Appendix I

2020, 2021 and 2022 Walla Walla District Supplemental Monitoring TDG Report

USACE Walla Walla District Summary of Supplemental TDG Monitoring Data for Water Years 2020, 2021 and 2022

Includes:

Ice Harbor (2020 Only), Lower Monumental (2020, 2021 and 2022), and Little Goose (2020, 2021 and 2022) Projects

USACE Walla Walla District Summary of Supplemental TDG Monitoring Data for Water Years 2020, 2021 and 2022

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1 ABSTRACT

The U.S. Army Corps of Engineers (USACE), Walla Walla District (CENWW), operated fourteen fixed-monitoring system (FMS) stations (eight seasonal and six year-round) for total dissolved gas (TDG), barometric pressure (BP), and temperature as part of their 2022 water-quality program. Starting in 2020, the spring spill requirements for fish passage were increased to 125% gas cap for 16 hours of day. The hydraulic design section observed significant changes in tailrace patterns and were concerned with the change in tailrace patterns causing high TDG in several locations not observed by the FMS. Therefore in 2020 additional temporary monitoring stations recording TDG were deployed in fishways at Ice Harbor, Lower Monumental and Little Goose as well as Little Goose powerhouse eddy. Based on these observations, additional TDG monitoring in 2021 and 2022 focused on TDG monitoring downstream of Lower Monumental and Little Goose. This Appendix summarizes the additional data from 2020, 2021 and 2022 and compares it to the fixed-monitoring stations. Some of the observations and conclusions from analysis of this data include:

- The 2020 measurement of TDG in the fishway entrances of Ice Harbor, Lower Monumental and Little Goose did not show major areas of concern. The Ice Harbor and Little Goose fishways did not have TDG levels that were a concern. The Lower Monumental fishway closely followed the forebay TDG which is expected since most of the adult fish ladder attraction water comes from the forebay. However, it was observed that the Lower Monumental forebay TDG had extended periods above 120% and some above 125% TDG. High TDG in the fish ladder can be of increased biological concern (compared to the tailwater) given the shallower water in the fish ladder preventing adequate depth for TDG compensation.
- The 2020 measurement of TDG at the edge of the Little Goose powerhouse eddy were very high and often exceeded 130% to 135%. The tailrace patterns during high spill may move this high TDG water down river along the south shore which would not be detected by the tailwater fixed-monitoring station for Little Goose that is located on the north shore.
- The high forebay TDG observed at both Ice Harbor and Lower Monumental raised concerns that the tailwater fixed-monitoring stations for the projects upstream (Lower Monumental and Little Goose, respectively) were missing areas of higher TDG water. This led to the effort to do additional TDG monitoring downstream of Lower Monumental and Little Goose in 2021.
- The supplemental TDG downstream monitoring at Lower Monumental and Little Goose in 2021 consisted of 4 temporary TDG stations being deployed downstream of each project. The spring 2021 had below average river discharge and therefore below average spill discharges. The 125% gas cap limit was never quite reached in 2021 at either of these two projects. However, two of the temporary TDG stations at each project consistently recorded higher TDG than the tailwater fixed-monitoring station. For Lower Monumental, two temporary TDG stations on the south shore recorded around 0.5-1% higher than the tailwater fixed-monitoring station. For Little Goose, two temporary TDG stations on the south shore recorded 1-2% higher at performance spill and 3-4% higher during the 125% gas cap spill periods.
- The supplemental TDG downstream monitoring at Lower Monumental and Little Goose in 2022 consisted of 2 temporary TDG stations downstream of each project.

Due to lower budgets and fewer available instruments only the two locations that recorded the highest values in 2021 were redeployed to approximately the same location in 2022. The spring 2022 had higher river discharges and spill discharges than 2021. The 125% gas cap limit was reached and exceeded for an extended time frame in 2022. However, the observations from the temporary stations were similar to 2021. For Lower Monumental, two temporary TDG stations on the south shore recorded around 0.5-1% higher than the tailwater fixed-monitoring station. For Little Goose, two temporary TDG stations on the south shore recorded 1-2% higher at performance spill and 2-6% higher during the higher spill periods.

- The Washington state TDG water quality standards specify only the tailwater fixed monitoring TDG gauges as compliance points during the spring spill season to limiting spill to the 125% limit. Therefore, high TDG recorded by these temporary stations is not considered an exceedance of the water quality requirements. However, the 125% limit was chosen based on balancing biological risk of gas bubble trauma with the desire to have more juvenile salmon pass the dam through the spillway. Therefore, these observations indicate that higher than 125% TDG water is passing downstream of these projects and the GBT risk may be higher than originally intended. The GBT risk during 125% gas cap spill may be significantly higher downstream of Little Goose. The GBT risk downstream of Lower Monumental may be similar to expectations but this is still uncertain due to high forebay readings still being observed at Ice Harbor. More detailed TDG monitoring along with GBT monitoring downstream of Little Goose is recommended.

2 PURPOSE

In addition to the basin-wide fixed-monitoring system (FMS) network, Walla Walla District (CENWW) of the U.S. Army Corps of Engineers (USACE) performed additional TDG monitoring in 2020, 2021 and 2022 to increase understanding of distribution of TDG under the 125% gas cap spill required during spring spill season by the fish passage plan. This Appendix documents and reviews the data from this additional TDG monitoring.

3 BACKGROUND

The existing tailwater fixed monitoring were established in the 1990's and early 2000's under the project operating conditions at the time where high spill discharges were not typically seen until the powerhouse capacity had been reached. The project operating conditions have a strong influence on how high TDG water downstream of the spillway distributes and mixes with lower TDG water downstream of a project. This mixing and distribution downstream of a project is often described as tailrace patterns. The current locations of the fixed monitoring tailwater stations were determined to be a reasonable location for monitoring TDG conditions downstream of the Walla Walla district dams for the tailrace patterns of the project operating conditions under which they were established. The fish passage spring spill requirements prior to 2018 are referred to as performance spill. The percentage of spill during performance spill varies from 20%-40% of the total project discharge (until forced spill due to powerhouse capacity). Starting in 2020 the fish passage spring spill requirements changed to requiring spill up to 125% TDG for 16 hours per day. The 125% gas cap spill can be up to 80-90% of the total project discharge since after minimum generation is met the rest of the river is spilled up to the 125% gas cap limit. The tailrace patterns are known to be significantly affected by the percentage of flow from the spillway and powerhouse. In 2020 multiple visits were made to McNary and all four the Lower Snake projects to observe and document the difference in tailrace patterns between performance spill and 125% gas cap spill. The changes in tailrace patterns observed confirmed the concern that the change in spring spill requirements resulted in a redistribution of TDG downstream of the projects. Some of the larger changes in tailrace patterns were seen at Lower Monumental and Little Goose and therefore the increased concern about the distribution of TDG at these projects. The changes in tailrace patterns at these dams are summarized in the following sections.

3.1 Changes in Lower Monumental tailrace patterns

Observations of the Lower Monumental tailrace patterns for both performance spill and 125% gas cap spill were made on four separate days in 2020 (4/17, 4/27, 5/4 and 5/21). The tailrace patterns observed on 5/4 are shown in Figure 3-1 and Figure 3-2. During the performance spill there is no recirculation in the tailrace, but 125% gas cap spill has a large eddy on the north shore. Under 125% gas cap flow, a significant portion of the spill flow is caught in the eddy and re-entrained into the highly aerated flow within the stilling basin and just downstream. A significant portion of the flow that escapes from this eddy distributes along the north shore downstream of the project opposite of the tailrace fixed monitoring station. The fish passage plan has the spill patterns which can influence TDG distribution. The spill patterns at Lower Monumental tend to be somewhat imbalanced below about 50 kcfs with more flow in the center and the north part of the spillway (and center of the dam) than in the south portion of the spillway. Above this flow the spill patterns become fairly uniform across the spillway.

Figure 3-1 – Lower Monumental tailrace surface flow pattern for 122 kcfs river discharge with 30% performance spill

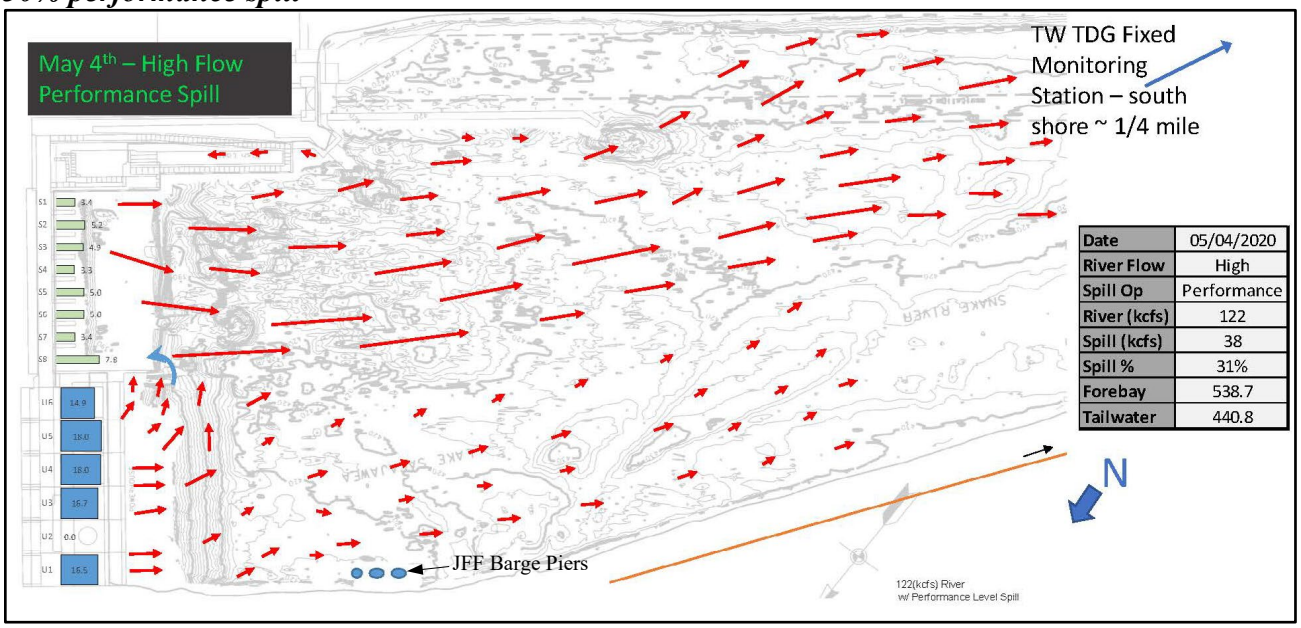
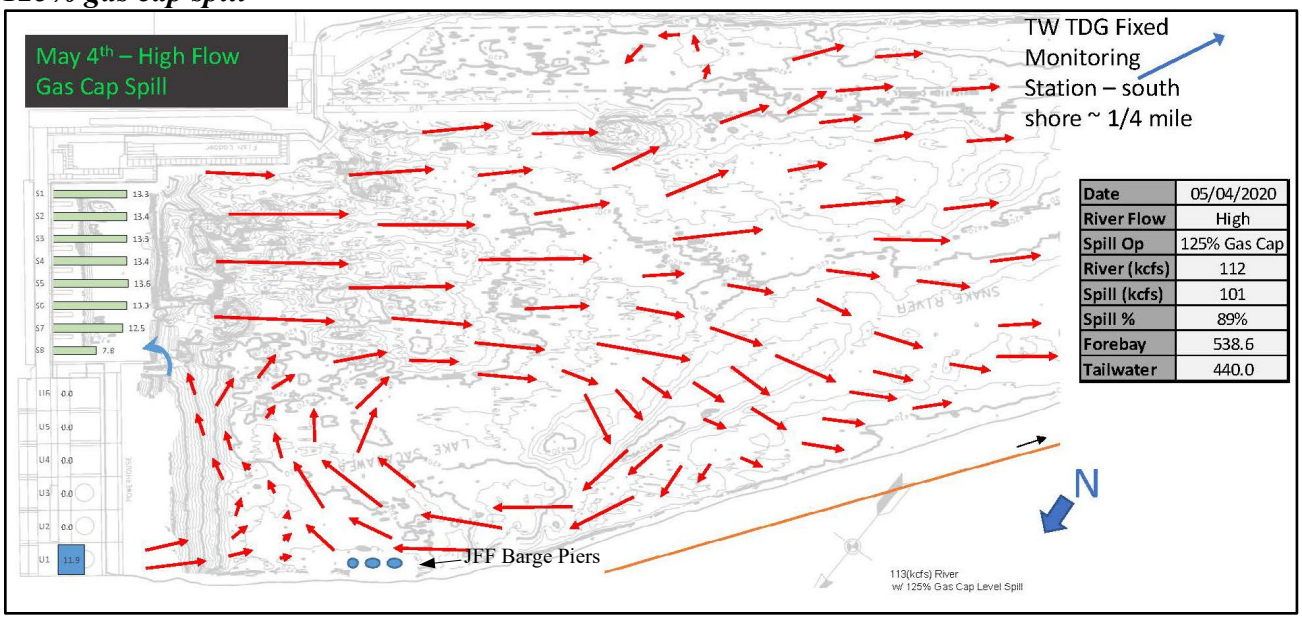


Figure 3-2 – Lower Monumental tailrace surface flow pattern for 112 kcfs river discharge with 125% gas cap spill



3.2 Changes in Little goose tailrace patterns

Observations of the Little Goose tailrace patterns for both performance spill and 125% gas cap spill were made on three separate days in 2020 (4/28, 5/4 and 5/22). The tailrace pattern observed on 5/4 are shown in Figure 3-3 and Figure 3-4. Eddies typically form on both the north and south shore when spilling a discharge of greater than about 20 kcfs. Therefore, it is not surprising that tailrace

surface flow patterns show eddies on the north and south shore under both performance and 125% gas cap spill with a high river discharge. However, the intensity of the south shore eddy is dramatically greater for the 125% gas cap spill than for the performance spill as depicted in Figure 3-3 and Figure 3-4. Additionally, under 125% gas cap flow a larger portion of the spill flow is caught in the south shore eddy and re-entrained into the highly aerated flow beneath the deflected jets within the stilling basin and just downstream. This allows the spill and powerhouse water to remain in a region of high air entrainment and increased pressures for an extended period, resulting in higher concentration of air being dissolved within the water column. Most of the flow that escapes the south shore eddy distributes along the south shore opposite of the tailrace fixed monitoring station. The fish passage plan has the spill patterns which can influence TDG distribution. The spill patterns at Little Goose are fairly uniform across the spillway except the ASW near the center of the dam.

Figure 3-3 – Little Goose tailrace surface flow pattern for 112 kcfs river discharge with 30% performance spill

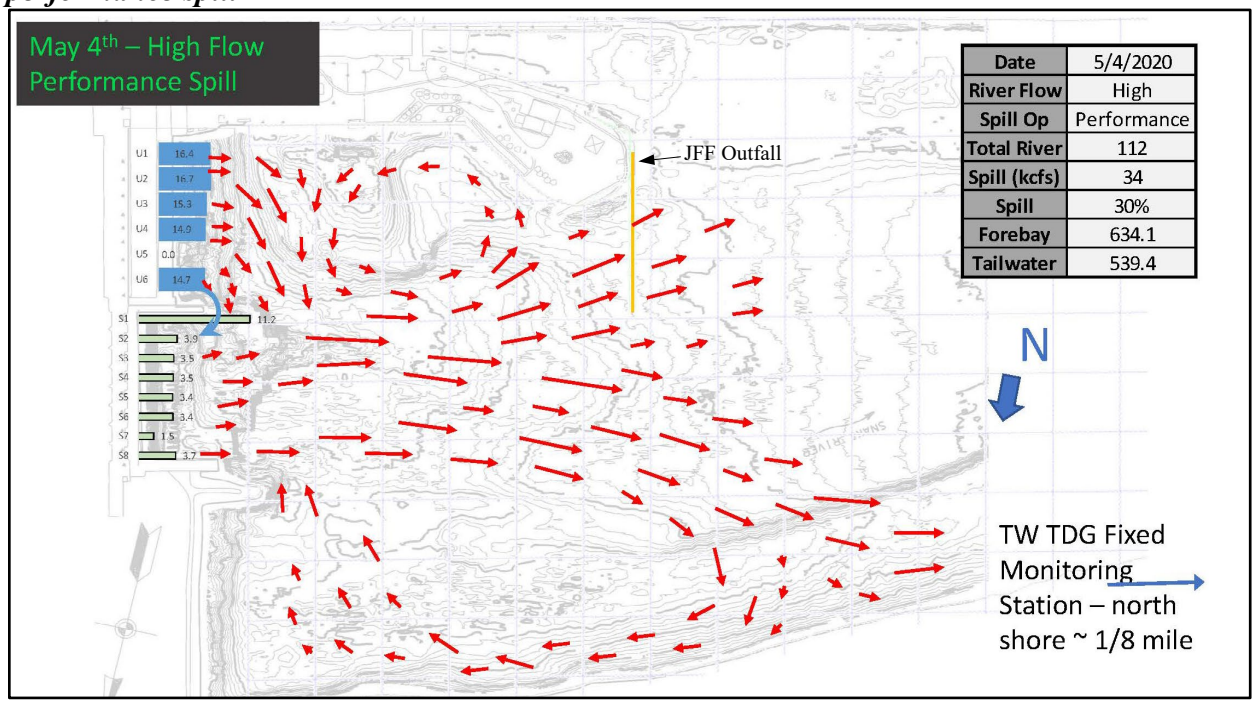
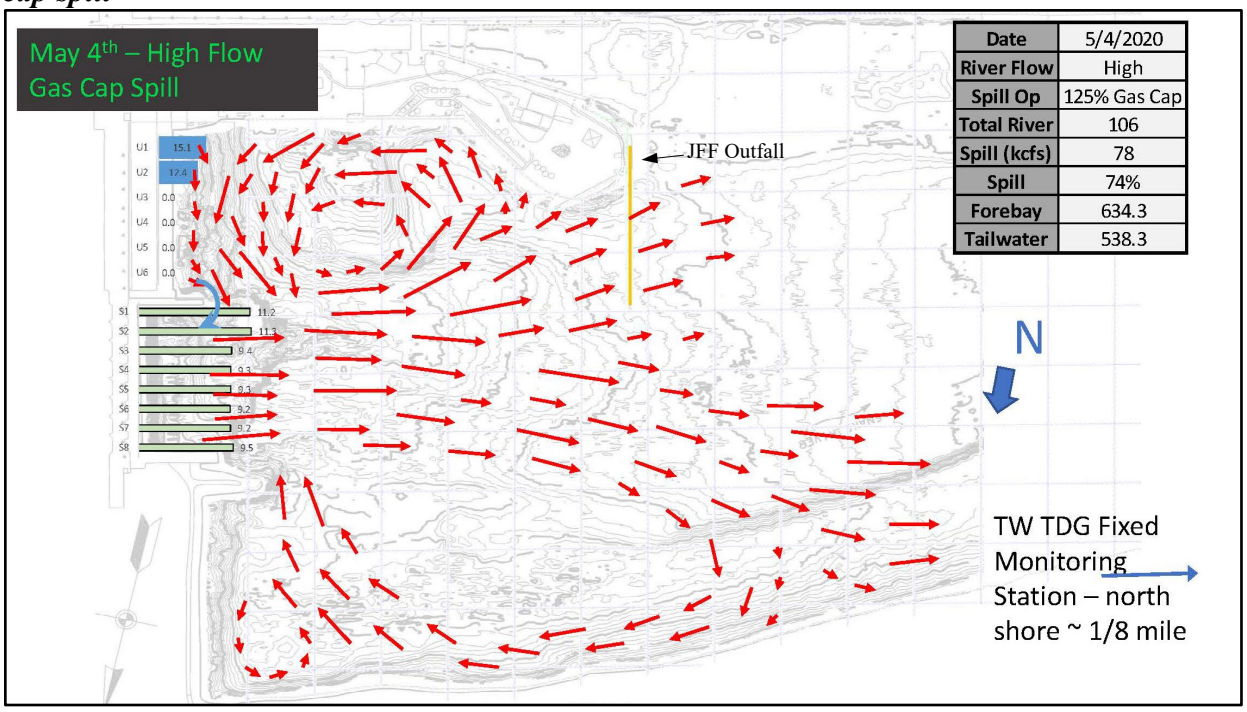


Figure 3-4 – Little Goose tailrace surface flow pattern for 106 kcfs river discharge with 125% gas cap spill



4 SCOPE

The purpose for TDG monitoring in general is to provide managers, agencies, and interested

parties with near real-time data for managing stream flows, spill, and percent TDG downstream from power-producing dams. The Washington state TDG water quality standards specify only the tailwater gauges as compliance points during the spring spill season, therefore the additional supplemental TDG monitoring is not intended to determine compliance with these standards. However as noted in the introduction these tailwater fixed monitoring gauges were established under different hydraulic conditions in the tailrace that exists during the 125% gas cap spill. The change in hydraulic conditions can result in redistribution of TDG in the tailrace that may not be adequately assessed by the existing fixed tailrace TDG monitoring stations. In 2020, the primary concern was areas of high TDG closer to the dam that may be redistributed by the auxiliary attraction pumps in the tailrace to the lower reaches of the adult fishways, such as main entrances, junction pools, and collection channels. This was to address concern with increased risk of gas bubble trauma in the adult fishways since depth compensation is more difficult with the lower water depth. In 2021 and 2022 the primary concern was that redistribution of TDG would cause the fixed tailwater monitoring station to no longer be representative of the TDG in the river downstream of the project. Limited budget and instrumentation were available to do this exploration therefore the monitoring was limited to areas thought to present the highest biological risk. As data was taken the measurement locations changed from year to year based on the previous data and the available budget.

For all three water years (2020, 2021 and 2022), the established forebay fixed monitoring stations were activated during the spring spill despite not being required for TDG compliance. The full data set for the additional forebay monitoring were previously documented in each water year and only samples are documented in this section.

In addition to the additional forebay monitoring, in the 2020 water year temporary TDG monitoring stations were installed near the main entrance nearest the auxiliary attraction pumps at three fishways (Little Goose south shore entrance, Lower Monumental north shore entrance, and Ice Harbor north shore entrance) to monitor TDG levels that adult fish would be exposed to as they traversed the fishways. Additionally, a temporary TDG monitoring station was installed to monitor TDG level in the Little Goose eddy due to the intensity of the eddy observed during 125% gas cap flow (see Figure 3-4).

In the 2021 water year, the primary concern was the TDG downstream of Lower Monumental and Little Goose. Therefore, four temporary TDG stations were installed downstream of each project in locations that were feasible to deploy and retrieve. In the 2022 water year, a lower budget and fewer available instruments required a prioritization of TDG monitoring. Therefore, two locations from 2021 were selected for temporary TDG stations were installed downstream of each project in 2022.

5 METHODS

5.1 Data Collection

The instrumentation at each temporary TDG station consisted of components provided by CENWW. Multiple Hydrolab® multi-parameter probes (*i.e.*, MS4A's and MS5's) were utilized with batteries that lasted for approximately 3 to 4 weeks of data recording. The in-place instruments were replaced with newly calibrated sondes if additional data was needed at the same location.

5.2 Laboratory Procedures

The TDG sensor measures the sum of the partial pressures of gaseous compounds dissolved in the water and reports the result in millimeters of mercury (mmHg). The TDG sensor requires a two-step calibration procedure (*i.e*., adjustments are made at two points on the calibration curve) that is completed prior to and after deployment. The atmospheric pressure data used to calibrate percent TDG was obtained from the fixed-monitoring stations at LMNW and LGSW.

The differences between laboratory barometric pressure and the pressure measured by the sonde were recorded before and after deployment. The slope of each sensor response was also evaluated to ensure that measurements were interpolated correctly over the full range of expected field values. To accomplish this task, a Heise™ PTE-1 hand-held certified pressure calibrator, calibrated yearly at the factory (primary standard) and an Ashcroft 2089 digital test gauge, also calibrated yearly at the factory, were used to apply pressure to the TDG sensor. Three hundred millimeters of mercury were added to the laboratory barometric pressure during the pre-deployment check and the differences between this measurement and the sensors' response were recorded. Similar tests were completed post-deployment when 100 mmHg was added to the laboratory barometric pressure, and the resulting differences were similarly recorded. Pre-deployment pressure tests were made without a membrane installed. Post-deployment tests were made with a dry membrane in place.

Each sonde also included a sensor for reporting water temperature in degrees Celsius (°C). Sensor thermometers are factory calibrated and cannot be adjusted. However, temperature sensor performance was evaluated pre- and post-deployment by comparing instrument readings to two Digi-Sense Traceable Scientific Thermistor Thermometers. Both of these instruments were checked quarterly against a National Institute of Standards and Technology (NIST) traceable Oakton Digital Temp-360 W lab thermistor.

5.3 Field Procedures

The differences in barometric pressure, water temperature, and TDG between a secondary standard instrument (*i.e.,* replacement sensor) and the fixed station monitors after three or four weeks of field deployment were measured and recorded as part of the field inspection and calibration procedure. These differences, defined as the secondary standard value minus the field instrument value, were used to compare and quantify the precision between two independent instruments. The Sutron® barometers at the fixed-monitoring stations were checked using a Novalynx® M2 Series hand-held digital barometer that is calibrated yearly at the factory. The water temperature and TDG comparisons were made *in situ* with the secondary standard (*i.e*., a recently calibrated Hydrolab®) positioned alongside the field Hydrolab®.

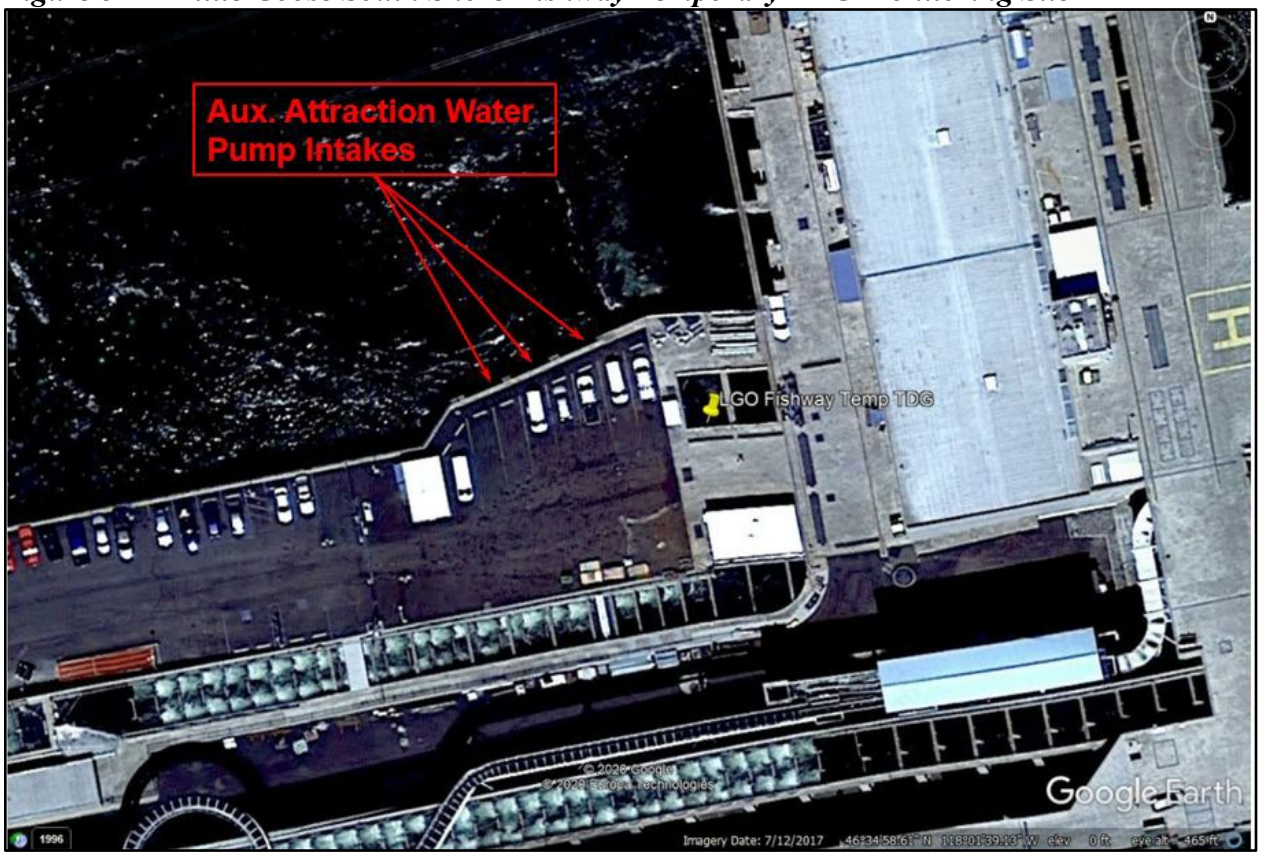
5.4 Deployment Locations

The locations selected for the temporary deployments were restricted to areas where the sondes could be deployed and retrieved by boat and outside the navigation channel. Each location was also selected to be in deep enough water, so the TDG measurements were not affected by surface waves. During 2021, temporary instrument deployments were located in 16 to 21 ft of water. The exception was the purple station was located at 43 ft of depth and Gold 5 was located at around 5 ft of depth. During 2022, the depths at most of the stations ranged from 16 to 43 ft – the exception was Gold 6 where the depths ranged from 4 to 27 ft.

5.4.1 2020 Deployment Locations

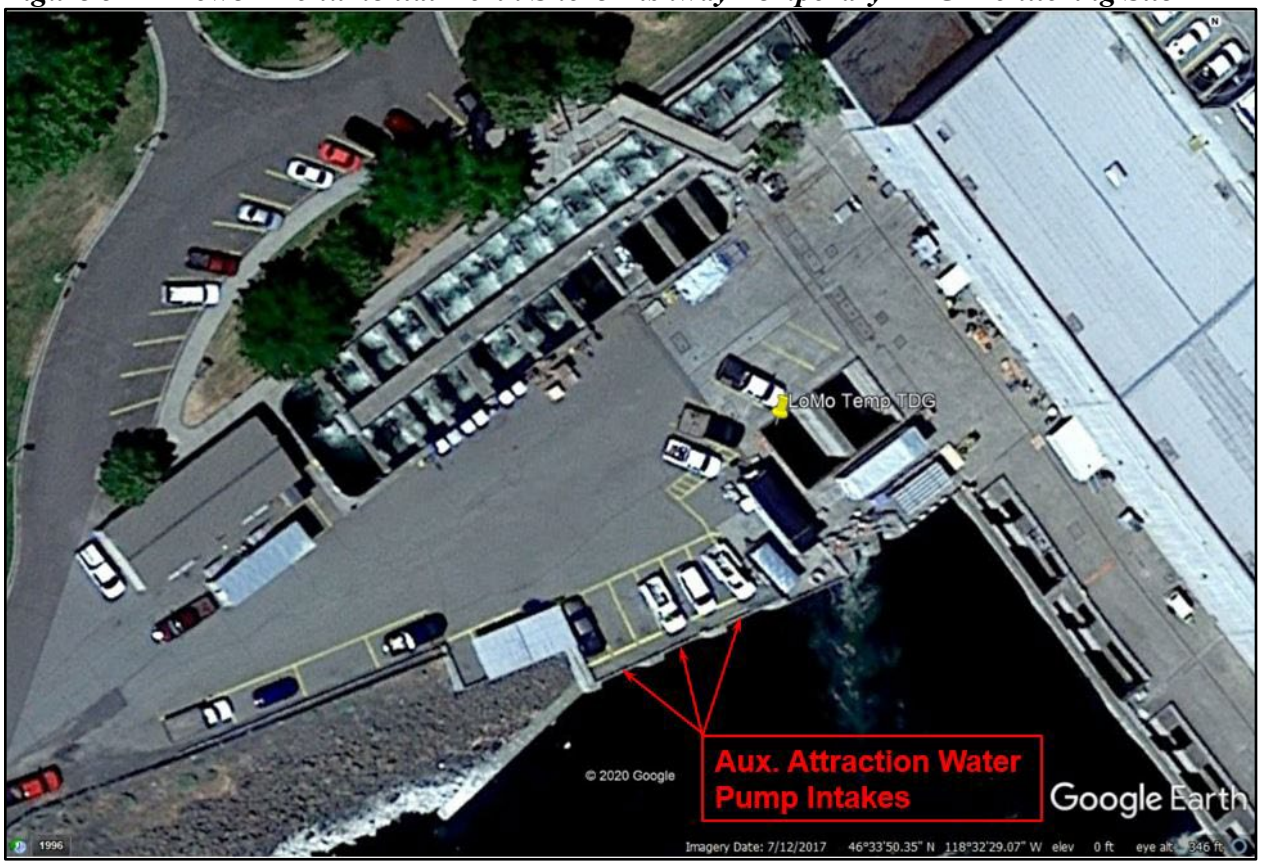
The temporary TDG monitoring station at the Little Goose south shore fishway entrance was installed on 14 May 2020 and removed on 26 June 2020 (Figure 5-1). This covered about the last half of the spring fish passage season (and a little beyond), when river discharges were highest, and therefore the most spill occurred. This station was located to be downstream of the largest auxiliary water supply diffuser but far enough upstream of the main entrance weirs to not be affected by any shallow air entrainment caused by the weirs.

Figure 5-1 – Little Goose South Shore Fishway Temporary TDG Monitoring Site



The temporary TDG monitoring station at the Lower Monumental north shore fishway entrance was installed on 19 May 2020 and removed on 24 June 2020 (Figure 5-2).

Figure 5-2 – Lower Monumental North Shore Fishway Temporary TDG Monitoring Site

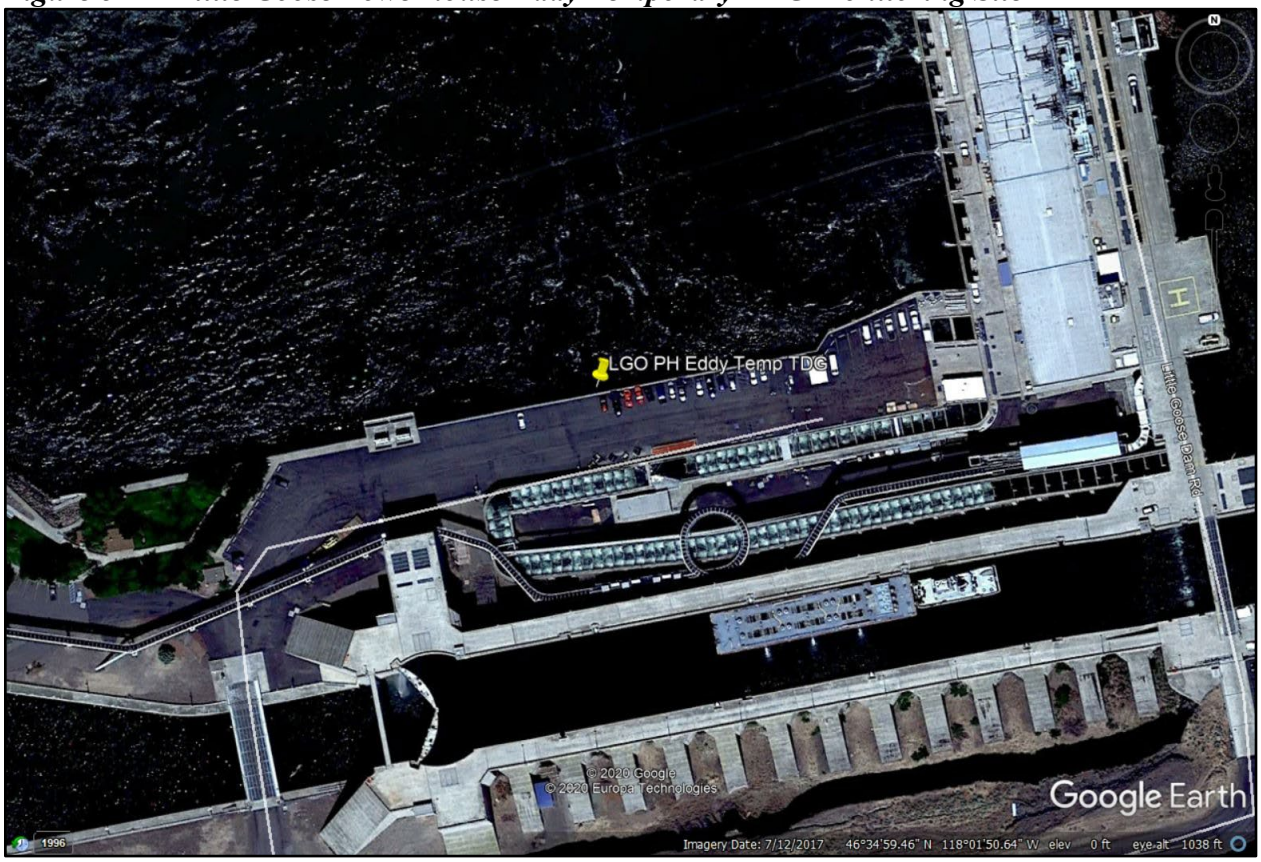


The temporary TDG monitoring station at the Ice Harbor north shore fishway entrance was installed on 11 May 2020 and removed on 22 June 2020 (Figure 5-3).

Figure 5-3 – Ice Harbor North Shore Fishway Temporary TDG Monitoring Site

The temporary TDG monitoring station at the Little Goose powerhouse eddy was installed on 14 May 2020 and removed on 26 June 2020 (Figure 5-4). It was installed just off the south shore wall between the navigation lock outfall and the fishway auxiliary attraction water pump intakes where there was an existing bracket for a tailwater temperature probe.

Figure 5-4 – Little Goose Powerhouse Eddy Temporary TDG Monitoring Site



5.4.2 2021 Deployment Locations

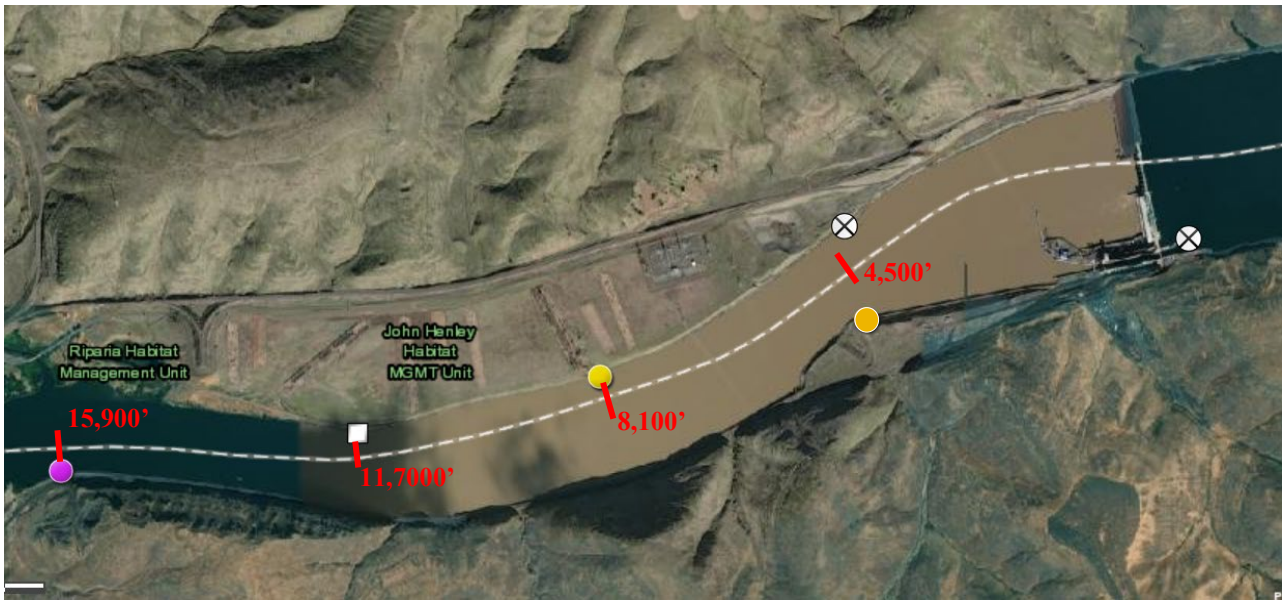
The temporary TDG monitoring stations in 2021 focused on monitoring conditions downstream of Lower Monumental and Little Goose. A location was chosen across the river from the tailwater fixed monitoring stations at each project and three locations further downstream on each side of the river for a total a four temporary TDG stations per project.

Downstream of Lower Monumental the four temporary TDG stations were installed between March 19 and 22, 2021 and removed on June 29, 2021. Replacement TDG stations were required halfway into this period due to battery life. The four stations are identified as the orange, blue, green, and red stations. Unfortunately, the first half of data for the green and red stations were lost due flooding of the instrument casing. The locations of the temporary TDG stations relative to the fixed monitoring stations (designated by a white circle with an X) are shown in Figure 5-5. Approximate distances downstream of the dam are shown on the figure.

Figure 5-5 – Lower Monumental Temporary TDG station deployment locations

Downstream of Little Goose four temporary TDG stations were installed on between March 19 and 24, 2021 and removed on between June 22 and 23, 2021. Replacement TDG stations were required halfway into this period due to battery life. The four stations are identified as the gold, yellow, white, and purple stations. The locations of the temporary TDG stations relative to the fixed monitoring stations (designated by a white circle with an X) are shown in Figure 5-6. Approximate distances downstream of the dam are shown on the figure.

Figure 5-6 – Little Goose Temporary TDG station deployment locations



5.4.3 2022 Deployment Locations

The temporary TDG monitoring stations in 2022 focused on monitoring conditions downstream of Lower Monumental and Little Goose. There were fewer remaining instruments available, and the monitoring budget was smaller therefore only two temporary monitoring stations were placed downstream of Lower Monumental and Little Goose respectively. The red and green stations were deployed in approximately the same location for Lower Monumental (see Figure 5-5) and the gold and purple stations were deployed in approximately the same location for Little Goose (see Figure 5-6).

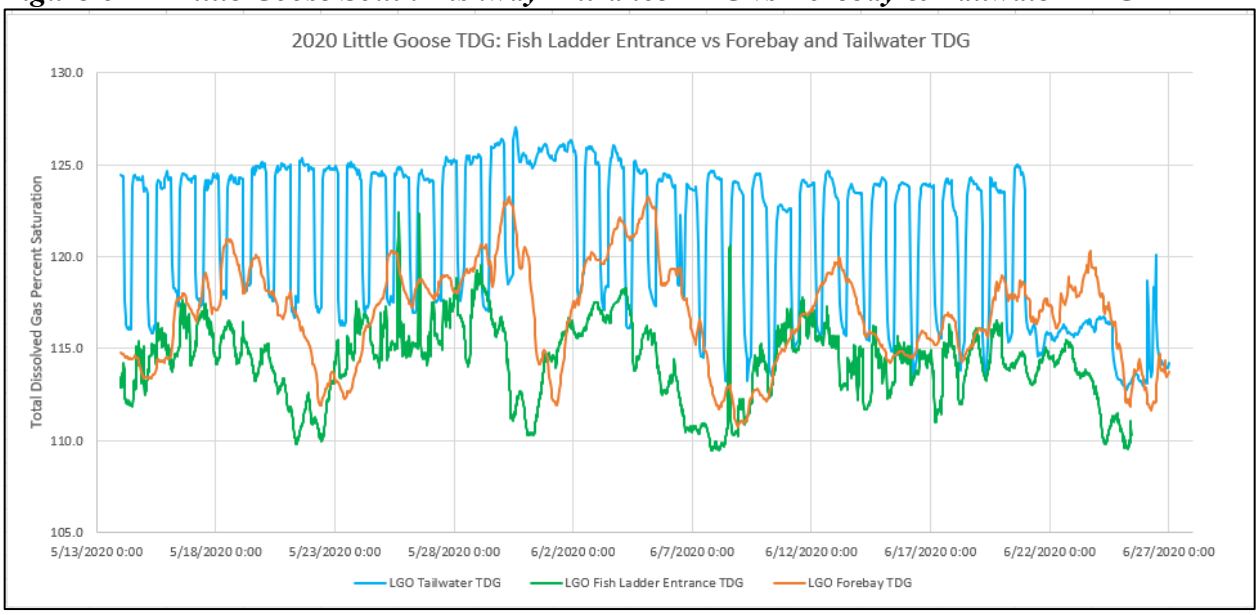
6 2020 RESULTS AND DISCUSSION

The locations of the additional temporary TDG monitoring in 2020 consisted of areas close to the dam including several within the fishway entrances. These are data is summarized by location. In addition, some observations from the additional forebay monitoring in 2020 are included.

6.1 Little Goose South Shore

Figure 6-1 shows the TDG measured at the temporary station in the Little Goose south shore fishway entrance, along with the TDG measured at the forebay and tailwater fixed monitoring stations. The TDG in the fishway generally tracks with the forebay TDG, although the TDG in the fishway is typically about 2 - 4% lower than the forebay readings. It appears that although there is a very strong eddy in the tailrace in front of the powerhouse that often extends upstream near the face of the powerhouse, most of the water entrained in the fishway auxiliary attraction water pump intakes comes from the forebay through the turbines. Elevated TDG in the adult fishway does not appear to be a concern at Little Goose.

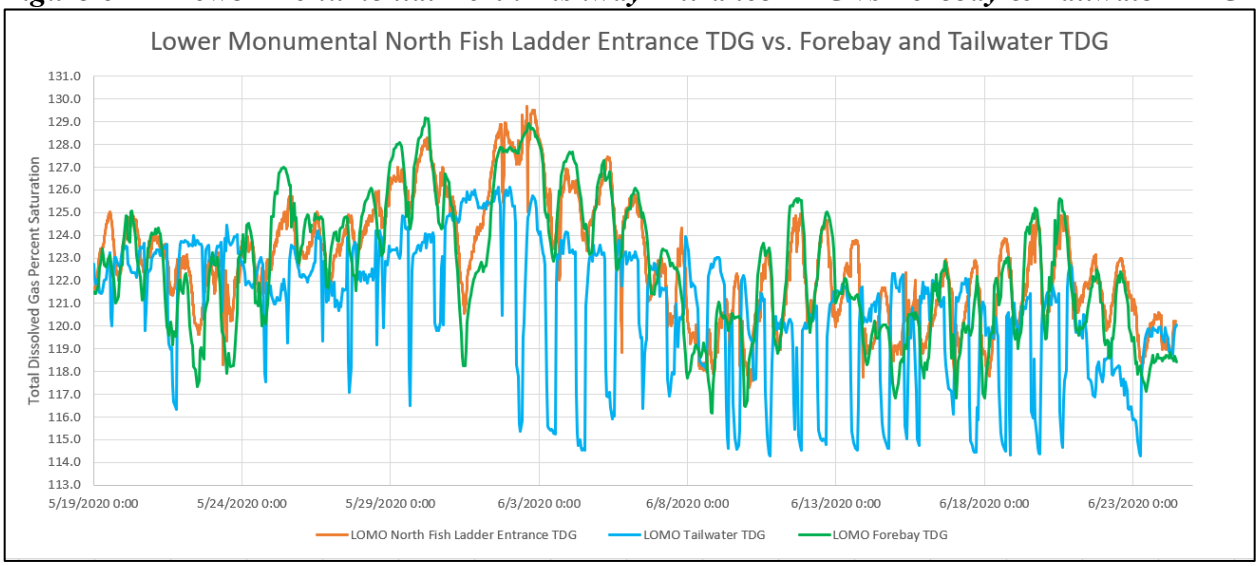
Figure 6-1 – Little Goose South Fishway Entrance TDG vs Forebay & Tailwater TDG



6.2 Lower Monumental North Shore

Figure 6-2 shows the TDG measured at the temporary station in the Lower Monumental north shore fishway entrance, along with the TDG measured at the forebay and tailwater fixed monitoring stations. The TDG in the fishway tracks closely with the forebay TDG, which wouldn't be a concern except that the forebay TDG at Lower Monumental was very high during some periods in 2020; higher than the tailwater TDG and exceeding the 125% gas cap for some periods. It appears that adult fish traversing the fishway were exposed to TDG levels above 125% for those periods with maximum TDG levels approaching 129%. These high TDG levels may have more of a negative impact on fish due to the shallower depth in the fishway than in the deeper water of the forebay or the tailwater.

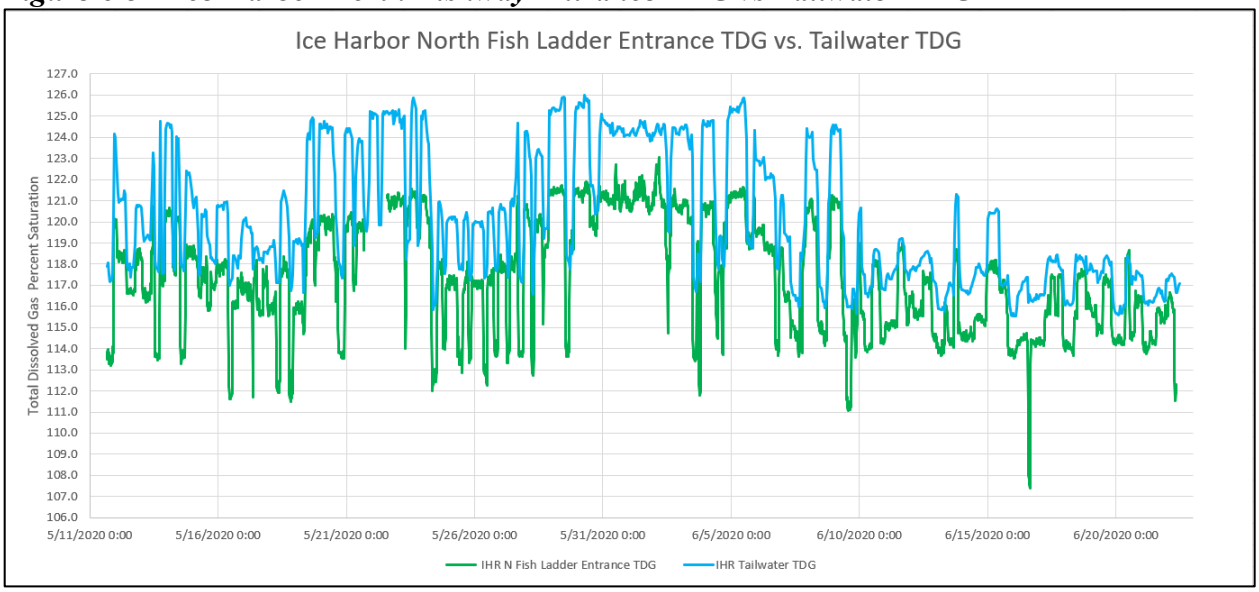
Figure 6-2 – Lower Monumental North Fishway Entrance TDG vs Forebay & Tailwater TDG



6.3 Ice Harbor North Shore

Prior to the 2020 fish passage season, the Ice Harbor north shore fishway was of special concern for elevated TDG because the auxiliary attraction water pump intakes are farther downstream than at other fishways, right on the northern edge of the spill plume. Figure 6-3 shows the TDG measured at the temporary station in the Ice Harbor north shore fishway entrance, along with the TDG measured at the tailwater fixed monitoring station. The TDG in the fishway generally tracks with the tailwater TDG, although the TDG in the fishway is typically about 2 - 4% lower than the tailwater readings. It appears that some amount of degassing occurs in the auxiliary attraction water supply system. Elevated TDG in the adult fishway does not appear to be a concern for fish at Ice Harbor after all. However, there may be some additional cavitation damage on the pumps due to this degassing.

Figure 6-3 – Ice Harbor North Fishway Entrance TDG vs Tailwater TDG

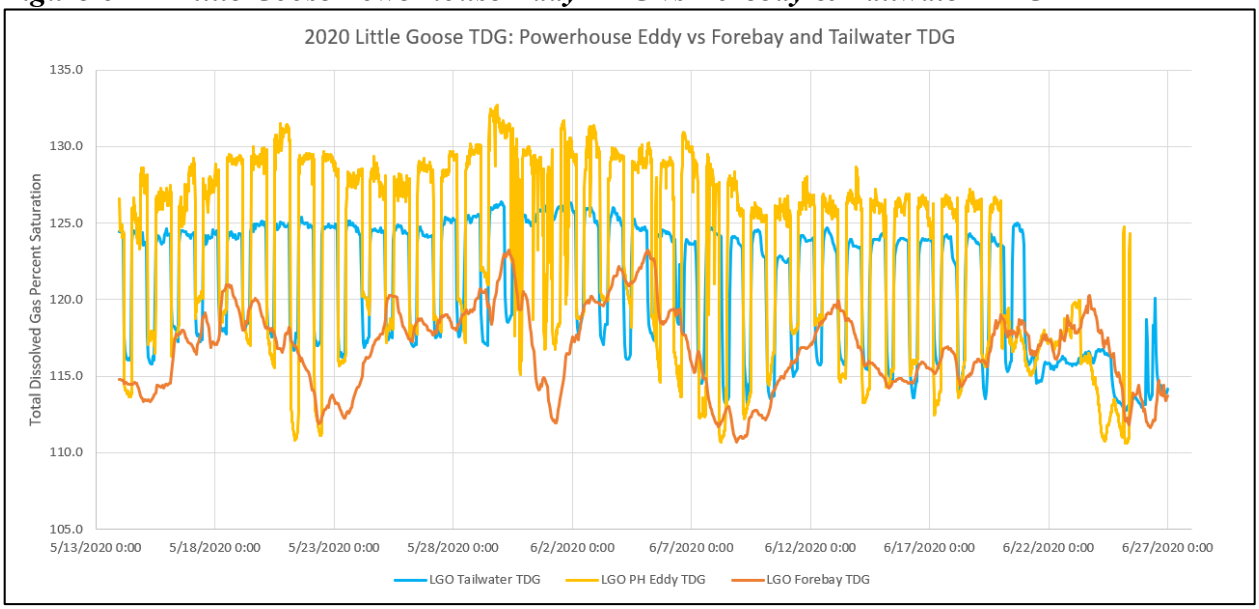


6.4 Little Goose Tailrace Powerhouse Eddy

During high spill levels relative to powerhouse operation a large eddy forms downstream of the powerhouse at Little Goose (similar to the other operating projects with spillway deflectors). This eddy occurs since the high spill flows entrain flow laterally from the edges of the outside spillway bays due to the low pressure under the jets. This entrainment increases the volume of water subject to high TDG concentration and with little powerhouse flow available for entrainment the spill flow itself becomes re-entrained, further increasing the saturation of flow on the powerhouse side of the spillway. Many of the juvenile fish passing over the spillway weir or through adjacent spill bays are likely entrained in the eddy during gas cap spill, and adult fish must traverse the eddy to find the powerhouse fishway entrances. Therefore, juvenile fish likely have longer egress times, adult fish likely experience delay in their upstream migration, and both may be exposed to elevated TDG levels even higher than the 125% gas cap for prolonged periods. The powerhouse eddy at Little Goose is one of the most intense and persistent of these eddies, so a temporary TDG monitoring station was installed to monitor TDG level in the eddy and test the theory that TDG levels in the eddy are higher than recorded at the tailwater TDG fixed monitoring station farther downstream.

Figure 6-4 shows the TDG measured at the temporary station in the Little Goose powerhouse eddy, along with the TDG measured at the forebay and tailwater fixed monitoring stations. As expected, the TDG in the powerhouse eddy tracks closely with the pattern of TDG measured at the tailwater TDG fixed monitoring station; however, the TDG is the eddy was generally 3-5% higher, with maximum values up to 132%. Even though a powerhouse eddy does still occur during performance spill, the TDG is not as elevated above the TDG measured at the tailwater fixed monitoring station during these times. Based on the tailrace patterns in Figure 3-4 this water likely eventually escapes the eddy along the south shore and may not mix with the remainder of the river prior to the tailwater fixed monitoring station.

Figure 6-4 – Little Goose Powerhouse Eddy TDG vs Forebay & Tailwater TDG

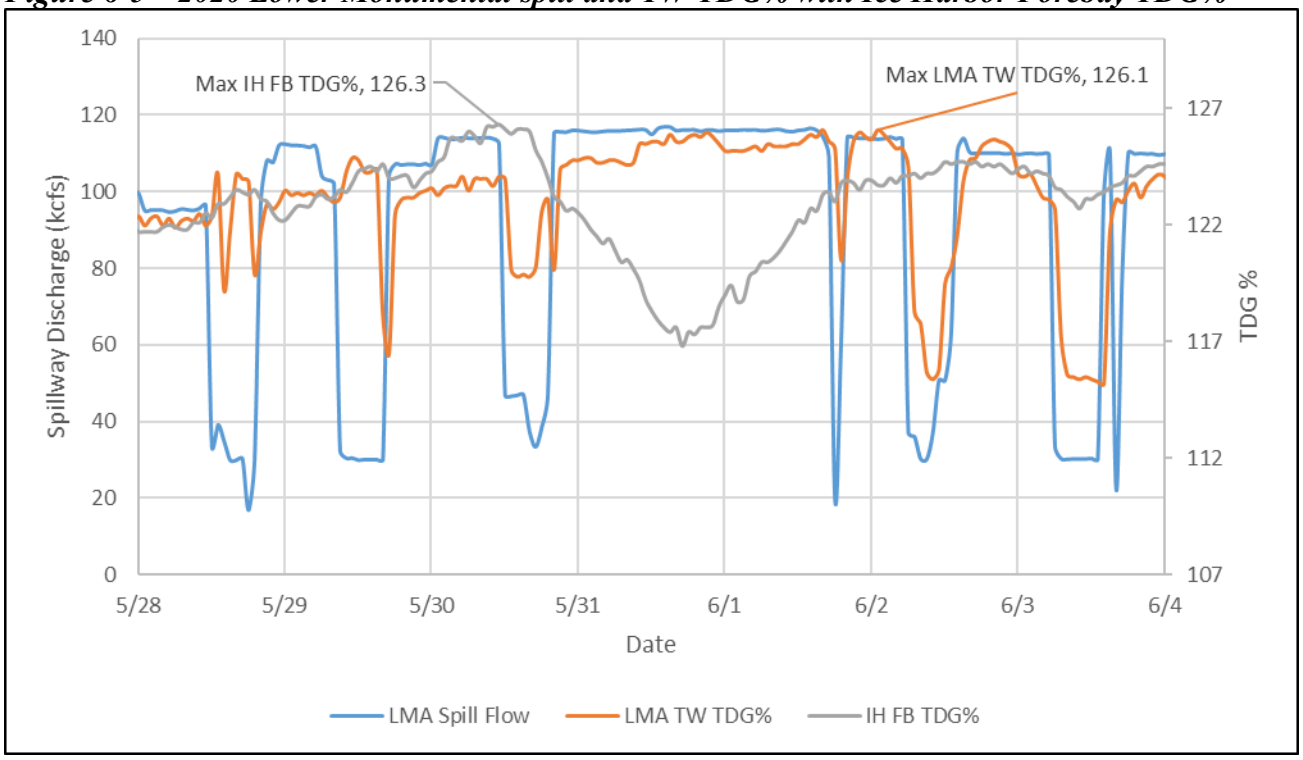


6.5 Forebay Monitoring at Ice Harbor and Lower Monumental

The additional forebay monitoring during the spring spill season at Lower Granite and McNary did not present any concerns as expected. Lower Granite does not have high spill conditions upstream of the project and water approaching the forebay at McNary is primarily from the Columbia rather than the Snake River. The forebay readings at Ice Harbor, Lower Monumental and Little Goose were elevated well above previous forebay TDG requirements during the highest spill conditions at the dams immediately upstream.

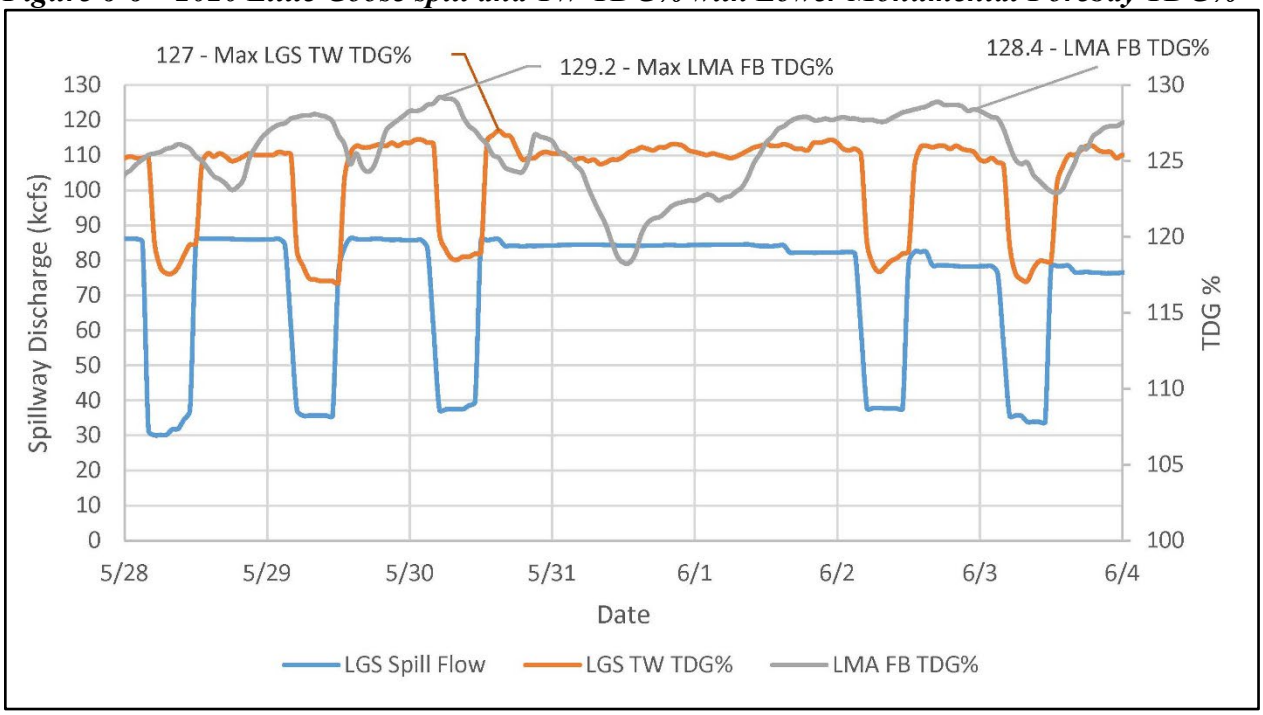
The highest week of forebay readings at Ice Harbor is shown in Figure 6-5. As can be seen the forebay readings at Ice Harbor remained above 115% and was mostly above 120% with a maximum TDG of 126.3%.

Figure 6-5 – 2020 Lower Monumental spill and TW TDG% with Ice Harbor Forebay TDG%



The highest week of forebay readings at Lower Monumental is shown in Figure 6-6. As can be seen the forebay readings at Lower Monumental mostly above 120% with a maximum TDG of 129.2%.

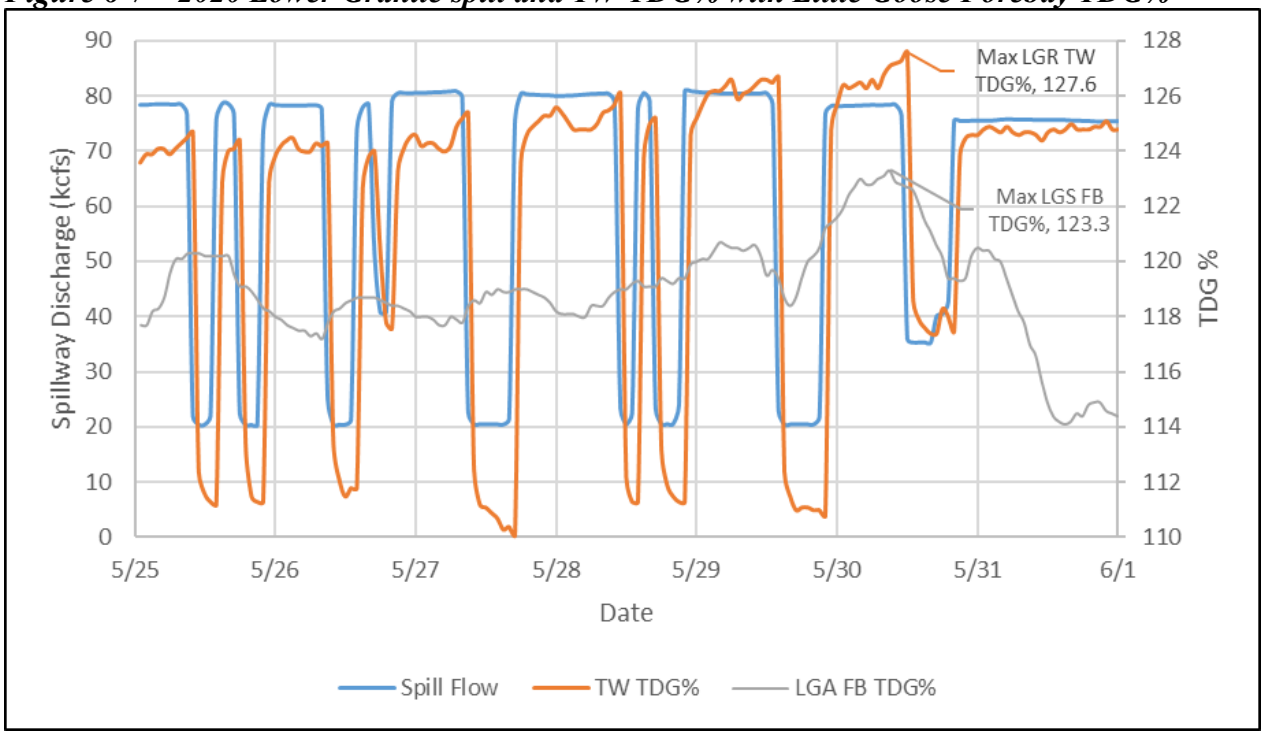
Figure 6-6 – 2020 Little Goose spill and TW TDG% with Lower Monumental Forebay TDG%



The highest week of forebay readings at Little Goose is shown in Figure 6-7. As can be seen the

forebay readings at Little Goose are mostly above 115% with a maximum TDG of 123.2%.

Figure 6-7 – 2020 Lower Granite spill and TW TDG% with Little Goose Forebay TDG%



6.6 Discussion

The TDG% observed within the adult fishway entrances at Ice Harbor and Little Goose was generally low enough that it was no longer a concern. The Lower Monumental adult fishway entrance readings did have high TDG concentration, but this generally followed the Lower Monumental forebay TDG readings which is not surprising given the primary source for the water in the lower portions of the fish ladder. The Little Goose powerhouse eddy did show very high TDG levels. This high TDG levels could expose both adult passing upstream and juvenile fish passing downstream. Additionally given the tailrace patterns under 125% gas cap spill, the high TDG water found in this eddy may stay on the south side of the river and be missed by the fixed tailwater TDG station.

The data observation of the fixed monitoring stations generally indicated that the operation of the spillway was adjusted well to achieve the requirements of the fish passage plan to spill up to 125% TDG at the tailwater fixed monitoring stations. There is an expected delay due to travel time for high TDG to arrive in the forebay of the next downstream dam. The Phase I Dissolved Gas Abatement study found that the travel time of high TDG water was generally around 2 days. In that time, the temperature and barometric pressure can change affecting the TDG%. Therefore, the TDG% in the forebay at the downstream dam is complex and at times could be expected to exceed the tailwater TDG%. However, the previous TDG requirement was for 5% lower TDG in the forebay than the tailwater indicating that the forebay readings are generally be expected to be lower than the upstream tailwater due to mixing and degassing during the travel time between the dams.

The TDG observations of the Ice Harbor and Lower Monumental forebays indicate high TDG levels that are above the upstream tailwater readings and high for extended periods of time. The Little Goose forebay TDG readings are elevated but were on average below the upstream tailwater readings. The extended high TDG levels in the forebays at Lower Monumental and Ice Harbor indicate that a significant length of the river likely had higher than 120% and even 125% TDG even though the tailwater TDG was general kept at 125%. One explanation is that the high TDG water in the Little Goose powerhouse eddy may not be fully mixing with the rest of the river prior to the Little Goose tailwater fixed monitoring station. Given the high TDG seen at Lower Monumental forebay this is likely the case. The powerhouse eddy at Lower Monumental was not monitored but it could also have TDG levels more than 125% given the high forebay TDG found at Ice Harbor. The 2020 observations, especially the high forebay readings at Lower Monumental and Ice Harbor, motivated additional TDG monitoring in 2021 and 2022 at Lower Monumental and Little Goose to better understand how TDG mixed and distributed downstream of these dams.

7 2021 RESULTS AND DISCUSSION

The locations of the additional temporary TDG monitoring in 2021 consisted of TDG downstream of the existing fixed tailwater monitoring stations at both Lower Monumental and Little Goose as shown in Figure 5-5 and Figure 5-6, respectively. To determine TDG% at these additional sites, the total gas pressure measured at these stations was divided by the barometric pressure measured at the fixed TW station. With the proximity of these sites to the fixed TW station there should be no differences in barometric pressure.

7.1 Lower Monumental

Figure 6-1 and Figure 7-2 shows the TDG measured at the temporary stations downstream of Lower Monumental compared to the fixed monitoring tailwater TDG% at Lower Monumental and the forebay TDG% at Ice Harbor. These weeks were the highest spill of the spring spill season in 2021 however none of the readings exceed 125% TDG. However, TDG at the red and green sites track with the fixed tailwater TDG% with a 1 to 2 hour delay. The fixed tailwater TDG reading itself has about a 2 to 3 hour delay from the change in spill conditions. The orange and blue temporary TDG sites, due not track well with changes in spill or changes in the fixed tailwater TDG readings. Even when accounting for the 2 days delay the Ice Harbor forebay TDG% does not seem to track well with any of the fixed or temporary stations downstream of Lower Monumental. Summary metrics over this same period show similar relationships to spill and between sites (Table 7-1 and Table 7-2). The red and green temporary TDG sites track with the fixed tailwater TDG% but are from 0% to 1% higher (Table 7-2). On average, the Ice Harbor forebay TDG is greater than the Lower Monumental fixed station tailwater TDG but maximum values are less. On average, the orange and blue site TDG is greater than the Lower Monumental fixed station tailwater TDG but no consistent pattern is notable with the other metrics.

Figure 7-1 – 2021 Lower Monumental spill and TW TDG% with temporary downstream TDG stations and Ice Harbor Forebay TDG% for 5/11 to 5/18/2021

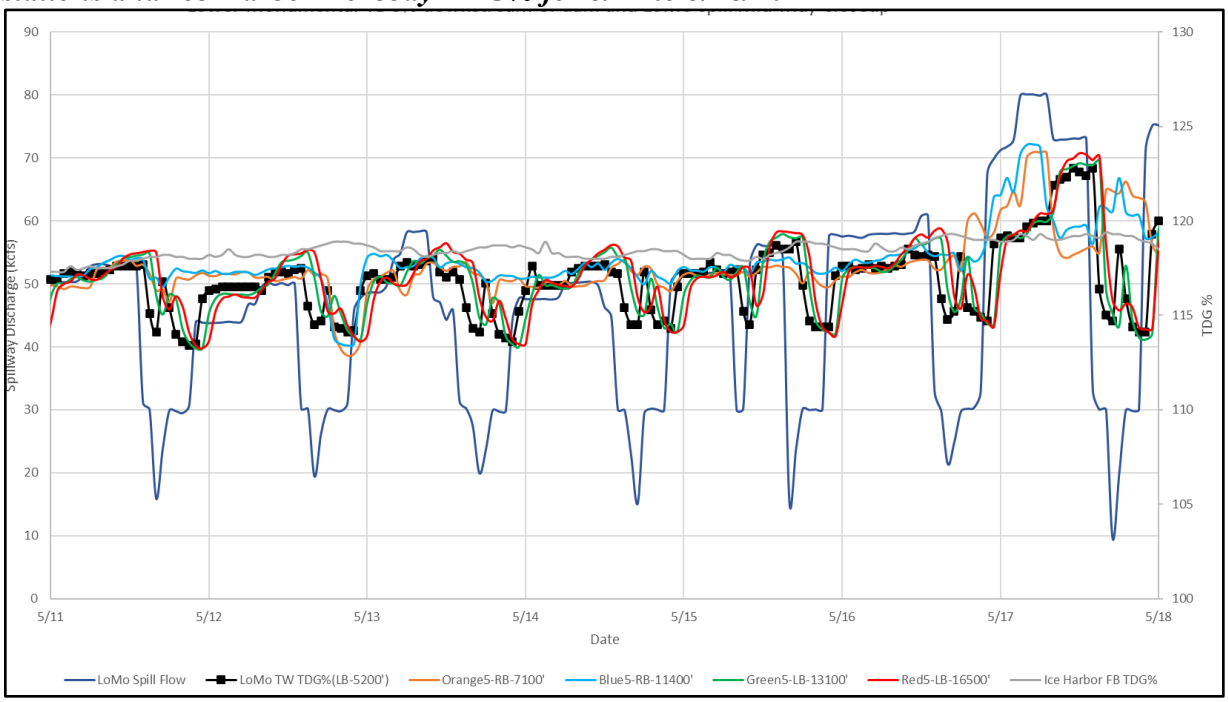


Figure 7-2 – 2021 Lower Monumental spill and TW TDG% with temporary downstream TDG stations and Ice Harbor Forebay TDG% for 6/1 to 6/8/2021

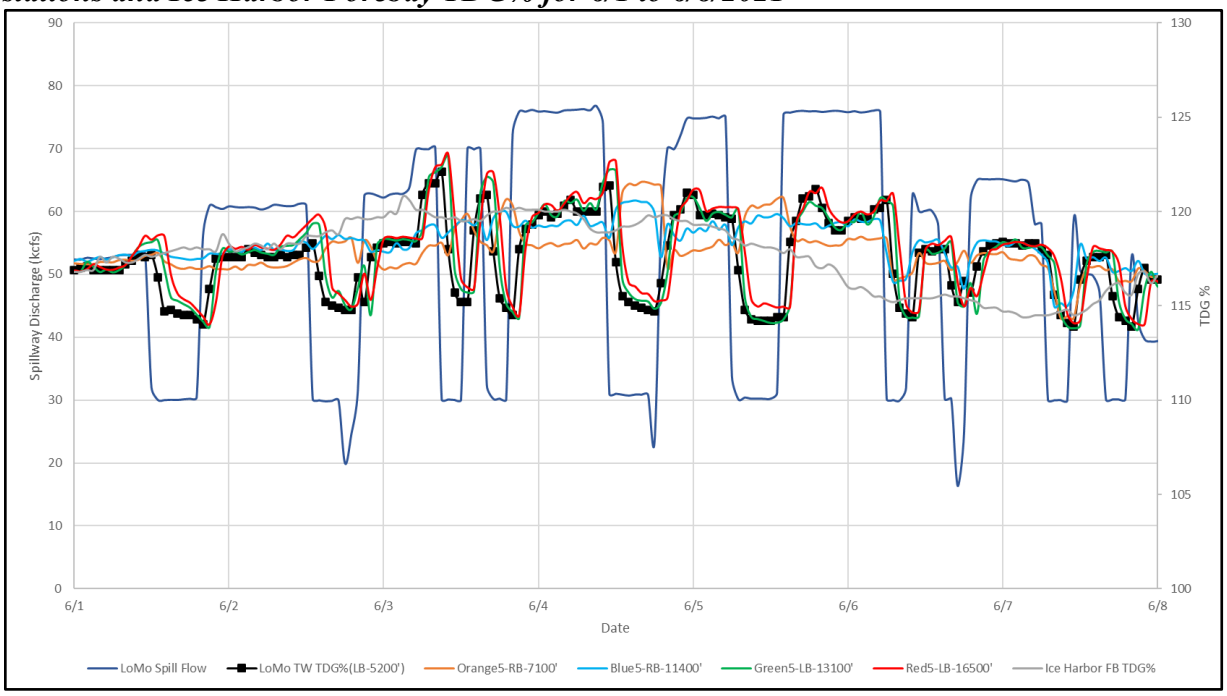


Table 7-1 – Data Table for Lower Monumental TW TDG% with temporary downstream TDG stations and Ice Harbor Forebay TDG% for 5/11 to 5/18/2021

Date	5/11/2021 0:00	5/11/2021 0:00	5/11/2021 0:00	5/11/2021 0:00	5/11/2021 0:00	5/11/2021 0:00
Range	5/18/2021 0:00	5/18/2021 0:00	5/18/2021 0:00	5/18/2021 0:00	5/18/2021 0:00	5/18/2021 0:00
	LMO TW	ORANGE-5	BLUE-5	GREEN-5	RED-5	IH FB
AVG	116.9	117.6	118.0	117.0	117.1	118.5
MAX	122.8	123.6	124.0	123.2	123.6	119.4
MIN	113.4	112.9	113.4	113.3	113.3	117.3
5%	**114.1**	116.3	116.7	113.9	**113.9**	117.6
25%	**115.4**	116.8	117.3	115.7	**115.6**	118.1
50%	**117.2**	117.2	117.6	116.9	**117.0**	118.4
75%	**117.6**	117.7	118.1	118.1	**118.3**	118.8
95%	**120.0**	121.4	121.1	120.0	**120.4**	119.2

Table 7-2 – Data Table for Lower Monumental TW TDG% with temporary downstream TDG stations and Ice Harbor Forebay TDG% for 5/31 to 6/7/2021

Date	5/31/2021 0:00	5/31/2021 0:00	5/31/2021 0:00	5/31/2021 0:00	5/31/2021 0:00	5/31/2021 0:00
Range	6/7/2021 0:00	6/7/2021 0:00	6/7/2021 0:00	6/7/2021 0:00	6/7/2021 0:00	6/7/2021 0:00
	LMO TW	ORANGE-5	BLUE-5	GREEN-5	RED-5	IH FB
AVG	117.5	118.0	118.5	117.7	117.9	118.0
MAX	122.1	121.6	120.6	122.9	123.1	120.8
MIN	114.0	116.4	115.9	113.9	114.0	114.7
5%	**114.4**	116.9	117.3	114.4	**114.9**	115.3
25%	**115.9**	117.2	117.7	115.8	**116.0**	116.8
50%	**117.6**	117.7	118.4	117.8	**118.0**	118.0
75%	**119.1**	118.4	119.3	119.5	**119.7**	119.5
95%	**120.9**	120.7	119.9	121.3	**121.2**	120.1

7.2 Little Goose

Figure 7-3 and Figure 7-4 show the TDG measured at the temporary stations downstream of Little Goose compared to the fixed monitoring tailwater TDG% at Little Goose and the forebay TDG% at Lower Monumental. The two weeks in Figure 7-3 and the one week in Figure 7-4 were the highest spill of the spring spill season in 2021. While the fixed TW monitoring station at Little Goose does not exceed 125% TDG, it can be seen that the purple and gold do exceed 125% TDG for extended periods of time. As expected, there is a slight delay for the reading of 0 to 2 hours for the gold station and 2-to-4-hour delay for the purple station compared to the fixed TW stations. The fixed tailwater TDG reading itself has about a 2 hour delay from the change in spill conditions. The white station (shown as green) tracks close to the fixed TW station in both Figure 7-3 and Figure 7-4 with a delay that is between the gold and purple stations. Meanwhile the yellow station tracks close to the fixed TW station in Figure 7-3 but does not track as close in Figure 7-4. It appears that when readings for the yellow station during the second deployment was about 12 hours off and when corrected the yellow station TDG data closely follows the fixed TW station. In addition to the graphs of the data it is also helpful to look at the tabulated data for these weeks that are shown in Table 7-3 and Table 7-4 (with the Table 7-4 including the estimated 12 hour offset). The data from both these tables indicate that the gold and purple temporary TDG sites are from 1% to almost 4% higher than the fixed tailwater TDG% with higher differences at higher TDG values. Additionally, it can be seen the Lower Monumental forebay fixed monitoring station has a higher average TDG%

than the fixed tailwater TDG% at Little Goose but it is lower than TDG measured at the gold and purple stations.

Figure 7-3 – 2021 Little Goose spill and TW TDG% with temporary downstream TDG stations and Lower Monumental Forebay TDG% for 5/11 to 5/18/2021

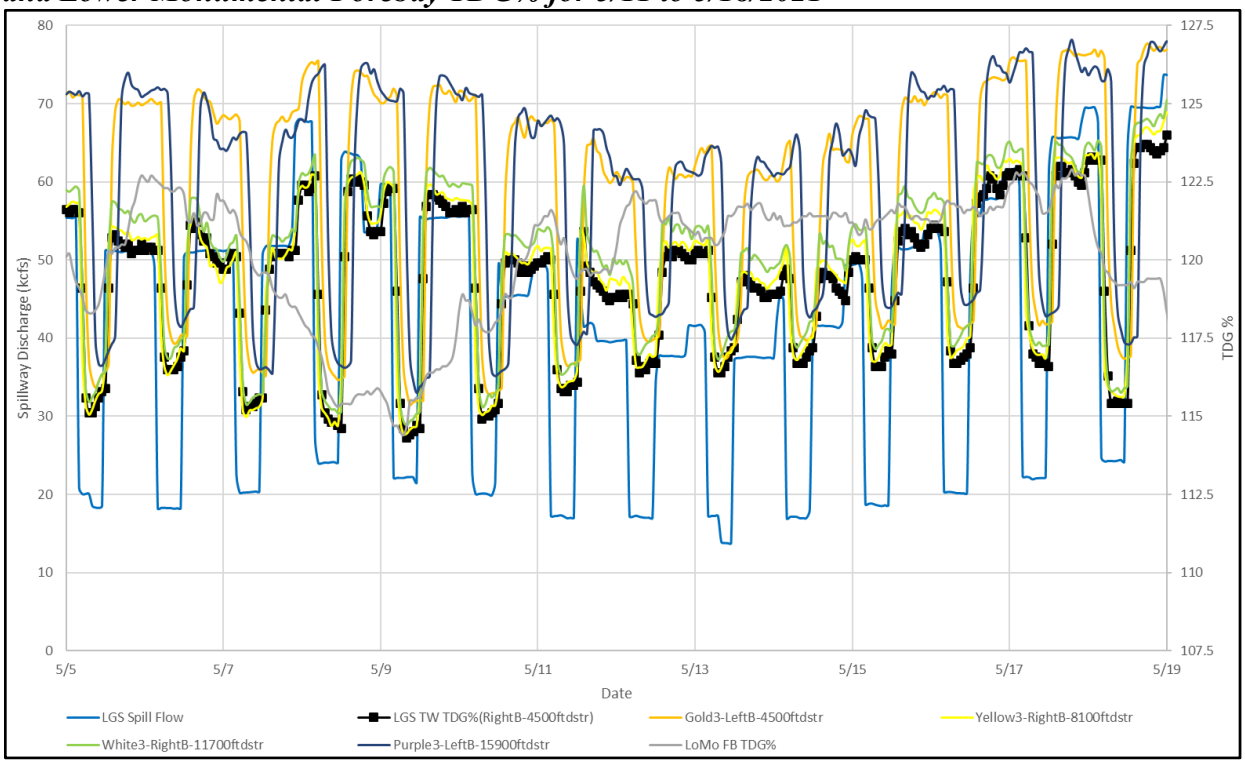


Figure 7-4 – 2021 Little Goose spill and TW TDG% with temporary downstream TDG stations and Lower Monumental Forebay TDG% for 5/31 to 6/7/2021

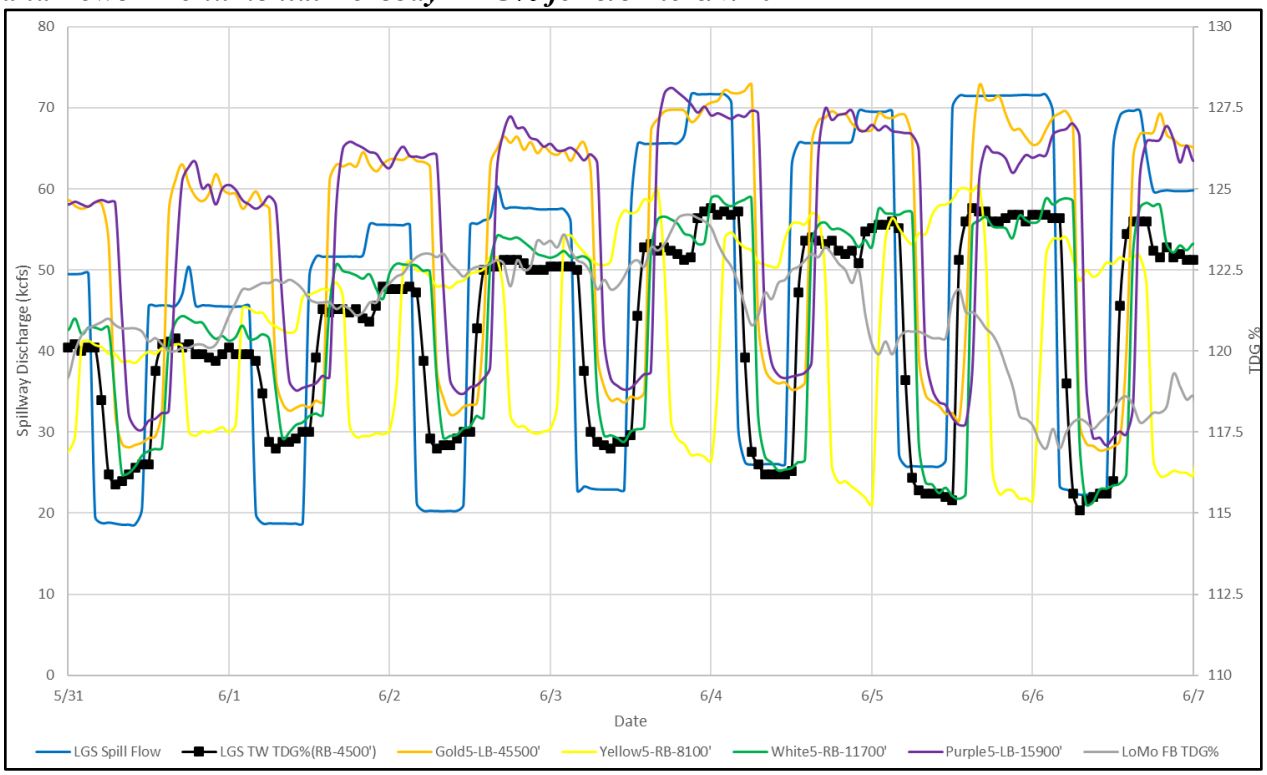


Table 7-3 – Data Table for Little Goose TW TDG% with temporary downstream TDG stations and Lower Monumental Forebay TDG% for 5/5 to 5/19/2021

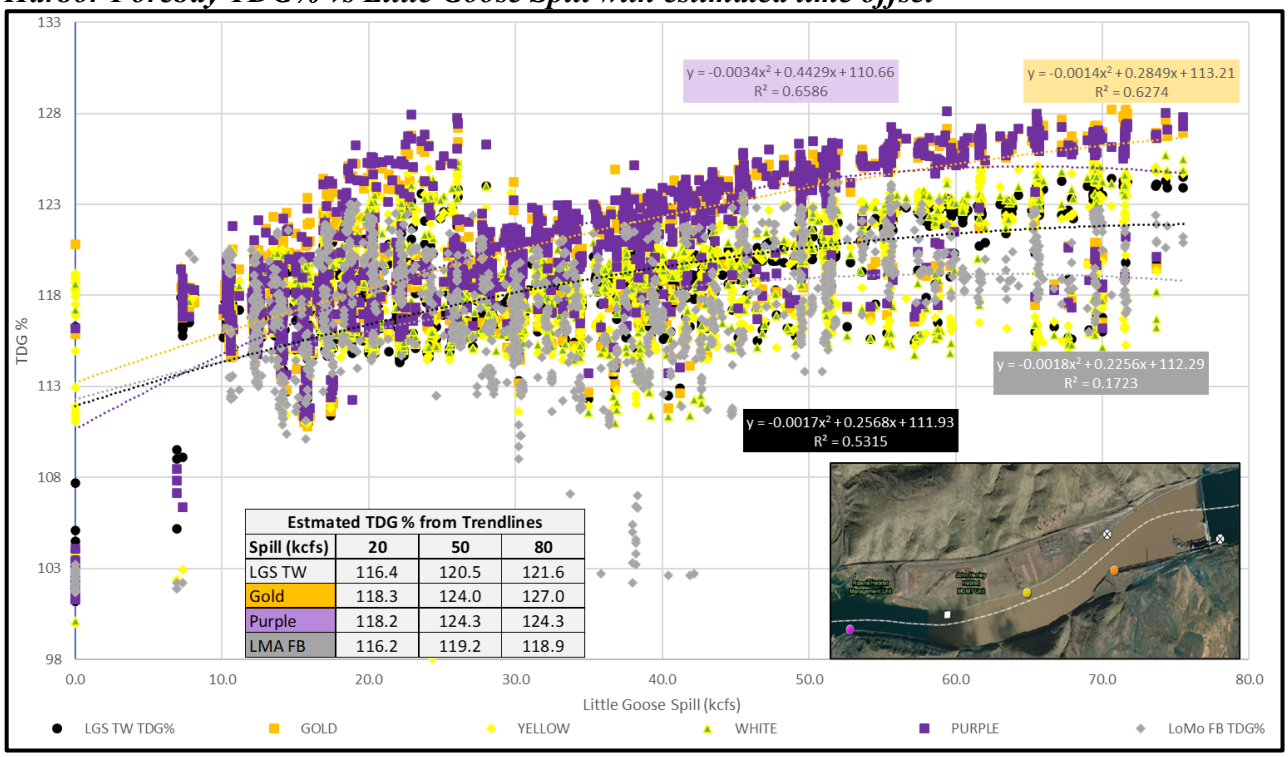
Date	5/5/2021 0:00	5/5/2021 0:00	5/5/2021 0:00	5/5/2021 0:00	5/5/2021 0:00	5/5/2021 0:00
Range	5/19/2021 0:00	5/19/2021 0:00	5/19/2021 0:00	5/19/2021 0:00	5/19/2021 0:00	5/19/2021 0:00
	LGO TW	GOLD-3	YELLOW-3	WHITE-3	PURPLE-3	LMO FB
AVG	119.3	122.3	119.6	120.1	122.5	120.1
MAX	124.0	126.9	124.7	125.1	127.0	122.9
MIN	114.3	115.4	114.4	114.7	115.8	114.4
5%	115.1	116.3	115.2	115.5	116.6	115.6
25%	117.0	118.0	117.1	117.6	118.7	119.1
50%	**119.8**	**123.6**	120.0	120.6	**123.6**	121.0
75%	**121.0**	**125.2**	121.5	122.0	**125.3**	121.5
95%	**123.0**	**126.6**	123.2	123.7	**126.3**	122.5

Table 7-4 – Data Table for Little Goose TW TDG% with temporary downstream TDG stations and Lower Monumental Forebay TDG% for 5/31 to 6/7/2021

Date	5/31/2021 0:00	5/31/2021 0:00	5/31/2021 0:00	5/31/2021 0:00	5/31/2021 0:00	5/31/2021 0:00
Range	6/7/2021 0:00	6/7/2021 0:00	6/7/2021 0:00	6/7/2021 0:00	6/7/2021 0:00	6/7/2021 0:00
0	LGO TW	GOLD-5	YELLOW-5	WHITE-5	PURPLE-5	LMO FB
AVG	120.7	123.7	120.8	121.0	123.7	121.2
MAX	124.4	128.2	125.1	124.8	128.1	124.2
MIN	115.1	116.9	115.3	115.3	117.1	117.0
5%	115.6	117.2	115.8	115.8	117.7	117.8
25%	117.5	118.9	117.6	117.7	119.3	120.2
50%	**121.4**	**125.7**	122.0	122.4	**125.7**	121.6
75%	**123.2**	**126.8**	122.9	123.6	**126.5**	122.6
95%	**124.2**	**127.8**	124.5	124.6	**127.4**	123.4

Due to the higher TDG% observed at the gold and purple stations, the correlation of spill discharge vs TDG% was also analyzed. As discussed above there is a time offset from a change in spill conditions due to travel time between the dam and the TDG stations. Therefore, estimated time offsets of 2 hours for the fixed TW station, 3 hours for the gold station, 4 hours for the purple station, 26 hours for the yellow station and 48 hours for the Lower Monumental fixed forebay station. Even with these offsets, the correlation of spill discharge and TDG% is not expected to be a perfect for any of the stations. Figure 7-5 presents the correlation with trendline equations across the 2021 spring spill season. Applying these time offsets did improve the correlation of spill and TDG but the yellow station and Lower Monumental fixed forebay stations were still quite poor correlations. There is a slightly better correlation of the gold and purple stations than the fixed TW station and with higher TDG where the delta increases with higher spill. Besides the fit, Figure 7-5 also shows the estimated TDG based on the trendline equations for the temporary and fixed stations for a range of spill discharges. No trendline was created for the yellow station due to the poor correlation with spill discharge.

Figure 7-5 – 2021 Spring spill Little Goose TW TDG% from Fixed & Temp Stations and Ice Harbor Forebay TDG% vs Little Goose Spill with estimated time offset



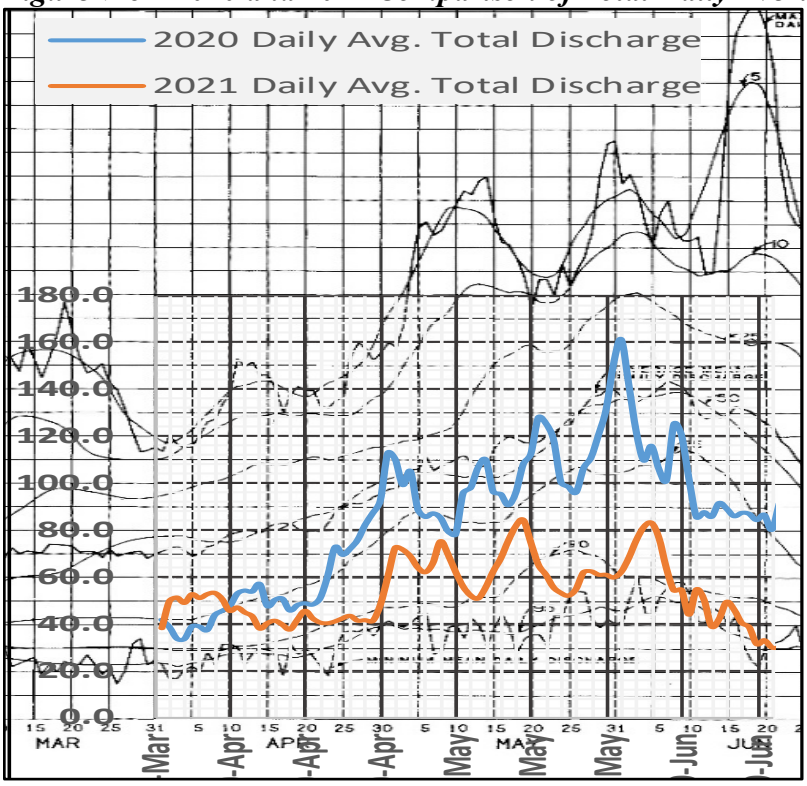
Estmated TDG % from Trendlines			
Spill (kcfs)	20	50	80
LGS TW	116.4	120.5	121.6
Gold	118.3	124.0	127.0
Purple	118.2	124.3	124.3
LMA FB	116.2	119.2	118.9

7.3 Discussion

The 125% gas cap was not reached in 2021 at either Little Goose or Lower Monumental per the readings on the fixed TW monitoring stations. This is mostly due to the below average spring discharge in 2021 compared to the above average spring discharge in 2020 as can be seen in Figure 7-6. Despite the lower spring spill discharge there was useful insights from the temporary TDG station data.

At Lower Monumental, the red and green stations did show consistently higher TDG than the fixed TW station, but this data was only minimally higher. The Ice Harbor forebay did still average levels that were near the same or slightly higher than the fixed TW station at Lower Monumental even though the average levels would be expected to be lower due to degassing. Therefore, it is possible that none of the temporary station locations chosen represented an average river TDG condition and that higher TDG was elsewhere in the river. The Phase I Dissolved Gas Abatement study report did indicate that it took many miles prior to full mixing of the TDG in the river and so a fully mixed would not be expected even at the red station location over 3 miles downstream.

Figure 7-6 – 2020 and 2021 Comparison of Total Daily Average Discharge at Little Goose



At Little Goose, the yellow and white stations on the right side of the river have a similar TDG as the fixed TW station, although there is a slight increase at the white station. Meanwhile the gold and purple stations on the left side of the river are consistently higher TDG than the fixed TW station. This TDG delta varies from 1% to 4% and increases at higher TDG and higher spill discharges. This indicates that higher TDG water tends to pass along the south side of the river and the difference from the north side of the river increases at the spill discharge increases. This correlates well with the theory that the higher intensity eddy at higher spill discharges (see Figure 3-3 and Figure 3-4) creates higher TDG levels on the south side of the river. It can also be observed in Table 7-3 and Table 7-4 that the Lower Monumental forebay TDG is similar or higher TDG than the fixed tailwater station at Little Goose. However, the Lower Monumental forebay TDG is typically 2 to 4% lower TDG than the purple station. Since some degassing would be expected between the dams this would be expected if the purple station is more representative of average river conditions, although full mixing would not be expected this distance downstream from the dam.

The correlation of spill discharge and TDG% is not great for any of the stations. One possible reason is that a constant time offset between the spill discharge and TDG reading was applied at each of the stations, and it likely varies with changing spill and total river flow conditions. However, it can be seen that the gold and purple station were usually higher than the fixed tailwater station at Little Goose during the 2021 spring spill season with values that exceed 125% even though the fixed tailwater station readings did not.

8 2022 RESULTS AND DISCUSSION

The locations of the additional temporary TDG monitoring in 2022 consisted of TDG downstream of the existing fixed tailwater monitoring stations at both Lower Monumental and Little Goose.

Only the red and green stations were deployed for Lower Monumental (see Figure 5-5) and the gold and purple stations were deployed for Little Goose (see Figure 5-6). Similar to 2021, the barometric pressure from the fixed TW station was used to determine the TDG% at these temporary stations.

8.1 Lower Monumental

Figure 8-1 and Figure 8-2 show the TDG measured at the temporary stations downstream of Lower Monumental compared to the fixed monitoring tailwater TDG% at Lower Monumental and the forebay TDG% at Ice Harbor. The spring spill season was a little higher discharge than 2022 in the middle of the season where 125% gas cap was reached as seen in Figure 8-1. However late in the spring spill season there was forced spill that pushed TDG higher than the 125% gas cap limit at the fixed tailwater station as seen in Figure 8-2. Similar to the 2021 the red and green temporary TDG sites do track with the fixed tailwater TDG% with a 1 to 2 hour delay. The fixed tailwater TDG reading itself has about a 2-3 hour delay from the change in spill conditions. In addition to the graphs of the data it is also helpful to look at the tabulated data for these weeks that are shown in Table 8-1. The data from Table 8-1 indicate that the red and green temporary TDG sites do track with the fixed tailwater TDG% but are from 0% to 1% higher with the red slightly higher than the green. Even though the spill discharge is significant higher in 2022, the delta from the fixed TW station seems to be consistent with 2021.

Figure 8-1 – 2022 Lower Monumental spill and TW TDG% with temporary downstream TDG stations and Ice Harbor Forebay TDG% for 5/18 to 5/25/2022

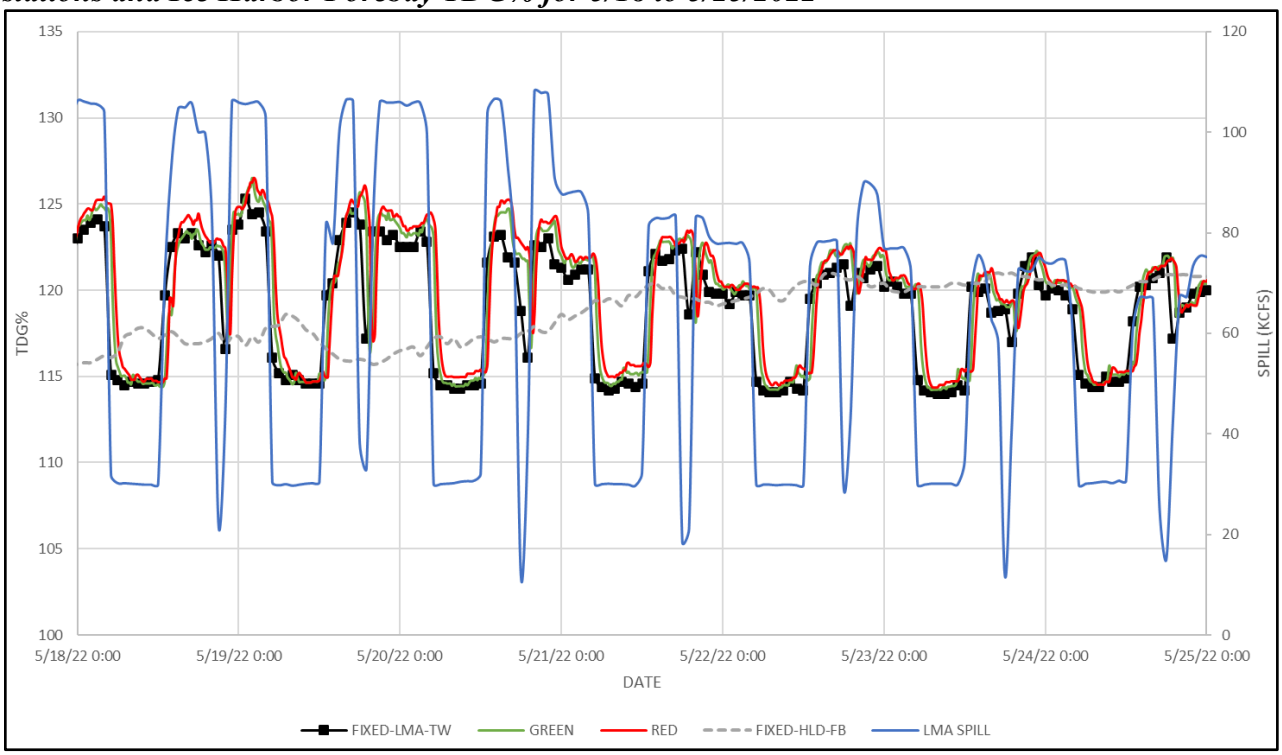


Figure 8-2 – 2022 Lower Monumental spill and TW TDG% with temporary downstream TDG stations and Ice Harbor Forebay TDG% for 6/8 to 6/15/2022

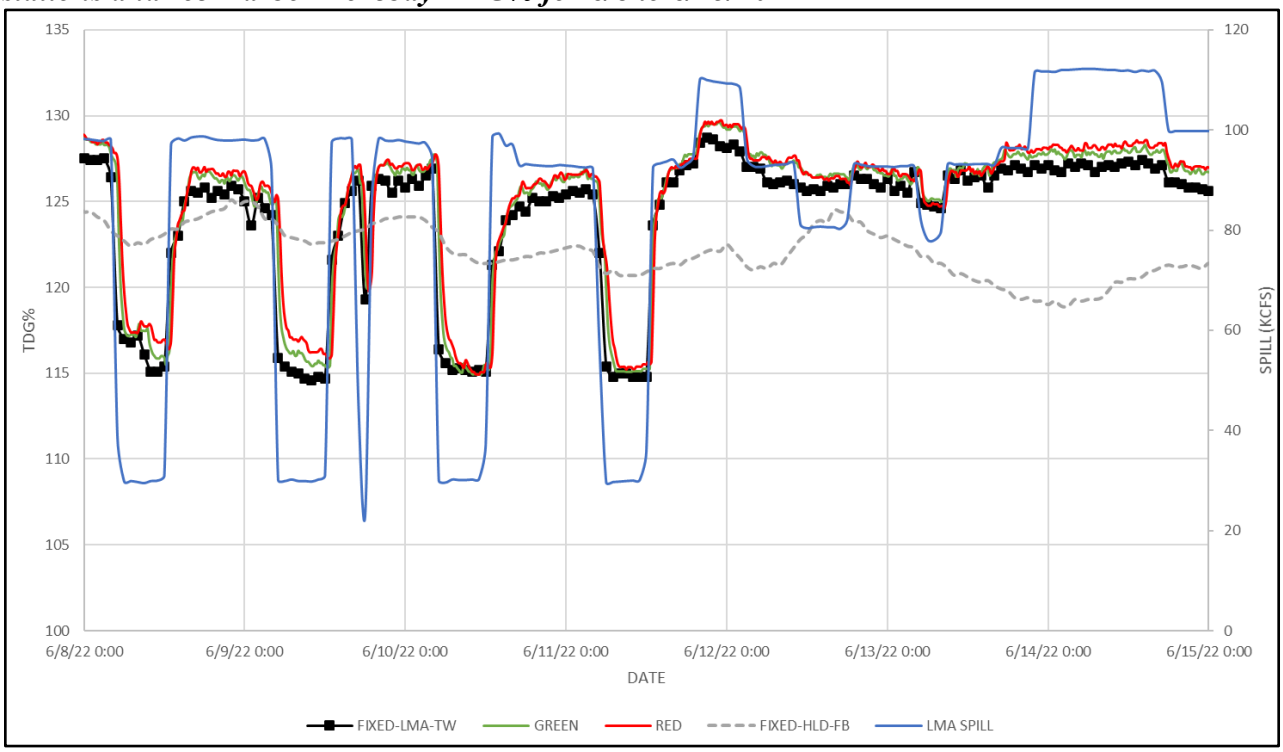


Table 8-1 – Data Table for Lower Monumental TW TDG% with temporary downstream TDG stations and Ice Harbor Forebay TDG% for 5/18 to 5/25/2022 and 6/8 to 6/15/22

Date	5/18/22 0:00				Date	6/8/22 0:00			
Range	5/25/22 0:00				Range	6/15/22 0:00			
	LGS-TW	GREEN	RED	LMA-FB		**LGS-TW**	GREEN	RED	LMA-FB
AVG	119.0	119.6	119.9	118.8	AVG	124.0	124.8	125.0	122.1
MAX	125.3	126.5	126.5	121.0	MAX	128.7	129.6	129.7	125.1
MIN	114.0	114.2	114.4	115.7	MIN	114.6	114.9	114.9	118.9
5%	114.2	114.4	114.7	116.0	5%	115.0	115.3	115.6	119.3
25%	114.8	115.2	115.5	117.2	25%	124.2	124.8	124.8	121.1
50%	119.8	120.4	120.5	119.4	50%	125.8	126.6	126.7	122.1
75%	121.9	122.5	122.8	120.3	75%	126.7	127.5	127.5	123.3
95%	123.8	124.5	125.0	120.9	95%	127.5	128.5	128.6	124.4

8.2 Little Goose

Figure 8-3 and Figure 8-4 show the TDG measured at the temporary stations downstream of Little Goose compared to the fixed monitoring tailwater TDG% at Little Goose and the forebay TDG% at Lower Monumental. The fixed forebay monitor at Lower Monumental was temporarily out of service for some of the time shown in these weeks as seen in Figure 8-3. The spring spill season was a little higher discharge than 2022 in the middle of the season where 125% gas cap was reached consistently as seen in Figure 8-3. However late in the spring spill season there was forced spill that pushed TDG higher than the 125% limit at the fixed tailwater station as seen in Figure 8-4. Similar to delay from a change in spill were seen in the readings in 2022 as in 2021. It can be seen the

purple and gold stations both track the fixed tailwater station but have readings with significantly higher TDG%. In addition to the graphs of the data it is also helpful to look at the tabulated data for these weeks that are shown in Table 8-2. The data in this table indicates that the gold and purple temporary TDG sites are from 2% to almost 6% higher than the fixed tailwater TDG% with higher differences at higher TDG values. This is consistent with 2021 but it can be seen that the delta becomes even larger at the higher spill discharges seen in 2022. Additionally, it can be seen the Lower Monumental forebay fixed monitoring station has the same or higher average TDG% than the fixed tailwater TDG% at Little Goose but it is lower than TDG measured at the gold and purple stations.

Figure 8-3 – 2022 Little Goose spill and TW TDG% with temporary downstream TDG stations and Lower Monumental Forebay TDG% for 5/29 to 6/5/2022

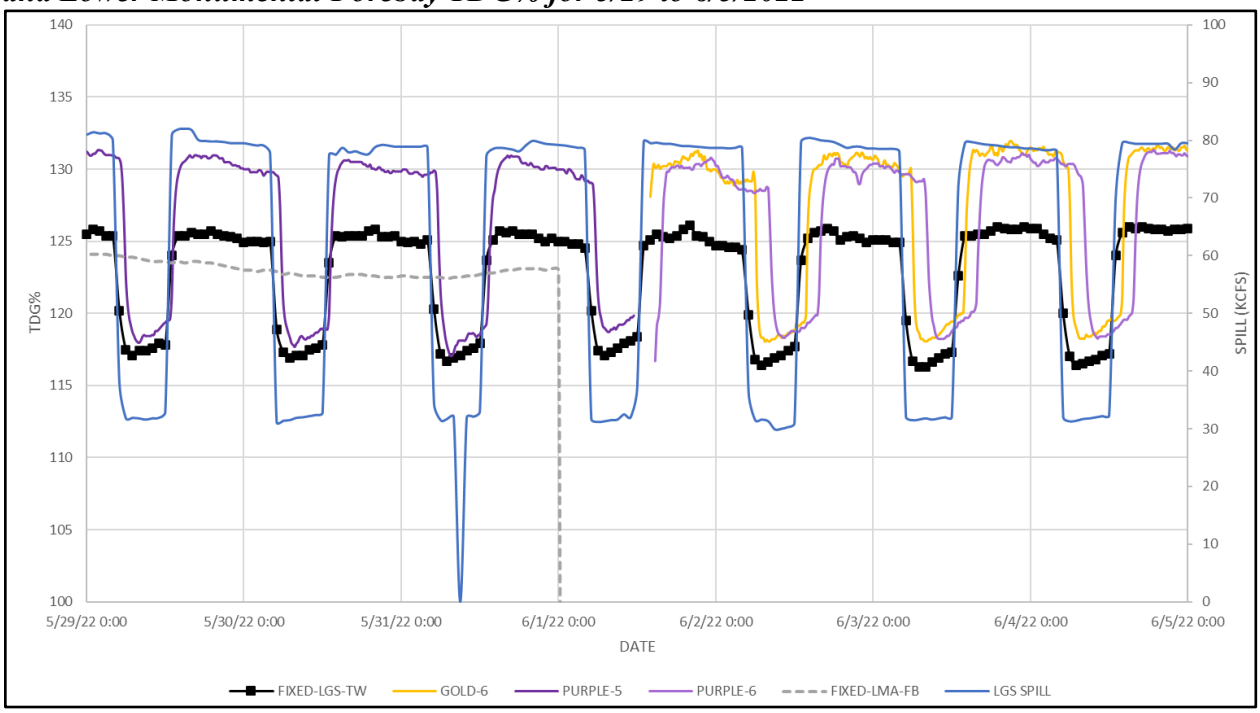


Figure 8-4 – 2022 Little Goose spill and TW TDG% with temporary downstream TDG stations and Lower Monumental Forebay TDG% for 6/11 to 6/18/2022

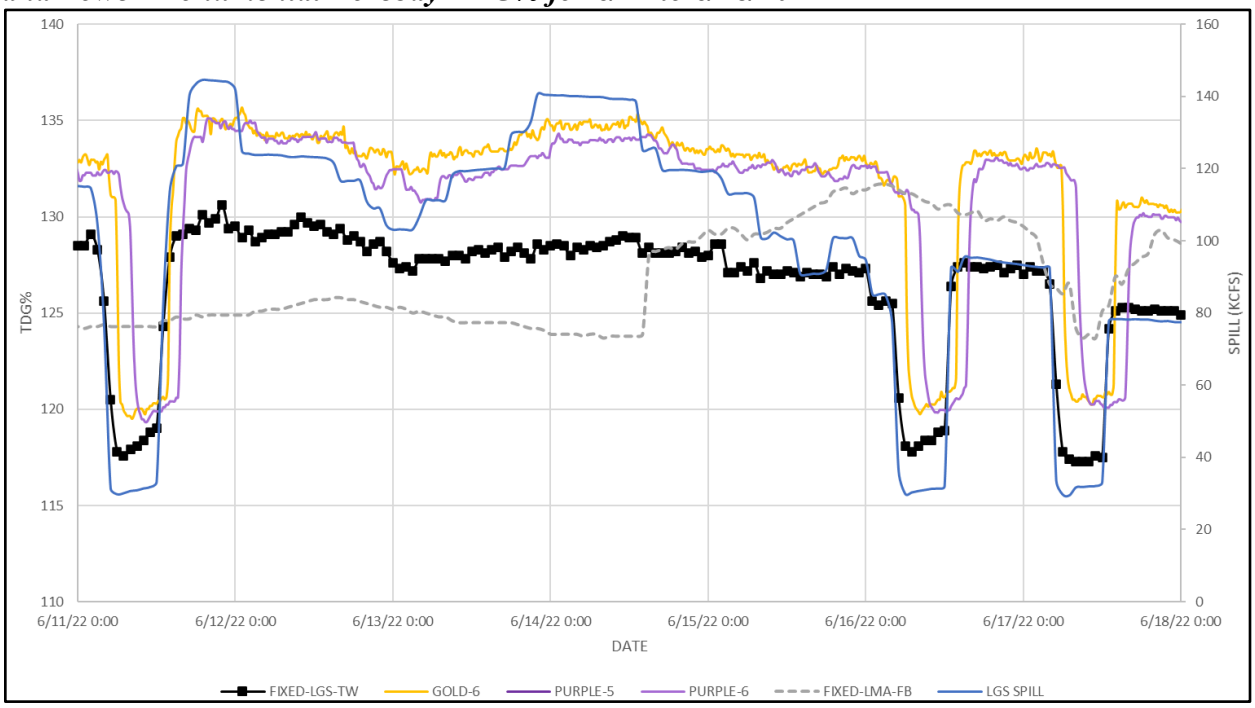
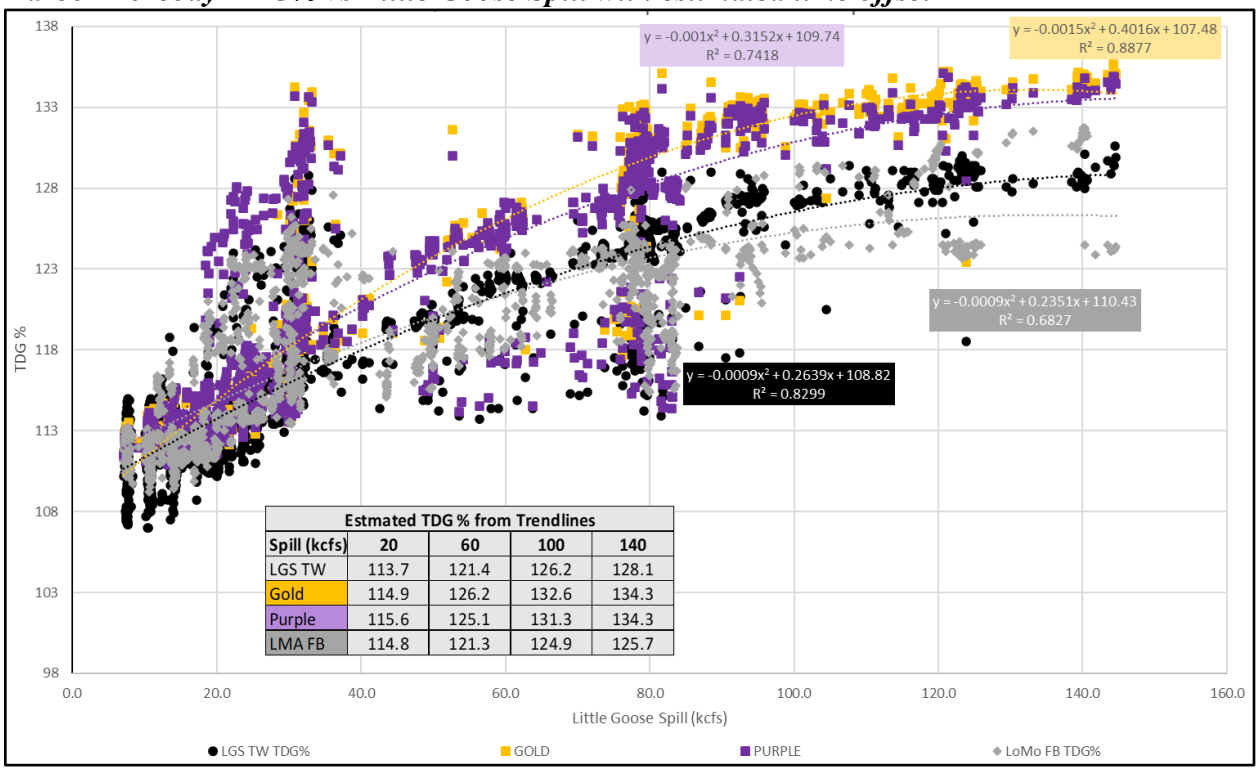


Table 8-2 – Data Table for Little Goose TW TDG% with temporary downstream TDG stations and Lower Monumental Forebay TDG% for 5/29 to 6/7/2022 and 6/11 to 6/18/22

Date	5/29/22 0:00					Date	6/11/22 0:00			
Range	6/7/22 0:00					Range	6/18/22 0:00			
	LGS-TW	GOLD	PURPLE-5	PURPLE-6	LMA-FB		**LGS-TW**	GOLD	PURPLE	LMA-FB
AVG	123.0	125.0	126.3	127.2	123.0	AVG	126.5	131.6	131.1	126.8
MAX	129.4	134.6	131.3	133.9	124.1	MAX	130.6	135.7	135.1	131.7
MIN	116.3	96.9	117.1	116.7	122.4	MIN	117.3	119.5	119.3	123.7
5%	116.8	97.5	118.1	118.5	122.5	5%	117.8	120.3	120.2	123.8
25%	117.9	119.4	119.2	120.4	122.6	25%	126.4	132.3	131.4	124.5
50%	125.1	130.2	129.8	130.0	123.0	50%	127.7	133.2	132.5	125.6
75%	125.6	131.3	130.3	130.7	123.5	75%	128.5	134.2	133.6	129.3
95%	128.7	134.0	131.0	133.1	124.0	95%	129.5	135.0	134.3	131.4

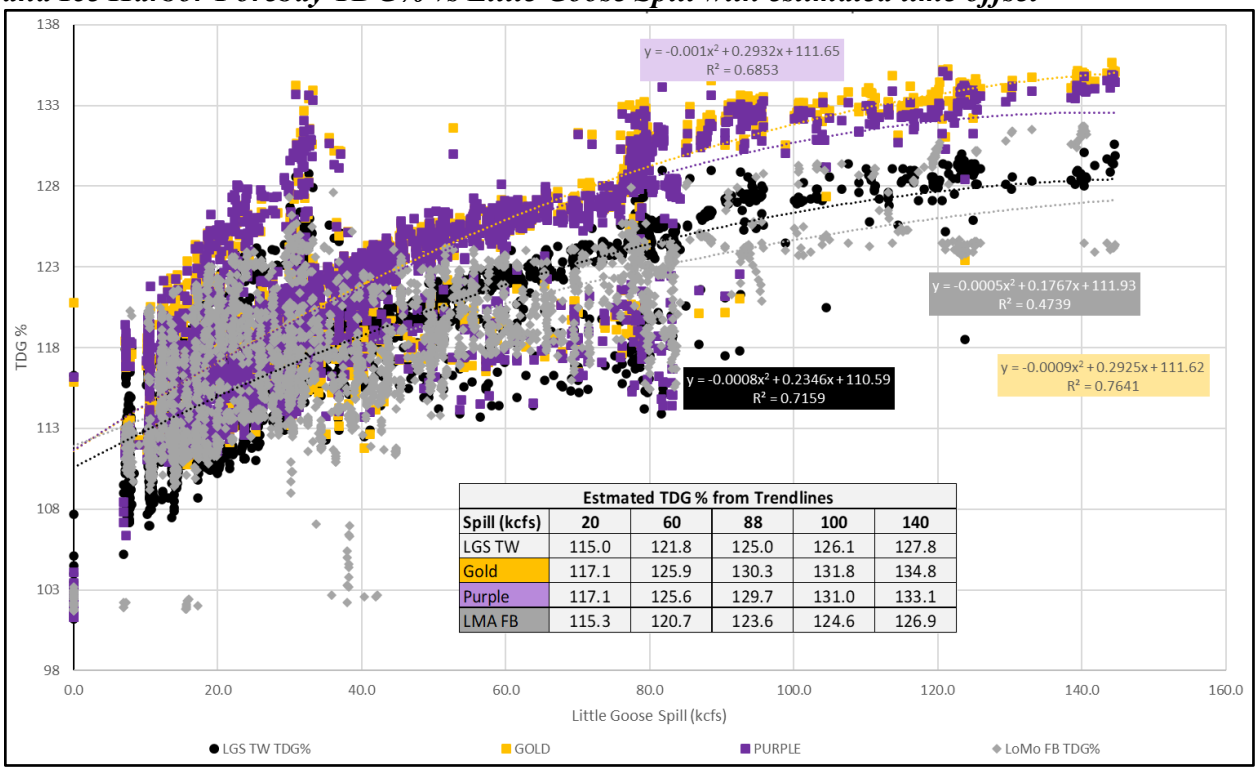
Due to the higher TDG% observed at the gold and purple stations, the correlation of spill discharge vs TDG% was also analyzed. The same time offsets were used as in 2021. Figure 8-5 presents the correlation with trendline equations across the 2022 spring spill season, while Figure 8-6 presents the correlation across both the 2021 and 2022 spring spill seasons combined. There is not a dramatic change across the seasons though there is more spread in the data including the 2021 data. Both Figure 8-5 and Figure 8-6 show the estimated TDG based on the trendline equations for the temporary and fixed stations for a range of spill discharges.

Figure 8-5 – 2022 Spring spill Little Goose TW TDG% from Fixed & Temp Stations and Ice Harbor Forebay TDG% vs Little Goose Spill with estimated time offset



Estmated TDG % from Trendlines				
Spill (kcfs)	20	60	100	140
LGS TW	113.7	121.4	126.2	128.1
Gold	114.9	126.2	132.6	134.3
Purple	115.6	125.1	131.3	134.3
LMA FB	114.8	121.3	124.9	125.7

Figure 8-6 – 2021 and 2022 Spring spill Little Goose TW TDG% from Fixed & Temp Stations and Ice Harbor Forebay TDG% vs Little Goose Spill with estimated time offset

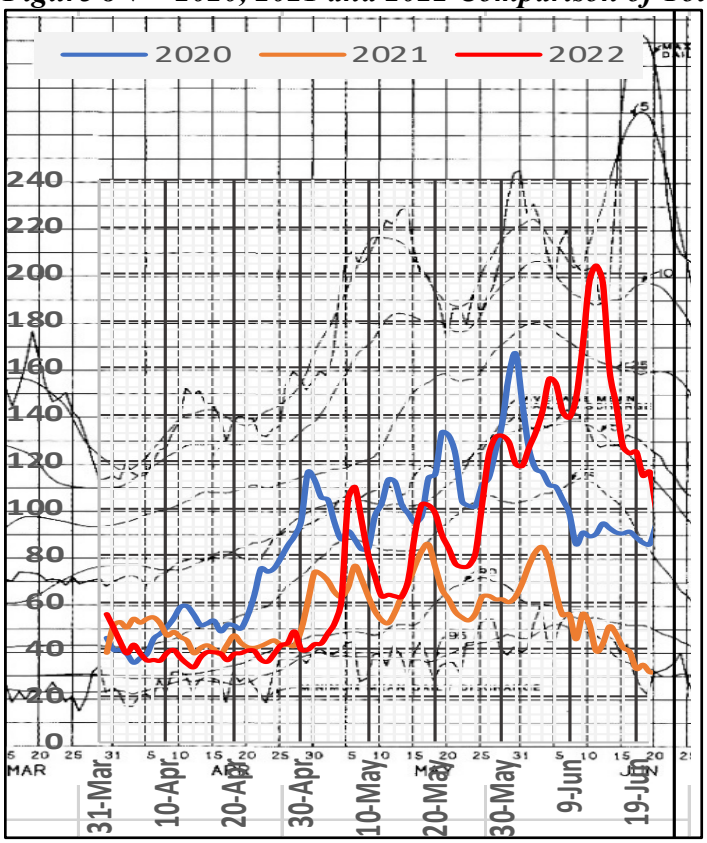


Estmated TDG % from Trendlines					
Spill (kcfs)	20	60	88	100	140
LGS TW	115.0	121.8	125.0	126.1	127.8
Gold	117.1	125.9	130.3	131.8	134.8
Purple	117.1	125.6	129.7	131.0	133.1
LMA FB	115.3	120.7	123.6	124.6	126.9

8.3 Discussion

The total river discharge was quite low during the early spring spill season in 2022 and in the middle of the season it was in between 2020 and 2021. However, late in the spring a much larger river discharge passed the projects resulting in forced spill well above the 125% gas cap. Figure 8-7 provides a comparison of daily average discharge at Little Goose for 2020, 2021 and 2022. The higher spill discharge did provide additional information on the TDG downstream of the two projects changes with increasing spill discharge.

Figure 8-7 – 2020, 2021 and 2022 Comparison of Total Daily Average Discharge at Little Goose



At Lower Monumental, the red and green stations did show consistently higher TDG than the fixed tailwater station like 2021. Table 8-1 does show that the delta between these stations and the fixed tailwater station did slightly increase with increasing spill but even at the highest discharges above the 125% gas cap these stations only read around 1% higher TDG. Unlike 2021, the Ice Harbor forebay TDG was generally lower than the fixed tailwater station at Lower Monumental. With unknown amount of degassing between the dams, it is inconclusive whether the fixed tailwater monitoring station, the temporary red station or an unmeasured third site are more representative of the average river TDG conditions downstream of Little Goose.

At Little Goose, similar to 2021, the gold and purple stations on the south side of the river are consistently higher TDG than the fixed tailwater station. In 2022, at higher spill discharges this TDG delta varied from 2% to 6% with the highest differences at high forced spill discharges. Similar to 2021, a reasonable explanation for this higher TDG on the south side of the river is the

increasing TDG coming for the eddy in front of the powerhouse that increases in intensity with increased spill discharges. The Lower Monumental forebay TDG often exceeded the fixed tailwater station at Little Goose when it would be expected to be lower due to degassing between the dams. While it is does seem that the tailwater the fixed monitoring station TDG is not representative of average river conditions without more information it is not known if the purple station is representative of the average river TDG downstream of the dam.

Figure 8-6 combines information from both 2021 and 2022 to try to correlate spill discharge with TDG at these monitoring stations downstream of Little Goose. The predicted delta between the fixed tailwater monitoring station and the gold or purple temporary stations are relatively small at 20 kcfs spill or below but becomes quite large at high spill discharges. The 125% gas cap is based on the fixed tailwater TDG station and the trendline indicates that this gas cap occurs at approximately 88 kcfs spill discharge. At this spill discharge the gold and purple stations would be predicted to measure approximately 130% TDG. If the gold or purple stations were used to establish the gas cap the spill discharge would be limited to slightly less than 60 kcfs.

9 OVERALL DISCUSSION

There were significant changes in tailrace patterns were observed at the U.S. Army Corps of Engineers (USACE), Walla Walla District (CENWW) projects during the increase to 125% gas cap during the 2020 spring spill for fish passage. These changes in tailrace patterns will change the distribution of TDG in the river that may not be observed by the fixed monitoring stations. The additional temporary TDG monitoring that were deployed and analyzed in 2020, 2021 and 2022 as well as the fixed forebay monitoring did show that there was a significant redistribution of TDG within the tailrace of several dams.

In 2020, high TDG was observed at the forebay fixed monitoring station of Lower Monumental and Ice Harbor that was above the upstream tailwater fixed monitoring station extended periods of time. While this is expected to occasionally occur due to changing environmental conditions (temperature and barometric pressure), in general the forebay TDG should be several percent less than tailwater TDG of the upstream dam due to degassing between the dams. At Little Goose, the tailrace eddy was also monitored in 2020 and very high TDG levels of 130% to 135% were measured. Based on the observed tailrace patterns it was conjectured that this water may be passing down the south side of the river resulting the high forebay TDG at Lower Monumental that is missed by the Little Goose tailwater fixed monitoring station. Given the high forebay TDG at Ice Harbor it was thought this could be occurring at Lower Monumental as well although no observations were made of the TDG in the Lower Monumental powerhouse eddy. While the Little Goose eddy is expected to have some of the higher TDG levels, other dams not monitored also have eddies at 125% gas cap spill that likely have elevated TDG levels as well.

In addition to the powerhouse eddy at Little Goose, TDG was measured at the fishway entrances of Ice Harbor, Lower Monumental and Little Goose in 2020. The Ice Harbor and Little Goose fishways did not have TDG levels that were greater than 125% and were typically less than 120% TDG. The Lower Monumental fishway closely followed the forebay TDG which is expected since most of the adult fish ladder attraction water comes from the forebay. However, with the Lower Monumental forebay TDG having high TDG (extended periods above 125% TDG) due to Little Goose spill, there is still a biological concern given the shallower water in the fish ladder preventing adequate depth for TDG compensation.

Given the observations of 2020, the focus of the additional temporary TDG monitoring in 2021 and 2022 was downstream of both Little Goose and Lower Monumental. There were 4 temporary TDG stations deployed downstream of each project in 2021 and only 2 temporary TDG stations deployed per project in 2022. In 2021, the 125% gas cap limit was not reached at either project. The spring 2022 had higher river discharges and spill discharges than 2021 resulting in the 125% gas cap limit being reached as well as exceeded (due to forced spill). Despite the difference similar observations were made in both years. For Lower Monumental, two temporary TDG stations on the south shore (green and red) recorded around 0.5-1% higher than the tailwater fixed-monitoring station and the delta only increased slightly with higher spill discharges. For Little Goose, two temporary TDG stations on the south shore recorded 2-6% higher than the fixed tailwater monitoring station during the higher spill periods with a significant increased delta with increasing spill discharge.

The spill patterns can also affect TDG distribution and are more imbalanced across the spillway at lower spill discharges. Lower Monumental has a more imbalanced spill pattern below 50 kcfs but Little Goose is relatively balanced across the discharge range except for the ASW. Generally, less TDG would be produced for the same spill discharge if the spill pattern is more uniform. Additionally, any change in spill pattern can affect TDG distribution. Unfortunately, the correlations between total spill discharge and TDG distribution cannot be separated from a specific spill pattern. Any future change in spill pattern would have to have the TDG data analyzed separately, however the spill patterns have been stable at most projects for a number of years.

The Washington state TDG water quality standards specify only the tailwater fixed monitoring TDG gauges as compliance points during the spring spill season for managing the spill up to but not exceeding 125% TDG. Therefore, the Corps is not interpreting TDG greater than 125% recorded at several of the temporary stations as an exceedance of the water quality requirements. However, the 125% limit was chosen based on balancing biological risk of gas bubble trauma (GBT) with the desire to have more juvenile salmon pass the dam through the spillway. Therefore, these observations indicate that higher than 125% TDG water is passing downstream of these projects and the GBT risk may be higher than originally intended. The GBT risk during 125% gas cap spill maybe significantly higher downstream of Little Goose. The GBT risk downstream of Lower Monumental maybe similar to expectations but this is still uncertain due to high forebay readings still being observed at Ice Harbor.

Based on the observations to date, additional TDG and GBT monitoring is recommended in 2023 and future years at both Lower Monumental and Little Goose but especially at Little Goose. While the temporary monitoring performed in 2022 is a minimum, to more fully determine the change in TDG distribution, more extensive TDG monitoring across the entire river needs to be performed for a full season or at least multiple different river discharges and operating conditions. The result of the more extensive TDG monitoring could be moving the fixed monitoring station or supplementing the fixed monitoring station to manage the project during high spill. A more detailed plan would need to be put together to determine how the more detailed monitoring should be conducted to cost effectively obtain the necessarily amount of additional information.