Breach of the Great Salt Lake

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Project Details

Name of project: **Comparison of Machine Learning Techniques for Predicting Complex Flows at the Breach of the Great Salt Lake**
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Project partners: Ryan C Rowland (rrowland@usgs.gov) & Michael L Freeman (mfreeman@usgs.gov), Utah Water Science Center, USGS, 2329 W Orton Circle, Salt Lake City, Utah 84119-2047
Proposed start and end date: 1st September 2021 to 6th May 2022

Budget Requested:

- **Task1:** Optimize the ANN model for predicting N-S/S-N flows and setup the data pipeline for flow profile prediction = 9/1/2021 to 10/31/2021 = 2070.17 $
- **Task2:** Develop the ANN model for predicting the velocity profile at the breach = 11/1/21 to 12/31/21 = 2070.17 $
- **Task3:** Optimize the ANN model for predicting the velocity profile and setup the pipeline to couple the ANN model with a PDE based quasi-2D model = 1/1/22 to 2/28/22 = 2356.67 $
- **Task4:** Train and optimize the coupled ANN and PDE based model = 3/1/22 to 5/6/22 = 2502.99 $
- **Travel:** For the ESIP summer meeting 2022 to present the results = 1000 $
- **TOTAL = 10,000 $ for about 8 months**

Project Outline

Project description: The Great Salt Lake (GSL) is a significant resource to Utah, contributing more than $1.3 billion annually to Utah's economy through mineral extraction and its world-leading brine shrimp production (Bioeconomics, 2012; Wurtsbaugh et al., 2016). The importance of GSL has resulted in significant research and monitoring efforts (Loving et al., 2000), especially since the construction of the Union Pacific Railroad Company (UPRR) causeway in 1959. The causeway divides approximately 1/3 of the lake from the southern portion, which has altered its characteristics including natural circulation, water and salt balances, etc. (Waddell and Bolke, 1973). Since 1959 the northern part of GSL has become more saline while salt content the southern portion has reduced (Stephens, 1990; Loving et al., 2000). The difference in salinity between the North and South have occurred despite the inclusion of two culverts in 1959 and the Lakeside breach in 1984. The original culverts were closed in December 2013 and until the new West Crack breach (see fig. 1b) was opened in December 2016, the WSE elevation of the North-arm of the lake was observed to have decreased (see fig. 1c) and the deep brine layer (DBL) in the South-arm was observed to have diminished (see fig. 1d) (Yang et al., 2019). **This points to the fact that the new West Crack breach is the location where most of the exchange of water and salt occurs between the North and South arms of the lake. Thus, in order to correctly estimate the salt mass balance of the lake, it is imperative to model the flow and salt transport through the West Crack breach accurately.**

Accurately estimating the complex buoyancy-driven flow and salinity through the breach in the causeway is important for predicting the long-term health of its ecosystem and related industries (Barnes and Wurtsbaugh, 2015; Naftz et al., 2011). Additionally, estimation of the height of the North-South flow at the West Crack breach will provide us a better chance to subdivide the salt mass in the South arm into a deep brine layer (DBL) and upper brine layer (UBL), as the North to South (N-S) flow at the breach primarily contributes to the DBL. One of the first dedicated hydraulics model to estimate the flow going through the culverts in the causeway was developed by Dr. Edward Holley (Holley and Waddell, 1976) and later advanced by Loving et al. (2000) to estimate GSL salinity and buoyancy-driven flow through the breach. The flows estimated by the older models do not agree with measured flows, especially for the new West Crack breach that opened in December, 2016. This is due to the fact that Holley and Waddell's (1976) model was derived for flow through culverts, which are significantly different geometrically from the bridges built over the breach (see fig. 1b). The current breach has components (e.g. piers) that are expected to make the flow three-dimensional (3D). Thus, the complex flow though the breach warrants the use of 3D computational fluid dynamics (CFD) models to accurately capture the flow dynamics, which our research group has been successfully developing for the last nine months (Dutta et al., 2021). **The main challenge with a CFD model of the flow though the breach is the computational cost, which makes it unsuitable for directly interfacing with large-scale hydrologic and salt-transport models typically used for water resources management (e.g. the Great Salt Lake Integrated Water Resources Management Model (GSLIM)).**

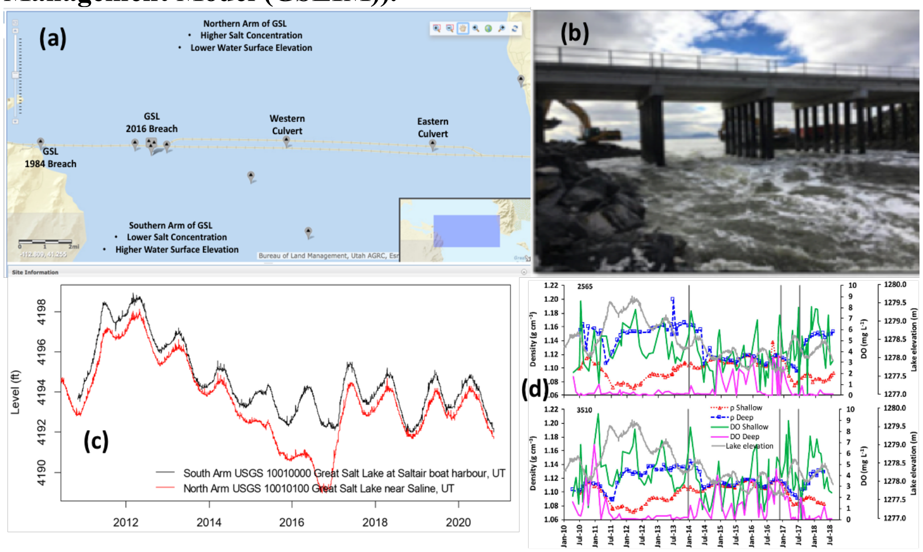

Figure 1: (a) An overview of the GSL Causeway noting flow conveyance features and the USGS measuring stations. (b) the new West Crack breach. (c) WSE of the North and South arms of the lake show significant divergence between 2013-2016. (d) Density data from the South arm of the lake show the disappearance of the DBL from 2014-2016 (Yang et al., 2019).

With the advent of big data, data-driven and machine-learning (ML) based models have become an important tool for accurately predicting complex flow and transport phenomena. The advantage of these models is that once they have been trained and tested using reliable measurements and data, they can predict different aspects of the phenomena almost real-time. Among different ML based approaches used for predicting flow phenomena, artificial neural networks (ANN) have been found to perform better than most correlation/statistics based models (Ghosh et al., 2014). Thus, we have been using data from USGS measurement stations (at and around the breach) to train and test an artificial neural network (ANN) based model to predict the total N-S and S-N flow through the breach. **Through the current proposal, we plan to explore different approaches that can be used to improve the ANN model currently under development, and develop and optimize ANN based models to predict the velocity profile of the flow at the breach. During the proposed research, we will not only be using traditional ANN based techniques, but also explore the hybrid approach of a coupled ANN and physics based model.**

Project objectives:
Technical/Scientific Objectives:
- **Objective1:** Within the framework of ANN models, what are the most optimal learning techniques for predicting net flow through the breach across flow-regimes.
- **Objective2:** Explore how well an ANN based framework perform to predict the velocity profile of the flow at the breach, and what are the learning techniques required to reach the optimal solution.
- **Objective3:** Improving velocity profile prediction using a hybrid approach of coupling the ANN based model with predictions from a physics based model obtained through solving PDEs.

Learning Objectives:
- **Objective1:** Train students in building data-driven models using real-world measurements for predicting complex natural phenomena, consequently learn how to use tools like Tensor Flow.
- **Objective2:** Train students in developing hybrid models that combine traditional approach of numerically solving PDEs with ML based models.

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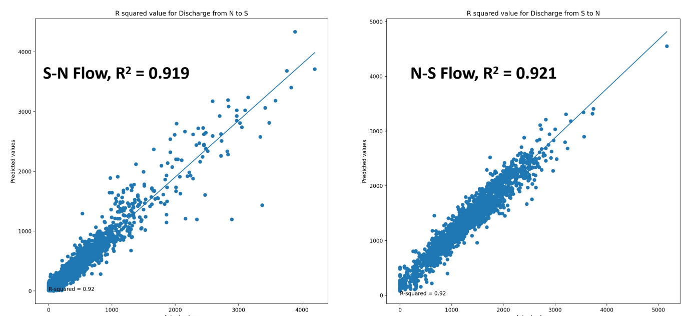
Project significance and impact: ML based approaches have been previously used to model different aspects of the GSL, e.g. to predict the water-level (Abdel-Hafez 2007) and to predict the flow through Lakeside breach (Freeman 2014). Though no models exist for real-time prediction of the complex flow through the new West Crack breach. The proposed study will help improve and bolster the model that can be used for predicting the net N-S and S-N flows through the breach, using automatic measurements taken at the USGS stations. This model once fully developed can be used in conjunction with water resources management tools like GSLIM, to provide an accurate estimate of the flow passing through the breach. This will go a long way in improving the accuracy of water and salt management models. Through the proposal, we will be exploring the efficacy of ANN based models for predicting the velocity profile of the flow. Which as far as we know would be the first attempt to do so using field data. Additionally, we will also be exploring the capabilities of a hybrid model, where we will be coupling a traditional PDE based solver with an ANN based model. Similar framework is known to work for idealized numerical experiments (Pathak et al., 2018), and this would be one of the first attempts to use it for predicting complex buoyancy-driven flow observed in nature.

Description of key project steps and timeline: Initial work on the project has been successful, with the prediction of the net S-N and N-S flow improving up to R^2 of 0.92 (from ~ 0.88), after cleaning the data of extreme outliers and increase in the size of the network from 64-32-1 to 64-48-32-16-1 (see figure inset). The ANN model used back-propagation for training, with the Adam optimizer, a variation of stochastic gradient decent, for minimizing the error. The current version of the model takes in water surface elevation at three locations, wind-speed, wind direction and specific conductivity difference between two sides of GSL as inputs. For the current proposal, the objectives have been divided into four tasks. Each task will be completed over a span of two months. The tasks are:



- **Task1: Optimize the ANN model for predicting N-S and S-N flows and setup the data pipeline for flow profile prediction.** The existing ANN model that predicts the N-S and S-N flow with fairly good accuracy will be further optimized to improve prediction accuracy. Different architecture, activation function, performance function, training function, and adaptation learning functions will be explored and their effect on the network performance documented. This time will also be utilized to setup the data pipeline for the ANN model to predict the velocity at the breach.
- **Task2: Develop the ANN model for predicting the velocity profile at the breach.** Inputs to the model will be the same as the model for predicting net N-S and S-N flows. The model will have ten outputs, corresponding to the ten vertical locations in the water column, where the velocity is measured.
- **Task3: Optimize the ANN model for predicting the velocity profile and setup the pipeline to couple the ANN model with a PDE based quasi-2D model.** The ANN model completed during Task2 will be further improved, using a process similar to the one used in Task1. Parallelly, the ANN model will be interfaced with the PDE based model, similar to the one developed by Holley and Waddell (1976), used for calculating the depth and average velocity of the N-S and S-N flows. The information from the PDE based model will be used in conjunction with ANN based model to improve the prediction of the velocity profile.
- **Task4: Train and optimize the coupled ANN and PDE based model**. Use the methodology similar to the one used in Task1 and Task3, to further optimize and improve the coupled model.

Description of additional funding currently supporting this work: Initial funding for the research came from Utah DNR. The current proposal will help continue the ANN model development portion of the previous research effort. Funds from Engineering Undergrad Research Program (EURP) will support the student developing the PDE based flow solver, which will eventually be coupled with the ANN model.

Outreach

What groups/audiences will be engaged in the project: Both undergraduate and graduate level students will be engaged during this research. We will try to recruit a graduate student from groups that are currently underrepresented in engineering and data sciences. The students that get trained during the program will be used to train the next cohort of students interested in using data-driven models to predict natural phenomena.
How will you share the knowledge generated by the project: The knowledge generated during the project will be published in peer reviewed journals (~ 2 papers), and a final report documenting all the findings in detail will be handed to ESIP Lab at the end of the project, and will be made publicly available. All the developed models will be shared through **github,** and the findings presented at the ESIP summer meeting in 2022.
Description of *who* (agencies/individuals) should be aware of this project (i.e. potential outreach targets): The agency that should be aware of these findings is USGS, as we will be working primarily with field data measured by USGS. This project could be featured as an example of how field data measured by USGS could be used for developing ANN based models. This project could also be useful to researchers trying to develop ANN based models using field-data for predicting complex flows.

Project Partners

Description of project partners (agencies/individuals) and their involvement: Ryan Rowland and Michael Freeman from the Utah Water Science Center, USGS will be our primary project partners. Michael and Ryan have been leading the complicated effort of measuring different aspects of the flow at and around the breach of GSL since 2016. We have been working together for the last 9 months towards the common goal of understanding and predicting the flow through the breach. They have been the primary point of contact, whenever we have needed inputs and insights about the measured field data.
How will this project engage members of the ESIP community: ESIP community will be engaged though presenting our results at the ESIP summer meeting. If possible, we can provide regular update about our progress through ESIP members' mailing list, and holding online discussion sessions with the members.

References:

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