2020 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 2020 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, 2018, and 2019 quarterly data monitoring reports and the 2017, 2018, and 2019 annual data monitoring reports were previously submitted (UP 2017a, 2017b, 2017c, 2018a, 2018b, 2018c, 2018d, 2018e, 2019a, 2019b, 2019c, 2019d, 2019e, 2020a, 2020b). The 2017 annual data monitoring report was approved by UDWQ on March 2, 2018 (UDWQ 2018b). The 2018 annual data monitoring report was approved by UDWQ on March 20, 2019 (UDWQ 2019b). The 2019 annual data monitoring report was approved by UDWQ on February 20, 2020 (UDWQ 2020b).

The 2020 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 2020 quarterly data monitoring reports (UP 2020c, 2020d, 2020e, 2021). The required contents of this annual report are set out in the CMMP, Section 3.10.2.

This 2020 annual data 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 2020 third-quarter 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 bridge site contours remain within 10% of as-built or agreed-upon altered geometry (UP 2016a, Performance Standard 1, Table 3-5).
2. 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 3-5).
3. 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).
4. 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).
5. Determine whether the average salinity in Gilbert Bay is within the UP/Utah Geological Survey historic and 2012 model salinity ranges (UP 2016a, Performance Standard 5, Table 3-6).

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 2020 monitoring on behalf of UP. Water quality monitoring occurred in 2020 in accordance with the CMMP (UP 2016a), SAP, and QAPP (UP 2016b), and methods were previously reported in the 2020 quarterly data monitoring reports (UP 2020c, 2020d, 2020e, 2021). This report summarizes the data that were previously reported.

2.1 Study Variances

During previous monitoring years, there have been 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 due to seasonal challenges with respect to the existing WSEs, head difference, flow, velocity, and the depth to the deeper north-to-south brine flow. Section 2.2 below discusses an augmentation to the sampling procedures for the bidirectional flow at the causeway opening to help mitigate future discrepancies.

As stated in the 2020 third-quarter data monitoring report (UP 2020e), during pre-trip calibration activities in August, the monitoring team noticed that the conductivity probe was not calibrating correctly. As a result, specific conductivity measurements were not taken during August or at the open-water monitoring sites during the third quarter of 2020.

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. The SAP requires only one duplicate to be collected at the causeway opening during the monthly monitoring event. This augmentation allows the field crew to further review the field screening results during sample collection to avoid future discrepancies. All other monitoring during 2020 was conducted in conformance with the SAP and the QAPP.

As soon as possible after the monitoring team noticed that the conductivity probe was not calibrating correctly in August 2020, the monitoring team worked with the original vendor to order a replacement conductivity probe. As a result, specific conductivity measurements were again taken starting in September at the causeway opening and in the fourth quarter of 2020 at the open-water monitoring sites.

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. Total dissolved solids (TDS) was detected in May, August, September, and November. Potassium was detected in January, June, and September. Sodium was detected in February, March, May, June, and September. However, the detected concentrations were near or below 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 equipment rinsate blanks.
  - Accuracy for causeway opening flow measurements were generally rated from poor to fair.
- **Representativeness**
  - All field measurements and samples were collected from locations and during seasonal monitoring events defined in the SAP.
- **Completeness**
  - Field and laboratory completeness requirements were met. All data were collected except for specific conductivity measurements at the open-water sites during the third quarter and at the causeway opening in August.
- **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 2020 quarterly data monitoring report (UP 2020c, 2020d, 2020e, 2021).

3.0 Summary of Results

The results of each 2020 monitoring event as well as the QA/QC review are presented in the four 2020 quarterly data monitoring reports, which were dated May 15, 2020; August 15, 2020; November 15, 2020; and February 1, 2021 (UP 2020c, 2020d, 2020e, 2021). 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 2020. The causeway opening geometry survey (required annually) occurred in August. 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 2020.

Table 1. Monitoring Event Dates in 2020

Month	Lake Water Chemistry Monitoring	Causeway Opening Geometry (Survey)	Additional Monitoring
January			1/7, 1/15
February	2/10, 2/12		2/12
March			3/5, 3/11
April			4/3, 4/7
May	5/28, 5/29		5/6, 5/21
June			6/4, 6/10
July			7/8, 7/10, 7/29
August	8/12, 8/13	8/12	8/5, 8/12
September			9/3, 9/15
October			10/1, 10/6
November	11/5		11/5
December			12/3, 12/8

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 2020 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. Specific conductivity data were not collected during the third-quarter monitoring event, as previously reported in Section 2.1 and in the 2020 third-quarter data monitoring report (UP 2020e).

3.1.1 Water Temperature

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

- General temperature variation corresponds seasonally, with the coldest temperatures during the winter (February 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 for each event, both spatially and vertically, in the upper brine layer. Density concentrations in Gilbert Bay were highest in November and lowest in February, and generally indicate the presence of a deep brine layer at the Gilbert Bay sampling sites.
- Density concentrations in Gunnison Bay were highest in November and lowest in February.

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 for each event, both spatially and vertically, in the upper brine layer. TDS concentrations in Gilbert Bay were highest in November and lowest in February, and generally indicate the presence of a deep brine layer at the Gilbert Bay sampling sites.
- TDS concentrations in Gunnison Bay were generally more variable than in Gilbert Bay. TDS concentrations in Gunnison Bay were highest in November and lowest in February.

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 for each event, both spatially and vertically, in the upper brine layer. The highest measurements were recorded in November and the lowest in May. Additional measurements of specific conductivity at greater depths help define the top elevation and indicate the presence of a deep brine layer at all three Gilbert Bay sampling sites during all monitoring events in 2020. The top of the deep brine layer varied from a WSE of about 4172.2 feet to 4174.4 feet.
- Specific conductivity measurements in Gunnison Bay were vertically similar for each event throughout the year. Specific conductivity was highest in February and lowest in November.

3.1.5 Cations and Anions

Cation and anion data are presented in Appendix C, Surface Water Analytical Results, in each 2020 quarterly data monitoring report (UP 2020c, 2020d, 2020e, 2021).

Figure 1. 2020 Lake Water Temperature Data for February (top left), May (top right), August (bottom left), and November (bottom right)

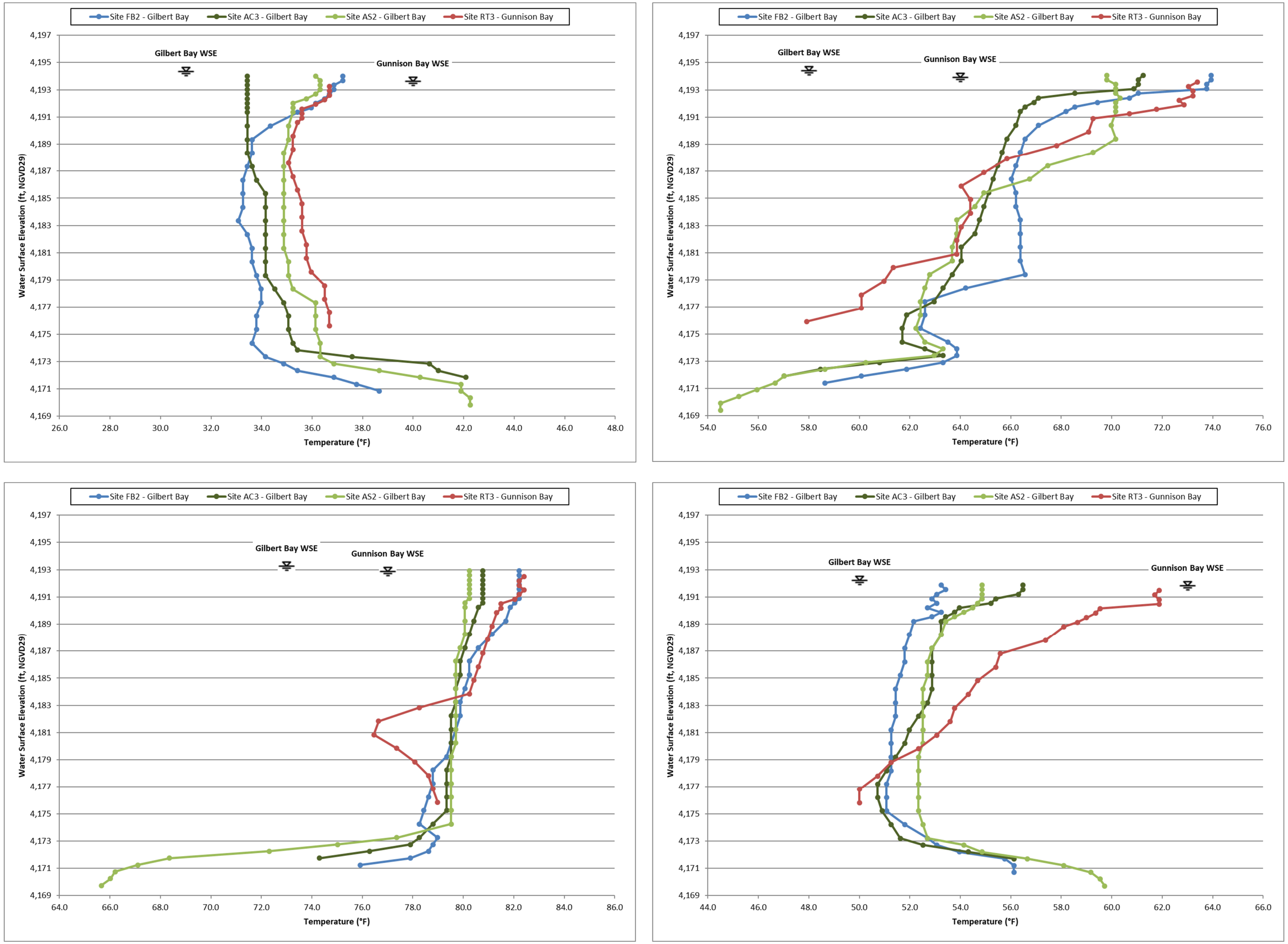


Figure 2. 2020 Lake Water Density Data for February (top left), May (top right), August (bottom left), and November (bottom right)

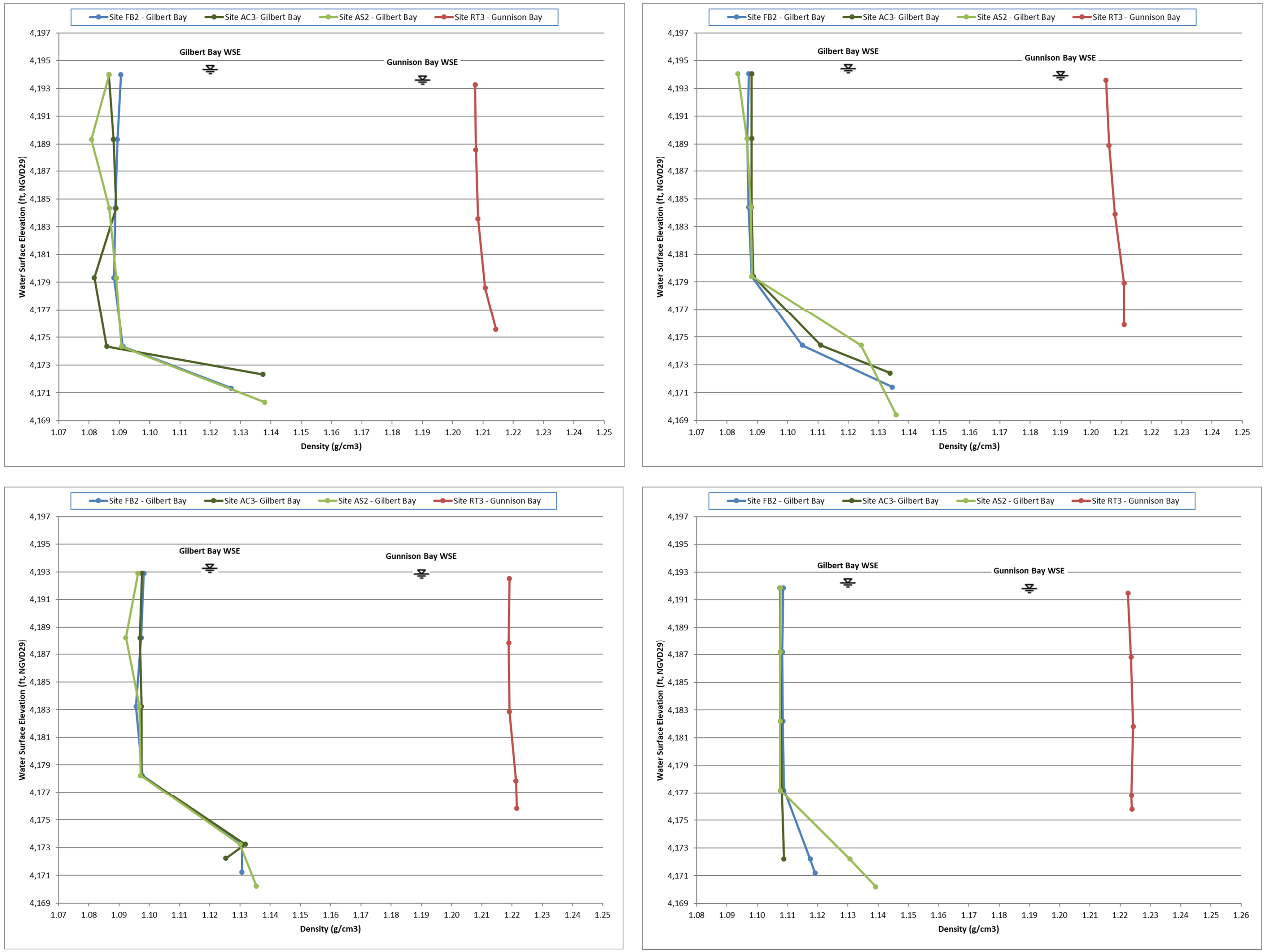


Figure 3. 2020 Lake Water TDS Data for February (top left), May (top right), August (bottom left), and November (bottom right)

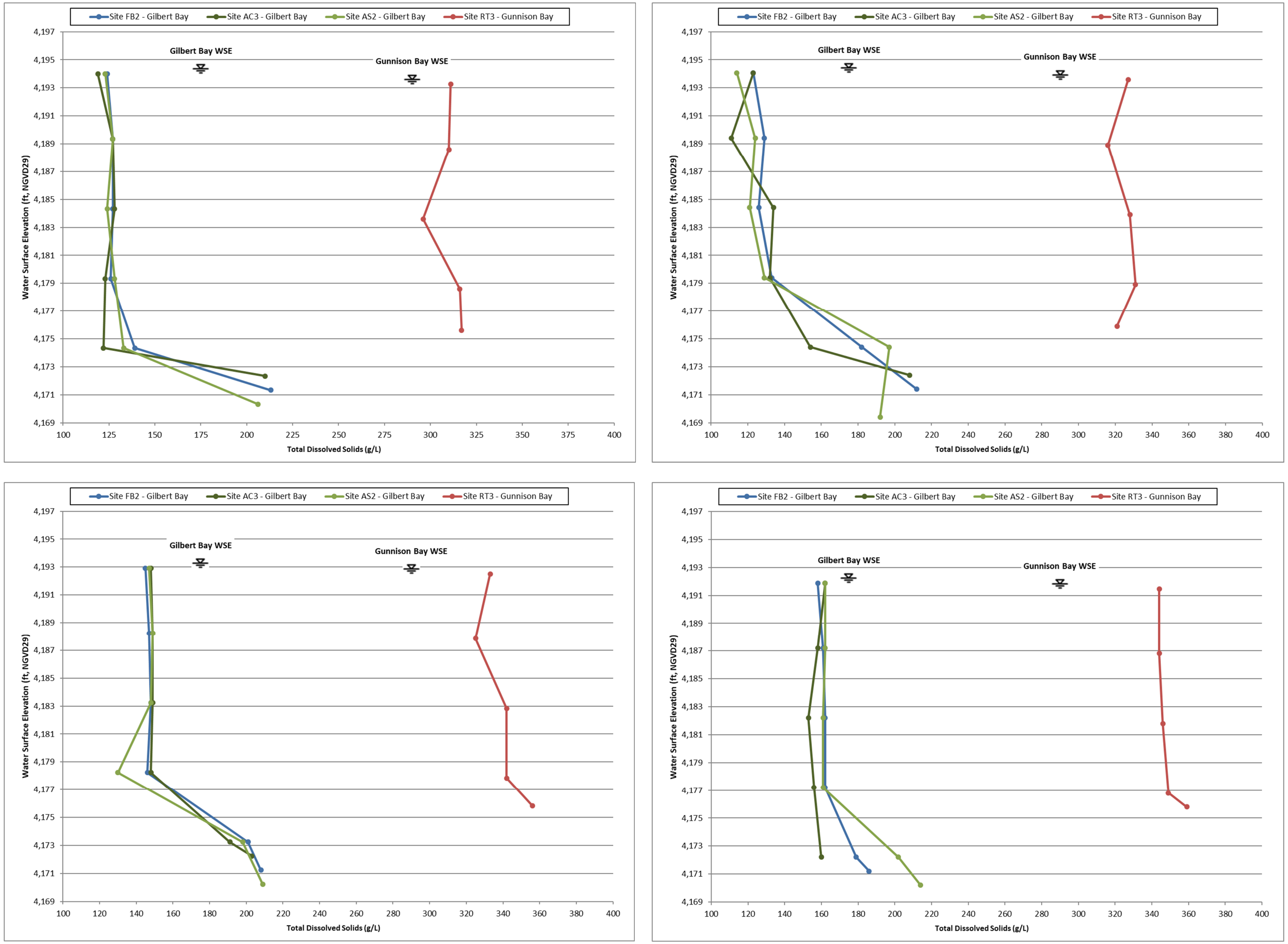
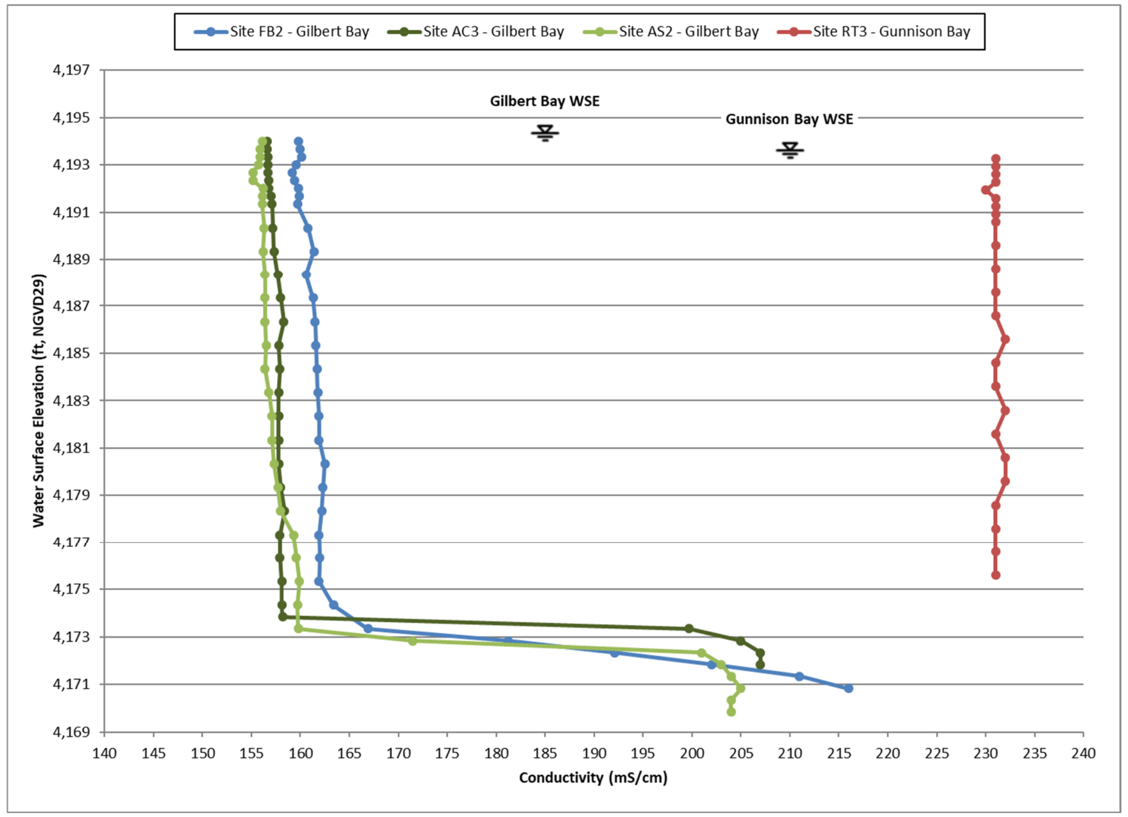
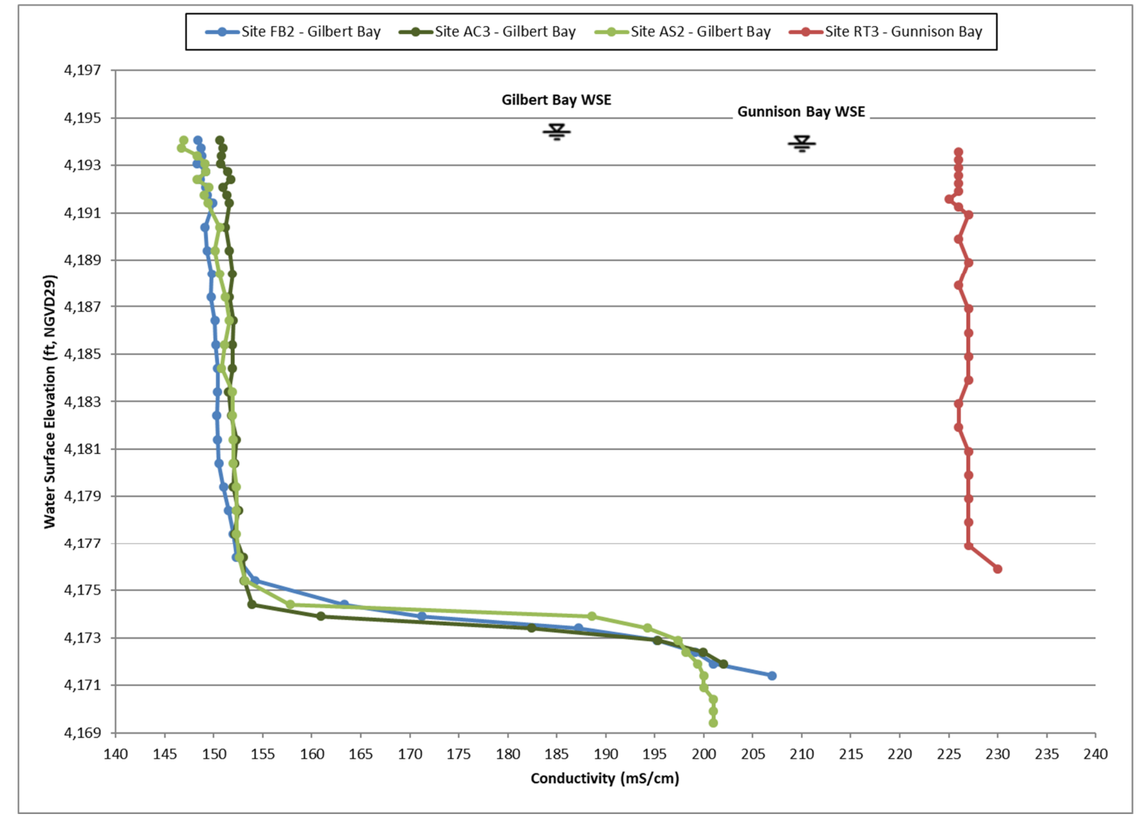
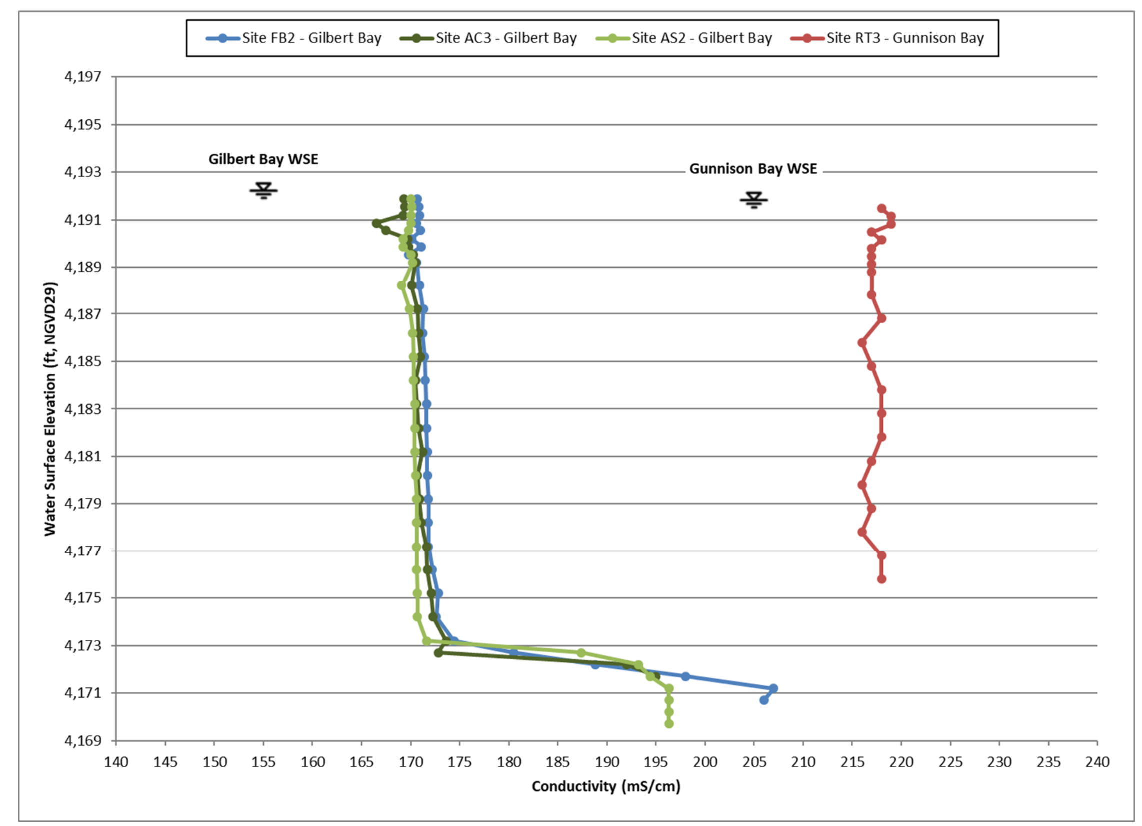


Figure 4. 2020 Lake Water Specific Conductivity Data for February (top left), May (top right), and November (bottom right)





No conductivity data recorded for August 2020;
see the 2020 third-quarter data monitoring report (UP 2020e).



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:

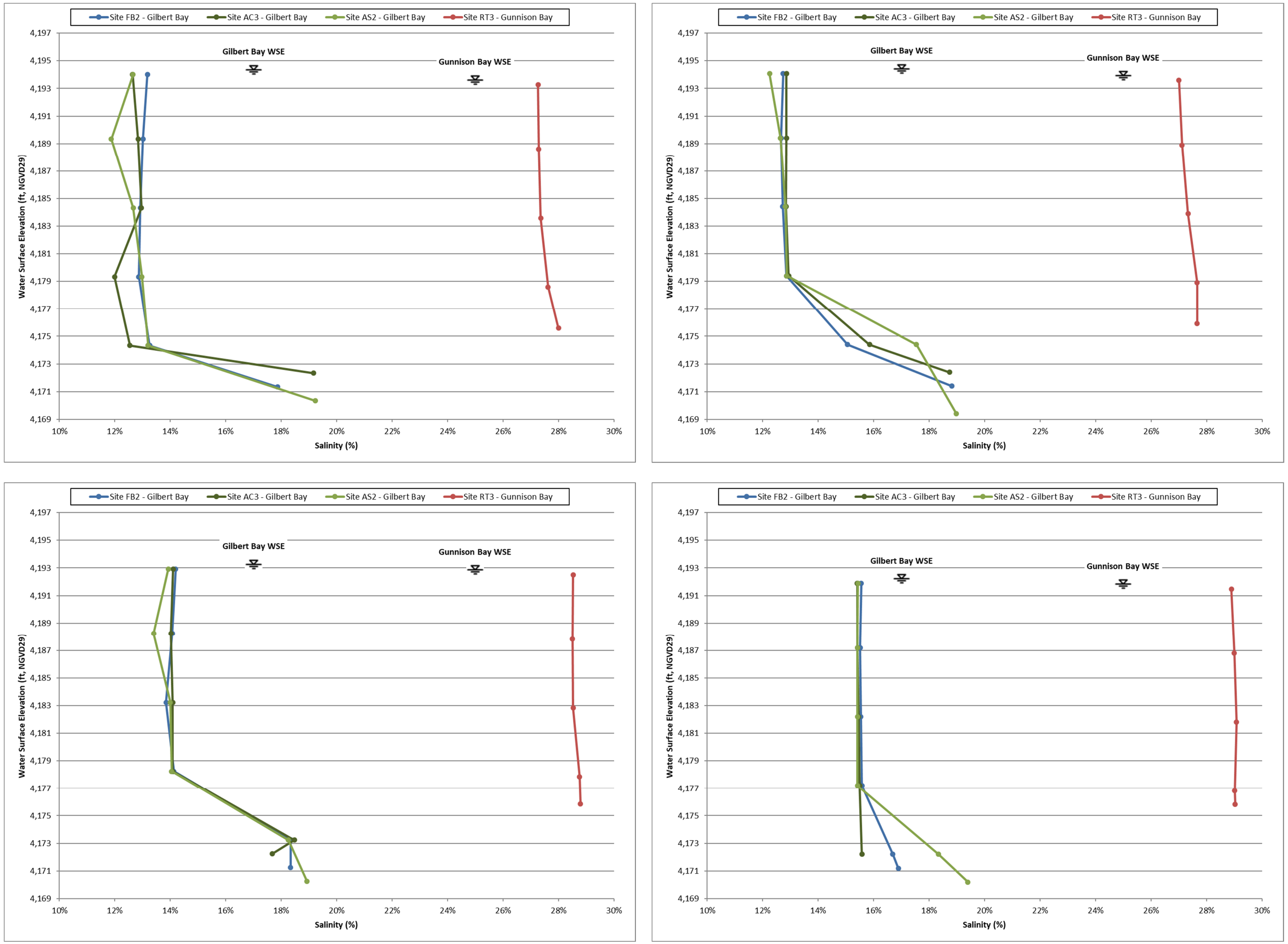
$$\text{Salinity, in percent} = \frac{C}{\rho(10)}$$

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

- Salinity, as calculated from density, at the sites in Gilbert Bay was similar for each event, both spatially and vertically, in the upper brine layer. Salinity was highest in November and lowest in February, and generally indicates the presence of a deep brine layer at the Gilbert Bay sampling sites.
- Salinity, as calculated from density, in Gunnison Bay was generally more variable than in Gilbert Bay. Salinity was highest in November and lowest in February.

This page is intentionally left blank.

Figure 5. 2020 Lake Water Salinity Data for February (top left), May (top right), August (bottom left), and November (bottom right)



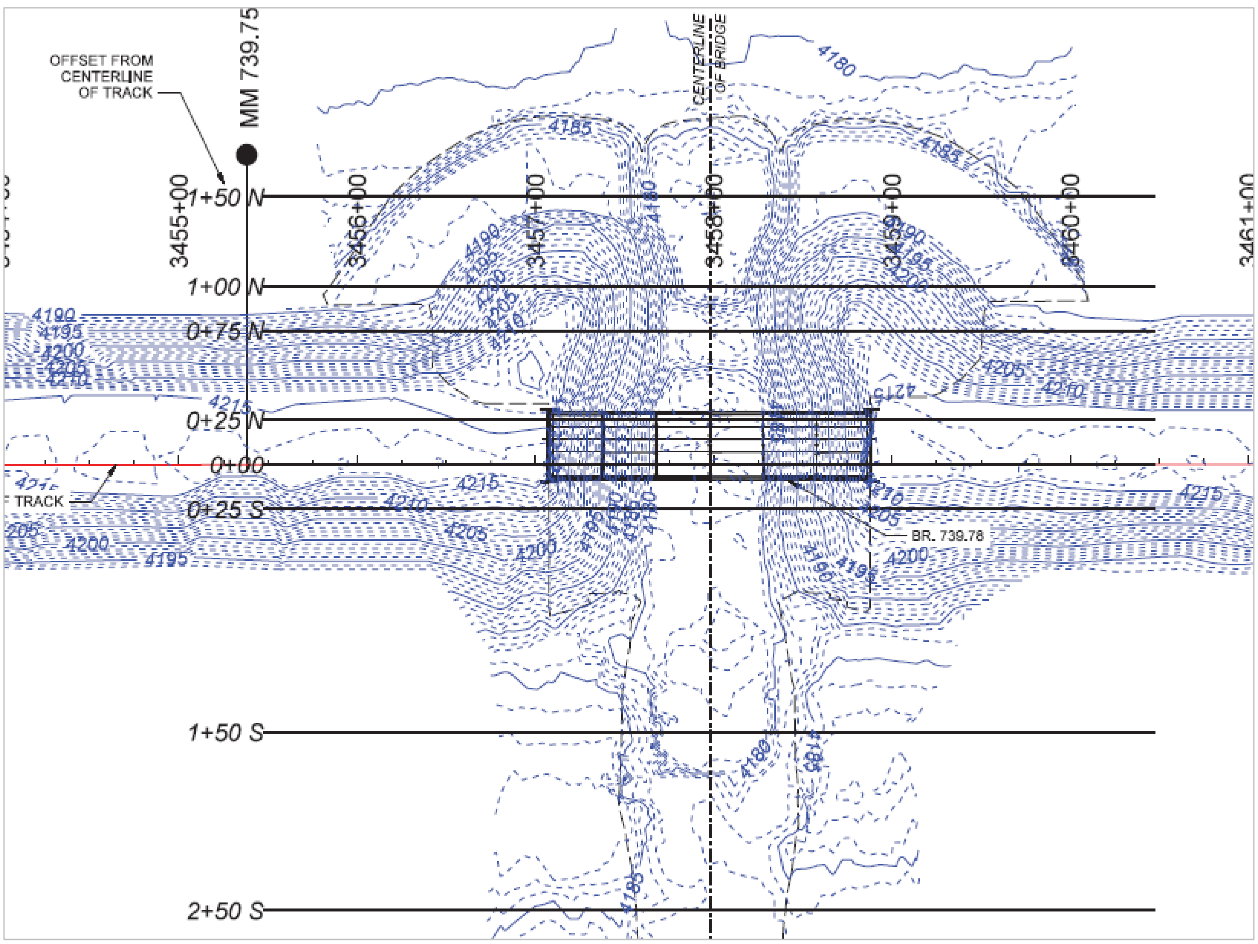
This page is intentionally left blank.

3.3 Causeway Opening Geometry

Causeway opening geometry measurements were taken in August 2020 in accordance with Section 3.10.1 of the CMMP (UP 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. UP has conducted semiannual surveys for 2017 and 2018 (the first 2 years of the monitoring period) and an annual survey for 2019 and 2020 (the third and fourth years of the monitoring period), thus meeting the permit requirements. An annual survey is scheduled for 2021.

Survey cross-section data collected in August 2020 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 2020 third-quarter data monitoring report and are summarized below (UP 2020e).

Figure 6. Locations of Geometric Cross-Sections



The results of the previously reported August 2020 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)

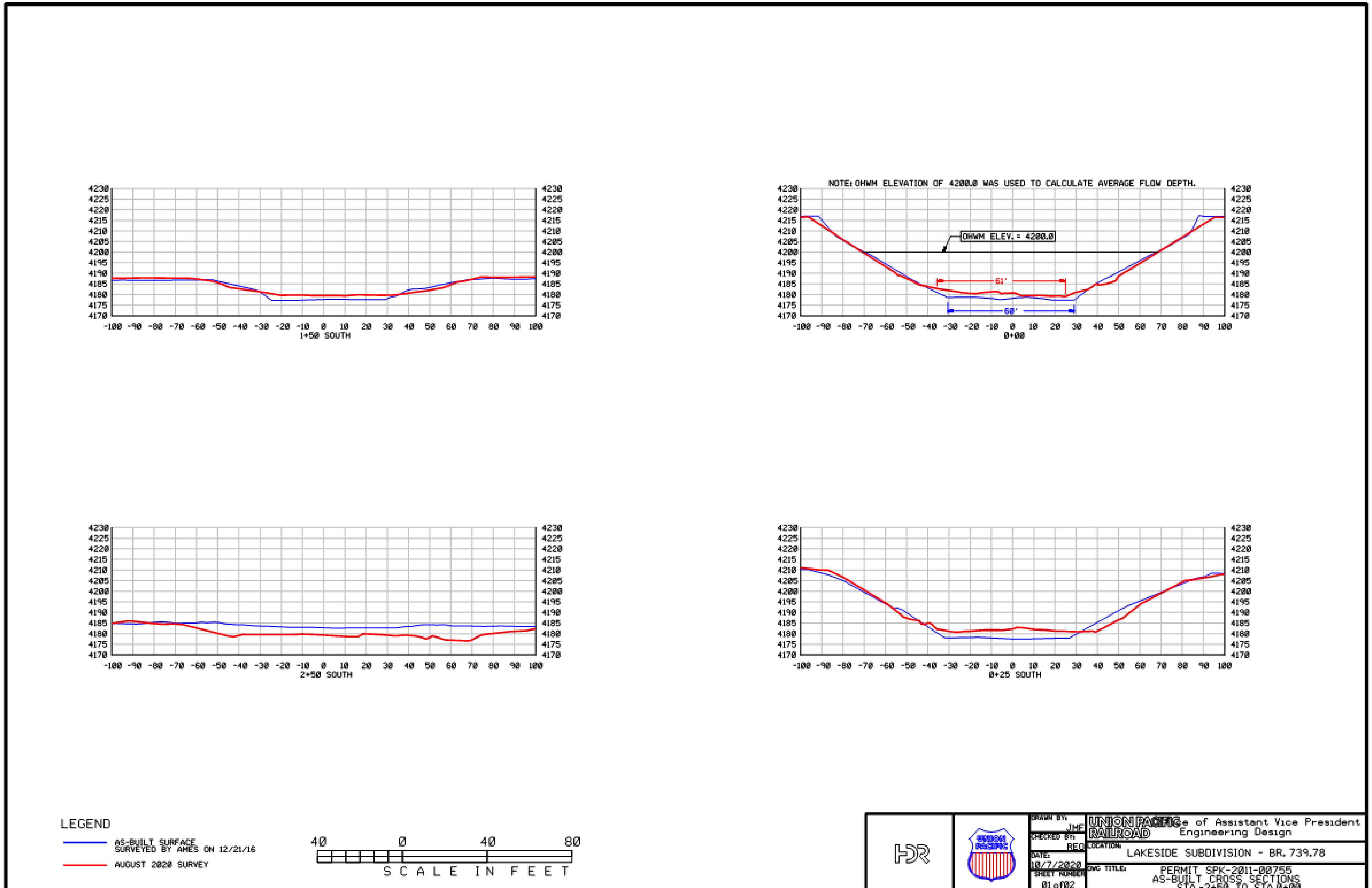
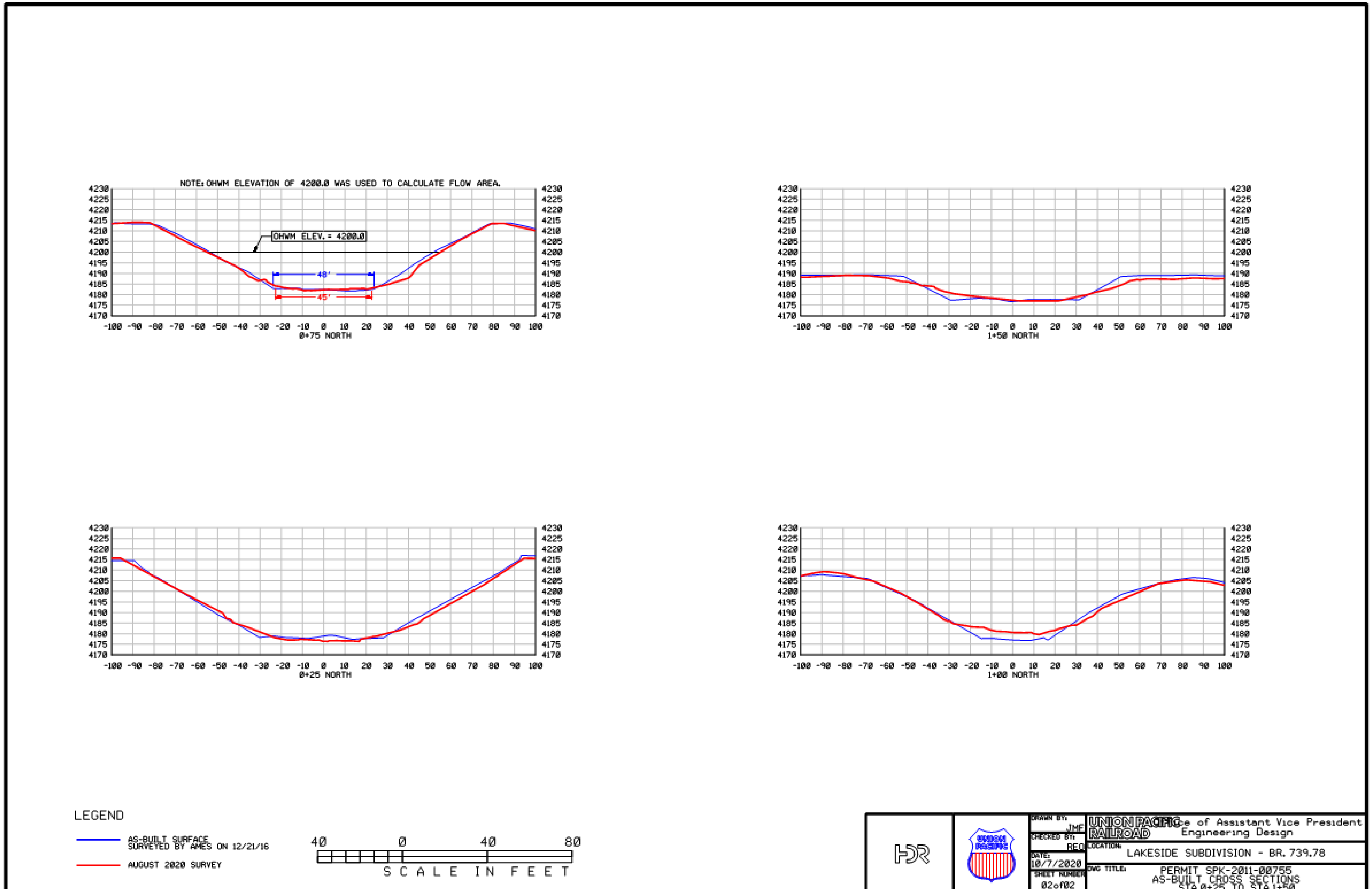


Figure 8. Cross-Section Geometry Comparison (2 of 2)



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). WSE data at the new causeway opening were collected and reported by USGS for USGS Site 10010024 (Great Salt Lake south side of causeway, 6 miles east of Lakeside, Utah) and USGS Site 10010027 (Great Salt Lake north side of causeway, 6 miles east of Lakeside, Utah). 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 (USGS Station 10010000, Great Salt Lake at Saltair Boat Harbor, Utah, and USGS Station 10010100, Great Salt Lake near Saline, Utah). These local WSEs more accurately define the head difference at the opening, which is a major component that affects the bidirectional flow through the opening.

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

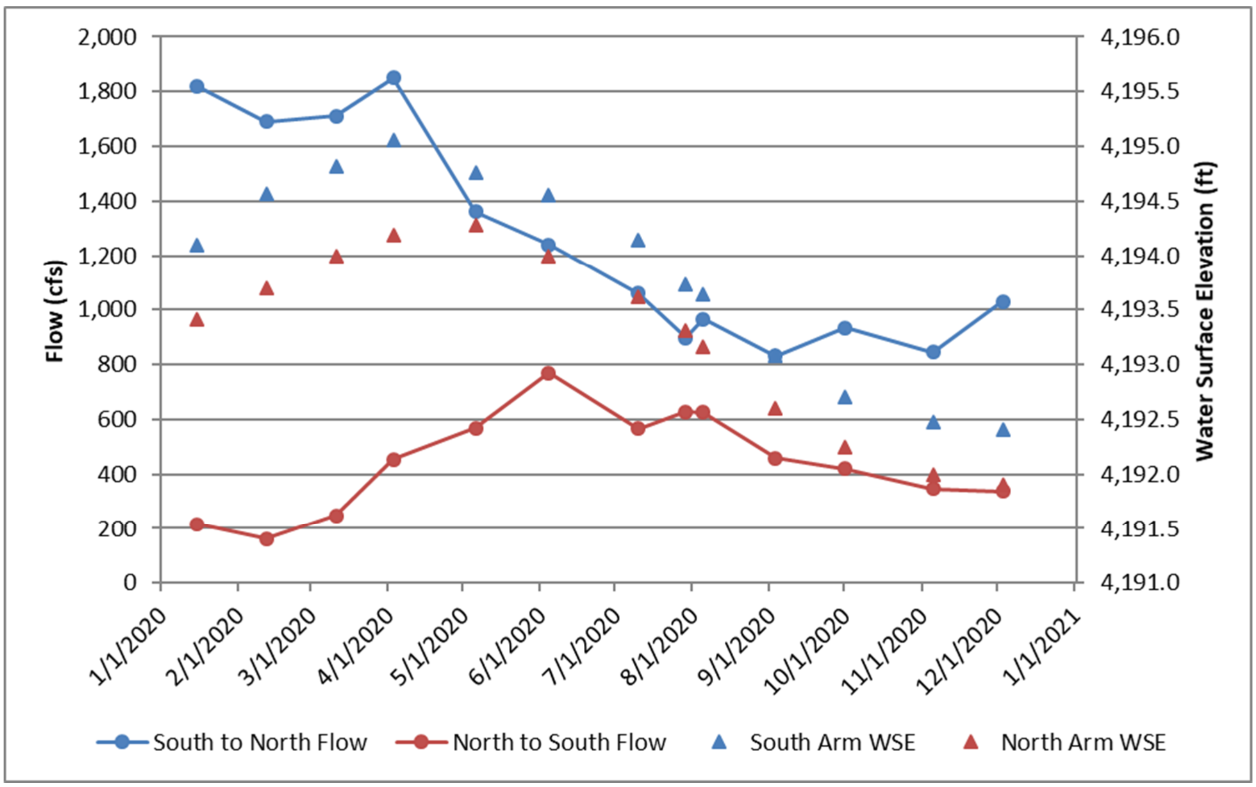


Table 2. Causeway Opening Flow Data and Depth at the Causeway Opening

Parameter	Unit	1/15/20	2/12/20	3/11/20	4/3/20	5/6/20	6/4/20	7/10/20	7/29/20	8/5/20	9/3/20	10/1/20	11/5/20	12/3/20
South-to-north flow[a]	cfs	1,820	1,690	1,710	1,850	1,360	1,240	1,060[f]	897	967[f]	832[f]	933	844	1,030
North-to-south flow[b]	cfs	217	163	249	454	568	769	567[f]	628	626[f]	459[f]	419	347	337
Average water depth in center bridge section[c]	feet	16.1[f]	16.6[f]	16.8[f]	17.1[f]	16.8[f]	16.6[f]	16.1	15.7	15.6	15.1	14.7	14.5	14.4
Flow measurement rating[a,b]	NA	Poor	Poor	Fair	Poor	Poor	Fair	Poor	Poor	Fair	Poor	Poor	Poor	Poor
Depth from water surface to North Arm brine[d]	feet	9.0	10.0	10.5	8.0	7.0	7.0	6.0	6.0	6.0	7.0	6.0	6.0	7.0
Depth of North Arm brine[e]	feet	7.1	6.6	6.3	9.1	9.8	9.6	10.1	9.7	9.6	8.1	8.7	8.5	7.4

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 2020 quarterly report.

Bidirectional flow through the causeway was reported and observed during January through December 2020 (Figure 9 above). South-to-north flows ranged from 832 to 1,850 cubic feet per second (cfs), and north-to-south flows ranged from 163 to 769 cfs.

The flow measurements during the 2020 events were rated as poor by USGS except for the events that occurred in April, June, and August, when the flow measurements were rated as fair. 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 2020. 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	1/7/20	2/12/20	3/5/20	4/7/20	5/21/20	6/10/20	7/8/20	8/12/20	9/15/20	10/6/20	11/5/20	12/8/20
South-to-North Flow													
Specific conductivity	mS/cm	156.2	152.6	138.0	146.3	149.7	148.0	158.1	—	162.3	168.0	169.8	174.6
Temperature	°C	1.5	1.2	6.1	11.0	16.1	18.6	23.2	26.8	19.8	18.8	11.4	2.6
Density	g/mL	1.0887	1.0814	1.0742	1.0833	1.0870	1.0896	1.0920	1.0974	1.1041	1.1048	1.1076	1.1088
TDS	mg/L	122,000	119,000	108,000	125,000	132,000	134,000	133,000	144,000	156,000	150,000	151,000	167,000
Salinity	Percent	12.93	11.95	10.96	12.21	12.70	13.05	13.37	14.09	14.97	15.06	15.42	15.58
Chloride	mg/L	71,200	71,600	60,900	66,200	72,000	74,400	74,500	79,400	84,500	85,900	87,900	94,100
Sulfate	mg/L	9,580	8,990	8,080	8,720	9,360	9,650	9,920	10,600	11,500	11,600	11,500	11,700
Calcium	mg/L	213	211	200	192	211	227	235	231	196	255	244	236
Magnesium	mg/L	4,500	4,320	3,980	4,010	4,430	4,790	4,870	5,000	5,320	5,690	5,470	5,470
Potassium	mg/L	2,690	2,700	2,320	2,480	2,610	2,820	2,970	3,020	3,240	3,420	3,310	3,200
Sodium	mg/L	36,800	36,200	32,800	33,100	36,000	37,900	39,600	40,900	42,900	46,400	44,800	43,600
North-to-South Flow													
Specific conductivity	mS/cm	223	229	227	224	224	217	231	—	220	223	218	218
Temperature	°C	2.5	2.2	4.4	10.6	16.3	18.5	24.5	27.0	20.7	19.0	11.4	3.9
Density	g/mL	1.2106	1.2072	1.1986	1.2017	1.1979	1.2091	1.2106	1.2182	1.2217	1.2214	1.2228	1.2226
TDS	mg/L	316,000	319,000	308,000	310,000	315,000	318,000	309,000	343,000	331,000	340,000	339,000	342,000
Salinity	Percent	27.61	27.24	26.30	26.64	26.22	27.45	27.61	28.43	28.80	28.77	28.92	28.90
Chloride	mg/L	173,000	188,000	172,000	176,000	166,000	175,000	175,000	185,000	186,000	190,000	189,000	200,000
Sulfate	mg/L	22,600	21,500	21,200	23,100	22,200	23,500	23,500	24,900	24,700	25,400	26,100	25,300
Calcium	mg/L	292	308	321	284	298	338	320	286	269	338	328	330
Magnesium	mg/L	11,100	11,500	12,000	10,600	10,600	12,300	11,100	10,600	11,500	12,800	12,400	12,600
Potassium	mg/L	6,700	7,350	6,930	6,710	6,330	7,320	6,870	6,250	7,160	7,820	7,680	7,480
Sodium	mg/L	85,500	90,600	90,600	83,600	83,900	94,900	94,400	87,000	91,900	101,000	96,100	93,600

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 total water depth, depth to the deep brine layer, and thickness of the deep brine layer for all monitoring events during 2020 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.

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

Parameter and Month Sampled	Gilbert Bay			Gunnison Bay
	Site FB2	Site AC3	Site AS2	Site RT3
Total Water Depth (feet)				
February	23.8	22.9	24.8	18.3
May	23.6	22.8	25.0	18.7
August	22.2	21.7	23.8	17.7
November	21.5	20.8	22.7	17.7
Depth from Water Surface to Deep Brine Layer (feet)				
February	21.5	21.0	21.5	NA
May	20.0	21.0	20.5	NA
August	20.5	19.0	20.0	NA
November	19.5	20.0	19.5	NA
Thickness of Deep Brine Layer (feet)				
February	2.3	1.9	3.3	NA
May	3.6	1.8	4.5	NA
August	1.7	2.7	3.8	NA
November	2.0	0.8	3.2	NA

NA = not applicable

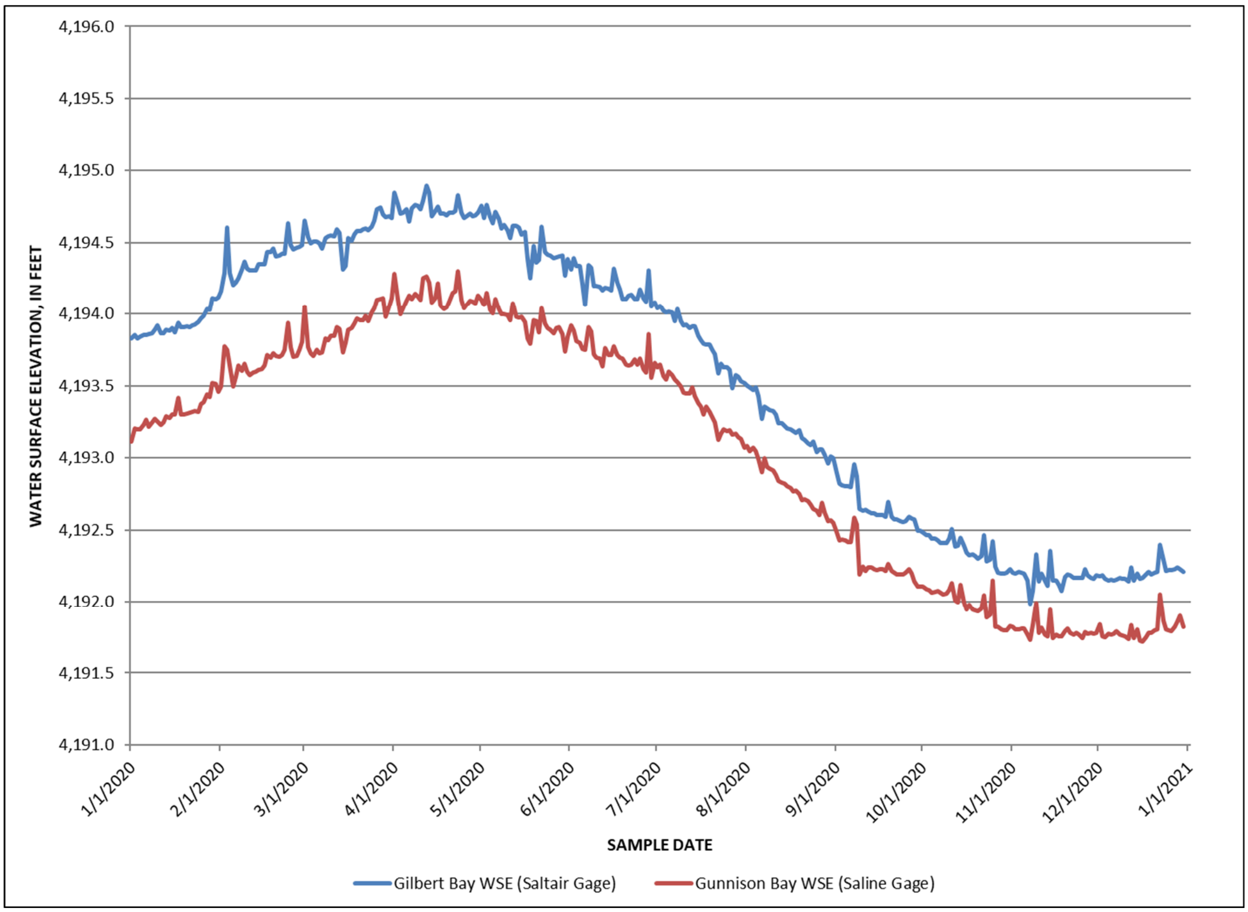
3.4.4 Monthly North and South Arm Water Surface Elevations

This section summarizes the Great Salt Lake WSE data during 2020.

Water Surface Elevation

UP acquired WSE data in 15-minute increments for Gilbert Bay and Gunnison Bay from the USGS website (USGS 2021; see Appendix A, Surface Water Elevation Data, of each quarterly data monitoring report). South Arm (Gilbert Bay) WSEs were obtained for USGS Station 10010000 (Great Salt Lake at Saltair Boat Harbor, UT), and North Arm (Gunnison Bay) WSEs were obtained for USGS Station 10010100 (Great Salt Lake near Saline, UT). Figure 10 shows the North Arm and South Arm WSEs during 2020.

Figure 10. Gilbert Bay and Gunnison Bay Water Surface Elevations in 2020



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 shows the South Arm WSE, the North Arm WSE, and the head difference for each day that water quality monitoring took place at the new causeway opening. 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 7, 2020	4,193.9	4,193.2	0.7
February 12, 2020	4,194.3	4,193.6	0.7
March 5, 2020	4,194.5	4,193.8	0.7
April 7, 2020	4,194.7	4,194.1	0.6
May 21, 2020	4,194.4	4,193.9	0.5
June 10, 2020	4,194.2	4,193.7	0.5
July 8, 2020	4,194.0	4,193.5	0.5
August 12, 2020	4,193.2	4,192.8	0.4
September 15, 2020	4,192.6	4,192.2	0.4
October 6, 2020	4,192.4	4,192.1	0.3
November 5, 2020	4,192.2	4,191.8	0.4
December 8, 2020	4,192.2	4,191.8	0.4

NGVD 29 = National Geodetic Vertical Datum of 1929
[a] USGS Station 10010000, Great Salt Lake at Saltair Boat Harbor, Utah
[b] USGS Station 10010100, Great Salt Lake near Saline, Utah

The 2020 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 increased evaporation and decreased inflows during the summer and fall. During 2020, the rise in the South Arm WSE was about 0.8 foot, while the decrease in the WSE was about 2.5 feet. The rise in the North Arm WSE was about 0.9 foot, while the decrease in the WSE was about 2.3 feet. Overall, the South Arm lake WSE fell about 1.7 feet, the North Arm lake WSE fell about 1.4 feet, and the head difference fell about 0.3 foot over 2020.

4.0 Attainment of Project Performance Standards

UP evaluated the 2020 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 fourth year of monitoring since the mitigation (causeway opening) construction was completed in December 2016.

4.1 Causeway Opening Geometry Performance Standards

Table 6 summarizes the results of the annual 2020 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	August 2020	
		Measured Value	% of As-Built
1. Average bridge side-slope contours, bottom channel width at Station 0+00 (feet)	60	61	102%
2. Flow cross-section area at invert berm, Station 0+75 (square feet)	1,333	1,390	104%
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	45	94%

Average Bridge Side-Slope Contour. Channel bottom width survey data were collected in August 2020 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 2020 annual survey, is 61 feet, compared to the as-built bottom width of 60 feet (see Figure 7 and Figure 8 above). The August cross-sectional area is within 10% of the as-built survey data, 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 August 2020 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 August 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 August 2020 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 August 2020 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 August 2020 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 August 2020 survey is 45 feet, compared to the as-built invert berm width of 48 feet. The invert berm width is within 10% of the as-built survey data, and no significant aggregation (accumulation) of debris nor degradation (erosion of armor rock or berm) is documented.

4.1.1 Performance Standards Discussion

The August 2020 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, 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. As discussed in the 2019 annual data monitoring report (UP 2020b) and in compliance with Section 3.12.1, Adaptive Management Plan, of the CMMP (UP 2016a), after the May 2019 survey indicated that the average water depth at the centerline of rail was outside project performance standard 3, UP further reviewed the invert survey data through the causeway opening to determine the extent of the effect, if any, that a decreased average water depth at the centerline of rail had on meeting the project goals. This further review included comparisons of the May 2019 survey data with the survey data reported in the 2017 and 2018 annual data monitoring reports and the collection and comparison of new survey data in September 2019. The general conclusions were reported as follows:

- There are some minor variations in the average water depth at the centerline of rail between survey events and when compared to the as-built survey data.
- There is generally limited accumulation of material in the channel invert at Station 0+00.
- The channel invert has been relatively stable since December 2017.

UP also concluded that these variations are not restricting bidirectional flow or the transfer of water and salt through the causeway opening since the channel invert at the centerline of rail (Station 0+00) is at a lower elevation than the top of the control berm (Station 0+75; also see project performance standards 2 and 4), which is still constraining north-to-south flows.

Evaluation of 2020 Survey Data. As previously stated, the May 2019 and August 2020 survey data show the average water depth at the centerline of rail to be 19.5 feet. In addition, the August 2020 survey data, together with the 2017, 2018, and 2019 survey data as reported in the respective annual data monitoring reports, show that the channel invert at the centerline of rail has continued to be relatively stable since December 2017. UP concludes that, even though the average water depth at the centerline of rail is outside project performance standard 3, the project is still meeting the project goals and the salt and water transfer through the causeway opening is not restricted by the channel invert at the centerline of rail. If any of the four project performance standards are not met from the annual survey that is scheduled for 2021, UP proposes to evaluate the new 2021 survey data in the same manner to determine whether maintenance activities are needed.

4.2 South Arm Salinity Performance Standard Range

The average South Arm salinity from the 2020 quarterly monitoring data was compared to the 2012 UP/USGS Model historic salinity 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 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 2020 indicate that monitored South Arm salinities are generally consistent with the UP/Utah Geological Survey (UGS) average historic South Arm salinities. As reported in the 2020 fourth-quarter data monitoring report (UP 2021), the November 2020 average South Arm salinity of 15.6% occurred when the South Arm WSE was 4192.2 feet, which is outside 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 WSEs.

Based on this analysis, UP has determined that the mitigation met the salinity performance standard (project performance standard 5) during 2020, so no adaptive management measures are required or proposed.

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

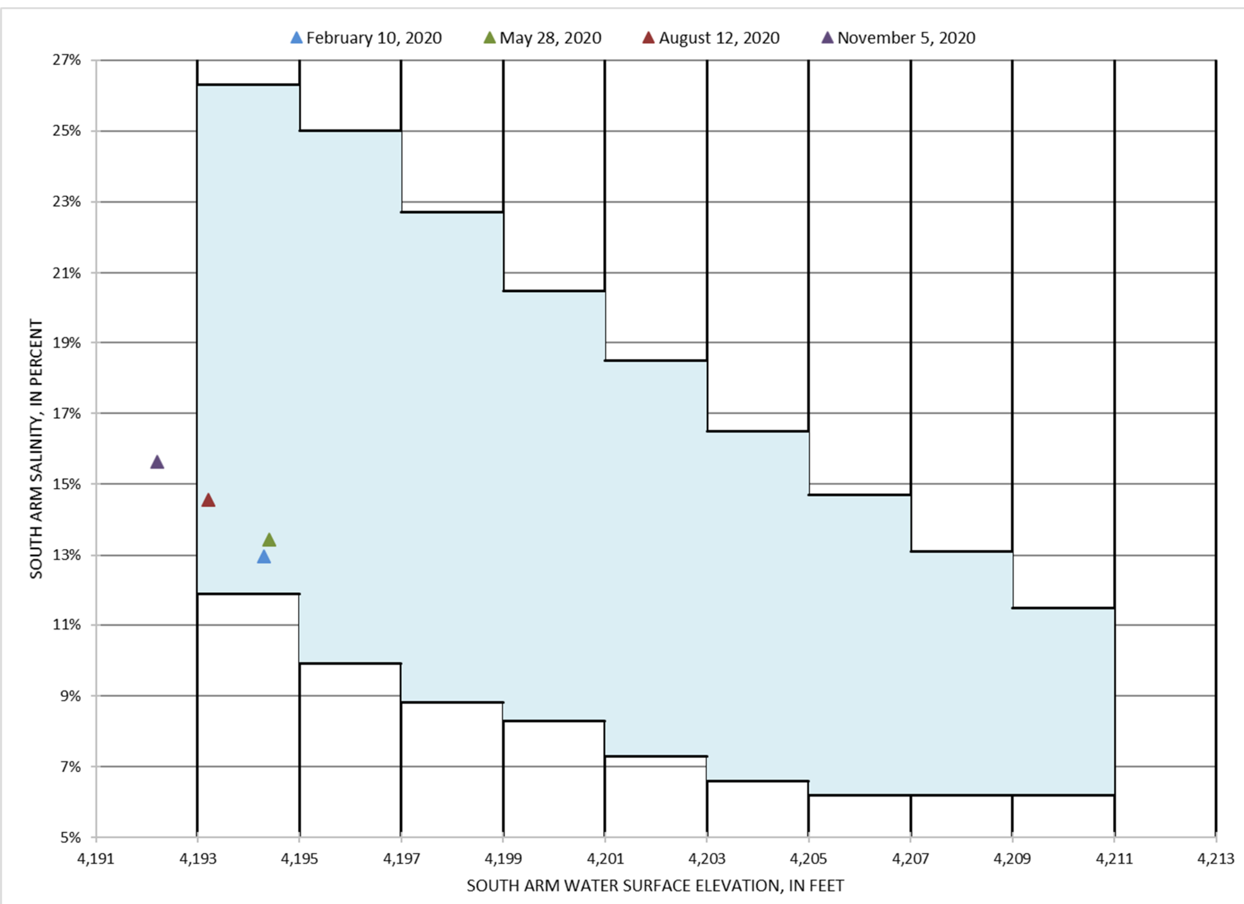


Table 7. Comparison of Monitored South Arm Salinity to Performance Standard Salinity Range by Water Surface Elevation

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 (%)			
February 2020	May 2020	August 2020	November 2020			February 2020	May 2020	August 2020	November 2020
			4,192.2	Below 4,193	Not established				15.6
4,194.3	4,194.4	4,193.2		4,193 up to 4,195	11.9 – 26.3	13.0	13.5	14.6	
				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 Karen Nichols of HDR. March 2.

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

2020 Letter from E. Brown Gaddis of UDWQ to Stephan L. Cheney, UP. February 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.

2020a Quarterly Data Monitoring Report – Fourth-Quarter 2019 Monitoring Results. February 1.

2020b 2019 Annual Data Monitoring Report. February 1.

2020c Quarterly Data Monitoring Report – First-Quarter 2020 Monitoring Results. May 15.

2020d Quarterly Data Monitoring Report – Second-Quarter 2020 Monitoring Results. August 15.

2020e Quarterly Data Monitoring Report – Third-Quarter 2020 Monitoring Results. November 15.

2021 Quarterly Data Monitoring Report – Fourth-Quarter 2020 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.

2021 Great Salt Lake – Lake Elevations. ut.water.usgs.gov/greatsaltlake/elevations. Accessed January 4, 2021.

This page is intentionally left blank.