2018 Annual Data Monitoring Report

Union Pacific Railroad Great Salt Lake Causeway Culvert Closure and Bridge Construction Project

SPK-2011-00755

February 1, 2019

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Contents

Tables

Figures

Acronyms

°C	degrees Celsius
cfs	cubic feet per second
CMMP	Updated Final Compensatory Mitigation and Monitoring Plan
DBL	deep brine layer
g/L	grams per liter
g/mL	grams per milliliter
GIS	geographic information systems
mg/L	milligrams per liter
NA	not applicable
NGVD 29	National Geodetic Vertical Datum of 1929
OHWM	ordinary high water mark
QA/QC	quality assurance/quality control
QAPP	Quality Assurance Project Plan
SAP	Sampling and Analysis Plan
TDS	total dissolved solids
UDWQ	Utah Division of Water Quality
UGS	Utah Geological Survey
UPRR	Union Pacific Railroad
USACE	U.S. Army Corps of Engineers
USGS	U.S. Geological Survey
WRI 4221	Water-Resources Investigations Report 00-4221
WSE	water surface elevation

1.0 Introduction

1.1 Background

Union Pacific Railroad (UPRR) submits this 2018 annual data monitoring report pursuant to Special Condition 1.b of the U.S. Army Corps of Engineers (USACE) Individual Permit (No. SPK 2011-00755) issued September 9, 2015 (USACE 2015a), and modifications, and Condition 7 of the Amended Utah 401 Water Quality Certification with Conditions (No. SPK 2011-00755), which was issued to UPRR by the Utah Division of Water Quality (UDWQ) on September 13, 2017 (UDWQ 2017), for the permanent closure of the east culvert.

The causeway opening, consisting of a new bridge, control berm, and south channel, were constructed to allow the transfer of water and salt between the North and South Arms of the Great Salt Lake to duplicate, as closely as possible, the transfer of water and salt that was previously provided by the now-closed east and west culverts. Construction of the causeway opening began in October 2015 and was completed in December 2016. Mitigation monitoring began in January 2017, after construction was completed. The 2017 quarterly data monitoring reports and the 2017 annual data monitoring report were previously submitted (UPRR 2017a, 2017b, 2017c, 2018a, 2018b). The 2017 annual data monitoring report was approved by UDWQ on March 2, 2018 (UDWQ 2018).

The monitoring events reported in this report were conducted in accordance with the Updated Final Compensatory Mitigation and Monitoring Plan (CMMP; UPRR 2016a) and the Sampling and Analysis Plan (SAP) and Quality Assurance Project Plan (QAPP) (UPRR 2016b), which were approved by UDWQ (UDWQ 2017) and previously reported in the 2018 quarterly data monitoring reports (UPRR 2018c, 2018d, 2018e, 2019). The required contents of this annual report are set out in the CMMP, Section 3.10.2.

This 2018 annual monitoring report presents the results of monthly water quality monitoring at the causeway opening, the results of quarterly North Arm and South Arm lake monitoring, and an assessment of the mitigation's success in meeting the performance standards established by the CMMP. This report also presents the results of "additional data" collection, as defined in the SAP. Biannual survey measurements of the project elements were required to be collected during this monitoring period and are included in this report.

1.2 Goals and Objectives

As described in the CMMP (UPRR 2016a) and SAP (UPRR 2016b), the goals of mitigation monitoring are to (1) facilitate determination of whether the performance standards described in the CMMP are being met and (2) provide additional information for salinity modeling and lake management as needed. The CMMP defines the project performance standards related to lake salinity and the new causeway opening geometry (UPRR 2016a). The following are the objectives of monitoring under the CMMP used to determine whether the mitigation is meeting the performance standards:

1. Determine whether the average salinity in Gilbert Bay is within the UPRR/Utah Geological Survey historic and 2012 model salinity ranges (UPRR 2016a, Table 3-7).
2. Determine whether the average bridge site contours remain within 10% of as-built or agreed-upon altered geometry (UPRR 2016a, Performance Standard 1, Table 3-5).
3. Determine whether the average cross-sectional area and geometry of the causeway opening are within 10% of the as-built or agreed-upon area (UPRR 2016a, Performance Standard 2, Table 3-1).
4. Determine whether the average water depth of the causeway opening is within 10% of as-built or agreed-upon altered depths (UPRR 2016a, Performance Standard 3, Table 3-5).
5. Determine whether the average control berm contours remain within 10% of as-built or agreed-upon altered geometry (UPRR 2016a, Performance Standard 4, Table 3-5).

The CMMP also includes additional data collection requirements that are not related to mitigation performance standards but will aid in future lake salinity modeling and management (UPRR 2016a, Section 3.11). Meeting the following monitoring objectives will provide this additional information:

1. Monitor and report bidirectional water flows through the causeway opening.
2. Compile and report North Arm (Gunnison Bay) and South Arm (Gilbert Bay) water surface elevations (WSE) on monitoring dates, as published on the U.S. Geological Survey's (USGS) Great Salt Lake website, for context.
3. Measure and report the presence and depth of the deep brine layer at the Gilbert Bay sampling sites.

2.0 Methods

HDR, Inc., and USGS conducted 2018 monitoring on behalf of UPRR. Water quality monitoring occurred in 2018 in accordance with the CMMP (UPRR 2016a), SAP, and QAPP (UPRR 2016b), and methods were previously reported in the 2018 quarterly data monitoring reports (UPRR 2018c, 2018d, 2018e, 2019). This report summarizes the data that were previously reported.

2.1 Study Variances

Monitoring during 2018 was conducted in conformance with the SAP and QAPP with no variances.

2.2 Corrective Actions

None.

2.3 Quality Assurance

All data were collected in accordance with the SAP's QAPP (UPRR 2016b). After each event, UPRR subjected all data to quality assurance/quality control (QA/QC) procedures including but not limited to spot checks of transcription, review of electronic data submissions for completeness, comparison of geographic information systems (GIS) maps with field notes on locations, and identification of any inconsistent data. UPRR also evaluated the analytical data for their consistency with the data quality objectives in the QAPP. The QAPP specifies representativeness, accuracy, precision, comparability, and completeness objectives for data acquisition (UPRR 2016b, Table 7-1).

As a result of this process, UPRR observed the following:

- **Precision**
  - Field duplicate sample results were generally less than 10% different from their corresponding primary samples. All results were less than 20% different from each other.
- **Accuracy and Bias**
  - Field instrument calibration met manufacturers' requirements.
  - Laboratory QA/QC met each laboratory's internal method requirements.
  - Laboratory analytes were generally not detected in field blank samples. Total dissolved solids (TDS) was detected in field blank samples near the reporting limit on February 14 and April 11. Potassium and sodium were detected near their reporting limits in field blank samples on June 7. However, the detected concentration was between 3 and 4 orders of magnitude less than the concentrations of the associated lake water samples.
  - Laboratory analytes were often detected in equipment rinsate blank samples. However, the detected concentrations were near the reporting limit between 3 and 4 orders of magnitude less than the concentrations of the associated lake water samples.
- **Representativeness**
  - All field measurements and samples were collected from locations and seasonal sampling events defined in the SAP.
- **Completeness**
  - Field and laboratory completeness requirements were met.
- **Comparability**
  - Field conditions were within the range of the selected in-situ meter and probe capabilities.
  - Laboratory method reporting limits were sufficient to detect concentrations in the lake and causeway samples.

Detailed QA documentation is provided in Appendix D, Data Quality Assurance Documentation, of each 2018 quarterly report (UPRR 2018c, 2018d, 2018e, 2019).

3.0 Summary of Results

The results of each 2018 monitoring event as well as the QA/QC review are presented in the four 2018 quarterly data monitoring reports, which were submitted on May 15, 2018; August 15, 2018; November 15, 2018; and February 1, 2019 (UPRR 2018c, 2018d, 2018e, 2019). Data packages (Level 2) and other supporting documentation are also provided in these four reports. A summary of the results is provided below.

Lake water chemistry monitoring occurred on a quarterly basis during 2018. The causeway opening geometry survey occurred biannually in June and November. Additional monitoring of flow and water quality at the causeway opening occurred on a monthly basis. Table 1 lists the dates of all 2018 monitoring events.

Table 1. Monitoring Event Dates in 2018

Month	Lake Water Chemistry Monitoring	Causeway Opening Geometry (Survey)	Additional Monitoring
January			1/3
February	2/6, 2/7		2/6
March			3/7
April			4/11
May	5/3, 5/4		5/3
June		June	6/7
July			7/12
August	8/7, 8/8		8/7
September			9/5
October			10/2
November	11/6, 11/7	November	11/6
December			12/6

3.1 North and South Arm Water Quality Parameters

The following water quality parameters were collected at each North Arm and South Arm sampling site for the quarterly 2018 monitoring event:

- Water temperature
- Density
- TDS
- Specific conductivity

These data are summarized below and shown in Figure 1, Figure 2, Figure 3, and Figure 4 respectively.

3.1.1 Water Temperature

Field-collected temperature data are shown in profiles (Figure 1). The following observations are made:

- General temperature variation corresponds seasonally, with the coldest temperatures during the winter (February event) and the warmest temperatures during summer (August event).

3.1.2 Density

Field-collected density data are shown in profiles (Figure 2). The following general observations are made:

- Density concentrations at the sites in Gilbert Bay were similar, both spatially and vertically throughout the year. Density concentrations in Gilbert Bay were highest in November and lowest in May.
- Density concentrations in Gunnison Bay were seasonally generally similar, with slightly lower densities in May.

3.1.3 Total Dissolved Solids (TDS)

Field-collected TDS data are shown in profiles (Figure 3). The following general observations are made:

- TDS concentrations at the sites in Gilbert Bay were similar, both spatially and vertically, throughout the year. TDS concentrations in Gilbert Bay were highest in November and lowest in May.
- TDS concentrations in Gunnsion Bay were slightly lower during the first two monitoring events than during the last two monitoring events.

3.1.4 Specific Conductivity

Field-collected specific conductivity data are shown in profiles (Figure 4). The following general observations are made:

- Specific conductivity measurements at the sites in Gilbert Bay were similar, both spatially and vertically, throughout the year in the upper brine layer. The highest measurements were recorded in November and the lowest in May. Additional measurements were taken (every 6 inches in the water column) to better define the presence of the deep brine layer. The specific conductivity data indicate that the deep brine layer was present at every Gilbert Bay sampling site for all four monitoring events, with the top of the deep brine layer varying from a WSE of about 4,173 feet to just below 4,175 feet.
- Specific conductivity measurements in Gunnison Bay were similar across all four monitoring events.

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Figure 1. 2018 Lake Water Temperature Data for February (top left), May (top right), August (bottom left), and November (bottom right)

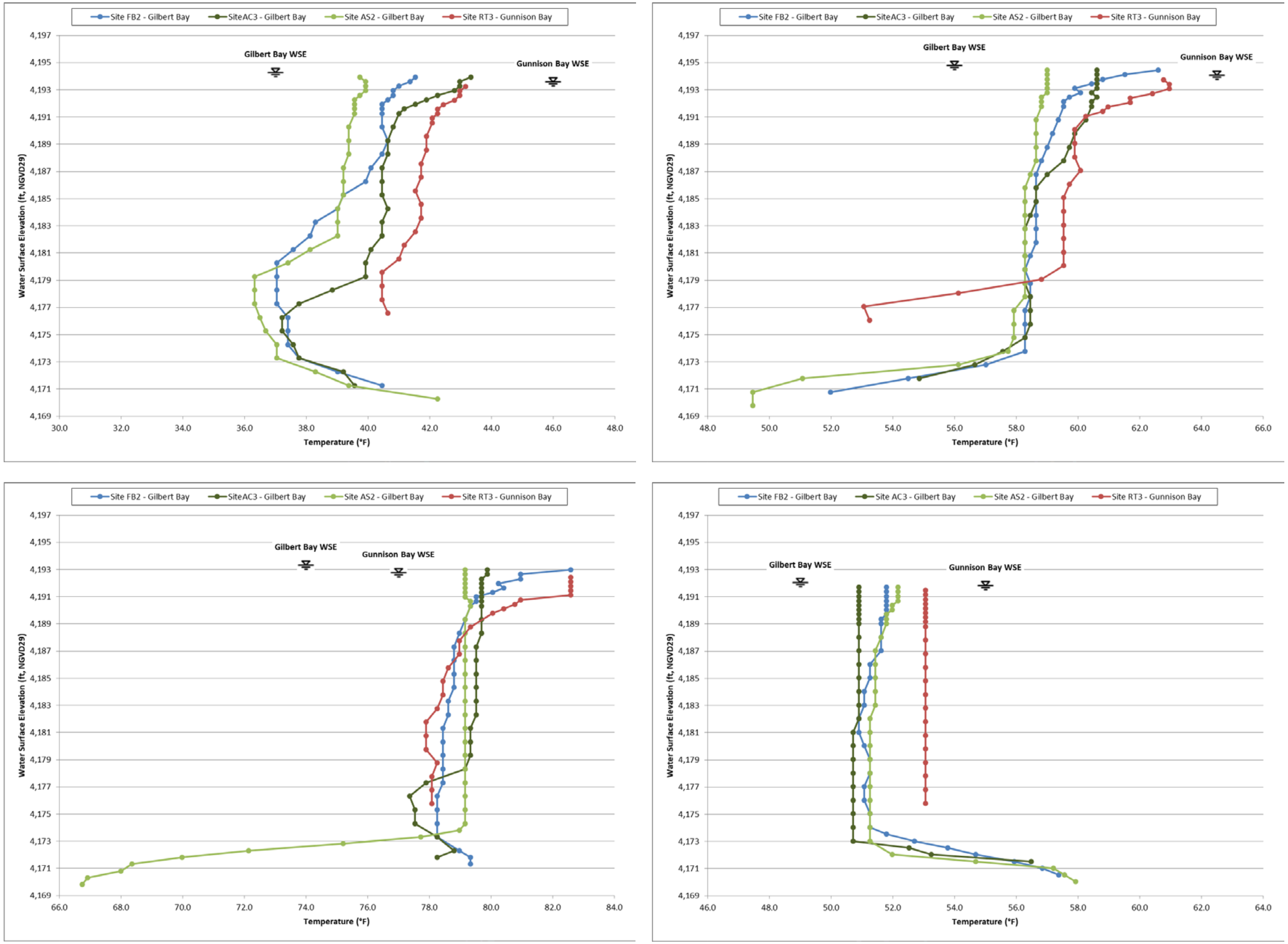


Figure 2. 2018 Lake Water Density Data for February (top left), May (top right), August (bottom left), and November (bottom right)

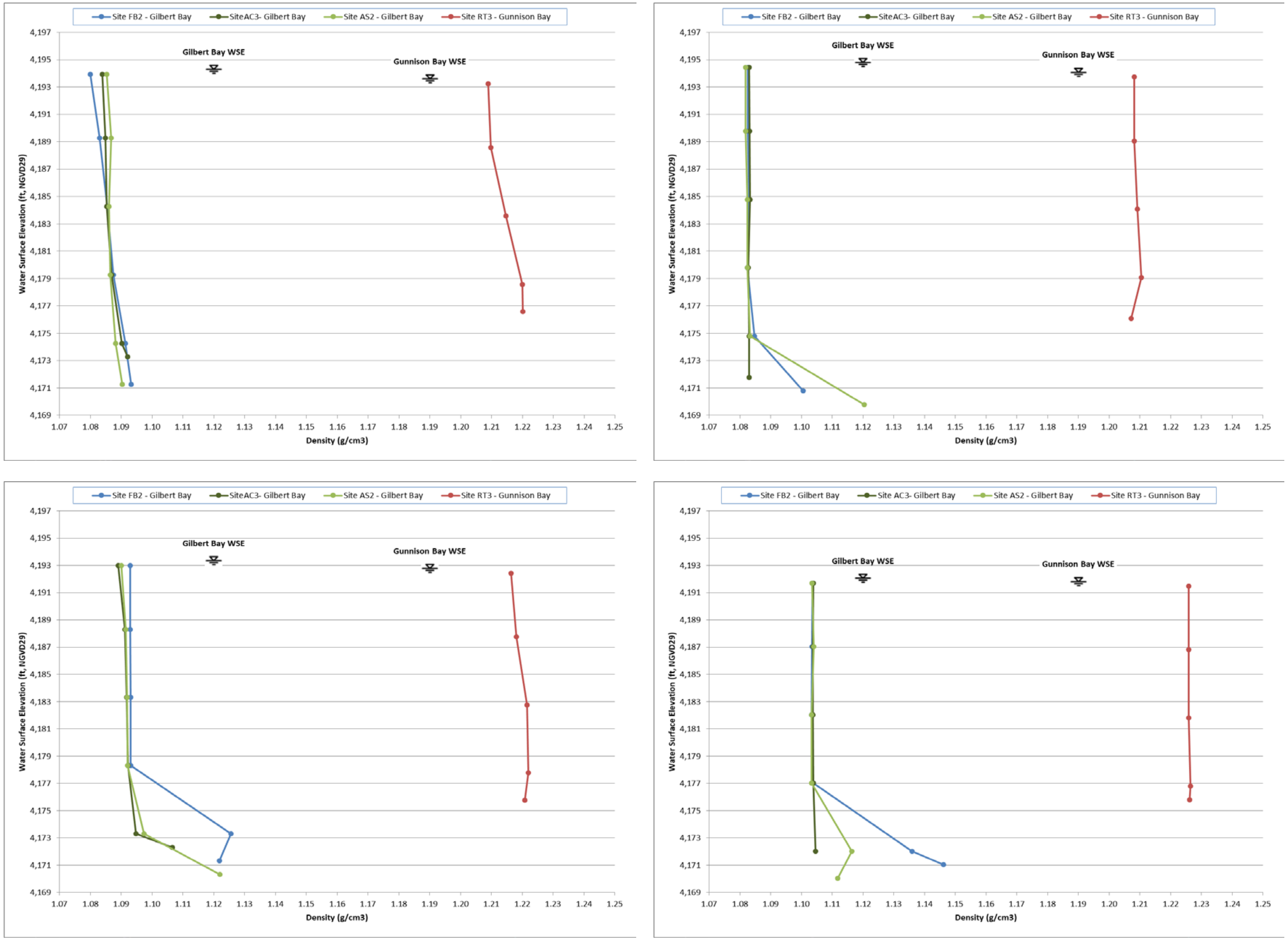


Figure 3. 2018 Lake Water TDS Data for February (top left), May (top right), August (bottom left), and November (bottom right)

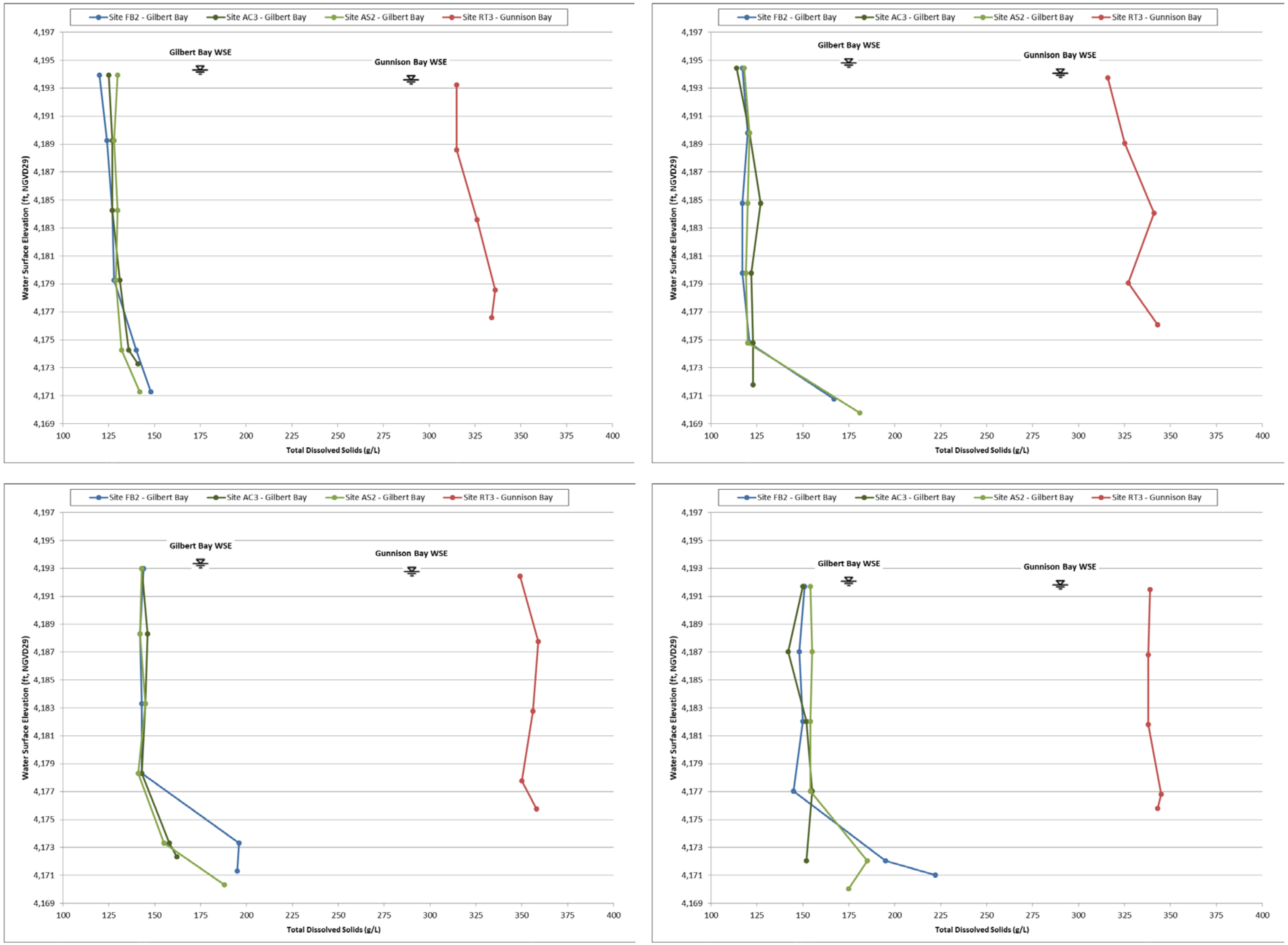
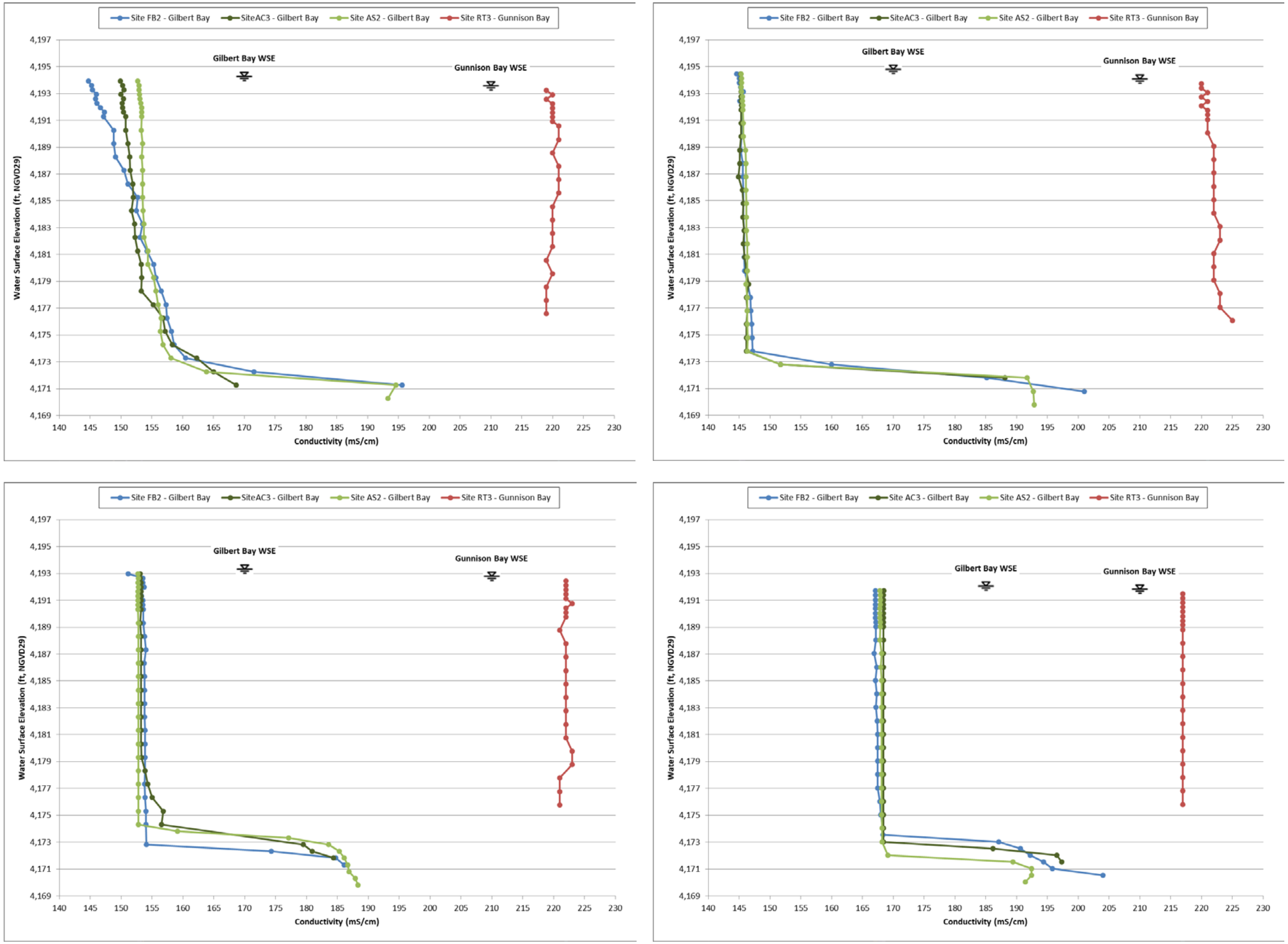


Figure 4. 2018 Lake Water Specific Conductivity Data for February (top left), May (top right), August (bottom left), and November (bottom right)



3.2 Lake Water Salinity

UPRR collected and reported the salinity for the discrete samples collected in the North and South Arms, based on density data. The sample salinity value was calculated using the USGS empirical formula as shown below and documented in Water-Resources Investigations Report 00-4221 (WRI 4221), *Water and Salt Balance of Great Salt Lake, Utah, and Simulation of Water and Salt Movement through the Causeway, 1987–98* (USGS 2000):

$$C = \frac{(\rho - 1)(1{,}000)}{0.63}$$

Where C = dissolved-solids concentration, in grams per liter (g/L)

ρ = density at 20 degrees Celsius, in g/mL

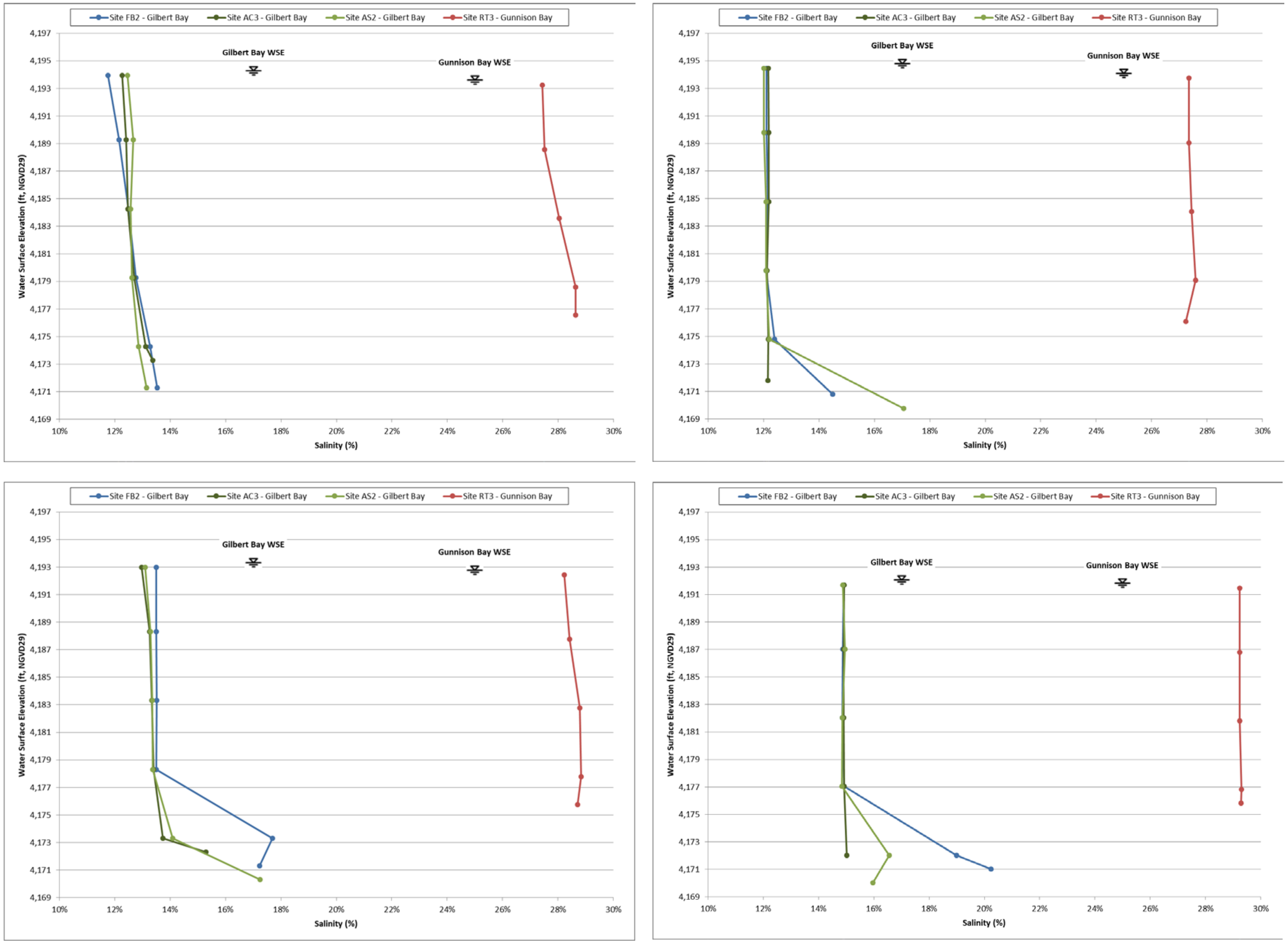
Then, using the measured density and calculated TDS, UPRR calculated the salinity using the following equation:

$$\text{Salinity, in percent} = \frac{C}{\rho(10)}$$

Salinity profile data are shown in Figure 5 for each monitoring event. The following general observations are made:

- Gunnison Bay salinity was lower in May and increased in November.
- Over the course of the 2018 monitoring events, the South Arm salinity was highest in November and lowest in May.

Figure 5. 2018 Lake Water Salinity Data for February (top left), May (top right), August (bottom left), and November (bottom right)



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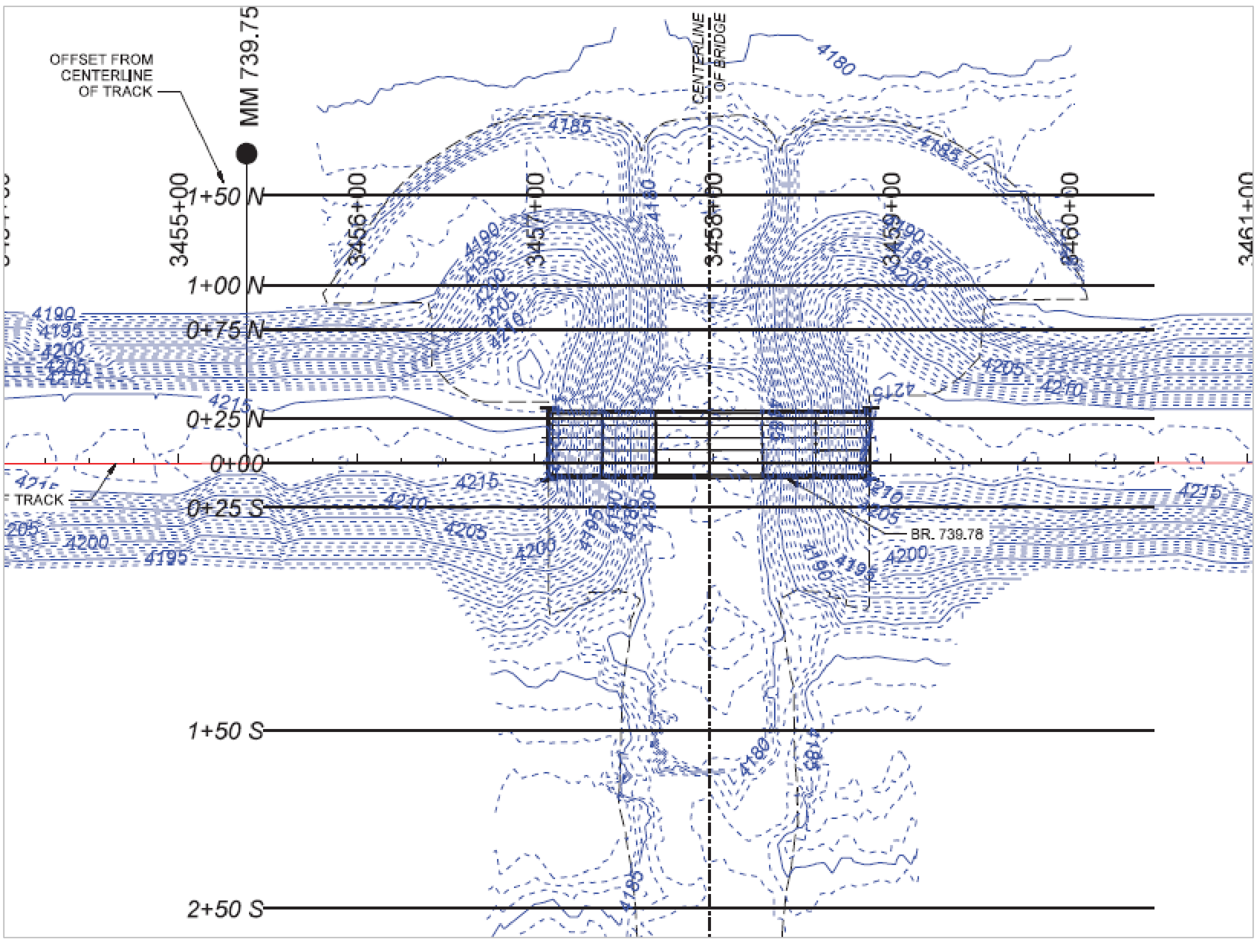
3.3 Causeway Opening Geometry

Causeway opening geometry measurements were taken in June and November 2018 in accordance with Section 3.10.1 of the CMMP (UPRR 2016a), which requires these measurements to be taken semiannually for the first 2 years of the 5-year monitoring period, then annually until the 5-year monitoring period is complete. UPRR has conducted semiannual surveys for 2017 and 2018, thus meeting the permit requirements. For 2019, an annual survey is scheduled to meet permit requirements.

Survey cross-section data collected in June and December 2018 were overlaid on the as-built survey data to determine whether the channel and control berm geometry and the average grading contours remain within 10% of the as-built geometry (UPRR 2016a). Figure 6 shows the locations of the as-built and biannual survey cross-sections.

Figure 6. Locations of Geometric Cross-Sections



The results of the June and December 2018 survey and the comparison to the as-built survey measurements are shown by cross-sections in Figure 7 and Figure 8.

Figure 7. Cross-Section Geometry Comparison (1 of 2)

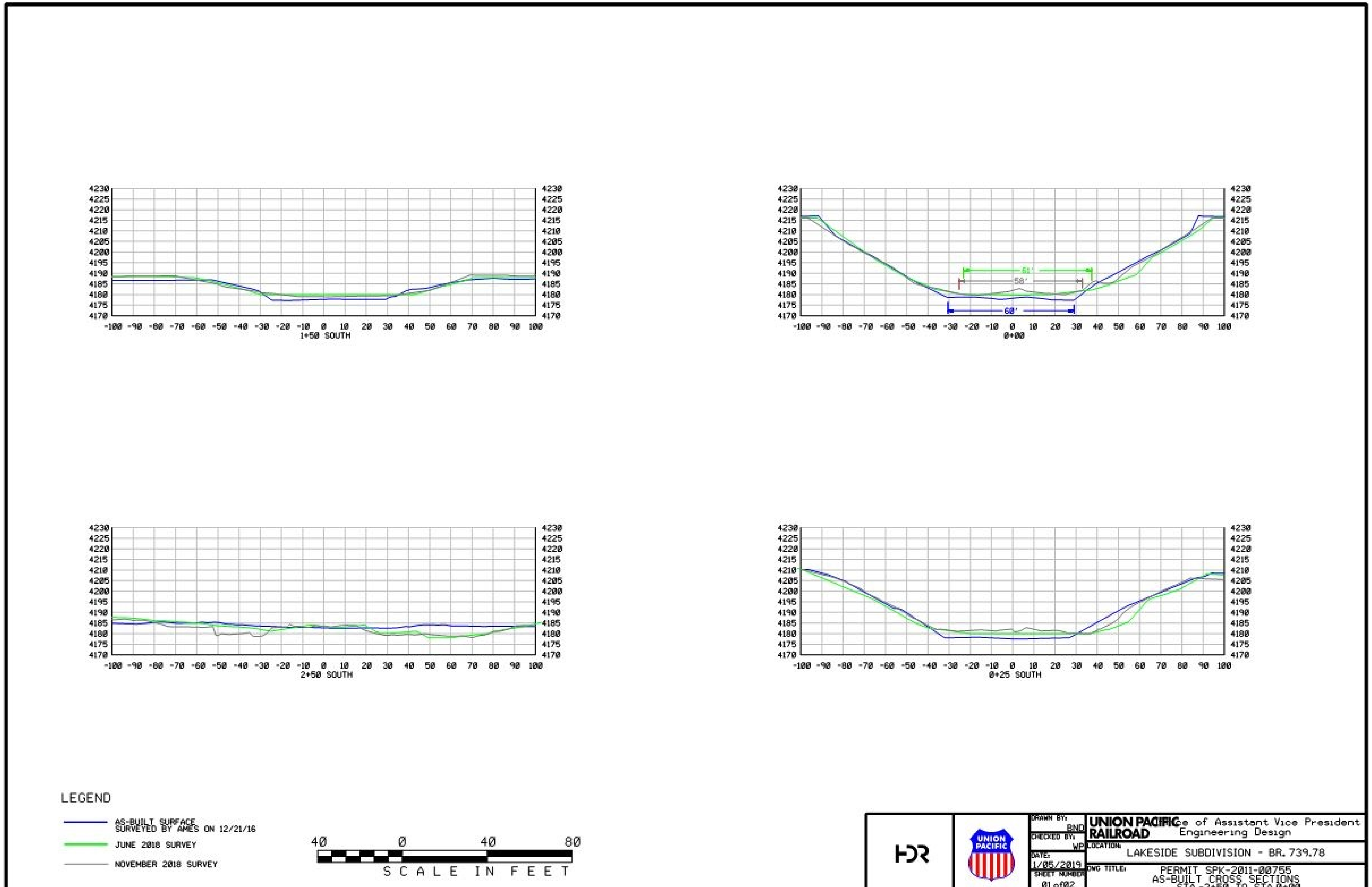
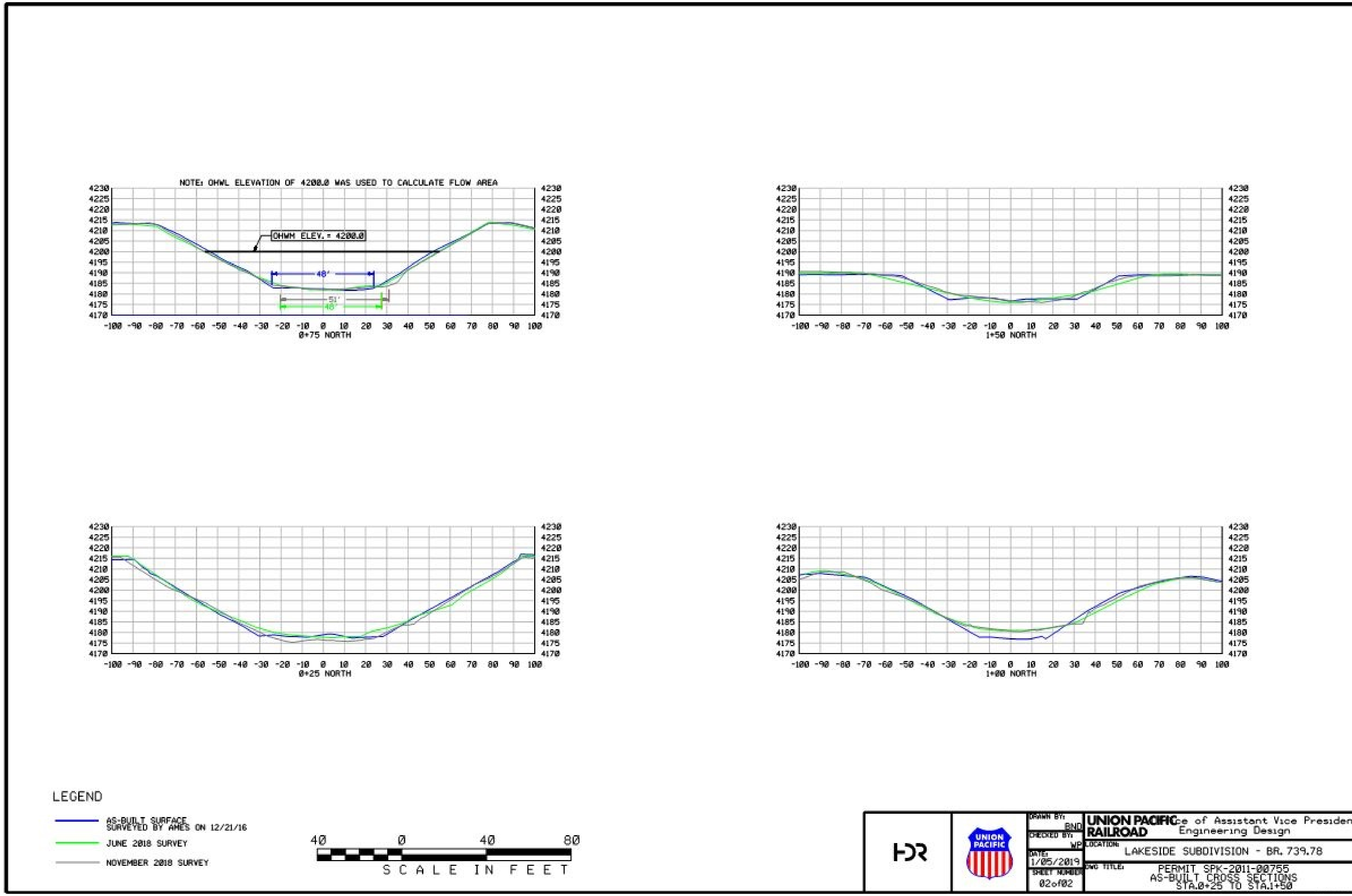


Figure 8. Cross-Section Geometry Comparison (2 of 2)



3.4 Additional Data Collected

3.4.1 Water Surface Elevation at and Flow Measurements through Causeway Opening

Flow measurements and ratings at the new causeway opening were collected and reported by USGS for USGS Site 10010025 (Great Salt Lake breach 6 miles east of Lakeside, Utah; south-to-north flow) and USGS Site 10010026 (Great Salt Lake breach 6 miles east of Lakeside, Utah; north-to-south flow). The flow and WSE data are graphically represented in Figure 9. Actual flow measurements and USGS flow ratings are shown in Table 2.

Note that the North and South Arm WSEs as reported at the causeway opening are for information only and might differ from the WSEs reported at the Saltair and Saline lake gages. These local WSEs more accurately define the head difference at the opening, a major component that affects the bidirectional flow through the opening.

Figure 9. Water Surface Elevation at and Flow through Causeway Opening

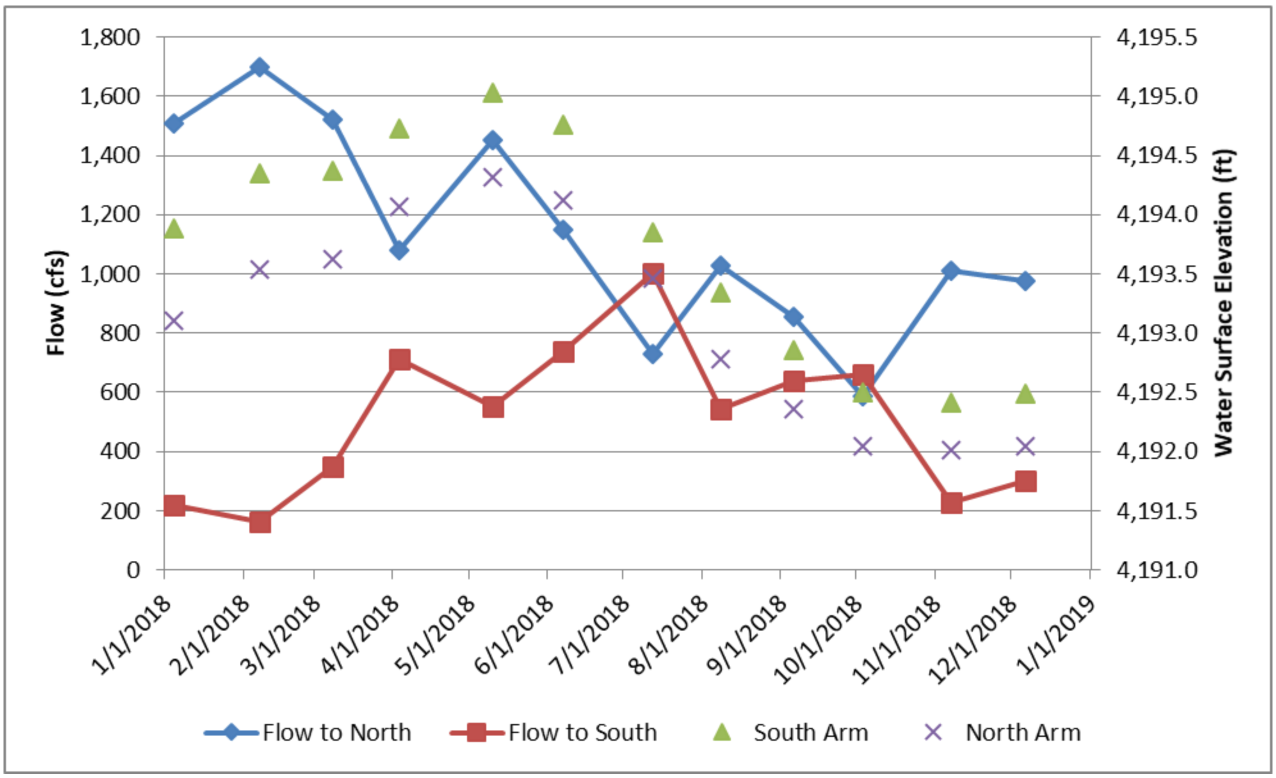


Table 2. Causeway Opening Flow Data and Depth at the Causeway Opening

Parameter	Unit	1/3/18	2/6/18	3/7/18	4/3/18	5/10/18	6/7/18	7/12/18	8/7/18	9/5/18	10/3/18	11/7/18	12/6/18
South-to-north flow[a]	cfs	1,510	1,700	1,520	1,080	1,450	1,150	728	1,030	856	588	1010	976
North-to-south flow[b]	cfs	218	162	347	711	550	736	1000	545	639	659	226	299
Average water depth in center bridge section[b]	feet	15.88	16.35	16.37	16.7	17.0	16.18	15.85	15.34	15.46	14.50	14.41	14.49
Flow measurement rating[c]	NA	Poor	Poor	Poor	Poor	Poor	Poor	Poor	Fair/ poor	Poor	Poor	Poor	Poor
Depth from water surface to North Arm brine[d]	feet	11	9	8	11	14	10	7	6	6	5	5	5
Depth of North Arm brine[e]	feet	4.88	7.35	8.37	5.7	3.0	6.18	8.85	9.34	9.46	9.5	9.4	9.5

cfs = cubic feet per second; NA = not applicable
Provisional data subject to revision.
[a] Reported on USGS website: https://waterdata.usgs.gov/nwis/measurements/?site_no=10010025.
[b] Average depth in the center bridge section as calculated based on the South Arm WSE and the average invert elevation of 4,178 feet.
[c] Reported on USGS website: https://waterdata.usgs.gov/nwis/measurements/?site_no=10010026.
[d] As measured by UPRR in the field.
[e] Calculated based on average water depth in center bridge section and depth from water surface to North Arm brine.

Bidirectional flow through the causeway was observed January–December 2018 (Figure 9 above). South-to-north flows ranged from 728 to 1,700 cubic feet per second (cfs), and north-to-south flows ranged from 162 to 1,000 cfs. The July monitoring event documented higher north-to-south flow than south-to-north flow for the first time since bidirectional flow first occurred in July 2017.

The flow measurements for most of the 2018 events were rated as poor by USGS. The flow measurement rating is used to describe the level of uncertainty, or accuracy, of the measurement reported. Excellent ratings indicate that 95% of the measurements are within 5% of the true value, while measurements that are rated as poor indicate that 95% of the measurements are beyond 15% of the true value. These ratings take into account the varying field conditions under which the measurements were taken.

3.4.2 Monthly Water Quality at Causeway Opening

Monthly observations and flow water quality measurements were collected monthly at the causeway opening in 2018. Water quality samples were collected from both the surface and from depth to characterize the quality of water flowing in both directions (Table 3).

Table 3. Monthly Water Quality Measurements at the Causeway Opening

Parameter	Unit	1/3/18	2/6/18	3/7/18	4/11/18	5/3/18	6/7/18	7/12/18	8/7/18	09/5/18	10/2/18	11/6/18	12/6/18
South-to-North Flow													
Specific conductivity	mS/cm	139.5	155.4	138.7	142.0	145.3	143.0	149.6	154.1	158.8	164.6	167.7	170.9
Temperature	°C	0.0	3.0	2.9	11.7	15.3	23.9	27.6	26.0	24.4	19.0	10.1	3.4
Density	g/mL	1.0731	1.0867	1.0780	1.0798	1.1002	1.0826	1.0886	1.0930	1.0959	1.0991	1.1044	1.1013
TDS	mg/L	106,000	129,000	118,000	119,000	111,000	127,000	136,000	136,000	148,000	151,000	152,000	153,000
Salinity	Percent	10.8	12.7	11.5	11.7	14.5	12.1	12.9	13.5	13.9	14.31	15.00	14.60
Chloride	mg/L	60,500	71,400	66,800	65,300	69,300	70,400	76,300	81,300	87,200	86,400	83,400	83,900
Sulfate	mg/L	7,850	9,510	8,380	8,370	8,920	9,080	9,730	10,300	10,700	10,900	10,600	10,600
Calcium	mg/L	222	223	197	219	205	226	229	230	261	251	252	291
Magnesium	mg/L	3,760	4,200	3,920	4,120	3,720	4,690	4,480	4,510	4,860	4,850	4,780	5,460
Potassium	mg/L	2,400	2,790	2,410	2,780	2,340	2,790	2,580	2,800	3,020	3,090	2,970	3,140
Sodium	mg/L	33,500	39,800	35,200	39,300	34,000	38,200	36,800	40,200	42,600	42,500	41,700	45,300
North-to-South Flow													
Specific conductivity	mS/cm	221	222	225	222	223	221	223	221	220	220	217	218
Temperature	°C	3.1	5.1	3.7	10.7	15.6	22.9	26.8	26.2	23.7	18.6	12.7	4.5
Density	g/mL	1.2138	1.2139	1.2072	1.2032	1.2084	1.2075	1.2101	1.2176	1.2227	1.2226	1.2242	1.2149
TDS	mg/L	325,000	328,000	304,000	315,000	319,000	337,000	335,000	350,000	351,000	342,000	345,000	342,000
Salinity	Percent	28.0	28.0	27.2	26.8	27.4	27.3	27.6	28.4	28.9	28.90	29.07	28.08
Chloride	mg/L	188,000	183,000	180,000	174,000	183,000	183,000	188,000	199,000	202,000	192,000	184,000	183,000
Sulfate	mg/L	23,900	25,900	22,100	23,900	24,200	24,100	24,200	27,200	29,500	28,400	27,400	25,900
Calcium	mg/L	373	337	312	298	326	302	307	290	388	345	320	384
Magnesium	mg/L	14,100	12,900	12,400	11,400	12,200	13,200	11,500	11,800	14,400	13,500	12,200	14,200
Potassium	mg/L	8,660	7,720	7,780	7,610	7,360	7,590	7,000	7,260	8,200	8,520	7,510	7,980
Sodium	mg/L	104,000	93,700	94,600	91,700	92,500	92,600	89,300	95,400	99,300	101,000	89,000	97,800

mS/cm = milliSiemens per centimeter, °C = degrees Celsius, g/mL = grams per milliliter, g/L = grams per liter, mg/L = milligrams per liter

3.4.3 Quarterly Measurements of the South Arm Deep Brine Layer

The range of WSEs, total water depth, and depth to brine layer for all monitoring events are summarized in Table 4. Temperature, density, TDS, conductivity, and salinity profiles are provided above in Figure 1, Figure 2, Figure 3, Figure 4, and Figure 5, respectively.

Depth to Brine Layer

Table 4 summarizes the total water depth and Gilbert Bay brine layer depth ranges observed in 2018.

Table 4. Total Water Depth, Depth to Deep Brine Layer, and Thickness of Deep Brine Layer

Parameter and Month Sampled	Gilbert Bay			Gunnison Bay
	Site FB2	Site AC3	Site AS2	Site RT3
Total Water Depth (feet)				
February	23.6	22.5	24.8	17.9
May	24.3	23.4	25.3	18.7
August	22.5	21.9	23.8	17.3
November	21.5	20.7	22.6	16.3
Depth from Water Surface to Deep Brine Layer (feet)				
February	23.0	No DBL observed	23.0	NA
May	23.0	23.0	23.0	NA
August	20.5	20.0	20.0	NA
November	19.0	19.5	20.5	NA
Thickness of Deep Brine Layer (feet)				
February	0.6	No DBL observed	1.8	NA
May	1.3	0.4	2.3	NA
August	2.0	1.9	3.8	NA
November	2.5	1.2	2.1	NA

DBL = deep brine layer; NA = not applicable

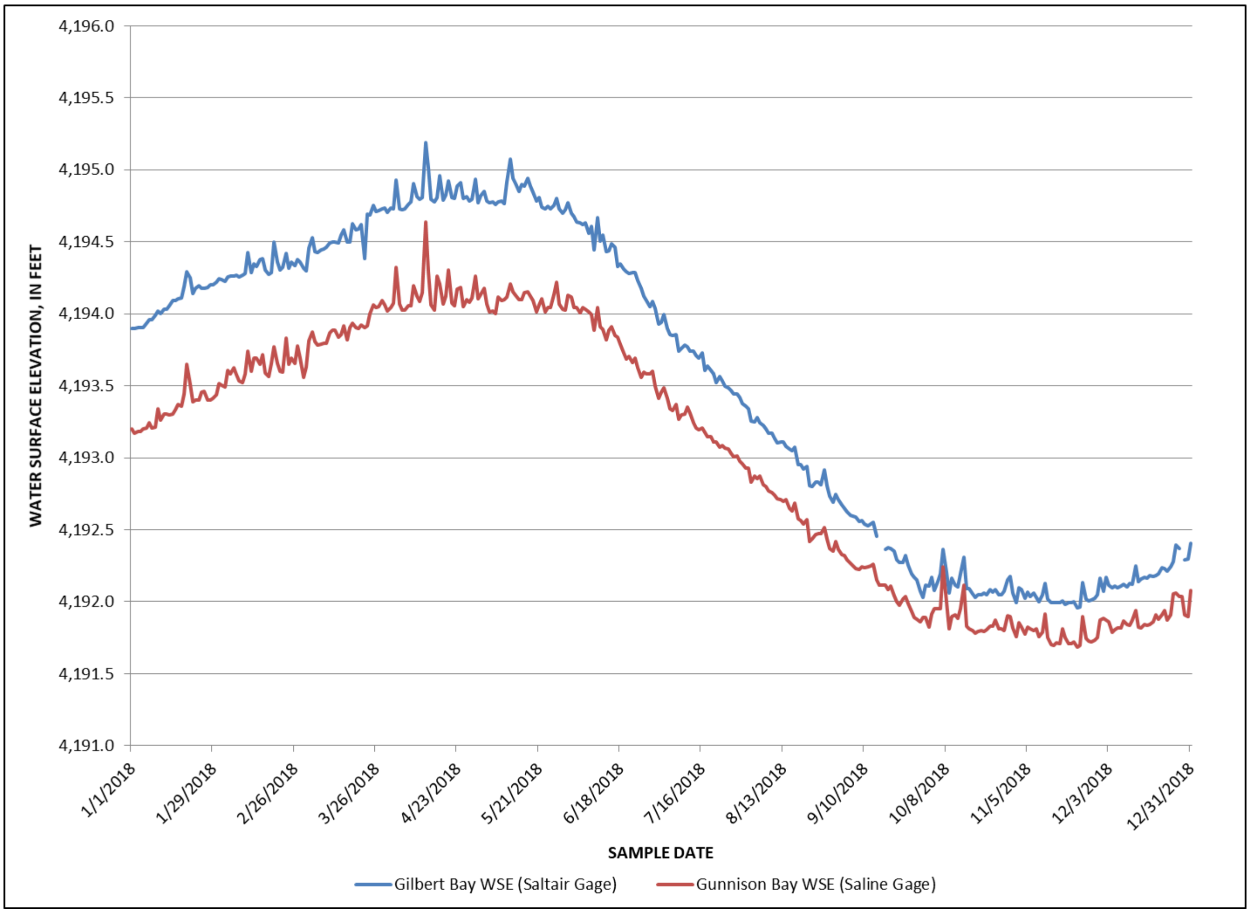
3.4.4 Monthly North and South Arm Water Surface Elevations

This section summarizes the lake WSE data during 2018.

Water Surface Elevation

UPRR acquired WSE data in 15-minute increments for Gunnison and Gilbert Bays from the USGS website (USGS 2018a; see Table 5, Surface Water Elevation Data, of each quarterly monitoring event report). South Arm WSEs were obtained for USGS Station 10010000 (Saltair gage), and North Arm WSEs were obtained for USGS Station 10010100 (Saline gage; see Figure 10).

Figure 10. South and North Arm Water Surface Elevations in 2018



Blue = South Arm (Gilbert Bay); **red** = North Arm (Gunnison Bay)

The difference between the North and South Arm WSEs is referred to as the head difference; it is obtained by subtracting the North Arm WSE from the South Arm WSE (Table 5). The USGS data presented in this report are reported by USGS as preliminary and will be updated when available.

Table 5. Monthly Water Surface Elevation and Computed Head Difference

Water Quality Sampling Date	Water Surface Elevation (feet NGVD 29)		Head Difference (feet)
	South Arm[a]	North Arm[b]	
January 3, 2018	4,193.9	4,193.2	0.7
February 6, 2018	4,194.3	4,193.6	0.7
March 7, 2018	4,194.4	4,193.8	0.6
April 11, 2018	4,194.8	4,194.1	0.7
May 3, 2018	4,194.8	4,194.1	0.7
June 7, 2018	4,194.6	4,194.0	0.6
July 12, 2018	4,193.8	4,193.3	0.5
August 7, 2018	4,193.3	4,192.8	0.5
September 5, 2018	4,192.8	4,192.3	0.5
October 2, 2018	4,192.1	4,191.9	0.2
November 6, 2018	4,192.0	4,191.8	0.2
December 6, 2018	4,192.1	4,191.8	0.3

NGVD 29 = National Geodetic Vertical Datum of 1929
[a] USGS Station 10010000, Saltair
[b] USGS Station 10010100, Saline

The 2018 WSE data collected and reported by USGS and provided in Table 5 above indicate that the South and North Arm WSEs rose and fell seasonally, responding to increased inflows during the spring and then increased evaporation and decreased inflows during the fall. During 2018, the rise in lake elevation was relatively small (about 1 foot), while the decrease in lake elevation was about 3 feet, which is considered normal.

4.0 Attainment of Project Performance Standards

UPRR evaluated the 2018 monitoring data collected and reported for causeway opening geometry performance standards 1, 2, 3, and 4 and salinity performance standard 5 as discussed in Section 1.2, Goals and Objectives. The data analysis is based on completion of the second year of monitoring, since the mitigation (causeway opening) construction was complete in December 2016.

4.1 Causeway Opening Geometry Performance Standards

Table 6 summarizes the results of the biannual 2018 surveys and the comparison to the as-built survey measurements. Discussion is provided following the table.

Table 6. Comparison of Measured Causeway Opening Geometry to Performance Standards

Performance Standard	As-Built	June 2018		November 2018	
		Measured Value	% of As-Built	Measured Value	% of As-Built
1. Average bridge side-slope contours, bottom channel width at Station 0+00 (feet)	60	61	102%	58	97%
2. Flow cross-section area at invert berm, Station 0+75 (square feet)[a]	1,333	1,342	101%	1,382	104%
3. Average water depth at bridge (feet)[b]	22	20	91%	19	86%
4. Average control berm contours, invert berm width at Station 0+75 (feet)	48	48	100%	51	106%

[a] Based on a WSE of 4,200 feet.

[b] Average water depth is based on a WSE of 4,200 feet and the measured invert at the rail centerline.

Average Bridge Side-Slope Contour. Channel bottom width survey data were collected in June and November from under the bridge at the rail centerline (Station 0+00) and were compared to channel bottom width as-built survey data. The bottom width, as measured by the two 2018 surveys, averages about 59.5 feet, compared to the as-built bottom width of 60 feet (see Figure 7 and Figure 8 above). The three cross-sections are consistent, and no significant aggregation (accumulation) of debris nor degradation (erosion of armor rock) is documented.

Flow Cross-Sectional Area at Invert Berm. Survey data were collected in June and November 2018 at the centerline of the invert berm (Station 0+75) and were compared to as-built survey data. From the cross-section data, a flow area was calculated with the invert berm top width and elevation and a WSE of 4,200 feet (the lake ordinary high water mark, or OHWM) (USACE 2015b). The June and November cross-sectional areas are within 10% of the as-built survey data. No significant change in flow cross-section area is documented.

Average Water Depth at Bridge. Channel bottom elevation survey data were collected in June and November 2018 at the centerline of the rail (Station 0+00) and were compared to as-built channel bottom elevation survey data. From the cross-section data, an average water depth was calculated based on a WSE of 4,200 feet (lake OHWM). The June water depth is within 10% of the as-built survey data. The November water depth was measured at 19 feet, compared to the as-built survey datum of 22 feet. The November measurement varies from the as-built survey datum by 14%.

Average Control Berm Contours. Invert berm width survey data were collected in June and November 2018 at the control invert berm cross-section (Station 0+75 North) and were compared to the invert berm width as-built survey data. The width, measured by the two surveys, averages 49.5 feet, compared to the as-built invert berm width of 48 feet. The invert berm width is consistent, and no significant aggregation (accumulation) of debris nor degradation (erosion of armor rock or berm) is documented.

Summary. The June biannual survey data and the comparative analysis to the as-built survey data indicate that the causeway opening's bridge site contours, average cross-section area, average water depth, and control berm contours meet project performance standards 1, 2, 3, and 4, respectively.

The November biannual survey data and the comparative analysis to the as-built survey data indicate that project performance standards 1, 2, and 4 are met. Project performance standard 3, average water depth at the bridge as measured at the centerline of the rail (Station 0+00), varies about 14% from the as-built measurement of 22 feet. Per the process in Section 3.12.1, Adaptive Management Plan, of the CMMP (UPRR 2016a), UPRR further reviewed all of the invert survey data throughout the causeway opening.

UPRR's further evaluation of the November 2018 channel invert data through the bridge shows that the north side of the bridge (Station 0+25) has a centerline water depth of 23.5 feet, while the center of the bridge (Station 0+00) and the south side of the bridge (Station 0+25) have centerline water depths of about 19 feet and 18 feet, respectively. These centerline water depth variations from the as-built survey data were not documented in the June 2018, May 2017 and December 2017 survey data and appear limited to the eastern half of two of three cross-sections. UPRR notes that the flow-limiting cross-section is at the invert berm, which meets performance standards, and that the apparent higher invert elevations under the bridge are not limiting bidirectional flow or restricting the transfer of water or salt through the causeway opening. UPRR proposes to verify these November 2018 measurements in 2019 and evaluate, at that time, the need to conduct any maintenance activities.

4.2 South Arm Salinity Performance Standard Range

The average South Arm salinity from the 2018 quarterly monitoring data was compared to the 2012 UPRR/USGS Model salinity range and historical range, consistent with Section 3.9.2, Table 3-7, and Appendix F of the CMMP (UPRR 2016a). This comparison is shown in Figure 11, and tabulated results are presented in Table 7.

The measured discrete vertical density samples were bathymetrically averaged using the USGS salt load calculation process developed for the 1998 USGS Model and documented in WRI 4221 (USGS 2000).

The South Arm quarterly average salinity data and the comparative analysis indicate that monitored South Arm salinities are generally consistent with the UPRR/Utah Geological Survey (UGS) average historic South Arm salinities. As reported in the 2018 fourth quarterly monitoring data report, the average February South Arm salinity of 15.2% occurred when the South Arm WSE was 4,192.3 feet. Due to the low water surface elevation of the lake in November 2018, the data are reported with the WSE below the

2012 UPRR/USGS Model range. However, the South Arm salinity is within the range that could be anticipated if the model salinity were extrapolated through lower lake WSEs.

Based on this analysis, UPRR has determined that the mitigation met the salinity performance standard (project performance standard 5) during 2018, so no adaptive management measures are required.

Figure 11. Final Monitoring Results Compared to UPRR/UGS Historic South Arm Salinity Range

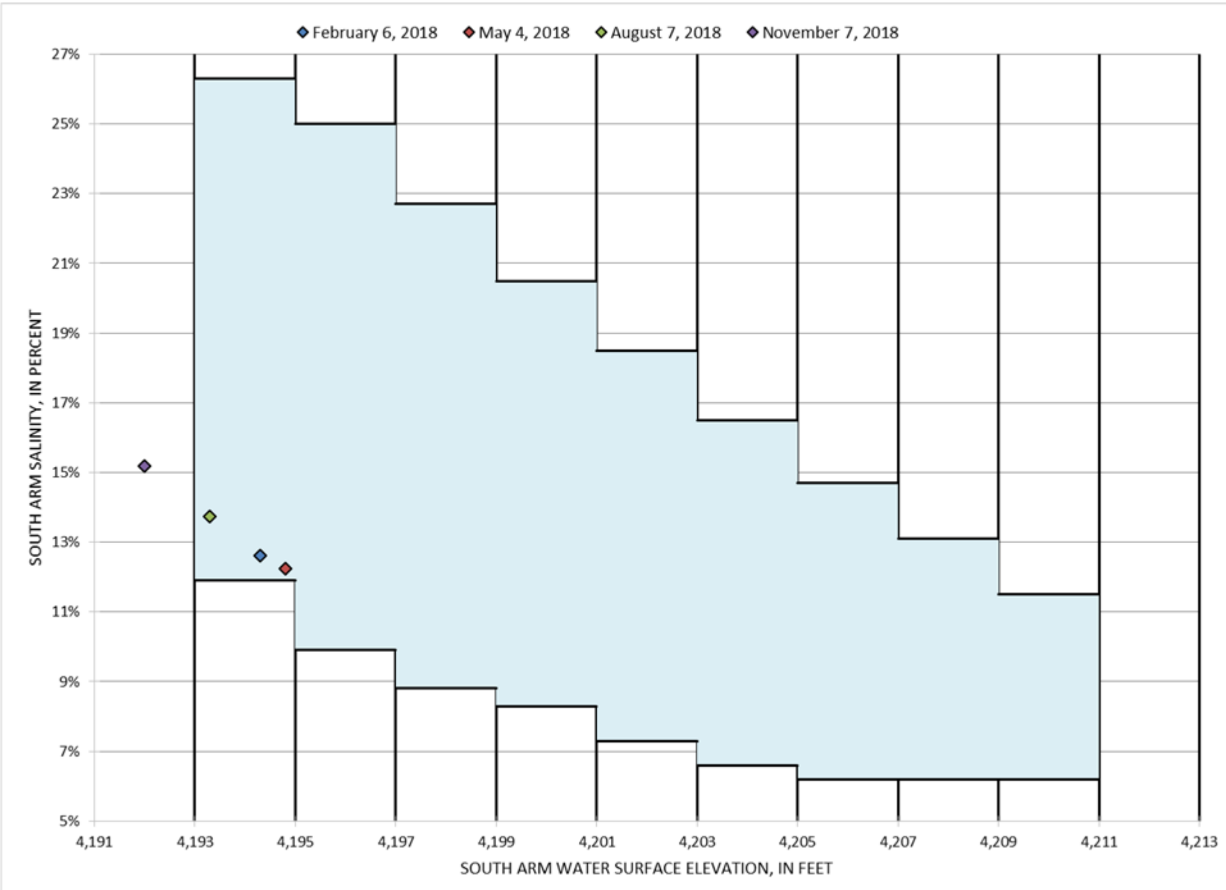


Table 7. Comparison of Monitored South Arm Salinity to Performance Standard Salinity Range by Water Surface Elevation

South Arm WSE					South Arm Salinity				
WSE on Monitoring Event Date (ft)						Average Salinity from Sampling Data (%)			
February 2018	May 2018	August 2018	November 2018	WSE Range (ft)	Performance Standard Salinity Range (%)	February 2018	May 2018	August 2018	November 2018
			4192.0	Below 4,193	Not established				15.2
4,194.3	4,194.8	4,193.3		4,193 up to 4,195	11.9 – 26.3	12.6	12.2	13.7	
				4,195 up to 4,197	9.9 – 25.0				
				4,197 up to 4,199	8.8 – 22.7				
				4,199 up to 4,201	8.3 – 20.5				
				4,201 up to 4,203	7.3 – 18.5				
				4,203 up to 4,205	6.6 – 16.5				
				4,205 up to 4,207	6.2 – 14.7				
				4,207 up to 4,209	6.2 – 13.1				
				4,209 up to 4,211	6.2 – 11.5				

ft = feet; WSE = water surface elevation

5.0 References

[UDWQ] Utah Division of Water Quality

2017 Amended 401 Water Quality Certification with Conditions. Water Quality Certification No.: Amended SPK 2011-00755 March 2, 2015. September 13.

2018 Email from W. Damery of UDWQ to K. Nichols of HDR. March 2.

[UPRR] Union Pacific Railroad

2016a Updated Final Compensatory Mitigation and Monitoring Plan, Union Pacific Railroad Great Salt Lake Causeway Culvert Closure and Bridge Construction Project. May 25.

2016b Final Sampling and Analysis Plan and Quality Assurance Project Plan. Union Pacific Railroad Great Salt Lake Causeway Culvert Closure and Bridge Construction Project. October.

2017a Quarterly Data Monitoring Report – First-Quarter 2017 Monitoring Results. May 11.

2017b Quarterly Data Monitoring Report – Second-Quarter 2017 Monitoring Results. August 15.

2017c Quarterly Data Monitoring Report – Third-Quarter 2017 Monitoring Results. November 7.

2018a Quarterly Data Monitoring Report – Fourth-Quarter 2017 Monitoring Results. February 1.

2018b 2017 Annual Data Monitoring Report. February 1.

2018c Quarterly Data Monitoring Report – First-Quarter 2018 Monitoring Results. May 15.

2018d Quarterly Data Monitoring Report – Second-Quarter 2018 Monitoring Results. August 15.

2018e Quarterly Data Monitoring Report – Third-Quarter 2018 Monitoring Results. November 15.

2019 Quarterly Data Monitoring Report – Fourth-Quarter 2018 Monitoring Results. February 1.

[USACE] United States Army Corps of Engineers

2015a Individual Permit SPK-2011-00755 for the Permanent Closure of the East Culvert and Bridge Construction, Great Salt Lake. September 7.

2015b Method for Identifying the Ordinary High Water Mark for the Great Salt Lake. Regulatory Division Memorandum 2015-02. September 28

[USGS] U.S. Geological Survey

2000 Water and Salt Balance of Great Salt Lake, Utah, and Simulation of Water and Salt Movement through the Causeway, 1987–98. Water-Resources Investigations Report 00-4221.

2018a Great Salt Lake – Lake Elevations. ut.water.usgs.gov/greatsaltlake/elevations. Accessed January 15, 2018.