

# 2017 Annual Data Monitoring Report

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

SPK-2011-00755

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## 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 2017 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 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 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 quarterly data monitoring reports (UPRR 2017a, 2017b, 2017c, 2018). The required contents of this annual report are set out in the CMMP, Section 3.10.2.

This 2017 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 2017 monitoring on behalf of UPRR. Water quality monitoring occurred in 2017 in accordance with the CMMP (UPRR 2016a), SAP, and QAPP (UPRR 2016b), and methods were previously reported in quarterly data monitoring reports (UPRR 2017a, 2017b, 2017c, 2018). This report summarizes the data that were previously reported.

### 2.1 Study Variances

Monitoring during 2017 was conducted in conformance with the SAP and QAPP with one variance:

- During the first quarter of 2017, floating sheets of ice precluded safe boat access to site AC3. A nearby accessible location was selected for open-water salinity sampling: site AC3 Var, located about 2 miles south of site AC3.

All other activities conformed to the SAP and QAPP.

### 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, with the exception of site AC3 during the first quarter. Ice flows prevented sampling at this location during the first quarter.
- **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 2017 quarterly report (UPRR 2017a, 2017b, 2017c, 2018).

### 3.0 Summary of Results

The results of each 2017 monitoring event as well as the QA/QC review are presented in the four 2016 quarterly data monitoring reports, which were submitted on May 11, 2017; August 15, 2017; November 7, 2017; and February 1, 2018 (UPRR 2017a, 2017b, 2017c, 2018). 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 2017. The causeway opening geometry survey occurred biannually in June and December. Additional monitoring of flow and water quality at the causeway opening occurred on a monthly basis. Table 1 lists the dates of all 2017 monitoring events.

**Table 1. Monitoring Event Dates in 2017**

Month	Lake Water Chemistry Monitoring	Causeway Opening Geometry (Survey)	Additional Monitoring
January			1/17, 1/24
February	2/13, 2/14		2/13
March			3/2
April			4/6, 4/11
May	5/9, 5/11		5/3, 5/11
June		6/7	6/7, 6/15
July			7/5, 7/6
August	8/8, 8/10		8/3, 8/10
September			9/6, 9/7
October			10/3, 10/13
November	11/8, 11/9		11/1, 11/9
December		12/7	12/7, 12/12

## 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 2017 monitoring event:

- Water temperature
- Density
- TDS

These data are summarized below and shown in Figure 1, Figure 2, and Figure 3 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 February and lowest in August.

### 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 February and lowest in August.

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Figure 1. 2017 Lake Water Temperature Data for February (top left), May (top right), August (bottom left), and November (bottom right)

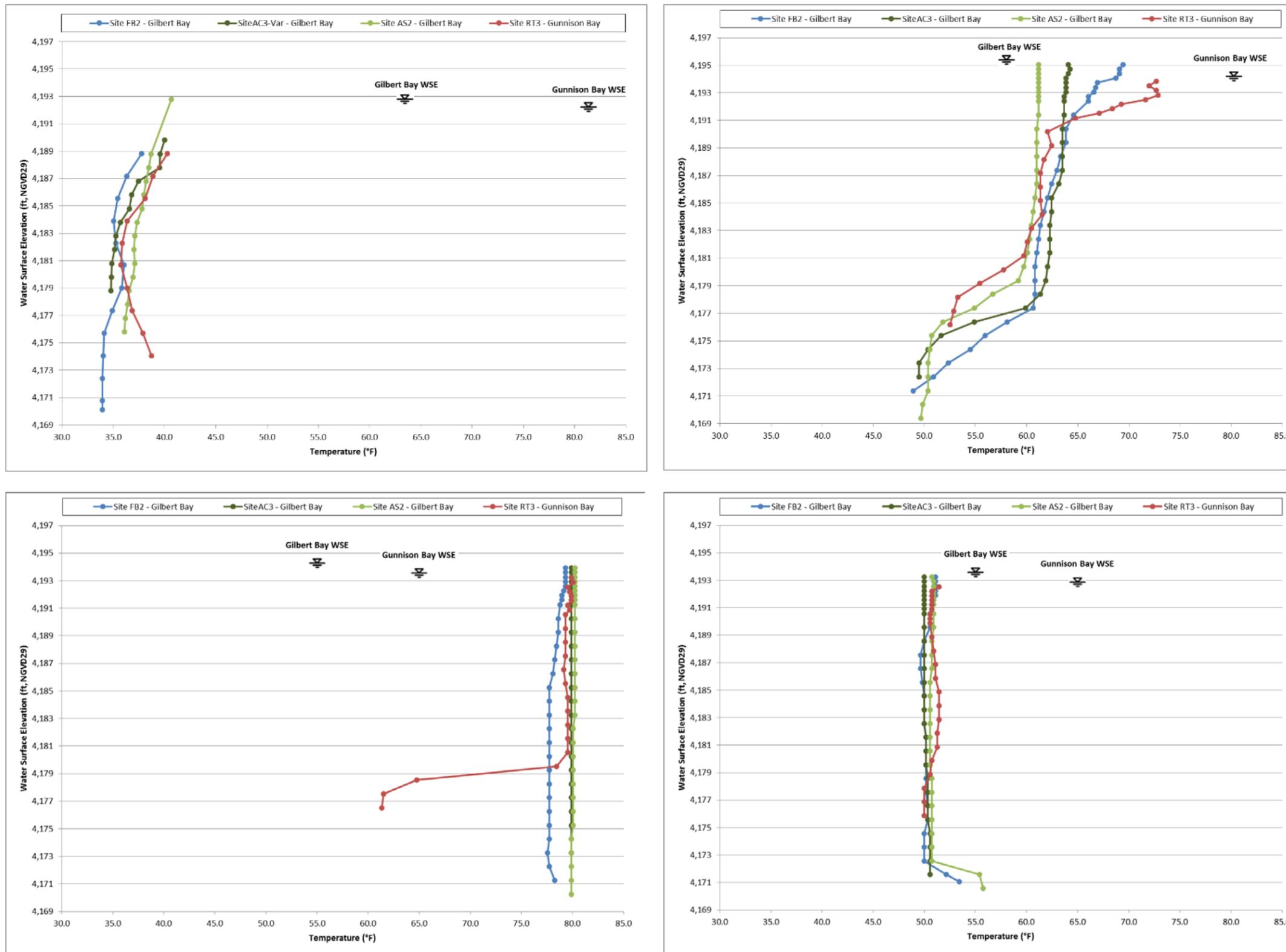


Figure 2. 2017 Lake Water Density Data for February (top left), May (top right), August (bottom left), and November (bottom right)

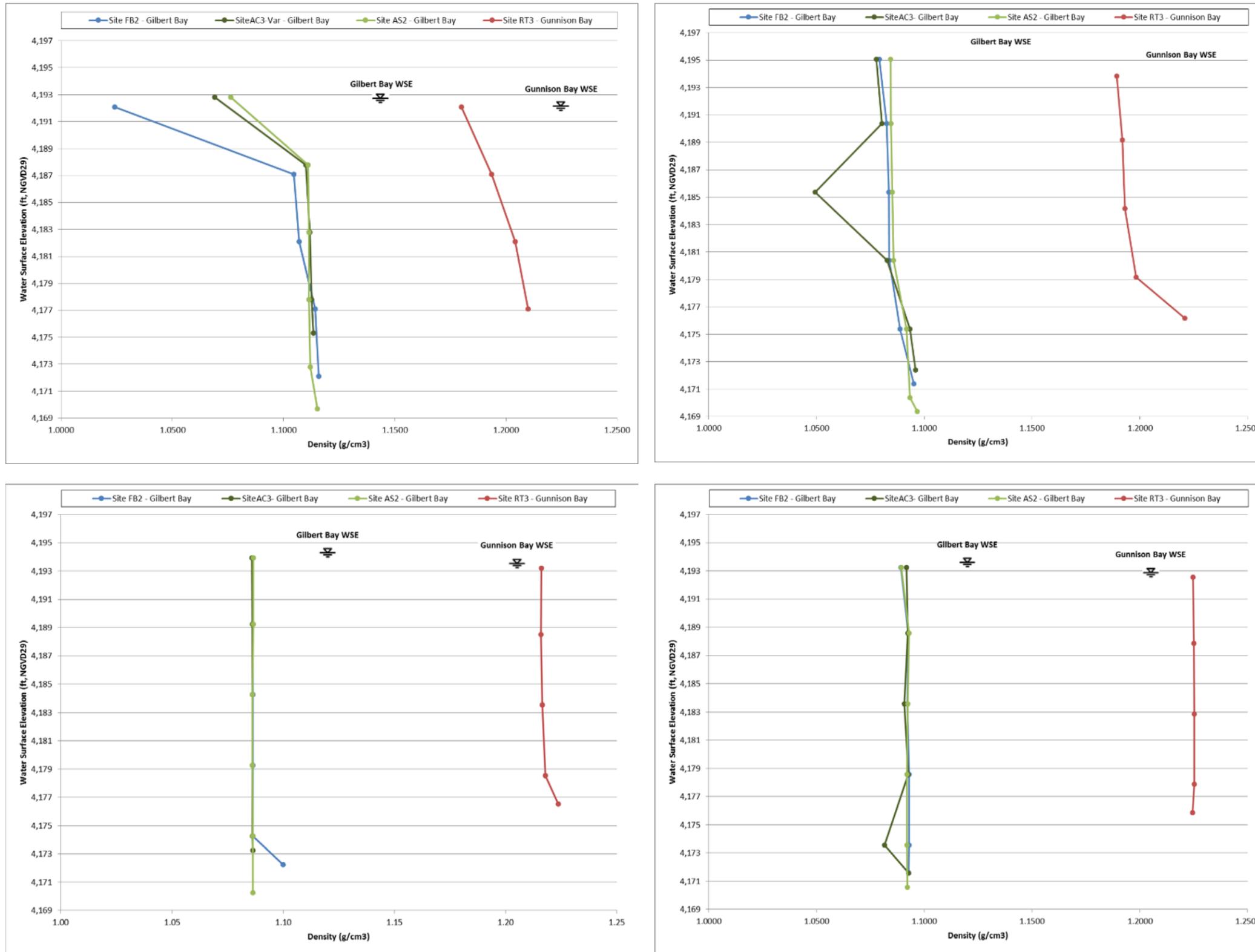
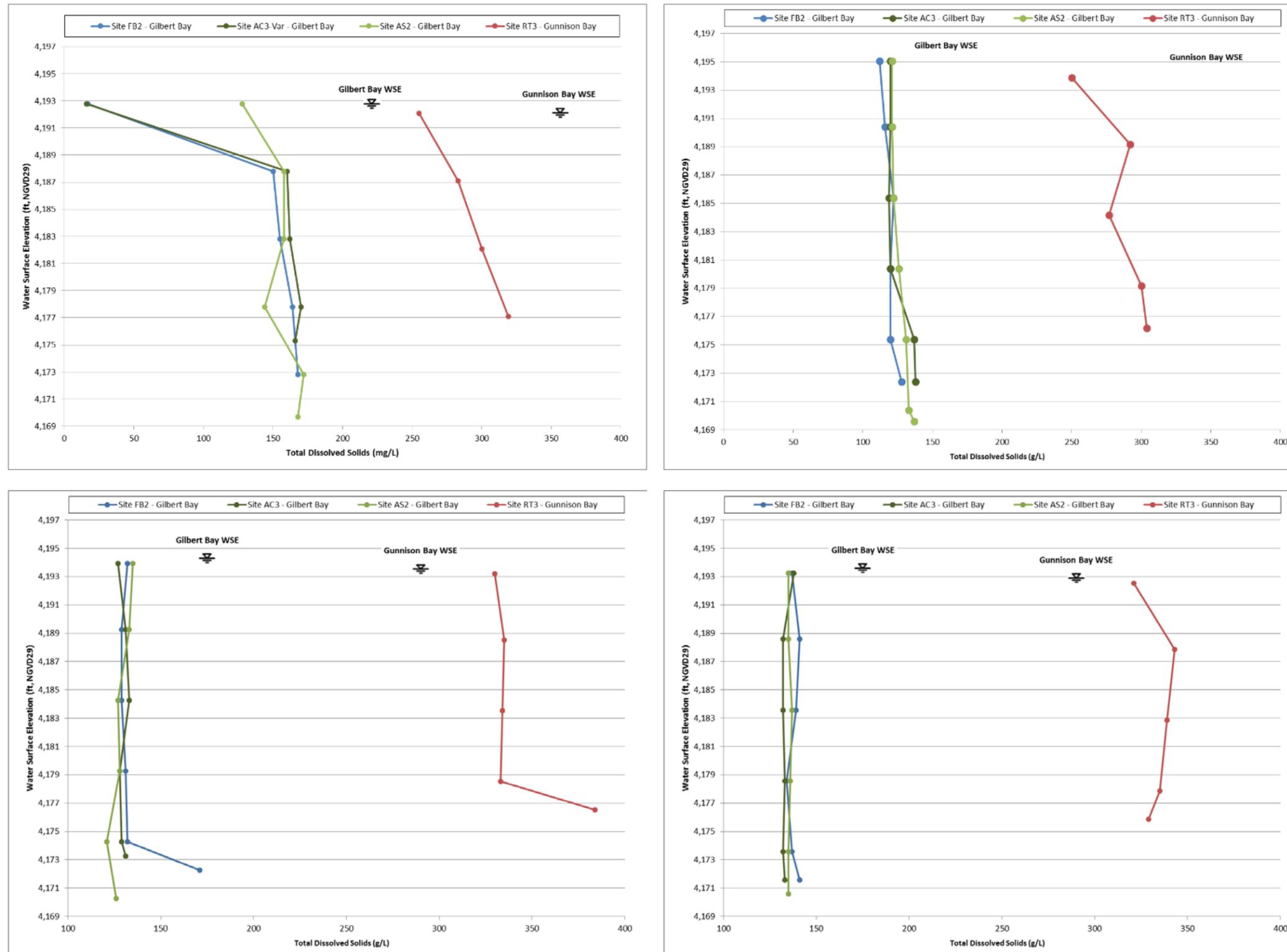


Figure 3. 2017 Lake Water TDS Data for February (top left), May (top right), August (bottom left), and November (bottom right)



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## 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)  
 $\rho$  = density at 20 degrees Celsius, in g/L

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

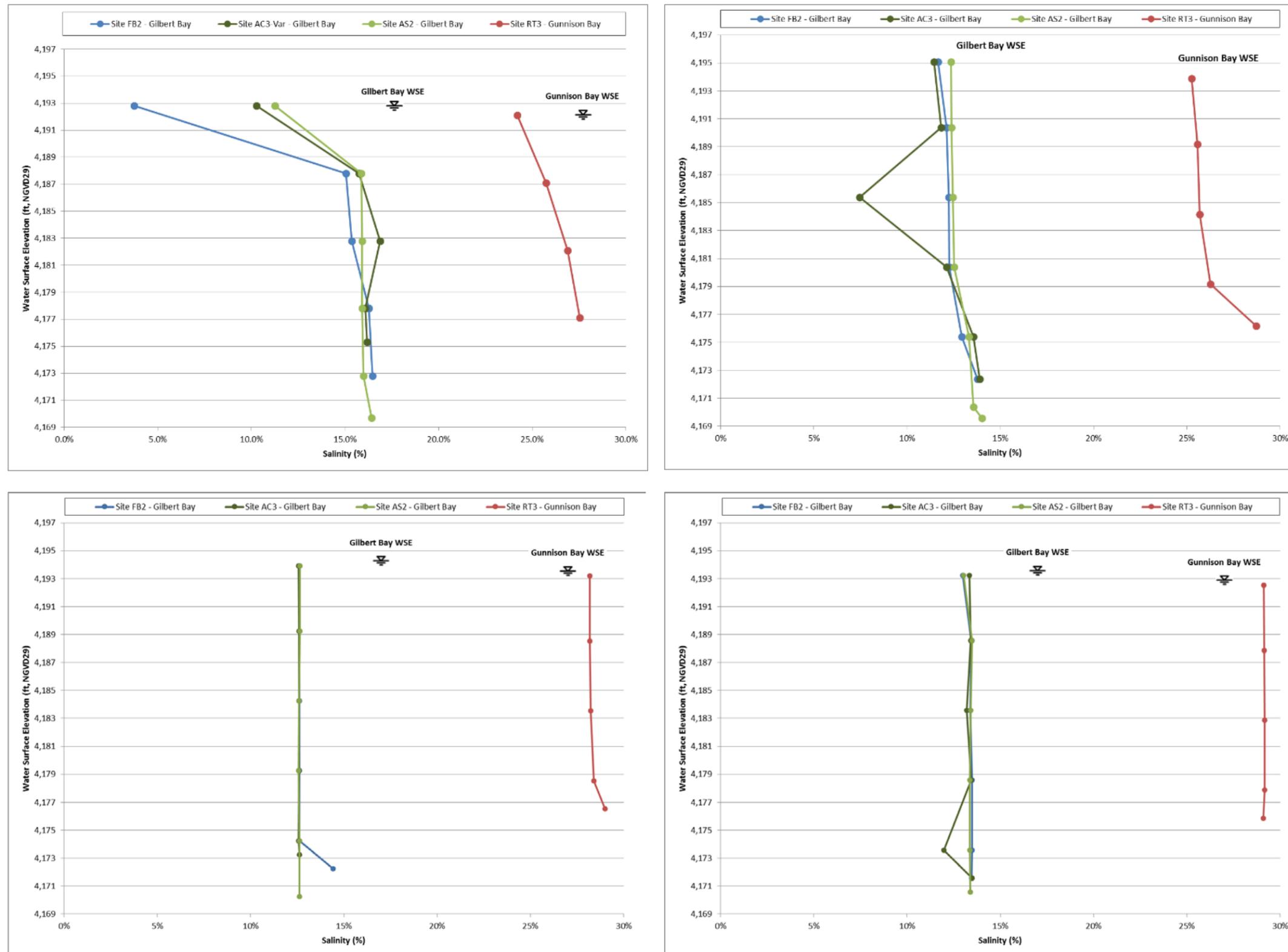
$$\text{Salinity, in percent} = \frac{C}{\rho(10)}$$

Salinity profile data are shown in Figure 4 for each monitoring event. The following general observations are made:

- Gunnison Bay salinity was lower in February and May and increased in August and November.
- Over the course of the 2017 monitoring events, South Arm salinity was the highest in February, slightly decreased in May, had its lowest reported value in August, and increased slightly in November.

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Figure 4. 2017 Lake Water Salinity Data for February (top left), May (top right), August (bottom left), and November (bottom right)



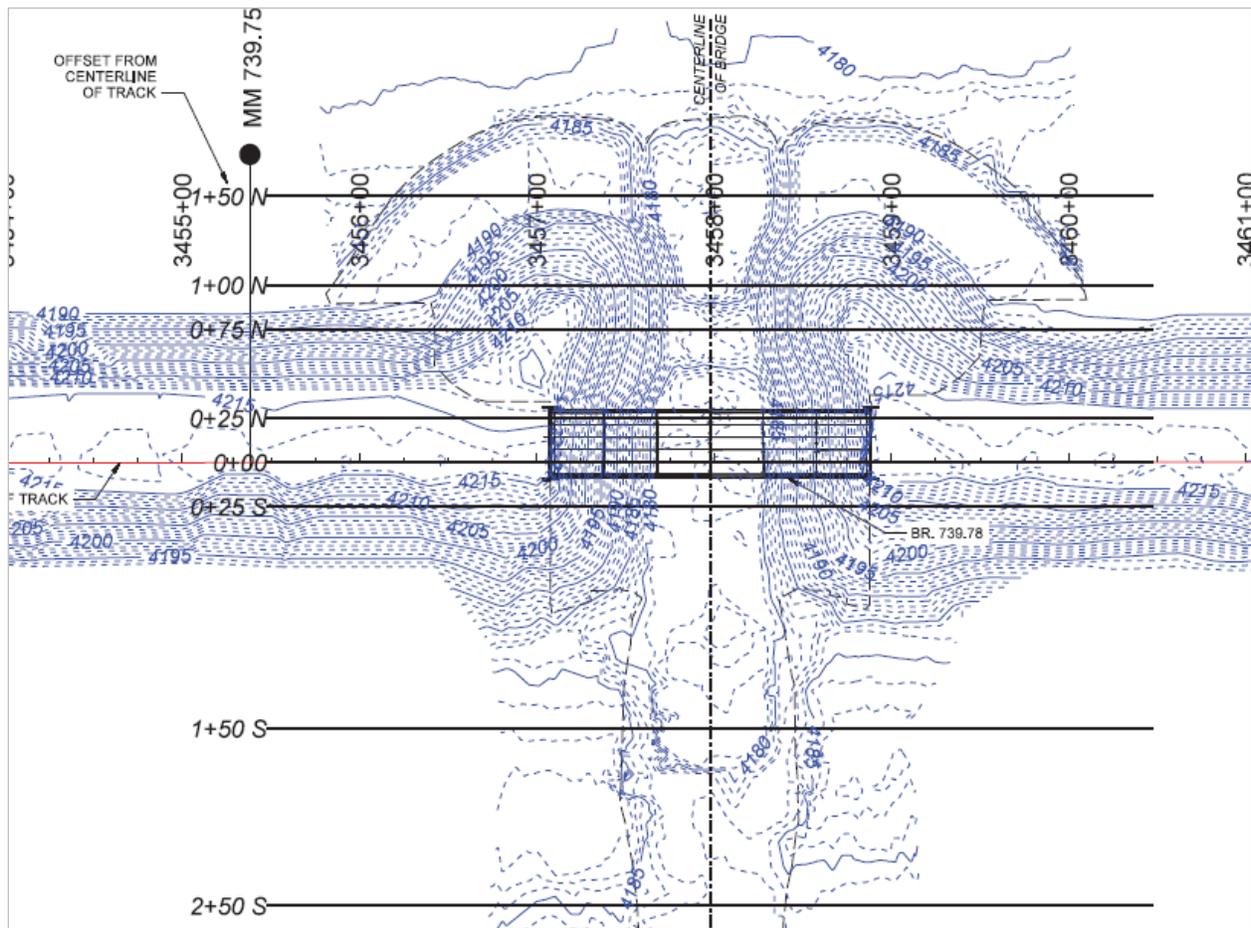
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### 3.3 Causeway Opening Geometry

Causeway opening geometry measurements were taken in May and December 2017 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.

Survey cross-section data collected in June and December 2017 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 5 shows the locations of the as-built and biannual survey cross-sections.

Figure 5. Locations of Geometric Cross-Sections



The results of the June and December 2017 survey and the comparison to the as-built survey measurements are shown by cross-sections in Figure 6 and Figure 7.

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Figure 6. Cross-Section Geometry Comparison (1 of 2)

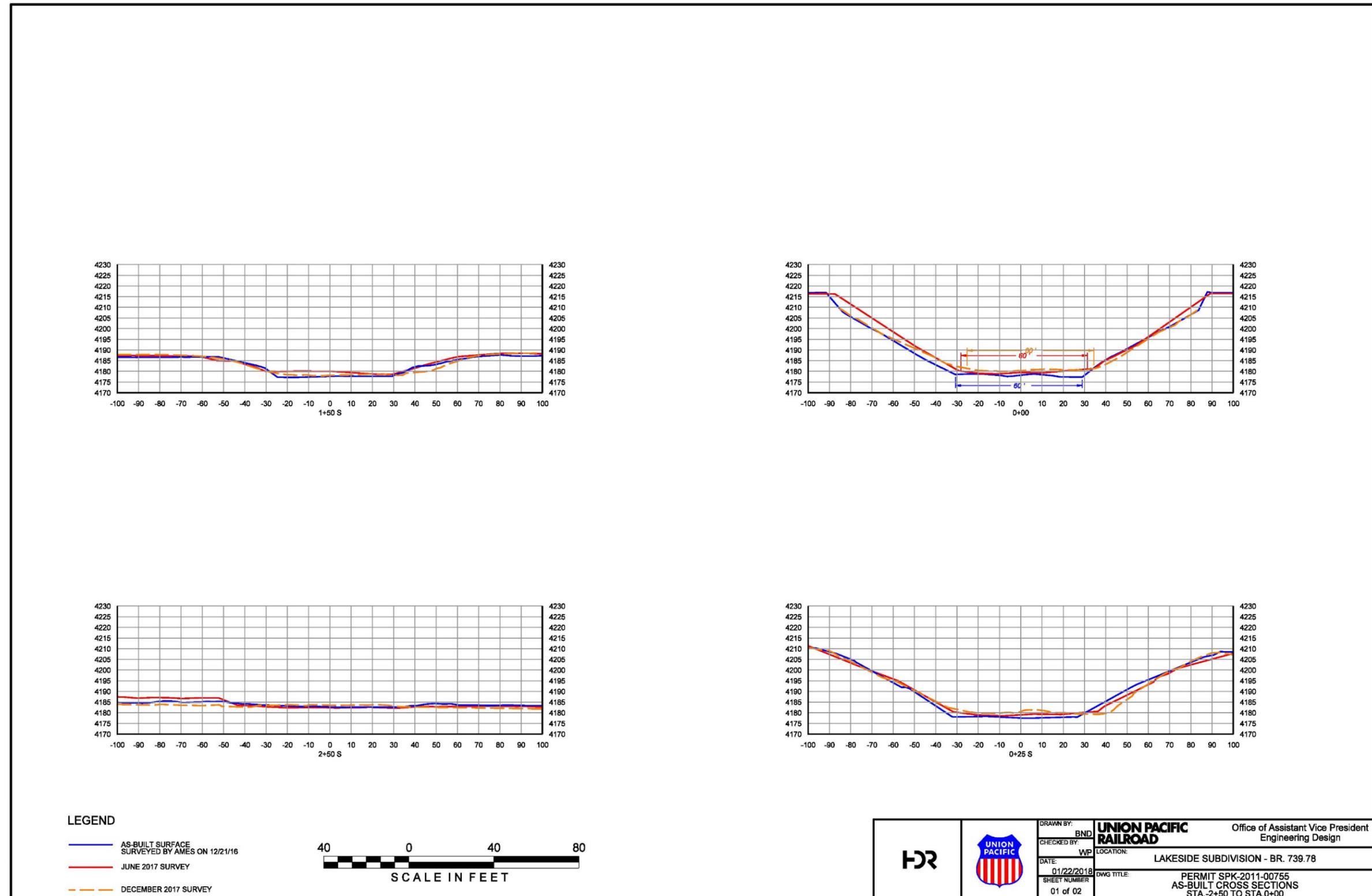
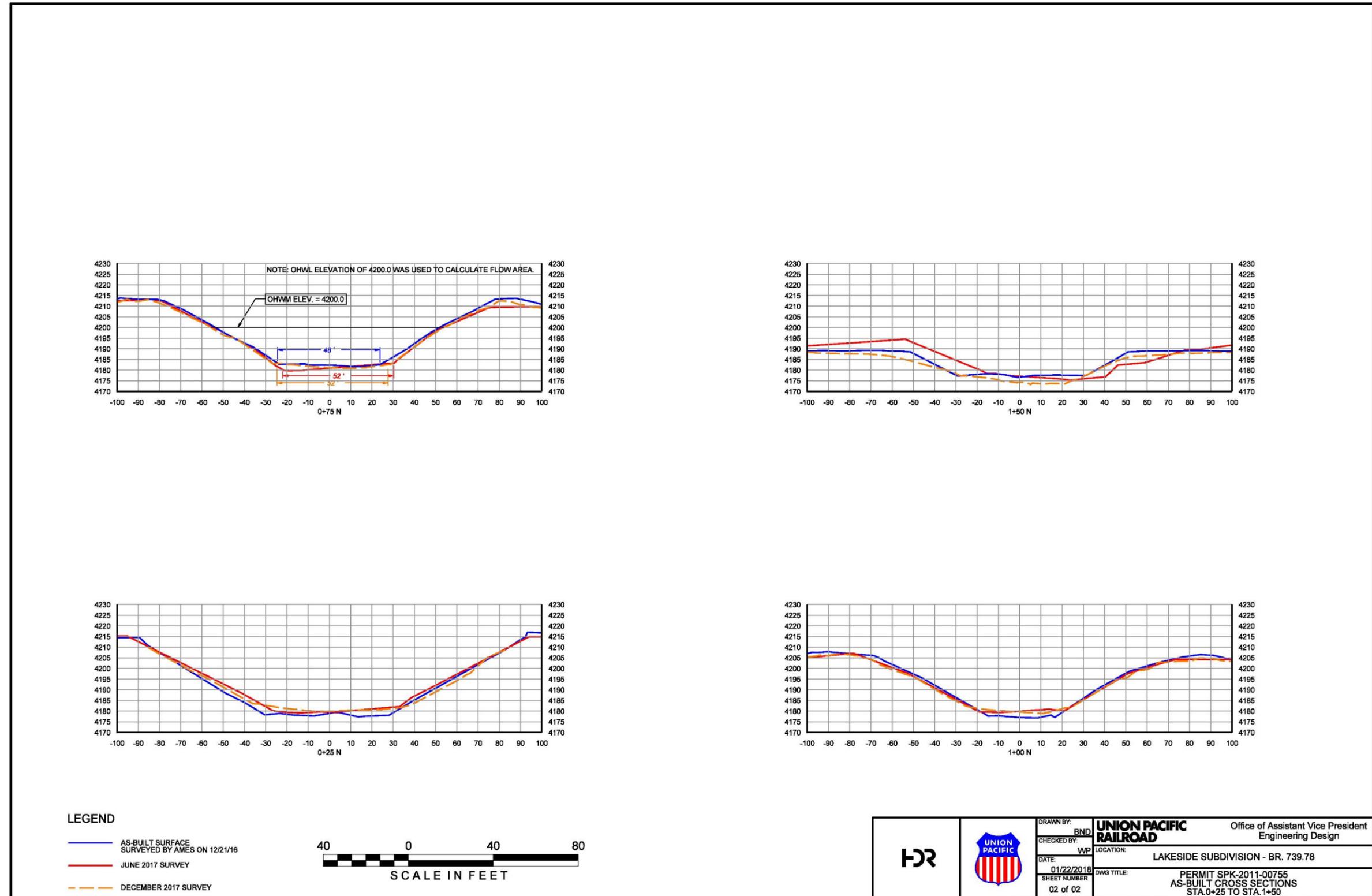


Figure 7. Cross-Section Geometry Comparison (2 of 2)



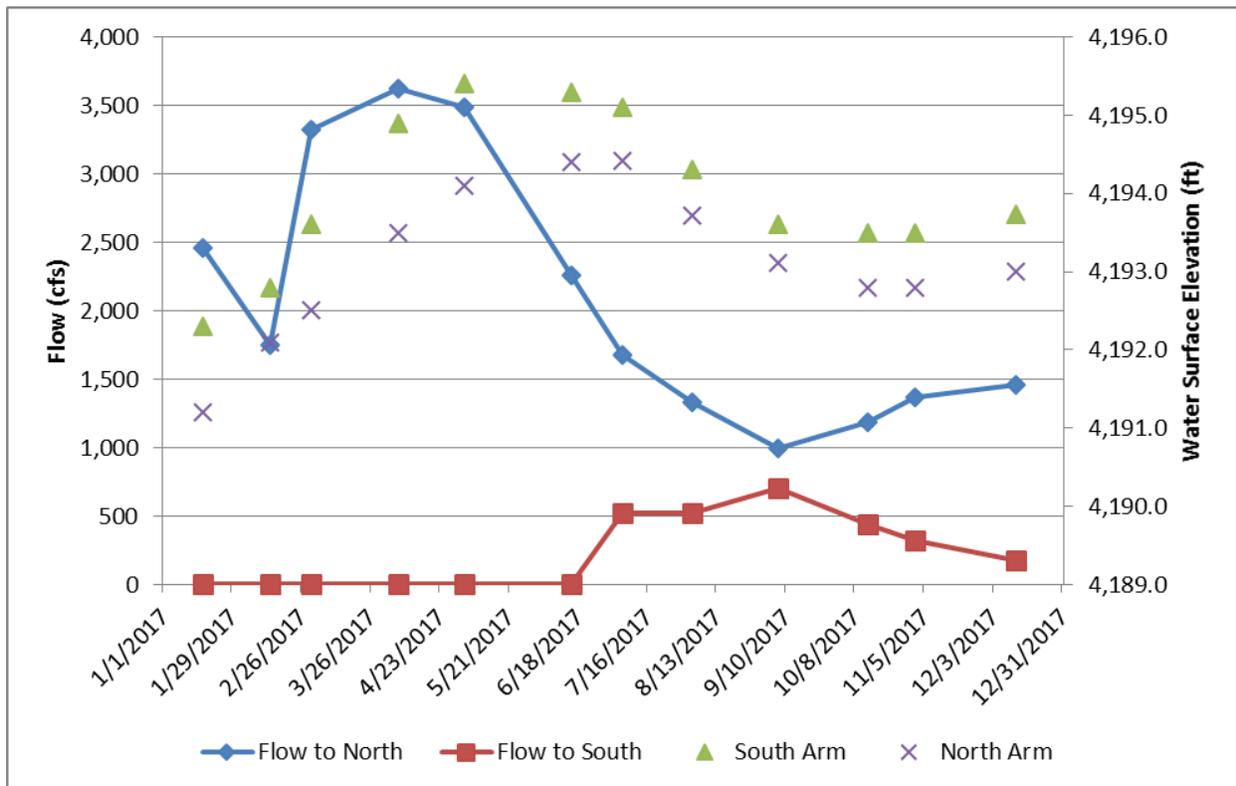
### 3.4 Additional Data Collected

#### 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 8. 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 water surface elevations 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 8. Water Surface Elevation at and Flow through Causeway Opening



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

Parameter	Unit	1/17/17	2/13/17	3/2/17	4/6/17	5/3/17	6/15/17	7/6/17	8/3/17	9/6/17	10/3/17	11/1/17	12/7/17
South-to-north flow <sup>a</sup>	cfs	2,460	1,750	3,320 <sup>b</sup>	3,620 <sup>b</sup>	3,490	2,260	1,680	1,330	993	1,190	1,370	1,460
North-to-south flow <sup>d</sup>	cfs	0	0	0	0	0	0	523	520	700	444	319	180
Average water depth in center bridge section <sup>d</sup>	feet	14.13	14.61	15.46	16.55	17.24	17.13	17.11	16.31	15.61	15.29	15.48	15.63
Flow measurement rating <sup>c</sup>	NA	Poor <sup>b</sup>	Fair	Poor	Fair	Good	Poor <sup>b</sup>	Poor	Poor	Poor	Poor	Poor	Poor
Depth from water surface to North Arm brine <sup>e</sup>	feet	NA	NA	NA	NA	NA	NA	14 <sup>b</sup>	5	4	5	6	10
Depth of North Arm brine <sup>f</sup>	feet	NA	NA	NA	NA	NA	NA	3.11 <sup>b</sup>	11.31	11.61	10.29	9.48	5.63

cfs = cubic feet per second; NA = not applicable

Provisional data subject to revision.

<sup>a</sup> Reported on USGS website: [https://waterdata.usgs.gov/nwis/measurements/?site\\_no=10010025](https://waterdata.usgs.gov/nwis/measurements/?site_no=10010025).

<sup>b</sup> Value has been reviewed and updated by USGS since the publication of the applicable 2017 quarterly report.

<sup>c</sup> Reported on USGS website: [https://waterdata.usgs.gov/nwis/measurements/?site\\_no=10010026](https://waterdata.usgs.gov/nwis/measurements/?site_no=10010026).

<sup>d</sup> Average depth in the center bridge section as calculated based on the South Arm WSE and the average invert elevation of 4,178 feet.

<sup>e</sup> As measured by UPRR in the field.

<sup>f</sup> Calculated based on average water depth in center bridge section and depth from water surface to North Arm brine.

Flow through the causeway was exclusively south to north after during the months of January–June 2017 (Figure 8 above). From July to December, bidirectional flow was reported. South-to-north flows ranged from 993 to 1,680 cubic feet per second (cfs), and north-to-south flows ranged from 180 to 700 cfs.

The flow measurements for most of the 2017 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 2017. 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	1/17/17	2/13/17	3/2/17	4/11/17	5/11/17	6/7/17	7/5/17	8/10/17	09/6/17	10/3/17	11/9/17	12/7/17
<b>South-to-North Flow</b>													
Specific conductivity	mS/cm	181	160	148	141.0	140.8	137.2	137.1	149.6	151.0	155.1	149.7	155.3
Temperature	°C	0.7	4.5	8.7	19.7	18.8	23.4	27.1	26.2	26.8	14.3	8.2	6.8
Density	g/mL	1.120	1.108	1.083	1.085	1.078	1.078	1.074	1.086	1.090	1.092	1.085	1.090
TDS	mg/L	178	153	136	128	117	117	115	136	145	132	127	129
Salinity	Percent	16.96	15.47	12.12	12.4	11.4	11.3	11.0	12.6	13.1	13.4	12.5	13.1
Chloride	mg/L	96,400	92,600	71,700	64,300	64,000	63,800	62,100	74,000	76,500	74,500	68,200	73,500
Sulfate	mg/L	11,500	11,100	8,640	8,710	8,170	8,270	8,020	9,100	9,480	9,370	8,960	9,610
Calcium	mg/L	293	259	205	230	222	212	207	257	240	238	242	249
Magnesium	mg/L	5,660	4,890	3,750	4,220	4,030	3,920	4,040	4,460	4,410	4,440	4,690	4,660
Potassium	mg/L	3,080	2,980	2,400	2,570	2,380	2,380	1,810	2,800	2,690	2,690	3,040	3,030
Sodium	mg/L	46,000	44,300	35,400	38,500	35,100	36,100	35,700	42,100	39,800	40,200	43,200	41,400
<b>North-to-South Flow</b>													
Specific conductivity	mS/cm	No flow measured through causeway opening						223.0	225.0	223.0	221.0	219.0	219.0
Temperature	°C							24.0	26.3	26.0	15.3	9.2	4.1
Density	g/mL							1.202	1.204	1.220	1.224	1.224	1.222
TDS	mg/L							318	289	400	325	341	332
Salinity	Percent							26.7	26.8	28.6	29.0	29.0	28.8
Chloride	mg/L							168,000	178,000	197,000	178,000	189,000	186,000
Sulfate	mg/L							24,100	24,600	26,300	26,100	27,500	25,400
Calcium	mg/L							308	357	329	380	330	356
Magnesium	mg/L							12,800	13,000	13,100	14,200	13,400	14,000
Potassium	mg/L							7,560	7,880	7,870	8,580	8,230	8,850
Sodium	mg/L							85,200	94,000	96,000	109,000	98,800	106,000

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, conductivity (density), TDS, and salinity profiles are provided in Figure 1, Figure 2, Figure 3, and Figure 4, respectively.

#### Depth to Brine Layer

Table 4 summarizes the total water depth and Gilbert Bay brine layer depth ranges observed in 2017.

**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
<b>Total Water Depth (feet)</b>				
February	22.0	17.7 (alternate site)	23.1	15.5
May	24.4	24.0	26.8	19.0
August	23.3	22.3	24.7	18.3
November	22.8	22.5	23.8	18.3
<b>Depth from Water Surface to Deep Brine Layer (feet)</b>				
February	No DBL observed	No DBL observed	No DBL observed	NA
May	No DBL observed	No DBL observed	No DBL observed	NA
August	22.0	No DBL observed	No DBL observed	NA
November	No DBL observed	No DBL observed	No DBL observed	NA
<b>Thickness of Deep Brine Layer (feet)</b>				
February	No DBL observed	No DBL observed	No DBL observed	NA
May	No DBL observed	No DBL observed	No DBL observed	NA
August	1.3	No DBL observed	No DBL observed	NA
November	No DBL observed	No DBL observed	No DBL observed	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 2017.

#### 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 9). 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**

South Arm Sampling Date	Water Surface Elevation (feet NGVD 29)		Head Difference (feet)
	South Arm <sup>a</sup>	North Arm <sup>b</sup>	
January 17, 2017	4,192.13	4,191.09	1.0
February 13, 2017	4,192.61	4,192.07	0.5
March 2, 2017	4,193.46	4,192.50	1.0
April 6, 2017	4,194.55	4,193.23	1.3
May 3, 2017	4,195.24	4,194.15	1.1
June 7, 2017	4,195.29	4,194.42	0.9
July 5, 2017	4,194.86	4,194.11	0.8
August 8, 2017	4,194.14	4,193.59	0.6
September 6, 2017	4,193.68	4,193.14	0.5
October 3, 2017	4,193.52	4,192.93	0.6
November 9, 2017	4,193.57	4,192.87	0.7
December 7, 2017	4,193.72	4,193.00	0.7

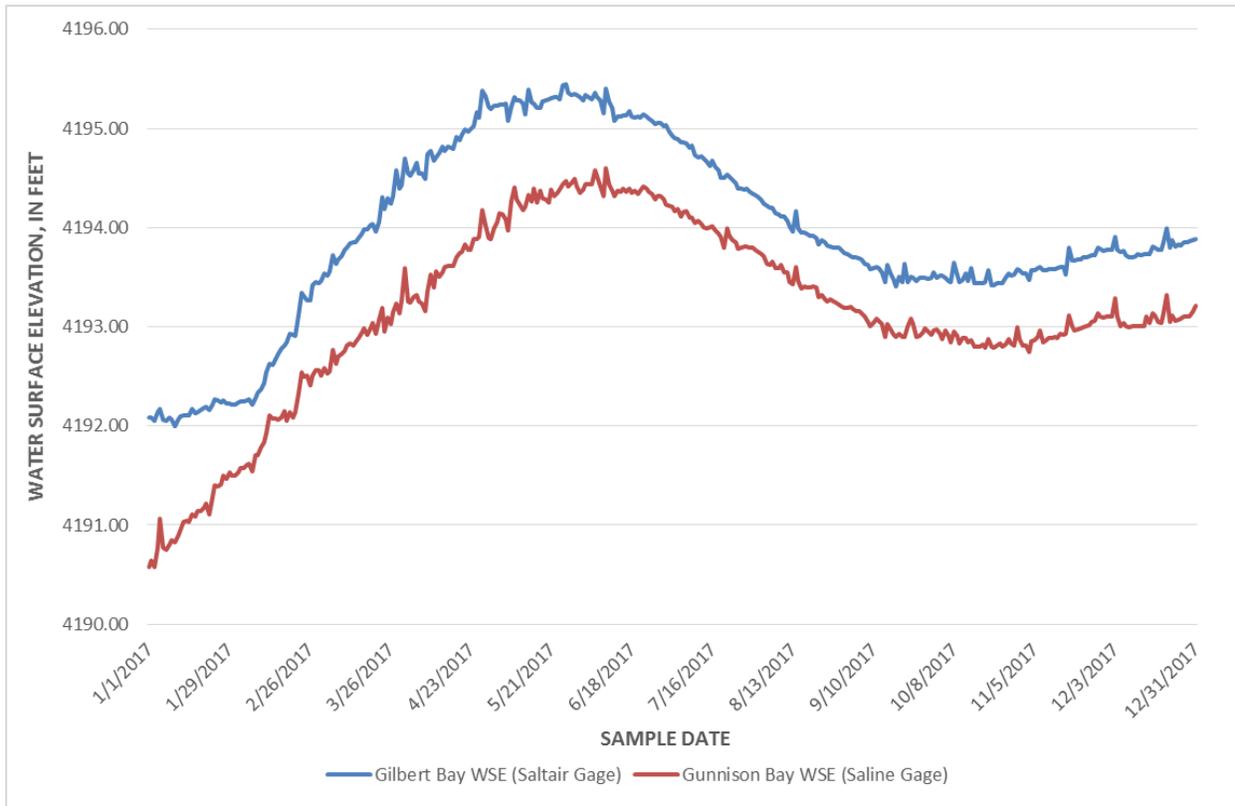
NGVD 29 = National Geodetic Vertical Datum of 1929

<sup>a</sup> USGS Station 10010000, Saltair

<sup>b</sup> USGS Station 10010100, Saline

The 2017 WSE data collected and reported by USGS and provided below indicate that, since the new causeway opened in December 2016, North Arm WSEs have increased dramatically. South Arm WSEs rose and fell seasonally, responding to increased inflows during the spring and then increased evaporation in the fall.

Figure 9. South and North Arm Water Surface Elevations in 2017



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

## 4.0 Attainment of Project Performance Standards

UPRR evaluated the 2017 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 first 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 2017 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 2017		December 2017	
		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	60	100%	60	100%
2. Flow cross-section area at invert berm, Station 0+75 (square feet) <sup>a</sup>	1,333	1,453	109%	1,444	108%
3. Average water depth at bridge (feet) <sup>b</sup>	22	21	95%	20	91%
4. Average control berm contours, invert berm width at Station 0+75 (feet)	48	52	108%	52	104%

<sup>a</sup> Based on a WSE of 4,200 feet.

<sup>b</sup> 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 for June and December, collected from under the bridge at the rail centerline (Station 0+00), were compared to channel bottom width as-built survey data. The bottom width, as measured by the two surveys, averages about 60 feet, compared to the as-built bottom width of 60 feet (see Figure 6 and Figure 7 above). The three cross-sections are consistent, and no aggregation (accumulation) of debris nor degradation (erosion of armor rock) is documented.

**Flow Cross-Sectional Area at Invert Berm.** Survey data for June and December, centerline of the rail (Station 0+75), 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 December cross-sectional areas are within 10% of the as-built survey data. No aggregation (accumulation) of debris nor degradation (erosion of armor rock) is documented.

**Average Water Depth at Bridge.** Channel bottom elevation survey data for June and December, collected from under the bridge (Station 0+00), and were compared to as-built channel bottom elevation survey data. From the cross-section data, a flow area was calculated with a WSE of 4,200 feet (lake OHWM). The June and December water depths are within 10% of the as-built survey data. No aggregation (accumulation) of debris nor degradation (erosion of armor rock) is documented.

**Average Control Berm Contours.** Invert berm width survey data for June and December, collected at the control invert berm cross-section (Station 0+75 North), were compared to the invert berm width as-built survey data. The width, measured by the two surveys, is 52 feet, compared to the as-built bottom width of 48 feet. The cross-sections are consistent, and no significant aggregation (accumulation) of debris nor degradation (erosion of armor rock or berm) is documented.

**Summary.** The 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. Although there is some variability in the survey data, the overall nominal line and grade of the control berm, channel bottom, and bridge side slopes remain consistent with the as-built conditions. This variability is due to the large size of the armor rock (4 to 6 feet in diameter) and the resulting uneven surveyed surfaces. This variability is within the accepted engineering expectations and tolerances and is expected to continue. Based on this analysis, UPRR has determined that the mitigation has met the geometry performance data during 2017, no adaptive management measures are required.

## 4.2 South Arm Salinity Performance Standard Range

The average South Arm salinity from the 2017 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 10, 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 2017 first quarterly monitoring data report, the average February South Arm salinity of 15.7% occurred when the South Arm WSE was 4,192.8 feet. Due to the low water surface elevation of the lake in February 2017, the data are reported when the WSE was below the 2012 UPRR/USGS Model range. The lake WSE rose, with increased surface flows, and the remaining three quarters that followed were reported within the 2012 UPRR/USGS Model range.

Based on this analysis, UPRR has determined that the mitigation met the salinity performance standard (project performance standard 5) during 2017, so no adaptive management measures are required.

Figure 10. Final Monitoring Results Compared to UPRR/UGS Historic South Arm Salinity Range

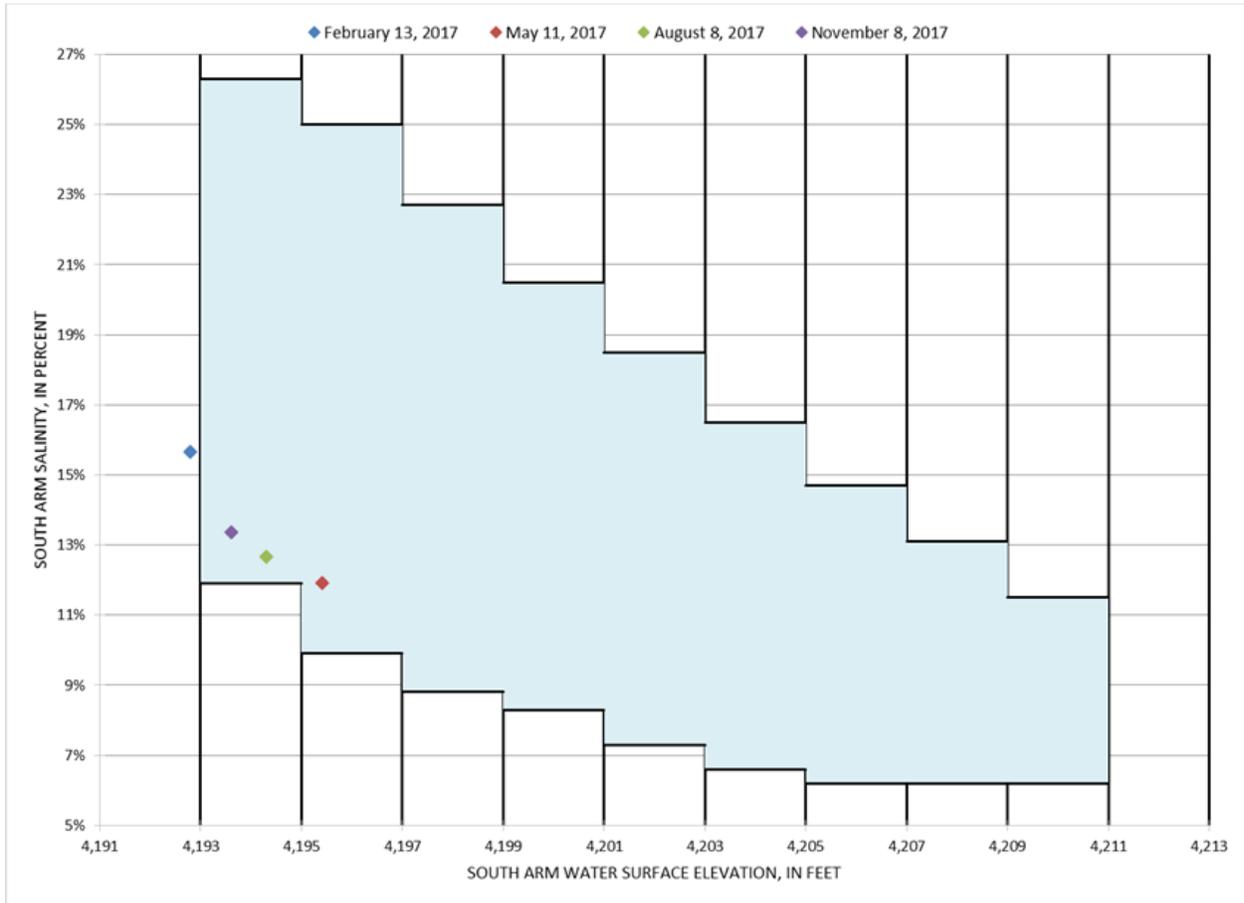


Table 7. Comparison of Monitored South Arm Salinity to Performance Standard Salinity Range by Water Surface Elevation

South Arm WSE		South Arm Salinity				
WSE on Monitoring Event Date (ft)	WSE Range (ft)	Performance Standard Salinity Range (%)	Average Salinity from Sampling Data (%)			
			February 2017	May 2017	August 2017	November 2017
4,192.8	Below 4,193	Not established	15.7			
4,194.3 / 4,193.6	4,193 up to 4,195	11.9 – 26.3			12.7	13.4
4,195.4	4,195 up to 4,197	9.9 – 25.0		11.9		
	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.

### [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.
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- 2017c Quarterly Data Monitoring Report – Third-Quarter 2017 Monitoring Results. November 7.
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### [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](http://ut.water.usgs.gov/greatsaltlake/elevations). Accessed January 15, 2018.