2019 Annual Data Monitoring Report

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

SPK-2011-00755

February 1, 2020

Prepared for
Union Pacific Railroad
Omaha, NE 68179

Prepared by
HDR, Inc.
2825 E. Cottonwood Parkway, Suite 200
Salt Lake City, UT 84121

This page is intentionally left blank.

Contents

Tables

Figures

Acronyms

°C	degrees Celsius
cfs	cubic feet per second
CMMP	Updated Final Compensatory Mitigation and Monitoring Plan
g/mL	grams per milliliter
GIS	geographic information systems
GPS	global positioning system
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
UP	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 (UP) submits this 2019 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 UP 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 and 2018 quarterly data monitoring reports and the 2017 and 2018 annual data monitoring reports were previously submitted (UP 2017a, 2017b, 2017c, 2018a, 2018b, 2018c, 2018d, 2018e, 2019a, 2019b). The 2017 annual data monitoring report was approved by UDWQ on March 2, 2018 (UDWQ 2018). The 2018 annual data monitoring report was approved by UDWQ on March 20, 2019 (UDWQ 2019).

The 2019 monitoring events reported in this report were conducted in accordance with the Updated Final Compensatory Mitigation and Monitoring Plan (CMMP; UP 2016a) and the Sampling and Analysis Plan (SAP) and Quality Assurance Project Plan (QAPP) (UP 2016b), which were approved by UDWQ (UDWQ 2017) and previously reported in the 2019 quarterly data monitoring reports (UP 2019c, 2019d, 2019e, 2020). The required contents of this annual report are set out in the CMMP, Section 3.10.2.

This 2019 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. Annual survey measurements of the project elements (as required during this monitoring period) were previously reported in the second quarter 2019 data monitoring report and are included and discussed in this report.

1.2 Goals and Objectives

As described in the CMMP (UP 2016a) and SAP (UP 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 (UP 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 UP/Utah Geological Survey historic and 2012 model salinity ranges (UP 2016a, Table 3-7).
2. Determine whether the average bridge site contours remain within 10% of as-built or agreed-upon altered geometry (UP 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 (UP 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 (UP 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 (UP 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 (UP 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 2019 monitoring on behalf of UP. Water quality monitoring occurred in 2019 in accordance with the CMMP (UP 2016a), SAP, and QAPP (UP 2016b), and methods were previously reported in the 2019 quarterly data monitoring reports (UP 2019c, 2019d, 2019e, 2020). This report summarizes the data that were previously reported.

2.1 Study Variances

The fourth-quarter 2019 monitoring report (UP 2020) includes a discussion regarding apparent discrepancies in some of the monthly bidirectional flow samples that have been collected and analyzed from the north-to-south flow characterization data at the causeway opening. UP believes that the north-to-south flow samples collected and analyzed during these events did not consist entirely of north-to-south brine. Collecting the north-to-south brine samples at the causeway opening can be seasonally challenging with respect to the existing WSEs, head difference, flow, velocity, and the depth to the deeper north-to-south brine flow.

2.2 Corrective Actions

UP augmented its monthly sampling procedures for bidirectional flow at the causeway opening beginning in December 2019 to collect a duplicate sample of both the south-to-north flow and the north-to-south flow at the causeway opening, which will allow the field crew to further review the field screening results during sample collection to avoid future discrepancies. The SAP requires only one duplicate to be collected at the causeway opening during the monthly monitoring event. All other monitoring during 2019 was conducted in conformance with the SAP and the QAPP.

2.3 Quality Assurance

All data were collected in accordance with the SAP's QAPP (UP 2016b). After each event, UP subjected all data to quality assurance (QA)/quality control (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. UP also evaluated the analytical data for their consistency with the data quality objectives in the QAPP. The QAPP specifies precision, accuracy and bias, representativeness, completeness, and comparability objectives for data acquisition (UP 2016b, Table 7-1).

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

- **Precision**
  - All water quality field duplicates met precision requirements.
- **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. Potassium was detected in a second quarter field blank and potassium and total dissolved solids (TDS) were detected in third quarter field blank samples. However, the detected concentrations were near their respective reporting limits, and were between 3 and 4 orders of magnitude less than the concentrations of the associated lake water samples. Therefore, no data were qualified because of analyte detections in field blanks.
  - Laboratory analytes were often detected in equipment rinsate blank samples. However, the detected concentrations were near the reporting limit and were between 3 and 4 orders of magnitude less than the concentrations of the associated lake water samples. Therefore, no data were qualified because of analyte detections in field blanks.
  - Accuracy for causeway opening flow and lake elevation measurements were generally rated from fair to poor.
- **Representativeness**
  - All field measurements and samples were collected from locations and seasonal monitoring events defined in the SAP.
- **Completeness**
  - Field and laboratory completeness requirements were met. All data were collected except for the USGS flow and surface water elevation data at the causeway opening in January.
- **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 2019 quarterly report (UP 2019c, 2019d, 2019e, 2020).

3.0 Summary of Results

The results of each 2019 monitoring event as well as the QA/QC review are presented in the four 2019 quarterly data monitoring reports, which were submitted on May 15, 2019; August 15, 2019; November 15, 2019; and February 1, 2020 (UP 2019c, 2019d, 2019e, 2020). 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 2019. The causeway opening geometry survey (required annually) occurred in May. Additional monitoring of flow and water quality at the causeway opening occurred on a monthly basis. Table 1 lists the dates of all HDR and USGS monitoring events in 2019.

Table 1. Monitoring Event Dates in 2019

Month	Lake Water Chemistry Monitoring	Causeway Opening Geometry (Survey)	Additional Monitoring
January			1/8
February			2/8, 2/12
March	3/15, 3/18		3/5, 3/18
April			4/4, 4/9
May		May	5/13
June	6/4		6/4, 6/5
July			7/9
August	8/14, 8/15		8/7, 8/14
September			9/5, 9/10
October	10/15, 10/16		10/2, 10/15
November			11/1, 11/11
December			12/3, 12/5

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 each 2019 quarterly monitoring event:

- Water temperature
- Density
- TDS
- Specific conductivity
- Cations and anions

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 (March event) and the warmest temperatures during the 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 for the upper brine layer. Density concentrations in Gilbert Bay were highest in October and lowest in June.
- Density concentrations indicate the presence of a deep brine layer at all four Gilbert Bay sampling sites.
- 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 for the upper brine layer. TDS concentrations in Gilbert Bay were highest in October and lowest in June.
- TDS concentrations indicate the presence of a deep brine layer at all four Gilbert Bay sampling sites.
- TDS concentrations in Gunnison Bay were more variable than in Gilbert Bay, especially during the March monitoring event. TDS concentrations were slightly lower in March and June than in August and October.

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 generally similar, both spatially and vertically, throughout the year in the upper brine layer. The highest measurements were recorded in March and the lowest in June. 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 4,171.5 feet to just below 4,173 feet.
- Specific conductivity measurements in Gunnison Bay were similar across all four monitoring events.

3.1.5 Cations and Anions

Cation and anion data are presented in Appendix C, Surface Water Analytical Results, in each 2019 quarterly report (UP 2019c, 2019d, 2019e, 2020).

Figure 1. 2019 Lake Water Temperature Data for March (top left), June (top right), August (bottom left), and October (bottom right)

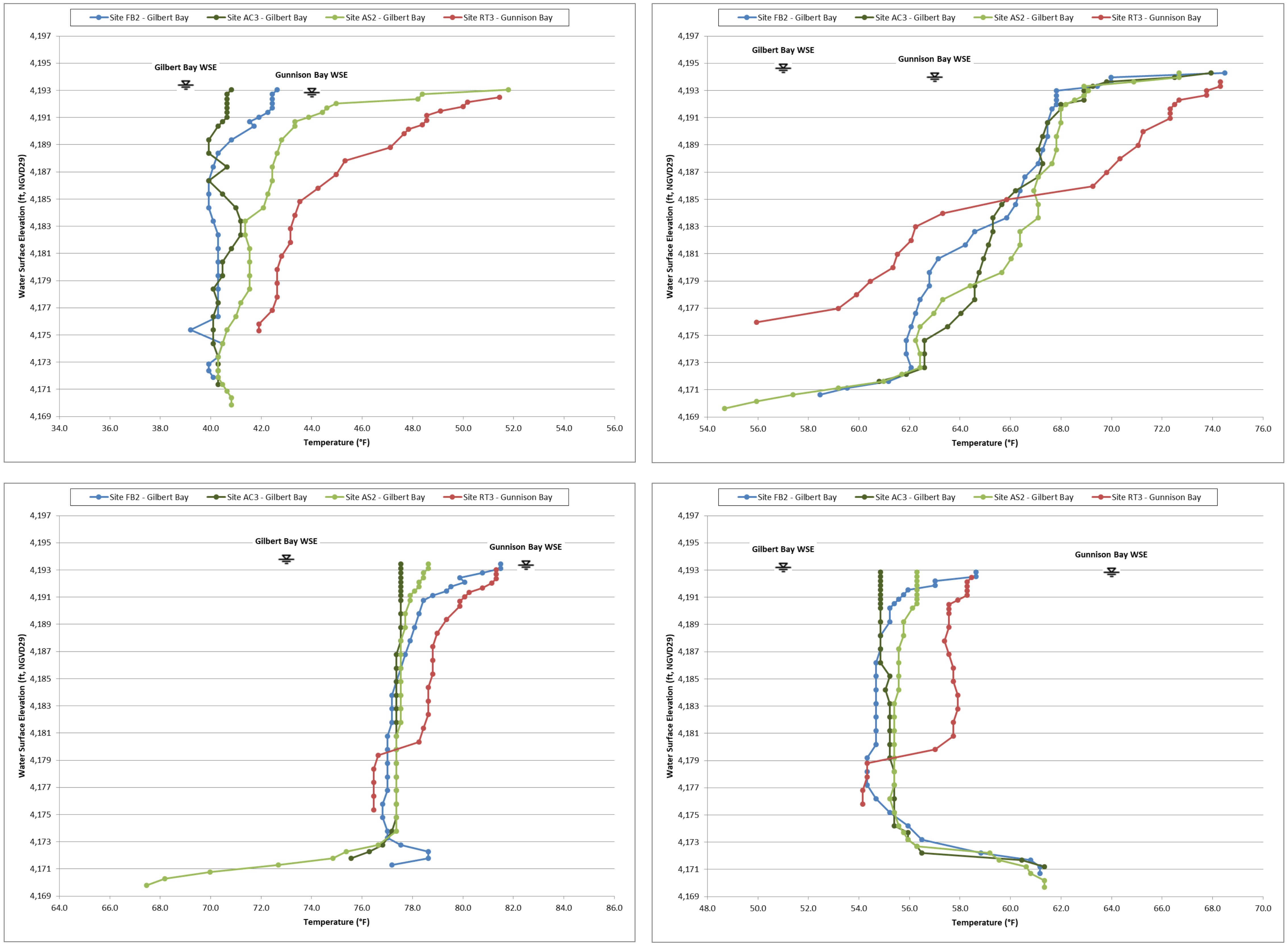


Figure 2. 2019 Lake Water Density Data for March (top left), June (top right), August (bottom left), and October (bottom right)

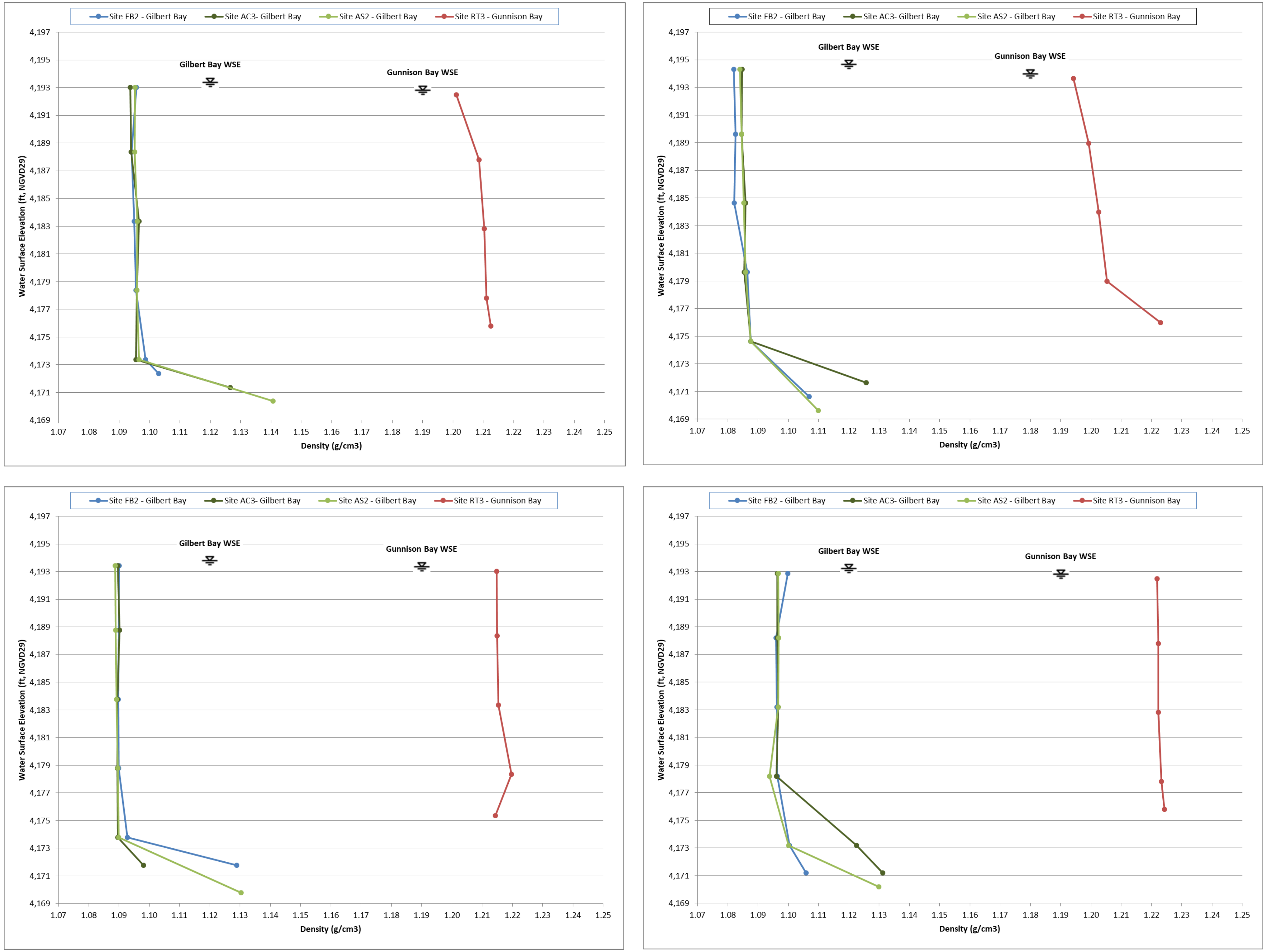


Figure 3. 2019 Lake Water TDS Data for March (top left), June (top right), August (bottom left), and October (bottom right)

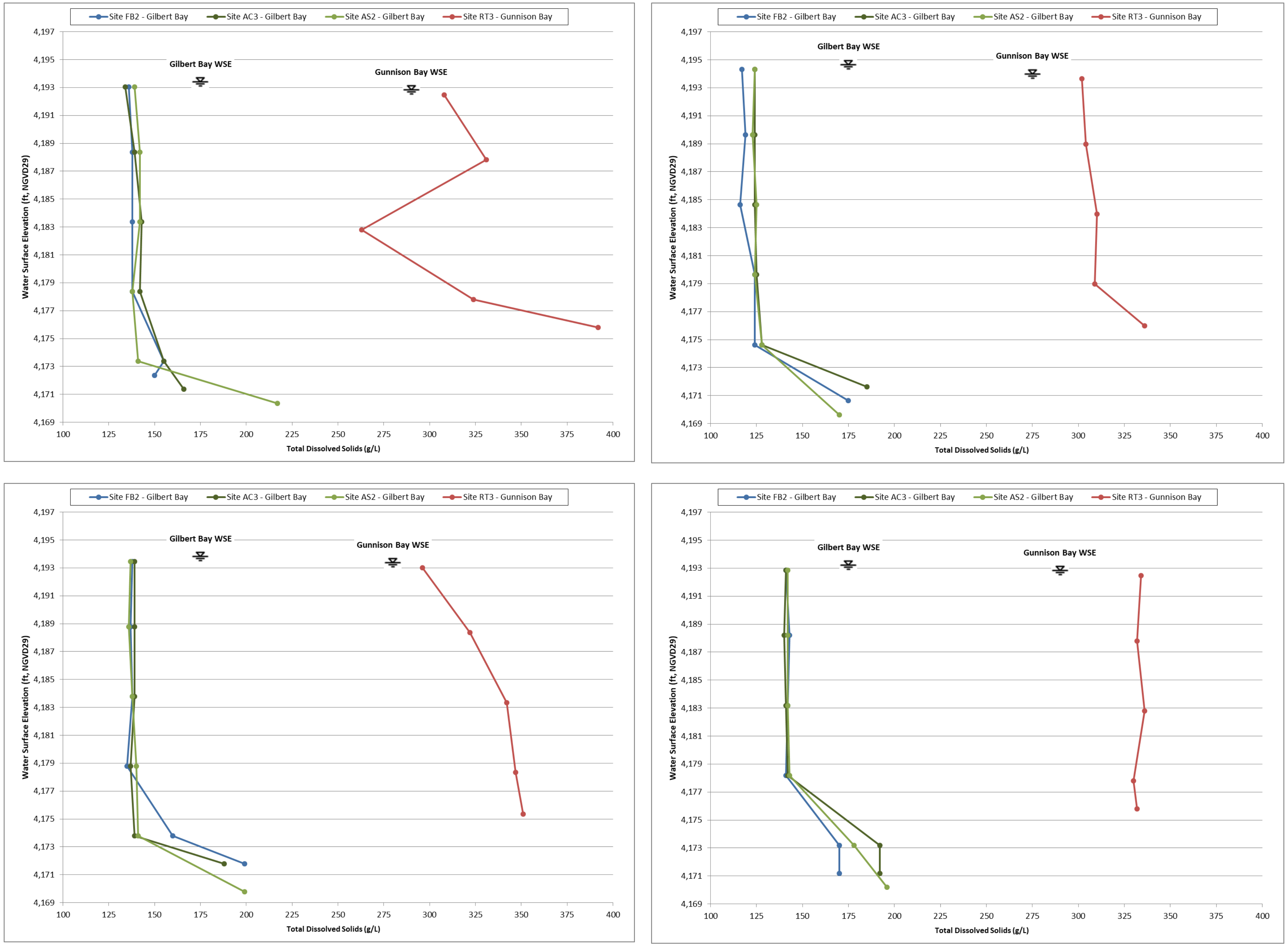
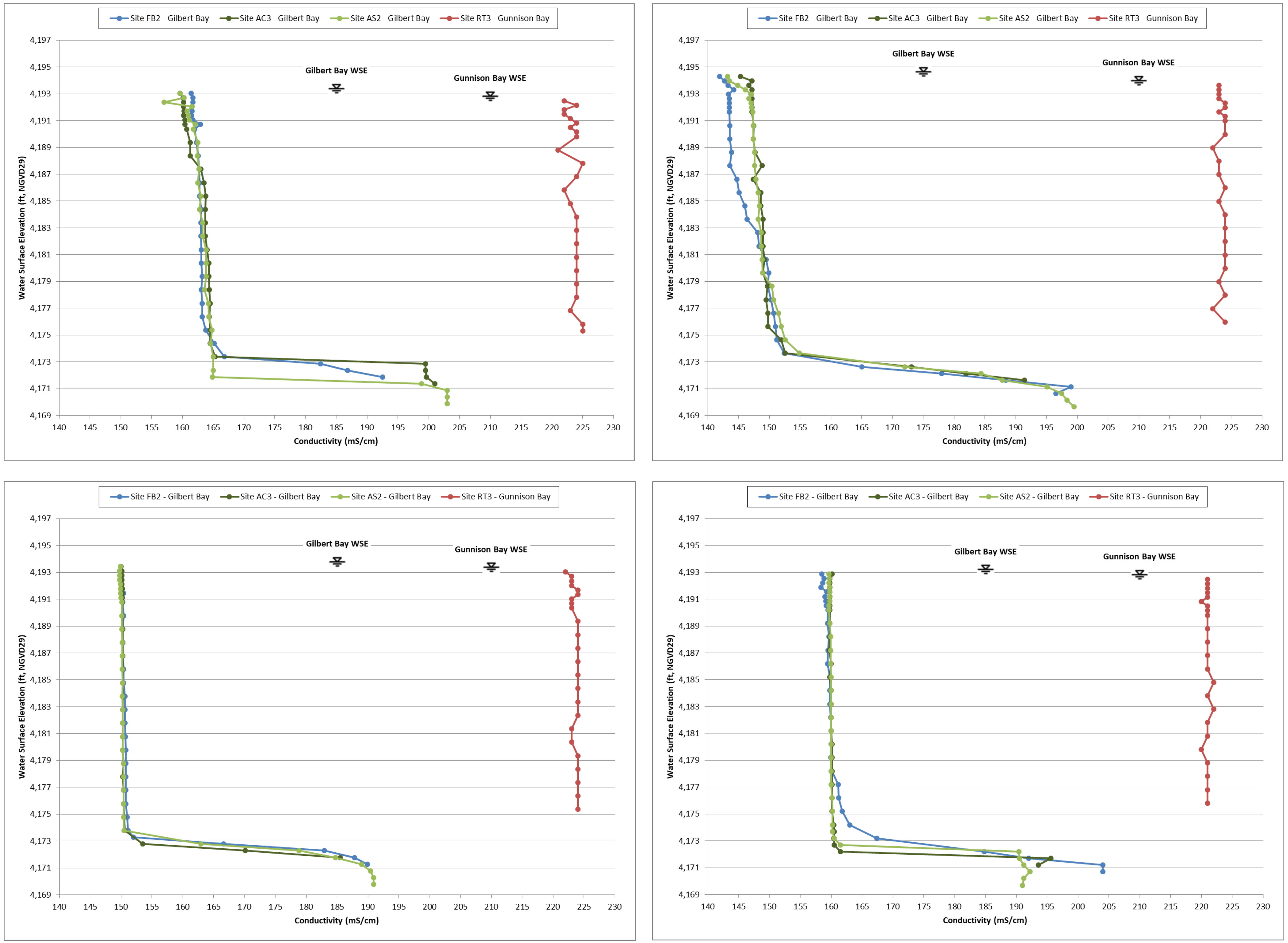


Figure 4. 2019 Lake Water Specific Conductivity Data for March (top left), June (top right), August (bottom left), and October (bottom right)



3.2 Lake Water Salinity

UP 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, UP calculated the salinity using the following equation:

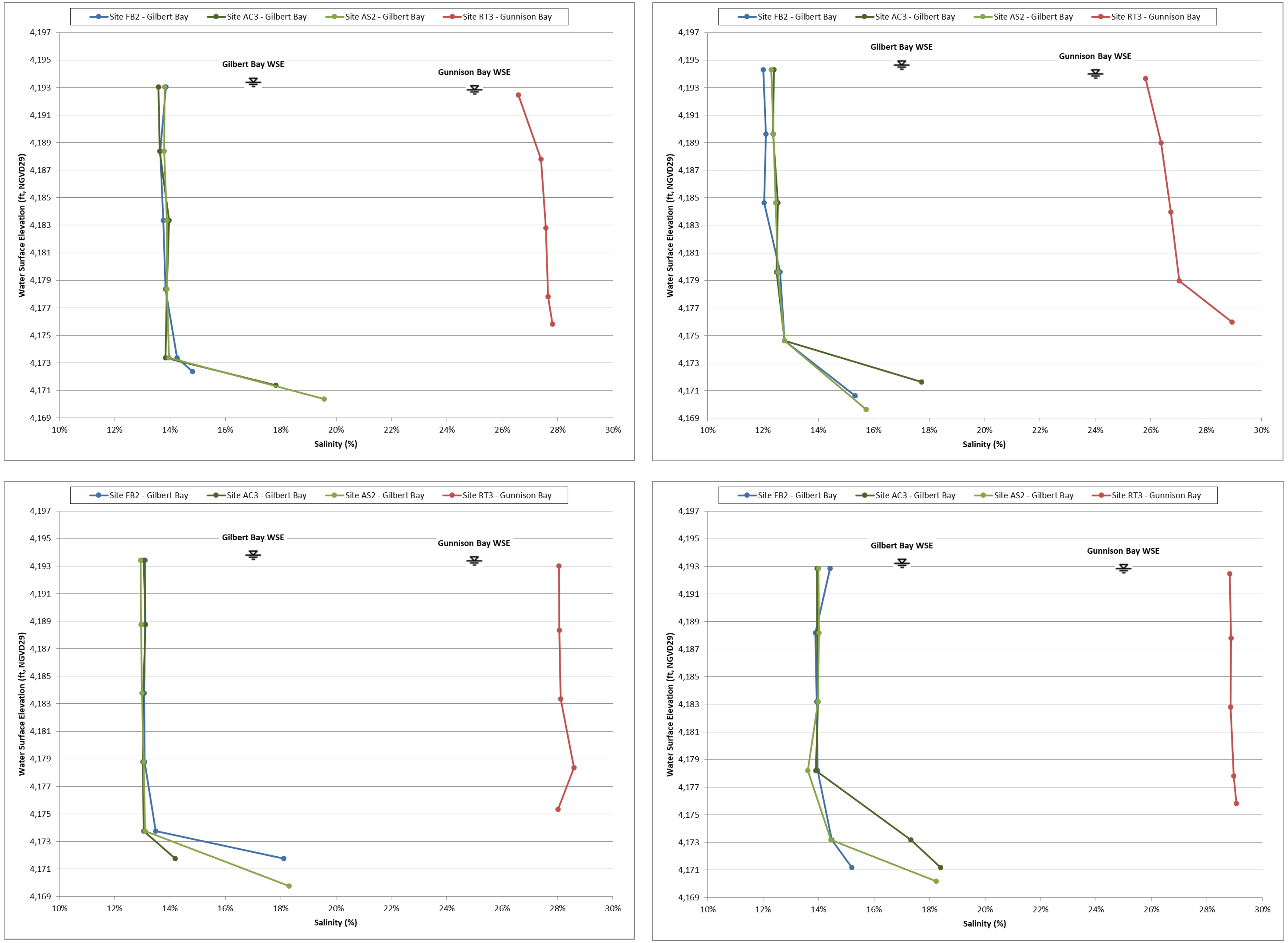
$$\text{Salinity, in percent} = \frac{C}{\rho(10)}$$

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

- Gunnison Bay salinity was generally lower in June and higher in October.
- Salinity, as calculated from density, indicates the presence of a deep brine layer at all four Gilbert Bay sampling sites.
- Over the course of the 2019 monitoring events, the South Arm salinity was highest in October and lowest in June.

This page is intentionally left blank.

Figure 5. 2019 Lake Water Salinity Data for March (top left), June (top right), August (bottom left), and October (bottom right)



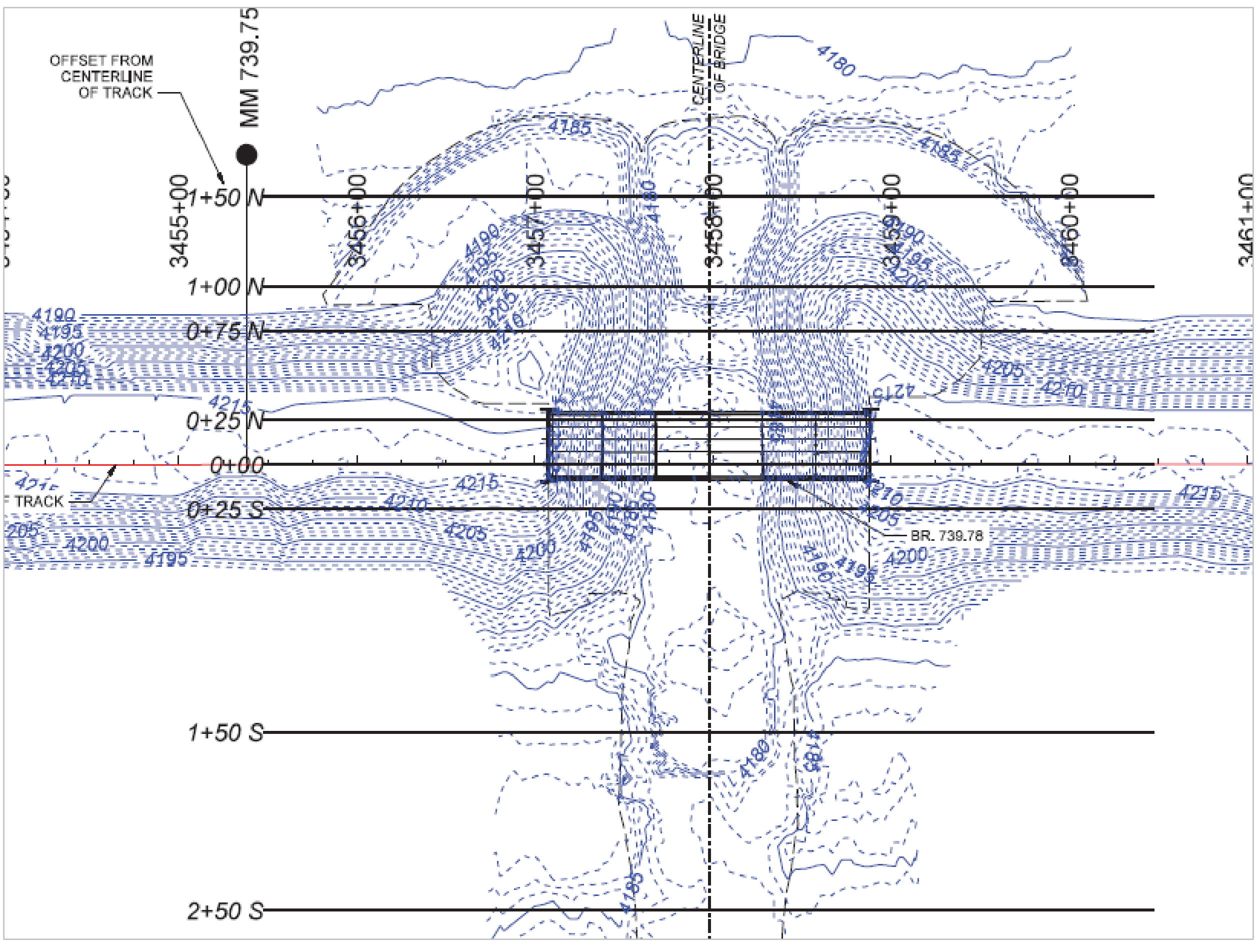
This page is intentionally left blank.

3.3 Causeway Opening Geometry

Causeway opening geometry measurements were taken in May 2019 in accordance with Section 3.10.1 of the CMMP (UP 2016a), which requires these measurements be taken semiannually for the first 2 years of the 5-year monitoring period, then annually until the 5-year monitoring period is complete. UP has conducted semiannual surveys for 2017 and 2018 (the first 2 years of the monitoring period) and an annual survey for 2019 (the third year of the monitoring period), thus meeting the permit requirements. For 2020 and 2021, an annual survey is scheduled.

Survey cross-section data collected in May 2019 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, which is the performance standard defined in the CMMP (UP 2016a). Figure 6 shows the locations of the as-built and annual survey cross-sections. These data were previously reported in the second-quarter 2019 monitoring report and are summarized below (UP 2019d).

Figure 6. Locations of Geometric Cross-Sections



The results of the previously reported May 2019 survey and the comparison to the as-built survey measurements are shown by cross-sections in Figure 7 and Figure 8.

This page is intentionally left blank.

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

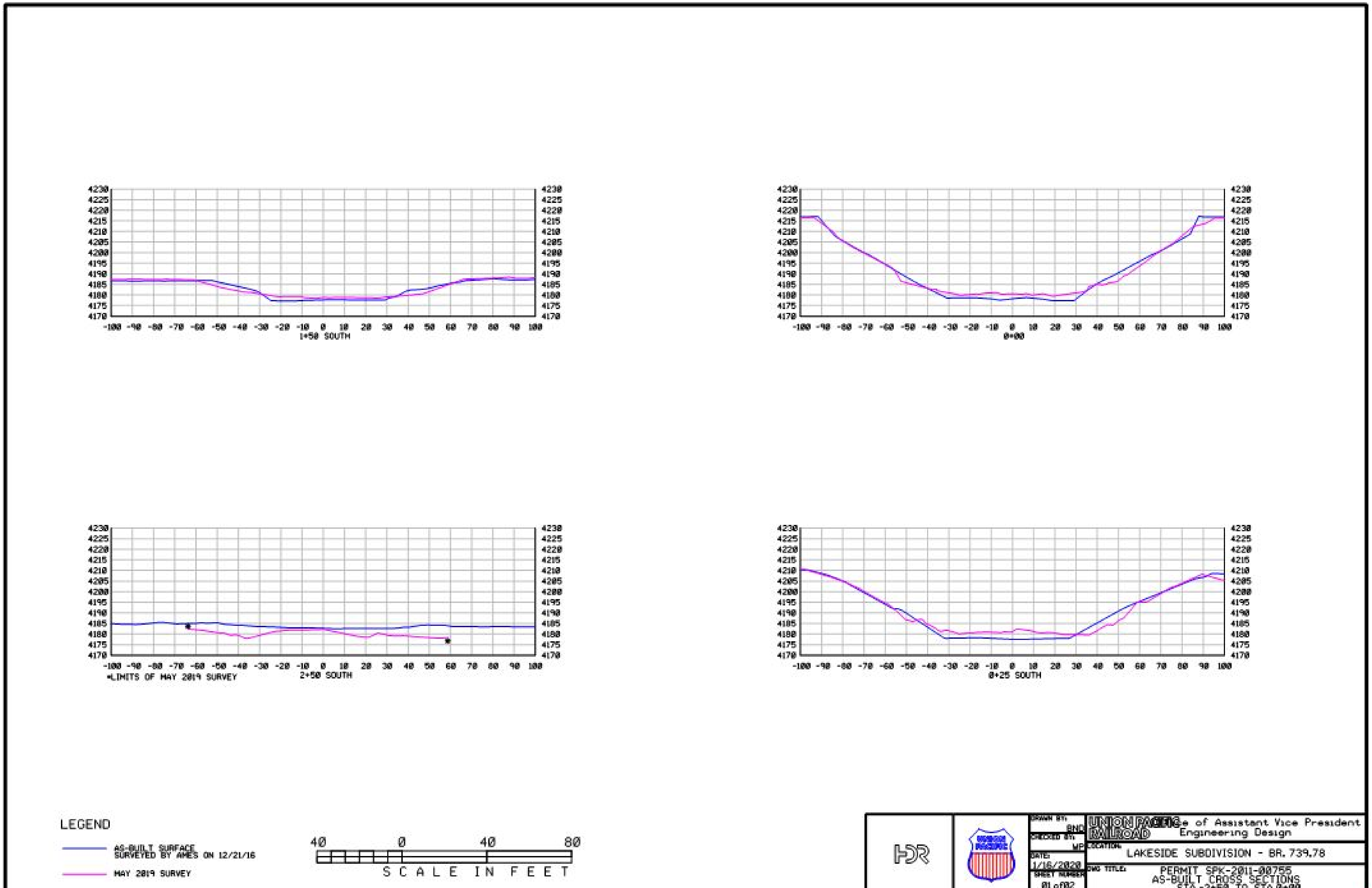
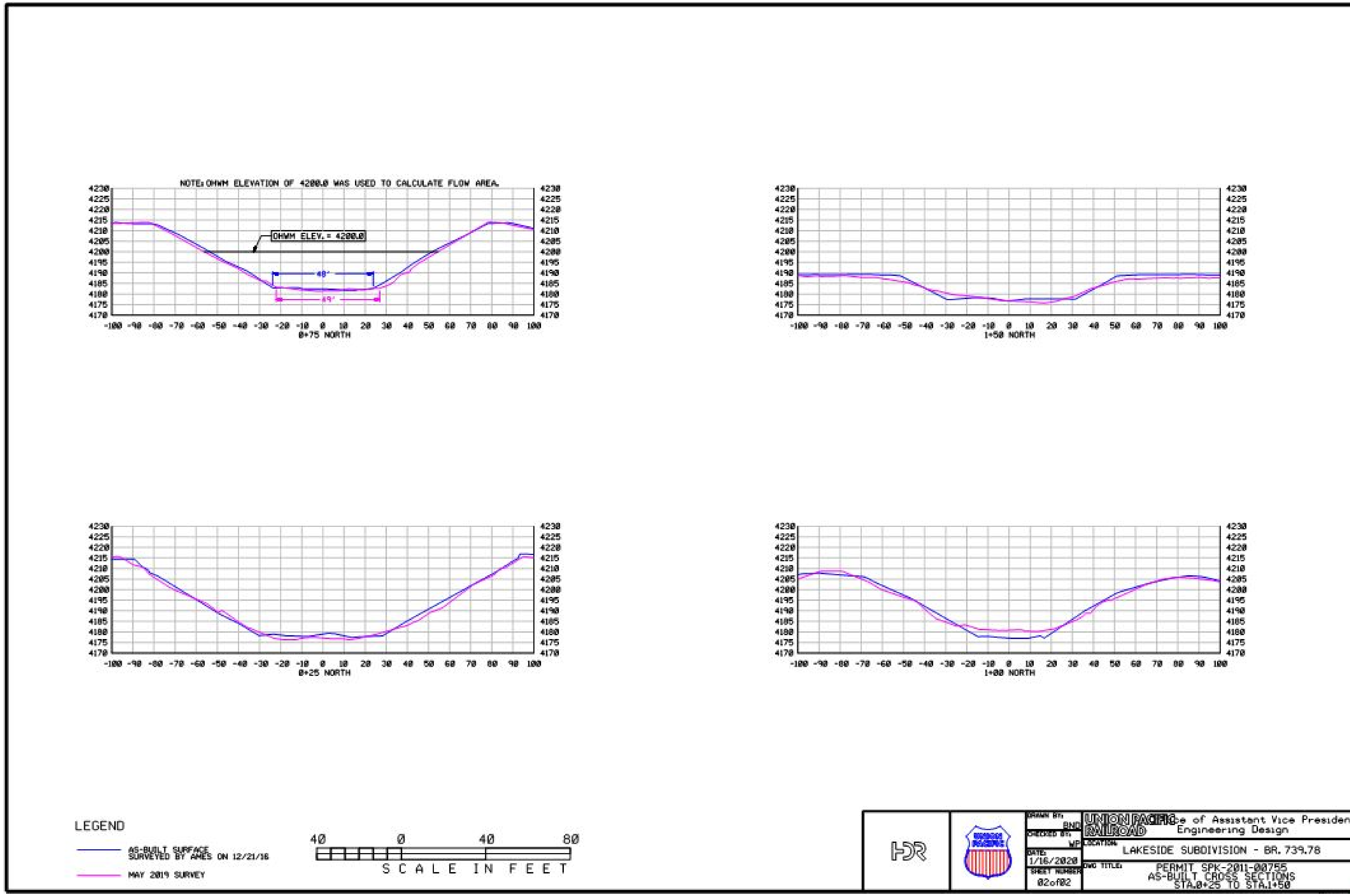


Figure 8. Cross-Section Geometry Comparison (2 of 2)



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

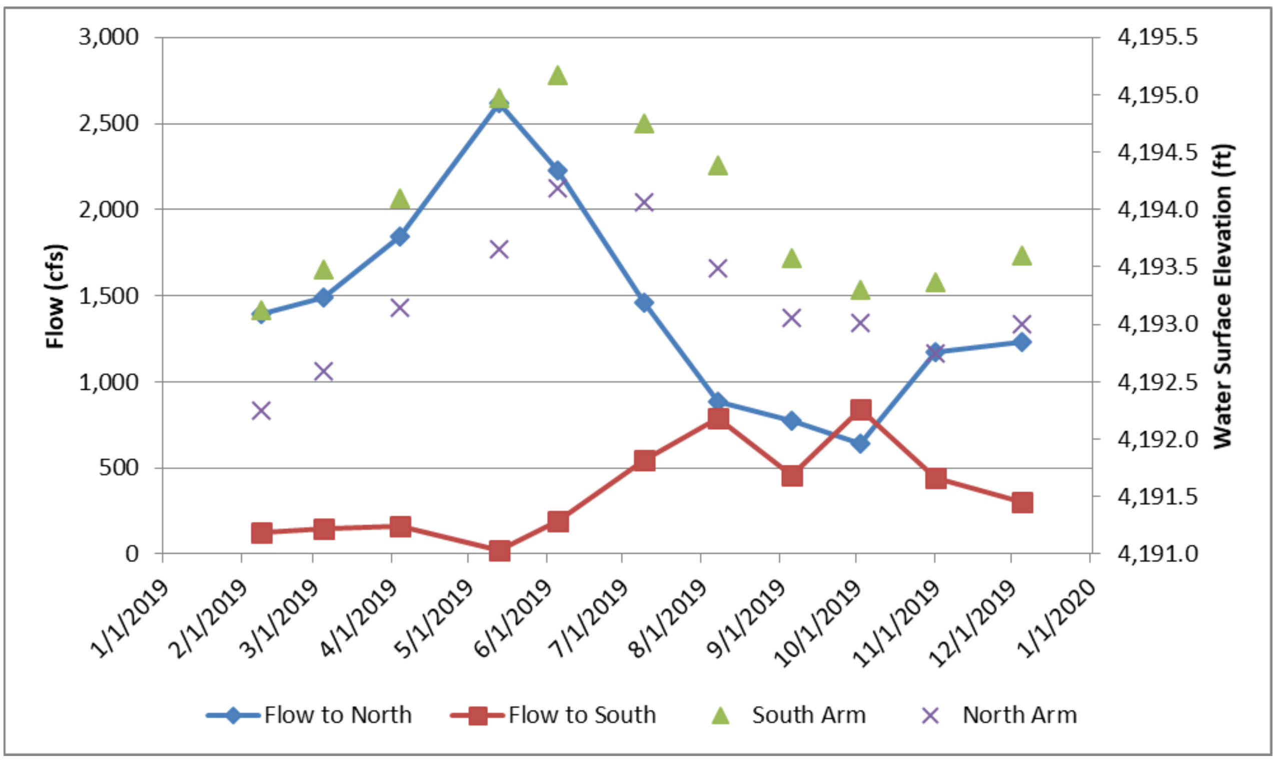


Table 2. Causeway Opening Flow Data and Depth at the Causeway Opening

Parameter	Unit	2/8/19	3/5/19	4/4/19	5/13/19	6/5/19	7/9/19	8/7/19	9/5/19	10/2/19	11/1/19	12/5/19
South-to-north flow[a]	cfs	1,390	1,490	1,840	2,620	2,230	1,460	882	773	642	1,170	1,230
North-to-south flow[b]	cfs	123	147	161	19.3	189	547	792	456	839	439	300
Average water depth in center bridge section[c]	feet	15.09	15.50	16.10	16.97[f]	17.17	15.85	16.75	15.58	15.30	15.37	15.62
Flow measurement rating[a,b]	NA	Fair / Poor	Poor	Poor	Fair / Poor	Fair / Poor	Fair	Poor	Fair	Poor	Fair	Poor
Depth from water surface to North Arm brine[d]	feet	11	10	6	13	10	8	6	5	6	5	7
Depth of North Arm brine[e]	feet	4.1	5.5	10.1	4.3	7.2	8.8	10.4	10.6	9.3	10.4	8.6

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] Reported on USGS website: https://waterdata.usgs.gov/nwis/measurements/?site_no=10010026.
[c] Average depth in the center bridge section as calculated based on the South Arm WSE and the average invert elevation of 4,178 feet.
[d] As measured by UP in the field.
[e] Calculated based on average water depth in center bridge section and depth from water surface to North Arm brine.
[f] Value has been reviewed and updated by USGS since the publication of the applicable 2019 quarterly report.

Bidirectional flow through the causeway was reported and observed during February through December 2019 (Figure 9 above). South-to-north flows ranged from 642 to 2,620 cubic feet per second (cfs), and north-to-south flows ranged from 19.3 to 839 cfs.

The flow measurements during the 2019 events were rated as both fair and 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 2019. 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	1/8/19	2/12/19	3/15/19	4/9/19	5/13/19	6/4/19	7/9/19	8/14/19	09/10/19	10/15/19	11/11/19	12/3/19
South-to-North Flow													
Specific conductivity	mS/cm	172.4	167.1	159.6	145.8	101.7	137.4	141.1	150.5	137.4	158.5	167.0	163.1
Temperature	°C	–0.1	0.7	6.2	13.4	17.5	19.3	23.0	25.6	19.3	12.5	6.8	3.3
Density	g/mL	1.0983	1.0902	1.0911	1.0854	1.0670	1.0761	1.0830	1.0897	1.0761	1.0920	1.0973	1.0914
TDS	mg/L	151,000	141,000	137,000	128,000	107,000	109,000	126,000	139,000	109,000	144,000	141,000	137,000
Salinity	Percent	14.21	13.13	13.25	12.49	9.97	11.23	12.16	13.07	11.23	13.37	14.07	13.29
Chloride	mg/L	83,400	79,400	75,200	73,200	57,700	62,500	70,800	74,200	79,200	76,700	78,400	76,600
Sulfate	mg/L	10,800	10,300	9,820	9,240	7,590	8,090	9,390	9,940	10,300	10,300	10,500	10,200
Calcium	mg/L	241	255	247	217	190	184	255	227	254	233	213	226
Magnesium	mg/L	5,040	4,990	4,870	4,250	3,590	3,510	4,660	4,730	4,580	4,890	4,760	4,700
Potassium	mg/L	2,990	2,980	2,940	2,620	2,270	2,220	3,110	3,020	3,500	3,130	2,860	2,800
Sodium	mg/L	41,400	42,200	41,900	36,800	33,200	30,500	40,600	36,000	39,600	40,700	38,600	37,700
North-to-South Flow													
Specific conductivity	mS/cm	225	224	225	218	223	225	217	224	223	221	225	222
Temperature	°C	1.4	2.3	6.8	11.3	16.8	16.5	24.1	24.7	24.8	13.1	7.8	5.8
Density	g/mL	1.1760	1.2118	1.2075	1.2076	1.1301	1.0863	1.1591	1.2138	1.2167	1.2208	1.2129	1.2198
TDS	mg/L	333,000	327,000	339,000	321,000	227,000	263,000	287,000	298,000	350,000	362,000	354,000	338,000
Salinity	Percent	23.76	27.74	27.28	27.29	18.27	12.61	21.79	27.96	28.27	28.71	27.86	28.60
Chloride	mg/L	188,000	178,000	178,000	178,000	125,000	143,000	161,000	176,000	189,000	189,000	181,000	182,000
Sulfate	mg/L	21,800	21,300	22,500	23,800	16,600	19,400	21,900	24,600	25,300	25,400	25,200	24,400
Calcium	mg/L	360	338	315	332	263	284	329	318	359	319	301	312
Magnesium	mg/L	14,200	12,800	12,000	12,600	8,200	9,730	10,900	11,700	12,700	12,400	11,900	11,800
Potassium	mg/L	8,300	7,510	7,160	7,690	5,140	6,310	7,090	7,690	8,210	7,980	7,290	7,210
Sodium	mg/L	94,700	89,800	87,700	96,900	69,000	78,500	88,300	89,200	105,000	97,200	91,100	89,900

mS/cm = milliSiemens per centimeter, °C = degrees Celsius, g/mL = grams per milliliter, 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 2019.

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	21.7	22.2	23.8	17.5
May	24.2	23.3	25.3	18.7
August	22.9	22.2	24.3	18.0
October	22.6	22.4	23.8	17.4
Depth from Water Surface to Deep Brine Layer (feet)				
February	20.5	20.5	22.0	NA
May	22.0	22.0	22.0	NA
August	20.5	21.5	21.0	NA
October	21.0	20.5	21.0	NA
Thickness of Deep Brine Layer (feet)				
February	1.2	1.7	1.8	NA
May	2.2	1.3	3.3	NA
August	2.4	0.7	3.3	NA
October	1.6	1.9	2.8	NA

NA = not applicable

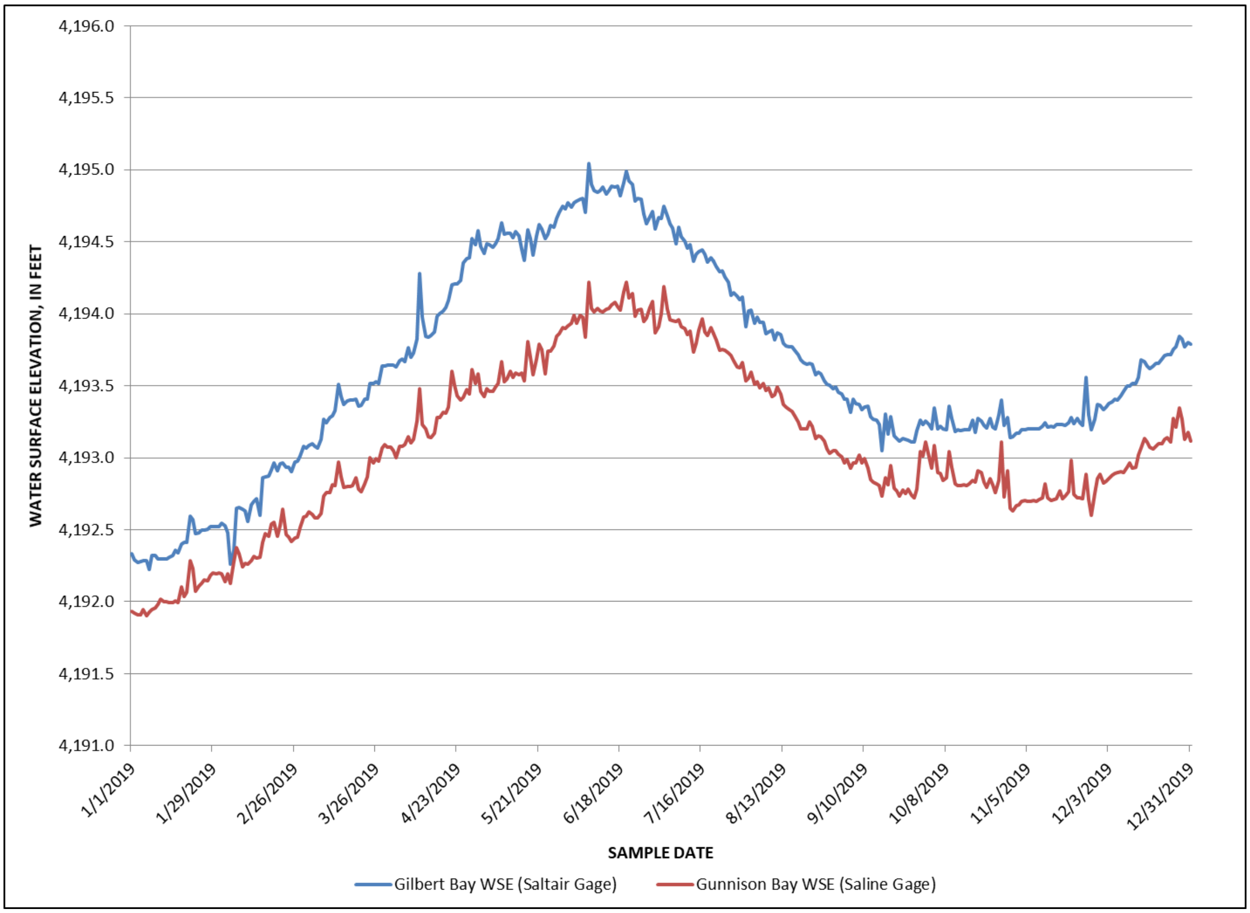
3.4.4 Monthly North and South Arm Water Surface Elevations

This section summarizes the lake WSE data during 2019.

Water Surface Elevation

UP acquired WSE data in 15-minute increments for Gunnison and Gilbert Bays from the USGS website (USGS 2020; 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 2019



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 after USGS conducts quality control and the data become final.

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 8, 2019	4,192.3	4,191.9	0.4
February 12, 2019	4,192.7	4,192.3	0.4
March 18, 2019	4,193.4	4,192.8	0.6
April 9, 2019	4,193.8	4,193.3	0.5
May 13, 2019	4,194.6	4,193.6	1.0
June 4, 2019	4,194.8	4,194.0	0.8
July 9, 2019	4,194.5	4,193.9	0.6
August 14, 2019	4,193.8	4,193.4	0.4
September 10, 2019	4,193.4	4,193.0	0.4
October 15, 2019	4,193.2	4,192.8	0.4
November 11, 2019	4,193.2	4,192.8	0.4
December 3, 2019	4,193.4	4,192.9	0.5

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

The 2019 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 2019, the rise in the South Arm WSE was about 2.5 feet, while the decrease in WSE about 1.6 feet. Overall, the South Arm lake WSE rose about 1.1 feet over the course of 2019.

4.0 Attainment of Project Performance Standards

UP evaluated the 2019 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 represents the third 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 annual 2019 survey 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 Value	May 2019	
		Measured Value	% of As-Built
1. Average bridge side-slope contours, bottom channel width at Station 0+00 (feet)	60	60	100%
2. Flow cross-section area at invert berm, Station 0+75 (square feet)	1,333	1,421	107%
3. Average water depth at bridge (feet)	22	19.5	89%
4. Average control berm contours, invert berm width at Station 0+75 (feet)	48	49	102%

Average Bridge Side-Slope Contour. Channel bottom width survey data were collected in May 2019 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 one 2019 survey, is 60 feet, compared to the as-built bottom width of 60 feet (see Figure 7 and Figure 8 above). The two 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 May 2019 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 Great Salt Lake ordinary high water mark, or OHWM) (USACE 2015b). The May cross-sectional area is 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 May 2019 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 (Great Salt Lake OHWM). The May 2019 measured water depth is outside 10% of the as-built survey data at 19.5 feet compared to the as-built survey datum of 22 feet, and varies by 2.5 feet (11%) from the as-built survey datum. This variance is described in more detail in Section 4.1.1.

Average Control Berm Contours. Invert berm width survey data were collected in May 2019 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 as measured by the May survey is 49 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.

4.1.1 Performance Standards Discussion

The May 2019 annual 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, and 4, respectively.

Project performance standard 3, average water depth at the bridge as measured at the centerline of the rail (Station 0+00), is reported at 19.5 feet and varies about 11% from the as-built measurement of 22 feet. Per Section 3.12.1, Adaptive Management Plan, of the CMMP (UP 2016a), UP further reviewed the invert survey data through the causeway opening to determine the extent of the effect, if any. The 2018 annual report noted that the average water depth at the bridge was measured at 19 feet. In the 2018 annual report, the review of the average water depths concluded that the extent of affected area was limited and that there were no constraints to bidirectional flow and the transfer of water and salt through the bridge opening.

For this report, UP further reviewed the bathymetric invert data through the causeway opening to evaluate the effect on the transfer of water and salt and bidirectional flow. UP's review of the May 2019 channel invert bathymetry data for performance standard 3 consisted of several metrics, including:

- Comparison of the May 2019 survey data with survey data reported for the 2017 and 2018 annual reports (UP 2018b and 2019b, respectively)
- Collection of survey data in September 2019

These reviews and evaluations are summarized below.

Comparison of the May 2019 Survey Data to Previous Survey Data. This evaluation shows that, since December 2017, the average water depth has been relatively stable, varying from 20 feet to 19 feet, with the May 2019 data showing an average water depth of 19.5 feet.

The survey methodology for collecting bathymetric data under the bridge was augmented in 2018. The as-built and 2017 survey methods relied solely on global positioning system (GPS) survey methodology and extrapolation between GPS survey points. GPS data collection is limited to areas where equipment can be connected to satellites. Because satellite signals are not available under the bridge, no GPS survey points could be collected. Therefore, bathymetric data under the bridge deck were defined by extrapolating the GPS data collected from points to the north and to the south of the bridge deck.

In 2018, UP began incorporating total station data collection methods to collect actual survey points under the bridge to supplement the GPS survey data in all other areas, and more field data were used to prepare the required bathymetry for analysis. The current methodology was implemented to provide more-accurate survey data under the bridge. Therefore, UP could reasonably expect that the as-built and 2017 survey data could differ slightly from the 2018 and 2019 survey data under the bridge because of the change in the survey methodology.

Collection of Additional Survey Data in September 2019. UP collected additional survey data in September 2019 to assist with further analysis of the May 2019 data. These September survey data were collected when the lake WSE and head difference (difference between the North and South Arm WSEs) is seasonally low, resulting in low flow velocities through the causeway opening, which facilitates easier data collection from a boat.

UP conducted this additional monitoring event in September 2019 to monitor the stability of the berm and channel and to determine whether maintenance activities were required. The September 2019 data for performance standards 1, 2, and 4 corresponded with the May 2019 data as well as the 2017 and 2018 survey results.

Evaluation of the September 2019 survey data shows that the centerline water depth (performance standard 3) was measured at 19.3 feet and is roughly consistent with the May 2019 and 2018 survey results for station 0+00. UP concludes that the higher channel invert at the bridge is not limiting bidirectional flow or restricting the transfer of water or salt through the causeway opening.

Summary. The data review findings for performance standard 3, which measures the water depth under the bridge, and the supplemental September 2019 survey results indicate that there are some minor variations in the average water depth under the bridge, that there is a generally limited accumulation of material in the channel invert section under the bridge at station 0+00, and that the channel invert has been relatively stable since December 2017.

However, as discussed in the 2018 annual report and above, these minor variations are not restricting the bidirectional flow and the transfer of water and salt through the causeway opening, since the channel invert is below the higher control berm elevation, which is still constraining north-to-south flows. The changes to the survey methodology implemented in 2018 allow UP to more accurately collect and analyze the channel bathymetry data. Therefore, UP proposes to evaluate the 2020 and 2021 survey data to determine whether maintenance activities are needed.

4.2 South Arm Salinity Performance Standard Range

The average South Arm salinity from the 2019 quarterly monitoring data was compared to the 2012 UP/USGS Model salinity range and historical range, consistent with Section 3.9.2, Table 3-7, and Appendix F of the CMMP (UP 2016a). This comparison is shown in Figure 11, and tabulated results are presented in Table 7.

The measured discrete samples for vertical density 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 for 2019 indicate that monitored South Arm salinities are generally consistent with the UP/Utah Geological Survey (UGS) average historic South Arm salinities, and they fall within the model range.

Based on this analysis, UP has determined that the mitigation met the salinity performance standard (project performance standard 5) during 2019, so no adaptive management measures are required or proposed.

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

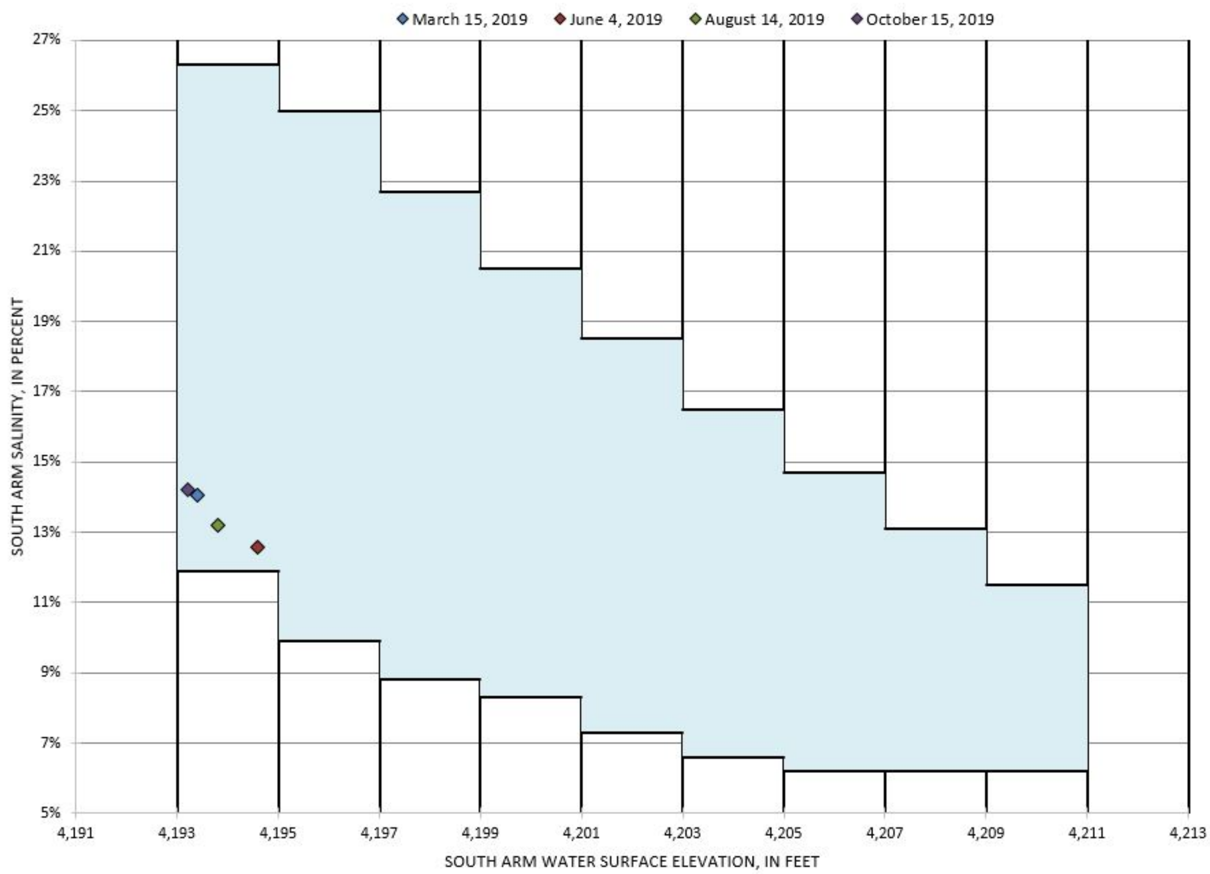


Table 7. Comparison of Monitored South Arm Salinity to Performance Standard Salinity Range by Water Surface Elevation

South Arm WSE					South Arm Salinity				
WSE on Monitoring Event Date (ft)[a]				WSE Range (ft)	Performance Standard Salinity Range (%)	Average Salinity from Sampling Data (%)			
March 2019	June 2019	August 2019	October 2019			March 2019	June 2019	August 2019	October 2019
				Below 4,193	Not established				
4,193.4	4,194.6	4,193.8	4,193.2	4,193 up to 4,195	11.9 – 26.3	14.1	12.6	13.2	14.2
				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
[a] As measured at the USGS Saltair (10010000) long-term water surface elevation gage for Gilbert Bay.

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.

2019 Letter from K. Shelly of UDWQ to Stephan L. Cheney, UP. March 20.

[UP] 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.

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

2019b 2018 Annual Data Monitoring Report. February 1.

2019c Quarterly Data Monitoring Report – First-Quarter 2019 Monitoring Results. May 15.

2019d Quarterly Data Monitoring Report – Second-Quarter 2019 Monitoring Results. August 15.

2019e Quarterly Data Monitoring Report – Third-Quarter 2019 Monitoring Results. November 15.

2020 Quarterly Data Monitoring Report – Fourth-Quarter 2019 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.

2020 Great Salt Lake – Lake Elevations. ut.water.usgs.gov/greatsaltlake/elevations. Accessed January 15, 2020.

This page is intentionally left blank.