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U.S. GEOLOGICAL SURVEY
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Re: U.S. Geological Survey Technical Review of the UPRR Great Salt Lake Causeway Bridge Construction Project Final Modeling Report

Dear Mr. Damery,

This letter documents the technical review by the U.S. Geological Survey of the final modeling report of the Great Salt Lake causeway culvert closure and bridge construction project dated April 4, 2014. The report is titled "Union Pacific Railroad Great Salt Lake Causeway Final Water and Salt Balance Modeling Report, Final Report – Modeling Steps 1, 2, and 3" and was prepared by HDR Engineering, Inc. for the Union Pacific Railroad. Comments were limited to technical issues and are listed below. The report was not reviewed for grammatical or editorial content. The scope of the U.S. Geological Survey review is detailed as follows.

- We reviewed the Step 1, Step 2, and Step 3 Final reports for conceptual design, modeling voracity, and technical concerns.
- We attended regular meetings to discuss comments and concerns with the modeling simulations and implementation of sensitivity and uncertainty into the simulations and the reports.
- We reviewed the Step 1 model code with the culverts for consistency in simulation output with Loving and others (2000).
- We analyzed revisions to the modeling code inputs to accommodate the new bridge design in Step 1.
- We analyzed the revisions to the modeling code and inputs to accommodate the culvert, the new bridge, and expanded model time period in Step 2.
- We analyzed revisions made to the modeling code to accommodate the culvert and the new bridge in Step 3 under variable hydrologic conditions.
- We compared the simulation results from HDR to our independent results using the same model code and inputs for each scenario (culverts and new bridge) for each Step of the report.
- We performed additional model sensitivity analysis to investigate the impacts of more recent estimates of groundwater inputs to Great Salt Lake (Brooks and others, in press).
- We performed additional model simulations to quantify the predictive capability of the model under the Step 3 hydrologic conditions over a longer (50 yr) simulation period.

Comments and suggestions from report review

Step 3, pp. 11, sect. 3.3: Inputs to the HDR model defining groundwater inflow to the Great Salt Lake were based on 1977 estimates (Waddell and Fields, 1977) described in Loving and others (2000). We note, however, that estimates of groundwater recharge to the lake have been made in other studies and publications including Waddell and others (1987), Clark and others (1990), Lambert (1995), and most recently, in Heilweil and others (2010). These more recent estimates vary significantly from the 1977 values used in the construction of the HDR salt-balance model and, depending on the sensitivity of the model to this groundwater inflow parameter, it would be possible that incorporation of these updated inflow estimates could affect model results. During our review we took the liberty of assessing HDR model sensitivity to the range of groundwater inflow values estimated in a USGS regional groundwater flow model recently developed and documented in Heilweil and others (2010); this range encompassed the estimates of the previous studies referenced above.

We found only very limited deviations between the final HDR model using the 1977 groundwater flow estimates (Waddell and Fields, 1977) and our model simulations using the more recent groundwater inflow estimation (Heilweil and others, 2010). The model is relatively insensitive to variations in incorporated groundwater inflow within the range of values that we tested. However, the modeling team might consider review of more-recent estimates of groundwater inflow in future model simulations for completeness.

Step 3, pp. 27, sect. 6.0: The HDR modeling team assumed a 25 year period as sufficient to achieve a “steady state” condition in order to observe and compare model results under various lake levels. However, it is not clear from the summaries and depictions of model results if a “steady state” condition, or sufficiently close to a steady-state condition, is actually achieved in all cases. In particular, the wet simulation appears to continue to show change across time-steps at the end of the 25 year simulation. During our review, we took the liberty of continuing the simulations for dry and mild conditions through a period of 50 years (fig. 1). We were unable to complete a simulation of 50 years for the wet simulation as one of the model limitations, the computed head in the north arm must always be less than the head in the south arm, was violated at about the 26 year mark. We prescribed a gradient cutoff of 0.0001 ft/ time step as a reasonable approximation of stability; however, steady conditions are significantly greater. Our results indicated that when beginning with the same initial conditions for the dry simulation, this threshold would be reached at time step 2352 – or 12.26 years, , well within the HDR 25-year simulation period. The length of time required for the prescribed stability threshold under the mild conditions is slightly greater at 19.13 yr (time step 3669). Assessment of the stability of the wet condition simulation; however, indicates that water surface elevation continues to rise and does not reach our designated gradient stability threshold by the end of the 25-year simulation (time-step 4889). However, during these wet conditions, the dissolved solids load in both the north and south parts (LN and LS) were fairly stable at a time-step of roughly 1350 or 7.04 yr. We suggest that the modelers expand their discussion of the selection of 25 years as the simulation period for comparison model results and suggest possibly documenting and justifying a criterion of change in computed model output values to assess the defined simulation period.

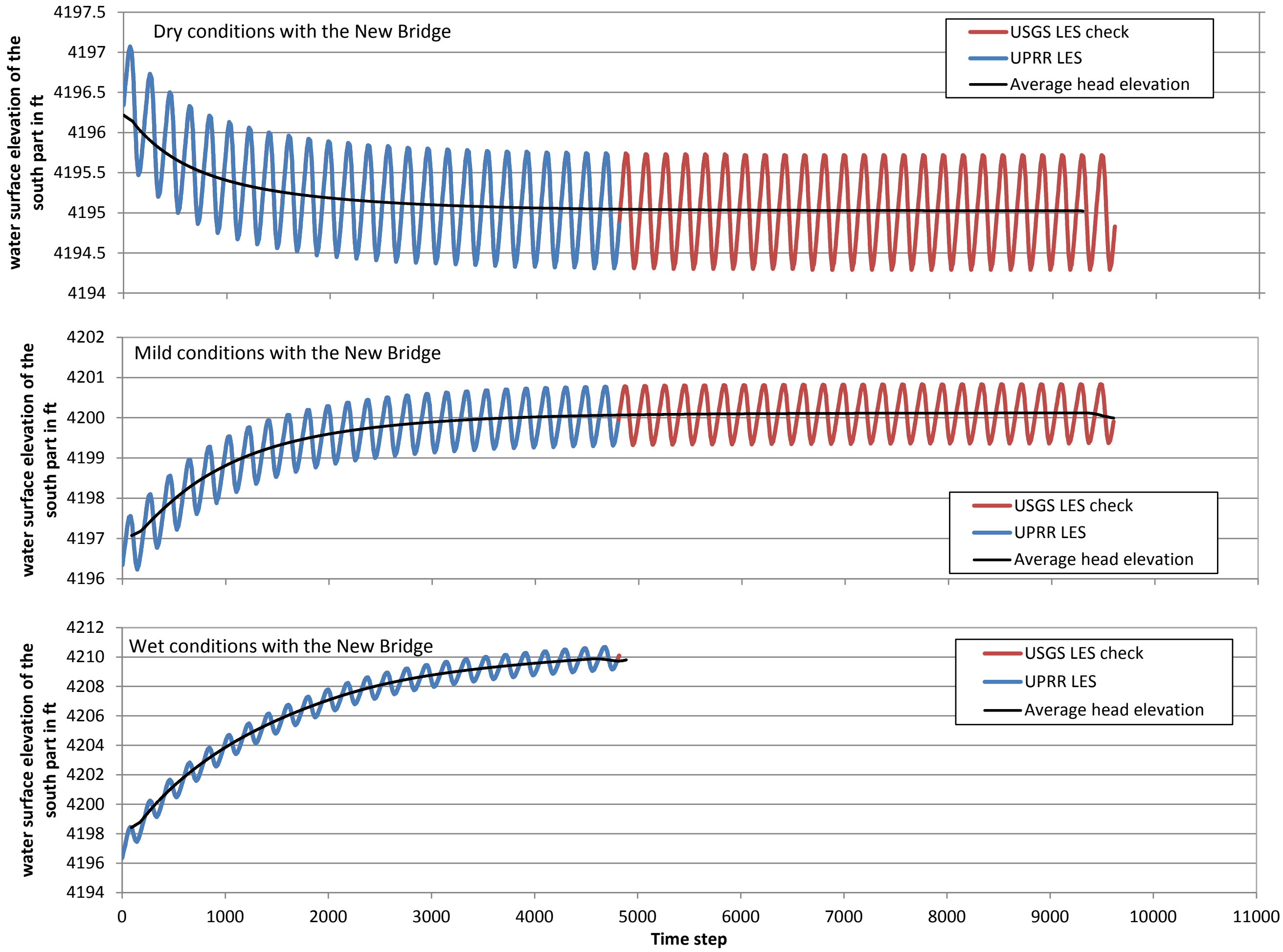

Fig. 1 – Asymptotic behavior of the water surface elevation under the dry, mild, and wet conditions for a period of 50 years.

Code Modifications: The modifications to the original simulation code, as completed by HDR, are generally described throughout the modeling reports; however, they do not explicitly describe the “detailed code modifications” as they suggest. We were unable to locate the revised modeling code with the modifications highlighted. We suggest that the parts of the code that were altered be identified so that the modeler can interpret the simulation results in conjunction with the original Loving and others (2000) simulations.

Comparison of HDR salt-balance model simulation output and independent USGS model simulation output

The U.S. Geological Survey attempted to reproduce the simulation results for each Step of the modeling process under the different conditions specified (culverts or new bridge). For Step 1, we found that the final model results of the culverts for our simulations using the same model input as the HDR model were identical to the results of HDR and the results presented by Loving and others (2000). The simulations with the new bridge for Step 1 showed higher deviations that ranged from 0 to 100 percent, particularly at individual timesteps. Although, the average model results for each of the computed parameters over the simulation period varied by less than 0.09 percent. For the culvert conditions of Step 2, the difference in simulation results ranged from 0 to 0.02 percent, with a negligible average difference. The bridge results for Step 2 again showed differences between the HDR and USGS model ranging from 0 to 100 percent with an average deviation less than 0.02 percent. The USGS utilized the same input files and model code with the purpose of exactly reproducing the simulation results. For Step 3 culvert conditions, we found that the difference in model results between our simulations and the same HDR results ranged from 0 to 9 percent for dry conditions to 0 to 100 percent differences for mild and wet conditions. However, the average deviation over the simulation period was less than 0.01 percent. The comparison of the USGS and HDR results for Step 3 under the new bridge conditions revealed differences that ranged from 0 to 100 percent for the dry, mild, and wet conditions; however, the average deviation over the simulation period was less than 0.1 percent.

The separate and independent comparisons of HDR and USGS simulation results to the original model results of Loving and others (2000) for the culvert scenario from 1987 to 1998 indicated model-computed values for all parameters that were identical to the fifth decimal place. Both HDR and the USGS were able to exactly reproduce the results reported by Loving and others, 2000. An example is provided in fig. 2.

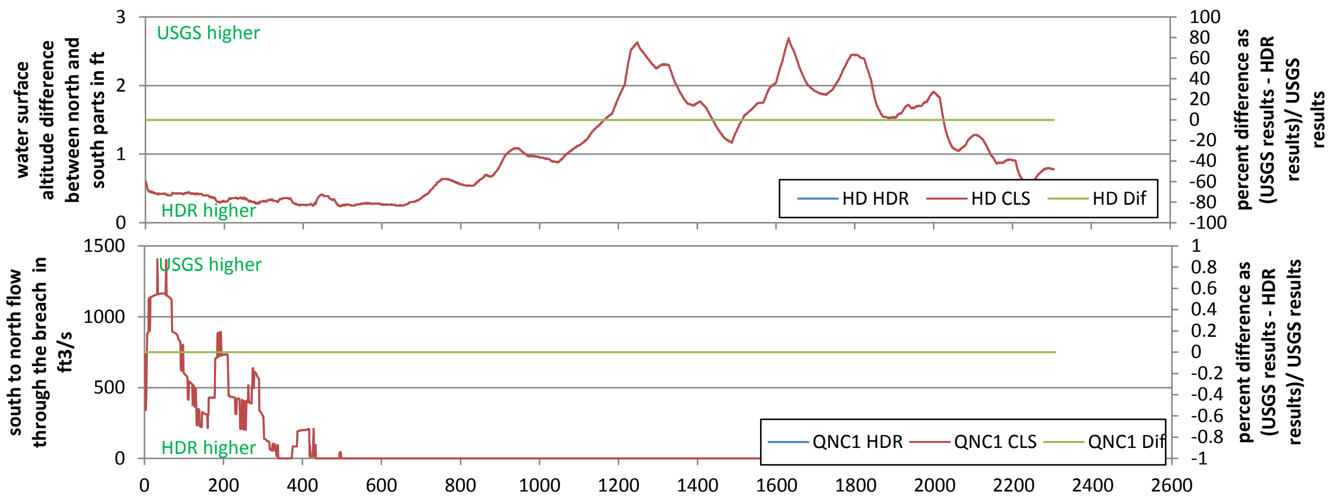

Fig. 2 – Example simulation results for Step 1 with the culvert conditions (Loving and others, 2000) between the HDR, Inc. modeling team results and those of the USGS. The normalized difference in model results as a percentage is also presented in green. The parameter HD is the head difference in ft and QNC1 is the flow from north to south for the breach opening in cubic feet per second, which are further described in Loving and others (2000).

The model code for the remainder of the modeling scenarios explicitly incorporated the submerged and unsubmerged equations of bidirectional and stratified flow of brine and water (Holley and Waddell, 1976). In the original model simulation, Loving and others (2000) incorporated these results in the input files rather than calculating them in the model because the culverts were partially filled and the geometry could not be exactly defined. Our current results indicate that by incorporating the equations of Holley and Waddell (1976) into the model code, some numerical instability in output is produced.

By examining the model output at individual time steps, our results revealed significant variations between the model computed values presented in the HDR reports and those obtained by the USGS. This was particularly evident in simulations that incorporated the implementation of the new bridge. Most of the simulations that incorporated the culverts (Step 1 Step 2) indicated a maximum discrepancy between HDR and USGS model results of 0.08%. However, model predictions produced in Step 3 for the mild and wet conditions indicate much greater variability in flow results (i.e.: QSC(1), QNC(1) that occasionally reaches 100% difference in results (fig. 3).

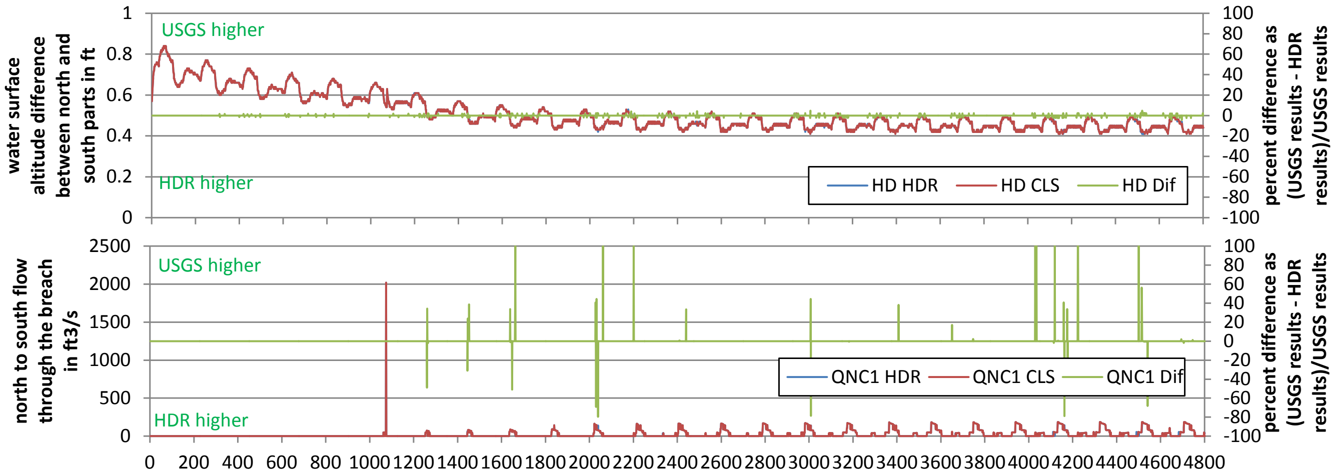

Fig. 3 – Example simulation results for Step 3 with the culvert implemented in mild hydrologic conditions between the HDR, Inc. modeling team results and those of the USGS. The normalized difference in model results as a percentage is also presented in green. The parameter HD is the head difference in ft and QNC1 is the flow from north to south for the breach opening in cubic feet per second, which are further described in Loving and others (2000).

These observed variations are attributed to either Fortran compiler differences, computational precision variation between computers, or numerical dispersion by solution methods. Often, the computational precision of the computed value is decreased, causing what appear to be numerical oscillations about a mean value. Figure 4 provides a representative example of these numerical fluctuations (or dispersion) that are shown between timestep 513 and 1180 with an oscillation of about 15 percent. Some parameters such as the head difference between the north and south arm (HD; fig. 2) are presented as very fine or precise lines on the time series with no numerical oscillation. Other computed parameters, particularly the flow parameters like QSC3 (flow from south to north through the new bridge) present thicker lines for some timesteps, which is indicative of the numerical dispersion.

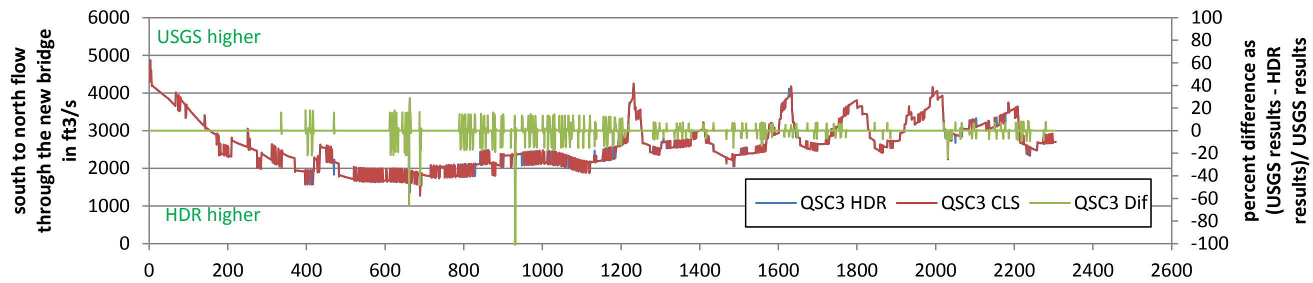

Fig. 4 –Simulation results for Step 1 with the new bridge between the HDR, Inc. modeling team results and those of the USGS. The normalized difference in model results as a percentage is also presented in green. The parameter QSC3is the flow from south to north for the new bridge opening in cubic feet per second, which is further described in Loving and others (2000).

Occasionally, a deviation in a given time step of the HDR model is balanced by a similar deviation in the USGS model at an adjacent timestep, suggesting small computational differences that are likely introduced by differences between Fortran compilers or computers. A representative example can be seen in fig. 5 at timestep 661 or 688.

A more important concern is that the explicit incorporation of the Holley and Waddell (1976) equations into the model code induces increased uncertainty imposed on the result at any single timestep. The green line in fig. 4 shows that 56% of the simulated period, there was a deviation between the HDR and USGS model results. This deviation was often near 18% of the modeled results. This suggests that there is a considerable amount of numerical uncertainty in the computed results produced from individual computers using the exact same model inputs and codes, which would be expected to be exactly the same. If we zoom into a smaller period, we are able to identify this numerical uncertainty or dispersion (fig. 5).

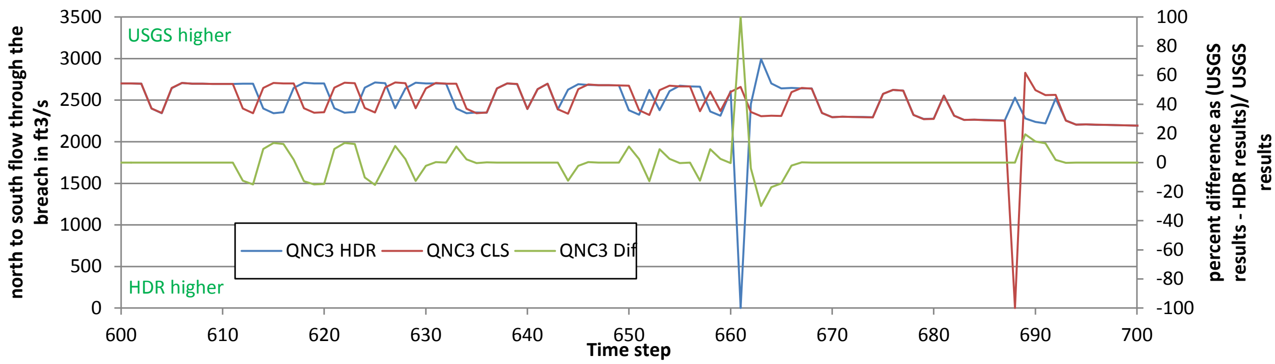

Fig. 5 –Representative example of the modeled numerical dispersion. Results are from Step 1 with the new bridge between the HDR, Inc. modeling team results and those of the USGS. The normalized difference in model results as a percentage is also presented in green. The parameter QNC3 is the flow from north to south for the new bridge opening in cubic feet per second, which is further described in Loving and others (2000).

By comparing fig. 5 from timestep 600 through 700, one can see that the numerical simulations performed separately by HDR and USGS are exactly the same. However, at timestep 611, the simulation results shift in phase until about timestep 636. This deviation produces nearly equivalent amplitude about the mean or uncertainty of nearly 15% and the phase shift attributes to the fluctuations in modeled differences. It appears that timestep 636 through 643, timestep 667 through 687, and timestep 692 through 700 are all exact reproductions between the HDR and USGS models. However, at the remainder of timesteps, significant and chaotic variations between simulations are observed. In fact, at timesteps 661 and 688, each of the model results provides a value of zero, which significantly increases the model uncertainty and creates model difference perturbations that last several timesteps.

The primary question of concern based on this uncertainty produced from different computers using the exact same model inputs is whether the deviations have a significant impact on overall model outputs. Therefore, the USGS compared the cumulative summation and average over the entire period of each parameter for each model step to calculate the percent difference between the HDR and USGS model results. We found that for Step 1, the results deviated on average less than 0.06 percent. The results were similar for the Step 2 comparison with the exception of QNC(1). In this case, less than 6 percent of the total period between 1998 and 2012 produced recorded flow from north to south through the breach. Therefore, the increased numerical dispersion coupled with the decreased period of observed values caused a slight increase in the average percent difference between models. However, it should be noted that this difference was still 0.24 percent. Again, the results for Step 3, under each of the conditions were similar to Step 1, with average deviations typically less than 0.06 percent. The predictive conditions for Step 3 under the wet hydrology with the new bridge indicated a 1.3 percent average difference between the HDR and USGS models for QNC(1) over the period of record.

These results all indicate that there are variations between the models for individual timesteps; however, these variations are limited to typically less than one tenth of a percent over the entire period of simulation. Therefore, we feel that care should be taken in how the model results are interpreted. The model results should be assessed in respect to the period of record for the investigation. It apprears that the discontinuous Holley and Waddel (1976) equations produce a numerical instability that injects a percent uncertainty into model computed values for parameters that utilize the equations in their solution. Although model results averaged of summed over periods of simulation time are less impacted, we believe that this numerical uncertainty should be considered by the modeling team when comparing the results of model runs simulating different conditions for specific time steps.

Conclusions

Overall, we found that the techniques and input data used in the modeling and report are consistent with the techniques and input data used in the previous USGS model simulations and reports. Modifications made to the USGS code as documented in USGS Water-Resources Investigations Report 00-4221 were warranted and consistent with previous versions of the code. Given the limitations of the modeling code, as documented in WRIR 00-4221, the findings documented in this report are reasonable unless noted in the comments above.

We believe that the model is suitable for predicting future effects on Great Salt Lake water and salt dynamics considering the above comments.

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Respectfully,

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