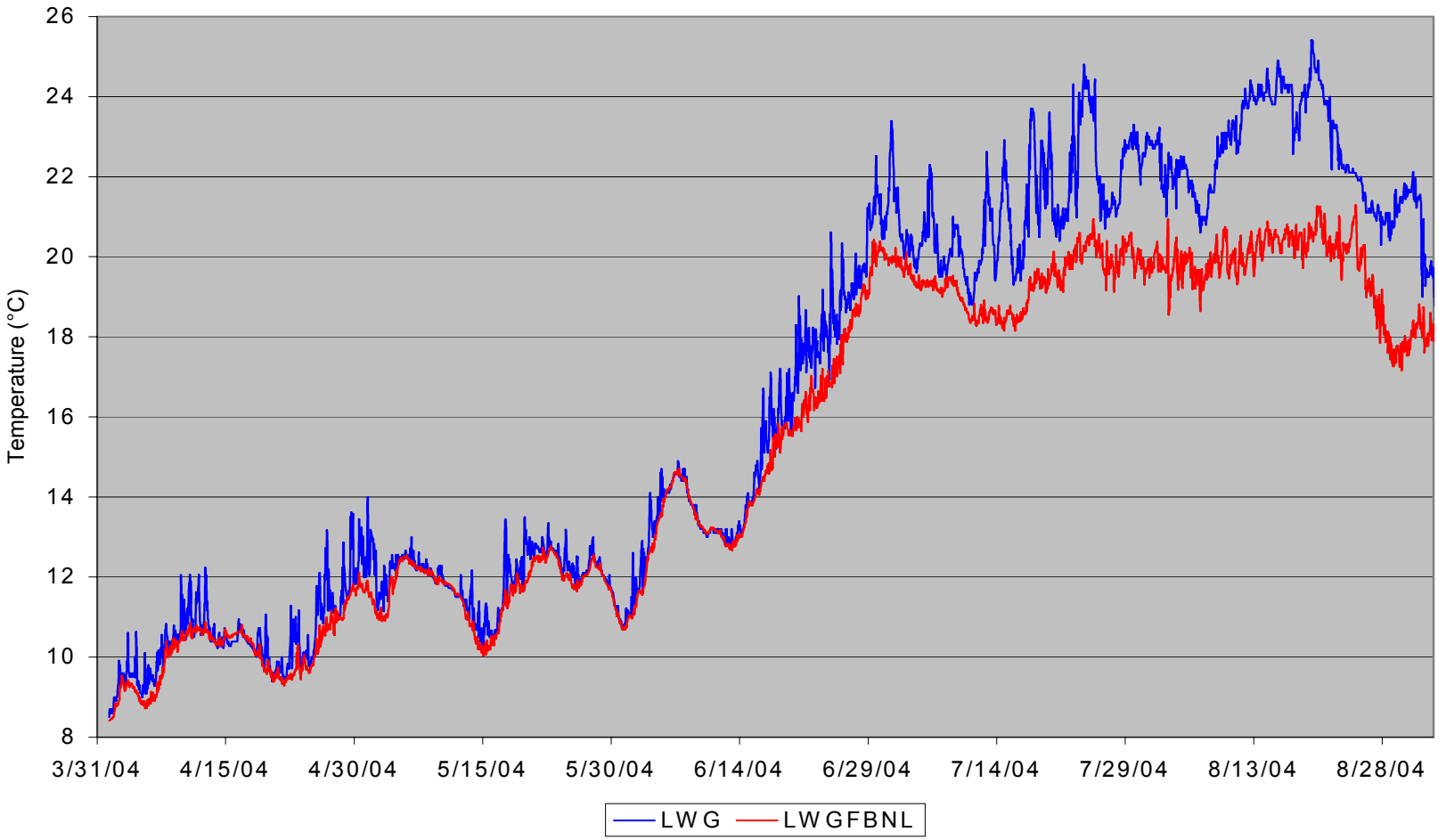


Figure 47. Lower Granite Dam Forebay Temperature, 2003.

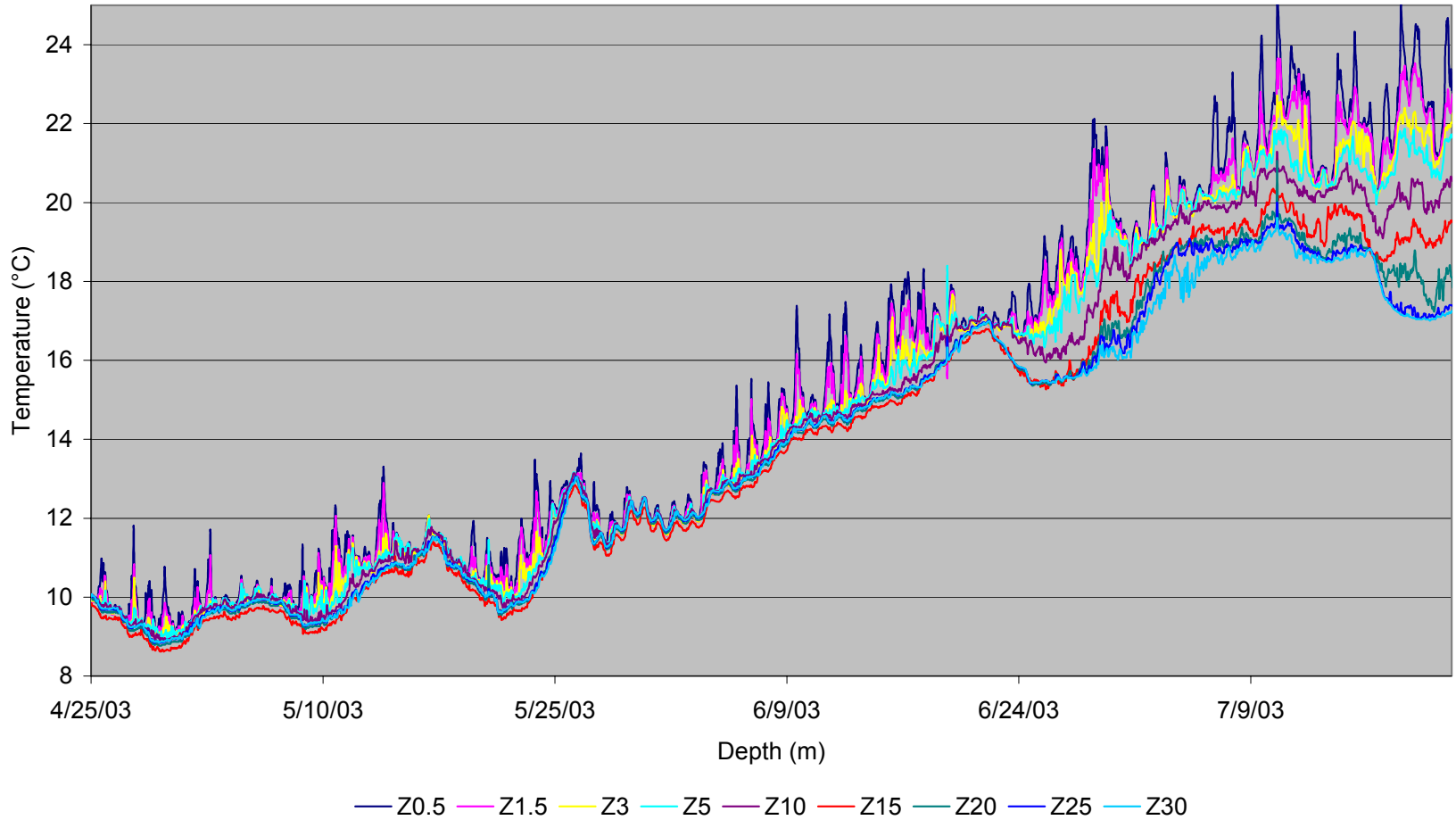


Figure 48. Lower Granite Dam forebay thermal profile, 2003.

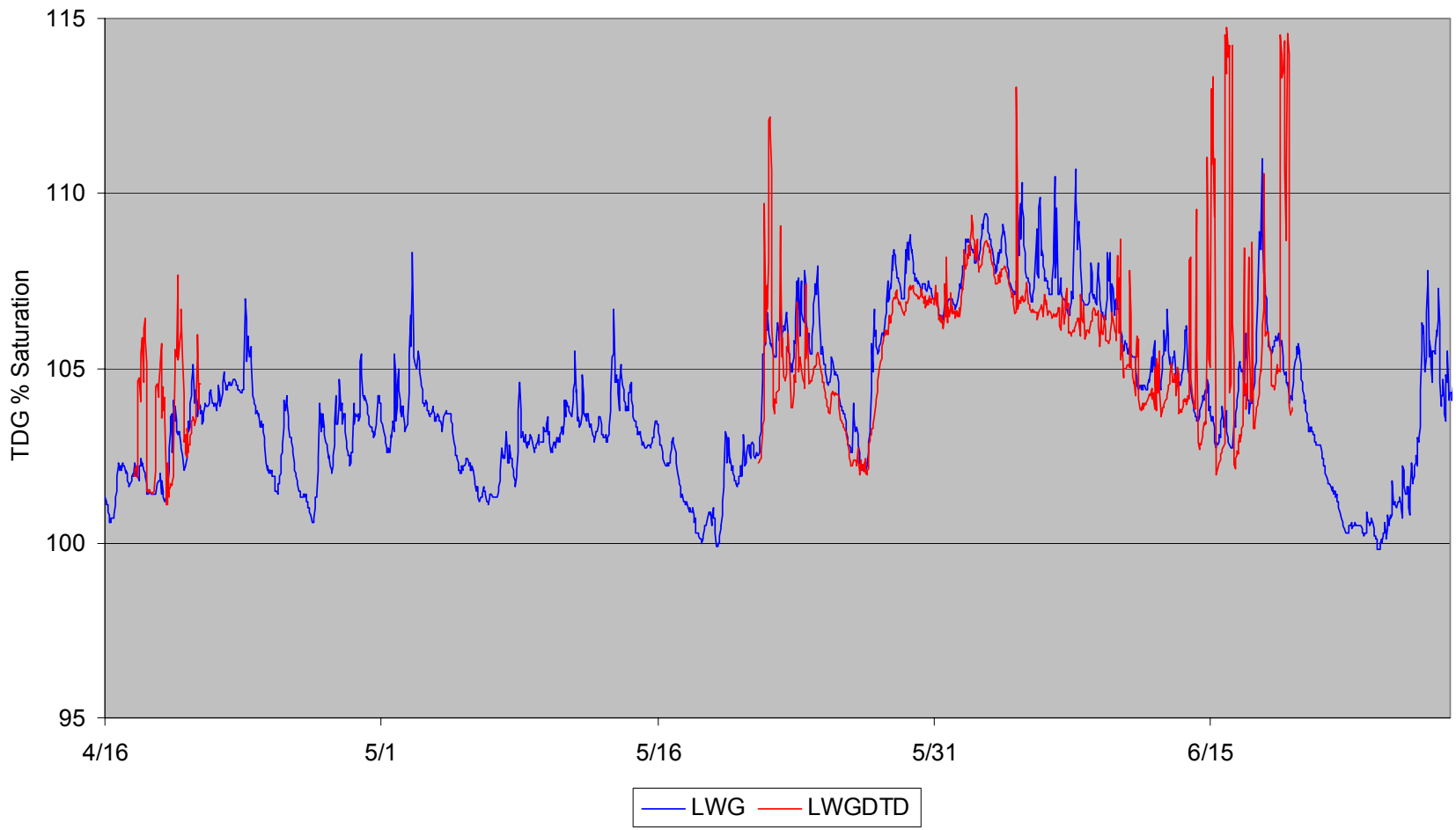


Figure 49. Lower Granite Dam TDG Saturation LWG and LWGDTD, 2003.

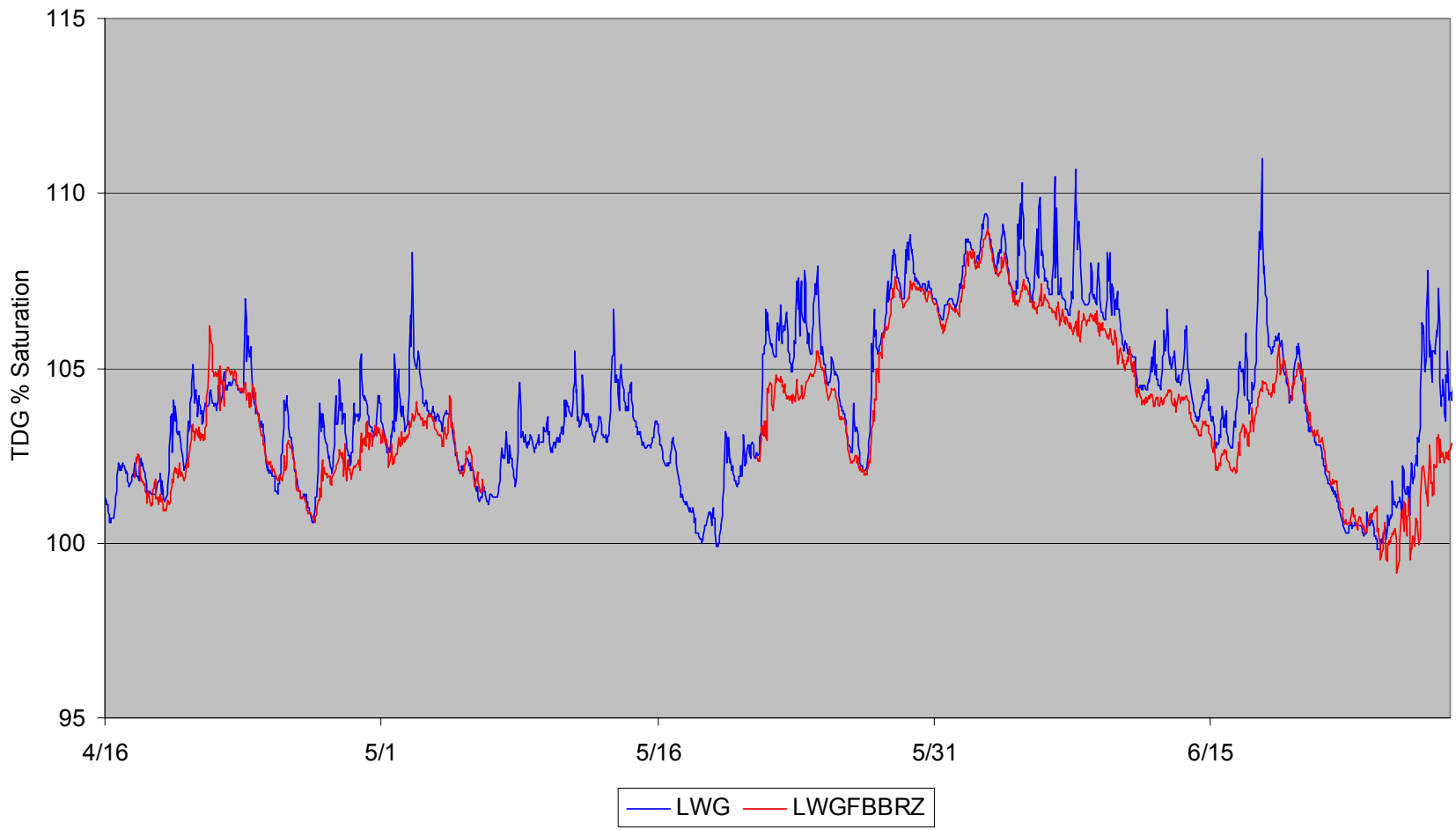


Figure 50. Lower Granite Dam TDG Saturation LWG and LWGFBBRZ, 2003.

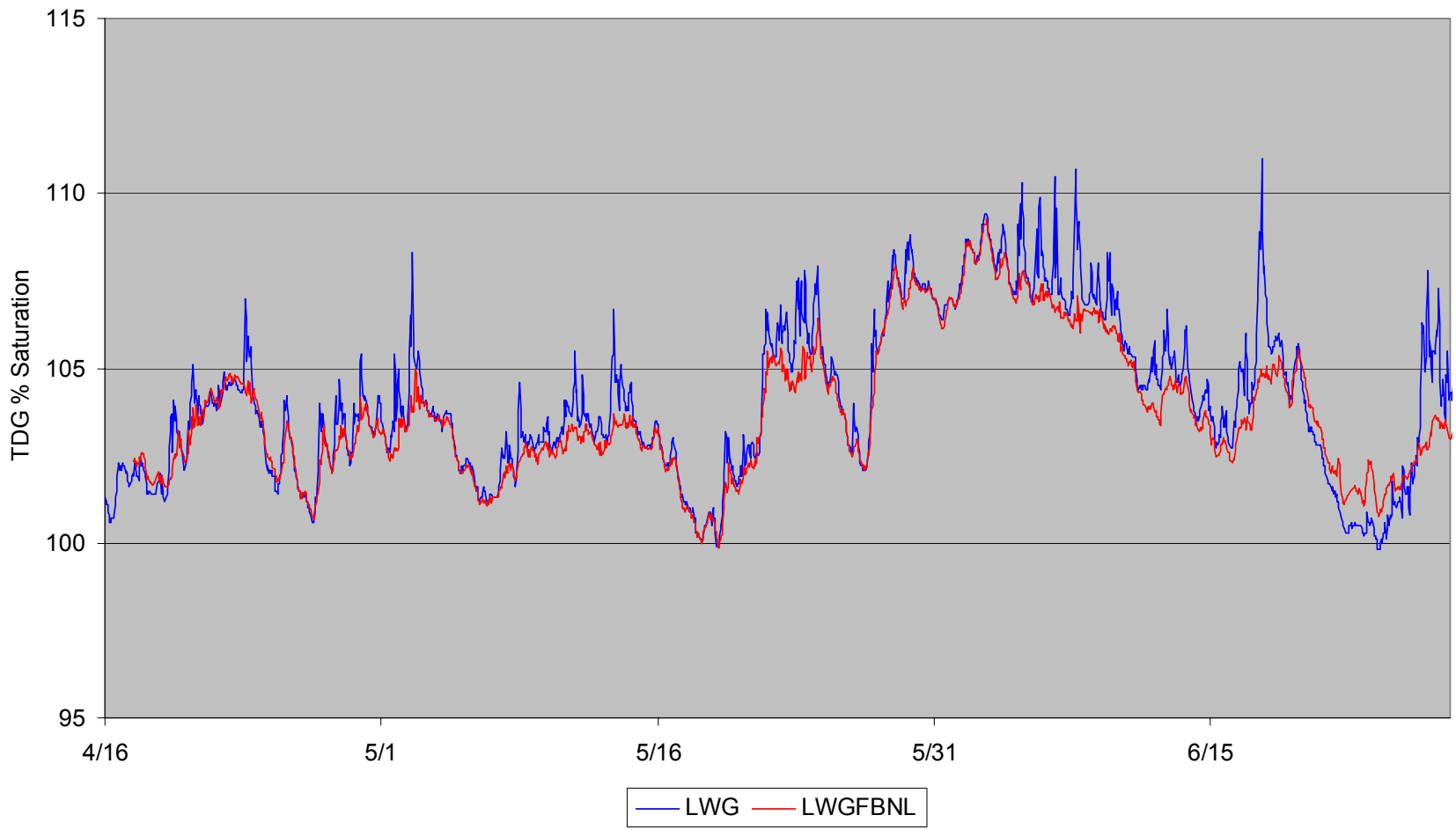


Figure 51. Lower Granite Dam TDG Saturation LWG and LWGFBNL, 2003.

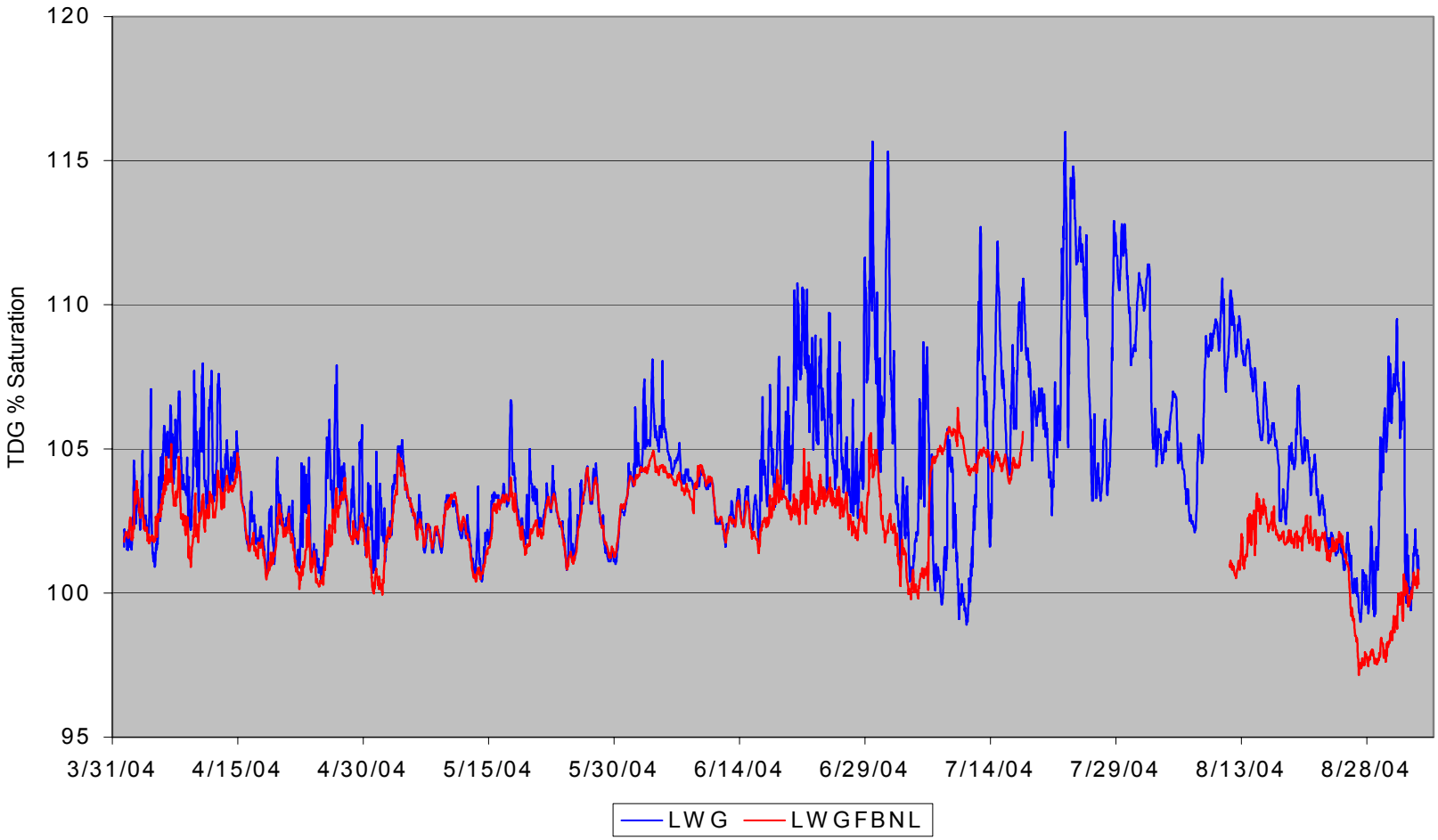


Figure 52. Lower Granite Dam TDG Saturation LWG and LWGFBNL, 2004.

TDG FOREBAY FIXED MONITORING STATION REVIEW AND EVALUATION FOR LOWER SNAKE RIVER PROJECTS AND MCNARY DAM, 2003-2004

Tables

Table 1. Compliance parameter calculated for McNary Dam TDG stations, 2003.

DATE	MCQO	MCQW	MCNDTD	MCNFBBRZP1	MCNFBFMSP1	MCNFBFMSP2
30-May-2003	115.16	115.12	114.33	115.22	114.66	115.04
31-May-2003	114.25	113.98	113.68	114.75	114.09	113.89
1-Jun-2003	113.98	113.27	114.11	115.22	113.64	113.22
2-Jun-2003	118.14	117.03	116.86	117.95	117.88	117.06
3-Jun-2003	118.49	117.48	115.91	117.20	118.21	117.39
4-Jun-2003	117.73	116.64	115.50	116.72	117.37	116.59
5-Jun-2003	117.61	117.55	115.77	116.90	117.22	116.62
6-Jun-2003	119.34	117.25	115.98	116.87	118.91	116.91
7-Jun-2003	118.33	117.52	115.22	116.20	118.13	117.48
8-Jun-2003	117.15	116.89	115.77	116.56	116.96	116.91
9-Jun-2003	116.16	115.51	114.77	115.61	115.95	115.56
10-Jun-2003	113.61	113.25	112.07	112.97	113.42	113.50
11-Jun-2003	110.97	111.63	109.72	110.47	110.74	111.68
12-Jun-2003	111.63	112.50	111.07	111.55	111.42	112.58
13-Jun-2003	112.64	111.99	111.63	112.25	112.30	112.13
14-Jun-2003	111.40	110.68	110.37	111.16	111.22	110.79
15-Jun-2003	114.00	111.25	110.10	110.56	113.63	111.30
16-Jun-2003	113.02	114.55	111.40	111.90	112.57	113.99
17-Jun-2003	114.82	115.26	113.07	113.69	114.50	115.45
18-Jun-2003	113.94	114.36	113.61	114.42	113.72	114.67
Average	115.1	114.7	113.5	114.4	114.8	114.6
Count	20	20	20	20	20	20
Exceedance	9	10	8	10	8	10
% Exceedance	45.00	50.00	40.00	50.00	40.00	50.00

Table 2. Compliance parameter calculated for Ice Harbor Dam TDG stations, 2003.

DATE	IHR	IHRDTD	IHRFBBRZ	IHRFBNL	IHRFBFMS
30-May-2003	118.93	118.40	119.10	118.96	119.01
31-May-2003	119.69	119.06	119.78	119.62	119.67
1-Jun-2003	123.12	122.36	123.15	122.99	123.20
2-Jun-2003	123.53	122.86	123.50	123.35	123.42
3-Jun-2003	122.13	121.42	122.35	122.22	122.08
4-Jun-2003	120.70	119.75	120.68	120.59	120.39
5-Jun-2003	120.00	118.99	119.71	119.51	119.53
6-Jun-2003	119.73	118.47	119.35	119.21	119.21
7-Jun-2003	118.92	117.42	118.05	117.87	117.85
8-Jun-2003	117.49	116.70	117.56	117.48	117.28
9-Jun-2003	115.47	114.95	115.54	115.48	115.45
10-Jun-2003	112.78	112.55	112.96	112.94	112.80
11-Jun-2003	111.21	110.86	111.02	110.75	110.93
12-Jun-2003	112.61	112.71	112.46	112.30	112.39
13-Jun-2003	111.96	112.59	112.08	111.95	111.96
14-Jun-2003	111.44	111.08	111.48	111.35	111.43
15-Jun-2003	112.55	112.32	112.00	111.85	111.87
16-Jun-2003	113.95	114.05	114.02	113.91	114.04
17-Jun-2003	117.20	116.32	116.53	116.56	116.80
18-Jun-2003	117.81	117.11	117.38	117.22	117.49
Average	117.1	116.5	116.9	116.8	116.8
Count	20	20	20	20	20
Exceedance	13	12	13	13	13
% Exceedance	65.00	60.00	65.00	65.00	65.00

Table 3. Compliance parameter calculated for Lower Monumental Dam TDG stations, 2003.

DATE	LMN	LMNDTD	LMNFBBRZ	LMNFBFMS	LMNFBNL
30-May-2003	123.67	123.24	123.37	123.23	124.35
31-May-2003	124.13	123.39	124.12	123.72	124.28
1-Jun-2003	128.66	127.75	128.42	129.05	129.34
2-Jun-2003	126.46	126.11	126.31	125.90	127.75
3-Jun-2003	123.57	122.91	123.34	122.99	124.32
4-Jun-2003	122.72	122.08	122.52	122.20	123.11
5-Jun-2003	120.77	119.93	119.99	119.90	121.60
6-Jun-2003	119.63	118.38	118.67	119.06	119.65
7-Jun-2003	117.93	116.82	117.01	117.07	118.04
8-Jun-2003	117.35	116.72	117.05	116.85	118.24
9-Jun-2003	113.65	113.64	113.91	113.43	114.69
10-Jun-2003	111.92	112.75	111.71	111.79	112.88
11-Jun-2003	112.64	112.00	112.13	112.27	113.07
12-Jun-2003	113.95	113.71	113.65	113.72	114.61
13-Jun-2003	115.79	115.16	115.05	115.42	115.64
14-Jun-2003	111.52	111.46	111.22	111.31	111.92
15-Jun-2003	111.72	111.77	111.39	111.52	111.93
16-Jun-2003	113.51	113.16	113.25	113.10	113.08
17-Jun-2003	115.50	114.57	114.21	114.71	115.15
18-Jun-2003	115.93	115.63	115.33	115.50	116.14
Average	118.05	117.56	117.63	117.64	118.49
Count	20	20	20	20	20
Exceedance	13	12	12	12	13
% Exceedance	65.00	60.00	60.00	60.00	65.00

Table 4. Compliance parameter calculated for Little Goose Dam TDG stations, 2003.

DATE	LGS	LGSDTD	LGSFBBRZ	LGSFBFMS	LGSFBNL
30-May-2003	120.98		120.51	120.71	119.85
31-May-2003	122.72		122.17	122.47	120.49
1-Jun-2003	126.73		126.25	126.41	124.96
2-Jun-2003	127.03		126.36	126.64	127.03
3-Jun-2003	124.30		123.99	123.90	125.08
4-Jun-2003	120.63		120.19	120.22	122.11
5-Jun-2003	118.19		117.38	117.75	119.37
6-Jun-2003	116.28		115.34	115.90	115.44
7-Jun-2003	114.44		113.73	113.69	113.73
8-Jun-2003	113.22		113.15	113.31	111.23
9-Jun-2003	112.18		111.77	112.34	109.49
10-Jun-2003	111.11		110.91	111.22	108.97
11-Jun-2003	110.73		110.37	110.89	109.18
12-Jun-2003	110.36		110.15	110.35	109.70
13-Jun-2003	110.76		110.48	110.81	110.12
14-Jun-2003	109.03		108.68	109.14	109.03
15-Jun-2003	108.20		108.36	108.21	108.96
16-Jun-2003	110.49		108.77	109.32	109.27
17-Jun-2003	111.56		111.27	111.32	110.68
18-Jun-2003	112.30		112.27	112.41	110.89
Average	115.56		115.10	115.35	114.78
Count	20	0	20	20	20
Exceedance	8	0	8	8	8
% Exceedance	40.00		40.00	40.00	40.00

Table 5. Compliance parameter calculated for Lower Granite Dam TDG stations, 2003.

DATE	LWG	LWGDTD	LWGFBBRZP2	LWGFBNL
30-May-2003	107.44	107.07	107.26	107.33
31-May-2003	106.99	107.05	106.73	106.92
1-Jun-2003	108.38	108.00	107.87	108.23
2-Jun-2003	109.08	108.73	108.63	108.89
3-Jun-2003	108.67	107.98	108.21	108.26
4-Jun-2003	108.79	107.87	107.41	107.64
5-Jun-2003	108.60	106.90	107.11	107.27
6-Jun-2003	108.13	106.75	106.85	107.03
7-Jun-2003	108.75	106.64	106.36	106.58
8-Jun-2003	107.43	106.57	106.49	106.65
9-Jun-2003	107.42	106.52	106.13	106.31
10-Jun-2003	105.93	106.12	105.39	105.51
11-Jun-2003	105.04	104.59	104.24	104.17
12-Jun-2003	105.57	104.88	104.25	104.51
13-Jun-2003	105.43	105.18	104.16	104.58
14-Jun-2003	104.18	105.78	103.40	103.63
15-Jun-2003	103.62	112.09	102.73	102.93
16-Jun-2003	104.99	106.65	103.08	103.40
17-Jun-2003	108.18	106.47	104.34	104.72
18-Jun-2003	106.07	109.13	105.03	105.12
Average	106.93	107.05	105.78	105.98
Count	20	20	20	20
Exceedance	0	0	0	0
% Exceedance	0.00	0.00	0.00	0.00

Table 6. Paired samples statistics for Forebay TDG stations, 2003.

		Mean	N	Std. Deviation	Std. Error Mean
Pair 1	MCQO	113.6469	55	2.82779	.38130
	MCQW	113.5330	55	2.76918	.37340
Pair 2	MCQO	113.6469	55	2.82779	.38130
	MCNDTD	111.9439	55	2.55346	.34431
Pair 3	MCQO	113.6469	55	2.82779	.38130
	MCNFBBRZP1	112.5329	55	2.70636	.36493
Pair 4	MCQO	113.6469	55	2.82779	.38130
	MCNFBFMSP1	113.2317	55	2.79599	.37701
Pair 5	MCQO	113.6469	55	2.82779	.38130
	MCNFBFMSP2	113.3864	55	2.68986	.36270
Pair 6	MCQW	113.5330	55	2.76918	.37340
	MCNDTD	111.9439	55	2.55346	.34431
Pair 7	MCQW	113.5330	55	2.76918	.37340
	MCNFBBRZP1	112.5329	55	2.70636	.36493
Pair 8	MCQW	113.5330	55	2.76918	.37340
	MCNFBFMSP1	113.2317	55	2.79599	.37701
Pair 9	MCQW	113.5330	55	2.76918	.37340
	MCNFBFMSP2	113.3864	55	2.68986	.36270
Pair 10	IHR	115.5976	54	3.09707	.42146
	IHRDTD	114.7643	54	2.89192	.39354
Pair 11	IHR	115.5976	54	3.09707	.42146
	IHRFBBRZ	115.2568	54	3.10908	.42309
Pair 12	IHR	115.5976	54	3.09707	.42146
	IHRFBFMS	115.1355	54	3.09051	.42056
Pair 13	IHR	117.0616	20	4.04229	.90388
	IHRFBNL	116.8062	20	4.05309	.90630
Pair 14	LMN	117.2425	27	4.93194	.94915
	LMNDTD	116.8380	27	4.71616	.90763
Pair 15	LMN	117.2425	27	4.93194	.94915
	LMNFBBRZ	116.8750	27	4.93932	.95057
Pair 16	LMN	117.2425	27	4.93194	.94915
	LMNFBFMS	116.7910	27	4.93428	.94960
Pair 17	LMN	117.2425	27	4.93194	.94915
	LMNFBNL	117.6738	27	5.03668	.96931
Pair 18	LGS	114.9259	28	5.66491	1.07057
	LGSFBBRZ	114.3262	28	5.67972	1.07337
Pair 19	LGS	114.9259	28	5.66491	1.07057
	LGSFBFMS	114.6811	28	5.60487	1.05922
Pair 20	LGS	114.9259	28	5.66491	1.07057
	LGSFBNL	113.9373	28	6.05994	1.14522
Pair 21	LWG	106.3443	32	1.91354	.33827
	LWGDTD	106.5247	32	1.81051	.32006
Pair 22	LWG	105.4903	48	2.07085	.29890
	LWGFBBRZP2	104.5124	48	1.91956	.27706
Pair 23	LWG	105.4903	48	2.07085	.29890
	LWGFBNL	104.7590	48	1.88759	.27245

Table 7. Paired Samples Tests for Forebay TDG stations, 2003.

		Paired Differences					t	df	Sig. (2-tailed)
					95% Confidence Interval of the Difference				
		Mean	Std. Deviation	Std. Error Mean	Lower	Upper			
Pair 1	MCQO - MCQW	.1139	1.04886	.14143	-.1696	.3975	.805	54	.424
Pair 2	MCQO - MCNDTD	1.7030	1.09191	.14723	1.4078	1.9982	11.567	54	.000
Pair 3	MCQO - MCNFBBRZP1	1.1140	1.19662	.16135	.7905	1.4374	6.904	54	.000
Pair 4	MCQO - MCNFBFMSP1	.4151	.17940	.02419	.3666	.4636	17.160	54	.000
Pair 5	MCQO - MCNFBFMSP2	.2605	1.04570	.14100	-.0222	.5432	1.847	54	.070
Pair 6	MCQW - MCNDTD	1.5891	1.00685	.13576	1.3169	1.8613	11.705	54	.000
Pair 7	MCQW - MCNFBBRZP1	1.0000	1.16804	.15750	.6843	1.3158	6.350	54	.000
Pair 8	MCQW - MCNFBFMSP1	.3012	1.06688	.14386	.0128	.5896	2.094	54	.041
Pair 9	MCQW - MCNFBFMSP2	.1466	.28676	.03867	.0691	.2241	3.791	54	.000
Pair 10	IHR - IHRDTD	.8333	.64707	.08805	.6567	1.0099	9.464	53	.000
Pair 11	IHR - IHRFBBRZ	.3408	.57525	.07828	.1838	.4978	4.354	53	.000
Pair 12	IHR - IHRFBFMS	.4622	.52236	.07108	.3196	.6048	6.502	53	.000
Pair 13	IHR - IHRFBNL	.2554	.32108	.07179	.1051	.4057	3.557	19	.002
Pair 14	LMN - LMNDTD	.4045	.45200	.08699	.2257	.5833	4.650	26	.000
Pair 15	LMN - LMNFBBRZ	.3675	.35539	.06840	.2269	.5081	5.373	26	.000
Pair 16	LMN - LMNFBFMS	.4515	.28775	.05538	.3377	.5653	8.153	26	.000
Pair 17	LMN - LMNFBNL	-.4313	.50819	.09780	-.6324	-.2303	-4.410	26	.000
Pair 18	LGS - LGSFBBRZ	.5996	.48168	.09103	.4129	.7864	6.587	27	.000
Pair 19	LGS - LGSFBFMS	.2448	.31520	.05957	.1226	.3670	4.109	27	.000
Pair 20	LGS - LGSFBNL	.9886	1.23306	.23303	.5105	1.4667	4.242	27	.000
Pair 21	LWG - LWGDTD	-.1804	2.14551	.37928	-.9539	.5932	-.476	31	.638
Pair 22	LWG - LWGFBBRZP2	.9780	.83551	.12060	.7354	1.2206	8.109	47	.000
Pair 23	LWG - LWGFBNL	.7314	.68185	.09842	.5334	.9293	7.431	47	.000

Table 8. Summary of fish spill compliance parameter comparison, 2004.

Project	Station	Average	Count	Exceedances	% Exceedances
McNary	MCQO	112.5	69	13	18.8
	MCNFBBRZ	109.1	69	0	0
	MCQW	111.2	73	10	13.7
	MCNFBNL	110.6	73	3	4.1
Ice Harbor	IHR	104.9	126	4	3.17
	IHRFBNL	103.9	126	3	2.38
Lower Monumental	LMN	105.4	139	2	1.44
	LMNFBNL	104.1	139	0	0
Little Goose	LGS	105.4	153	2	1.31
	LGSFBNL	103.8	153	0	0
Lower Granite	LWG	104.6	131	0	0
	LWGFBNL	102.7	131	0	0

Table 9. Summary of compliance with water quality standard for TDG, 2004.

Project	Station	Average	Count	Exceedances	% Exceedances
Ice Harbor	IHR	104.3	3040	357	11.74
	IHRFBNL	103.6	3040	333	10.95
Lower Monumental	LMN	104.0	2791	86	3.08
	LMNFBNL	103.0	2791	19	0.68
Little Goose	LGS	103.7	2868	189	6.59
	LGSFBNL	102.3	2868	28	0.98
Lower Granite	LWG	103.7	2573	27	1.05
	LWGFBNL	102.2	2573	0	0

Table 10. Paired samples tests for forebay TDG stations using fish spill waiver value, 2004.

Station Pair	Paired Differences					t	df	Sig. (2-tailed)
	Mean	Std. Deviation	Std. Error Mean	95% Confidence Interval of the Difference				
				Lower	Upper			
IHRFBNL - IHR	-1.0125	1.22738	.10934	-1.2289	-.7961	-9.259	125	.000
LGSFBNL - LGS	-1.6042	2.61133	.21181	-2.0227	-1.1857	-7.574	151	.000
LMNFBNL - LMN	-1.2949	1.73798	.14795	-1.5875	-1.0023	-8.752	137	.000
LWGFBNL - LWG	-1.8358	2.38835	.20947	-2.2502	-1.4213	-8.764	129	.000
MCNFBBRZP1 - MCNFBNL	-.2051	.73512	.16438	-.5492	.1389	-1.248	19	.227
MCNFBBRZP1 - MCQO	-3.4258	2.48478	.30132	-4.0273	-2.8244	-11.369	67	.000
MCNFBNL - MCQW	-.5232	.96627	.11388	-.7502	-.2961	-4.594	71	.000
MCQO - MCQW	.9885	1.70795	.15216	.6874	1.2896	6.497	125	.000

Table 11. Paired samples tests for forebay TDG stations using water quality standard (110% TDG), 2004.

Station Pair	Paired Differences					t	df	Sig. (2-tailed)
	Mean	Std. Deviation	Std. Error Mean	95% Confidence Interval of the Difference				
				Lower	Upper			
IHRFBNL – IHR	-.7170	1.28807	.02336	-.7628	-.6712	-30.692	3039	.000
LGSFBNL – LGS	-1.2171	2.53886	.04197	-1.2994	-1.1349	-28.999	3658	.000
LMNFBNL – LMN	-.8981	1.69677	.02953	-.9560	-.8402	-30.412	3300	.000
LWGFBNL – LWG	-1.3966	2.41129	.04315	-1.4812	-1.3120	-32.367	3122	.000
MCNFBBRZP1 – MCNFBNL	-.3021	.94950	.04259	-.3858	-.2184	-7.092	496	.000
MCNFBBRZ – MCQO	-2.3226	2.79481	.06908	-2.4581	-2.1871	-33.624	1636	.000
MCNFBNL – MCQW	-.3423	1.02903	.02470	-.3908	-.2939	-13.861	1735	.000
MCQO - MCQW	.3132	3.35663	.06108	.1934	.4330	5.128	3019	.000