Estimated Energy and Emissions Impacts of Pumping Pacific Ocean Water to Great Salt Lake

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Abstract

Great Salt Lake has receded in recent years. Among many options proposed to augment inflows is a pipeline from the Pacific Ocean. To inform discussion, we estimate a lower bound for the ongoing energy requirements, assuming one-third of the recommended additional inflow will be pumped through a single, smooth, large-diameter diameter pipeline along a fictitious, shortest route without mountains. Accordingly, pumping would require at least 400 megawatts of electricity during operation, an amount equivalent to a large power plant, or 11% of Utah's annual electricity demand. Given current energy prices and fuel mixes, the electricity would cost over $300,000,000 annually and emit nearly 1,000,000 metric tons of carbon dioxide annually, equivalent to 200,000 passenger vehicles. The figures could easily triple with longer routes, mountainous terrain, higher flows, smaller diameters, multiple pipelines, less-efficient pumps, and any required treatment. We present this estimate trusting that feasibility studies will include complete details.

Figure 1: Great Salt Lake

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Abstract

Great Salt Lake has receded in recent years. Among many options proposed to augment inflows is a pipeline from the Pacific Ocean. We estimate a lower bound for the ongoing energy requirements, assuming one-third of the recommended additional inflow will be pumped through a single, smooth, large-diameter diameter pipeline along a fictitious, shortest route without mountains, considering elevation change and head loss. Pumping would require at least 400 megawatts of electricity during operation, an amount equivalent to a large power plant, or 11% of Utah's annual electricity demand. Given current energy prices and fuel mixes, the electricity would cost over $300,000,000 annually and emit nearly 1,000,000 metric tons of carbon dioxide annually, equivalent to 200,000 passenger vehicles. The figures could easily triple with longer routes, mountainous terrain, higher flows, smaller diameters, multiple pipelines, less-efficient pumps, and any required treatment. We present this to better inform discussions on alternatives and to help allocate scarce planning and analysis resources. Any alternative selected for consideration would execute a feasibility study will that would include complete details. This estimate provides a template for ranking or eliminating potential alternatives to large, complex projects in addition to providing specific details to help select alternatives for the Great Salt Lake.

Keywords: Great Salt Lake, drought, pipeline, Utah

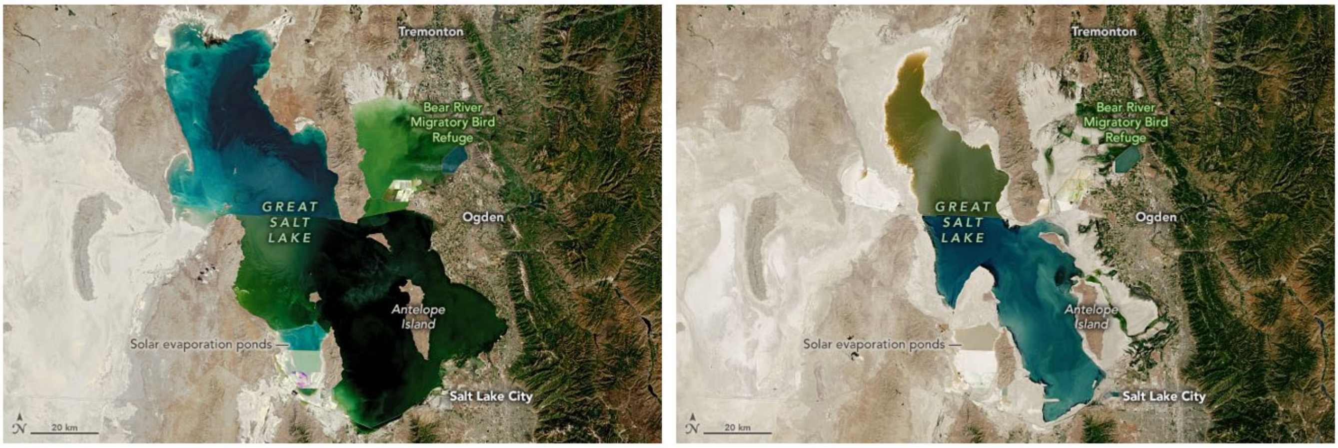

Figure 1. *Great Salt Lake in June 1985 (left) and July 2022 (right). NASA Earth Observatory/Landsat.*

Introduction

Great Salt Lake, located in northern Utah, USA, is a keystone ecosystem and economic resource in the western hemisphere (Baxter and Butler 2020; USGS 2023). The lake has endured several wet and dry cycles over its recorded history (Stephens 1990), including a high in 1986, after which large pumps were installed in case water needed to be drained to avoid flooding adjacent land, but these were never operated. In late 2022, water levels hit record lows and salinity hit record highs (USGS 2023). Figure 1 shows the two extremes with high levels in 1985 and low levels in 2022 on the left and right panels, respectively. As summarized by

Figure 2. *Notional pipeline route used for this analysis that includes total elevation change, but no terrain details.*

Abbott et al. (2023) and Null and Wurtsbaugh (2020), in recent years Great Salt Lake has receded because of excessive consumptive water use and drought. The lower lake levels significantly affect the regional ecology and have potential negative environmental, health, social, and economic impacts.

Among many alternatives proposed to rescue Great Salt Lake (Abbott et al. 2023; Great Salt Lake Strike Team 2023) is a pipeline from the Pacific Ocean (Maffly 2022), pumping water some 1,000 km inland with an elevation change of 1,280 m—not counting major mountain ranges or other local terrain features along the route. While the idea sounds extreme, so are the circumstances, some argue, and all options should be kept open, but scarce time, money, and resources should be focused on workable, feasible alternatives. First proposed in May 2022, the project is under consideration and is an ongoing subject of public discourse. The amount of pumping required would consume considerable energy, creating another dependency in the water–energy nexus (Gleick 1994; Scott et al. 2011; Hamiche et al. 2016; Sowby 2018) with potential significant impacts related to energy production and cost.

We present a lower-bound estimate on the energy requirements of such a pipeline only considering total elevation change and major head loss. We do not consider any planning, land acquisition, design, construction, permitting, finance, or other operation and maintenance costs, and we do not give an opinion on the necessity or ultimate feasibility of the project. Rather, we provide a minimal hydraulic and energy demands analysis early in the process in order to inform Great Salt Lake stakeholders, decision makers, and the public on one aspect of the project. This initial analysis for large projects can be used to determine if more detailed analysis or study is warranted. The data on energy requirements and costs will help stakeholders and decision makers better allocate resources when analysing alternatives.

Analysis

To estimate the energy use, we employ fundamental equations of hydraulics: the energy equation between two points, the Hazen–Williams equation for head loss, and the pump equation for power demand. In simple terms, we compute the energy to lift water from sea level to lake level, along with friction loss and pump inefficiency. We then present the estimated energy requirements in the context of power plant size, Utah's annual electricity use, electricity costs, and carbon dioxide equivalent (CO_2e) emissions. This is a "first-order" or "order-of-magnitude" analysis that can be used to rank alternatives. We describe the steps below.

Researchers have recommended that Great Salt Lake requires an additional 1.5×10^9 m^3/yr to recover (Abbott et al. 2023). We assume one-third of that flow, 0.5×10^9 m^3/yr, could come by pumping water from the Pacific Ocean and the remainder could come from within the watershed. We assume a notional route that is the shortest straight-line distance between the ocean and the lake, about 880 km, roughly between San Francisco and Salt Lake City (Figure 2). We ignore any other elevation changes due to mountains, additional lengths of an actual route, additional energy requirements because of local elevation changes (i.e., mountains), or construction issues along the route. This analysis provides a minimum estimate, or lower bound, of the energy use associated with pumping. Any actual energy uses would be larger, and depending on route selection and pipeline design, could be significantly higher.

We analyze lifting water from the Pacific Ocean (point 1) to Great Salt Lake (point 2) with the general equation (Mott and Untener 2015):

$$\frac{P_1}{\gamma} + z_1 + \frac{v_1^2}{2g} + h_A = \frac{P_2}{\gamma} + z_2 + \frac{v_2^2}{2g} + h_L$$

Because the project would move water between two open water bodies, we may eliminate the pressure terms (atmospheric assumption) and the velocity terms (large reservoir assumption) on each side:

$$z_1 + h_A = z_2 + h_L$$

Rearranging, the expression becomes:

$$h_A = (z_2 - z_1) + h_L$$

where h_A is the total head added by pumping, h_L is the total head loss due to friction, and z_1 and z_2 are the elevations of the Pacific Ocean and Great Salt Lake, respectively. The expression says that the head added by pumping must equal the difference in elevation between the Pacific Ocean and Great Salt Lake plus the head loss that occurs in the pipeline. This is a first-order energy computation; any actual project would require significant additional energy.

Total head, h_A, is the elevation difference between Great Salt Lake and sea level (the datum), or 1,280 m. We compute head loss, h_L, using the empirical Hazen–Williams formula (Mott and Untener 2015):

$$\boldsymbol{h_L = \frac{10.67 L Q^{1.85}}{C^{1.85} D^{4.87}}}$$

where Q is the flow rate (0.5×10^9 m^3/yr or 15.9 m^3/s), L is pipe length (880,000 m), C is the roughness factor, and D is the pipe diameter. We assume a smooth pipe with a roughness value C of 140 (Mott and Untener 2015). We assume a 3.0 m diameter pipe, which is about the practical limit of large-diameter pipelines and a reasonable size for conveying the assumed flow without excessive head loss due to velocity (about 2.2 m/s for our assumptions). We ignore any minor friction losses from pipe fittings. These assumptions result in a head loss of 795 m:

$$h_L = \frac{10.67(880{,}000)(15.9)^{1.85}}{140^{1.85} 3.0^{4.87}} = 795 \text{ m}$$

We now calculate the total head required as the elevation difference, 1,280 m, plus the head loss of 795 m, to estimate the total head as 2,075 m. Figure 3 shows a hydraulic profile of these results.

Next we estimate the power required to increase the head of water by 2,075 m. We use the equation for pump power P_P (Mott and Untener 2015):

$$P_P = \frac{Q h_A \gamma}{\eta}$$

where γ is the specific weight of water and η is the efficiency of the pumping system. We assume the specific weight of water, γ, equal to 9.81 kN/m^3 and a rather high-efficiency pumping system where η is 0.80 to provide a lower bound. Then

$$P_P = \frac{\left(15.9 \frac{\text{m}^3}{\text{s}}\right)(2{,}075 \text{ m})\left(9.81 \frac{\text{kN}}{\text{m}^3}\right)}{0.80} \approx 400{,}000 \frac{\text{kN} \cdot \text{m}}{\text{s}}$$

$$= 400{,}000 \text{ kW} = 400 \text{ MW}$$

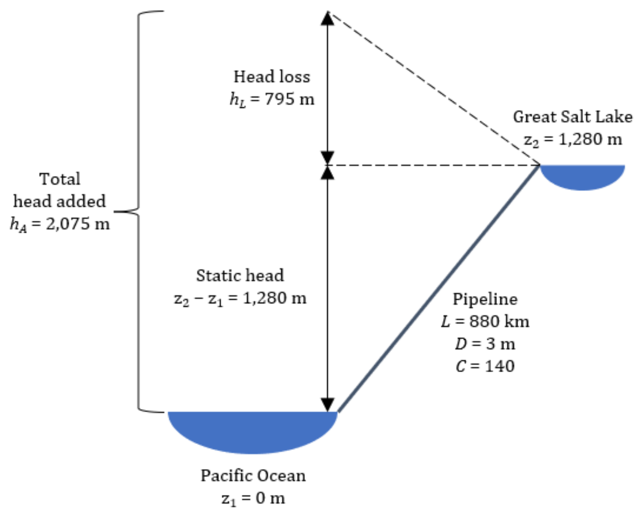

Figure 3. *Hydraulic profile.*

This value, based on ideal conditions, represents a *lower bound* on the energy requirement for raising the water over a notional, straight-line route that does not consider local terrain or realistic deviations. This does not include any other energy required for the system.

Even as a lower bound, 400 MW is a significant power requirement. It is equivalent to the output of a large power plant. (For comparison, the gas-fired Currant Creek Generating Station near Mona, Utah, has a 500 MW capacity.) The 400 MW power requirement is equivalent to 11% of Utah's 2021 electricity use of 32,768,000 MWh, based on 2021 data from the U.S. Energy Information Administration (EIA 2023a). At 2021 prices for industrial electricity in western states—about \$0.06/kWh to \$0.15/kWh (EIA 2023b)—purchasing a constant demand of 400 MW would cost over \$300,000,000/yr. This ongoing cost is in addition to what would likely be a multi-billion-dollar capital outlay for pipeline construction. According to the U.S. Environmental Protection Agency's Emissions & Generation Resource Integrated Database (eGRID) (EPA 2023), the

2020 fuel mix in western states (the NWPP subregion) generates about 274 kgCO_2e/MWh, so a constant demand of 40 0 MW would emit 960,000 tCO_2e/yr. The emissions would be equivalent to more than 200,000 passenger vehicles, which each emit about 4.6 tCO_2e/yr on average (EPA 2022). For 2021, Utah had about 1,200,000 registered passenger vehicles, so 200,000 is approximately 17% (Utah State Tax Commission 2021). While 400 MW is a lower bound for the energy required to lift the water, actual energy requirements, again only for moving the water, could easily be three times higher because of longer routes, mountainous terrain, higher flow rates, smaller pipe diameters, multiple pipelines, less-efficient pumps, and any required treatment such as filters.

This is a first-order estimate based on the assumptions we made to determine a realistic lower bound. Actual alternatives may use significant different values. For example, we assumed a flow of 0.5×10^9 m^3/yr; however, an actual project may assume a lower or higher flow, depending on actual needs, potentially resulting in lower or higher energy requirements dependant on flow, pipe size, and route specifics. An actual pipeline would need to cross mountains and would require additional energy to lift the water. While some energy may be recovered through turbines on the downhill runs, the net lift of 1,280 m cannot be avoided, and any mountain crossing would increase the energy requirements.

To estimate the amount of carbon potentially emitted by the project, we assumed the current energy mix in Utah and other western states in the NWPP subregion. The project could be powered by cleaner energy, but 400 MW is a considerable demand for current renewable technologies in Utah (EIA 2023c) and would require significant new investment in energy infrastructure. We assumed the route would be the shortest distance between the ocean and the lake, which is not feasible. Any actual route would be longer and include mountains and other terrain features, which would increase energy demands. We mention these details to provide context for our estimate. It is only meant to start the discussion, to provide managers and policymakers with an estimate of potential effort.

We provide the estimate to guide these and other similar discussions. We feel that issues such as water shortages and associated mitigation strategies should focus on efforts that are attainable, especially in the short term. Often, discussions seem to focus on solutions that later prove to be unworkable. These solutions, while important to initially consider, should be evaluated for feasibility along with alternatives. This allows scarce resources to be allocated more effectively rather than being spent on unrealistic alternatives.

In this short paper, we estimated a lower bound for energy requirements to pump water from the Pacific Ocean to Great Salt Lake. We have deliberately restricted our analysis to just one operational element of a potential major project. Any feasibility study will require conceptualization and analysis of the full system. We trust that the ultimate decision on proceeding with the pipeline will realistically consider all such elements, as well as the many alternative solutions already proposed within the Great Salt Lake watershed itself.

This analysis is important for two reasons. The first is the very specific issue of low water levels in Great Salt Lake. More importantly, this paper provides a template for researchers and others grappling with large projects and very public, but potentially non-viable, solutions and a need to allocate scarce resources to evaluate alternatives.

Conclusions

We estimate the lower bound for energy costs to pipe water from the Pacific Ocean to Great Salt Lake is at least 400 MW of electricity. The amount is equivalent to the full output of a large power plant or 11% of Utah's annual electricity demand. At current rates, the electricity required would cost over $300,000,000/yr and emit nearly 1,000,000 tCO_2e/yr, the same as 200,000 passenger vehicles, which is 17% of the number of vehicles registered in Utah. Such energy demand would bring major infrastructural, financial, and environmental impacts. Just this one early glimpse of the project illuminates serious challenges to its completion.

We present these figures as lower bounds on energy demands for discussion purposes, recognizing that they could quickly escalate with choices of route, equipment, and flow rate that differ from the unrealistic ideal conditions we assumed. We provide this analysis not as an opinion on the necessity of the pipeline but as technical information to inform discussion alongside other alternatives, including ones proposed from within the Great Salt Lake watershed (Abbott et al. 2023; Great Salt Lake Strike Team 2023). We hope this work can help focus analysis on feasible solutions as well as provide a guide for similar situations in other locations. This type of order-of-magnitude analysis can be used by other projects to help allocate scarce resources when evaluating complex mitigation projects.

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