2018 Annual
Data Monitoring Report

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

SPK-2011-00755

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

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

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

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


1.2 Goals and Objectives

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

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

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

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

2.0 Methods

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

2.1 Study Variances

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

2.2 Corrective Actions

None.
2.3 Quality Assurance

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

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

- **Precision**
  - Field duplicate sample results were generally less than 10% different from their corresponding primary samples. All results were less than 20% different from each other.

- **Accuracy and Bias**
  - Field instrument calibration met manufacturers’ requirements.
  - Laboratory QA/QC met each laboratory’s internal method requirements.
  - Laboratory analytes were generally not detected in field blank samples. Total dissolved solids (TDS) was detected in field blank samples near the reporting limit on February 14 and April 11. Potassium and sodium were detected near their reporting limits in field blank samples on June 7. However, the detected concentration was between 3 and 4 orders of magnitude less than the concentrations of the associated lake water samples.
  - Laboratory analytes were often detected in equipment rinsate blank samples. However, the detected concentrations were near the reporting limit between 3 and 4 orders of magnitude less than the concentrations of the associated lake water samples.

- **Representativeness**
  - All field measurements and samples were collected from locations and seasonal sampling events defined in the SAP.

- **Completeness**
  - Field and laboratory completeness requirements were met.

- **Comparability**
  - Field conditions were within the range of the selected in-situ meter and probe capabilities.
  - Laboratory method reporting limits were sufficient to detect concentrations in the lake and causeway samples.

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

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

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

3.1 North and South Arm Water Quality Parameters

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

- Water temperature
- Density
- TDS
- Specific conductivity

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

Table 1. Monitoring Event Dates in 2018

<table>
<thead>
<tr>
<th>Month</th>
<th>Lake Water Chemistry Monitoring</th>
<th>Causeway Opening Geometry (Survey)</th>
<th>Additional Monitoring</th>
</tr>
</thead>
<tbody>
<tr>
<td>January</td>
<td></td>
<td></td>
<td>1/3</td>
</tr>
<tr>
<td>February</td>
<td>2/6, 2/7</td>
<td></td>
<td>2/6</td>
</tr>
<tr>
<td>March</td>
<td></td>
<td></td>
<td>3/7</td>
</tr>
<tr>
<td>April</td>
<td></td>
<td></td>
<td>4/11</td>
</tr>
<tr>
<td>May</td>
<td>5/3, 5/4</td>
<td></td>
<td>5/3</td>
</tr>
<tr>
<td>June</td>
<td></td>
<td>June</td>
<td>6/7</td>
</tr>
<tr>
<td>July</td>
<td></td>
<td></td>
<td>7/12</td>
</tr>
<tr>
<td>August</td>
<td>8/7, 8/8</td>
<td></td>
<td>8/7</td>
</tr>
<tr>
<td>September</td>
<td></td>
<td></td>
<td>9/5</td>
</tr>
<tr>
<td>October</td>
<td></td>
<td></td>
<td>10/2</td>
</tr>
<tr>
<td>November</td>
<td>11/6, 11/7</td>
<td>November</td>
<td>11/6</td>
</tr>
<tr>
<td>December</td>
<td></td>
<td></td>
<td>12/6</td>
</tr>
</tbody>
</table>
3.1.1  Water Temperature

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

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

3.1.2  Density

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

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

3.1.3  Total Dissolved Solids (TDS)

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

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

3.1.4  Specific Conductivity

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

- Specific conductivity measurements at the sites in Gilbert Bay were similar, both spatially and vertically, throughout the year in the upper brine layer. The highest measurements were recorded in November and the lowest in May. Additional measurements were taken (every 6 inches in the water column) to better define the presence of the deep brine layer. The specific conductivity data indicate that the deep brine layer was present at every Gilbert Bay sampling site for all four monitoring events, with the top of the deep brine layer varying from a WSE of about 4,173 feet to just below 4,175 feet.
- Specific conductivity measurements in Gunnison Bay were similar across all four monitoring events.
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Figure 1. 2018 Lake Water Temperature Data for February (top left), May (top right), August (bottom left), and November (bottom right)
Figure 2. 2018 Lake Water Density Data for February (top left), May (top right), August (bottom left), and November (bottom right)
Figure 3. 2018 Lake Water TDS Data for February (top left), May (top right), August (bottom left), and November (bottom right)
Figure 4. 2018 Lake Water Specific Conductivity Data for February (top left), May (top right), August (bottom left), and November (bottom right)
3.2 Lake Water Salinity

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

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

Where

- \( C \) = dissolved-solids concentration, in grams per liter (g/L)
- \( \rho \) = density at 20 degrees Celsius, in g/mL

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

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

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

- Gunnison Bay salinity was lower in May and increased in November.
- Over the course of the 2018 monitoring events, the South Arm salinity was highest in November and lowest in May.
Figure 5. 2018 Lake Water Salinity Data for February (top left), May (top right), August (bottom left), and November (bottom right)
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3.3 **Causeway Opening Geometry**

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

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

**Figure 6. Locations of Geometric Cross-Sections**

The results of the June and December 2018 survey and the comparison to the as-built survey measurements are shown by cross-sections in Figure 7 and Figure 8.
Figure 7. Cross-Section Geometry Comparison (1 of 2)
Figure 8. Cross-Section Geometry Comparison (2 of 2)
3.4 Additional Data Collected

3.4.1 Water Surface Elevation at and Flow Measurements through Causeway Opening

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

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

Figure 9. Water Surface Elevation at and Flow through Causeway Opening
### Table 2. Causeway Opening Flow Data and Depth at the Causeway Opening

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

- 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> 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>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> As measured by UPRR in the field.
- <sup>e</sup> Calculated based on average water depth in center bridge section and depth from water surface to North Arm brine.
Bidirectional flow through the causeway was observed January–December 2018 (Figure 9 above). South-to-north flows ranged from 728 to 1,700 cubic feet per second (cfs), and north-to-south flows ranged from 162 to 1,000 cfs. The July monitoring event documented higher north-to-south flow than south-to-north flow for the first time since bidirectional flow first occurred in July 2017.

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

### 3.4.2 Monthly Water Quality at Causeway Opening

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

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

mS/cm = milliSiemens per centimeter, °C = degrees Celsius, g/mL = grams per milliliter, g/L = grams per liter, mg/L = milligrams per liter
3.4.3 Quarterly Measurements of the South Arm Deep Brine Layer

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

Depth to Brine Layer

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

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

<table>
<thead>
<tr>
<th>Parameter and Month Sampled</th>
<th>Gilbert Bay</th>
<th>Gunnison Bay</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Site FB2</td>
<td>Site AC3</td>
</tr>
<tr>
<td><strong>Total Water Depth (feet)</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>February</td>
<td>23.6</td>
<td>22.5</td>
</tr>
<tr>
<td>May</td>
<td>24.3</td>
<td>23.4</td>
</tr>
<tr>
<td>August</td>
<td>22.5</td>
<td>21.9</td>
</tr>
<tr>
<td>November</td>
<td>21.5</td>
<td>20.7</td>
</tr>
<tr>
<td><strong>Depth from Water Surface to Deep Brine Layer (feet)</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>February</td>
<td>23.0</td>
<td>No DBL observed</td>
</tr>
<tr>
<td>May</td>
<td>23.0</td>
<td>23.0</td>
</tr>
<tr>
<td>August</td>
<td>20.5</td>
<td>20.0</td>
</tr>
<tr>
<td>November</td>
<td>19.0</td>
<td>19.5</td>
</tr>
<tr>
<td><strong>Thickness of Deep Brine Layer (feet)</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>February</td>
<td>0.6</td>
<td>No DBL observed</td>
</tr>
<tr>
<td>May</td>
<td>1.3</td>
<td>0.4</td>
</tr>
<tr>
<td>August</td>
<td>2.0</td>
<td>1.9</td>
</tr>
<tr>
<td>November</td>
<td>2.5</td>
<td>1.2</td>
</tr>
</tbody>
</table>

DBL = deep brine layer; NA = not applicable
### 3.4.4 Monthly North and South Arm Water Surface Elevations

This section summarizes the lake WSE data during 2018.

**Water Surface Elevation**

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

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

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

### Table 5. Monthly Water Surface Elevation and Computed Head Difference

<table>
<thead>
<tr>
<th>Water Quality Sampling Date</th>
<th>Water Surface Elevation (feet NGVD 29)</th>
<th>Head Difference (feet)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>South Arm(^a)</td>
<td>North Arm(^b)</td>
</tr>
<tr>
<td>January 3, 2018</td>
<td>4,193.9</td>
<td>4,193.2</td>
</tr>
<tr>
<td>February 6, 2018</td>
<td>4,194.3</td>
<td>4,193.6</td>
</tr>
<tr>
<td>March 7, 2018</td>
<td>4,194.4</td>
<td>4,193.8</td>
</tr>
<tr>
<td>April 11, 2018</td>
<td>4,194.8</td>
<td>4,194.1</td>
</tr>
<tr>
<td>May 3, 2018</td>
<td>4,194.8</td>
<td>4,194.1</td>
</tr>
<tr>
<td>June 7, 2018</td>
<td>4,194.6</td>
<td>4,194.0</td>
</tr>
<tr>
<td>July 12, 2018</td>
<td>4,193.8</td>
<td>4,193.3</td>
</tr>
<tr>
<td>August 7, 2018</td>
<td>4,193.3</td>
<td>4,192.8</td>
</tr>
<tr>
<td>September 5, 2018</td>
<td>4,192.8</td>
<td>4,192.3</td>
</tr>
<tr>
<td>October 2, 2018</td>
<td>4,192.1</td>
<td>4,191.9</td>
</tr>
<tr>
<td>November 6, 2018</td>
<td>4,192.0</td>
<td>4,191.8</td>
</tr>
<tr>
<td>December 6, 2018</td>
<td>4,192.1</td>
<td>4,191.8</td>
</tr>
</tbody>
</table>

NGVD 29 = National Geodetic Vertical Datum of 1929  
\(^a\) USGS Station 10010000, Saltair  
\(^b\) USGS Station 10010100, Saline

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

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

4.1 Causeway Opening Geometry Performance Standards

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

<table>
<thead>
<tr>
<th>Performance Standard</th>
<th>As-Built</th>
<th>June 2018</th>
<th>November 2018</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Measured Value</td>
<td>% of As-Built</td>
<td>Measured Value</td>
</tr>
<tr>
<td>1. Average bridge side-slope contours, bottom channel width at Station 0+00 (feet)</td>
<td>60</td>
<td>61</td>
<td>102%</td>
</tr>
<tr>
<td>2. Flow cross-section area at invert berm, Station 0+75 (square feet)a</td>
<td>1,333</td>
<td>1,342</td>
<td>101%</td>
</tr>
<tr>
<td>3. Average water depth at bridge (feet)b</td>
<td>22</td>
<td>20</td>
<td>91%</td>
</tr>
<tr>
<td>4. Average control berm contours, invert berm width at Station 0+75 (feet)</td>
<td>48</td>
<td>48</td>
<td>100%</td>
</tr>
</tbody>
</table>

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

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

Flow Cross-Sectional Area at Invert Berm. Survey data were collected in June and November 2018 at the centerline of the invert berm (Station 0+75) and were compared to as-built survey data. From the cross-section data, a flow area was calculated with the invert berm top width and elevation and a WSE of 4,200 feet (the lake ordinary high water mark, or OHWM) (USACE 2015b). The June and November cross-sectional areas are within 10% of the as-built survey data. No significant change in flow cross-section area is documented.
**Average Water Depth at Bridge.** Channel bottom elevation survey data were collected in June and November 2018 at the centerline of the rail (Station 0+00) and were compared to as-built channel bottom elevation survey data. From the cross-section data, an average water depth was calculated based on a WSE of 4,200 feet (lake OHWM). The June water depth is within 10% of the as-built survey data. The November water depth was measured at 19 feet, compared to the as-built survey datum of 22 feet. The November measurement varies from the as-built survey datum by 14%.

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

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

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

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

### 4.2 South Arm Salinity Performance Standard Range

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

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

The South Arm quarterly average salinity data and the comparative analysis indicate that monitored South Arm salinities are generally consistent with the UPRR/Utah Geological Survey (UGS) average historic South Arm salinities. As reported in the 2018 fourth quarterly monitoring data report, the average February South Arm salinity of 15.2% occurred when the South Arm WSE was 4,192.3 feet. Due to the low water surface elevation of the lake in November 2018, the data are reported with the WSE below the
2012 UPRR/USGS Model range. However, the South Arm salinity is within the range that could be anticipated if the model salinity were extrapolated through lower lake WSEs.

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

**Figure 11. Final Monitoring Results Compared to UPRR/USGS Historic South Arm Salinity Range**
Table 7. Comparison of Monitored South Arm Salinity to Performance Standard Salinity Range by Water Surface Elevation

<table>
<thead>
<tr>
<th>South Arm WSE</th>
<th>South Arm Salinity</th>
</tr>
</thead>
<tbody>
<tr>
<td>WSE on Monitoring Event Date (ft)</td>
<td>WSE Range (ft)</td>
</tr>
<tr>
<td>February 2018</td>
<td>May 2018</td>
</tr>
<tr>
<td>4192.0</td>
<td>Below 4,193</td>
</tr>
<tr>
<td>4,194.3</td>
<td>4,194.8</td>
</tr>
<tr>
<td>4,195 up to 4,197</td>
<td>9.9 – 25.0</td>
</tr>
<tr>
<td>4,197 up to 4,199</td>
<td>8.8 – 22.7</td>
</tr>
<tr>
<td>4,199 up to 4,201</td>
<td>8.3 – 20.5</td>
</tr>
<tr>
<td>4,201 up to 4,203</td>
<td>7.3 – 18.5</td>
</tr>
<tr>
<td>4,203 up to 4,205</td>
<td>6.6 – 16.5</td>
</tr>
<tr>
<td>4,205 up to 4,207</td>
<td>6.2 – 14.7</td>
</tr>
<tr>
<td>4,207 up to 4,209</td>
<td>6.2 – 13.1</td>
</tr>
<tr>
<td>4,209 up to 4,211</td>
<td>6.2 – 11.5</td>
</tr>
</tbody>
</table>

ft = feet; WSE = water surface elevation
5.0 References

[UDWQ] Utah Division of Water Quality
2018 Email from W. Damery of UDWQ to K. Nichols of HDR. March 2.

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

[USACE] United States Army Corps of Engineers
2015b Method for Identifying the Ordinary High Water Mark for the Great Salt Lake. Regulatory Division Memorandum 2015-02. September 28