SPILL DATA EVALUATION

ROCKY REACH DAM 2011-2012

Prepared for

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ACRONYMS AND ABBREVIATIONS

Chelan PUD	Chelan County Public Utility District No. 1
FERC	Federal Energy Regulatory Commission
ft	foot
GBD	gas bubble disease
h	hour
kcfs	thousand cubic feet per second
TDG	total dissolved gas
7Q10	river discharge (flow) occuring for a period of 7 days on average once in 10 years

SUMMARY

This report provides an analysis of total dissolved gas (TDG) data for Rocky Reach Dam obtained during tests of four spill gate configurations. Three of these configurations used four gates that are not included in the gate configurations currently used at the spill levels tested. Data was obtained for spill periods of 2011 and 2012 for the forebay and downstream monitoring locations. The analysis was undertaken to identify differences in TDG levels produced using each of the spill gate configurations at Rocky Reach Dam. Downstream data was collected at a monitoring station placed on the end of the fish bypass system rather than at a bridge further downstream in many previous years. The fish bypass location appears to be primarily in flow from the spillway with less dilution by powerhouse discharge than the downstream location.

Spilling water at Rocky Reach Dam produces supersaturation just as at other dams. Previous monitoring at Rocky Reach has shown that a major factor determining downstream TDG levels is the level of dissolved gas in the water arriving at the forebay, which may affect the TDG levels in spilled water as well as the powerhouse discharge. Generally, TDG levels in the forebay water increase at the same time that spill occurs or increases at Rocky Reach Dam, because increasing river flows result in increasing spill at upstream dams. However, the right angle physical configuration of the spillway and powerhouse together with previous monitoring indicate that there is potential spill through one or more gate configurations that might produce higher or lower TDG levels than other gate configurations.

The four spill gate configurations were tested under routine operating conditions to provide a record of TDG supersaturation levels produced as a means to guide future spill gate operations. The objective was to identify the operating configuration(s) that produce the lowest TDG levels. The four configurations tested were Fish Spill (standard gate configuration for adult fish guidance using gates 2-8), TDG Spill, Shallow Arc Spill, and Flattened Spill. The latter three configurations used gates 2-9 and gates 11-12 in 2011 (gate 10 was out for maintenance), and gates 2-10 and gate 12 in 2012 (gate 11 was inoperable due to maintenance).

The Fish Spill configuration tended to increase TDG downstream from the dam and produced the highest TDG levels of the four configurations tested. The TDG Spill, Shallow Arc Spill, and Flattened Spill configurations tended to produce small reductions in TDG levels from the forebay to the downstream monitoring station. Because of the similar number of gates used for the TDG Spill, Shallow Arc Spill, and Flattened Spill configurations, the differences between these configurations were not always clear or consistent. However, the Flattened Spill configuration tended to produce more consistent and slightly greater reductions in downstream TDG levels, than the other configurations.

The basic difference between Fish Spill and the other configurations is the number of gates used to discharge a given amount of flow. The Fish Spill used only seven gates, while the other configurations employed ten gates each. Spreading spill over a greater number of gates generally tends to minimize the production of TDG levels downstream.

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INTRODUCTION

Chelan PUD is required by the 401 Water Quality Certification for the Rocky Reach Project to "…implement alternative spillway operations, using any of gates 2 through 12. Analysis of this operation is required to determine whether TDG levels can be reduced without adverse effects on fish passage…." Chelan PUD implemented testing of 4 spillway configurations (standard/fish and three others) in June and July 2011, and repeated the testing in June and July 2012. This report provides an analysis of the total dissolved gas (TDG) supersaturation data collected during the two test years to determine if any of the four configurations is/are better than the others at minimizing TDG supersaturation in downstream water, and if so, under what conditions is/are said configuration(s) the "best performer(s)".

Gate configuration refers to the use of different combinations of gates, amounts of discharge through individual gates, and/or numbers of gates to pass flow at a dam. It is common for different spill gate configurations to produce higher or lower TDG levels than other gate configurations at a dam. The 401 Water Quality Certification requirement for the Rocky Reach Dam is intended to identify the spill gate configuration that will produce the lowest levels of TDG.

This report provides an analysis of the routine total dissolved gas data collected between the forebay of Rocky Reach Dam and the forebay of Rock Island Dam (Figure 1) during the spill periods of 2011 and 2012. During this period various spill gate configurations were tested to provide a record of TDG supersaturation levels produced by these configurations as a means to guide future spill gate operations. The comparison of gate configurations was intended to identify the operating configurations that would produce the least TDG in downstream water.

During the Columbia River's high flow period total dissolved gas is commonly at elevated levels in Rocky Reach Dam's forebay due to spill at upstream dams. The objective of this analysis is to determine the operational configuration(s) that will avoid or minimize increases in TDG supersaturation in water spilled at Rocky Reach Dam.

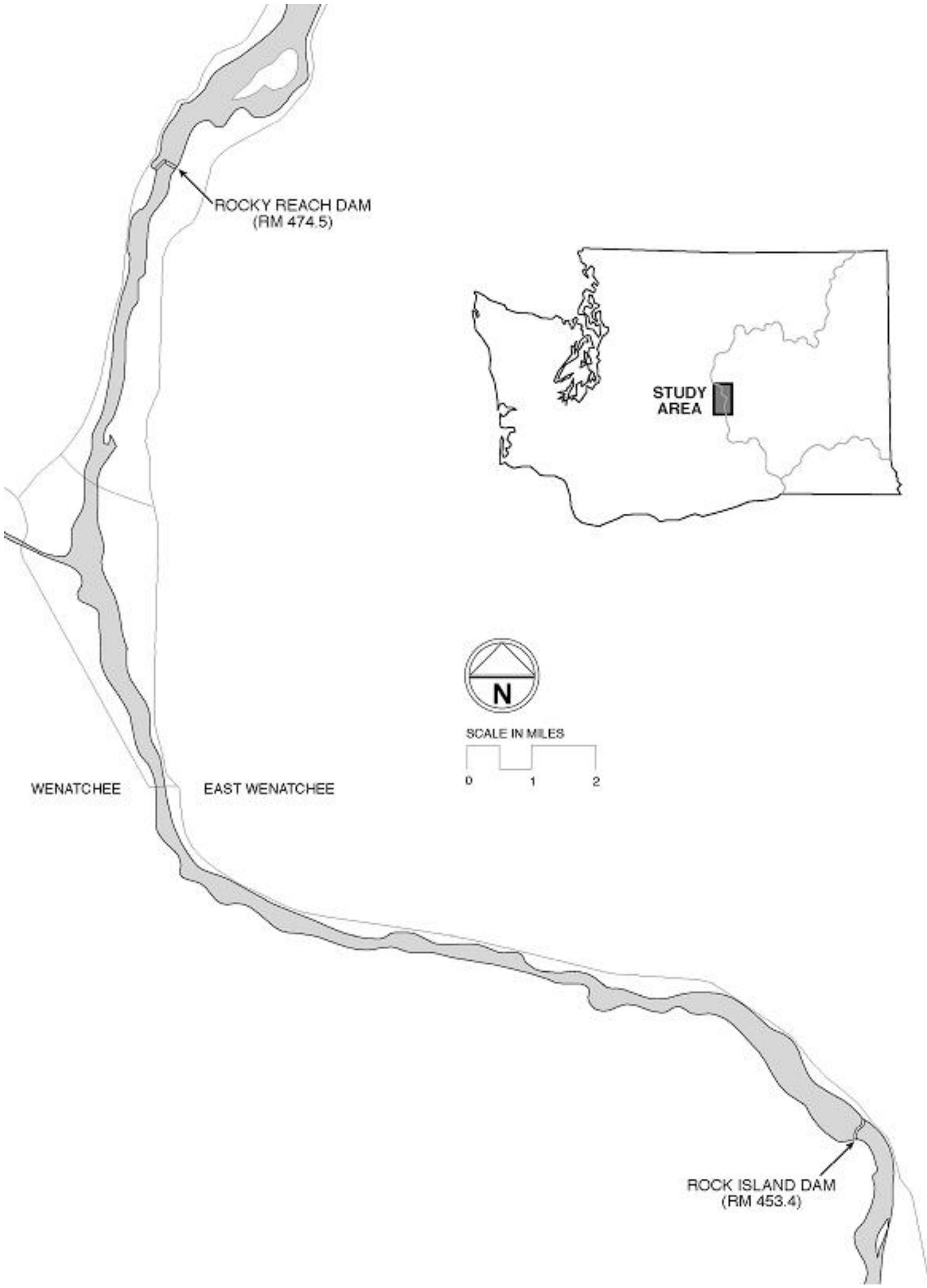


Figure 1 Columbia River from Rocky Reach Dam to Rock Island Dam.

BACKGROUND

Rocky Reach Dam is unusual in that the powerhouse and spillway are constructed in a right-angle arrangement that provides opposing discharges. With the powerhouse and spillway arranged at approximately 90° to each other, there is the potential for the spillway discharge to mix with the powerhouse discharge prior to the entrained air reaching the surface. An interaction of this nature generally produces increases in the TDG levels of both the spillway and powerhouse discharges. Such an interaction results in both the loss of the dilution factor provided by most powerhouse discharges and an actual increase in the TDG levels of the powerhouse water. This interaction of the two flows appears to be most likely to occur with spill from the right side of the spillway and turbine discharge from the higher numbered units (Units 8-11). However, some spill gate configurations at Rocky Reach Dam tend to reduce TDG levels measured at the downstream location as compared to the forebay monitoring station. Earlier TDG monitoring in the Rocky Reach tailrace occurred well downstream from the dam (Army Corps of Engineers 2003) where powerhouse and spillway discharges are likely to be somewhat mixed. In the 2011 and 2012 tests the monitoring location was moved upstream to about 1/3 mile downstream from the spillway to the fish bypass discharge that appears to experience primarily water from the spillway.

Previously, monitoring of spillway conditions showed that the TDG saturation in water exiting the spillway was a function of the spill pattern, spillway discharge amount, and to a lesser extent, powerhouse operations (Army Corps of Engineers 2003). The TDG levels in spilled water was determined to be a linear function of spillway discharge for a given spill pattern. Greater powerhouse discharges were observed to reduce the TDG levels at stations on the spillway side of the channel. The maximum TDG levels observed downstream from the stilling basin did not exceed 120 % for spill volumes as high as 58 kcfs using the standard spill pattern during 2002 (Schneider and Wilhelms 2006).

According to Schneider and Wilhelms (2006) the Rocky Reach spillway and stilling basin have hydraulic structures that moderate the dam's TDG exchange characteristics. These structures include the spillway nappe deflector, continuous baffle, and high stilling basin end sill that provides energy dissipation over the short length of the stilling basin. The combination of efficient energy dissipation in the shallow stilling basin together with an end sill that produces a surface oriented jet entering the adjoining tailwater channel result in TDG pressures that are similar to projects with retrofitted TDG abatement structures.

PROJECT DESCRIPTIONS

Rocky Reach Dam is a mainstem Columbia River located at river mile 453.4. The angled dam is 2,460 ft, long with a 1,090 ft long powerhouse parallel to the river channel and a 740 ft long spillway perpendicular to the river channel (Figure 2). The original river channel ran through what is now the left embankment and spillway. There are 11 recently modified fish friendly turbines at Rocky Reach Dam, providing a total hydraulic capacity of 217.5 kcfs. The left bank spillway has 12 spill bays equipped with tainter gates. Each spill bay is 50 ft wide.

Figure 2. Aerial view of Rocky Reach Dam (Google Earth 2012).

METHODS

This analysis was performed using routine TDG monitoring data obtained during specific operating configurations used during the spill periods of 2011 and 2012. Beginning in 1997 Chelan Co. PUD began collecting data appropriate for this analysis. No attempt has been made during the period of available data to operate the dams in a manner that would produce conditions specific for any operational configuration. Data are recorded during routine operating configurations used to provide spill for fish passage or pass flows in excess of hydraulic capacity.

The spill data collected by Chelan PUD during 2011 and 2012 includes forebay and tailrace TDG (% and mmHg), barometric pressure, forebay and tailrace temperature, forebay and tailrace water surface elevations, total discharge, powerhouse discharge, and spillway discharge. The data were provided by Chelan PUD in spreadsheet format for the 4 configurations tested (standard/fish pattern and three others) and the schedule for testing. Each configuration was tested for 24 h at a time in 2011 and 12 h at a time in 2012.

Total dissolved gas levels are monitored with tensiometers located at fixed sites in the forebay and tailrace. The forebay monitoring location was on the upstream face of the dam. The tailrace location was located at the end of the fish bypass system approximately 1/3 mile downstream from the spillway. The downstream monitoring in many previous years was conducted about three miles downstream rather at a bridge. The fish bypass location appears to be primarily in flow from the spillway with less dilution by powerhouse discharge than the previous downstream location. The Army Corps of Engineers (2003) monitoring a strong lateral gradient in TDG levels occurs to the Highway 97 Bridge and that these lateral gradients became more pronounced with greater spill discharges.

Hydrolab DataSonde4 tensiometers were deployed at the monitoring sites. The forebay monitoring instrument was attached to the upstream face of the dam, with the probe installed inside a conduit. The Hydrolab probes were submersed to a depth of approximately 15 ft, and connected to a meter and data-logging device that records hourly TDG and temperature data, 24 h/day during the spill period.

These evaluations compare four basic gate configurations that were tested (Fish, TDG, Flattened, and Shallow Arc), under a variety of flow conditions. Each gate configuration specified the gates to be used, and the specification for the gate opening (feet), depending on the total spill capacity needed. However, the gates were opened or closed in 2-foot increments, so that during periods of low total spill volume, all the gates specified for a particular configuration could not be used. As a result, there were typically little or no differences between the configurations, in the amount of spill through each individual gate, when the total spill rates were low (Appendix A).

The Fish Spill configuration typically used only 7 of the 12 available spill gates (Gates 2 through 8), and typically with higher flow volumes through the middle gates than through the outside gates. The other configurations typically used gates 2-9 and gates 11-12 in 2011, and gates 2-10 and gate 12 in 2012. Gate 1 is not used during normal project operations and gates 10 and 11 were out for maintenance in 2011 and 2012, respectively.

The TDG Spill configuration was similar to Fish Spill, with greater flow volumes through the middle gates, except that 10 gates were used instead of seven. The Shallow Arc Spill configuration also tended to have greater spill volumes through the middle gates, the difference between gates was substantially less than either the Fish or TDG Spill configurations. The Flattened configuration consisted of roughly equal spill volumes through all 10 gates.

Each of the configurations determined the specific gates to use for spilling water, and the relative amounts of spill through each of these gates. However, the actual amount of spill through each individual gate within the configuration could vary, depending on overall project operations and flow conditions in the river. Despite these variations, the spill conditions typically remained relatively consistent for a number of hours each day. In 2011, the objective was to use a different configuration each day and to maintain the test configuration throughout the day. In 2012, the objective was also to use a different configuration each day, but to maintain the configuration for about 11 hours each day, typically from 0800-1900 h.

Comparisons between configurations were made using the difference between hourly average TDG levels recorded in the forebay and the tailrace stations. Due to a number of factors, a single value could not be determined to account for the lag time between recordings at the two stations. These factors include the variability in the water particle travel time between stations (which varies with total river flow) and the variability in the amount of time for downstream TDG levels to equilibrate following changes in gate configurations (which varied with total flow and total spill volumes). Therefore, comparisons between configurations were made using the patterns of the TDG levels recorded over multiple hours, but only when total spill volumes and the spill volumes through the individual gates remained relatively constant. These comparison periods typically started several hours after a spill configuration change, to account for some lag time between monitoring stations, and typically ended when the spill conditions changed. Therefore, the length of these comparison periods could vary from day to day.

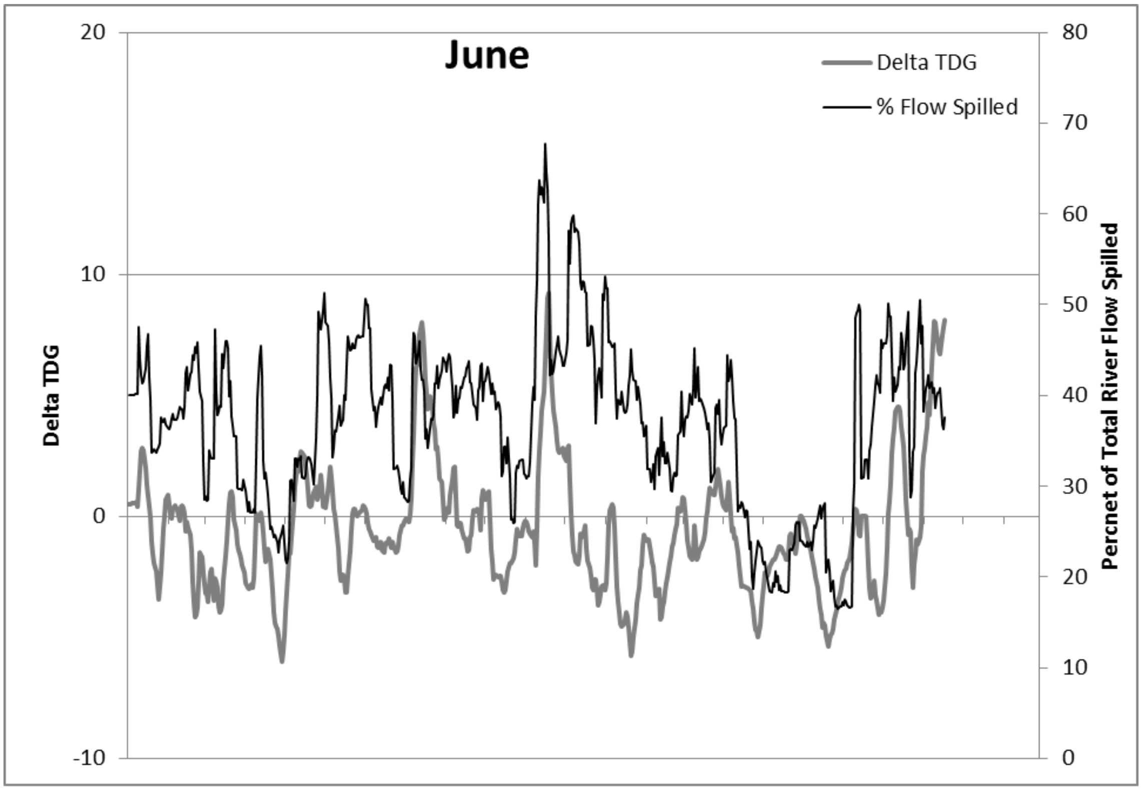
RESULTS

The results of the TDG gate configuration tests are presented below by year due to differences in test conditions during the two years. The test data are evaluated for both changes in TDG levels from the forebay to the tailrace and the maintenance of TDG levels at 120 % of saturation or lower. During both years substantially high levels of spill occurred during the test periods, frequently excreeding the 7Q10 for Rocky Reach Dam.

2011 TDG FOREBAY vs. DOWNSTREAM

In 2011 the spill tests were conducted between June 5 and July 29, testing a different spill configuration each day, and typically maintaining the test configuration for about 11 h or more. However, on some days the variations in flow through the individual gates, total spill volume, or the overall spill configuration did not remain consistent enough to determine a pattern of downstream TDG levels. In addition, the actual spill patterns are essentially the same for the different spill configurations being tested, when total spill volumes are low (see Appendix A). Therefore, some daily data were not used for configuration comparisons.

Overall, the variations in test conditions each day, as well as the typical variations in spill configurations during non-test periods, resulted in highly variable downstream TDG levels in 2011 (Figure 3). During June and July of 2011 peak spill (181 kcfs) occurred on June 18, which corresponded to the peak in downstream TDG level of about 137% of saturation. This downstream TDG level was about 9% of saturation higher than the forebay TDG level (delta TDG) during this peak spill and peak downstream TDG level. Fish Spill was used during this peak spill period, as well as when the highest delta TDG (+13% of saturation) occurred in 2011. This peak in delta TDG occurred with a total spill volume of 154 kcfs, substantially (27 kcfs) lower than the 181 kcfs peak spill. The smallest delta TDG (-6% of saturation) occurring during 2011 on a number of occasions and under several spill configurations.



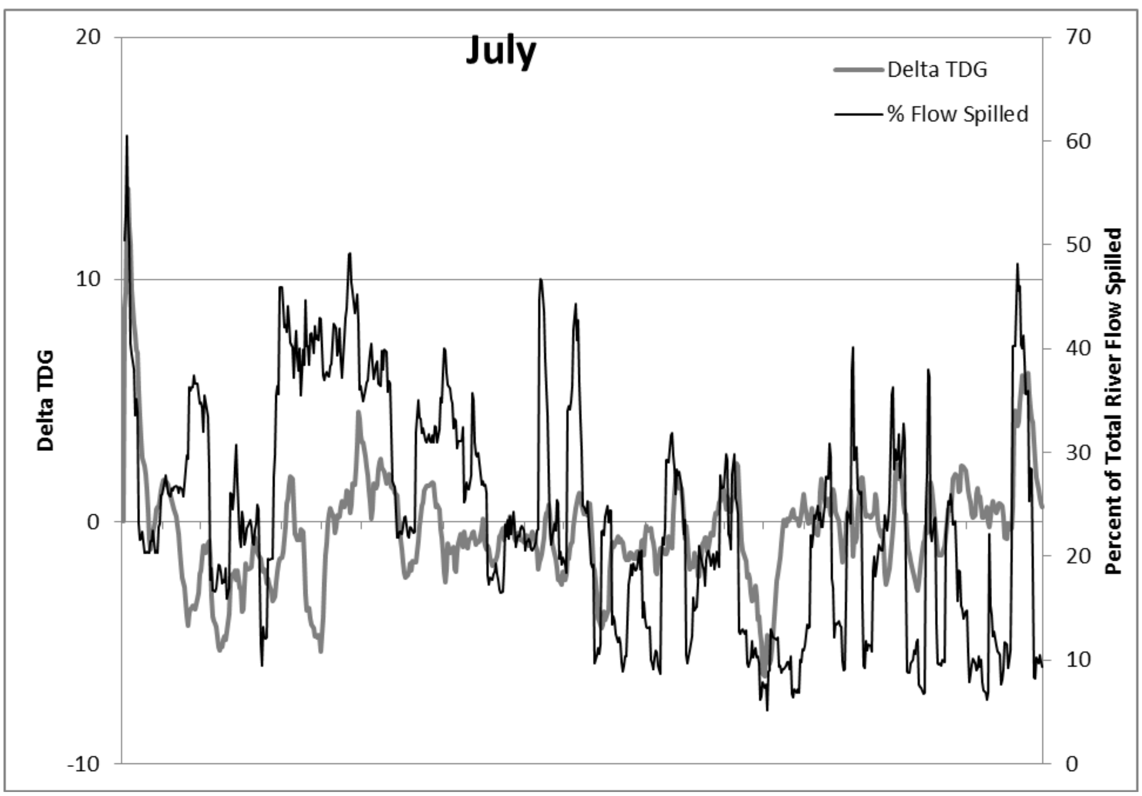


Figure 3. Difference between hourly average forebay and downstream TDG (Delta TDG), and the percent of total hourly river flow spilled in June and July, 2011.

Fish Spill

There were 12 days of Fish Spill in 2011 when the spill configurations were sufficiently stable for up to about 12 h. During these 12 Fish Spill periods, delta TDG ranged from +8.1 to -3.7 % of saturation, and total spill ranged from about 40 to 140 kcfs (Figures 4 through 7). Overall, the downstream TDG levels tended to be similar or higher than forebay levels (increased delta TDG) during most of these Fish Spill comparison periods. In contrast, the few periods with negative delta TDG typically occurred when total spill levels were relatively low (<about 60 kcfs) and the differences in spill volume between individual gates were small (i.e. similar to Flattened Spill than Fish Spill).

TDG spill

There were 10 days of TDG Spill in 2011, when the spill configurations were sufficiently stable for up to about 12 h, to assure that TDG equilibration occurred at the downstream monitoring station. During these 10 TDG Spill periods, delta TDG ranged from +5.4 to -3.4% of saturation, and total spill ranged from about 40 to 150 kcfs (Figures 8 through 10). Overall, the downstream TDG levels tended to be similar or lower than forebay levels (negative delta TDG) during most of these TDG Spill comparison periods. In addition, the few periods with positive delta TDGs typically occurred when total spill levels were relatively low (<about 60 kcfs), except for June 11 when total spill was about 140 kcfs, although delta TDG was only slightly positive (about +2% of saturation) during that test period.

Shallow Arc Spill

There were 12 days of Shallow Arc Spill in 2011, when the spill configurations were sufficiently stable for up to about 12 h. During these 12 Shallow Arc Spill periods, delta TDG ranged from +2.0 to -4.4% of saturation, and total spill ranged from about 40 to 142 kcfs, although most of these periods had total spill levels less than about 100 kcfs (Figures 11 through 13). Overall, the downstream TDG levels tended to be similar or lower than forebay levels (negative delta TDG) during most of these Shallow Arc Spill comparison periods. Although delta TDGs were typically negative, a number of the spill comparison periods were more like the Flattened Spill configuration than the Shallow Arc Spill configuration (see Figures 11 through 14).

Flattened Spill

There were 13 days of Flattened Spill in 2011, when the spill configurations were sufficiently stable for up to about 12 hours. During these 13 Flattened Spill periods, delta TDG ranged from +4.6 to -6.0% of saturation, and total spill ranged from about 34 to 110 kcfs, although all but one of these periods had total spill levels less than about 100 kcfs (Figures 11 through 14). Overall, the downstream TDG levels tended to be similar or lower than forebay levels (negative delta TDG) during most of these Flattened Spill comparison periods. Although there were frequent periods of negative delta TDGs during periods of Flattened Spill, the total spill volumes were also typically low (see Figures 12 through 15).

All configurations

The 2011 spill tests indicate that the Fish Spill configurations tended to provide the least benefits of reducing the downstream TDG levels, with the majority of the tests producing positive delta spill levels, including the highest delta TDG (+8.1% of saturation) in any of the test periods. The Fish Spill configuration was also being used when the highest single hourly delta TDG level (+13% of saturation) occurred in 2011. Shallow Arc Spill tended to produce moderate reductions in downstream TDG (negative delta TDG) under a variety of total spill volume conditions. Flattened Spill and TDG Spill configurations typically produced reductions in downstream TDG. Although Flattened Spill produced larger reductions in downstream spill (up to about -6% of saturation) these occurred under relatively low total spill conditions (100 kcfs or less). The TDG Spill tended to produce negative delta TDG levels over a wider range of total spill (to about 150 kcfs), although these delta TDG levels were typically small (-2% of saturation).

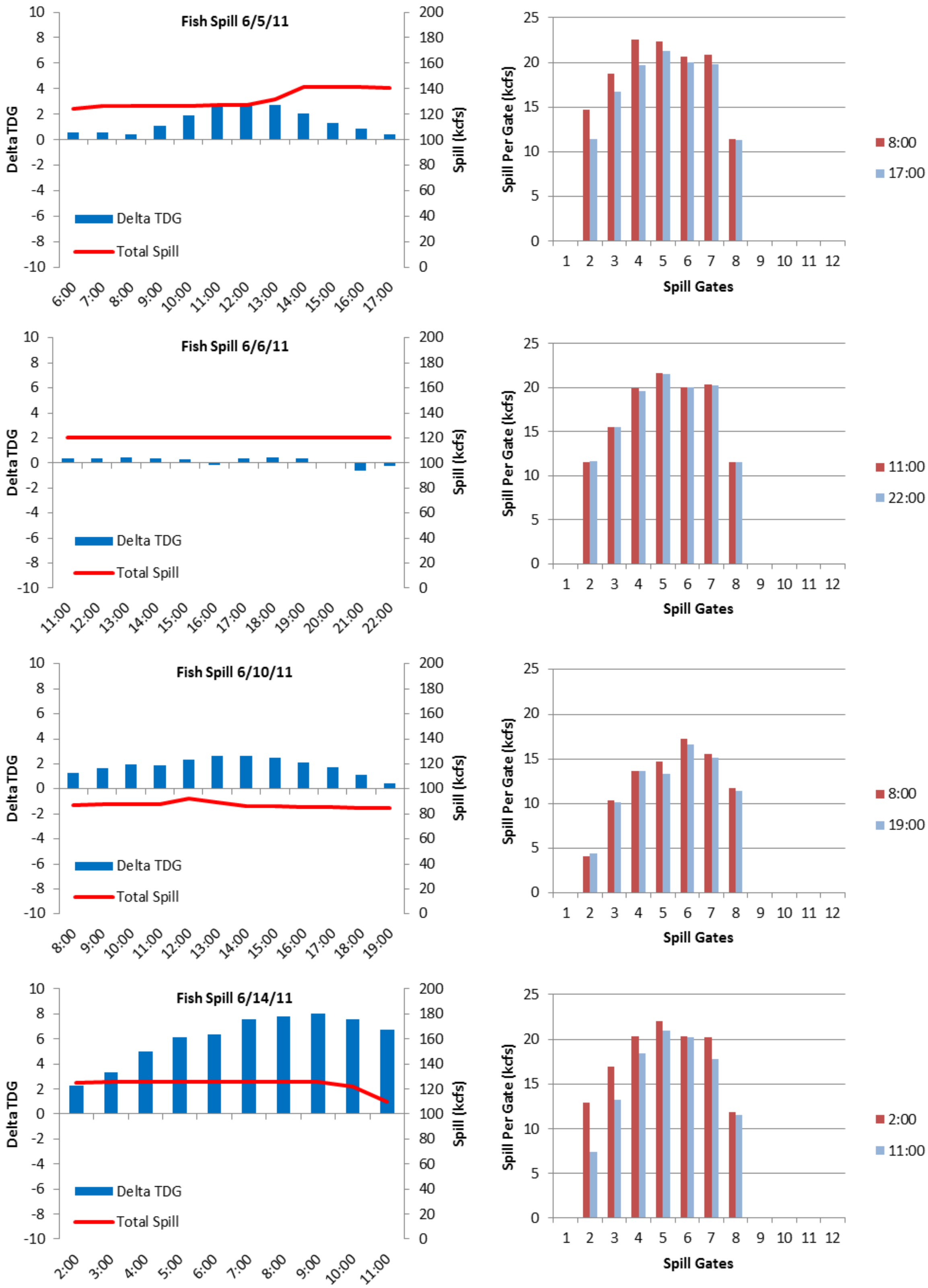


Figure 4. Delta TDG levels and total spill volumes (left), and volumes and distribution of spill through each gate (right) for the Fish Spill test configurations (June 5-14, 2011).

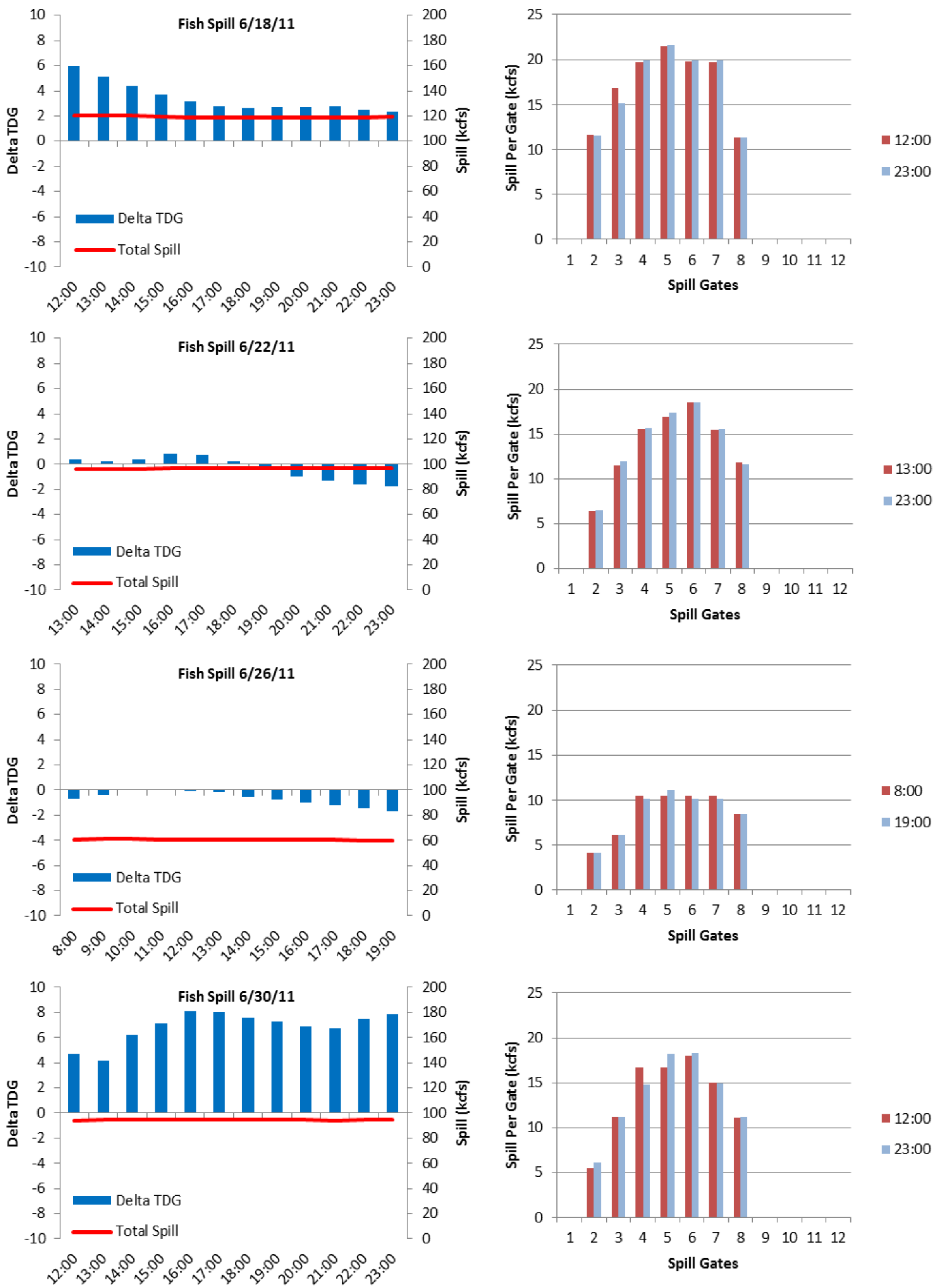


Figure 5. Delta TDG levels and total spill volumes (left graphs), and volumes and distribution of spill through each gate (right graphs) for the Fish Spill test configurations (June 18-30, 2011).

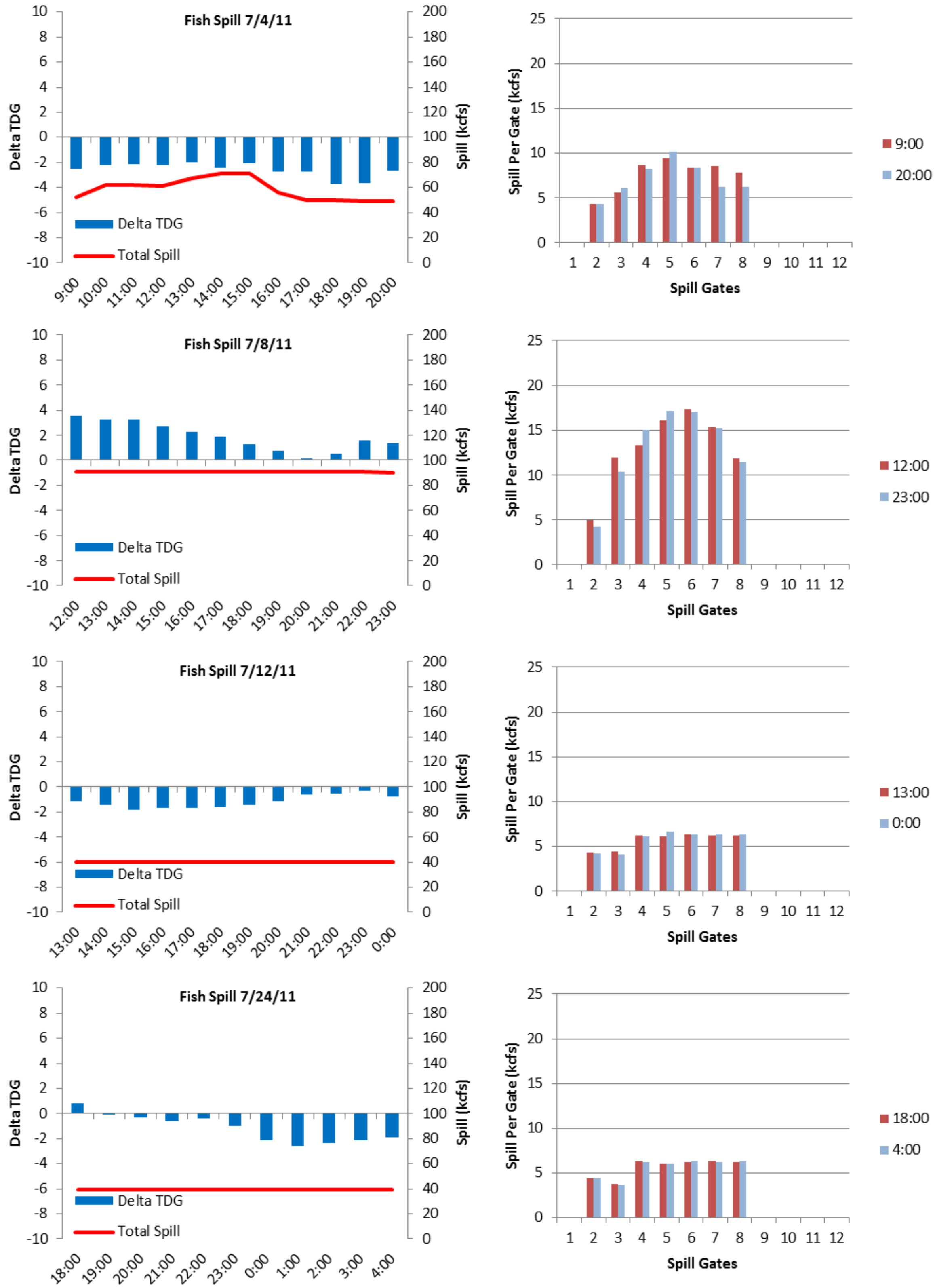


Figure 6. Delta TDG levels and total spill volumes (left graphs), and volumes and distribution of spill through each gate (right graphs) for the Fish Spill test configurations (July 4-24, 2011).

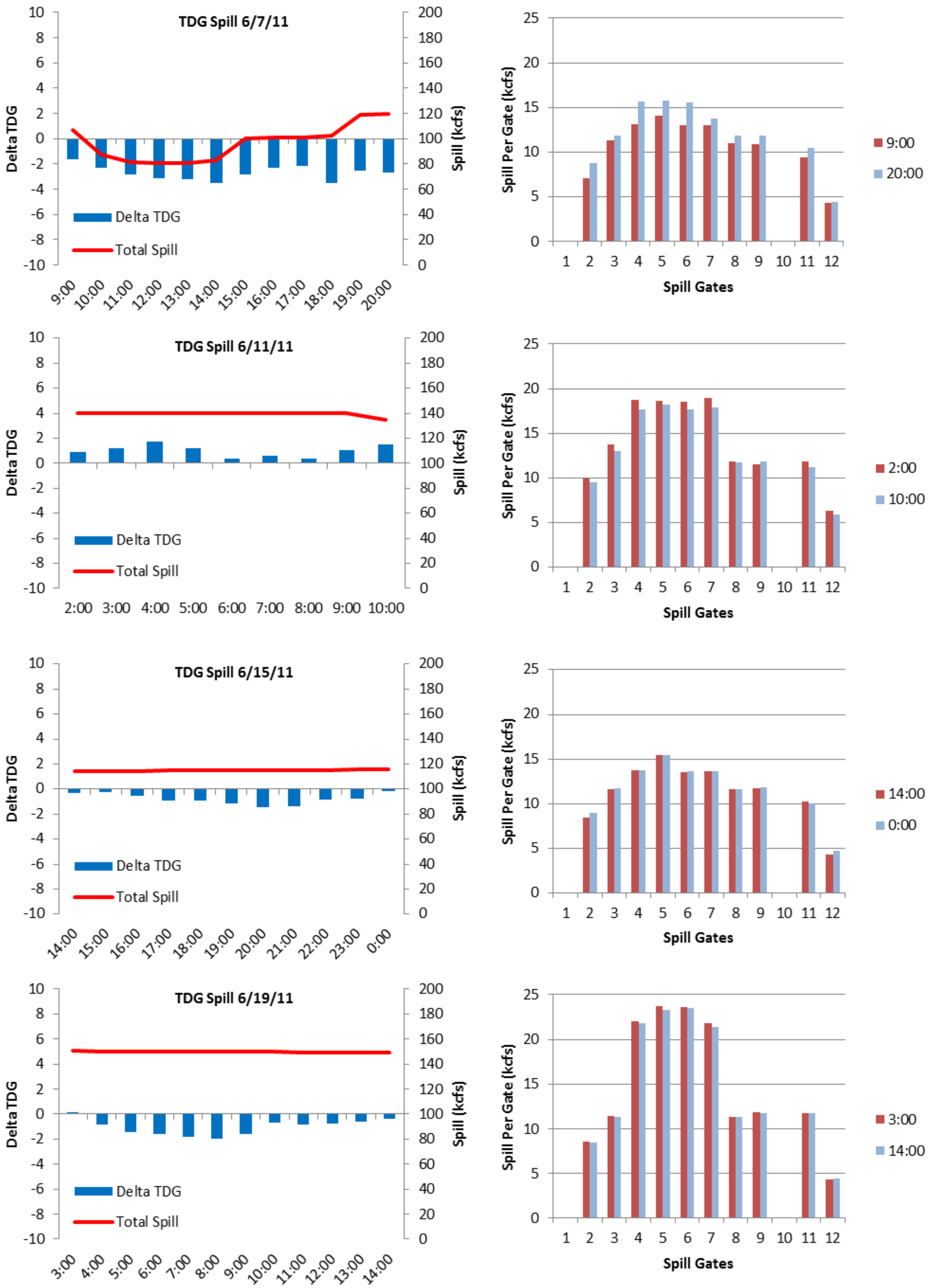


Figure 7. Delta TDG levels and total spill volumes (left graphs), and volumes and distribution of spill through each gate (right graphs) for TDG Spill test configurations (June 7-19, 2011).

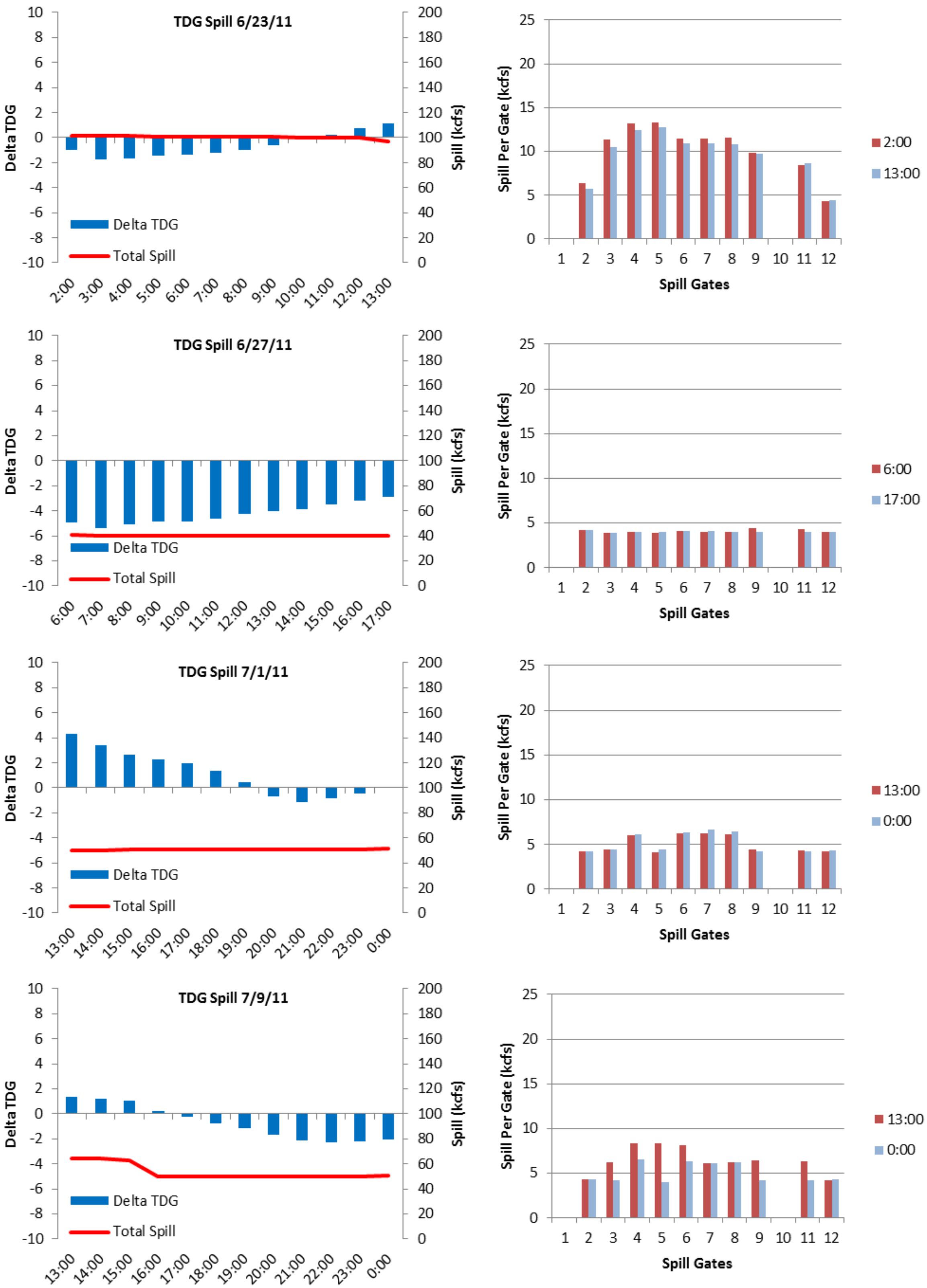


Figure 8. Delta TDG levels and total spill volumes (left graphs), and volumes and distribution of spill through each gate (right graphs) for TDG Spill test configurations (June 23-July 9, 2011).

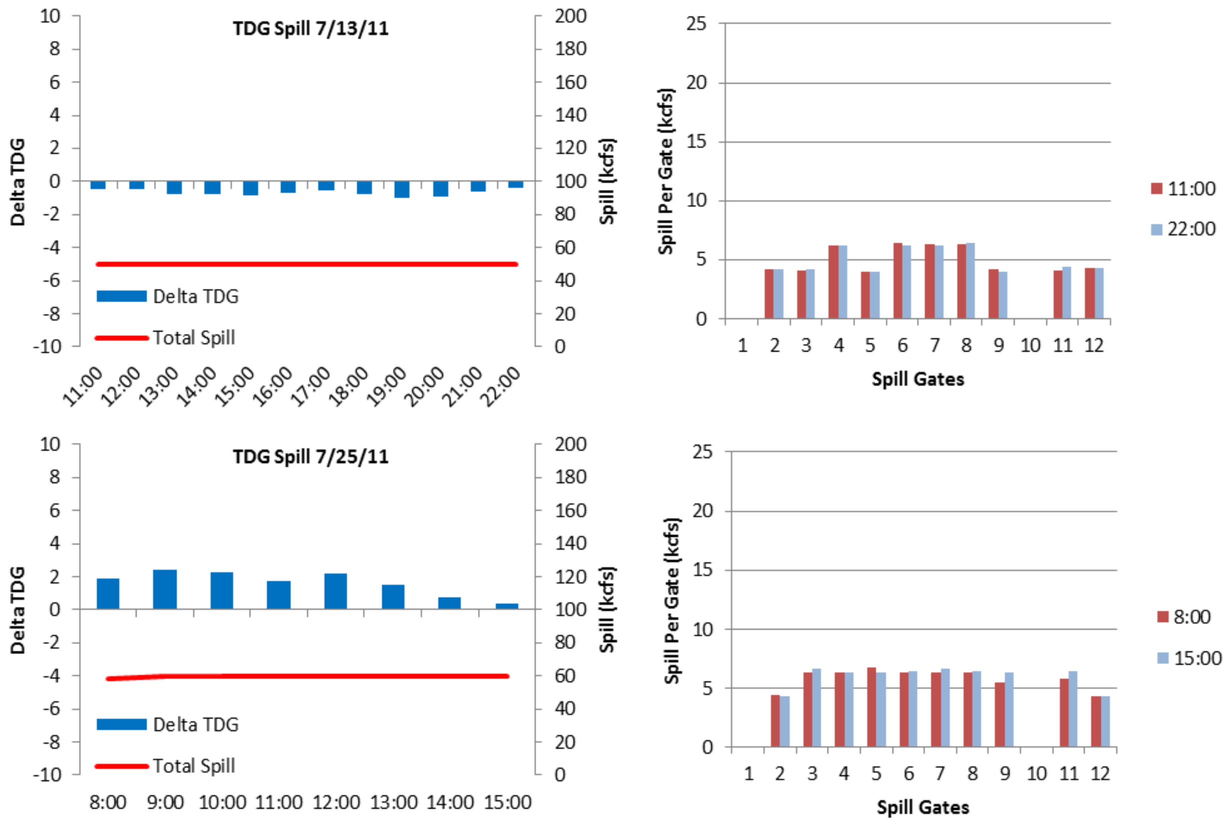


Figure 9. Delta TDG levels and total spill volumes (left graphs), and volumes and distribution of spill through each gate (right graphs) for TDG Spill test configurations (June 13-25, 2011).

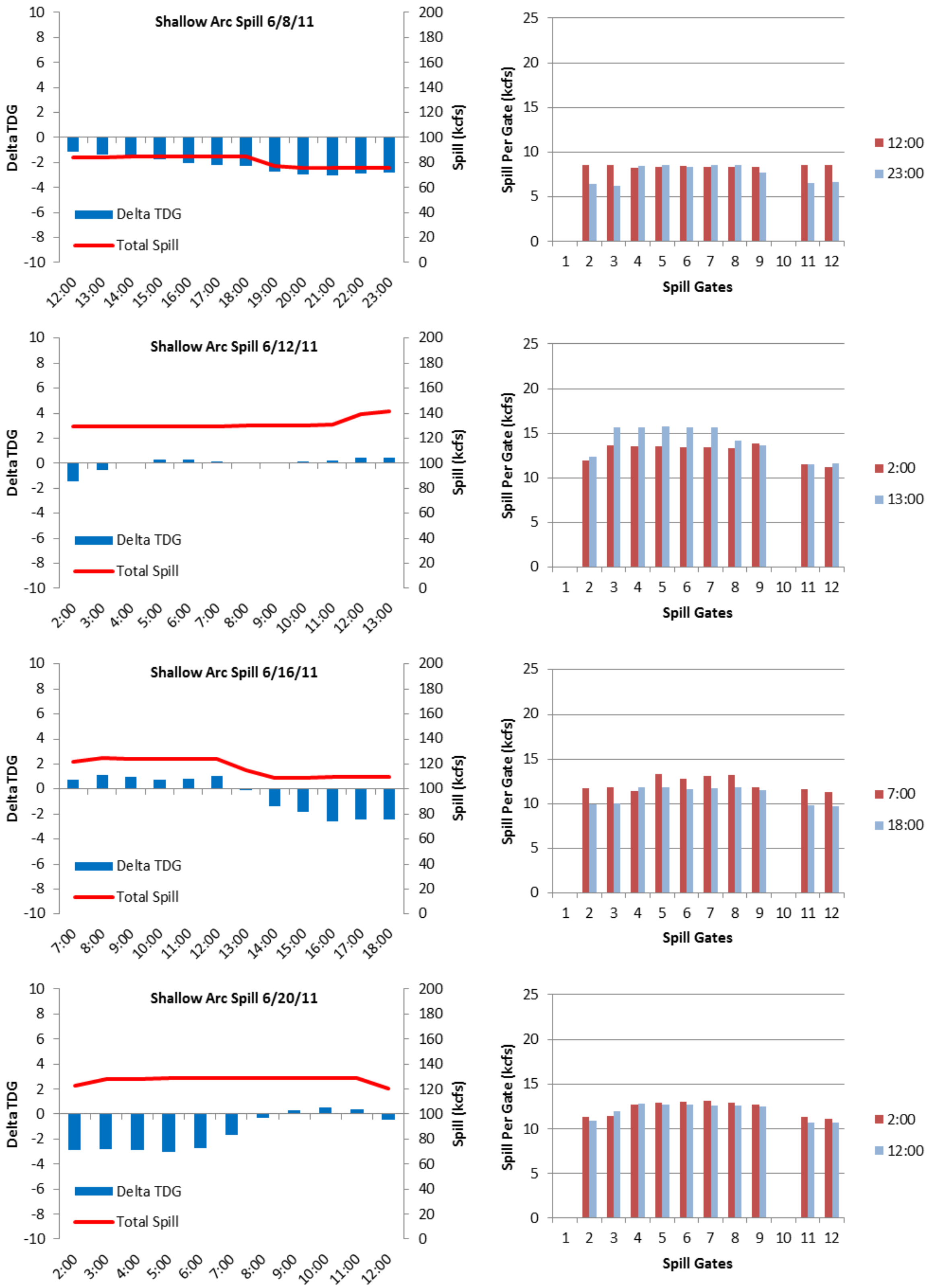


Figure 10. Delta TDG levels and total spill volumes (left graphs), and volumes and distribution of spill through each gate (right graphs) for Shallow Arc Spill test configurations (June 8-20, 2011).

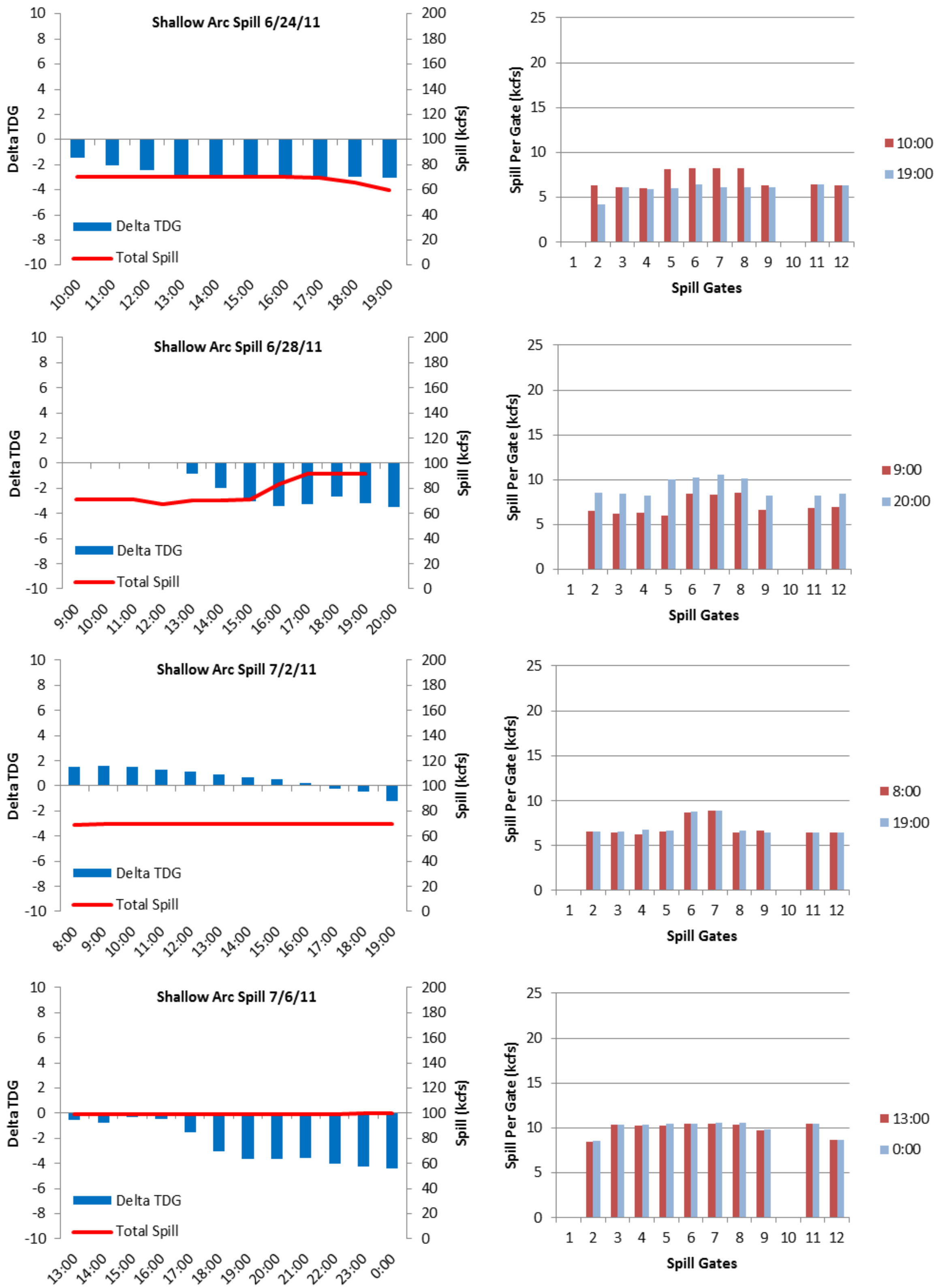


Figure 11. Delta TDG levels and total spill volumes (left graphs), and volumes and distribution of spill through each gate (right graphs) for Shallow Arc Spill tests (June 24-July 6, 2011).

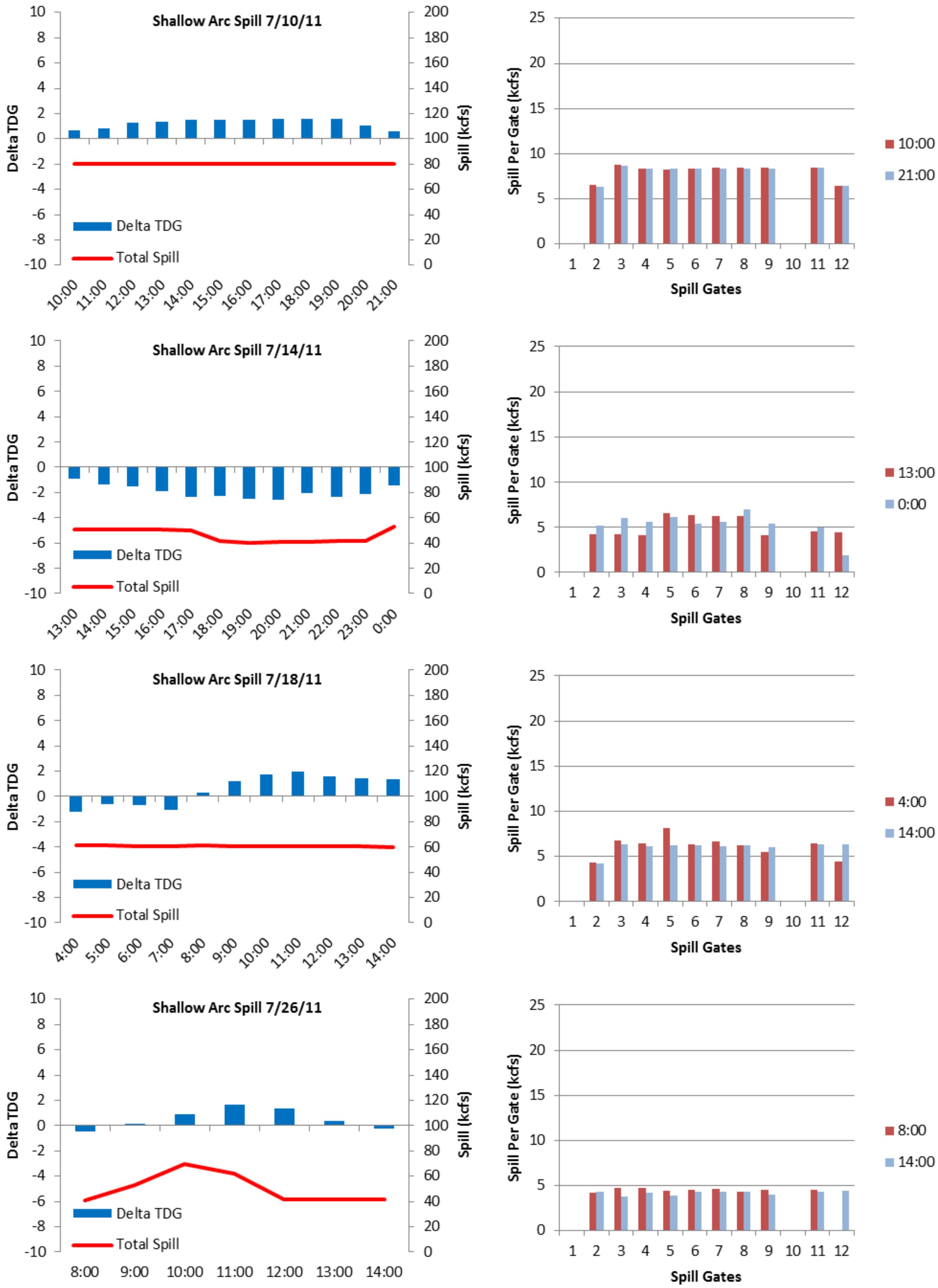


Figure 12. Delta TDG levels and total spill volumes (left graphs), and volumes and distribution of spill through each gate (right graphs) for Shallow Arc Spill tests (July 10-26, 2011).

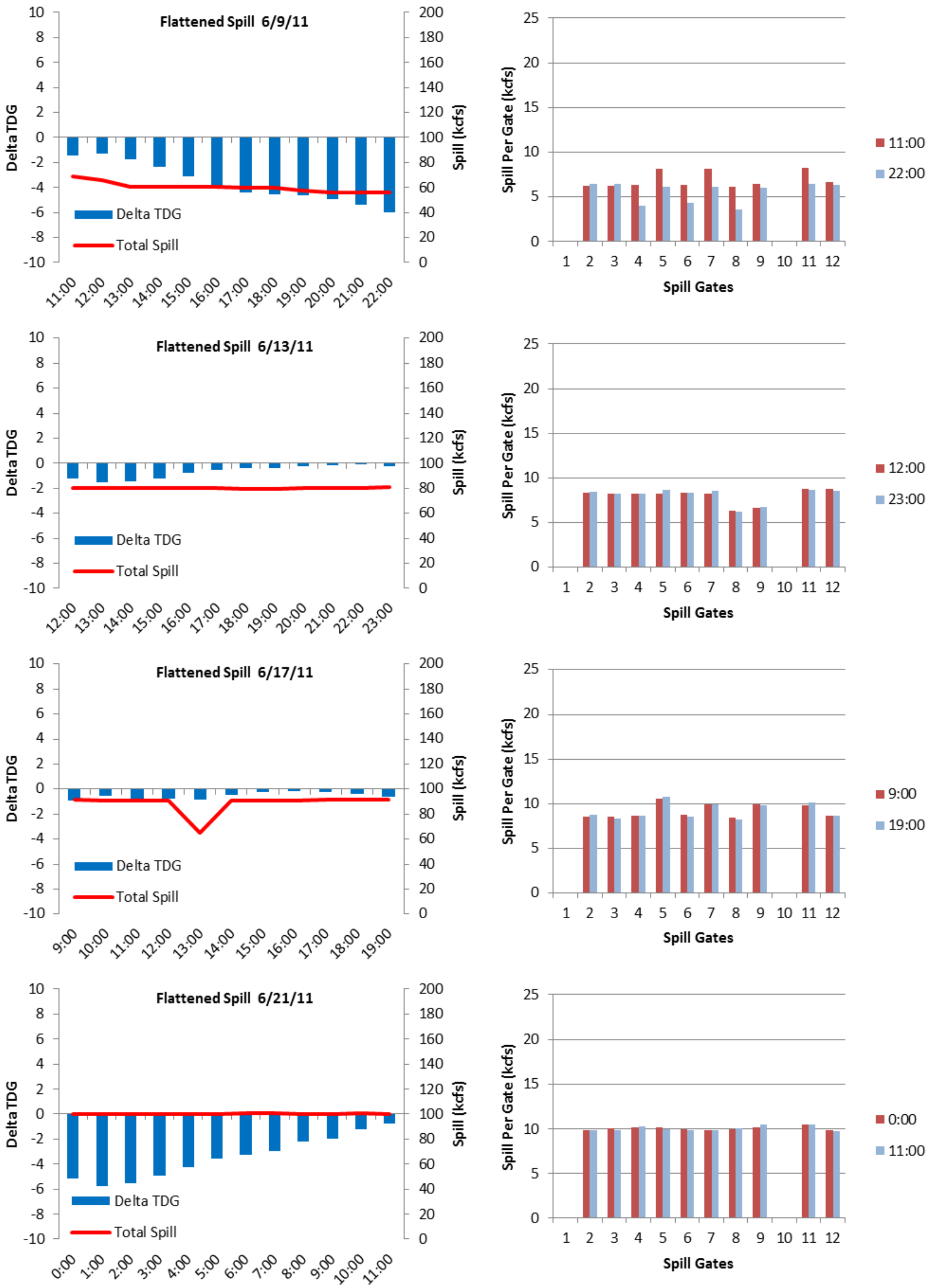


Figure 13. Delta TDG levels and total spill volumes (left graphs), and volumes and distribution of spill through each gate (right graphs) for Flattened Spill tests (June 9-21(00-1100hr), 2011).

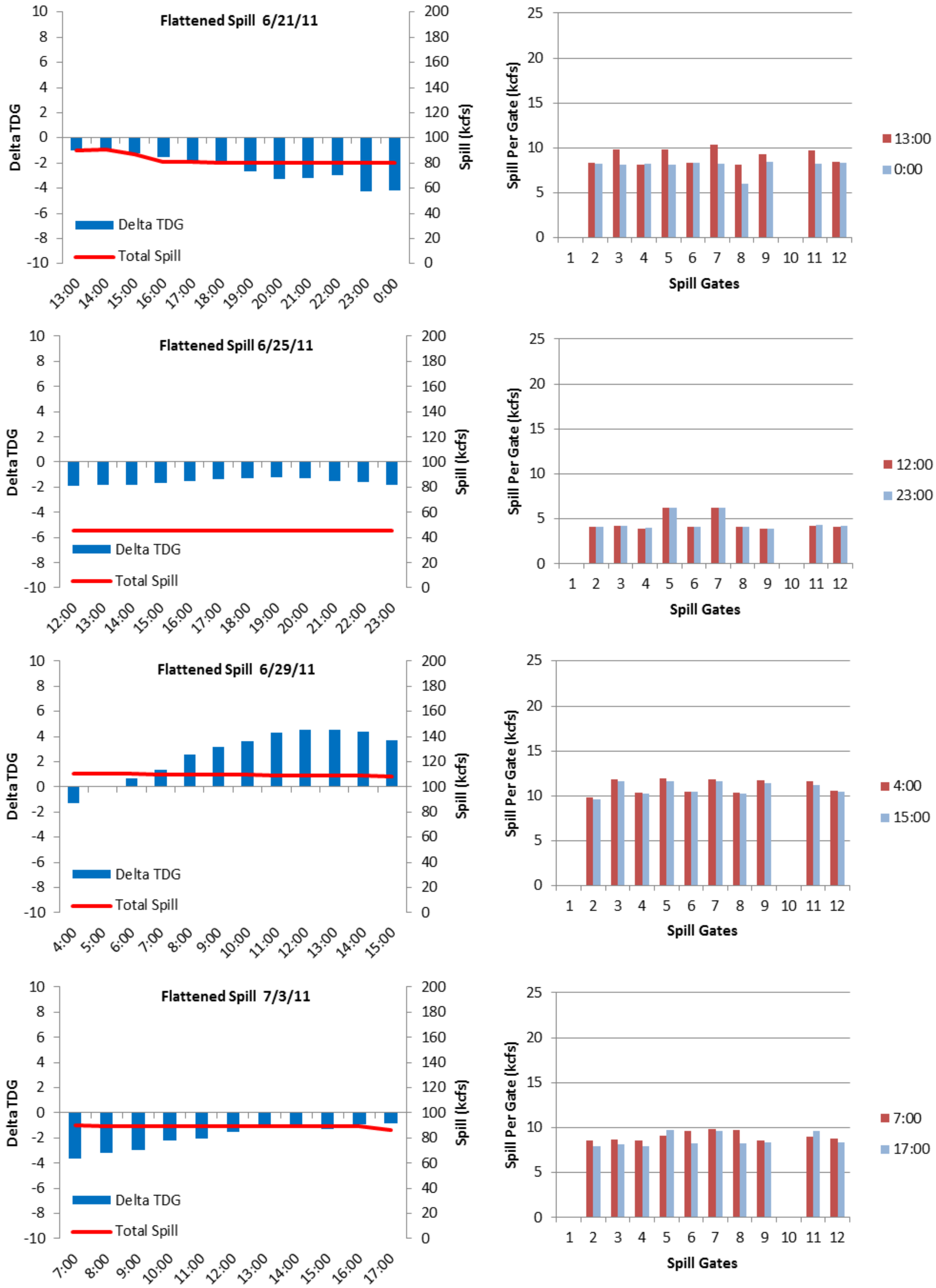


Figure 14. Delta TDG levels and total spill volumes (left graphs), and volumes and distribution of spill through each gate (right graphs) for Flattened Spill tests (June 21(13-2300 hr)- July 3, 2011).

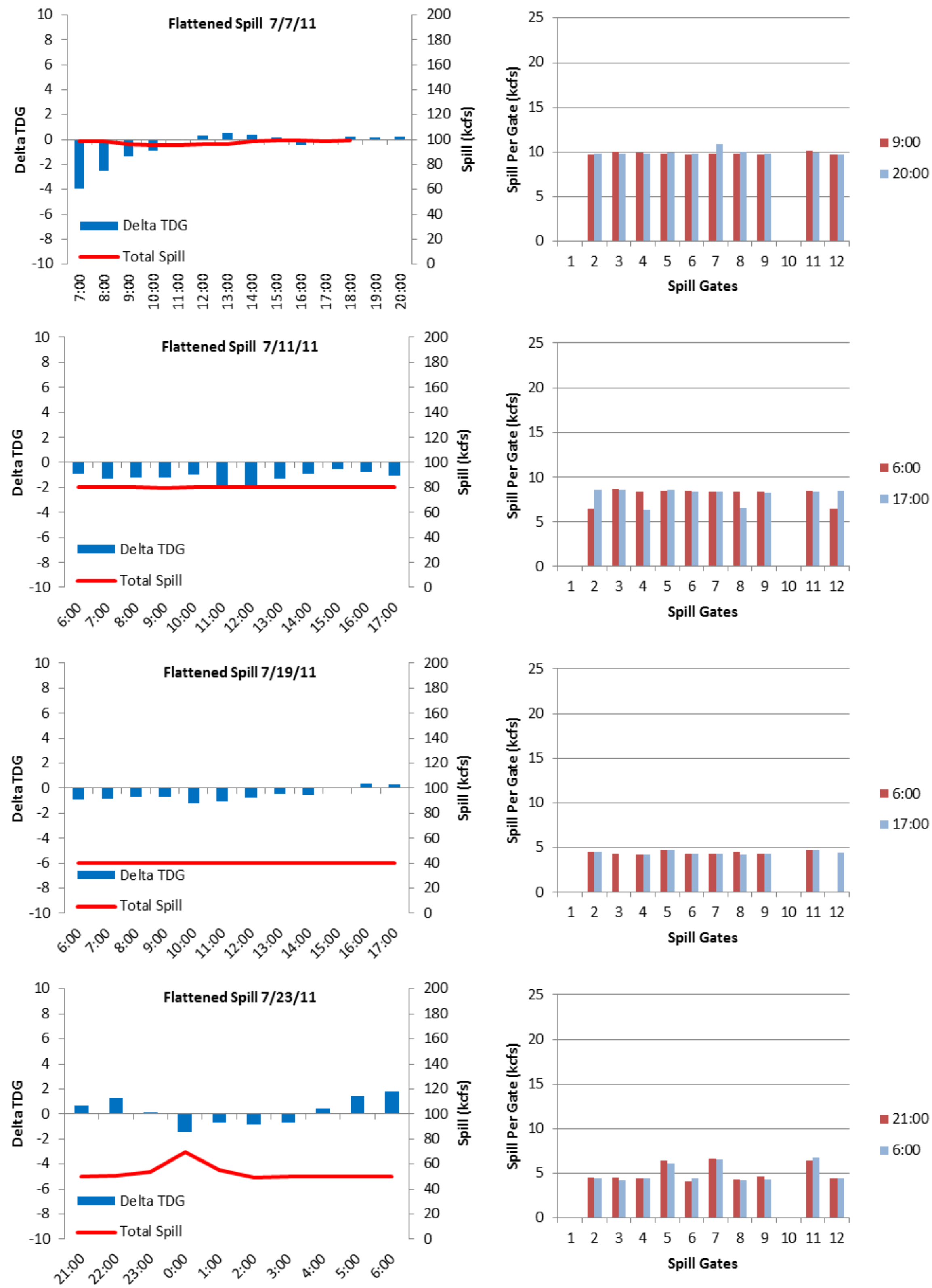


Figure 15. Delta TDG levels and total spill volumes (left graphs), and volumes and distribution of spill through each gate (right graphs) for Flattened Spill tests (July 7- July 23, 2011).

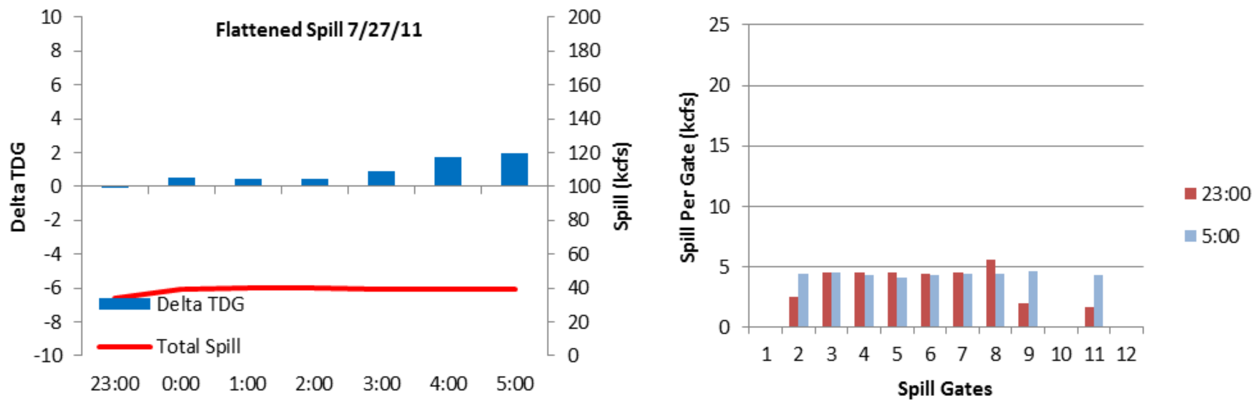


Figure 16. Delta TDG levels and total spill volumes (left graphs), and volumes and distribution of spill through each gate (right graphs) for Flattened Spill tests (July 27, 2011).

2012 TDG FOREBAY vs. DOWNSTREAM

In 2012 the spill tests were conducted between June 18 and July 29, testing a different spill configuration each day, and typically maintaining the test configuration for about 12 hours each day. However, on some days the variations in flow through the individual gates, total spill volume, or the overall spill configuration did not remain consistent for long enough to determine a pattern of downstream TDG levels. In addition, the actual spill patterns are essentially the same for the different spill configurations being tested when total spill volumes are low (see Appendix A). Therefore, some daily data were not used for configuration comparisons.

Overall, the variations in test conditions each day, as well as the typical variations in spill configurations during non-test periods, resulted in variable downstream TDG levels in 2012 (Figure 17). During June and July of 2012 peak spill (198 kcfs) occurred on June 29, which corresponded to the peak in downstream TDG level of about 132% of saturation. However, the forebay TDG levels were also about 132% of saturation on the same day (June 29). The TDG Spill configuration was used during this peak spill period, and produced the greatest TDG reduction (negative delta TDG) of -8% of saturation observed in 2012. In contrast, the peak increase in delta TDG (+7% of saturation) occurred on June 20 during a Flattened Spill configuration, with a total spill volume of about 70 kcfs, substantially lower than the 198 kcfs peak spill of 2012.

Fish Spill

There were 13 days of Fish Spill in 2012 when the spill configurations were sufficiently stable for about 12 h, to assure that TDG equilibration occurred at the downstream monitoring station during the test. During these 12 Fish Spill periods, delta TDG ranged from +5.5 (June 24) to -4.9 % of saturation (July 21), and total spill ranged from about 40 kcfs (July 29) to 170 kcfs (June 30) (Figures 16 through 19). Overall, positive delta TDG levels typically occurred in June and early July (see Figures 18 and 21), negative delta TDG typically occurred starting July 14 (see Figures 19 and 20), despite similar total spill volumes. During a number of the Fish Spill tests, the flow through the individual gates changed to a slightly flatter distribution toward the end of the test period. This frequently resulted in lower delta TDG levels, compared to the typical arched distribution of the Fish Spill configuration (see June 23 and 30, and July 14, 15, and 22).

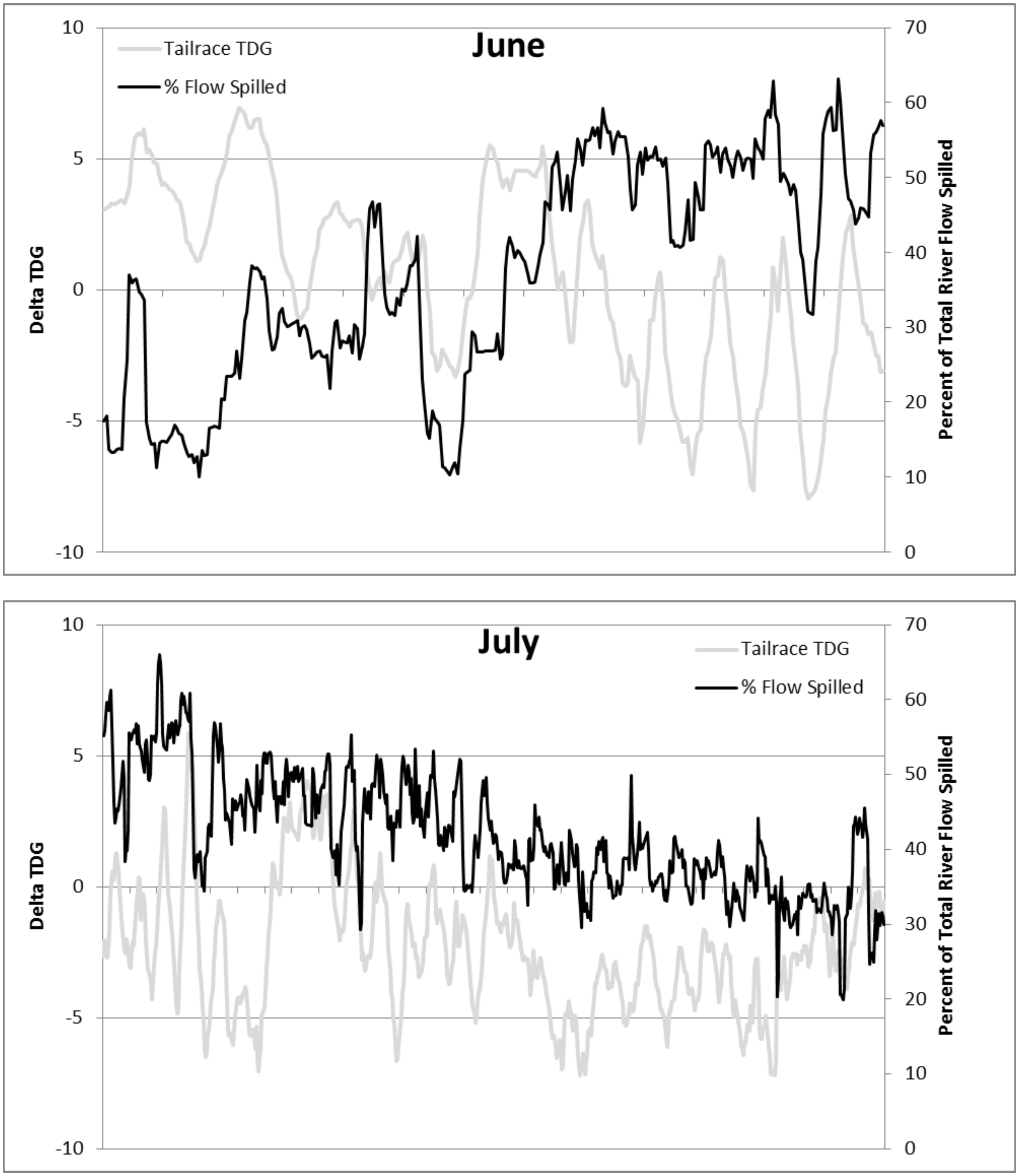


Figure 17. Difference between hourly average forebay and downstream TDG (Delta TDG), and the percent of total hourly river flow spilled in June and July, 2012.

TDG Spill

There were 11 days of TDG Spill in 2012, when the spill configurations were sufficiently stable for about 12 h, to assure that TDG equilibration occurred at the downstream monitoring station during the test. During these 11 TDG Spill periods, delta TDG ranged from + 6.1% of saturation (June 18) to -8.0% of saturation (June 29), and total spill ranged from about 30 kcfs (June 18) to 170 kcfs (June 26) (Figures 20 through 22). Overall, the downstream TDG levels tended to be lower than forebay levels (negative delta TDG) during most of these TDG Spill comparison periods. The one substantial exception was on June 18, although the total spill volumes were generally lower than any of the other TDG Spill periods, and distribution of flow through the individual gates changed substantially during the June 18 test (see Figure 20).

Shallow Arc Spill

There were 9 days of Shallow Arc Spill in 2012, when the spill configurations were sufficiently stable for about 12 hours. During these 9 Shallow Arc Spill periods, delta TDG ranged from +2.9% of saturation (July 10) to -7.2% of saturation (July 18), and total spill ranged from about 70 to 160 kcfs, and most of these periods had total spill levels of about 100 kcfs or more (Figures 23 through 25). Overall, the downstream TDG levels tended to be similar or lower than forebay levels (negative delta TDG) during most of these Shallow Arc Spill comparison periods. Although delta TDGs were typically negative, a number of the spill comparison periods were more like the Flattened Spill configuration than the Shallow Arc Spill configuration (typically during the latter hours of the spill test periods), which tended to further reduce downstream TDG levels (more negative delta TDG).

Flattened Spill

There were 10 days of Flattened Spill in 2012, with the spill configurations relatively stable for about 12 hours. During these 10 Flattened Spill periods, delta TDG ranged from +6.8% of saturation (June 20) to -7.4% of saturation (July 3), and total spill ranged from about 70 to 170 kcfs, although most of the test periods had total spill levels of 100 kcfs or more (Figures 26 through 28). Overall, the downstream TDG levels tended to be lower than forebay levels (negative delta TDG) during most of these Flattened Spill comparison periods.

All Configurations

The 2012 spill tests indicate that the Fish Spill configurations tended to provide the least benefits of reducing the downstream TDG levels, with a maximum reduction (delta TDG) of -4.9% of saturation. Shallow Arc Spill typically produced relatively large reductions in downstream TDG (negative delta TDG) under a variety of total spill volume conditions, with the greatest negative delta TDG of -7.2% of saturation. Flattened Spill and TDG Spill configurations also typically produced reductions in downstream TDG, up to -7.4% of saturation, also during relatively high total spill volumes (typically 100 kcfs or more). TDG Spill also typically produced negative delta TDG levels over a relatively wide range of total spill (to about 170 kcfs).

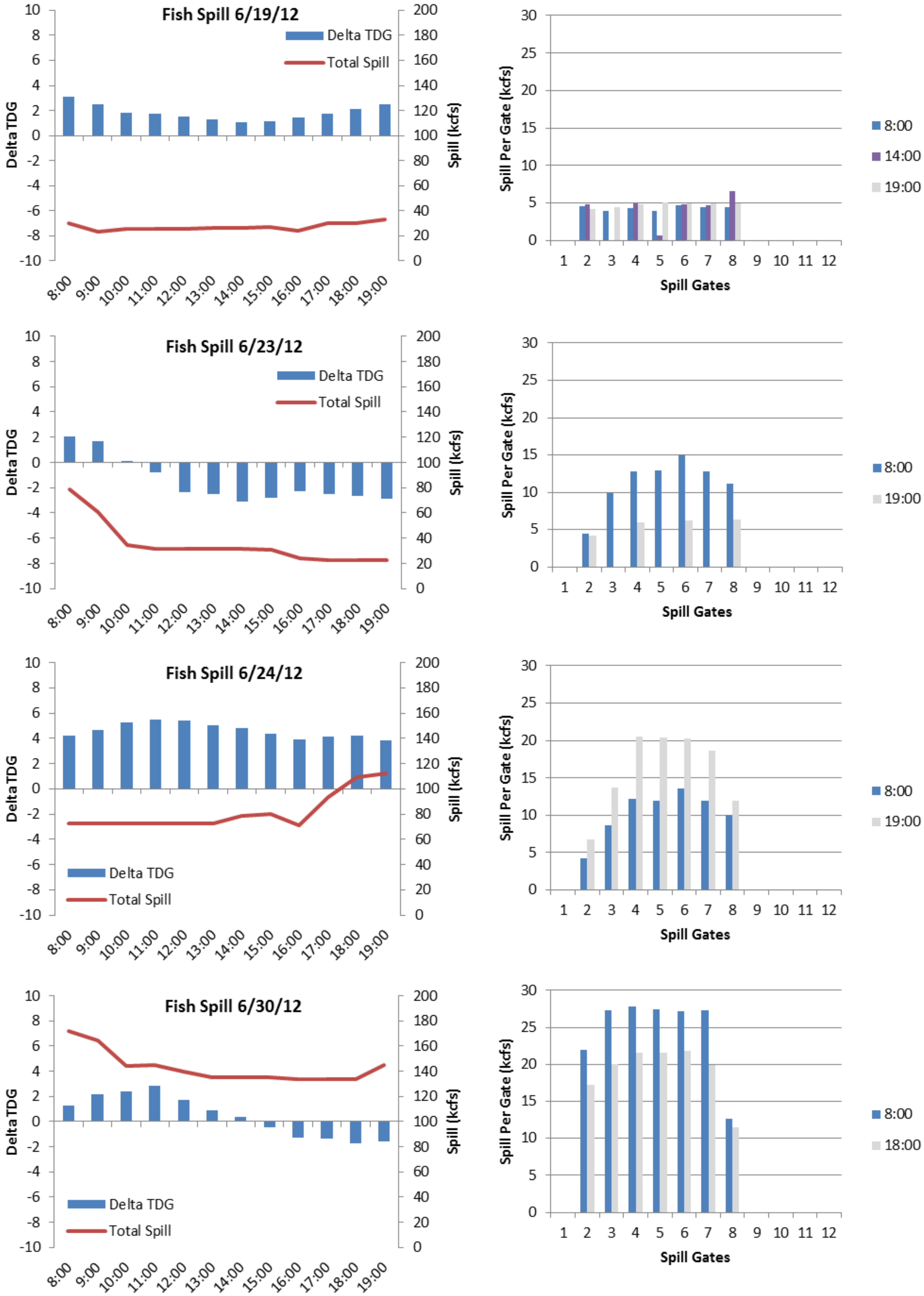


Figure 18. Delta TDG levels and total spill volumes (left), and volumes and distribution of spill through each gate (right) for Fish Spill tests (June 19-30, 2012).

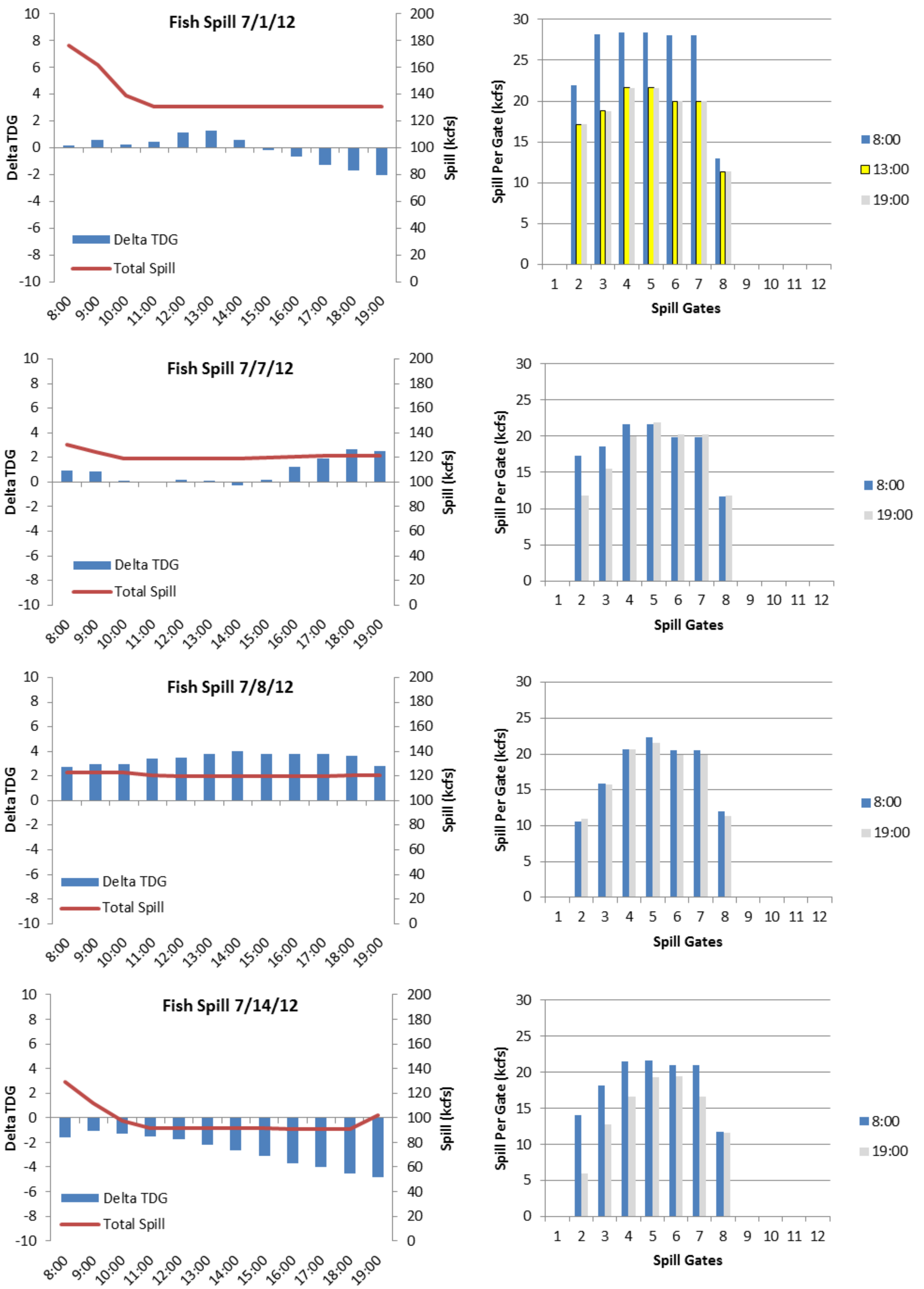


Figure 19. Delta TDG levels and total spill volumes (left), and volumes and distribution of spill through each gate (right) for Fish Spill tests (July 1-14, 2012).

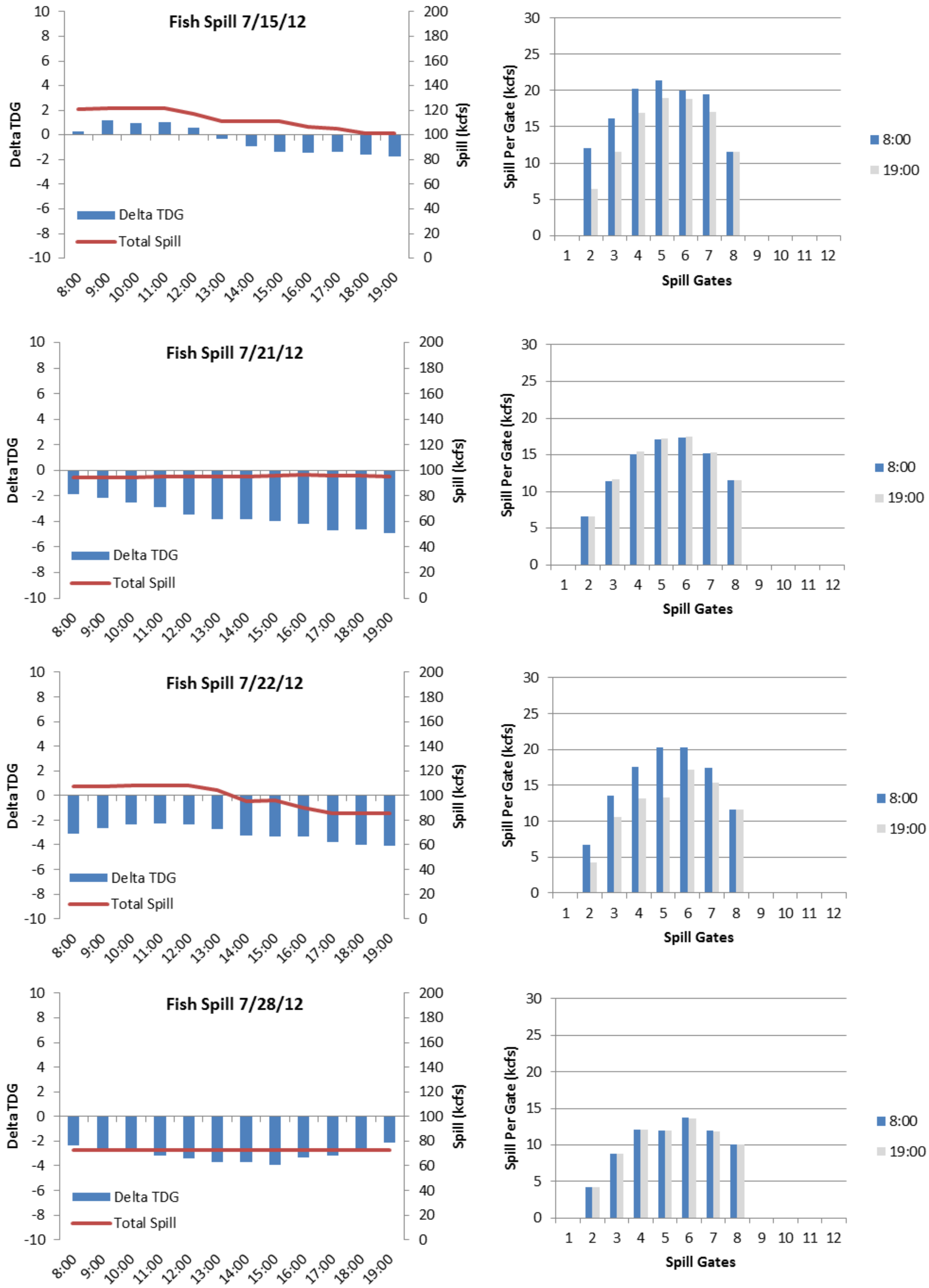


Figure 20. Delta TDG levels and total spill volumes (left), and volumes and distribution of spill through each gate (right) for Fish Spill tests (July 15-28, 2012).

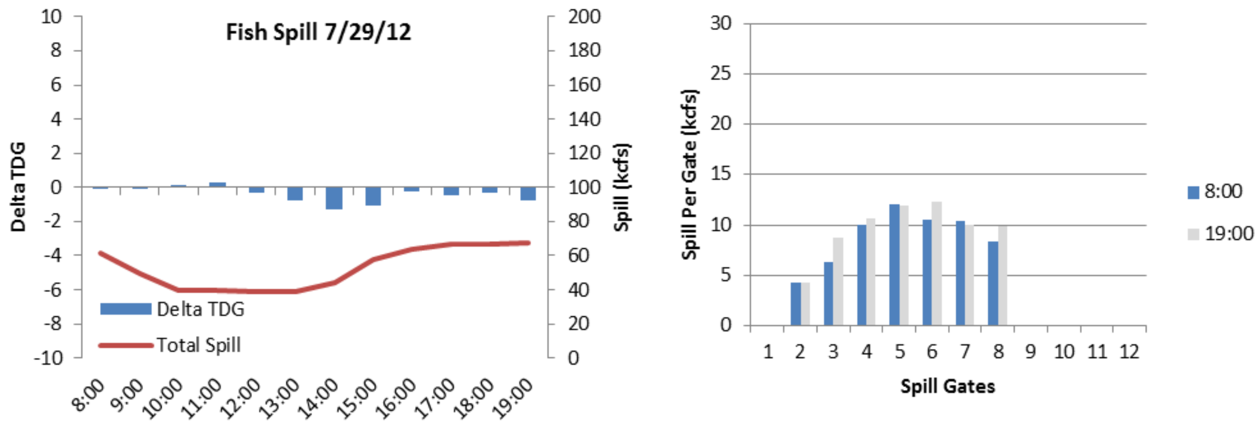


Figure 21. Delta TDG levels and total spill volumes (left), and volumes and distribution of spill through each gate (right) for Fish Spill tests (July 29, 2012).

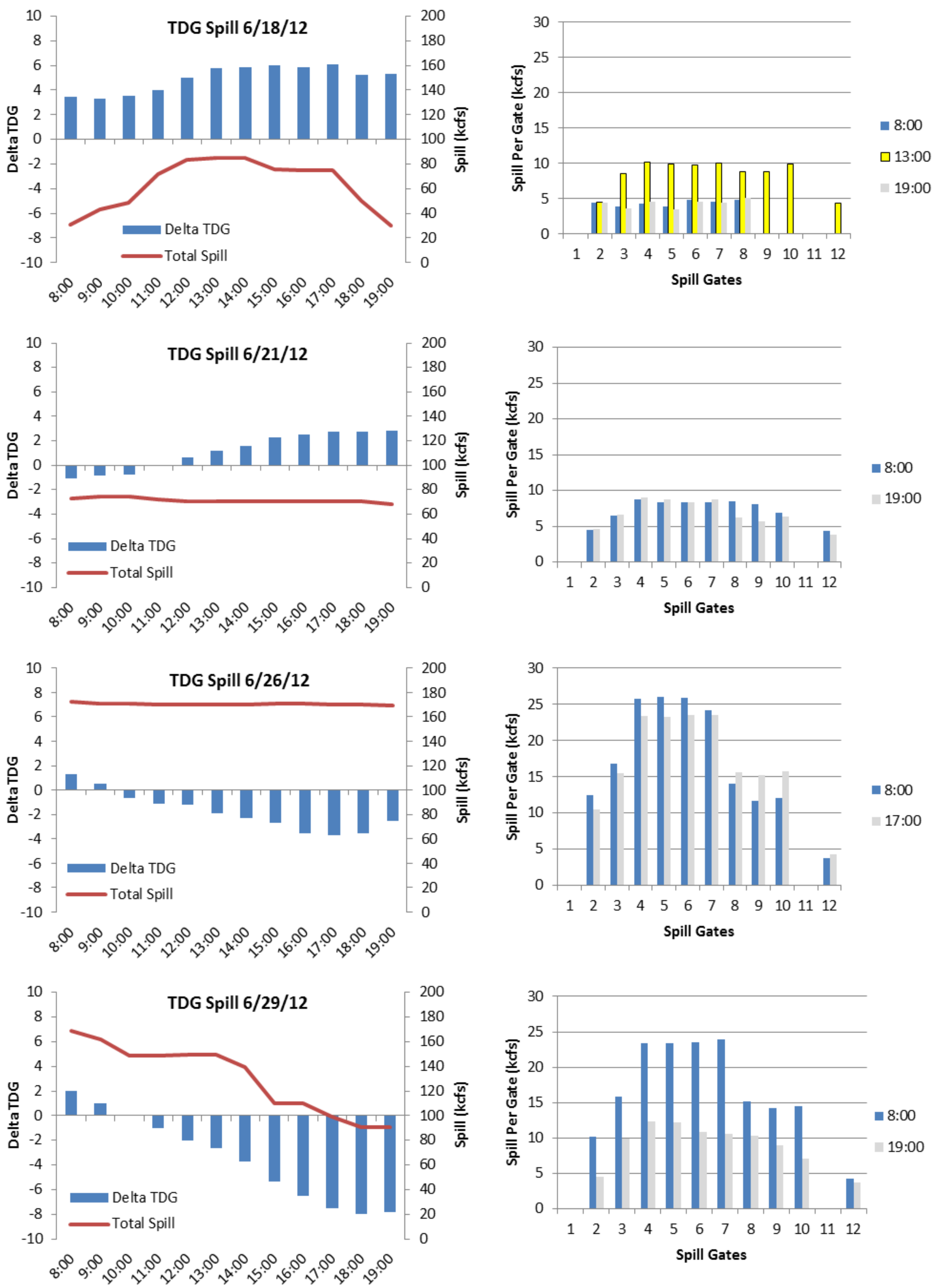


Figure 22. Delta TDG levels and total spill volumes (left), and volumes and distribution of spill through each gate (right) for TDG Spill tests (June 18-29, 2012).

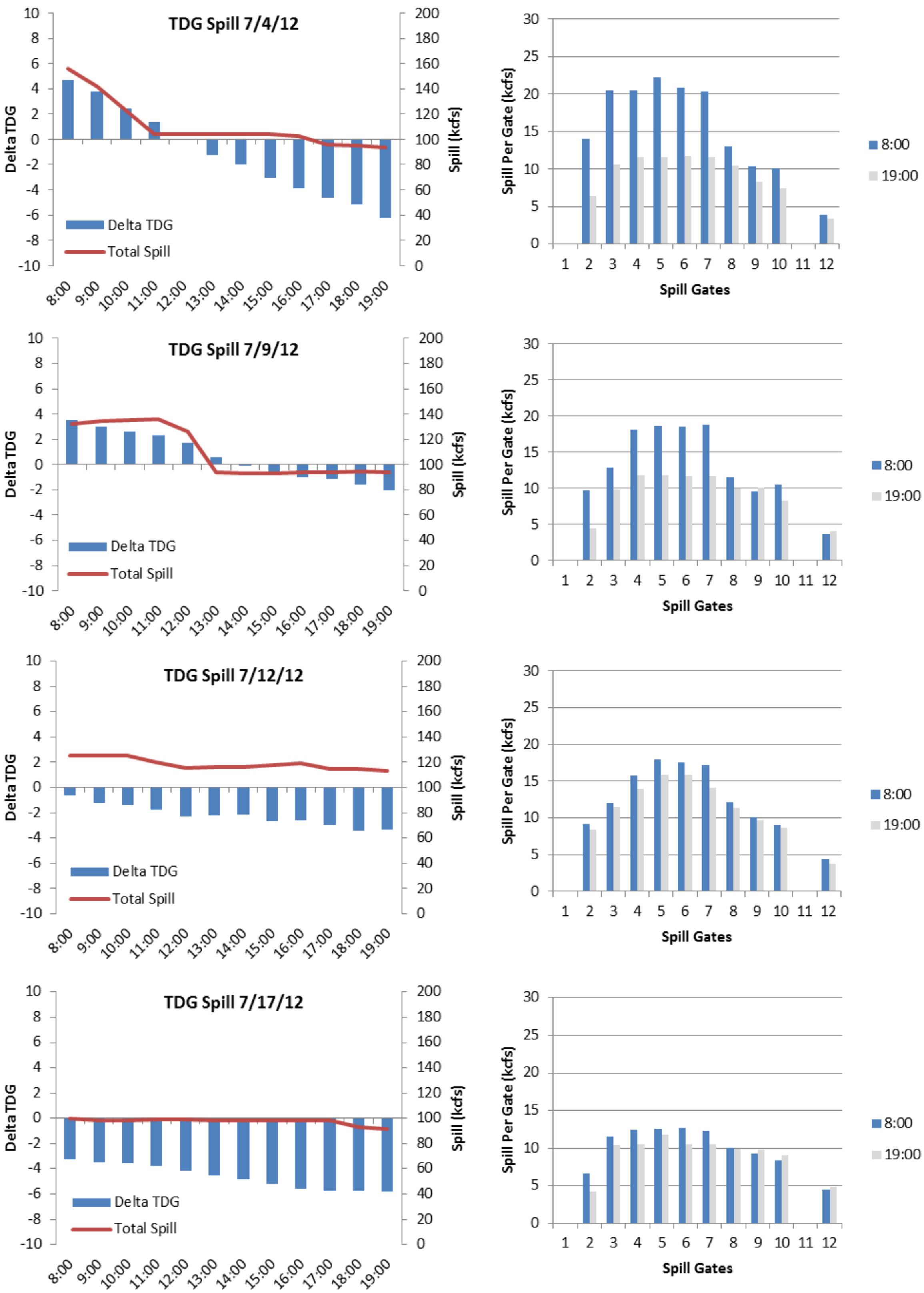


Figure 23. Delta TDG levels and total spill volumes (left), and volumes and distribution of spill through each gate (right) for TDG Spill tests (July 4-17, 2012).

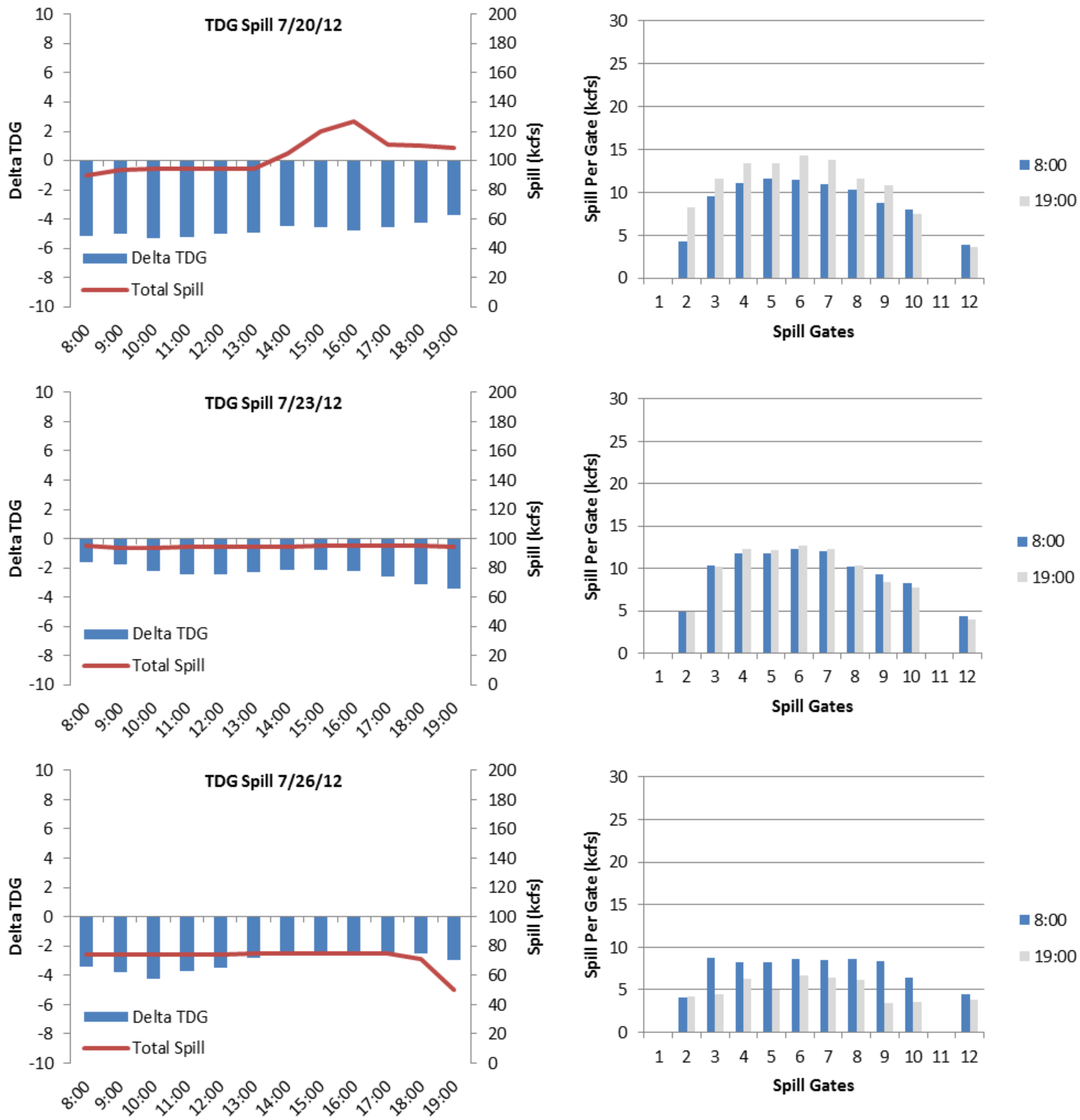


Figure 24. Delta TDG levels and total spill volumes (left), and volumes and distribution of spill through each gate (right) for TDG Spill tests (July 20-26, 2012).

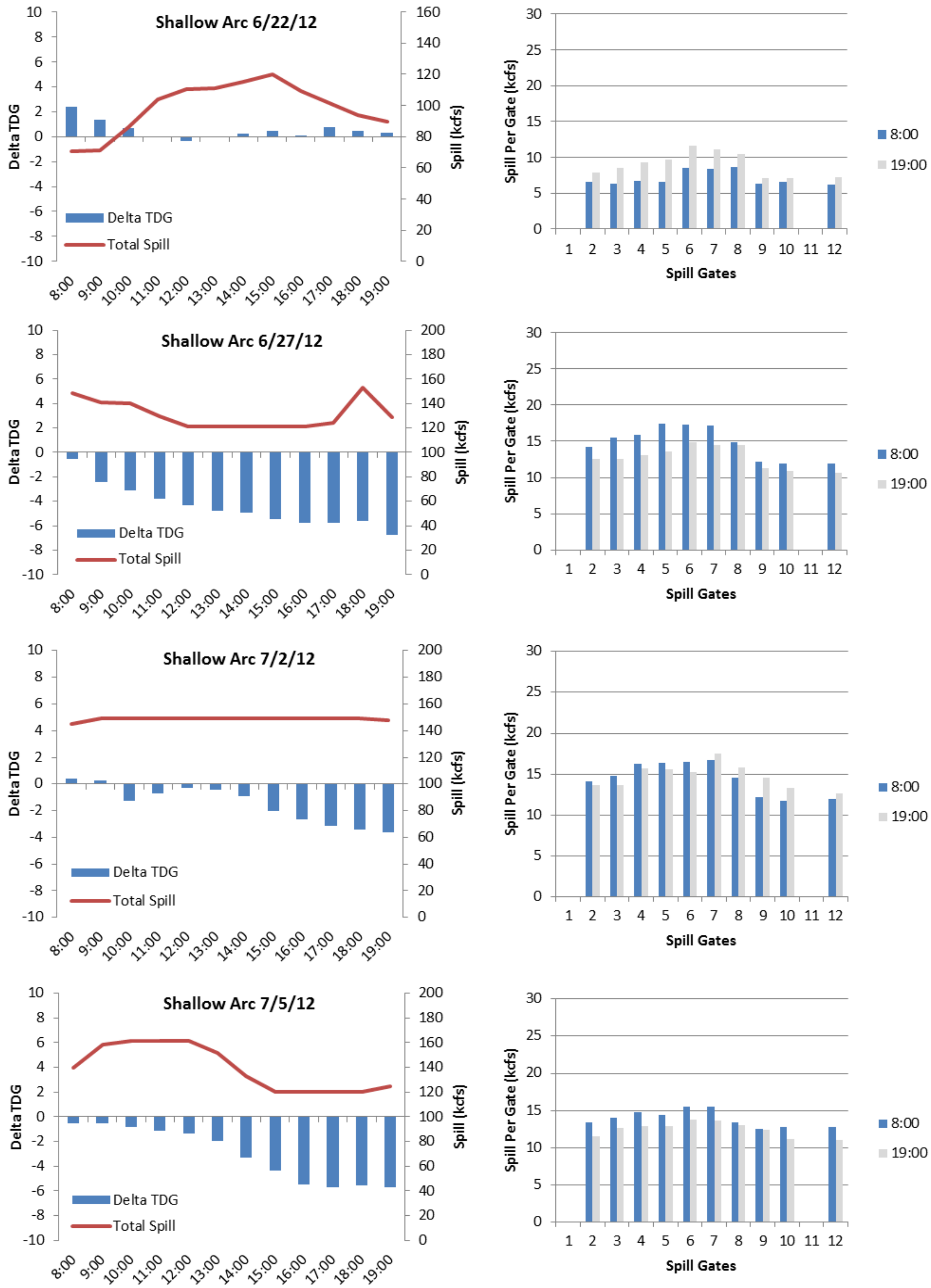


Figure 25. Delta TDG levels and total spill volumes (left), and volumes and distribution of spill through each gate (right) for Shallow Arc tests (July 22-July 5, 2012).

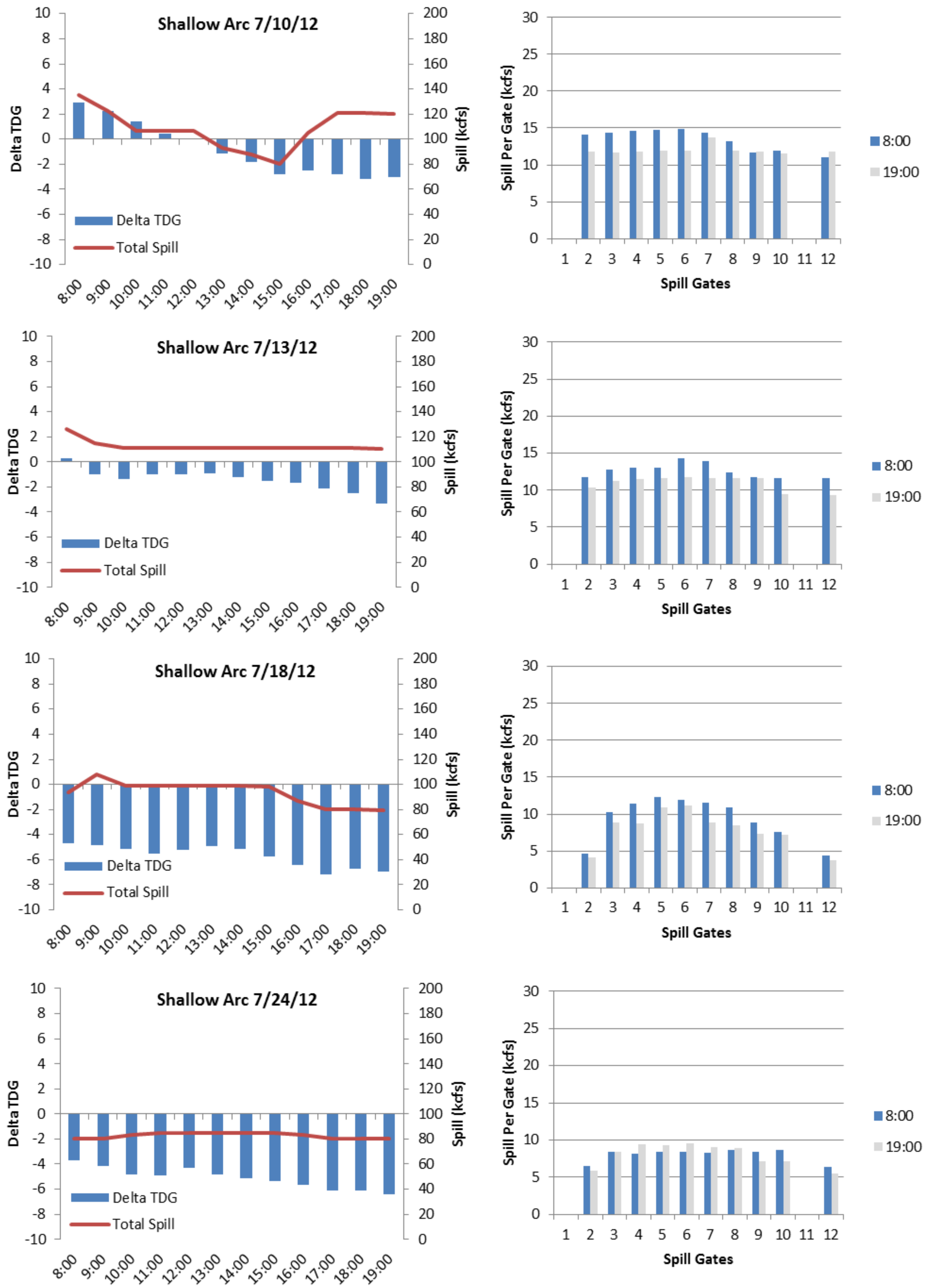


Figure 26. Delta TDG levels and total spill volumes (left), and volumes and distribution of spill through each gate (right) for Shallow Arc tests (July 10-24, 2012).

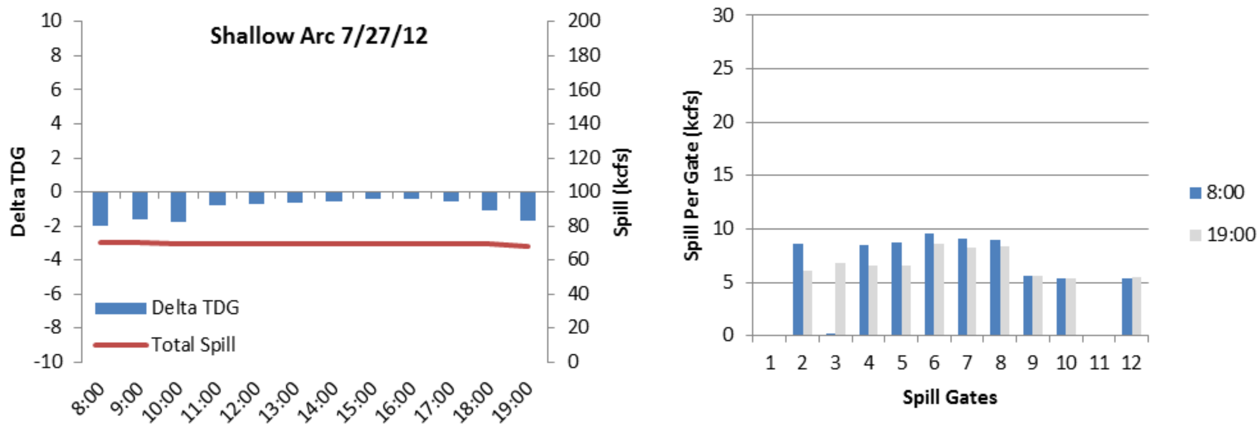


Figure 27. Delta TDG levels and total spill volumes (left), and volumes and distribution of spill through each gate (right) for Shallow Arc tests (July 27, 2012).

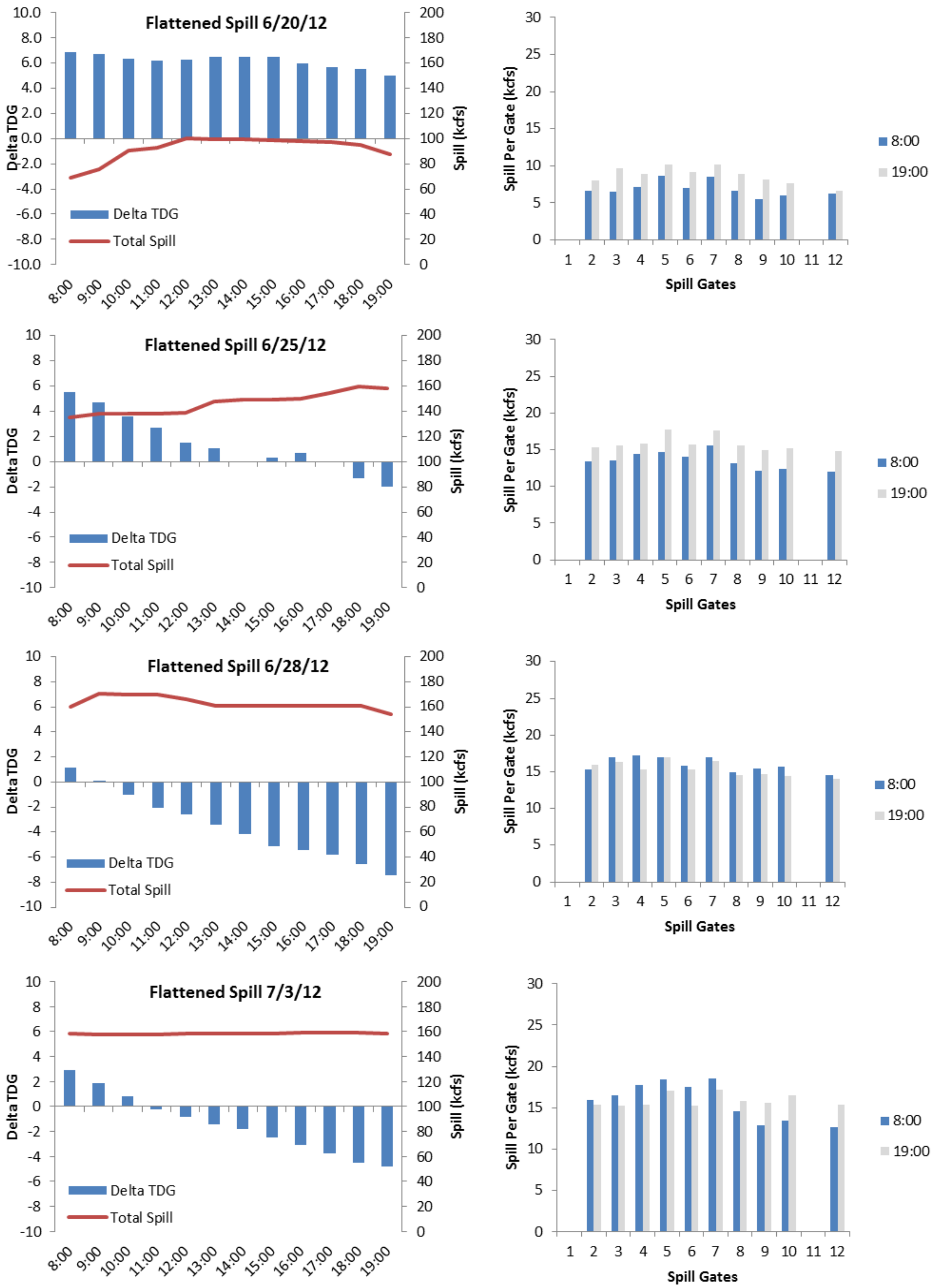


Figure 28. Delta TDG levels and total spill volumes (left), and volumes and distribution of spill through each gate (right) for Flattened Spill tests (June 20-July 3, 2012).

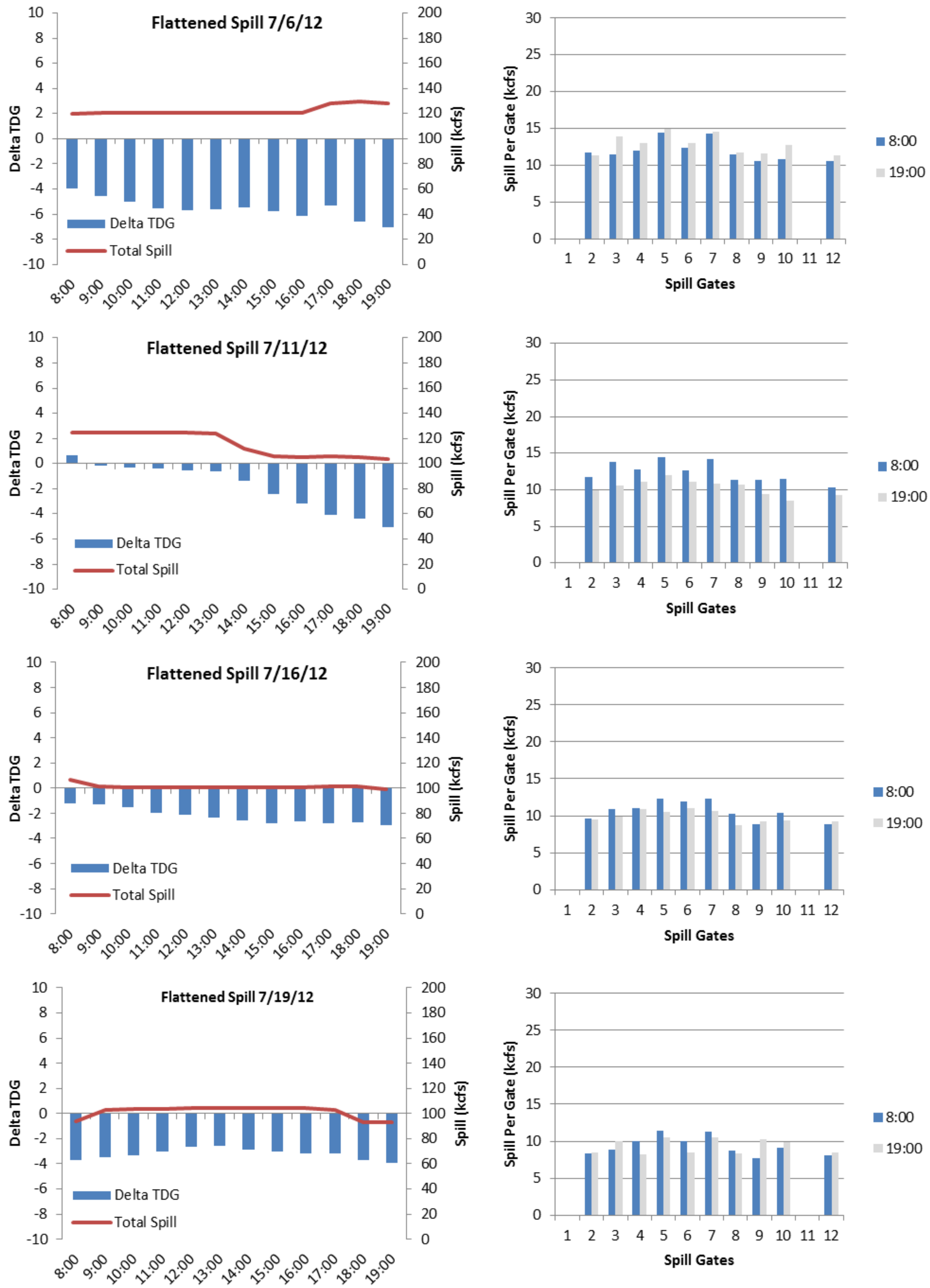


Figure 29. Delta TDG levels and total spill volumes (left), and volumes and distribution of spill through each gate (right) for Flattened Spill tests (July 6-19, 2012).

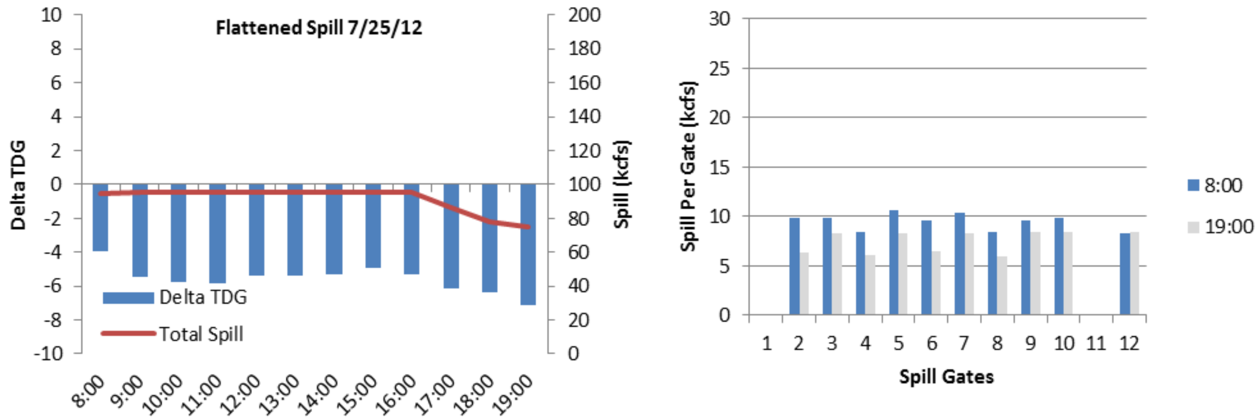


Figure 30. Delta TDG levels and total spill volumes (left), and volumes and distribution of spill through each gate (right) for Flattened Spill tests (July 25, 2012).

120 % TDG EXCEEDENCE

The spill configuration tests of 2011 and 2012 were conducted to determine if the tested spill configurations prove to provide a practical means to maintain TDG levels in spilled water within the 120% criterion for total river discharge less than the 7Q10. The 7Q10 discharge is approximately 260 kcfs for Rocky Reach Dam. However, during the 2011 and 2012 spill seasons the total river discharge at Rocky Reach Dam frequently exceeded 260 kcfs.

The 2011 and 2012 test data monitored downstream TDG levels near the spillway at a location where spilled water appears to receive little or no dilution by powerhouse discharge. Thus, these values do not represent the TDG levels that occurred in most of the reach between Rocky Reach and Rock Island Dams after water from the two sources has mixed when the forebay TDG levels are lower than the spilled water TDG levels. However, as shown in the two previous sections, the spilled water can at times have lower TDG than the forebay water.

The TDG levels produced in spilled water with each of the configurations during each year as compared to total river flow (discharge) are shown in Figure 31. It is clear that TDG levels commonly exceeded 120 % of saturation for each of the spill configurations. In both years total river flows during many of the tests exceeded the 7Q10 flow.

In 2012 with total river flows of about 180 to 280 kcfs more tests resulted in TDG levels at or below 120 % of saturation than with the same total river flows during the 2011 tests (Figure 31).

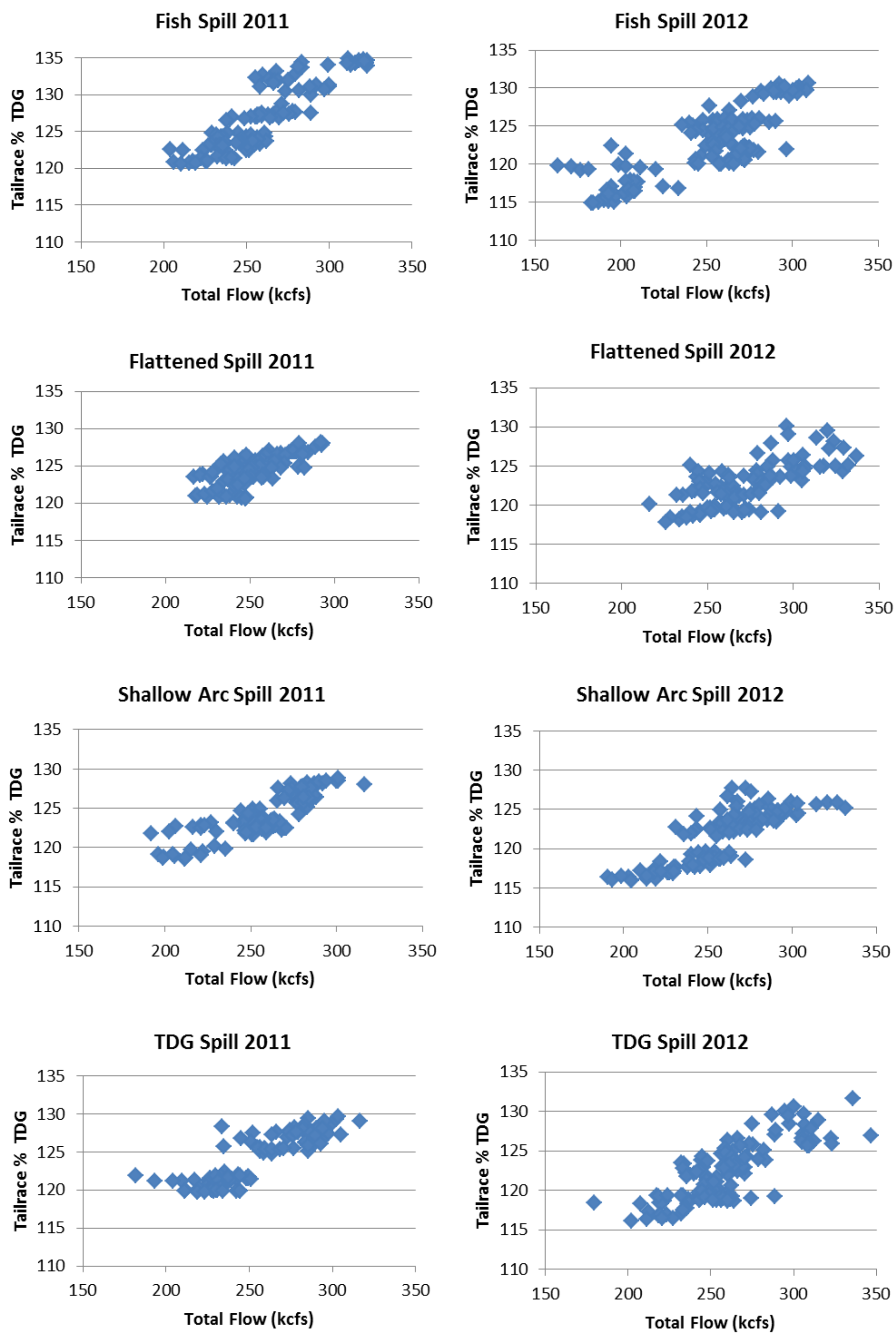


Figure 31. TDG levels for each configuration vs Total Flow.

Similar results are shown by the comparison of TDG levels vs. spill volume as shown in Figure 32. For each of the spill configurations TDG levels in the tailrace were more frequently at or below 120 % of saturation in 2012 than in 2011.

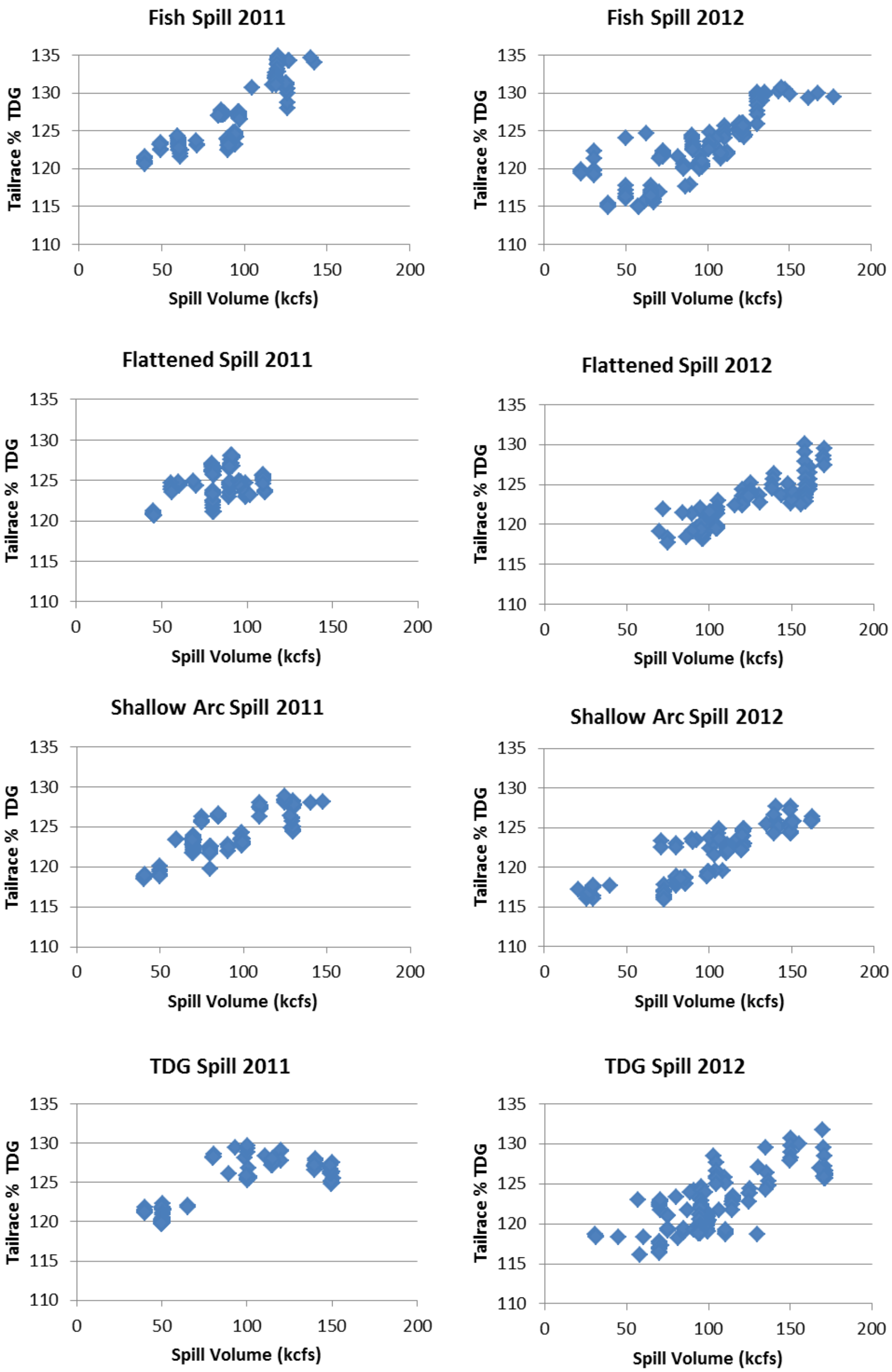


Figure 32. TDG levels for each configuration vs Spill Volume.

A comparison of forebay and tailrace levels for both 2011 and 2012 test data does not provide an indication of the difference between the frequency of <120 % of saturation levels for the two years (Figure 33). (Army Corps of Engineers 2003) The series of outlier data points to the left are from a day when the TDG configuration spill pattern was used, while the other three outlier groups are from days with Fish Spill. However, the configurations in 2012 were controlled better than in 2011, which may account for the overall tighter distribution in 2012.

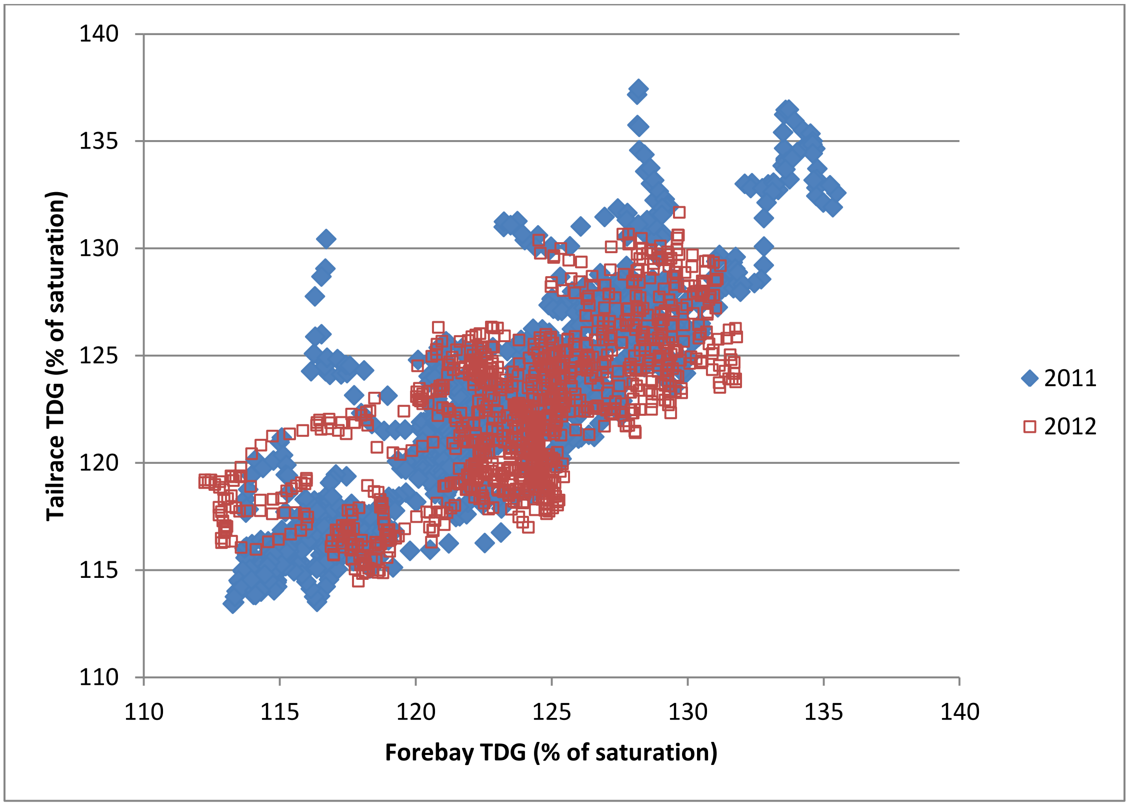


Figure 33. Forebay vs. Tailrace TDG levels during 2011 and 2012 test periods.

DISCUSSION

With the exception of the Fish Spill configuration, the configurations tested in 2011 and 2012 produced similar results for reducing TDG levels downstream of Rocky Reach Dam. The primary difference between Fish Spill and the other configurations is the number of gates used to spill a given amount of flow. The Fish Spill used only seven gates, while the other configurations employed ten gates each. Spreading spill over a greater number of gates generally tends to minimize the production of TDG levels downstream, as appears to be the case at Rocky Reach Dam.

Each of the four spill configurations produced some TDG levels of 120 % of saturation or less at the lower spill volumes tested. Although the occurrence of TDG levels of 120 % of saturation generally occurred with spill volumes less than 120 kcfs, these occurrences were not consistently associated with any specific factor. Frequently spill volumes less than 120 kcfs also produced TDG levels in >120 % of saturation.

The greater occurrence of TDG levels <120 % of saturation during 2012 than 2011 is not due to an obvious factor measured during the tests. Although the configurations typically used gates 2-9 and gates 11-12 in 2011, and gates 2-10 and gate 12 in 2012, there is no obvious reason that this difference would have produced the difference in recorded values <120 %. Gates 10 was out for maintenance in 2011 and gate 11 in 2012.

Because of the similar number of gates used for the TDG Spill, Shallow Arc Spill, and Flattened Spill configurations, the differences between configurations were not always clear or consistent. However, the Flattened Spill configuration tended to result in more consistent and slightly greater reductions in downstream TDG levels than the TDG and Shallow Arc configurations. The TDG and Shallow Arc configurations appeared to perform slightly better when the spill distributions approached a flatter pattern (less difference between the amounts of spill passing through each of the gates).

In addition to the similar number of gates used in the configurations, other factors tended to confound the test results. The variations in total river flow throughout the testing period, likely resulted in small variations in water travel times between the forebay and downstream monitoring stations due to the close proximity of the downstream station to the spillway. This variability, along with the relatively continuous variations in project operations during specific spill tests, as well as differences (spill level and spill distribution between gates) between the replicate configuration tests, make it difficult to match a particular configuration with a specific downstream result. The operational changes are evident in the comparisons of the spill distribution for each spill test, at the start and end of the tests (the right graphs in the configuration test figures). In some situations these changes in distribution resulted in substantially altering the configuration, such that it resembled one of the other test configurations. The overall results of these operational changes are evident in the typical pattern of gradually changing delta TDG values throughout many of the spill tests. Even over the course of the 12-h tests, delta TDG levels typically did not reach a stable and consistent result.

In order to more accurately evaluate spill configurations the test configurations would need to remain unchanged for longer periods of time. These changes would likely result in improvements in assigning specific downstream results to a particular configuration.

CONCLUSIONS

The 2011 and 2012 spill configuration tests results do not demonstrate a reliable configuration for producing TDG levels not exceeding 120 % of saturation in the spilled water during high river flow conditions. Although each of the spill configurations produced some TDG values at or less than 120 % of saturation, the same or similar flows also produced TDG levels exceeding 120 % of saturation. The Fish Spill tended to produce TDG levels similar to those of the other three configurations when spillway discharges were about 120 kcfs or lower.

The Shallow Arc Spill configuration produced relatively consistent decreases in TDG levels from the forebay to tailrace in both years, although the reductions were greater and more consistent in 2012 (often -5 to -6% of saturation), than in 2011 (typically about -2% of saturation). Flattened, Shallow Arc, and TDG Spill typically produced negative delta TDG levels in both years, with Flattened Spill producing slightly more consistent results. Flattened Spill typically resulted in similar or greater negative delta TDG levels than the other two configurations, although the differences were relatively small. In addition to the Flattened Spill configuration being slightly better at reducing downstream TDG levels, the other configurations also tended to be slightly better at reducing downstream TDG levels when the configuration was flattened (i.e. when spill was distributed equally through all operating gates).

Total spill discharges during most of the 2011 test configurations were relatively low (median of 79 kcfs and a peak of 180 kcfs) as compared to the 2012 spill discharges were substantially higher with a median of 104 kcfs and a peak of 199 kcfs. However, 79 kcfs is a high spill for Rocky Reach Dam where spills greater than 60-70 kcfs tend to be rare except when total river flow exceeds the 7Q10 (252 kcfs). Most of the tests in 2011 were conducted under total spill conditions of 100 kcfs or less, while the 2012 tests typically occurred with spill levels greater than 100 kcfs. In both years, the Fish Spill configurations tended to provide the least benefits for reducing the downstream TDG levels, with the majority of the tests producing increases in TDG levels (delta typically about +5.5% of saturation), including the highest delta TDG (+8.1 % of saturation) observed in 2011.

REFERENCES

Army Corps of Engineers, 2003. Total dissolved gas exchange during spillway operations at Rocky Reach Dam, April 26-May 3, 2002. Report to Public Utility District No. 1 of Chelan County, Wenatchee, Washington. 137 p.

Schneider, M. l., and S. C. Wilhelms. 2006. Rocky Reach Dam: operational and structural total dissolved gas management. Draft report to Public Utility District No. 1 of Chelan County, Wenatchee, Washington. 91 p.

APPENDIX A
Spill Gate Configurations

Fish Spill Pattern

Total Feet of Gate Open	Gate 2	Gate 3	Gate 4	Gate 5	Gate 6	Gate 7	Gate 8	Estimated Flow in CFS
2							2	4334
3							3	6501
4					2		2	8668
5					2		3	10835
6					3		3	13002
7			2		2		3	15169
8			2		3		3	17336
9			3		3		3	19476
10	2		2		3		3	21640
11	2		3		3		3	23804
12	2		3		3	2	2	25968
13	2		3		3	2	3	28132
14	2		3		3	3	3	30296
15	2		3	2	3	2	3	32460
16	2		3	2	3	3	3	34624
17	2		3	3	3	3	3	36788
18	2	2	3	3	3	3	3	38124
19	2	2	3	3	3	3	3	40242
20	2	2	3	4	3	3	3	42360
21	2	3	3	4	3	3	3	44478
22	2	3	3	4	4	3	3	46596
23	2	3	3	5	4	3	3	48714
24	2	3	4	5	4	3	3	50832
25	2	3	4	5	4	4	3	52950
26	2	3	4	5	4	4	4	55068
27	2	3	5	5	4	4	4	57186
28	2	3	5	5	5	4	4	59304
29	2	3	5	5	5	5	4	61422
30	2	3	5	6	5	5	4	63540
31	2	3	5	6	5	5	5	65658
32	2	3	5	6	6	5	5	67776
33	2	4	5	6	6	5	5	69894
34	2	4	5	6	7	5	5	72012
35	2	4	6	6	7	5	5	74130
36	2	4	6	6	7	6	5	76248
37	2	4	6	6	7	6	6	78366
38	2	4	6	6	8	6	6	80484
39	2	4	6	7	8	6	6	82602
40	2	4	6	7	8	7	6	84720
41	2	5	6	7	8	7	6	86838

The configuration above was used in 2011 and 2012.

TDG Spill Pattern

Total Feet of Gate Open	Gate 2	Gate 3	Gate 4	Gate 5	Gate 6	Gate 7	Gate 8	Gate 9	Gate 10	Gate 11	Gate12	Estimated flow in CFS
2							2					4334
3							3					6501
4					2		2					8668
5					2		3					10835
6			2		2		2					13002
7			2		2		3					15169
8	2		2		2		2					17336
9	2		2		2		3					19503
10	2		2		2	2	2					21640
11	2		2		2	2	3					23837
12	2		2	2	2	2	2					26004
13	2		2	2	2	2	3					28171
14	2	2	2	2	2	2	2					30338
15	2	2	2	2	2	2	3					32505
16	2	2	2	2	2	2	2	2				34672
17	2	2	2	2	2	2	3	2				36839
18	2	2	2	2	2	2	2	2		2		39006
19	2	2	2	2	2	2	3	2		2		41173
20	2	2	2	2	2	2	2	2		2	2	43340
21	2	2	2	2	2	2	3	2		2	2	45507
22	2	2	2	2	3	2	3	2		2	2	47674
23	2	2	3	2	3	2	3	2		2	2	49841
24	2	2	3	2	3	3	3	2		2	2	52008
25	2	2	3	3	3	3	3	2		2	2	54175
26	2	3	3	3	3	3	3	2		2	2	56342
27	2	3	3	3	3	3	3	3		2	2	58509
28	2	3	3	3	3	3	3	3		3	2	60676
29	2	3	3	4	3	3	3	3		3	2	62794
30	2	3	4	4	3	3	3	3		3	2	64912
31	2	3	4	4	4	3	3	3		3	2	67030
32	2	3	4	4	4	4	3	3		3	2	69148
33	2	3	4	4	4	4	4	3		3	2	71266
34	2	3	4	4	4	4	4	4		3	2	73384
35	2	4	4	4	4	4	4	4		3	2	75502
36	2	4	4	4	4	4	4	4		4	2	77620
37	2	4	4	5	4	4	4	4		4	2	79738
38	2	4	4	5	5	4	4	4		4	2	81856
39	2	4	5	5	5	4	4	4		4	2	83974
40	2	4	5	5	5	5	4	4		4	2	86092
41	2	4	5	5	5	5	5	4		4	2	88210
42	2	4	5	5	5	5	5	5		4	2	90328
43	2	4	5	6	5	5	5	5		4	2	92446
44	2	5	5	6	5	5	5	5		4	2	94564
45	2	5	6	6	5	5	5	5		4	2	96682
46	2	5	6	6	6	5	5	5		4	2	98800
47	2	5	6	6	6	6	5	5		4	2	100918
48	3	5	6	6	6	6	5	5		4	2	103036
49	3	6	6	6	6	6	5	5		4	2	105154
50	3	6	6	6	6	6	6	5		4	2	107272
51	3	6	6	7	6	6	6	5		4	2	109390
52	3	6	7	7	6	6	6	5		4	2	111508
53	3	6	7	7	7	6	6	5		4	2	113626
54	3	6	7	7	7	7	6	5		4	2	115744
55	3	6	7	7	7	7	6	6		4	2	117862
56	4	6	7	7	7	7	6	6		4	2	119980
57	4	6	7	7	7	7	6	6		5	2	122098
58	4	6	7	8	7	7	6	6		5	2	124216
59	4	6	7	8	8	7	6	6		5	2	126334
60	4	6	8	8	8	7	6	6		5	2	128452
61	4	6	8	8	8	8	6	6		5	2	130570
62	4	6	8	9	8	8	6	6		5	2	132688
63	4	6	8	9	9	8	6	6		5	2	134806
64	4	6	8	9	9	9	6	6		5	2	136924
65	4	6	9	9	9	9	6	6		5	2	139042
66	4	6	9	10	9	9	6	6		6	2	141160
67	4	6	9	10	10	9	6	6		6	2	143278
68	4	6	10	10	10	9	6	6		6	2	145396
69	4	6	10	10	10	10	6	6		6	2	147514

The configuration above was used in 2011. This configuration was modified in 2012 to replace Gate 11 with Gate 10.

Shallow Arc Pattern

Total Feet of Gate Open	Gate 2	Gate 3	Gate 4	Gate 5	Gate 6	Gate 7	Gate 8	Gate 9	Gate 10	Gate 11	Gate 12	Estimated Flow in CFS
2							2					4334
3							3					6501
4					2		2					8668
5					2		3					10835
6			2		2		2					13002
7			2		2		3					15169
8	2		2		2		2					17336
9	2		2		2		3					19503
10	2		2		2	2	2					21640
11	2		2		2	2	3					23837
12	2		2	2	2	2	2					26004
13	2		2	2	2	2	3					28171
14	2	2	2	2	2	2	2					30338
15	2	2	2	2	2	2	3					32505
16	2	2	2	2	2	2	2	2				34672
17	2	2	2	2	2	2	3	2				36839
18	2	2	2	2	2	2	2	2		2		39006
19	2	2	2	2	2	2	3	2		2		41173
20	2	2	2	2	2	2	2	2		2	2	43340
21	2	2	2	2	2	3	2	2		2	2	45507
22	2	2	2	2	3	3	2	2		2	2	47674
23	2	2	2	2	3	3	3	2		2	2	49841
24	2	2	2	3	3	3	3	2		2	2	52008
25	2	2	2	3	3	3	3	3		2	2	54175
26	2	2	3	3	3	3	3	3		2	2	56342
27	2	2	3	3	3	3	3	3		3	2	58509
28	2	3	3	3	3	3	3	3		3	2	60676
29	2	3	3	3	3	3	3	3		3	3	62794
30	3	3	3	3	3	3	3	3		3	3	65010
31	3	3	3	3	3	4	3	3		3	3	67128
32	3	3	3	3	4	4	3	3		3	3	69246
33	3	3	3	3	4	4	4	3		3	3	71364
34	3	3	3	4	4	4	4	3		3	3	73482
35	3	3	4	4	4	4	4	3		3	3	75600
36	3	3	4	4	4	4	4	4		3	3	77718
37	3	4	4	4	4	4	4	4		3	3	79836
38	3	4	4	4	4	4	4	4		4	3	81954
39	4	4	4	4	4	4	4	4		4	3	84072
40	4	4	4	4	4	4	4	4		4	4	86190
41	4	4	4	4	4	5	4	4		4	4	88308
42	4	4	4	4	5	5	4	4		4	4	90426
43	4	4	4	4	5	5	5	4		4	4	92544
44	4	4	4	5	5	5	5	4		4	4	94662
45	4	4	5	5	5	5	5	4		4	4	96780
46	4	4	5	5	5	5	5	5		4	4	98898
47	4	5	5	5	5	5	5	5		4	4	101016
48	4	5	5	5	5	5	5	5		5	4	103134
49	5	5	5	5	5	5	5	5		5	4	105252
50	5	5	5	5	5	5	5	5		5	5	107370
51	5	5	5	5	5	6	5	5		5	5	109488
52	5	5	5	5	6	6	5	5		5	5	111606
53	5	5	5	5	6	6	6	5		5	5	113724
54	5	5	5	6	6	6	6	5		5	5	115842
55	5	5	6	6	6	6	6	5		5	5	117960
56	5	5	6	6	6	6	6	6		5	5	120078
57	5	6	6	6	6	6	6	6		5	5	122196
58	5	6	6	6	6	6	6	6		6	5	124314
59	6	6	6	6	6	6	6	6		6	5	126432
60	6	6	6	6	6	6	6	6		6	6	128550
61	6	6	6	6	6	7	6	6		6	6	130668
62	6	6	6	6	7	7	6	6		6	6	132786
63	6	6	6	6	7	7	7	6		6	6	134904
64	6	6	6	7	7	7	7	6		6	6	137022
65	6	6	7	7	7	7	7	6		6	6	139140
66	6	6	7	7	7	7	7	7		6	6	141258
67	6	7	7	7	7	7	7	7		6	6	143376
68	6	7	7	7	7	7	7	7		7	6	145494
69	7	7	7	7	7	7	7	7		7	6	147612

The configuration above was used in 2011. This configuration was modified in 2012 to replace Gate 11 with Gate 10.

Flattened Spill Pattern

Total Feet of Gate Open	Gate 2	Gate 3	Gate 4	Gate 5	Gate 6	Gate 7	Gate 8	Gate 9	Gate 10	Gate 11	Gate 12	Estimated Flow in CFS
2							2					4334
3							3					6501
4					2		2					8668
5					2		3					10835
6					2		2			2		13002
7					2		3			2		15169
8			2		2		2			2		17336
9			2		2		3			2		19503
10			2		2		2			2	2	21640
11			2		2		3			2	2	23837
12	2		2		2		2			2	2	26004
13	2		2		2		3			2	2	28171
14	2		2		2	2	2			2	2	30338
15	2		2		2	2	3			2	2	32505
16	2		2		2	2	2	2		2	2	34672
17	2		2		2	2	3	2		2	2	36839
18	2		2	2	2	2	2	2		2	2	39006
19	2		2	2	2	2	3	2		2	2	41173
20	2	2	2	2	2	2	2	2		2	2	43340
21	2	2	2	2	2	3	2	2		2	2	45507
22	2	2	2	3	2	3	2	2		2	2	47674
23	2	2	2	3	2	3	2	2		3	2	49841
24	2	2	2	3	2	3	2	3		3	2	52008
25	2	3	2	3	2	3	2	3		3	2	54175
26	2	3	2	3	2	3	2	3		3	3	56342
27	3	3	2	3	2	3	2	3		3	3	58509
28	3	3	2	3	3	3	2	3		3	3	60676
29	3	3	3	3	3	3	2	3		3	3	62794
30	3	3	3	3	3	3	3	3		3	3	65010
31	3	3	3	3	3	4	3	3		3	3	67128
32	3	3	3	4	3	4	3	3		3	3	69246
33	3	3	3	4	3	4	3	3		4	3	71364
34	3	3	3	4	3	4	3	4		4	3	73482
35	3	4	3	4	3	4	3	4		4	3	75600
36	3	4	3	4	3	4	3	4		4	4	77718
37	4	4	3	4	3	4	3	4		4	4	79836
38	4	4	3	4	4	4	3	4		4	4	81954
39	4	4	4	4	4	4	3	4		4	4	84072
40	4	4	4	4	4	4	4	4		4	4	86190
41	4	4	4	4	4	5	4	4		4	4	88308
42	4	4	4	5	4	5	4	4		4	4	90426
43	4	4	4	5	4	5	4	4		5	4	92544
44	4	4	4	5	4	5	4	5		5	4	94662
45	4	5	4	5	4	5	4	5		5	4	96780
46	4	5	4	5	4	5	4	5		5	5	98898
47	5	5	4	5	4	5	4	5		5	5	101016
48	5	5	4	5	5	5	4	5		5	5	103134
49	5	5	5	5	5	5	4	5		5	5	105252
50	5	5	5	5	5	5	5	5		5	5	107370
51	5	5	5	5	5	6	5	5		5	5	109488
52	5	5	5	6	5	6	5	5		5	5	111606
53	5	5	5	6	5	6	5	5		6	5	113724
54	5	5	5	6	5	6	5	6		6	5	115842
55	5	6	5	6	5	6	5	6		6	5	117960
56	5	6	5	6	5	6	5	6		6	6	120078
57	6	6	5	6	5	6	5	6		6	6	122196
58	6	6	5	6	6	6	5	6		6	6	124314
59	6	6	6	6	6	6	5	6		6	6	126432
60	6	6	6	6	6	6	6	6		6	6	128550
61	6	6	6	6	6	7	6	6		6	6	130668
62	6	6	6	7	6	7	6	6		6	6	132786
63	6	6	6	7	6	7	6	6		7	6	134904
64	6	6	6	7	6	7	6	7		7	6	137022
65	6	7	6	7	6	7	6	7		7	6	139140
66	6	7	6	7	6	7	6	7		7	7	141258
67	7	7	6	7	6	7	6	7		7	7	143376
68	7	7	6	7	7	7	6	7		7	7	145494
69	7	7	7	7	7	7	6	7		7	7	147612

The configuration above was used in 2011. This configuration was modified in 2012 to replace Gate 11 with Gate 10.