Bridge Evaluation Report

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

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1.0 Introduction

1.1 Background

The Union Pacific Railroad (UPRR) operates trains on a rock-fill causeway built by UPRR's predecessor in 1959 across the Great Salt Lake. Until recently, water and salt were conveyed back and forth between the lake's North and South Arms through two culverts, an existing 300-foot-long bridge, and the causeway rock fill.

When inspections revealed that the culverts were in the process of failing (collapsing), UPRR met with the U.S. Army Corps of Engineers (USACE), the Utah Division of Water Quality (UDWQ), and other agencies and then applied in May 2011 for the necessary approvals to close the two culverts. UPRR also proposed to construct a 180-foot-long bridge to compensate for the loss of water and salt transfer between the North and South Arms that the culverts had been providing before their closure.

An extensive regulatory review process ensued. As that process continued, the condition of the culverts also continued to deteriorate. In November 2012 and December 2013, it became necessary for UPRR to close the west and then the east culvert under separate emergency authorizations from USACE when additional inspections identified the imminent risk of culvert failure. The December 2013 emergency closure of the east culvert also required the approval of UDWQ. The east culvert closure authorization was temporary, and UPRR submitted applications to USACE and UDWQ for authorization of permanent closure of the east culvert and construction of a 180-foot-long bridge as compensatory mitigation for the loss of aquatic functions that would result from the project overall.

1.2 UPRR Modeling and Impacts Analysis Plan and Modeling Report

During the process of reviewing UPRR's original proposal, USACE, UDWQ, and other federal and state agencies raised a number of concerns about the potential impacts of the project and the adequacy of UPRR's evaluation of potential impacts up to that point.

On February 21, 2013, USACE summarized these concerns as follows:

> There remain uncertainties about the ability for the new breach to provide the same functions as the culverts and the [proposed compensatory mitigation bridge] exacerbating the differing salinity concentrations between the North and South Arms of the lake.

In a June 26, 2013, letter to UPRR, USACE cited

> … continuing concerns that closure of the west [culvert] and the construction of the new bridge could result in more than minimal impacts to the Great Salt Lake ecosystem. UPRR has not adequately demonstrated that the construction of the bridge (design and location) will offset the impacts of closing the culverts and not further exacerbate the salinity concentration difference and reduce the bi-directional flows between the North and South Arms of the lake.

USACE, UDWQ, and virtually every agency commenting on UPRR's proposal insisted that, in order to evaluate the project's potential impacts adequately, UPRR must update, calibrate, and use the U.S. Geological Survey's (USGS) Water and Salt Balance Model of the Great Salt Lake, Utah (referred to in this report as the 1998 USGS Model). In particular, the 1998 USGS Model was seen as an essential tool for evaluating the impacts of UPRR's proposal on the lake's water and salt balance.

In response to these concerns, UPRR undertook a major re-evaluation of potential project impacts in April 2013. After extensive review of the issues raised by USACE, UDWQ, and the coordinating agencies, UPRR submitted on September 25, 2013, a comprehensive plan to complete its impacts analysis. The central element of the plan was conducting the modeling that the agencies had emphasized was necessary to evaluate the effects of the project on the lake's water and salt balance.

The plan also provided for adjusting UPRR's proposal for a 180-foot-long bridge as needed to ensure that the bridge provided the same functions as the culverts as directed by USACE. Specifically, as reflected in USACE's direction to UPRR, UPRR's regulatory obligation is to meet the mitigation objective described by USACE to show that the project will have less than minimal effects on Great Salt Lake resources and the environment. That objective is to duplicate the aquatic functions of the culverts as they were operating before closure. Therefore, UPRR included the following additional action in its plan that would occur if the modeling results indicated that the 180-foot-long bridge would not closely duplicate the functions of the culverts in terms of the bridge's effects on water and salt balance:

> … based on the results of this impacts re-evaluation, UPRR is prepared to adjust its bridge proposal in a manner that would result in the function of the bridge and its effect on the water and salt balance more closely resembling the predicted effects of the 2012 culverts.

Following completion of any bridge adjustment to more closely align the bridge design with the function of the culverts, the September 25 plan called for an evaluation of potential impacts on other lake resources, such as brine shrimp and wildlife, that could be affected by changes to the water and salt balance that would have occurred if the compensatory mitigation bridge did not duplicate the functions of the culverts closely enough. Finally, UPRR would prepare a revised compensatory mitigation and monitoring plan keyed to the results of this overall impacts re-evaluation effort.

After presenting its plan to USACE, UDWQ, and coordinating agencies for input, UPRR implemented its September 25, 2013, plan. First, UPRR conducted its three-step water and salt balance modeling effort based on the 1998 USGS Model, which is regarded as the best available method to analyze the potential impacts of this project. The 1998 USGS Model was 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).

As described above, the objective of UPRR's three-step water and salt balance modeling plan was to determine the effects of closing the east and west culverts and constructing the proposed 180-foot-long bridge in the railroad causeway on the water and salt balance between the North and South Arms of the Great Salt Lake. In May 9, 2014, correspondence to UPRR commenting on UPRR's application and supporting materials for Clean Water Act

Section 401 certification, UDWQ emphasized the role of the UPRR modeling effort in the evaluation and mitigation of potential water quality impacts. Consistent with the mitigation objectives stated by USACE in the correspondence quoted above, UDWQ stated:

> The USGS Water and Salt Balance Model of Great Salt Lake has been accepted for use in determining the permanent mitigation for the east culvert closure. Therefore, for the purposes of the alternatives analysis, it is acceptable to use salt load or salinity as a surrogate for the [parameters of concern] identified.

To implement UPRR's September 25, 2013 plan, UPRR modified the 1998 USGS Model to allow a comparison of two simulations at each step of the modeling process:

- A simulation of the baseline conditions with regard to the elevation and flow capabilities of the culverts before they were closed (free-flowing culverts as they existed in November 2012 before the west culvert was closed)
- A simulation of the proposed 180-foot-long bridge for water surface elevations (WSEs) and salt loads of the North and South Arms for each of three modeling steps

The three steps in the modeling plan are referred to as:

- **Modeling step 1** – development of the 1998 UPRR/USGS Model to run under historic hydrologic conditions for the period 1987–1998 and simulations
- **Modeling step 2** – development and calibration of the 2012 UPRR/USGS Model to run under historic hydrologic conditions for the period 1987–2012, calibration, and simulations
- **Modeling step 3** – development of the 2012 UPRR/USGS Varying Hydrology Model to run under constant wet, mild, and dry conditions for 25 years and simulations

UPRR documented the results of the three-step water and salt balance modeling plan in the *Union Pacific Railroad Great Salt Lake Causeway Final Water and Salt Balance Modeling Report – Modeling Steps 1, 2, and 3* (UPRR 2014). The results indicated that the proposed 180-foot-long bridge would result in a denser (more saline) South Arm than what would have occurred with the culverts for each step of the modeling plan. Because the mitigation objective is to duplicate the functions of the culverts as closely as possible, UPRR undertook the additional evaluation as described in its September 25, 2013, plan. The objective of this evaluation was to identify design adjustments that would result in a bridge that is predicted to duplicate the aquatic functions of the culverts more closely than would the 180-foot-long bridge, as predicted under the varying conditions evaluated under the modeling effort.

Producing a different water and salt balance than the culverts could result in adverse impacts on other lake resources. It could also produce conditions that could be considered by some stakeholders to be beneficial or improvements in lake conditions. However, UPRR's regulatory responsibility in this permitting setting is to satisfy USACE's stated mitigation objective (to duplicate the functions of the culverts as closely as possible), leaving to the regulatory and management agencies the determination of actions necessary to improve or enhance lake conditions and balance competing interests.

1.3 Bridge Evaluation Report

This report evaluates the effects of various alternative bridge geometries on the water and salt balance between the North and South Arms of the Great Salt Lake and compares these effects to the culvert simulation. The evaluation uses the UPRR/USGS models created for modeling steps 2 and 3. This evaluation was conducted to determine the appropriate bridge size to meet the objective of UPRR's compensatory mitigation proposal. This mitigation objective is to duplicate, as closely as possible, the transfer of water and salt that was occurring with the culverts functioning as documented in November 2012 when it was necessary to close the first culvert (the west culvert).

2.0 Bridge Evaluation Methodology

This section describes the evaluation methodology that UPRR used when comparing alternative bridge sizes using the 2012 UPRR/USGS Model and the 2012 UPRR/USGS Varying Hydrology Model (modeling steps 2 and 3, respectively). UPRR evaluated alternative bridge geometry to determine whether an alternative bridge geometry, other than that provided by the proposed 180-foot-long bridge with an invert elevation of 4,178 feet, would better meet the mitigation objective based on water and salt balance modeling results. This objective is to duplicate, as closely as possible, the transfer of water and salt that was occurring with the culverts functioning as documented in November 2012 when it was necessary to close the first culvert (the west culvert).

The location of the mitigation bridge along the causeway would not change.

2.1 Alternative Bridge Geometry Selection

UPRR chose alternative bridge geometry based on bridge constructability and on information and methodologies developed in the 1998 USGS modeling effort and presented in the USGS WRI 4221 document. Based on the modeling results presented in the Final Report (UPRR 2014), UPRR determined that the causeway with the proposed 180-foot-long bridge would transfer more salt to the South Arm than would the causeway with the free-flowing culverts and that a reduced bridge opening would be necessary to match more closely the effects of the culvert simulations on water and salt balance.

The proposed 180-foot-long bridge consisted of six 30-foot-long spans. UPRR removed a single 30-foot-long span to create a 150-foot-long bridge for the alternative bridge width to be evaluated.

In WRI 4221, USGS evaluated potential modifications to the 300-foot-long bridge (the breach) using the model simulations by comparing lake salinity effects from various opening geometries. USGS's evaluation compared multiple embankment opening combinations (depth and width) and the effect on lake salinity (as a percentage of South Arm to North Arm total dissolved solids [TDS] concentrations). The evaluation data were presented in Figure 18 of WRI 4221, producing a family of curves, which indicated that, by increasing the opening depth, the South Arm gained more salt than by increasing the opening width (USGS 2000).

Following this example, UPRR determined that a causeway with a reduced depth of the proposed opening would reduce the salt transfer between the North and South Arms to be more in line with the salt transfer with the culverts and would be more effective in doing so than would reducing the width of the openings. Therefore, UPRR decided to evaluate the alternative bridge width (150 feet long) with varying inverts (bottom elevations).

The culvert simulations and 180-foot-long bridge simulations were reported previously in the UPRR final report and are included in this report for reference and comparison purposes (UPRR 2014). UPRR modified the models created in modeling steps 2 and 3 to evaluate three alternative bridge simulations. The culvert and 180-foot-long bridge simulations are described below along with the three alternative bridge geometries (Alternatives B, C, and D):

- **Culvert Simulation:** Simulated conditions for the east and west culverts before the west culvert was closed in 2012.
  - East and west culvert invert elevations are set at their 2012 elevation of 4,173 feet.
  - Culvert flows are calculated using Holley's equations and are represented as free flowing. These equations, developed by Dr. E.R. Holley, were included in the 1998 USGS Model code and are discussed in Appendices D and E of WRI 4221.
  - Existing 300-foot-long bridge is as described in WRI 4221, including changes to reflect new geometry since August 2000 (UDWR 2001).
  - Causeway fill conductivity is as described in WRI 4221. It was reviewed during the 2012 UPRR/USGS Model calibration effort and was not changed.
- **Proposed Bridge (180 feet long), Alternative A Simulation:** Simulated conditions with the proposed bridge.
  - Flow through the culverts is removed.
  - New bridge geometry is added (180-foot-long span with a bottom width of 61 feet and an invert elevation of 4,178 feet) to replace the culverts. Flows through the new bridge are calculated using Holley's equations.
  - Existing 300-foot-long bridge is as described in WRI 4221, including changes to reflect new geometry since August 2000 (UDWR 2001).
  - Causeway fill conductivity is as described in WRI 4221. It was reviewed during the 2012 UPRR/USGS Model calibration effort and was not changed.
- **Alternative B Bridge Simulation:** Simulated conditions with alternative bridge geometry.
  - Flow through the culverts is removed.
  - New bridge geometry is added (150-foot-long span with a bottom width of 31 feet and an invert elevation of 4,178 feet) to replace the culverts. Flows through the new bridge are calculated using Holley's equations.
  - Existing 300-foot-long bridge is as described in WRI 4221, including changes to reflect new geometry since August 2000 (UDWR 2001).
  - Causeway fill conductivity is as described in WRI 4221. It was reviewed during the 2012 UPRR/USGS Model calibration effort and was not changed.

- **Alternative C Bridge Simulation:** Simulated conditions with alternative bridge geometry.
    - Flow through the culverts is removed.
    - New bridge geometry is added (150-foot-long span with a bottom width of 49 feet and an invert elevation of 4,183 feet) to replace the culverts. Flows through the new bridge are calculated using Holley's equations.
    - Existing 300-foot-long bridge is as described in WRI 4221, including changes to reflect new geometry since August 2000 (UDWR 2001).
    - Causeway fill conductivity is as described in WRI 4221. It was reviewed during the 2012 UPRR/USGS Model calibration effort and was not changed.
- **Alternative D Bridge Simulation:** Simulated conditions with alternative bridge geometry.
    - Flow through the culverts is removed.
    - New bridge geometry is added (150-foot-long span with a bottom width of 66 feet and an invert elevation of 4,188 feet) to replace the culverts. Flows through the new bridge are calculated using Holley's equations.
    - Existing 300-foot-long bridge is as described in WRI 4221, including changes to reflect new geometry since August 2000 (UDWR 2001).
    - Causeway fill conductivity is as described in WRI 4221. It was reviewed during the 2012 UPRR/USGS Model calibration effort and was not changed.

2.2 Model Simulation Comparison Parameters

UPRR compared the effects of the five simulations under each of the models (the 2012 UPRR/USGS Model and the 2012 UPRR/USGS Varying Hydrology Model) for each of the three selected hydrologic conditions on the North and South Arm lake parameters described below.

For the 2012 UPRR/USGS Model, UPRR compared:

- North and South Arm average salinities, TDS concentrations, and salt loads
- North and South Arm ending condition (2012) salinities, TDS concentrations, and salt loads
- Total causeway flows south to north and north to south
- Ratio of south-to-north total causeway flow to north-to-south total causeway flow
- Ratio of North Arm TDS concentrations to South Arm TDS concentrations

For the 2012 UPRR/USGS Varying Hydrology Model, lake conditions for the last year of the model (at equilibrium), for each hydrologic condition, were averaged for:

- North and South Arm last-year average (equilibrium) salinities, TDS concentrations, and salt loads
- Total causeway flows south to north and north to south, at equilibrium
- Ratio of south-to-north total causeway flow to north-to-south total causeway flow
- Ratio of North Arm TDS concentrations to South Arm TDS concentrations

The two models are based on different lake conditions, so it is not possible to directly compare the alternative bridge geometries between the two models. For the 2012 UPRR/ USGS Model, lake conditions are never at equilibrium due to the variability of the annual hydrology. For the 2012 UPRR/USGS Varying Hydrology Model, the annual hydrology was held constant so that equilibrium conditions could be reached. These conditions were created by design, since it is more difficult to evaluate the effects of various bridge geometries when the hydrology is also changing every year and these changes are affecting the water and salt balance in the lake.

UPRR determined that, based on specific modeled parameters, a comparison of the lake responses for the bridge alternative simulations to the lake responses for the culvert simulations can be used as tool to identify a bridge alternative that more closely meets the objective of the compensatory mitigation. This objective is to duplicate, as closely as possible, the transfer of water and salt that was occurring with the culverts functioning as documented in November 2012 when it was necessary to close the first culvert (the west culvert).

3.0 Simulations Using the UPRR/USGS Models

The 2012 UPRR/USGS Model and 2012 UPRR/USGS Varying Hydrology Model were used to compare the total causeway bidirectional flows, lake salinities, and total salt load for the North and South Arms for different inflows and outflows for the following two simulations:

- **Culvert Simulation:** The east and west culverts are represented as they existed in 2012: open and free flowing, and the elevations of the culvert inverts were those from November 2012. For this simulation, there are three mechanisms for transferring water and salt through the causeway: the existing 300-foot-long bridge, the two culverts, and the causeway fill.
- **Alternative Bridge Simulations:** The alternative bridges are included as a defined opening in the causeway, and the two culverts are removed. For each of these simulations, there are three mechanisms for transferring water and salt through the causeway: the existing 300-foot-long bridge, the specific alternative bridge size, and the causeway fill.

3.1 Culvert Simulation

In the culvert simulation, the east and west culverts were represented as unobstructed (free flowing) and at their vertical position as of 2012. The models treat both culverts as a single combined channel with a total width of 30 feet. The models calculate flows through the existing 300-foot-long bridge and culvert openings using the option to compute flows with Holley's equations in place of the option to read in measured flows. The model representation of the causeway fill flows and the existing 300-foot-long bridge flows were unchanged. This methodology is the same as what was reported in more detail in the UPRR final report (UPRR 2014).

The elevations and geometries of the east and west culverts are shown in Table 1. These dimensions and elevations are rounded from actual culvert survey data, and the difference between the model parameters and the surveyed data is considered negligible. These geometries and invert elevations were used in the culvert simulation with both models.

Table 1. Elevations of the East and West Culverts, 2012
in feet

Culvert	Floor Elevation (NGVD 29)	Top Elevation (NGVD 29)	Inside Width
West	4,173	4,194	15
East	4,173	4,194	15

Source: UPRR 2011
NGVD 29 = National Geodetic Vertical Datum of 1929

3.2 Alternative Bridge Simulations

For the proposed bridge (180-foot-long bridge) simulations using the 2012 UPRR/USGS Model and the 2012 UPRR/USGS Varying Hydrology Model, a new channel for conveying water and salt (that is, the proposed bridge) was added, and flow through the culverts was removed (UPRR 2014). For each alternative bridge size simulation, the bridge channel for conveying water and salt was specifically defined for each alternative, and flow through the culverts was removed. The model representation of the causeway fill flows and existing 300-foot-long bridge flows were unchanged from the USGS model representations.

The flows through the existing bridge and alternatively sized bridges were calculated using Holley's equations. The geometries and elevations of the proposed bridge alternatives are illustrated in Figure 1 and listed in Table 2.

Figure 1. Alternative Bridge Sizes

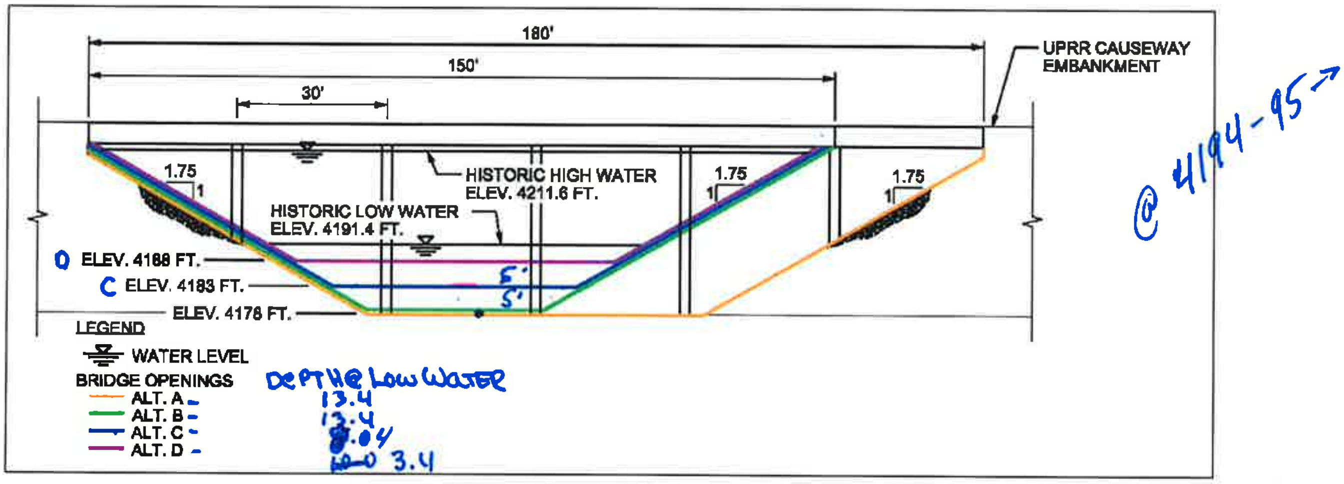

Table 2. Summary of Alternative Bridge Geometry Parameters

in feet

Alternative	Top Width	Bottom Width	Channel Bottom Elevation (NGVD 29)	Low Chord Elevation (NGVD 29)	Increase in Width per Increased Foot of Elevation
A	180	61	4,178	4,212	3.5
B	150	31	4,178	4,212	3.5
C	150	49	4,183	4,212	3.5
D	150	66	4,188	4,212	3.5

4.0 Model Results

This section discusses the results of the 2012 UPRR/USGS Model and the 2012 UPRR/USGS Varying Hydrology Model for the culvert and alternative bridge simulations. Model results for specific parameters for the period 1987–2012 and for each of the three hydrologic conditions are summarized and/or shown on time series graphs. For the results of the 2012 UPRR/USGS Varying Hydrology Model, particular attention is given to the later stages of the period of the model simulation in which the WSEs and salinities reach equilibrium.

4.1 Flow and TDS Concentration Ratio Comparison

For a given inflow to the lake and resulting lake level, changes to the causeway characteristics (openings and hydraulic characteristics of the fill) will result in changes in bidirectional flows through the causeway. The size of the proposed openings affects the flows through the existing bridge and causeway fill. Therefore, for the evaluation of the proposed bridge opening, it is necessary to include the flows through the other causeway openings and fill, both for evaluation of efficiency and to keep the analysis in the proper overall context, whereby the "relative contribution" of a change in bridge design to the overall conditions is evaluated. Thus, for evaluating the proposed bridge openings, UPRR determined that it was necessary to compare the total causeway flows for each direction, south to north and north to south. The ratio of the total flows ultimately defines the ratio of the salinities (as represented by TDS concentrations) between the North and South Arms.

WRI 4221 identified that, for a given ratio of south-to-north causeway flow to north-to-south causeway flow, there is a certain ratio of TDS concentrations in the North Arm to that in the South Arm (USGS 2000). USGS determined that the flow ratios will generally increase or decrease proportionally to an increase or decrease in head difference. Also, if the ratio of total south-to-north causeway flow to north-to-south causeway flow decreases, then the ratio of TDS concentrations of the South Arm to that of the North Arm will increase. Conversely, if the ratio of flows increases, then the ratio of TDS concentrations of the South Arm to the North Arm will decrease. The following equation in WRI 4221 describes this relationship:

$$\frac{\text{South-to-north causeway flow}}{\text{North-to-south causeway flow}} = \frac{\text{North Arm TDS concentration}}{\text{South Arm TDS concentration}}$$

Using this relationship, USGS assessed lake conditions in a system context to better understand the interaction between lake levels and causeway characteristics on bidirectional flows, the interface layer elevation between the two flows, and the overall effect on lake salinity and salt loads of the two arms. Based on the USGS evaluations documented in WRI 4221, UPRR determined that using these ratios could assist with UPRR's alternative bridge geometry evaluation since, together, these two ratios characterize causeway properties relative to each other. To meet the mitigation objective, the preferred bridge size and design should produce overall causeway flow and TDS concentration ratios under each modeling step that are as close to the ratios for the culverts as possible.

Table 3 identifies the total causeway flows and ratios for the culvert simulation and for each alternative bridge simulation using the 2012 UPRR/USGS Model. Table 4, Table 5, and Table 6 identify the total causeway flows and ratios for the culvert simulation and for each alternative bridge simulation using the 2012 UPRR/USGS Varying Hydrology Model for the wet, mild, and dry hydrologic cycles.

Note that, for the simulation results using the 2012 UPRR/USGS Varying Hydrology Model, average conditions are represented for the last year of the model, when the lake conditions are at equilibrium. As in the modeling step 3 progress report, *equilibrium* is defined as the point where minimal changes in lake elevation and salinity are occurring from year to year during the model simulation (UPRR 2014).

The proposed and alternatively sized bridges might convey more water in each direction than the culverts under certain lake levels and might affect flow and salt movement through the causeway fill and existing 300-foot-long bridge. However, the ratio of total causeway bidirectional flows to the TDS concentrations of the North and South Arms can be compared to determine which alternative bridge geometry simulation most closely matches the culvert simulation.

Table 3. 2012 UPRR/USGS Model – Comparison of Total Flow, Ratio of Flows, and Ratio of TDS Concentrations

Parameter	Culverts	180-foot-long bridge, 4,178 feet (Alt. A)	150-foot-long bridge, 4,178 feet (Alt. B)	150-foot-long bridge, 4,183 feet (Alt. C)	150-foot-long bridge, 4,188 feet (Alt. D)
Average total flow south-to-north, cfs	1,984	3,356	2,861	2,562	2,188
Average total flow north-to-south, cfs	917	2,162	1,687	1,398	1,039
Ratio of the average total south-to-north flow to north-to-south flow	2.16	1.55	1.70	1.83	2.11
Ratio of the average TDS concentration in North Arm to South Arm	1.94	1.50	1.61	1.72	1.90

cfs = cubic feet per second

Table 4. 2012 UPRR/USGS Varying Hydrology Model, Wet Cycle – Comparison of Total Flow, Ratio of Flows, and Ratio of TDS Concentrations at Equilibrium

Parameter [a]	Culverts	180-foot-long bridge, 4,178 feet (Alt. A)	150-foot-long bridge, 4,178 feet (Alt. B) [b]	150-foot-long bridge, 4,183 feet (Alt. C)	150-foot-long bridge, 4,188 feet (Alt. D)
Average total flow south-to-north, cfs	5,825	7,151	6,809	6,520	6,284
Average total flow north-to-south, cfs	3,548	4,817	4,497	4,224	3,999
Ratio of the average total south-to-north flow to north-to-south flow	1.64	1.48	1.51	1.54	1.57
Ratio of the average TDS concentration in North Arm to South Arm	1.56	1.40	1.43	1.47	1.49

[a] Flows and concentrations are averaged over the last year of the simulation, when the model is at equilibrium.

[b] The Alternative B model was terminated during year 12 for the wet cycle. Flows and ratios for Alternative B are estimated.

Table 5. 2012 UPRR/USGS Varying Hydrology Model, Mild Cycle – Comparison of Total Flow, Ratio of Flows, and Ratio of TDS Concentrations at Equilibrium

Parameter [a]	Culverts	180-foot-long bridge, 4,178 feet (Alt. A)	150-foot-long bridge, 4,178 feet (Alt. B)	150-foot-long bridge, 4,183 feet (Alt. C)	150-foot-long bridge, 4,188 feet (Alt. D)
Average total flow south-to-north, cfs	3,403	4,367	3,867	3,574	3,210
Average total flow north-to-south, cfs	1,969	2,907	2,414	2,131	1,779
Ratio of the average total south-to-north flow to north-to-south flow	1.73	1.50	1.60	1.68	1.80
Ratio of the average TDS concentration in North Arm to South Arm	1.68	1.46	1.55	1.63	1.75

[a] Flows and concentrations are averaged over the last year of the simulation, when the model is at equilibrium.

Table 6. 2012 UPRR/USGS Varying Hydrology Model, Dry Cycle – Comparison of Total Flow, Ratio of Flows, and Ratio of TDS Concentrations at Equilibrium

Parameter [a]	Culverts	180-foot-long bridge, 4,178 feet (Alt. A)	150-foot-long bridge, 4,178 feet (Alt. B)	150-foot-long bridge, 4,183 feet (Alt. C)	150-foot-long bridge, 4,188 feet (Alt. D)
Average total flow south-to-north, cfs	2,120	2,799	2,326	1,930	1,409
Average total flow north-to-south, cfs	1,181	1,822	1,365	987	500
Ratio of the average total south-to-north flow to north-to-south flow	1.79	1.54	1.70	1.96	2.82
Ratio of the average TDS concentration in North Arm to South Arm	1.74	1.49	1.65	1.88	2.60

[a] Flows and concentrations are averaged over the last year of the simulation, when the model is at equilibrium.

4.2 Salt Balance Comparison

The 2012 UPRR/USGS Model and the 2012 UPRR/USGS Varying Hydrology Model compute the North and South Arm salt loads and resulting North and South Arm salinities based on the ability to convey water and salt in both directions through the causeway fill and openings (UPRR 2014). For a given amount of inflow and the resulting WSE, the conveyance properties of the causeway and its openings will largely determine the transfer of water and salt through the causeway.

UPRR used the two models to compare North and South Arm salt loads and salinities for the culvert simulation and each of the alternative bridge size simulations.

4.2.1 Salt Load Comparison

UPRR compared the South and North Arm salt loads with the culvert and alternative bridge simulations for each model. Table 7 shows summary comparison data for the 2012 UPRR/USGS Model. For this model, the WSE varies over the 26-year period, with the South Arm gaining and losing salt. The Alternative D simulation results in a salt load over time that is closest to the culvert simulation. Figure 2 illustrates the South Arm salt load over time for the 2012 UPRR/USGS Model culvert and alternative bridge simulations.

Table 7. 2012 UPRR/USGS Model – Salt Load Comparison

in billion tons

Parameter	Culverts	180-foot-long bridge, 4,178 feet (Alt. A)	150-foot-long bridge, 4,178 feet (Alt. B)	150-foot-long bridge, 4,183 feet (Alt. C)	150-foot-long bridge, 4,188 feet (Alt. D)
Average South Arm dissolved salt load	2.04	2.39	2.28	2.19	2.03
Ending South Arm dissolved salt load (2012)	1.40	2.15	1.88	1.65	1.31
Average North Arm dissolved and precipitated salt load	2.53	2.18	2.29	2.38	2.54
Ending North Arm dissolved and precipitated salt load (2012)	3.15	2.40	2.67	2.91	3.25

Figure 2. 2012 UPRR/USGS Model – South Arm Salt Load Comparison

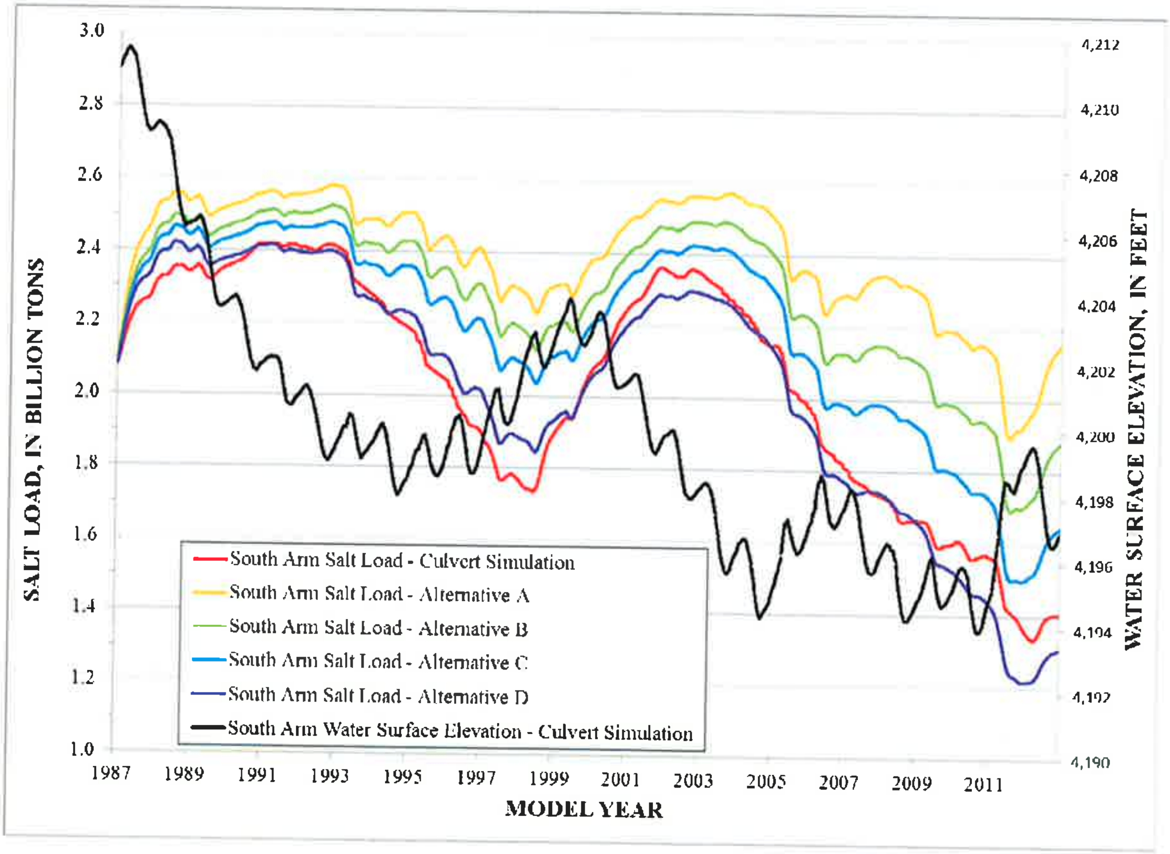

Table 8, Table 9, and Table 10 below show summary data for the wet, mild, and dry hydrologic cycles run with the 2012 UPRR/USGS Varying Hydrology Model. These average salt loads are averaged over the last year of the 25-year model period. The WSEs at equilibrium are about 4,209 feet, 4,200 feet, and 4,195 feet for the wet, mild, and dry hydrologic cycles, respectively. ↳ here last in 2001 -

- **Wet Cycle.** For the 2012 UPRR/USGS Varying Hydrology Model, wet cycle, with a WSE of about 4,209 feet, Alternative D aligns most closely with the culverts for the average North and South Arm salt loads at equilibrium. The model for Alternative B did not complete the 25-year cycle and was terminated during year 12, so the results for Alternative B did not reach equilibrium. Therefore, UPRR determined an estimate of conditions at equilibrium for Alternative B.
- **Mild Cycle.** For the 2012 UPRR/USGS Varying Hydrology Model, mild cycle, with a WSE of about 4,200 feet, Alternative C aligns most closely with the culverts for the average North and South Arm salt loads at equilibrium.
- **Dry Cycle.** For the 2012 UPRR/USGS Varying Hydrology Model, dry cycle, with a WSE of about 4,195 feet, a bridge size between those of Alternatives B and C would align most closely with the culverts for the average North and South Arm salt loads at equilibrium.

Table 8. 2012 UPRR/USGS Varying Hydrology Model, Wet Cycle – Salt Load Comparison at Equilibrium

4209

in billion tons

Parameter [a]	Culverts	180-foot-long bridge, 4,178 feet (Alt. A)	150-foot-long bridge, 4,178 feet (Alt. B) [b]	150-foot-long bridge, 4,183 feet (Alt. C)	150-foot-long bridge, 4,188 feet (Alt. D)
Average South Arm dissolved salt load	2.33	2.45	2.43	2.40	2.38
Average North Arm dissolved and precipitated salt load	2.22	2.10	2.13	2.15	2.17

[a] Salt load is averaged over the last year of the simulation, when the model is at equilibrium.

[b] The Alternative B model was terminated during year 12 for the wet cycle. Salt loads for Alternative B are estimated.

Table 9. 2012 UPRR/USGS Varying Hydrology Model, Mild Cycle – Salt Load Comparison at Equilibrium

4200

in billion tons

Parameter [a]	Culverts	180-foot-long bridge, 4,178 feet (Alt. A)	150-foot-long bridge, 4,178 feet (Alt. B)	150-foot-long bridge, 4,183 feet (Alt. C)	150-foot-long bridge, 4,188 feet (Alt. D)
Average South Arm dissolved salt load	2.32	2.47	2.40	2.35	2.26
Average North Arm dissolved and precipitated salt load	2.23	2.09	2.16	2.21	2.29

[a] Salt load is averaged over the last year of the simulation, when the model is at equilibrium.

Table 10. 2012 UPRR/USGS Varying Hydrology Model, Dry Cycle – Salt Load Comparison at Equilibrium

4195

in billion tons

Parameter [a]	Culverts	180-foot-long bridge, 4,178 feet (Alt. A)	150-foot-long bridge, 4,178 feet (Alt. B)	150-foot-long bridge, 4,183 feet (Alt. C)	150-foot-long bridge, 4,188 feet (Alt. D)
Average South Arm dissolved salt load	1.85	2.18	1.94	1.68	1.18
Average North Arm dissolved and precipitated salt load	2.71	2.38	2.61	2.87	3.37

[a] Salt load is averaged over the last year of the simulation, when the model is at equilibrium.

4.2.2 Salinity Comparison

Table 11 compares the South and North Arm salinities for the culvert and alternative bridge simulations. For the 2012 UPRR/USGS model simulations, the WSE varies over the 26-year period as a result of causeway characteristics and varying inflow, with the South Arm gaining and losing salt over time. The Alternative D simulation results in a closer salinity over time to the culvert simulation than do the other alternatives. Figure 3 illustrates the South Arm salinity over time for the 2012 UPRR/USGS Model culvert and alternative bridge simulations.

Table 11. 2012 UPRR/USGS Model – Salinity Comparison

Parameter	Culverts	180-foot-long bridge, 4,178 feet (Alt. A)	150-foot-long bridge, 4,178 feet (Alt. B)	150-foot-long bridge, 4,183 feet (Alt. C)	150-foot-long bridge, 4,188 feet (Alt. D)
South Arm					
Average South Arm salinity, %	14.3	17.0	16.2	15.6	14.5
Ending South Arm salinity, % (2012)	12.3	18.1	16.2	14.4	11.9
Average South Arm TDS concentration, g/L	158	191	181	173	160
Ending South Arm TDS concentration, g/L (2012)	133	205	181	159	129
North Arm					
Average North Arm salinity, %	25.6	24.1	24.6	24.9	25.4
Ending North Arm salinity, % (2012)	28.4	28.1	28.1	28.1	28.2
Average North Arm TDS concentration, g/L	307	286	292	297	304
Ending North Arm TDS concentration, g/L (2012)	346	341	341	341	343

TDS = total dissolved solids, g/L = grams per liter

Figure 3. 2012 UPRR/USGS Model – South Arm Salinity Comparison

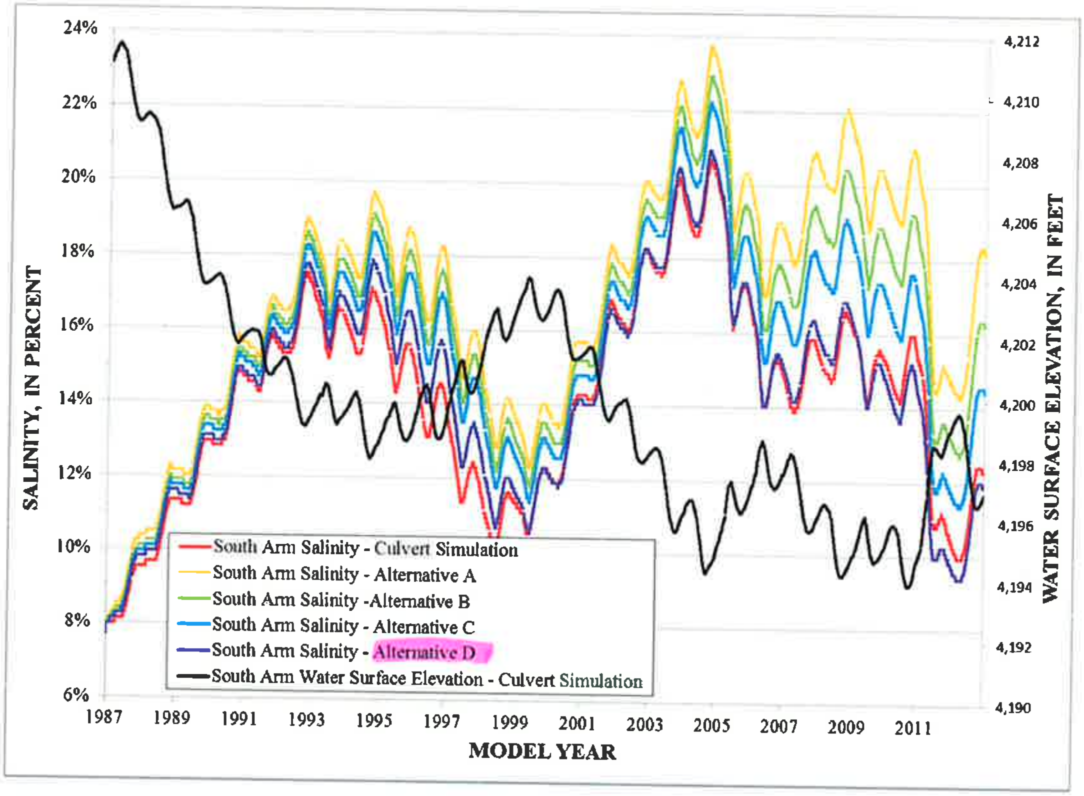

Table 12, Table 13, and Table 14 show summary data for the wet, mild, and dry hydrologic cycles, respectively, run with the 2012 UPRR/USGS Varying Hydrology Model. Average salinity and TDS concentrations are shown representing the average condition at equilibrium (the average of the values for the last model year).

Table 12. 2012 UPRR/USGS Varying Hydrology Model, Wet Cycle – Salinity Comparison at Equilibrium

Parameter [a]	Culverts	180-foot-long bridge, 4,178 feet (Alt. A)	150-foot-long bridge, 4,178 feet (Alt. B) [b]	150-foot-long bridge, 4,183 feet (Alt. C)	150-foot-long bridge, 4,188 feet (Alt. D)
Average South Arm salinity, %	9.4	9.9	9.8	9.7	9.6
Average North Arm salinity, %	14.3	13.5	13.7	13.8	14.0
Average South Arm TDS concentration, g/L	100	106	105	103	102
Average North Arm TDS concentration, g/L	157	148	150	151	153

[a] Salt load is averaged over the last year of the simulation, when the model is at equilibrium at a South Arm WSE of 4,209 feet.

[b] The Alternative B model simulation terminated during year 12 for the wet cycle. Salinity and TDS concentration values for Alternative B are estimated.

Table 13. 2012 UPRR/USGS Varying Hydrology Model, Mild Cycle – Salinity Comparison at Equilibrium

Parameter [a]	Culverts	180-foot-long bridge, 4,178 feet (Alt. A)	150-foot-long bridge, 4,178 feet (Alt. B)	150-foot-long bridge, 4,183 feet (Alt. C)	150-foot-long bridge, 4,188 feet (Alt. D)
Average South Arm salinity, %	15.7	16.7	16.2	15.9	15.4
Average North Arm salinity, %	24.7	23.2	23.9	24.4	25.2
Average South Arm TDS concentration, g/L	175	186	181	177	171
Average North Arm TDS concentration, g/L	292	272	281	288	299

[a] Salt load is averaged over the last year of the simulation, when the model is at equilibrium at South Arm WSE of 4,200 feet.

Table 14. 2012 UPRR/USGS Varying Hydrology Model, Dry Cycle – Salinity Comparison at Equilibrium

Parameter [a]	Culverts	180-foot-long bridge, 4,178 feet (Alt. A)	150-foot-long bridge, 4,178 feet (Alt. B)	150-foot-long bridge, 4,183 feet (Alt. C)	150-foot-long bridge, 4,188 feet (Alt. D)
Average South Arm salinity, %	17.4	20.0	18.3	16.2	12.1
Average North Arm salinity, %	28.0	28.0	28.0	28.0	28.0
Average South Arm TDS concentration, g/L	196	228	207	181	131
Average North Arm TDS concentration, g/L	340	340	340	340	340

[a] Salt load is averaged over the last year of the simulation, when the model is at equilibrium at South Arm WSE of 4,195 feet.

Figure 4 compares the South Arm salinity for the culverts and each bridge alternative for the wet, mild, and dry hydrologic cycles.

Figure 4. 2012 UPRR/USGS Varying Hydrology Model – Average Annual South Arm Salinity Comparison at Equilibrium

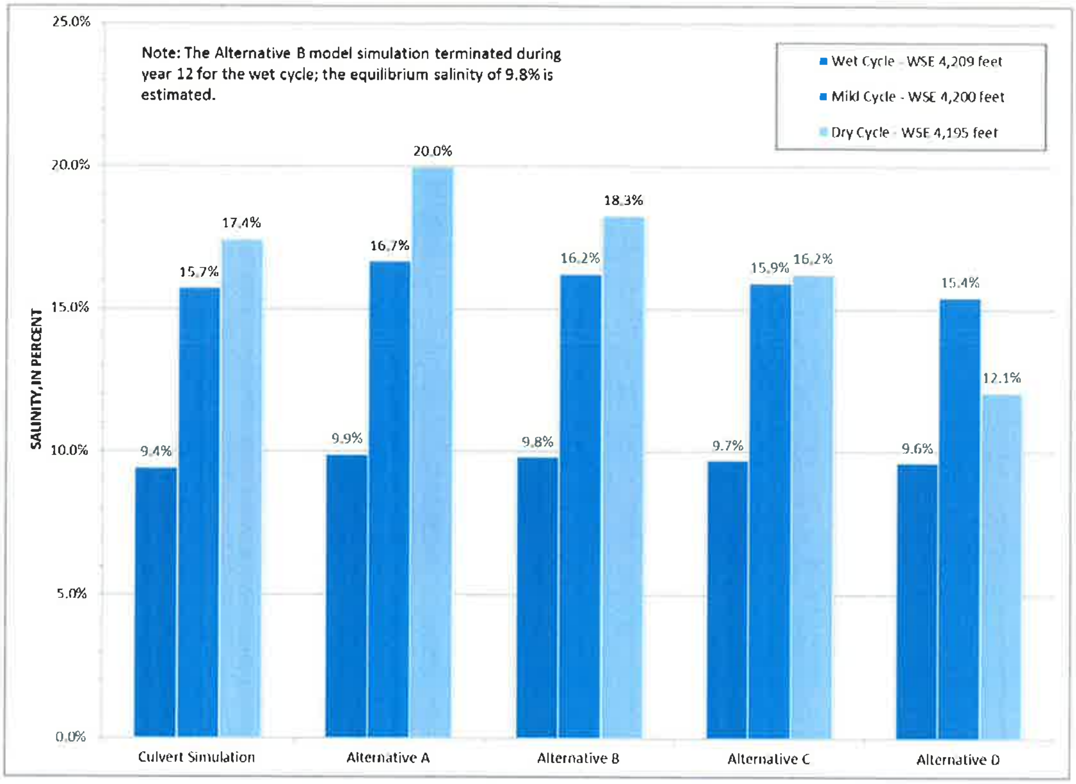

Table 12, Table 13, Table 14, and Figure 4 above show the average North and South Arm salinities at equilibrium with WSEs about 4,209 feet, 4,200 feet, and 4,195 feet for the wet, mild, and dry hydrologic cycles, respectively, for the culvert simulation compared to the same parameters for each bridge alternative.

- **Wet Cycle.** For the 2012 UPRR/USGS Varying Hydrology Model, wet cycle, with a WSE of about 4,209 feet, the North and South Arm salinities for Alternative D align most closely with the culverts for the average and ending South Arm salt load. The model for Alternative B did not complete the 25-year cycle and terminated during year 12, so the results for Alternative B did not reach equilibrium. UPRR determined an estimate of lake conditions for Alternative B, which is shown in Figure 4.
- **Mild Cycle.** For the 2012 UPRR/USGS Varying Hydrology Model, mild cycle, with a WSE of about 4,200 feet, the North and South Arm salinities for Alternative C align most closely with the culverts for the average and ending South Arm salt load.
- **Dry Cycle.** For the 2012 UPRR/USGS Varying Hydrology Model, dry cycle, with a WSE of about 4,195 feet, the South Arm salinities for a bridge size between those of Alternatives B and C would align most closely with the culverts for the average and ending South Arm salt load. For the dry hydrologic cycle, the North Arm is at saturation for the culvert and all bridge alternatives.

5.0 Analysis of Results and Discussion

UPRR prepared a final report describing the results of the water and salt balance modeling effort that compared Great Salt Lake conditions for the proposed 180-foot-long bridge to the east and west culverts at their November 2012 position (UPRR 2014). The objective of the modeling plan was to determine the effects of closing the culverts and constructing the 180-foot-long bridge in the railroad causeway on the water and salt balance between the North and South Arms of the Great Salt Lake. The final report identified that the 180-foot-long bridge simulation resulted in a denser (more saline) South Arm than the culvert simulation for all modeling steps.

UPRR conducted this evaluation to determine whether an alternative bridge size, other than the proposed 180 feet, would better meet the objective of the mitigation based on water and salt balance modeling results. This objective is to duplicate, as closely as possible, the transfer of water and salt that was occurring with the culverts functioning as documented in November 2012 when it was necessary to close the first culvert (the west culvert).

This report describes the evaluation of various bridge sizes on the water and salt balance between the North and South Arms of the Great Salt Lake and compares these effects to the culvert simulation. The evaluation uses the UPRR/USGS models created for modeling steps 2 and 3. Four alternative bridge sizes were incorporated into the step 1 and 2 model codes for comparison to the culvert simulation. UPRR compared the following North and South Arm lake conditions.

For the 2012 UPRR/USGS Model, UPRR compared:

- North and South Arm Average salinities, TDS concentrations, and salt loads
- North and South Arm ending condition (2012) salinities, TDS concentrations, and salt loads
- Total causeway flows south to north and north to south
- Ratio of south-to-north total causeway flow to north-to-south total causeway flow
- Ratio of North Arm TDS concentrations to South Arm TDS concentrations

For the 2012 UPRR/USGS Varying Hydrology Model, lake conditions for the last year of the model (at equilibrium), for each hydrologic condition, were averaged for:

- North and South Arm last-year average (equilibrium) salinities, TDS concentrations, and salt loads
- Total causeway flows south-to north and north-to-south, at equilibrium
- Ratio of south-to-north total causeway flow to north-to-south total causeway flow
- Ratio of North Arm TDS concentrations to South Arm TDS concentrations

Based on the analysis described in this report and summarized in Table 15, UPRR has determined that the results of the simulation of the 150-foot-long bridge with an invert at 4,183 feet (Alternative C) most closely match the results of the culvert simulation most of the time. A summary comparison of the modeling results for all alternatives for specific parameters is presented in Appendix A.

Table 15. Summary of Bridge Alternative Analysis

Model	**180-foot-long bridge, 4,178 feet (Alt. A)**	**150-foot-long bridge, 4,178 feet (Alt. B)**	**150-foot-long bridge, 4,183 feet (Alt. C)**	**150-foot-long bridge, 4,188 feet (Alt. D)**
2012 UPRR/USGS Model	4th-best match 4	3rd-best match 3	2nd-best match 2	Best match [illegible]
2012 UPRR/USGS Varying Hydrology Model, wet cycle	4th-best match 4	3rd-best match 3	2nd-best match 2	Best match 1
2012 UPRR/USGS Varying Hydrology Model, mild cycle	4th-best match 4	3rd-best match 3	Best match [illegible]	2nd-best match 2
2012 UPRR/USGS Varying Hydrology Model, dry cycle	3rd-best match 3	Best match 1	2nd-best match 2	4th-best match 4
Total points (lowest points represent best match)	**15**	**10**	**7**	**8**
Overall rank	**4**	**3**	**1**	**2**

6.0 Summary and Mitigation Proposal

UPRR prepared the final report (UPRR 2014) that discussed the results of the water and salt balance modeling that compared Great Salt Lake conditions resulting from the proposed 180-foot-long bridge simulation to the simulation with the east and west culverts at their November 2012 position. The final report indicated that the model simulations of the proposed 180-foot-long bridge resulted in a denser (more saline) South Arm than the culvert simulations for each modeling step.

As described in Section 1.2, UPRR Modeling and Impacts Analysis Plan and Modeling Report, and Section 2.1, Alternative Bridge Geometry Selection, the mitigation objective of the project is to duplicate, as closely as possible, the transfer of water and salt that was occurring with the culverts functioning as documented in November 2012 when it was necessary to close the first culvert (the west culvert). Consistent with this objective, UDWQ recently has emphasized the role of the UPRR modeling effort and has identified impacts on salt load and salinity, which was the focus of the modeling effort, as a surrogate for water quality parameters of concern in the evaluation and mitigation of potential water quality impacts (UDWQ 2014).

The modeling summarized in the final report reflected that the 180-foot-long bridge did not meet the mitigation objective because the causeway with the 180-foot-long bridge transferred more net salt from the North Arm to the South Arm than did the causeway with the free-flowing culverts. By conducting the bridge adjustment analysis called for in the September 25, 2013 plan, UPRR determined that the proposed 180-foot-long bridge should be made smaller to better match the lake conditions with the free-flowing culverts.

This report evaluated the effects of various bridge geometries on the water and salt balance between the North and South Arms and compared these effects to the culvert simulation. The evaluation used the UPRR/USGS models created for modeling steps 2 and 3. This evaluation was conducted to determine the appropriate bridge size to meet UPRR's compensatory mitigation obligations. The mitigation objective to meet this obligation is to duplicate, as closely as possible, the transfer of water and salt that was occurring with the culverts functioning as documented in November 2012 when it was necessary to close the first culvert (the west culvert).

Based on this evaluation, UPRR proposes to change the geometry of the compensatory mitigation measure to replace the aquatic function of the culverts by constructing Alternative C, a 150-foot-long bridge with an invert elevation of 4,183 feet. Applying the modeling used to conduct the impact analysis, the simulated conveyance properties of the causeway with this new bridge geometry best match the lake salinities and salt loads compared to the simulation of the causeway conveyance properties with the free-flowing culverts.

The following sections compare the Alternative C model simulations directly to the culvert simulations for both the 2012 UPRR/USGS Model and 2012 UPRR/USGS Varying Hydrology Model. The model simulations for Alternative C for the 2012 UPRR/USGS Model and the 2012 UPRR/USGS Varying Hydrology Model are provided in Appendices B and C, respectively.

6.1 Salt Load and Salinity Comparison

Figure 2 and Figure 3 on pages 17 and 21 above show the comparison between the simulation with the Alternative C bridge geometry (150-foot-long bridge with an invert elevation of 4,183 feet) and the culvert simulation for salt load and salinity, respectively, using the 2012 UPRR/USGS Model, modeling step 2.

Figure 5 and Figure 6 on pages 29and 30 below show the comparison of the South Arm salt loads and salinities, respectively, with the Alternative C and culvert simulations for each hydrologic cycle, modeling step 3.

6.2 Revised Mitigation Proposal

UPRR proposes to construct a 150-foot-long bridge with an invert elevation of 4,183 feet for the compensatory mitigation to replace the aquatic function of the free-flowing culverts. The bridge will be constructed at the same location along the causeway, about 5 miles west of Lakeside, Utah.

Based on the analysis described in this report and constructability considerations, UPRR has determined that the results of the water and salt balance model simulations for the 150-foot-long bridge with an invert at 4,183 feet most closely match the results for the free-flowing culvert simulation most of the time.

For the 2012 UPRR/USGS Model, the culvert simulation resulted in a range of South Arm salinities from 8% to about 20.7%, with an average of 14.3% and an ending salinity of 12.3%. The bridge simulation (150-foot-long bridge) resulted in a range of South Arm salinities from 8% to 22.2%, with an average of 15.6% and an ending salinity of 14.4%. The bridge simulation shows an increase in South Arm salinity of about 1.3% (average) and 2.1% (ending) compared to the culvert simulation.

For the 2012 UPRR/USGS Model, the culvert simulation resulted in a range of South Arm salt loads from 1.3 billion tons to 2.4 billion tons, with average of 2 billion tons and an ending salt load of 1.4 billion tons. The bridge simulation (150-foot-long bridge) resulted in a range of South Arm salt loads from 1.5 billion tons to 2.5 billion tons, with an average of 2.2 billion tons and an ending salt load of 1.7 billion tons. The bridge simulation shows an increase in South Arm salt load of about 0.2 billion tons (average) and 0.3 billion tons (ending) compared to the culvert simulation.

This analysis shows that there will be no substantial increase or decrease in these lake condition parameters (salinities and salt loads) as a result of replacing the free-flowing culverts that existed in the causeway as of November 2012 with the 150-foot-long bridge at an invert elevation of 4,183 feet. This bridge geometry best replaces the aquatic function of the culverts and provides water and salt transfer through the causeway similar to that provided by the free-flowing culverts. UPRR will use this bridge geometry to evaluate impacts on lake resources.

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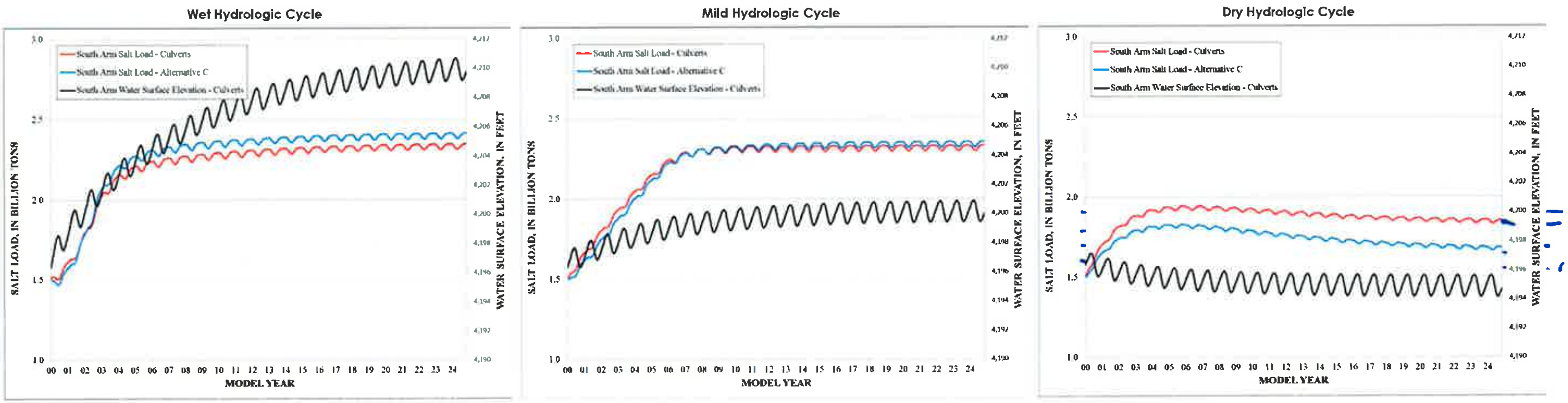
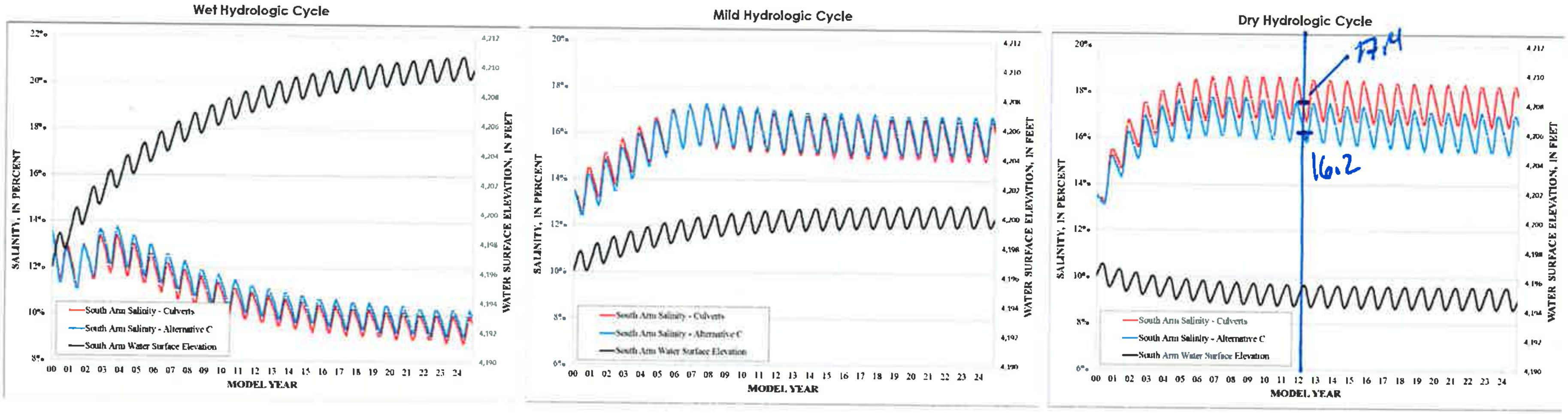
Figure 5. 2012 UPRR/USGS Varying Hydrology Model – Alternative C Simulation, Salt Load Comparison



=1.85
=1.68
.63

?

Figure 6. 2012 UPRR/USGS Varying Hydrology Model – Alternative C Simulation, North and South Arm Salinity Comparison


Wet Hydrologic Cycle

Mild Hydrologic Cycle

Dry Hydrologic Cycle

7.0 References

[UDWQ] Utah Division of Water Quality

2014 Letter to UPRR, subject "Level II Antidegradation Review Comments." May 9.

[UDWR] Utah Division of Water Resources

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[UPRR] Union Pacific Railroad

2011 Pre-Construction Notification for Culvert Closing and Bridge Construction. July.

2014 Union Pacific Railroad Great Salt Lake Causeway Final Water and Salt Balance Modeling Report – Modeling Steps 1, 2, and 3. April 4.

[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. pubs.er.usgs.gov/publication/wri004221.

APPENDIX A

2012 UPRR/USGS Model and 2012 UPRR/USGS Varying Hydrology Model – Bridge Evaluation Summary

2012 UPRR/USGS Model – Bridge Evaluation Summary

2012 UPRR/USGS Varying Hydrology Model – Bridge Evaluation Summary

2012 UPRR/USGS Varying Hydrology Model
Bridge Evaluation Summary

Parameter[1]	WET					MILD					DRY				
	Culverts	180-foot Bridge Invert 4,178 feet Alt. A	150-foot Bridge Invert 4,178 feet Alt. B[2]	150-foot Bridge Invert 4,183 feet Alt. C	150-foot Bridge Invert 4,188 feet Alt. D	Culverts	180-foot Bridge Invert 4,178 feet Alt. A	150-foot Bridge Invert 4,178 feet Alt. B	150-foot Bridge Invert 4,183 feet Alt. C	150-foot Bridge Invert 4,188 feet Alt. D	Culverts	180-foot Bridge Invert 4,178 feet Alt. A	150-foot Bridge Invert 4,178 feet Alt. B	150-foot Bridge Invert 4,183 feet Alt. C	150-foot Bridge Invert 4,188 feet Alt. D
SALINITY															
Equilibrium Avg. SA Salinity, %	9.4	9.9	9.8	9.7	9.6	15.7	16.7	16.2	15.9	15.4	17.4	20.0	18.3	16.2	12.1
Long-Term Avg. SA Salinity, %	10.7	11.4	11.2	11.0	10.7	15.7	16.8	16.2	15.8	14.9	17.3	19.6	18.1	16.4	13.3
Min/Max SA Salinity, %	8.8/13.5	9.3/15.1	10.4/14.3	9.1/13.8	9.0/13.5	12.6/17.1	13.1/18.6	12.7/17.9	12.4/17.3	11.9/16.4	13.2/18.6	13.5/21.1	13.4/19.5	13.1/17.8	11.3/15.3
Equilibrium Avg. SA TDS, g/l	100	106	105	103	102	175	186	181	177	171	196	228	207	181	131
Long-Term Avg. SA TDS, g/l	115	123	121	118	115	174	188	181	175	165	195	224	204	183	146
Min/Max SA TDS, g/l	94/148	98/167	111/157	97/151	95/148	137/192	143/211	138/202	135/194	129/183	144/211	148/243	146/222	143/200	122/170
Equilibrium Avg. NA Salinity, %	14.3	13.5	13.7	13.8	14.0	24.7	23.2	23.9	24.4	25.2	28.0	28.0	28.0	28.0	28.0
Long-Term Avg. NA Salinity, %	17.9	16.9	17.2	17.5	17.8	25.8	24.4	25.1	25.6	26.4	28.0	28.0	28.0	28.0	28.1
Min/Max NA Salinity, %	13.8/28.0	13.0/28.0	15.6/28.0	13.4/28.0	13.5/28.3	23.8/28.5	22.4/28.3	22.9/28.5	23.5/28.5	24.2/28.5	27.0/28.6	26.3/28.6	26.8/28.6	27.0/28.6	27.3/28.6
Equilibrium Avg. NA TDS, g/l	157	148	150	151	153	292	272	281	288	299	340	340	340	340	340
Long-Term Avg. NA TDS, g/l	204	190	194	198	202	308	288	298	306	317	340	339	340	340	341
Min/Max SA TDS, g/l	151/340	141/340	173/340	146/340	148/344	279/348	260/344	268/348	276/348	286/348	325/349	316/349	322/349	325/349	330/349
SALT LOAD (values in billion tons)															
Equilibrium Avg. SA Load	2.33	2.45	2.43	2.40	2.38	2.32	2.47	2.40	2.35	2.26	1.85	2.18	1.94	1.68	1.18
Long-Term Avg. SA Load	2.21	2.36	2.32	2.27	2.22	2.21	2.38	2.29	2.22	2.08	1.87	2.16	1.96	1.74	1.36
Ending SA Load	2.35	2.47	2.45	2.42	2.39	2.33	2.48	2.41	2.36	2.27	1.85	2.18	1.95	1.68	1.18
Min/Max SA Load	1.50/2.35	1.50/2.47	1.50/2.40	1.47/2.42	1.41/2.39	1.50/2.33	1.50/2.48	1.50/2.41	1.50/2.36	1.47/2.27	1.50/1.94	1.50/2.24	1.50/2.04	1.50/1.83	1.17/1.58
Equilibrium Avg. NA Load	2.22	2.10	2.13	2.15	2.17	2.23	2.09	2.16	2.21	2.29	2.71	2.38	2.61	2.87	3.37
Long-Term Avg. NA Load	2.34	2.19	2.24	2.28	2.33	2.34	2.17	2.26	2.34	2.47	2.68	2.39	2.59	2.81	3.19
Ending NA Load	2.20	2.09	2.12	2.14	2.16	2.22	2.07	2.14	2.20	2.28	2.70	2.37	2.60	2.87	3.37
Min/Max NA Load	2.20/3.05	2.09/3.05	2.16/3.05	2.14/3.08	2.16/3.14	2.22/3.05	2.07/3.05	2.14/3.05	2.20/3.05	2.28/3.08	2.61/3.05	2.31/3.05	2.52/3.05	2.72/3.05	2.98/3.38
TOTAL CAUSEWAY FLOW (values for last year in cubic feet per second)[3]															
Average Total Flow South-to-North	5,825	7,151	6,809	6,520	6,284	3,401	4,367	3,867	3,574	3,210	2,120	2,799	2,326	1,930	1,409
Average Total Flow North-to-South	3,548	4,817	4,497	4,224	3,999	1,969	2,907	2,414	2,131	1,779	1,181	1,822	1,365	987	500
TOTAL CAUSEWAY FLOW AND CONCENTRATION RATIOS[3]															
Average Total Flow South-to-North/ North-to-South	1.64	1.48	1.51	1.54	1.57	1.73	1.50	1.60	1.68	1.80	1.79	1.54	1.70	1.96	2.82
Average TDS NA/SA[4]	1.56	1.40	1.43	1.47	1.49	1.68	1.46	1.55	1.63	1.75	1.74	1.49	1.65	1.88	2.60
Average TDS SA/NA, % (See WRI 4221, Figure 18)[4]	64	71	70	68	67	60	69	64	61	57	58	67	61	53	38
OVERALL RANK	NA	4	3	2	1	NA	4	3	1	2	NA	3	1	2	4

Notes:

1. SA = South Arm, NA = North Arm. TDS = Total Dissolved Solids. Equilibrium averages are calculated based on values from the last modeled year. Long-term averages are calculated based on the modeled 25-year period, with the exception of values for Alternative B for the wet hydrologic conditions (see Note 2). Minimum and maximum values are calculated based on the modeled 25-year period. Salt loads are totals (i.e., the North Arm load includes both the dissolved and precipitated loads).
2. The Alternative B model terminated during year 12 for the wet hydrologic conditions. Equilibrium averages, long-term averages, and ratios for this model run are estimated.
3. Average total causeway flows are equilibrium (last year) averages, and the total causeway flow and concentration ratios reflect equilibrium values.
4. The TDS concentration ratios are expressed both as NA/SA (as a fraction) and as SA/NA (as a percent). Both expressions are used in WRI 4221, with the latter being used in Figure 18.

KEY

🟩	1st-Best Match
🟩	2nd-Best Match
🟨	3rd-Best Match
🟧	4th-Best Match

2012 UPRR/USGS Model
Bridge Evaluation Summary

Parameter[1]	Culverts	180-foot Bridge Invert 4,178 feet Alt. A	150-foot Bridge Invert 4,178 feet Alt. B	150-foot Bridge Invert 4,183 feet Alt. C	150-foot Bridge Invert 4,188 feet Alt. D
SALINITY					
Average SA Salinity, %	14.3	17.0	16.2	15.6	14.5
Ending SA Salinity, %	12.3	18.1	16.2	14.4	11.9
Min/Max SA Salinity, %	8.0/20.7	8.0/23.8	8.0/22.9	8.0/22.2	8.0/20.9
Average SA TDS, g/l	158	191	181	173	160
Ending SA TDS, g/l	133	205	181	159	129
Min/Max SA TDS, g/l	84/238	84/279	84/268	84/259	84/241
Average NA Salinity, %	25.6	24.1	24.6	24.9	25.4
Ending NA Salinity, %	28.4	28.1	28.1	28.1	28.2
Min/Max NA Salinity, %	16.2/28.7	15.0/28.7	15.3/28.7	15.5/28.7	15.9/28.7
Average NA TDS, g/l	307	286	292	297	304
Ending NA TDS, g/l	346	341	341	341	343
Min/Max NA TDS, g/l	181/351	165/351	170/351	171/351	176/351
SALT LOAD (values in billion tons)					
Average SA Load	2.04	2.39	2.28	2.19	2.03
Ending SA Load	1.40	2.15	1.88	1.65	1.31
Min/Max SA Load	1.34/2.42	1.90/2.58	1.70/2.53	1.5/2.48	1.22/2.42
Average NA Load	2.53	2.18	2.29	2.38	2.54
Ending NA Load	3.15	2.40	2.67	2.91	3.25
Min/Max NA Load	2.07/3.22	1.93/2.99	1.98/3.00	2.02/3.05	2.08/3.34
TOTAL CAUSEWAY FLOW (values in cubic feet per second)					
Average Total Flow South-to-North	1,984	3,356	2,861	2,562	2,188
Average Total Flow North-to-South	917	2,162	1,687	1,398	1,039
TOTAL CAUSEWAY FLOW AND TOTAL DISSOLVED SOLIDS CONCENTRATION RATIOS					
Average Total Flow South-to-North/ North-to-South	2.16	1.55	1.70	1.83	2.11
Average TDS NA/SA[2]	1.94	1.50	1.61	1.72	1.90
Average TDS SA/NA, % (See WRI 4221, Figure 18)[2]	51	67	62	58	53
OVERALL RANK	NA	4	3	2	1

Notes:

1. SA = South Arm, NA = North Arm. TDS = Total Dissolved Solids. Salt loads are totals (i.e., the North Arm load includes both the dissolved and precipitated loads).

2. The TDS concentration ratios are expressed both as NA/SA (as a fraction) and as SA/NA (as a percent). Both expressions are used in WRI 4221, with the latter being used in Figure 18.

KEY

🟩	1st-Best Match
🟩	2nd-Best Match
🟨	3rd-Best Match
🟧	4th-Best Match

APPENDIX B

2012 UPRR/USGS Model Bridge Alternative C Simulation – Model Code and Input and Output Files

2012 UPRR/USGS Water Balance Code
(WBprogram_Update_ver4.f)

Water Balance Input File
(WB_inputfile_1987-2012.txt)

Water Balance Output Files
(WB_output1.txt)
(WB_output2.txt)

2012 UPRR/USGS Salt Balance Model Code – Bridge Alternative C
(SB_1987-2012_New_Bridge_Run4.f)

Salt Balance Input File
(SB_inputfile_1987-2012.txt)

Bridge Alternative C Simulation Output File
(2012_longoutput_AltC.txt)

```
      PROGRAM WaterBalance

C     THIS VERSION MODIFIED BY STEPHEN C. ERTMAN, HDR|HYDROQUAL, FOR USE
C     IN SUPPORT OF UNION PACIFIC RAILROAD.

C     This is the calibrated WATER BALANCE PROGRAM
C     The calibration period is 1987-2012

      IMPLICIT NONE ! Must declare all variables

C     INITIAL CONDITIONS AND CONSTANTS
      INTEGER, PARAMETER::

C     YEARMAX=12 FOR 1987-1998 RUN; SCE/20131202
C    -  EAVMAX=91,TWELVE=12,YEARFIRST=1987,YEARMAX=12,YRCAL=10

C     YEARMAX=26 FOR 1987-2012 RUN; SCE/20131202
     -  EAVMAX=91,TWELVE=12,YEARFIRST=1987,YEARMAX=26,YRCAL=10

      INTEGER
     -  EAV,EAVNUM,EAVVAL,EAVVALN,EAVVALS,ELEV,EP,MON,VOLNUM,YR
      REAL, PARAMETER::
     -  ENIFIRST=4210.35,
     -  ESIFIRST=4210.97,
     -  EVAPCAL=1.00,
     -  FTFC=1.0/12.0,
     -  INFLOCAL=1.00,
     -  PAAOG=16.43,
     -  PAASLC=14.69,
     -  PAATO=16.05,
     -  PRECIPCAL=1.00
      REAL
     -  AAPEN(3,6),AAPES(3,6),AQENX,AQESX,AQENXC,AQESXC,AQINX,AQISX,
     -  AN,AS,CAUS,CN,CS,DIFFN,DIFFS,DIFVS,EAVN(3,0:EAVMAX),
     -  EAVS(3,0:EAVMAX),EAVS1(3,0:EAVMAX),EAVS2(3,0:EAVMAX),
     -  ENI,ESI,EMI(0:TWELVE),EAI(0:YEARMAX),ENMES(TWELVE,YEARMAX),
     -  ESMES(TWELVE,YEARMAX),EAAN,EAAS,EAN,EAS,EN,ES,EMN,EMS,
     -  HVNC,HVNM,HVSC,HVSM,HVOLN,HVOLS,PAAN,PAAS,PFAC,PMN,PMS,
     -  PMSLC(0:TWELVE,0:YEARMAX),PMOG(0:TWELVE,0:YEARMAX),
     -  PMTO(0:TWELVE,0:YEARMAX),QSNET,QB(0:TWELVE,0:YEARMAX),
     -  QW(0:TWELVE,0:YEARMAX),QJ(0:TWELVE,0:YEARMAX),
     -  QS(0:TWELVE,0:YEARMAX),QTN(0:TWELVE,0:YEARMAX),
     -  QTS(0:TWELVE,0:YEARMAX),RTNC,RTNM,RTSC,RTSM,
     -  SCFN(TWELVE,YEARMAX),SCFS(TWELVE,YEARMAX),SUMPMN,
     -  SUMPMS,SUMQTN,SUMQTS,VNM(0:TWELVE*YEARMAX),
     -  VSM(0:TWELVE*YEARMAX),VNC,VNIC,VSC,VSIC,VNFIRST,
     -  VSFIRST,WESTP(0:TWELVE,0:YEARMAX)

      SUMPMN=0.
      SUMPMS=0.
      SUMQTN=0.
      SUMQTS=0.

C     OPEN FILES
C     OPEN (UNIT=15,FILE='waterin.txt',STATUS='OLD')        !SCE/20131202
      OPEN (UNIT=15,FILE='waterin2012_VER6.txt',STATUS='OLD') !SCE
      OPEN (UNIT=16,FILE='output1.txt',STATUS='UNKNOWN')
      OPEN (UNIT=17,FILE='readcheck.txt',STATUS='UNKNOWN')
      OPEN (UNIT=18,FILE='output2.txt',STATUS='UNKNOWN')
      REWIND (UNIT=15)
      REWIND (UNIT=16)
      REWIND (UNIT=17)
      REWIND (UNIT=18)

C     READ IN MEASURED ELEVATIONS FOR NORTH AND SOUTH PARTS
      READ (15,10) ((ENMES(MON,YR),MON=1,TWELVE),YR=1,YEARMAX)
      READ (15,10) ((ESMES(MON,YR),MON=1,TWELVE),YR=1,YEARMAX)
      WRITE(17,10) ((ENMES(MON,YR),MON=1,TWELVE),YR=1,YEARMAX)
      WRITE(17,10) ((ESMES(MON,YR),MON=1,TWELVE),YR=1,YEARMAX)
```

```fortran
   10 FORMAT (6(1X,F7.2))
      DO YR=1,YEARMAX
        DO MON=1,TWELVE
          IF((ENMES(MON,YR).LT.4190.).OR.(ENMES(MON,YR).GT.4215.)) THEN
            PRINT*,"ERROR: ENMES IS OUT OF RANGE: ", ENMES(MON,YR)
            PRINT*,"MON= ",MON,"YR= ",YR
            STOP
          ELSEIF((ESMES(MON,YR).LT.4190.).OR.(ESMES(MON,YR).GT.4215.))
     1    THEN
            PRINT*,"ERROR: ESMES IS OUT OF RANGE: ", ESMES(MON,YR)
            PRINT*,"MON= ",MON,"YR= ",YR
            STOP
          ENDIF
        ENDDO
      ENDDO

C     READ IN AVERAGE ANNUAL PRECIPITATION AND EVAPORATION
C     TABLES FOR NORTH AND SOUTH PARTS
      READ (15,20) ((AAPEN(EP,ELEV),EP=1,3),ELEV=1,6)
      READ (15,20) ((AAPES(EP,ELEV),EP=1,3),ELEV=1,6)
      WRITE(17,20) ((AAPEN(EP,ELEV),EP=1,3),ELEV=1,6)
      WRITE(17,20) ((AAPES(EP,ELEV),EP=1,3),ELEV=1,6)
   20 FORMAT (F10.1,2F10.2)
      EP=1
      DO ELEV=1,6
        IF((AAPEN(EP,ELEV).LT.4190.).OR.(AAPEN(EP,ELEV).GT.4220.)) THEN
          PRINT*,"ERROR: AAPEN IS OUT OF RANGE: ", AAPEN(MON,YR)
          PRINT*,"EP= ",EP,"ELEV= ",ELEV
          STOP
        ELSEIF((AAPES(EP,ELEV).LT.4190.).OR.(AAPES(EP,ELEV).GT.4220.))
     1  THEN
          PRINT*,"ERROR: AAPES IS OUT OF RANGE: ", AAPES(MON,YR)
          PRINT*,"EP= ",EP,"ELEV= ",ELEV
          STOP
        ENDIF
      ENDDO
      DO EP=2,3
        DO ELEV=1,6
          IF((AAPEN(EP,ELEV).LT.0.).OR.(AAPEN(EP,ELEV).GT.99.)) THEN
            PRINT*,"ERROR: AAPEN IS OUT OF RANGE: ", AAPEN(MON,YR)
            PRINT*,"EP= ",EP,"ELEV= ",ELEV
            STOP
          ELSEIF((AAPES(EP,ELEV).LT.0.).OR.(AAPES(EP,ELEV).GT.99.))
     1    THEN
            PRINT*,"ERROR: AAPES IS OUT OF RANGE: ", AAPES(MON,YR)
            PRINT*,"EP= ",EP,"ELEV= ",ELEV
            STOP
          ENDIF
        ENDDO
      ENDDO

C     READ IN ELEVATION-AREA-VOLUME TABLES OF NORTH AND
C     SOUTH PARTS
      READ (15,30) ((EAVN(EAV,EAVVAL),EAV=1,3),EAVVAL=1,EAVMAX)
      READ (15,30) ((EAVS1(EAV,EAVVAL),EAV=1,3),EAVVAL=1,EAVMAX)
      READ (15,30) ((EAVS2(EAV,EAVVAL),EAV=1,3),EAVVAL=1,EAVMAX)
      WRITE(17,30) ((EAVN(EAV,EAVVAL),EAV=1,3),EAVVAL=1,EAVMAX)
      WRITE(17,30) ((EAVS1(EAV,EAVVAL),EAV=1,3),EAVVAL=1,EAVMAX)
      WRITE(17,30) ((EAVS2(EAV,EAVVAL),EAV=1,3),EAVVAL=1,EAVMAX)
   30 FORMAT (F10.1,2F10.0)

C     READ IN INFLOW DATA
      READ (15,40) ((QB(MON,YR),MON=1,TWELVE),YR=1,YEARMAX)
      WRITE(17,40) ((QB(MON,YR),MON=1,TWELVE),YR=1,YEARMAX)
      READ (15,40) ((QW(MON,YR),MON=1,TWELVE),YR=1,YEARMAX)
      WRITE(17,40) ((QW(MON,YR),MON=1,TWELVE),YR=1,YEARMAX)
      READ (15,40) ((QJ(MON,YR),MON=1,TWELVE),YR=1,YEARMAX)
      WRITE(17,40) ((QJ(MON,YR),MON=1,TWELVE),YR=1,YEARMAX)
      READ (15,40) ((QS(MON,YR),MON=1,TWELVE),YR=1,YEARMAX)
```

```
      WRITE(17,40) ((QS(MON,YR),MON=1,TWELVE),YR=1,YEARMAX)
      READ (15,40) ((QTN(MON,YR),MON=1,TWELVE),YR=1,YEARMAX)
      WRITE(17,40) ((QTN(MON,YR),MON=1,TWELVE),YR=1,YEARMAX)
   40 FORMAT (6F10.0)

C    READ IN MONTHLY PRECIPITATION AT SLC AIRPORT, OGDEN SUGAR F, TOOELE
      READ (15,50) ((PMSLC(MON,YR),MON=1,TWELVE),YR=1,YEARMAX)
      READ (15,50) ((PMOG(MON,YR),MON=1,TWELVE),YR=1,YEARMAX)
      READ (15,50) ((PMTO(MON,YR),MON=1,TWELVE),YR=1,YEARMAX)
      WRITE(17,50) ((PMSLC(MON,YR),MON=1,TWELVE),YR=1,YEARMAX)
      WRITE(17,50) ((PMOG(MON,YR),MON=1,TWELVE),YR=1,YEARMAX)
      WRITE(17,50) ((PMTO(MON,YR),MON=1,TWELVE),YR=1,YEARMAX)
   50 FORMAT (12F6.2)

C     READ IN MONTHLY FRACTIONS FOR ANNUAL EVAPORATION
      READ (15,60) (EMI(MON),MON=1,TWELVE)
      WRITE(17,60) (EMI(MON),MON=1,TWELVE)
   60 FORMAT (12F6.3)
      DO MON=1,TWELVE
        IF((EMI(MON).LT.0).OR.(EMI(MON).GT.1.))THEN
          PRINT*,"ERROR: EMI IS OUT OF RANGE: ",EMI(MON)
          PRINT*,"MON= ",MON
          STOP
        ENDIF
      ENDDO

C     READ IN ANNUAL FRACTIONS OF AVERAGE ANNUAL EVAPORATION
      READ (15,70) (EAI(YR),YR=1,YEARMAX)
      WRITE(17,70) (EAI(YR),YR=1,YEARMAX)
C     FORMAT STATEMENT 70 IS DEPENDENT ON # YEARS IN CALIBRATION PERIOD
C70    FORMAT (100F6.2)
70    FORMAT (13F6.2)  !FORMATTED FOR YEARMAX=26; SCE/20131202
      DO YR=1,YEARMAX
        IF((EAI(YR).LT.0).OR.(EAI(YR).GT.1.))THEN
          PRINT*,"ERROR: EAI IS OUT OF RANGE: ",EAI(YR)
          PRINT*,"YR= ",YR
          STOP
        ENDIF
      ENDDO

C     READ IN SALINITY CORRECTION FACTORS FOR EVAPORATION FOR THE
C     NORTH AND SOUTH PARTS
      READ (15,80) ((SCFN(MON,YR),MON=1,TWELVE),YR=1,YEARMAX)
      READ (15,80) ((SCFS(MON,YR),MON=1,TWELVE),YR=1,YEARMAX)
      WRITE(17,80) ((SCFN(MON,YR),MON=1,TWELVE),YR=1,YEARMAX)
      WRITE(17,80) ((SCFS(MON,YR),MON=1,TWELVE),YR=1,YEARMAX)
   80 FORMAT (12F6.3)

C     READ IN WEST POND PUMPING/RETURN FLOWS DURING 1987-92
      READ (15,85) ((WESTP(MON,YR),MON=1,TWELVE),YR=1,YEARMAX)
      WRITE(17,85) ((WESTP(MON,YR),MON=1,TWELVE),YR=1,YEARMAX)
   85 FORMAT(12F8.0)

C     SUM INFLOWS TO THE SOUTH PART OF LAKE
      DO YR=1,YEARMAX
        DO MON=1,TWELVE
          QTS(MON,YR)=QB(MON,YR)+QW(MON,YR)+QJ(MON,YR)+QS(MON,YR)
        ENDDO
      ENDDO

C     DEFINE INITIAL VALUES FOR VOLNUM, ENI, AND ESI
      EAVS=EAVS1
      VOLNUM=1
      ENI=ENIFIRST
      ESI=ESIFIRST

C     DETERMINE THE LARGEST ELEVATION IN EAV TABLE LESS THAN ENI AND
C     ITS CORRESPONDING NUMBER EAVVALN
      EAVVAL=1
```

```fortran
      DO WHILE((ENI.GE.EAVN(1,EAVVAL)).AND.(EAVVAL.LE.EAVMAX))
        EAVVALN=EAVVAL
        EAVVAL=EAVVAL+1
      ENDDO

C     DETERMINE THE LARGEST ELEVATION IN EAV TABLE LESS THAN ESI AND
C     ITS CORRESPONDING NUMBER EAVVALS
      EAVVAL=1
      DO WHILE((ESI.GE.EAVS(1,EAVVAL)).AND.(EAVVAL.LE.EAVMAX))
        EAVVALS=EAVVAL
        EAVVAL=EAVVAL+1
      ENDDO

C     WRITE HEADERS TO OUTPUT FILES
      WRITE (16,90)
   90 FORMAT (32X,'LAKE ELEVATIONS (FEET)',/,22X,'NORTH',26X,'SOUTH',
     - /,'YEAR',3X,'MONTH',2X,'COMPUTED',4X,'MEASURED',2X,'DIFFN',5X,
     - 'COMPUTED',4X,'MEASURED',2X,'DIFFS')
      WRITE (16,140)YEARFIRST-1,12,ENI,ENIFIRST,0.0,ESI,ESIFIRST,0.0
      WRITE (18,95)
   95 FORMAT (5X,'AQESXC',5X,'AQENXC',6X,'AQESX',6X,'AQENX',6X,'AQISX',
     - 6X,'AQINX',9X,'AS',9X,'AN',7X,'SCFS',7X,'SCFN')

C     EAI IS ADJUSTED FOR EACH YEAR TO CALIBRATE THE WATER BALANCE
      EAI(1) =0.76  ! 1987
      EAI(2) =0.86  ! 1988
      EAI(3) =0.89  ! 1989
      EAI(4) =0.86  ! 1990
      EAI(5) =0.86  ! 1991
      EAI(6) =0.86  ! 1992
      EAI(7) =0.86  ! 1993
      EAI(8) =0.86  ! 1994
      EAI(9) =0.86  ! 1995
      EAI(10)=0.86  ! 1996
      EAI(11)=0.94  ! 1997
      EAI(12)=0.86  ! 1998
      EAI(13)=0.84  ! 1999
      EAI(14)=0.95  ! 2000
      EAI(15)=0.94  ! 2001
      EAI(16)=0.89  ! 2002
      EAI(17)=1.02  ! 2003
      EAI(18)=0.94  ! 2004
      EAI(19)=0.72  ! 2005
      EAI(20)=0.92  ! 2006
      EAI(21)=0.96  ! 2007
      EAI(22)=0.98  ! 2008
      EAI(23)=0.87  ! 2009
      EAI(24)=0.99  ! 2010
      EAI(25)=0.77  ! 2011
      EAI(26)=1.13  ! 2012

C     INTERPOLATE NORTH PART VOLUME AT THE BEGINING OF 1ST MONTH
      EAVVAL=EAVVALN-10
      DO WHILE((ENIFIRST.GE.EAVN(1,EAVVAL)).AND.(EAVVAL.LE.EAVMAX))
        EAVVAL=EAVVAL+1
      ENDDO
      VNFIRST=(EAVN(3,EAVVAL)-EAVN(3,EAVVAL-1))*
     -  (ENIFIRST-EAVN(1,EAVVAL-1))/(EAVN(1,EAVVAL)-EAVN(1,EAVVAL-1))+
     -  EAVN(3,EAVVAL-1)

C     INTERPOLATE SOUTH PART VOLUME AT THE BEGINING OF 1ST MONTH
      EAVVAL=EAVVALS-10
      DO WHILE((ESIFIRST.GE.EAVS(1,EAVVAL)).AND.(EAVVAL.LE.EAVMAX))
        EAVVAL=EAVVAL+1
      ENDDO
      VSFIRST=(EAVS(3,EAVVAL)-EAVS(3,EAVVAL-1))*
     -  (ESIFIRST-EAVS(1,EAVVAL-1))/(EAVS(1,EAVVAL)-EAVS(1,EAVVAL-1))+
     -  EAVS(3,EAVVAL-1)

```

```
C *********************************************************************
C *                           MAIN LOOP                                *
C *********************************************************************
C     COMPUTE INTERPOLATION RATIO FOR EAVN TABLE (RTNM), USING
C     MEASURED ELEVATION OF NORTH PART
      DO YR=1,YEARMAX
        DO MON=1,TWELVE
          EAVVAL=EAVVALN-10
          IF(YR.GE.8) EAVS=EAVS2
          DO WHILE((ENMES(MON,YR).GE.EAVN(1,EAVVAL))
     1    .AND.(EAVVAL.LE.EAVMAX))
            EAVVAL=EAVVAL+1
          ENDDO
          RTNM=(ENMES(MON,YR)-EAVN(1,EAVVAL-1))/
     1     (EAVN(1,EAVVAL)-EAVN(1,EAVVAL-1))
C     COMPUTE AREA (AN) AND VOLUME (VNM) OF NORTH PART, USING
C     MEASURED ELEVATION
          AN=RTNM*(EAVN(2,EAVVAL)-EAVN(2,EAVVAL-1))+EAVN(2,EAVVAL-1)
          VNM(VOLNUM)=RTNM*(EAVN(3,EAVVAL)-EAVN(3,EAVVAL-1))
     1      +EAVN(3,EAVVAL-1)
C     COMPUTE CHANGE IN VOLUME (HVNM) BASED ON MEASURED ELEVATIONS
          IF (YR.EQ.1.AND.MON.EQ.1) VNM(VOLNUM-1)=VNFIRST
          HVNM=VNM(VOLNUM)- VNM(VOLNUM-1)
C     COMPUTE INTERPOLATION RATIO AND INITIAL VOLUME (VNIC) OF NORTH
C     PART USING COMPUTED ELEVATION
C     ASSUME IN EAV TABLE THAT NEW ENI IS LESS THAN +-10 NUMBERS AWAY
C     FROM OLD ENI
          EAVNUM=EAVVALN-10
          EAVVAL=EAVNUM
          DO WHILE((ENI.GE.EAVN(1,EAVVAL)).AND.(EAVVAL.LE.EAVMAX))
           EAVVAL=EAVVAL+1
          ENDDO
          RTNC=(ENI-EAVN(1,EAVVAL-1))/(EAVN(1,EAVVAL)- EAVN(1,EAVVAL-1))
          VNIC=RTNC*(EAVN(3,EAVVAL)-EAVN(3,EAVVAL- 1))+EAVN(3,EAVVAL-1)
C     COMPUTE INTERPOLATION RATIO FOR EAVS TABLE (RTSM), USING
C     MEASURED ELEVATION OF SOUTH PART
C     ASSUME IN EAV TABLE THAT NEW ESI IS LESS THAN +-10 NUMBERS AWAY
C     FROM OLD ESI
          EAVNUM=EAVVALS-10
          EAVVAL=EAVNUM
          DO WHILE((ESMES(MON,YR).GE.EAVS(1,EAVVAL))
     1     .AND.(EAVVAL.LE.EAVMAX))
            EAVVAL=EAVVAL+1
          ENDDO
          RTSM=(ESMES(MON,YR)-EAVS(1,EAVVAL-1))/
     1      (EAVS(1,EAVVAL)-EAVS(1,EAVVAL-1))
C     COMPUTE AREA (AS) AND VOLUME (VSM) OF SOUTH PART, USING
C     MEASURED ELEVATION
          AS=RTSM*(EAVS(2,EAVVAL)-EAVS(2,EAVVAL-1))+EAVS(2,EAVVAL-1)
          VSM(VOLNUM)=RTSM*(EAVS(3,EAVVAL)-EAVS(3,EAVVAL-1))
     1      +EAVS(3,EAVVAL-1)
C     COMPUTE CHANGE IN VOLUME (HVSM) BASED ON MEASURED ELEVATIONS
          IF (YR.EQ.1.AND.MON.EQ.1) VSM(VOLNUM-1)=VSFIRST
          HVSM=VSM(VOLNUM)-VSM(VOLNUM-1)
C     COMPUTE INTERPOLATION RATIO AND INITIAL VOLUME (VSIC) OF SOUTH
C     PART USING COMPUTED ELEVATION
          EAVVAL=EAVNUM
          DO WHILE((ESI.GE.EAVS(1,EAVVAL)).AND.(EAVVAL.LE.EAVMAX))
            EAVVAL=EAVVAL+1
          ENDDO
          RTSC=(ESI-EAVS(1,EAVVAL-1))/(EAVS(1,EAVVAL)- EAVS(1,EAVVAL-1))
          VSIC=RTSC*(EAVS(3,EAVVAL)-EAVS(3,EAVVAL-1))+EAVS(3,EAVVAL-1)
C     COMPUTE INTERPOLATION RATIO (CS) FOR AVERAGE ANNUAL PRECIPITATION
C     AND AVERAGE ANNUAL EVAPORATION FOR SOUTH PART, USING MEASURED
C     ELEVATIONS
          ELEV=2
          DO WHILE((ESMES(MON,YR).GE.AAPES(1,ELEV)).AND.(ELEV.LE.6))
            ELEV=ELEV+1
          ENDDO
```

```fortran
          CS=(ESMES(MON,YR)-AAPES(1,ELEV-1))/
     1          (AAPES(1,ELEV)-AAPES(1,ELEV-1))
          PAAS=CS*(AAPES(2,ELEV)- AAPES(2,ELEV-1))+AAPES(2,ELEV-1)
          EAAS=CS*(AAPES(3,ELEV)-AAPES(3,ELEV- 1))+AAPES(3,ELEV-1)
C     COMPUTE INTERPOLATION RATIO (CN) FOR AVERAGE ANNUAL PRECIPITATION
C     AND AVERAGE ANNUAL EVAPORATION FOR NORTH PART, USING MEASURED
C     ELEVATIONS
          ELEV=2
          DO WHILE((ENMES(MON,YR).GE.AAPEN(1,ELEV)).AND.(ELEV.LE.6))
            ELEV=ELEV+1
          ENDDO
          CN=(ENMES(MON,YR)-AAPEN(1,ELEV-1))/
     1      (AAPEN(1,ELEV)-AAPEN(1,ELEV-1))
          PAAN=CN*(AAPEN(2,ELEV)- AAPEN(2,ELEV-1))+AAPEN(2,ELEV-1)
          EAAN=CN*(AAPEN(3,ELEV)-AAPEN(3,ELEV- 1))+AAPEN(3,ELEV-1)
C     COMPUTE MONTHLY PRECIPITATION FOR SOUTH PART OF LAKE (PMS),
C     INCLUDES CONVERSION FROM INCHES TO ACRE-FEET
          PFAC=((PMSLC(MON,YR)/PAASLC)+(PMOG(MON,YR)/PAAOG)
     1      +(PMTO(MON,YR)/PAATO))/3
          PMS=PFAC*PAAS*FTFC*AS*PRECIPCAL
C     COMPUTE MONTHLY PRECIPITATION FOR NORTH PART OF LAKE (PMN),
C     INCLUDES CONVERSION FROM INCHES TO ACRE-FEET
          PMN=PFAC*PAAN*FTFC*AN*PRECIPCAL
C     COMPUTE ANNUAL EVAPORATION FOR SOUTH PART OF LAKE
          EAS=EAAS*EAI(YR)
C     COMPUTE ANNUAL EVAPORATION FOR NORTH PART OF LAKE
          EAN=EAAN*EAI(YR)
C     COMPUTE MONTHLY EVAPORATION FOR SOUTH PART OF LAKE,
C     INCLUDES CONVERSION FROM INCHES TO ACRE-FEET AND
C     SALINITY CORRECTION FACTOR, SCFS
          EMS=(EAS*EMI(MON))*(FTFC*AS)*(SCFS(MON,YR))
          IF  (YR.EQ.YRCAL)  EMS=EMS*EVAPCAL
C     COMPUTE MONTHLY EVAPORATION FOR NORTH PART OF LAKE,
C     INCLUDES CONVERSION FROM INCHES TO ACRE-FEET AND
C     SALINITY CORRECTION FACTOR, SCFN
          EMN=(EAN*EMI(MON))*(FTFC*AN)*(SCFN(MON,YR))
          IF  (YR.EQ.YRCAL)  EMN=EMN*EVAPCAL

C     INCREASE STREAMFLOW AND GROUND-WATER INFLOW BY FACTOR INFLOCAL
          QTS(MON,YR)=INFLOCAL*QTS(MON,YR)
          QTN(MON,YR)=INFLOCAL*QTN(MON,YR)
C     EVAPORATION (Ac-Ft/Day) FOR CALIBRATION OF THE W&S BALANCE MODEL
          AQESXC=EMS*12.0/(365.0)
          AQENXC=EMN*12.0/(365.0)
C     EVAPORATION (Ft/Day) FOR THE PREDICTIVE W&S BALANCE MODEL
          AQESX=AQESXC/(AS*SCFS(MON,YR))
          AQENX=AQENXC/(AN*SCFN(MON,YR))
C     INFLOW FOR THE WATER AND SALT BALANCE MODEL
          AQISX=(PMS+QTS(MON,YR))*12.0/365.0
          AQINX=(PMN+QTN(MON,YR))*12.0/365.0
          SUMPMS=SUMPMS + PMS
          SUMPMN=SUMPMN + PMN
          SUMQTS=SUMQTS + QTS(MON,YR)
          SUMQTN=SUMQTN + QTN(MON,YR)
C     COMPUTE NET FLOW THROUGH CAUSEWAY FROM SOUTH TO NORTH
          CAUS=HVNM+EMN-PMN-QTN(MON,YR)+WESTP(MON,YR)
C     COMPUTE NET INFLOW TO THE SOUTH PART AS CAUSEWAY FLOW IS
C     SUBTRACTED FROM QTS(MON,YR)
          QSNET=QTS(MON,YR)-CAUS
C     COMPUTE CHANGE IN VOLUME FOR TIME STEP (1 MONTH) FOR SOUTH PART
          HVSC=(PMS+QSNET)-(EMS)
C     COMPUTE CHANGE IN VOLUME FOR TIME STEP (1 MONTH) FOR NORTH PART
          HVNC=(CAUS+PMN+QTN(MON,YR))-(EMN+WESTP(MON,YR))
C     COMPUTE DIFFERENCE BETWEEN MEASURED AND COMPUTED VOLUMES FOR
C     EACH TIME STEP (ONE MONTH)
          HVOLN=HVNM-HVNC
          HVOLS=HVSM-HVSC
C     COMPUTE NEW VOLUMES AT END OF TIME STEP (VNC,VSC)
          VNC=VNIC+HVNC
```

```fortran
          VSC=VSIC+HVSC
C     COMPUTE DIFFERENCE BETWEEN COMPUTED AND MEASURED TOTAL VOLUME
          DIFVS=VSM(VOLNUM)-VSC
C     INTERPOLATE NEW ELEVATION FOR NORTH PART FROM NEW VOLUME (VN)
C     ASSUME IN EAV TABLE THAT NEW ENI IS LESS THAN +-3 NUMBERS AWAY
C     FROM OLD ENI
          EAVNUM=EAVVALN-3
          EAVVAL=EAVNUM
          DO WHILE((VNC.GE.EAVN(3,EAVVAL)).AND.(EAVVAL.LE.EAVMAX))
            EAVVAL=EAVVAL+1
          ENDDO
          EN=((VNC-EAVN(3,EAVVAL-1))/(EAVN(3,EAVVAL)-EAVN(3,EAVVAL-1)))*
     1        (EAVN(1,EAVVAL)-EAVN(1,EAVVAL-1))+EAVN(1,EAVVAL-1)
          EAVVALN=EAVVAL
C     INTERPOLATE NEW ELEVATION FOR SOUTH PART FROM NEW VOLUME (VS)
C     ASSUME IN EAV TABLE THAT NEW ESI IS LESS THAN +-10 NUMBERS AWAY
C     FROM OLD ESI
          EAVNUM=EAVVALS-3
          EAVVAL=EAVNUM
          DO WHILE((VSC.GE.EAVS(3,EAVVAL)).AND.(EAVVAL.LE.EAVMAX))
            EAVVAL=EAVVAL+1
          ENDDO
          ES=((VSC-EAVS(3,EAVVAL-1))/(EAVS(3,EAVVAL)-EAVS(3,EAVVAL-1)))*
     1     (EAVS(1,EAVVAL)-EAVS(1,EAVVAL-1))+EAVS(1,EAVVAL-1)
          EAVVALS=EAVVAL
          DIFFS=ESMES(MON,YR)-ES
          DIFFN=ENMES(MON,YR)-EN

C *********************************************************************
C *                       WRITE TO OUTPUT FILES                       *
C *********************************************************************
          WRITE(18,100) AQESXC,AQENXC,AQESX,AQENX,AQISX,AQINX
     -     ,AS,AN,SCFS(MON,YR),SCFN(MON,YR)
  100     FORMAT(2F11.2,2F11.8,2F11.2,2f11.2,2f11.8)

C     WRITE CALIBRATION VARIABLES
          WRITE (*,130)YR,MON,HVSM,HVSC,HVOLS,VSM(VOLNUM),VSC,DIFVS
          IF(VSM(VOLNUM).LT.0)THEN
            PRINT*,"ERROR: NEGATIVE VSM(VOLNUM): ",VSM(VOLNUM)
            STOP
          ENDIF
          IF(VSC.LT.0)THEN
            PRINT*,"ERROR: NEGATIVE VSC: ",VSC
            STOP
          ENDIF
  130     FORMAT (' YR= ',I2,' MO= ',I2,6F10.0)

C     WRITE THE COMPUTED AND MEASURED MONTHLY ELEVATIONS FOR NORTH AND
C     SOUTH PARTS OF THE LAKE BY YEARS (19xx) = YEARFIRST+YR-1
          WRITE (16,140)YEARFIRST+YR-1,MON,EN,ENMES(MON,YR),DIFFN,ES,
     1      ESMES(MON,YR),DIFFS
  140     FORMAT (I4,I6,2F12.2,F7.2,F13.2,F12.2,F7.2)

C     DEFINE INITIAL ELEVATIONS AS FINAL ELEVATIONS FROM LAST TIME STEP
          ENI=EN
          ESI=ES
C     INCREASE COUNTER FOR VOLUMES BY 1
          VOLNUM=VOLNUM+1

        ENDDO
      ENDDO
      STOP
      END

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4210.50 4210.75 4210.85 4210.90 4210.75 4210.35
4209.85 4209.35 4208.80 4208.65 4208.65 4208.65
4208.85 4208.75 4208.65 4208.45 4208.30 4207.95
4207.25 4206.55 4206.00 4205.65 4205.60 4205.65
4205.70 4205.75 4205.95 4205.75 4205.55 4205.10
4204.70 4204.10 4203.6  4203.4  4203.5  4203.5
4203.6  4203.5  4203.7  4203.6  4203.3  4203.0
4202.5  4201.9  4201.5  4201.3  4201.1  4201.0
4201.1  4201.3  4201.3  4201.3  4201.3  4201.0
4200.6  4200.2  4199.8  4199.6  4199.5  4199.5
4199.5  4199.7  4199.8  4199.7  4199.2  4198.8
4198.3  4197.8  4197.5  4197.4  4197.2  4197.2
4197.4  4197.6  4197.6  4197.6  4197.4  4197.3
4196.9  4196.6  4196.4  4196.7  4196.7  4197.0
4197.2  4197.4  4197.9  4197.9  4197.9  4197.6
4197.1  4196.7  4196.6  4196.6  4196.7  4196.8
4197.1  4197.3  4197.4  4197.4  4197.8  4198.0
4197.8  4197.3  4197.1  4196.9  4196.9  4197.1
4197.3  4197.5  4197.7  4197.9  4198.0  4197.8
4197.6  4197.2  4197.0  4196.8  4196.9  4197.1
4197.5  4197.7  4198.1  4198.5  4198.6  4198.7
4198.6  4198.5  4198.7  4198.6  4199.0  4199.0
4199.5  4199.9  4200.5  4200.9  4201.4  4201.9
4201.8  4201.5  4201.4  4201.3  4201.4  4201.5
4202.20 4202.40 4202.80 4202.90 4203.10 4203.20
4202.90 4202.60 4202.10 4201.90 4201.90 4202.00
4202.20 4202.70 4202.90 4202.80 4202.70 4202.10
4201.60 4201.20 4200.80 4200.70 4200.60 4200.60
4200.70 4200.90 4200.90 4200.90 4200.60 4200.20
4199.70 4199.10 4198.70 4198.40 4198.50 4198.70
4198.80 4199.00 4199.00 4199.20 4199.00 4198.60
4198.00 4197.30 4197.10 4196.90 4196.90 4197.00
4197.10 4197.30 4197.20 4197.20 4197.00 4196.50
4196.00 4195.50 4195.00 4194.70 4194.60 4194.80
4194.90 4195.30 4195.50 4195.60 4195.40 4194.90
4194.50 4194.00 4193.70 4193.80 4193.60 4193.80
4194.60 4194.80 4195.00 4195.40 4196.20 4196.40
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4194.00 4193.50 4193.10 4192.90 4192.90 4193.50
4193.80 4194.30 4194.90 4195.50 4196.50 4197.10
4197.10 4197.00 4196.70 4196.70 4196.90 4197.00
4197.40 4197.60 4197.80 4197.90 4197.50 4197.00
4196.50 4196.00 4195.60 4195.40 4195.50 4195.80
4211.16 4211.35 4211.54 4211.43 4211.22 4210.91
4210.40 4209.69 4209.18 4209.07 4209.06 4209.04
4209.03 4209.12 4209.01 4209.00 4208.59 4208.28
4207.57 4206.96 4206.35 4206.04 4205.93 4205.91
4205.90 4205.99 4206.18 4206.07 4205.86 4205.35
4204.74 4204.43 4204.12 4203.81 4203.80 4203.79
4203.77 4203.86 4204.05 4204.04 4203.53 4203.22
4202.71 4202.20 4201.84 4201.73 4201.62 4201.61
4201.70 4201.89 4201.97 4201.96 4202.05 4201.84
4201.33 4200.82 4200.61 4200.50 4200.69 4200.78
4200.87 4201.26 4201.34 4201.23 4200.72 4200.31
4199.90 4199.29 4198.83 4198.63 4198.62 4198.92
4199.22 4199.61 4200.21 4200.31 4200.70 4200.80
4200.40 4199.89 4199.64 4199.74 4199.53 4199.63
4199.63 4199.82 4200.02 4200.22 4200.01 4199.51
4198.91 4198.10 4197.55 4197.54 4197.74 4197.94
4198.43 4198.63 4198.93 4199.12 4199.82 4200.12
4199.61 4198.91 4198.51 4198.40 4198.40 4198.60
4198.89 4199.29 4199.78 4200.18 4200.17 4199.96
4199.36 4198.75 4198.35 4198.14 4198.43 4198.80
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