404 IP Response to Comments

US Magnesium Canal Continuation Project

SPK-2008-01773

October 28, 2022

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Acronyms and Abbreviations

AF	acre-feet
AFY	acre-feet per year
CFR	Code of Federal Regulations
DA	Department of the Army
et al.	and others
GSL	Great Salt Lake
IP	Individual Permit
NGVD 29	National Geodetic Vertical Datum of 1929
Project	US Magnesium Canal Continuation Project
US	United States
USACE	United States Army Corps of Engineers
USGS	United States Geological Survey
WSE	water surface elevation

1.0 Introduction

This document responds to public and stakeholders' comments on US Magnesium's Individual Department of the Army (DA) Permit application (SPK-2008-01773) for impacts to wetlands and other waters of the United States associated with the US Magnesium Canal Continuation Project (Project). These comments are summarized in the DA letter dated September 29, 2022 (USACE 2022) (Appendix A). The proposed activity is extending the Applicant's intake canals between its magnesium-processing facility and the South Arm of the Great Salt Lake (GSL).

2.0 Response to Comments

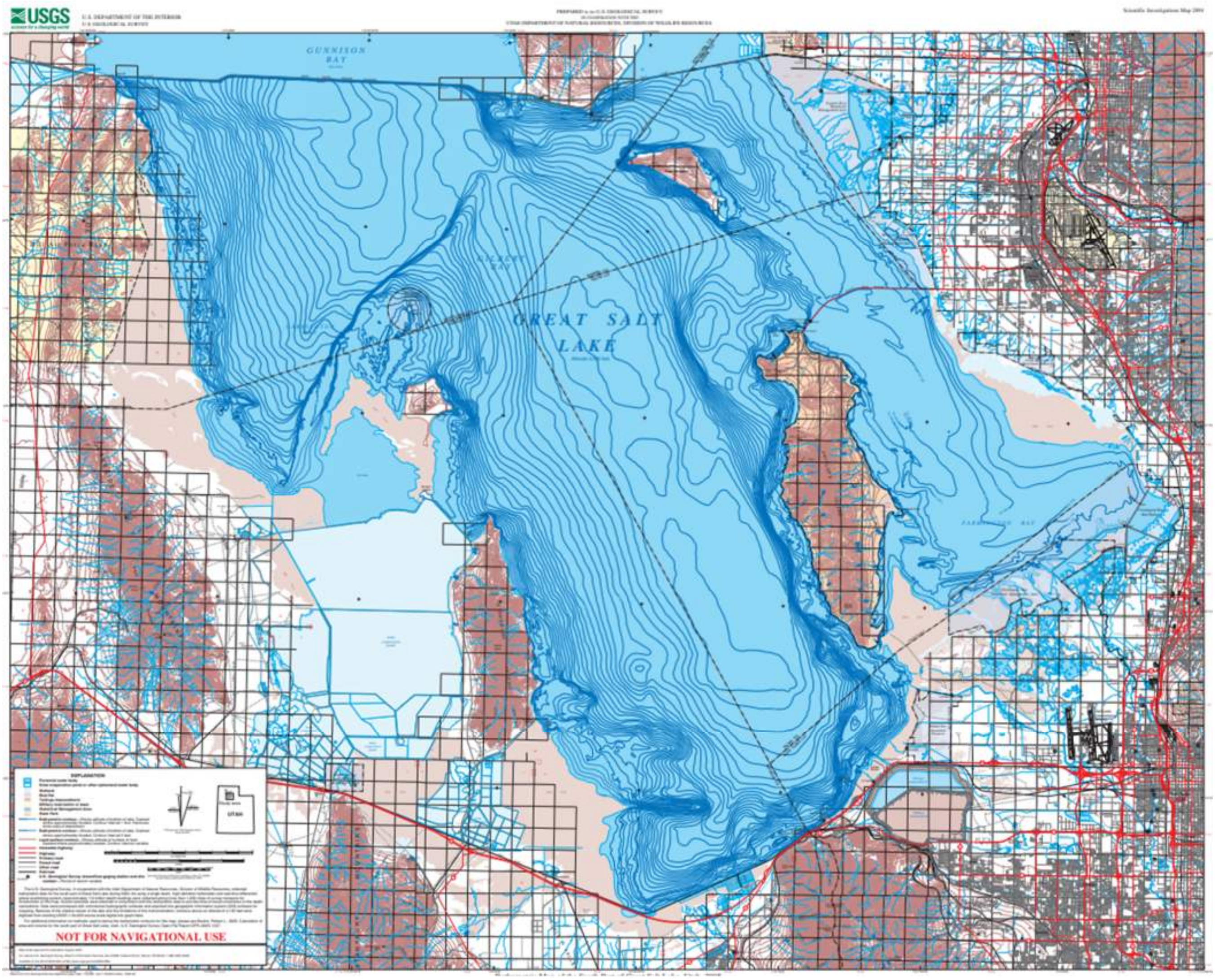
2.1 Comment 1 – Potential Lake Response to Operations

We have concerns regarding the project's potential direct or indirect effects on GSL levels. Specifically, how and to what extent could the proposed activity result in increased GSL water consumption, thereby lowering lake levels and further exacerbating an ongoing environmental concern? What percentage of the current GSL volume (south arm only) does your withdrawal constitute now and would that percentage change after project completion? Please provide an analysis to address these concerns.

Operations at the Applicant's facility would continue after the proposed activity is completed. No new water withdrawals are planned as part of the proposed activity. It is worth noting that the proposed activity would not increase or decrease the water volume in the South Arm, since lake bed material would be shifted from one location in the South Arm to another.

The rest of this response discusses the expected change in South Arm volume, by percentage, due to continued operation of the Applicant's facility and the associated change in the South Arm's water surface elevation (WSE). The analysis is based on US Geological Survey (USGS) South Arm bathymetry and stage (elevation)–volume relationships (USGS 2005). The USGS South Arm bathymetry is shown in Figure 1.

Figure 1. USGS South Arm Bathymetry



Based on these bathymetry data, USGS prepared estimates of South Arm water volume and surface area compared to South Arm WSE. USGS presented the data in tabular format (USGS 2005), which the Applicant used to create the elevation–volume curve shown in Figure 2.

Figure 2. USGS South Arm Elevation–Volume Curve

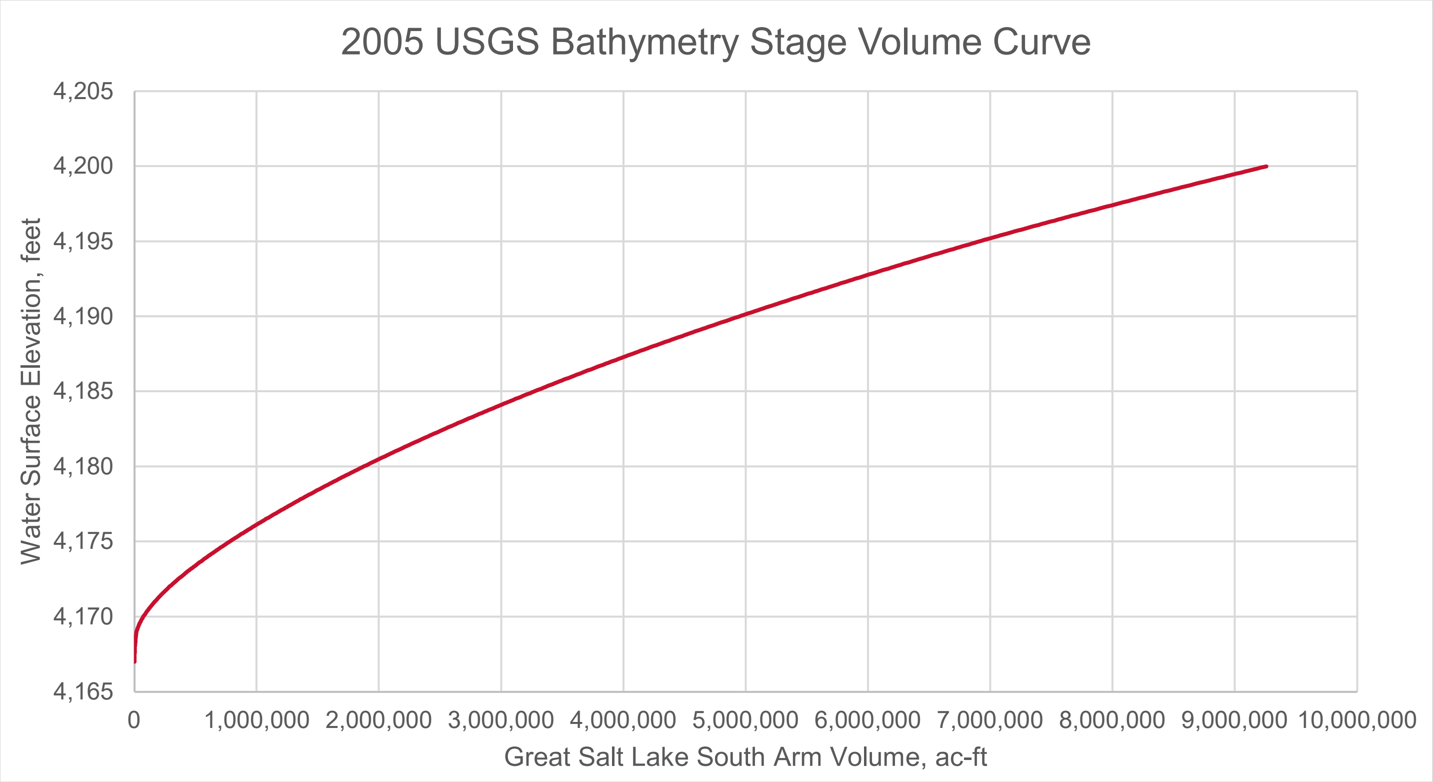


Table 1 shows how the facility operations with the proposed activity would affect the South Arm's WSE over a calendar year. These results are based on a maximum withdrawal of 109,500 acre-feet per year (AFY) and the Applicant's recent 5-year average of 50,000 AFY at the current South Arm WSE. See Section 2.2 for additional discussion regarding annual water withdrawal rates.

Table 1. Projected Effects of Facility Operations on South Arm WSE

Value	With withdrawal of 109,500 AFY (Applicant's full use of its water right)	With withdrawal of 50,000 AFY (Applicant's average withdrawal from the last 5 years)
Current total South Arm volume	~ 4,551,800 AF	~ 4,551,800 AF
Current South Arm WSE	4,188.91 feet NGVD 29	4,188.91 feet NGVD 29
Withdrawal as percent of current total South Arm volume	2.4%	1.1%
Change in South Arm WSE vs. current South Arm WSE	–0.31 foot	–0.14 foot
South Arm WSE after withdrawal	4,188.60 feet NGVD 29	4,188.77 feet NGVD 29

Note: All values are presented as of October 1, 2022.

The Applicant would continue to operate its facility during the proposed activity. The withdrawal of South Arm water would be within the Applicant's current water right, mineral lease, and royalty provisions.

2.2 Comment 2 – Future Operations with Proposed Activity

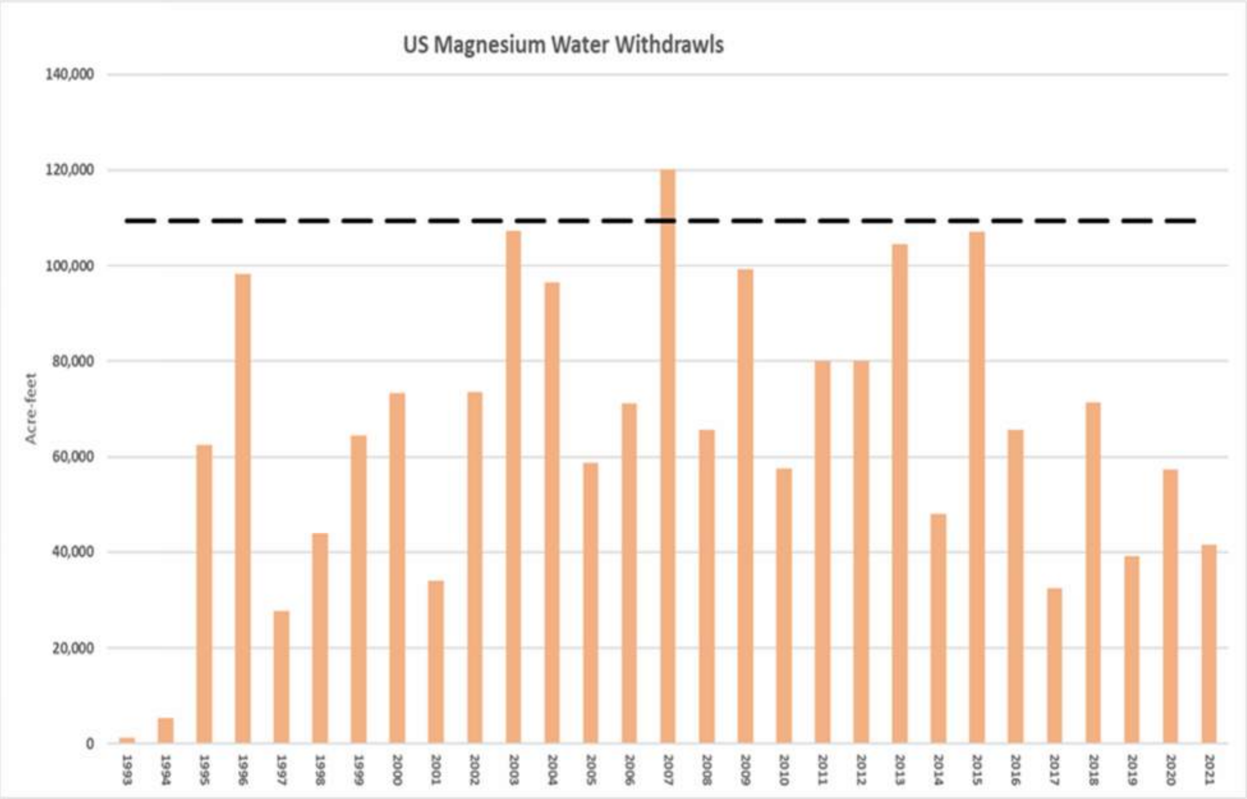
What effect will the proposed activity have on normal facility operations? Is the intent to increase production to allow for maximum production/normal operations or is the intent to maintain reduced operations at the minimum necessary to prevent a lapse in production during this abnormally dry period? Please provide clarification.

The Applicant intends that the operation of its facility would remain consistent with its past operational protocols after the proposed activity (extending the Applicant's South Arm intake canals) is completed. The proposed activity would not significantly change these operational protocols. The Applicant intends to continue to meet its business needs through mineral extraction according to its granted water rights and mineral leases.

The Applicant has a water right to withdraw 109,500 AFY from the South Arm. Table 2 shows the Applicant's actual South Arm water withdrawals for the past 28 years.

As shown in Table 2, the Applicant's year-to-year withdrawals vary significantly based on many factors including the previous year's production, pond capacity, inventory, summer evaporation weather, pond maintenance, equipment resources, South Arm salinity and magnesium concentrations, South Arm WSE, and other processes at the Applicant's facility. In the future, the Applicant might conceivably need to withdraw less South Arm water to produce the same volume of products as the South Arm's salinity increases and, correspondingly, magnesium concentrations increase.

Table 2. US Magnesium South Arm Water Withdrawals, 1993–2021



2.3 Comment 3 – South Arm Salinity Analysis

Provide an analysis of what salinity levels would be if the GSL dropped to the 4,188-foot elevation, how that compares to current salinity levels, and at what lake elevation the salinity levels become too high to sustain current ecological functions. There may be existing information and modeling available from the State of Utah to aid in gathering this information. If a correlation can be shown between continued operations from the proposed project and GSL salinity levels, can a planned reduction in operation and/or water withdrawals be implemented if GSL salinity approaches critical concentrations?

The Applicant has reviewed lake management documents in order to relate lake WSE and salinity (see Sections 2.3.1 and 2.3.2 below). The Applicant, having participated in the various lake technical and advisory committees, understands that no single document states a lake salinity value that is detrimental to its overall ecological functions.

Current lake salinity values, as well as lake levels, are published on the USGS Great Salt Lake Hydro Mapper (https:// webapps.usgs.gov/gsl). Note that the salinity value presented on the Hydro Mapper is the average salinity of the upper brine layer at a specific location in Gilbert Bay of the South Arm, not an average salinity value of the entire South Arm. For this reason, the salinity value presented on the Hydro Mapper might not be directly comparable to the salinity values in the lake management documents or matrices discussed in the following sections.

2.3.1 Salinity Analysis

The Utah Division of Forestry, Fire and State Lands (UFFSL) prepared the *Final Great Salt Lake Comprehensive Management Plan and Record of Decision* (CMP) in 2013 (UFFSL 2013). In the CMP, UFFSL created a Great Salt Lake Matrix (2013 GSL Matrix) that identified the physical, biological, wetland, recreation, economy, and land use characteristics of the GSL at various lake WSEs. The matrix is shown in Appendix B.

The CMP identified that the South Arm's salinity is inversely related to the South Arm's WSE; in other words, a higher South Arm WSE results in a lower salinity concentration in the South Arm. Due to ongoing drought conditions, the South Arm is currently decreasing in WSE and increasing in salinity. The 2013 GSL Matrix estimates the South Arm's salinity to be about 17% for a South Arm WSE of 4,190 feet (current) and 19% for a South Arm WSE of 4,188 feet.

2.3.2 GSL Ecological Functions

In 2021, the State of Utah and the Great Salt Lake Advisory Committee produced the report *Influence of Salinity on the Resources and Uses of Great Salt Lake* (GLSAC 2021). The report supplemented, in part, the 2013 UFFSL CMP. The 2021 document identified various uses of the GSL, including recreation, biology, infrastructure, aquatic, terrestrial, vegetative, and avian. A summary matrix was included in the 2021 document that qualitatively classified the identified uses as either a benefit or an adverse effect compared to a range of lake WSEs and salinities. It is interesting to note that one use might benefit from higher salinity while other uses could be harmed, thereby making management and planning efforts for the lake complex. The following sections summarize additional information from the 2013 GSL Matrix (UFFSL 2013) and the 2021 GSL Salinity Matrix (GLSAC 2021).

2013 GSL Matrix

The 2013 GSL Matrix produced by UFFSL identifies that most of the physical and biological characteristics of the GSL are impacted by the lake's varying WSE. Some ecologies benefit from low salinity (and the associated high WSEs), while others benefit from higher salinity. The 2013 GSL Matrix identifies the same characteristics for GSL Planning Zone 1, which ranges from 4,193 feet down to 4,188 feet (the lowest lake WSE assessed).

- GSL Planning Zone 1, 1.4% probability of occurrence
- Ecological function – saline/withdrawn
- Islands are accessible by land
- Wetland areas are transitioning from beneficial to adversely affected (expected for some of the managed wetland bank areas)
- Bird resources were not assessed due to lack of data
- Recreation resources are shown as beneficial for duck hunting and beach access, adverse for boating
- Cultural sites were identified as exposed
- Brine shrimp resources were identified as adverse
- Mineral extraction activities were identified as adverse with limited pumping capability
- No major impacts to transportation facilities (Interstate 80 and the Salt Lake City International Airport)
- Safety resources were identified as adverse or ceased

2021 GSL Salinity Matrix

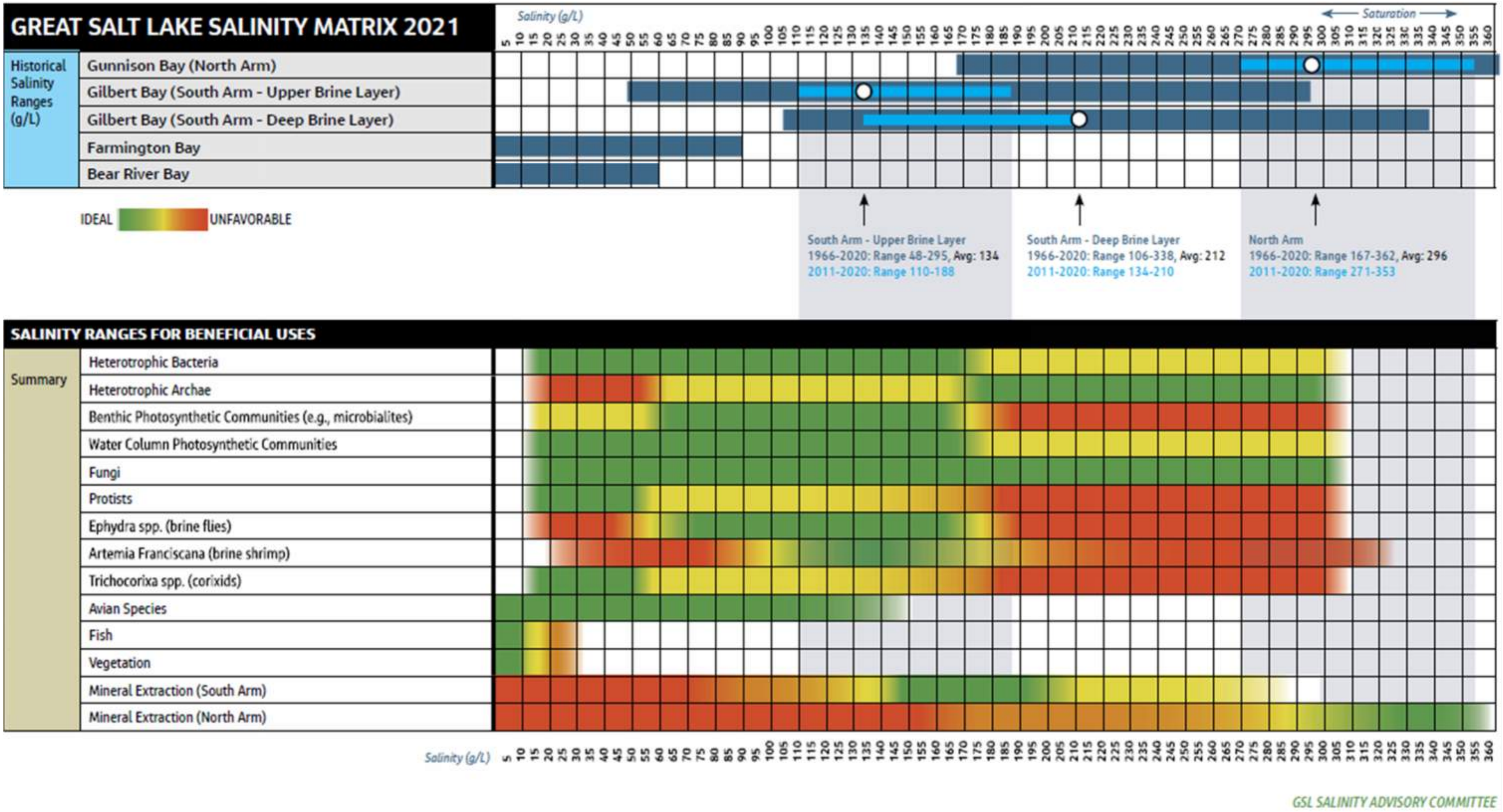
The 2013 GSL Matrix has been updated, in part, by the Great Salt Lake Advisory Committee's 2021 report *Influence of Salinity on the Resources and Uses of Great Salt Lake* (GSLAC 2021) (Appendix C). The updated study focuses on the GSL's beneficial uses and how they exist in a range of salinities from ideal to unfavorable.

The report begins with the qualifying statement:

> There are simply inadequate data to precisely isolate and fully describe the ecological response to changes in salinity. Describing GSL's salinity, isolating the influence of salinity from the myriad of variables that influence the lake's resources, and interpreting what might be physiological limits versus other ecological influences are just some of the significant challenges to be overcome….

With this in mind, the updated 2021 GSL Salinity Matrix, as shown in Figure 3, indicates that there is a wide band of effects, both favorable and unfavorable, across the spectrum of specific GSL uses.

Figure 3. 2021 GSL Salinity Matrix



South Arm - Upper Brine Layer
1966-2020: Range 48-295, Avg: 134
2011-2020: Range 110-188

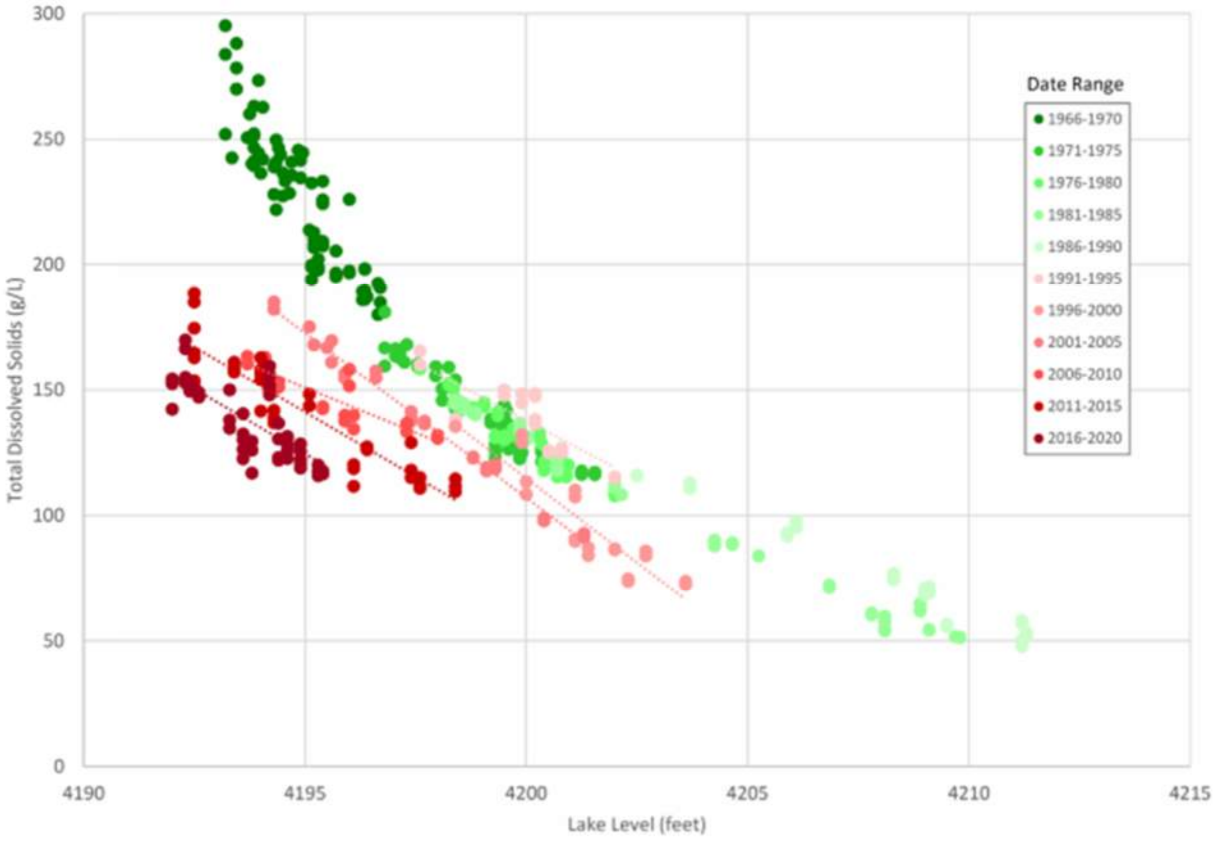
South Arm - Deep Brine Layer
1966-2020: Range 106-338, Avg: 212
2011-2020: Range 134-210

North Arm
1966-2020: Range 167-362, Avg: 296
2011-2020: Range 271-353

GSL SALINITY ADVISORY COMMITTEE

The committee also updated the South Arm total dissolved solids data for various South Arm WSEs, as shown in Figure 4. The figure indicates that no historic total dissolved solids data are available for the lower range of South Arm WSEs. The 2021 report discusses the salt transfer between the South Arm and the North Arm of the GSL as well as the general observation that the South Arm is becoming fresher over time due to inflows and salt transfer to the North Arm.

Figure 4. Utah Geological Survey South Arm Elevation–TDS Curves



Source: Utah Geological Survey Great Salt Lake Brine Chemistry Database (data are from sample sites AS2, AC3, FB2 at ~10 feet deep; trend lines are linear)

The 2021 report includes the following statement regarding salt withdrawal by the extraction industries:

> … While mineral and salt extraction accounts for some removal of salt from the overall lake system (Mills et al. 2020), available data suggest that riverine input of dissolved solids to the lake either exceeds or substantially offsets the amount of salt removed by extraction (Shope and Angeroth 2015).

The 2021 report concludes with the observation that various uses of the GSL are interconnected and states that:

> …The complexity of these interdependencies is what has made GSL such a unique, thriving, and resilient ecosystem and [a] benefit to industry, recreational users and the communities within its watershed. As a result, the matrix also illustrates that the salinity of GSL cannot be managed to a singular value or threshold. The lake's salinity is very dynamic and has varied, does vary, and will vary spatially and temporally.

These documents (the 2021 committee report and the 2013 CMP) are two of the many studies that have been conducted on the GSL's ecosystem, its natural and anthropogenic uses, and how they are interdependent on a complex saline terminal lake.

2.4 Comment 4 – North Arm to Upland Canal Alternative

We appreciate the project alternatives considered in the application materials. Has US Magnesium evaluated the feasibility of any alternatives involving an upland trench system to convey north arm water to the facility? For example, from the Lakeside area and along the toe of the Lakeside Mountains to the North Arm of the GSL to capture higher concentration brine? Please clarify the viability of such an alternative.

The Applicant has evaluated alternatives and appreciates the additional inquiry regarding the feasibility of using an upland trench system to convey North Arm brine to the facility. Although using the North Arm brine would be advantageous for the Applicant, such an alternative does not meet the Applicant's immediate need to access the brine supply necessary to maintain its operations. The feasibility of accessing North Arm brine with an upland trench might be considered by the Applicant in the future, but additional planning and analysis is required before it could be implemented.

The Applicant has conducted a preliminary analysis of the alternative and developed a conceptual layout. Appendix D shows the conceptual layout. It is important to note that extensive data collection, analysis, and design is still needed and that the conceptual layout is not a final design.

The Applicant's preliminary conclusions based on the conceptual layout are as follows.

- Placing the alignment farther west onto higher elevations and/or onto federal land is not feasible. Encroachments below the ordinary high water mark are unavoidable in both the North Arm and South Arm.
- A new conveyance trench would extend about 22,000 feet into the North Arm to reach the 4,185-foot lake bed contour.
- Work would be required outside the Applicant's current lease area.
- New pumping station(s) would need to be designed for site-specific conditions (geotechnical, structural, lake WSEs, etc.). Prepackaged pumping stations would not work.
- Conveying the North Arm brine for about 25 miles would present significant operational challenges that the Applicant would need to overcome.

2.5 Comment 5 – Cultural Analysis

The application materials indicate that a cultural resource survey of the project area will be provided. In order to complete Section 106 consultation, we will need this information, in accordance with the Utah State Historic Preservation Office Archeological Compliance Guidance document: https://drive.google.com/file/d/1_e2QLxR2pLUBns2l2GyDbomzJeWTH_Wu/view.

The Applicant understands the need for a cultural resource assessment and is committed to completing the assessment before permitted construction activities begin. Given the timelines needed to adequately conduct the assessment, the Applicant's emergency situation, and the need to begin the proposed activity, the Applicant requests that completing the cultural resource assessment be included as a conditional approval with the application.

2.6 Comment 6 – Microbialite Survey

Due to the potential presence of microbialites (stromatolites) within or adjacent to the project area, we will need an aquatic resource survey detailing information on the location and quality of these resources, as well as a detailed description of the potential impacts resulting from the proposed activities. Compensatory mitigation may be required for unavoidable impacts to these resources.

The Applicant understands the need for a microbialite survey and is committed to completing the survey before permitted construction activities begin. Given the timelines needed to adequately conduct the survey, the Applicant's emergency situation, and the need to begin the proposed activity, the Applicant requests that completing the microbialites survey be included as a conditional approval with the application.

The microbialites survey will identify the location and quality of the microbialites within the canal extension and deposition areas. The survey will also quantify the expected impacts, the measures taken to avoid impacts, and potential compensation for unavoidable impacts to microbialites.

2.7 Comment 7 – Lake Bed Function Assessment

The creation of the new segment of canal will result in the change in use from lakebed habitat to a component of the minerals production facility, which will likely require future impacts and modifications to the area. As such, the Corps considers this action a loss of waters and will require compensation. Please provide a plan to compensate for these losses of function and services. Further, the side-casting of the dredged material onto the lakebed may also impact the functions/services of the lakebed and may also require additional compensatory mitigation depending on changes in lakebed elevations. Please provide additional rationale to support that the impacts would be minimal and/or propose design changes related to placement of spoil materials to reduce the depth of deposition, such as increasing the distance from the canal that the spoils are redeposited. Increasing the distance from the canal beyond 150 feet would decrease the height of any spoil deposition.

The Applicant maintains that the proposed activity would not result in the loss of lake bed functions or services. Supporting information has been provided to USACE in the 404 Individual Permit Application. In this information, the proposed activity was identified on maps and in plan and profiles showing that the proposed activity would occur in a unique area of the lake, and the proposed practices would not change the existing lake bed to wetlands or uplands. The intake canals would be extended to allow the intake canal and deposition area to remain as functional lake bed area of the GSL, and no additional impacts or modifications are proposed. No berms, permanent facility structures, or other operating facilities are planned to be placed into the canal or deposition areas.

Previous construction and operation of the intake canals in the lake bed are a testament to how the extended intake canals would operate in harmony with lake bed functions and services. The proposed activity would mirror the successful approach to constructing and operating the existing canals. As with the existing canals, the proposed activity would not affect lake functions or services (that is, inundation patterns, navigability, or aquatic function). The proposed activity would not replace lake bed with dry land nor change the open-water lake bed to wetlands or uplands.

The proposed activity would occur in a unique area of the lake—located along the vast western edge of Gilbert Bay, sited in the deeper open-water area with varying lake bed topographical elevations, and within land already under a lease agreement with the State of Utah. The proposed activity is planned to avoid significant effects on lake bed function and services. A topographic analysis of the lake bed found that the lake bed in the project area undulates (swells and rolls) and varies in elevation by about 2 feet.

By placing the dredged lake bed material within this area, the deposition area would mimic and reflect the natural variability of the lake bed within the Applicant's leased land boundary. This proposal was based on minimizing impacts to lake bed elevations, thereby allowing navigability and inundation of open waters.

In response to the comment above regarding increasing the deposition area and thereby decreasing the spoil depth, the Applicant has conducted further design analysis to determine whether it could implement thin-layer placement (TLP) of dredged lake bed material over a larger area that is within the current leased boundary. The Applicant maintains that it could adopt USACE's suggestion to spread the dredged material over a larger area at a lesser depth—that is, to a maximum depth of 6 inches—while keeping construction and operating activities within the current leased boundary. Please see Appendix E for a diagram of the potential deposition area based on the suggested TLP process. Again, this refined approach would not result in any loss of lake bed functions or services and should not, therefore, trigger compensatory mitigation. The remainder of this response provides additional information regarding the TLP approach, further supporting authorization of the proposed activity.

The TLP approach is defined in the USACE Engineer Research and Development Center (ERDC) technical note TN-19-1, *Thin Layer Placement: Technical Definition for US Army Corps of Engineers Applications* (Appendix F), as the

> … [p]urposeful placement of thin layers of sediment (e.g., dredged material) in an environmentally acceptable manner to achieve a target elevation or thickness. Thin layer placement projects may include efforts to support infrastructure and/or create, maintain, enhance, or restore ecological function.

The technical note states the benefits of the TLP approach as avoiding negative impacts to navigation safety and biological resources—negative impacts that are commonly associated with depositing dredged material to a thicker depth.

The technical note does not prescribe a required thickness associated with the TLP approach. The Applicant reviewed projects that used the TLP approach and found that a depth of 6 to 12 inches was required. The 6-inch TLP approach was described in the USACE Federal Contract Opportunity for **W9127822B0004 – IFB for 27-30in Cutterhead Pipeline Dredge for Dredging in Alabama, Florida, and Mississippi** (https://govtribe.com/opportunity/federal-contract-opportunity/w9127822b0004-ifb-for-27-30in-cutterhead-pipeline-dredge-for-dredging-in-alabama-florida-and-mississippi-dot-w9127822d0029).

The TLP approach would be conducted in such a manner that the dredged lake bed material would settle out in the designated open-water disposal areas in thin layers as per the guidelines in 40 CFR Section 230.11. Based on the Applicant's review of the relevant 404(b)(1) factors identified in Section 230.11(f)(2), the TLP process would not significantly change the depth of the lake water; the lake's current velocity, direction, or variability; or the degree of turbulence in the disposal area. The disposal process would not cause stratification or obstructions over the disposal area, so it would allow for navigation. The TLP process would not create additional erosion, slumping, or lateral displacement of surrounding lake bed areas that could adversely affect areas outside the perimeters of the disposal area by changing or destroying habitat or prohibiting navigability. Finally, placing dredged lake bed material would not change the salinity of the lake.

The Applicant proposes this refined deposition approach and maintains that extending the intake canals would not result in any loss of lake bed functions or services and should not, therefore, trigger compensatory mitigation.

3.0 References

[GSLAC] Great Salt Lake Advisory Committee

2021 Influence of Salinity on the Resources and Uses of Great Salt Lake. Open-File Report 736. Utah Geological Survey. July.

[UFFSL] Utah Division of Forestry, Fire and State Lands

2013 Final Great Salt Lake Comprehensive Management Plan and Record of Decision. March 27.

[USACE] United States Army Corps of Engineers

2022 Summary of Comments for Response. September 29.

[USGS] United States Geological Survey

2005 Bathymetric Map of the South Part of Great Salt Lake, Utah, 2005.

US Magnesium

2022 404 IP Application and Supplemental Information.

Appendix A. US Army Corps Comment Letter dated September 27, 2022

DEPARTMENT OF DEFENSE
UNITED STATES OF AMERICA

DEPARTMENT OF THE ARMY
U.S. ARMY CORPS OF ENGINEERS, SACRAMENTO DISTRICT
1325 J STREET
SACRAMENTO CA 95814-2922

September 29, 2022

Regulatory Branch (SPK-2008-01773)

US Magnesium
Attn: Mr. Tim Gribben
238 North 2200 West
Salt Lake City, Utah 84116
tgribben@usmagnesium.com

Dear Mr. Gribben:

We have received comments and concerns related to your application and in response to our Public Notice Number SPK-2008-01773 for your proposed project. We are enclosing copies of those for your response (enclosure). We have also identified the following items and issues for your response and/or additional information:

1. We have concerns regarding the project's potential direct or indirect effects on Great Salt Lake (GSL) levels. Specifically, how and to what extent could the proposed activity result in increased GSL water consumption, thereby lowering lake levels and further exacerbating an ongoing environmental concern? What percentage of the current GSL volume (south arm only) does your withdrawal constitute now and would that percentage change after project completion? Please provide an analysis to address these concerns.

2. What effect will the proposed activity have on normal facility operations? Is the intent to increase production to allow for maximum production/normal operations or is the intent to maintain reduced operations at the minimum necessary to prevent a lapse in production during this abnormally dry period? Please provide clarification.

3. Provide an analysis of what salinity levels would be if the GSL dropped to the 4,188 elevation, how that compares to current salinity levels, and at what lake elevation the salinity levels become too high to sustain current ecological functions. There may be existing information and modeling available from the State of Utah to aid in gathering this information. If a correlation can be shown between continued operations from the proposed project and GSL salinity levels, can a planned reduction in operation and/or water withdrawals be implemented if GSL salinity approaches critical concentrations?

4. We appreciate the project alternatives considered in the application materials. Has U.S. Magnesium evaluated the feasibility of any alternatives involving an upland

trench system to convey north arm water to the facility? For example, from the Lakeside area and along the toe of the Lakeside Mountains to the North Arm of the GSL to capture higher concentration brine? Please clarify the viability of such an alternative.

5. The application materials indicate that a cultural resource survey of the project area will be provided. In order to complete Section 106 consultation, we will need this information, in accordance with the Utah State Historic Preservation Office Archeological Compliance Guidance document: https://drive.google.com/file/d/1_e2QLxR2pLUBns2l2GyDbomzJeWTH_Wu/view

6. Due to the potential presence of microbialites (stromatolites) within or adjacent to the project area, we will need an aquatic resource survey detailing information on the location and quality of these resources, as well as a detailed description of the potential impacts resulting from the proposed activities. Compensatory mitigation may be required for unavoidable impacts to these resources.

7. The creation of the new segment of canal will result in the change in use from lakebed habitat to a component of the minerals production facility, which will likely require future impacts and modifications to the area. As such, the Corps considers this action a loss of waters and will require compensation. Please provide a plan to compensate for these losses of function and services. Further, the side-casting of the dredged material onto the lakebed may also impact the functions/services of the lakebed and may also require additional compensatory mitigation depending on changes in lakebed elevations. Please provide additional rationale to support that the impacts would be minimal and/or propose design changes related to placement of spoil materials to reduce the depth of deposition, such as increasing the distance from the canal that the spoils are redeposited. Increasing the distance from the canal beyond 150 feet would decrease the height of any spoil deposition.

You should provide your responses and any additional information within 30 calendar days from the date of this letter, or request a time extension, to a specific date and in writing, by that time. Otherwise, we will consider your application withdrawn. Our withdrawal of your application does not preclude you from submitting the requested information, including any additional information you want us to consider, at a later date. In that event we can reactivate and continue processing your application. We encourage you to use this opportunity to resolve or rebut objections and to ensure all available information is in our administrative record. The decision to issue or deny a Department of the Army permit is our responsibility and we will consider all factors of the public interest in making that decision.

Please refer to identification number SPK-2008-01773 in any correspondence concerning this project. If you have any questions, please contact me at the Bountiful Regulatory Office, 533 West 2600 South, Suite 150, Bountiful, Utah 84010, by email at

Michael.A.Pectol@usace.army.mil, or telephone at (801) 295-8380 ext. 8315. For more information regarding our program, please visit our website at *www.spk.usace.army.mil/Missions/Regulatory.aspx*.

Sincerely,

Michael Pectol
Project Manager
Nevada-Utah Section

Enclosure

cc:
William Pope, HDR Engineering (william.pope@hdrinc.com)

Appendix B. 2013 UFFSL GSL Level Matrix

GSL LAKE LEVEL MATRIX

1-Mar-13

Zone boundary transition

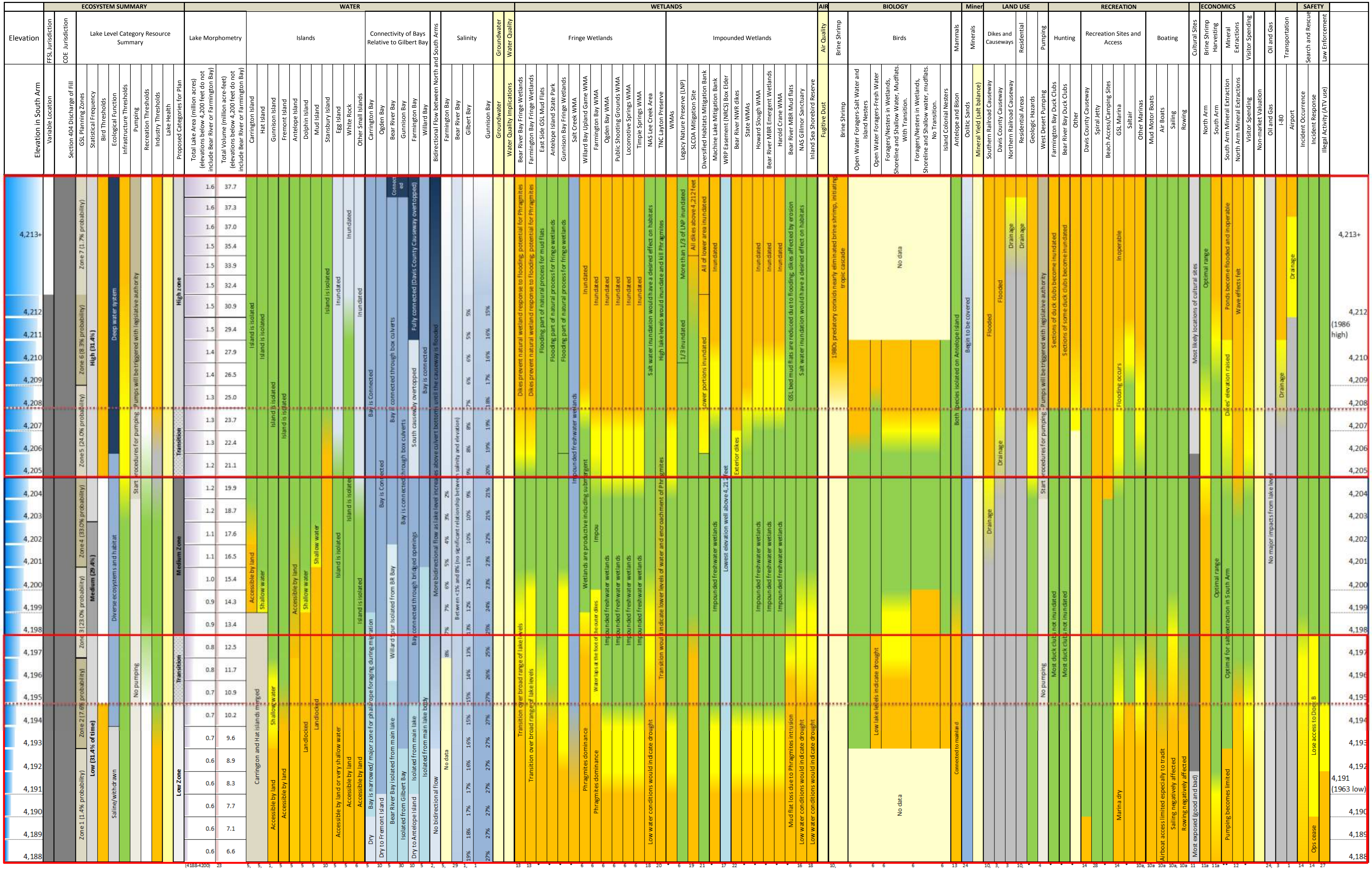
Zone boundary

Beneficial for resource — transition — Adverse for resource

Gray scale is descriptive only to show differences in categories etc.

Blue scale represents value-neutral changes in lake characteristics

Incomplete data or information gap



Elevation in South Arm	Total Lake Area (million acres) (elevations below 4,200 feet do not include Bear River or Farmington Bay)	Total Volume (million acre-feet) (elevations below 4,200 feet do not include Bear River or Farmington Bay)	Salinity: Farmington Bay	Salinity: Bear River Bay	Salinity: Gilbert Bay	Salinity: Gunnison Bay	Elevation
4,213+	1.6	37.7					4,213+
	1.6	37.3					
	1.6	37.0					
	1.5	35.4					
	1.5	33.9					
	1.5	32.4					
4,212	1.5	30.9			5%	15%	4,212 (1986 high)
4,211	1.5	29.4			5%	16%	
4,210	1.4	27.9			6%	16%	4,210
4,209	1.4	26.5			6%	17%	4,209
4,208	1.3	25.0			7%	18%	4,208
4,207	1.3	23.7		Between <1% and 8% (no significant relationship between salinity and elevation)	8%	19%	4,207
4,206	1.3	22.4			8%	19%	4,206
4,205	1.2	21.1			9%	20%	4,205
4,204	1.2	19.9	2%		9%	21%	4,204
4,203	1.2	18.7	3%		10%	21%	4,203
4,202	1.1	17.6	4%		10%	22%	4,202
4,201	1.1	16.5	5%		11%	23%	4,201
4,200	1.0	15.4	6%		12%	23%	4,200
4,199	0.9	14.3	7%		12%	24%	4,199
4,198	0.9	13.4	7%		13%	29%	4,198
4,197	0.8	12.5	8%		13%	25%	4,197
4,196	0.8	11.7	No data		14%	26%	4,196
4,195	0.7	10.9			15%	27%	4,195
4,194	0.7	10.2			15%	27%	4,194
4,193	0.7	9.6			16%	27%	4,193
4,192	0.6	8.9			16%	27%	4,192
4,191	0.6	8.3			17%	27%	4,191 (1963 low)
4,190	0.6	7.7			17%	27%	4,190
4,189	0.6	7.1			18%	27%	4,189
4,188	0.6	6.6			19%	27%	4,188

ECOSYSTEM SUMMARY

- FFSL Jurisdiction: Variable Location
- COE Jurisdiction: Section 404 Discharge of Fill
- Lake Level Category Resource Summary:
  - GSL Planning Zones: Zone 7 (1.7% probability); Zone 6 (8.3% probability); Zone 5 (24.0% probability); Zone 4 (33.0% probability); Zone 3 (23.0% probability); Zone 2 (7.6% probability); Zone 1 (1.4% probability)
  - Statistical Frequency: High (31.4%); Medium (29.4%); Low (31.4% of time)
  - Bird Thresholds
  - Ecological Function: Deep water system; Diverse ecosystems and habitat; Saline/withdrawn
  - Infrastructure Thresholds
  - Pumping: Pumps will be triggered with legislative authority; Start procedures for pumping; No pumping
  - Recreation Thresholds
  - Industry Thresholds
  - Lake Health
  - Proposed Categories for Plan: High zone; Transition; Medium Zone; Transition; Low Zone

WATER

- Lake Morphometry: Total Lake Area; Total Volume — Reference: (4188-4200) 7, 8; (4200-4213) 9; 23
- Islands:
  - Carrington Island: Island is isolated; Accessible by land; Carrington and Hat islands merged — Reference: 5, 4
  - Hat Island: Island is isolated; Shallow water — Reference: 5, 6
  - Gunnison Island: Island is isolated; Shallow water; Accessible by land — Reference: 1, 5, 10
  - Fremont Island: Island is isolated; Accessible by land — Reference: 5
  - Antelope Island: Accessible by land; Shallow water — Reference: 5
  - Dolphin Island: Shallow water; Landlocked — Reference: 5
  - Mud Island: Landlocked — Reference: 5
  - Stansbury Island — Reference: 10
  - Egg Island: Island is isolated; Inundated; Island is isolated; Accessible by land or very shallow water — Reference: 5
  - White Rock: Inundated; Island is isolated; Accessible by land — Reference: 5
  - Other Small Islands: Inundated; Island is isolated; Accessible by land — Reference: 6
- Connectivity of Bays Relative to Gilbert Bay:
  - Carrington Bay: Bay is Connected; Dry — Reference: 5
  - Ogden Bay: Bay is Connected; Bay is narrowed/ major zone for phalarope foraging during migration; Dry to Fremont Island — Reference: 10
  - Bear River Bay: Connected; Bay is connected through box culverts; Willard spur Isolated from BR Bay; Bear River Bay isolated from main lake — Reference: 5
  - Gunnison Bay: Bay is connected through box culverts; Isolated from Gilbert Bay — Reference: 30
  - Farmington Bay: Fully connected (Davis County Causeway overtopped); South causeway overtopped; Bay connected through bridged openings; Dry to Antelope Island; Isolated from main lake — Reference: 10
  - Willard Bay: Bay is connected; Isolated from main lake body — Reference: 5
- Bidirectional Flow between North and South Arms: More bidirectional flow as lake level increases above culvert bottoms until the causeway is flooded; No bidirectional flow — Reference: 2, 30
- Salinity: Farmington Bay — Reference: 5, 2, 3; Bear River Bay — Reference: 29; Gilbert Bay — Reference: 1, 3; Gunnison Bay — Reference: 1
- Groundwater: Groundwater
- Water Quality: Water Quality Implications

WETLANDS

- Fringe Wetlands:
  - Bear River Bay Fringe Wetlands: Dikes prevent natural wetland response to flooding, potential for Phragmites; Transition over broad range of lake levels — Reference: 13
  - Farmington Bay Fringe Wetlands: Dikes prevent natural wetland response to flooding, potential for Phragmites; Transition over broad range of lake levels — Reference: 13
  - East Side GSL Mud Flats: Flooding part of natural process for mud flats — Reference: *
  - Antelope Island State Park: Flooding part of natural process for fringe wetlands — Reference: *
  - Gunnison Bay Fringe Wetlands: Flooding part of natural process for fringe wetlands — Reference: *
  - Salt Creek WMA: Impounded freshwater wetlands — Reference: *
  - Willard Bay Upland Game WMA: Inundated; Wetlands are productive including submergent; Phragmites dominance — Reference: 6
  - Farmington Bay WMA: Inundated; Impou; Water laps at the foot of the outer dikes; Phragmites dominance — Reference: 6
  - Ogden Bay WMA: Inundated; Impounded freshwater wetlands — Reference: 6
  - Public Shooting Grounds WMA: Inundated; Impounded freshwater wetlands — Reference: 6
  - Locomotive Springs WMA: Inundated; Impounded freshwater wetlands — Reference: 6
  - Timpie Springs WMA: Inundated; Impounded freshwater wetlands — Reference: 6
  - NAS Lee Creek Area: Salt water inundation would have a desired effect on habitats; Low water conditions would indicate drought — Reference: 18
  - TNC Layton Preserve: High lake levels would inundate and kill Phragmites; Transition would indicate lower levels of water and encroachment of Phragmites — Reference: 20
- Impounded Wetlands:
  - WMAs — Reference: *
  - Legacy Nature Preserve (LNP): More than 1/3 of LNP inundated; 1/3 inundated — Reference: 6
  - SLCDA Mitigation Site: All dikes above 4,212 feet — Reference: 19
  - Diversified Habitats Mitigation Bank: All of lower area inundated; Lower portions inundated — Reference: 21
  - Machine Lake Mitigation Bank: Inundated; Impounded freshwater wetlands — Reference: *
  - WRP Easement (NRCS) Box Elder: Lowest elevation well above 4,21[illegible] feet — Reference: 17
  - Bear River NWR dikes: Exterior dikes — Reference: 22
  - State WMAs — Reference: *
  - Howard Slough WMA: Inundated; Impounded freshwater wetlands — Reference: *
  - Bear River MBR Emergent Wetlands: Inundated; Impounded freshwater wetlands — Reference: *
  - Harold Crane WMA: Inundated; Impounded freshwater wetlands — Reference: *
  - Bear River MBR Mud flats: GSL bed mud flats are reduced due to flooding; dikes affected by erosion; Mud flat loss due to Phragmites intrusion — Reference: *
  - NAS Gillmor Sanctuary: Salt water inundation would have a desired effect on habitats; Low water conditions would indicate drought — Reference: 16
  - Inland Sea Shorebird Reserve: Low water conditions would indicate drought — Reference: 18

AIR

- Air Quality: Fugitive Dust

BIOLOGY

- Brine Shrimp: 1980s predatory corixids nearly eliminated brine shrimp, initiating tropic cascade — Reference: 10, 11a
- Birds:
  - Open Water Foragers-Salt Water and Island Nesters: No data — Reference: 6
  - Open Water Foragers-Fresh Water: Low lake levels indicate drought — Reference: 6
  - Foragers/Nesters in Wetlands, Shoreline and Shallow Water, Mudflats. With Transition. — Reference: 6
  - Foragers/Nesters in Wetlands, Shoreline and Shallow water, mudflats. No Transition. — Reference: 6
  - Island Colonial Nesters: No data — Reference: 6
- Mammals: Antelope and Bison: Both species isolated on Antelope Island; Connected to mainland — Reference: 13

Miner

- Minerals: Oolitic Sands: Begin to be covered — Reference: 24
- Mineral Yield (salt balance)

LAND USE

- Dikes and Causeways:
  - Southern Railroad Causeway: Flooded; Drainage — Reference: 10, 11
  - Davis County Causeway: Flooded; Drainage — Reference: 3, 15
  - Northern Railroad Causeway: Drainage — Reference: 3
- Residential: Residential Areas: Drainage — Reference: 10, 15
- Geologic Hazards — Reference: *
- Pumping: West Desert Pumping: Pumps will be triggered with legislative authority; Start procedures for pumping; No pumping — Reference: 4

RECREATION

- Hunting:
  - Farmington Bay Duck Clubs: Sections of duck clubs become inundated; Most duck clubs not inundated — Reference: *
  - Bear River Bay Duck Clubs: Sections of some duck clubs become inundated; Most duck clubs not inundated — Reference: *
  - Other — Reference: *
- Recreation Sites and Access:
  - Davis County Causeway — Reference: 14
  - Spiral Jetty — Reference: 28
  - Beach Access/Camping Sites — Reference: *
  - GSL Marina: Inoperable; Flooding occurs; Marina dry — Reference: 14
  - Saltair — Reference: *
  - Other Marinas — Reference: 10a, 11, 27
- Boating:
  - Mud Motor Boats — Reference: 10a
  - Air Boats: Airboat access limited especially to tradit — Reference: 10a
  - Sailing: Sailing negatively affected — Reference: 10a, 14
  - Rowing: Rowing negatively affected — Reference: 10a

ECONOMICS

- Cultural Sites: Most likely locations of cultural sites; Most exposed (good and bad) — Reference: 11
- Brine Shrimp Harvesting:
  - North Arm: Optimal range — Reference: 11a
  - South Arm: Optimal range — Reference: 11a
- Mineral Extractions:
  - South Arm Mineral Extraction: Ponds become flooded and inoperable; Dikes' elevation raised; Optimal for salt extraction in South Arm; Pumping becomes limited — Reference: **
  - North Arm Mineral Extractions: Wave effects felt — Reference: 12
- Visitor Spending: Visitor Spending — Reference: *
- Non-market Valuation
- Oil and Gas: No major impacts from lake level — Reference: 24, 26
- Transportation:
  - I-80: Drainage — Reference: 3
  - Airport: Drainage — Reference: 1

SAFETY

- Search and Rescue:
  - Incident Occurrence — Reference: 14
  - Incident Response: Lose access to Dock B; Ops cease — Reference: 14
- Law Enforcement: Illegal Activity (ATV use) — Reference: 27

Reference

* "The lake level values associated with this resource are based on collective knowledge and judgment of the GSLCMP Planning Team."

** Reference Confidential

Appendix C. 2021 GSL Technical Committee Report

Influence of Salinity on the Resources and Uses of Great Salt Lake

by

Great Salt Lake Salinity Advisory Committee

Suggested citation:

Great Salt Lake Salinity Advisory Committee, 2021, Influence of salinity on the resources and uses of Great Salt Lake: Utah Geological Survey Open-File Report 736, 23 p., https://doi.org/10.34191/OFR-736.

Disclaimer

OPEN-FILE REPORT 736
UTAH GEOLOGICAL SURVEY
a division of
UTAH DEPARTMENT OF NATURAL RESOURCES
2021

BACKGROUND

The purpose of this open-file release is to make the attached document prepared by the Great Salt Lake Salinity Advisory Committee available to the public, part of the permanent record, and citable for future reference. The Great Salt Lake Salinity Advisory Committee is a group of scientists and stakeholders convened by the Utah Division of Forestry, Fire and State Lands and the Utah Division of Water Quality. The committee was formed in early 2018. Their goal and purpose, as stated in their charter (version 3), follows:

> The goal of the Great Salt Lake (GSL) Salinity Advisory Committee (SAC) is to provide recommendations for long-term management of the salinity of GSL to the Utah Division of Forestry, Fire and State Lands (FFSL) and the Utah Division of Water Quality (UDWQ) that maximize the benefits of GSL in accordance with the public trust doctrine and protect the designated uses of GSL in accordance with the Utah Water Quality Act.
>
> The purpose of the SAC is to review and interpret results from GSL salinity research and monitoring activities and make recommendations to FFSL and UDWQ regarding potential modifications to the UPRR causeway opening, berm or channel and long-term management of the salinity of GSL.

The following document was prepared in large part by Jeff DenBleyker (Jacobs), the facilitator of the committee, with significant input and review by various committee members and outside experts. Specific contributions are noted within the document.

The 2021 members of the Great Salt Lake Salinity Advisory Committee are:

Cory Angeroth, U.S. Geological Survey

Jamie Barnes, Utah Division of Forestry, Fire and State Lands (co-chair)

Bonnie Baxter, Westminster College

Thomas Bosteels, Great Salt Lake Brine Shrimp Cooperative

Jaimi Butler, Westminster College (alternate)

Jeff DenBleyker, Jacobs (facilitator)

Jim Harris, Utah Division of Water Quality (co-chair)

Joe Havasi, Compass Minerals

Tim Hawkes, Great Salt Lake Brine Shrimp Cooperative (alternate)

Ben Holcomb, Utah Division of Water Quality (alternate)

Elliot Jagniecki, Utah Geological Survey (alternate)

Paul Jewell, University of Utah (alternate)

Bill Johnson, University of Utah

Bill Kerner, Compass Minerals (alternate)

Krishna Khatri, Utah Division of Water Resources (alternate)

John Luft, Utah Division of Wildlife Resources

Craig Miller, Utah Division of Water Resources

Ryan Rowland, U.S. Geological Survey (alternate)

Andrew Rupke, Utah Geological Survey

Kyle Stone, Utah Division of Wildlife Resources (alternate)

Tom Tripp, US Magnesium

Laura Vernon, Utah Division of Forestry, Fire and State Lands (alternate)

Great Salt Lake
Salinity Advisory Committee

Memorandum

Subject Influence of Salinity on the Resources and Uses of Great Salt Lake

Completed by **Great Salt Lake Salinity Advisory Committee**

Cory Angeroth/USGS
Bonnie Baxter/Westminster
Jaimie Barnes/FFSL - co-chair
Thomas Bosteels/GSLBSC*
Jeff DenBleyker/Jacobs - facilitator
Joe Havasi/Compass Minerals
Elliot Jagniecki/UGS (alternate)
Bill Johnson/Univ of Utah
John Luft/DWiR
Craig Miller/DWRe
Ryan Rowland/USGS (alternate)
Andrew Rupke/UGS
Kyle Stone/DWiR (alternate)
Tom Tripp/Tooele County & US Magnesium
Jim Harris/DWQ - co-chair
Laura Vernon/FFSL (alternate)

Date July 27, 2021

The salinity of Great Salt Lake (GSL) plays a very influential role in shaping the lake's unique ecological, recreational, and mineral resource uses. This memorandum summarizes a review of the literature and GSL databases to describe critical salinity ranges that influence these resources and uses. It presents a GSL Salinity Matrix intended to provide decision-makers with an important illustration; not to predict how GSL's salinity will change, but to illustrate the potential consequences of salinity changes.

All Salinity Advisory Committee (SAC) members and subcommittee participants are thanked for their participation, discussion, input, and review of this document. The participation of the individuals listed in Table 1 was critical for completion of this work.

Table 1. GSL SAC Subcommittee Members

Ecology Subcommittee	Geochemistry Subcommittee
Bonnie Baxter/Westminster	Joe Havasi/Compass Minerals
Thomas Bosteels/GSLBSC	Elliot Jagniecki/UGS
Jaimi Butler/Westminster	Bill Johnson/Univ of Utah
Jim Harris/DWQ	Jim Harris/DWQ
Heidi Hoven/National Audubon Society	Craig Miller/DWRe
Craig Miller/DWRe	Ryan Rowland/USGS
Kyle Stone/DWiR	Andrew Rupke/UGS
Brian Tavernia/National Audubon Society	Tom Tripp/Tooele County
Laura Vernon/FFSL	Laura Vernon/FFSL

Notes:
DWiR = Division of Wildlife Resources
DWRe = Division of Water Resources
DWQ = Division of Water Quality
FFSL = Division of Forestry, Fire and State Lands
GSLBSC = Great Salt Lake Brine Shrimp Co-operative
UGS = Utah Geological Survey
USGS = U.S. Geological Society

1. Purpose and Need

A high priority identified by the GSL SAC was to develop a means to interpret salinity data and evaluate their significance. A means was needed to answer questions such as, does the observed or forecasted salinity support the lake's uses? Or, how might a change in salinity influence those uses? Answering these questions was determined to be central to many of the SAC's objectives. Completing this task as a committee facilitated important discussions and understanding among committee members (Objective Number [No.] 1 in the SAC's charter). Completion of the task will support efforts to identify gaps in data and understanding of the lake (Objective No. 2 in the SAC's charter). It will also be used to better understand how changes in the lake's salinity may influence changes in the lake's uses and to make recommendations to FFSL and DWQ (Objective No. 3 in the SAC's charter). Such a tool will be valuable for effective adaptive management of the lake.

2. Methodology

The 2013 Great Salt Lake Comprehensive Management Plan (UDNR 2013) includes a lake water level matrix that illustrates the benefit or impact of different lake water levels (y-axis) to the numerous resources and uses of GSL (x-axis). The SAC decided to develop a similar matrix for salinity to serve as a companion to the GSL water level matrix. The GSL Salinity Matrix will provide lake users, researchers, managers, and regulators a practical means to interpret salinity data and evaluate their significance for GSL. The SAC intends for this matrix to be a starting point. It is intended to be a tool that is useful today but will continue to be improved into tomorrow.

The GSL SAC (Table 1) formed two subcommittees (ecology and geochemistry) in April 2020 to develop the GSL Salinity Matrix. SAC members began by identifying key GSL resources and uses to include in the evaluation. The two subcommittees then worked to identify and review historical data, survey the literature, review and discuss findings, and summarize the results in a matrix. The GSL Salinity Matrix included in Figure 1 is thus the product of several evolutions; the SAC expects that this evolution will continue. The effort to develop the GSL Salinity Matrix has already resulted in several new lines of inquiry. It is important to note that Figure 1 is a summary of a more detailed salinity matrix, with references, that is included in Attachment A.

3. Discussion

The GSL Salinity Matrix is focused largely upon the open water systems of GSL, including Farmington Bay and Bear River Bay but with a primary focus upon Gilbert Bay (South Arm) and Gunnison Bay (North Arm). As such, the GSL Salinity Matrix may not include all beneficial uses, especially in upland, shoreline, or estuarine areas of the lake. Additional uses may be added and changes may be made as the GSL Salinity Matrix continues to evolve.

There are simply inadequate data to precisely isolate and fully describe the ecological response to changes in salinity. Describing GSL's salinity, isolating the influence of salinity from the myriad of variables that influence the lake's resources, and interpreting what might be physiological limits versus other ecological influences are just some of the significant challenges to be overcome. The GSL Salinity Matrix attempts to differentiate between salinities that are "ideal", or where the abundance or productivity of a use is high, and salinities that may be "unfavorable", or where conditions may limit the abundance or productivity of the use based upon the SAC's best understanding of the lake and literature. The reader is advised to not interpret the GSL Salinity Matrix as a listing of thresholds, but rather as a guide that describes how uses may change even as the lake's salinity changes.

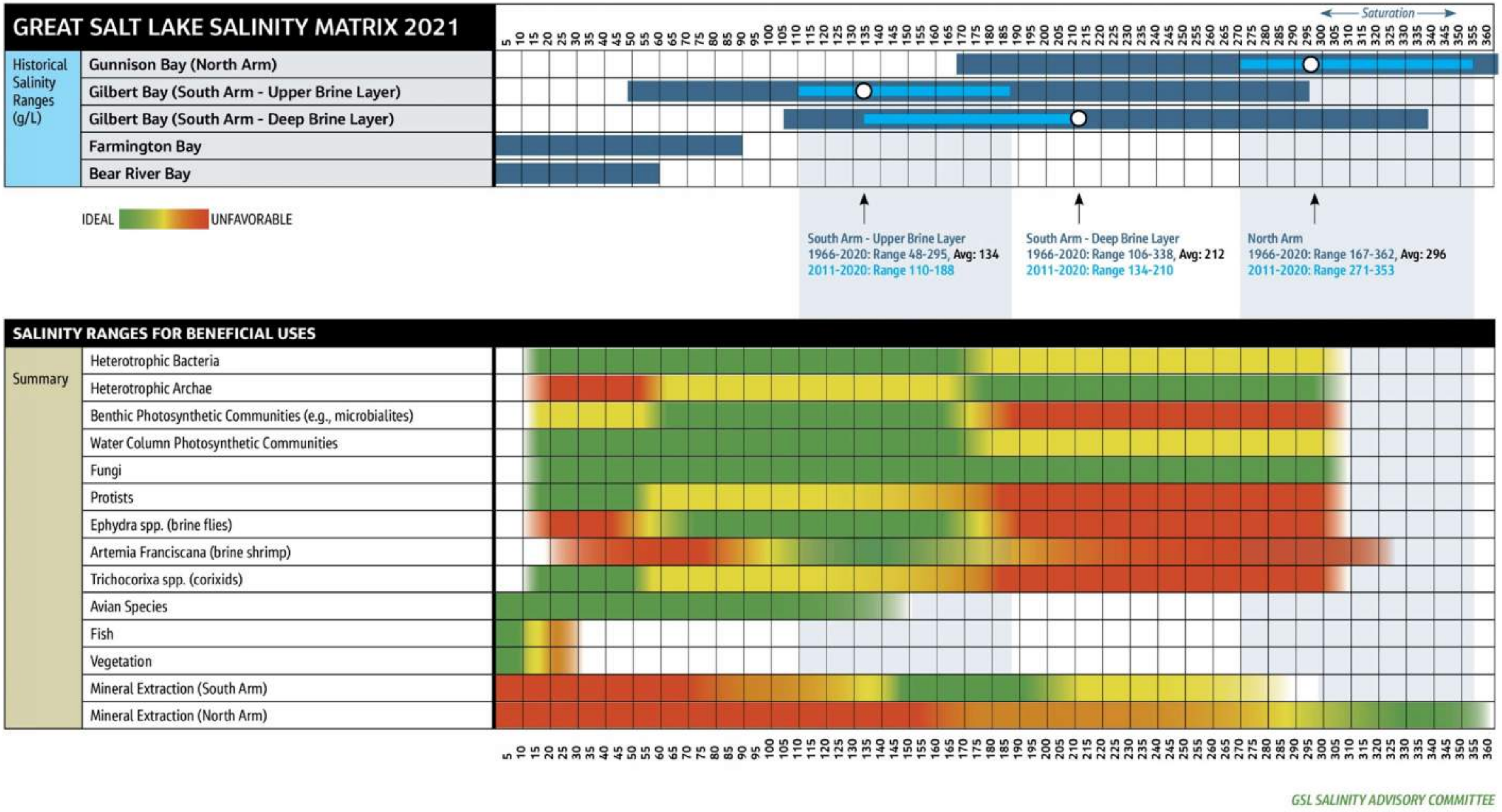


Figure 1. Great Salt Lake Salinity Matrix, 2021

The SAC recognizes that any attempt to simplify and describe these complex dynamics in one figure comes with a risk of oversimplification. Thus, the SAC provides the following discussion to augment the noted references in interpreting and understanding the GSL Salinity Matrix.

3.1 Typical Salinity Ranges Observed in Great Salt Lake

Contributed by Andrew Rupke

The salinity of the brine in GSL depends upon a variety of factors, but GSL's water level and constructed divisions in the lake are primary drivers. In general, as GSL's water level rises, salinity decreases and vice versa (Figure 2). The division of the lake by the rockfill railroad causeway has resulted in the North Arm and South Arm of the lake developing different salinity regimes. The vast majority of fresh water enters the lake in the South Arm, and water flow through the causeway is restricted; thus, the North Arm of the lake is more saline than the South Arm and is often at or near saturation with respect to halite. The salinity (and density) and head differential between the North and South Arms has also resulted in bi-directional flow through the causeway openings and the development of a discrete deep brine layer (DBL) in the South Arm that is higher in density and salinity than the rest of the South Arm water column (Figure 2).

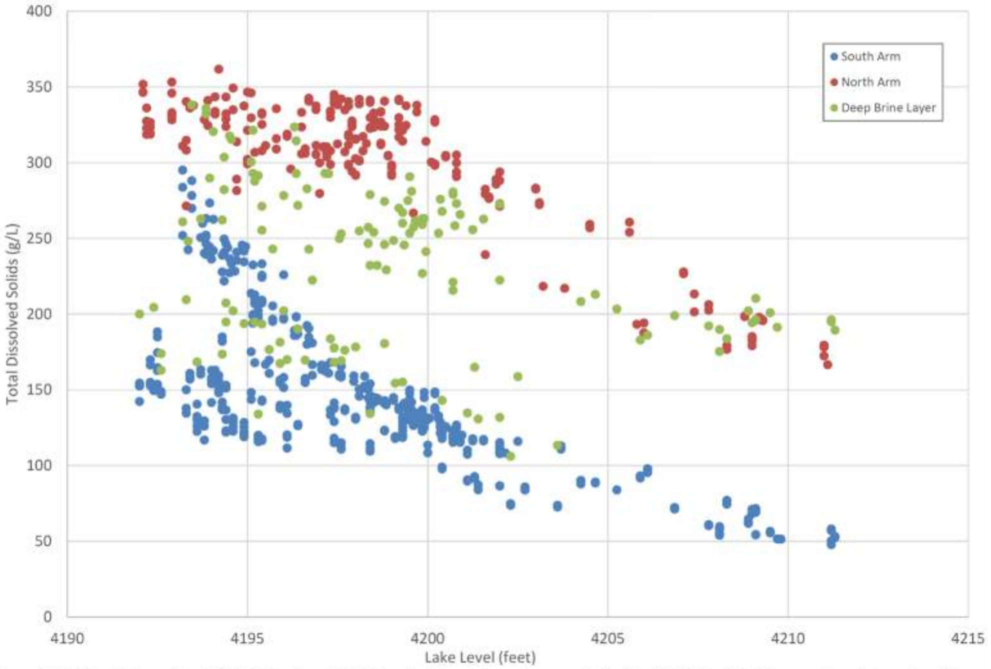
From 1966 through 2020, the measured salinity of the South Arm (excluding the DBL) has ranged from 48 to 295 grams per liter (g/L) (average of 134 g/L [based on an average of the annual averages]), but has not been above 200 g/L since 1970 (Figures 3 and 4). An inverse relationship between salinity and lake level exists, but an overall freshening of the South Arm has occurred since the 1990s that cannot simply be attributed to changing lake level (Figure 4). The lowest salinities in the South Arm occurred during high lake levels of the late 1980s. In the last 10 years (2011 to 2020), salinity in the South Arm has ranged from 110 to 188 g/L (with an average of 137 g/L). Available data show a discernible DBL in the South Arm as early as 1966, and the salinity of the DBL, when present, ranges from 106 to 338 g/L (Figures 2 and 3) and averages 212 g/L. In the last 10 years, the salinity range of the DBL, when present, is 134 to 210 g/L (with an average of 178 g/L) (Figure 3).

The measured salinity in the North Arm, from 1966 through 2020, has ranged from 167 to 362 g/L (Figures 2 and 3) (with an average of 296 g/L) and, in the last 10 years, has fluctuated between 271 and 353 g/L (with an average of 316 g/L) (Figure 3). Similar to the South Arm, the lowest salinities in the North Arm also occurred during high lake levels in the late 1980s.

The freshening of the South Arm over time, as noted previously and shown in Figure 4, is likely indicative of a net migration of salt from the South Arm to the North Arm since the completion of the railroad causeway. This net movement of salt sustains the higher salinities of the North Arm as well as the substantial salt crust that resides on the floor of the North Arm (Rupke et al. 2016). While mineral and salt extraction accounts for some removal of salt from the overall lake system (Mills et al. 2020), available data suggest that riverine input of dissolved solids to the lake either exceeds or substantially offsets the amount of salt removed by extraction (Shope and Angeroth 2015).

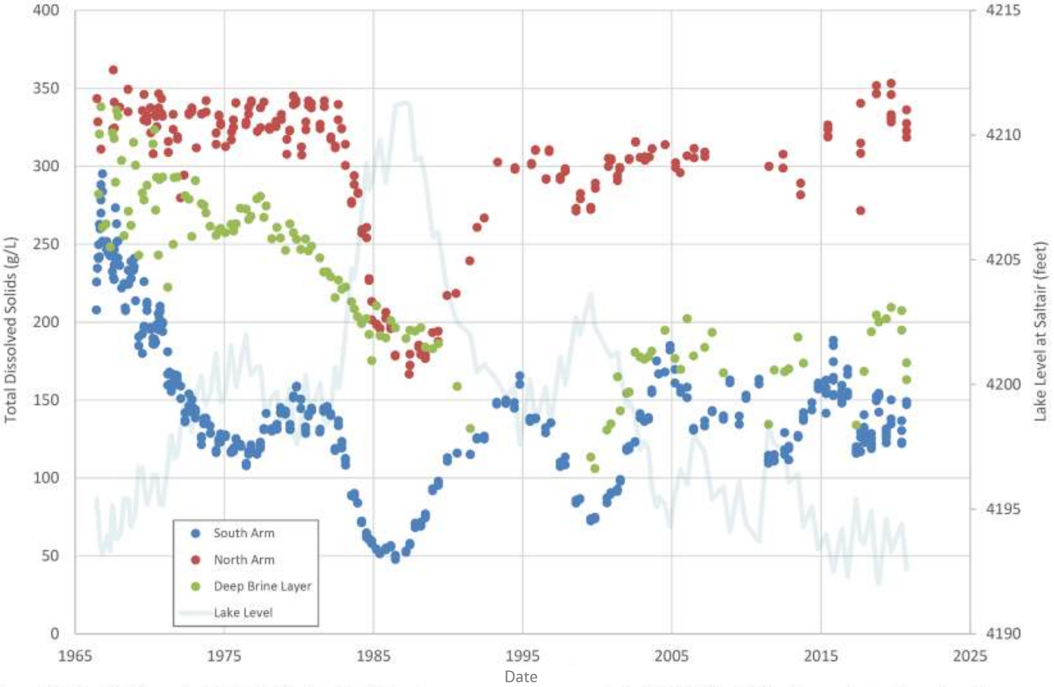
This discussion is based on the UGS's Brine Chemistry Database, which includes data from 1966 through the present. Ranges for the North and South Arms are based on brine measurements near a depth of 10 feet at South Arm sites AS2, FB2, and AC3 and North Arm sites LVG4 and RD2. Data from the DBL are from the deepest samples at site AS2 when a DBL is discernibly present. Salinities are calculated as the sum of sodium (Na), potassium (K), magnesium (Mg), calcium (Ca), chloride (Cl), and sulfate (SO_4) ion concentrations from laboratory analysis. The UGS database can be found at https://geology.utah.gov/docs/xls/GSL_brine_chem_db.xlsx.

Based on observations, experimentation, and modeling, the North Arm lake waters appear to reach saturation at about 1.22 grams per cubic centimeter at 20.0 degrees Celsius (Jagniecki and Rupke, in preparation). Based on historical data from the UGS Brine Chemistry Database, salinity levels in the North Arm range from about 300 to 350 g/L at that density.



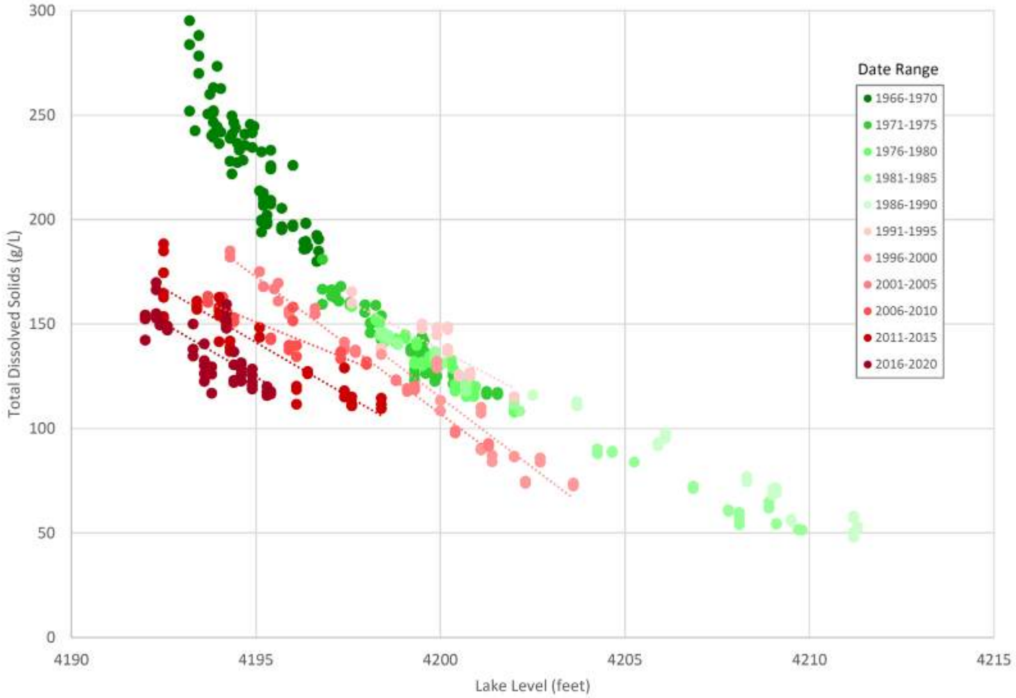
Source: Utah Geological Survey Great Salt Lake Brine Chemistry Database (south arm data are from sample sites AS2, AC3, FB2 at ~10 feet deep; north arm data are from sites LVG4 and RD2 at ~10 feet deep; deep brine layer data are from the deepest sample at site AS2 when a deep brine layer is present)

Figure 2. Great Salt Lake Water Salinities Generally Decline as Water Levels Increase (1966 to 2020)



Source: Utah Geological Survey Great Salt Lake Brine Chemistry Database (south arm data are from sample sites AS2, AC3, FB2 at ~10 feet deep; north arm data are from sites LVG4 and RD2 at ~10 feet deep; deep brine layer data are from the deepest sample at site AS2 when a deep brine layer is present); Lake level data are from U.S. Geological Survey

Figure 3. Great Salt Lake Salinity and Water Level Changes (1966 to 2020)



Source: Utah Geological Survey Great Salt Lake Brine Chemistry Database (data are from sample sites AS2, AC3, FB2 at ~10 feet deep; trend lines are linear)

Figure 4. Salinities of the South Arm, Great Salt Lake (1966 to 2020)

3.2 Microbial Diversity

Contributed by Bonnie Baxter, PhD

The microbial communities in GSL are composed predominantly of halophilic (salt-thriving) archaea and bacteria; however, eukaryotic algae, protozoa, and fungi are also present. In general, the higher the salinity, the more archaeal genera are present relative to bacterial genera, and the less diversity is expected of the eukaryotic microorganisms. These assemblages of microorganisms must be dynamic, responding to the changes in salinity that GSL experiences. Salinity gradients especially impact the microbial communities in the less saline South Arm of the lake. The hypersaline North Arm resident microorganisms are more stable over seasons, have a lower phylogenetic diversity, and are not as impacted by changes in salinity (since their range begins above 180 g/L, and this brine has not dropped below that concentration in many years). Environmental, temporal, and spatial factors that impact salinity can drive which species are represented in the community. Salinity stratification, such as the occurrence of the DBL, may impact the microbial communities, affecting nutrient availability and sequestering bacterial species in the sediment that methylate mercury. Metabolic activities in GSL microbes, such as nutrient cycling, in general, occur more slowly as the salinity increases. Salinity is not the only driver of changes in microbial communities; the organisms also stratify due to light penetration or anaerobic/aerobic compartments.

The primary productivity of the lake is certainly higher in the South Arm, as microbes that do photosynthesis are mostly located there, with the exception of *Dunaliella salinia* and *Tetracystis* sp. in the North Arm. GSL has a thriving photoautotrophic, or phytoplankton, community, the diversity of which is controlled by salinity, but also temperature, and seasonal grazing by invertebrates. *Dunaliella virdis* in the South Arm water column may be the most important food source for *Artemia*. Current studies (in progress) seek to measure photosynthetic activity in the water column versus the microbialites on the lake bottom. Preliminary data reveal productivity is far higher in the benthic region, and there may be both primary and secondary producers, making the lower rung of the GSL food web very complex. Experiments in the laboratory (lab) and lake have identified a cyanobacteria species from the genus, *Euhalothece*, and the diatom, *Navicula,* as architects of the microbialites, which are organosedimentary calcium carbonate structures produced by microbial action. In GSL, the microbialites are lined with mats that contain these dominant species alongside less prevalent bacteria and archaea. *Artemia* adults and *Ephedra* larvae graze on the mats, while the flies pupate here, but their contribution to the nutrient supplies in the lake is likely more profound. The salinity threshold for productive microbialites is not clear; however, at 250 g/L salinity and above, microbialites in the North Arm become vestiges, as confirmed in both biology and geology experiments. Lab studies indicate a drop in chlorophyll when grown in concentrations as low as 150 g/L salt, but we do not have data between 150 and 250 g/L. These structures are likely the most significant microbial communities of GSL in terms of supporting the consumers of the food web, and they should be designated a “keystone” microbial community to monitor alongside salinity changes.

All of the information in Section 3.2 is reviewed in Baxter and Zalar (2019).

3.3 Brine Flies

The genus *Ephedra*, more commonly known as brine flies, have been a common sight along the shorelines of GSL; they have been observed by Fremont (1845) and Captain Stansbury (1852) through present times. *Ephydra* are an essential food source for the bird populations using the lake (Belovsky et al. 2011) and an essential component of the lake’s food web (Winget et al. 1972, Collins 1980).

Ephydra have been observed to be tolerant of a wide range of salinities in GSL. Nemenz (1960) documented *E. cinerea* at GSL at salinities of greater than 260 g/L; however, Collins (1980) further noted that fly populations were low at these high salinities. Aldrich (1912) documented large numbers of *E. gracilis* and *E. hians* at GSL at an estimated salinity of 195 g/L in 1908. Winget et al. (1972) noted numbers of *Ephydra* had been observed to be increasing over the period of 1968 to 1971, to the point where they were considered a considerable nuisance along the shoreline and plans were actively being developed to eradicate them. Collins (1980) estimated that the lake’s salinity had ranged from 240 to 170 g/L over that time (1968 to 1971). Contemporary observations confirm that *Ephydr*a have been present at GSL at the lower salinities of 180 to 115 g/L observed in the South Arm in the last 10 years.

There are likely many ecological factors that influence the *Ephydra* of GSL. Herbst (1999) observed that the occurrence of different species of *Ephydra* (*E. gracilis* and *E. hians*) at GSL may be a factor of water chemistry in addition to salinity. Barrett and Belovsky (2020) noted that the lake substrate (*Ephydra* prefer microbiolites) and water nutrients, temperature, and salinity all influence *Ephydra* populations. Belovsky et al. (2011) found that brine fly larvae are impacted seven times more by temperature than by salinity and the availability of food. Analyses by Barrett and Belovsky (2020) of potential future conditions affected by climate change indicate that lower salinities and warmer water temperatures could positively influence the abundance of *Ephydra*. However, they concluded that the lack of long-term *Ephydra* datasets prevents an analysis that could adequately describe how *Ephydra* population dynamics are impacted by GSL salinity.

Herbst’s (1999) overview of the dynamics of *Ephydra* in the saline waters of the Great Basin notes that the geochemistry of the lake and the physiology of different *Ephydra* species play an important role in which species are present. Herbst (1999) states that the optimum salinity range for *E. hians* is from 25 to 100 g/L; for *E. gracilis,* it is 100 to 200 g/L. This is consistent with Collins’ (1980) observations that dilution of GSL’s chloride waters increased the abundance of *E. hians* where otherwise only *E. gracilis* was present before.

3.4 Artemia

Contributed by Thomas Bosteels and Phil Brown

The genus *Artemia* is renowned for its ability to survive both extreme salinities and a very broad range of salinity. The *Artemia franciscana* population in the GSL does appear to exemplify this durability, persisting for millennia in a dynamic lake system with a remarkable disparity in salinity across time and space. However, this legendary plasticity may create the misleading impression that this population can survive any salinity range present in the dynamic GSL, and that the population was healthy and thriving across every salinity observed during the past 40 years of record. The critical reality is more complicated. An abundance of evidence from GSL and elsewhere demonstrates that the GSL *Artemia* population has an optimal salinity range in which the population is likely to thrive, and outside which the population will be strongly limited by ecological interactions and physiological stress.

Artemia are remarkable osmoregulators, which can survive in salinities ranging from merely brackish (5 g/L) to nearly salt-saturated (260 g/L). *Artemia* do so by maintaining a dilute haemolymph through the active expelling of salts from the body at a metabolic cost (Croghan 1958a, b, c). Hypersaline waters are oxygen-poor, particularly during periods of lower phytoplankton production, and *Artemia* manage this stress through the production of efficient respiratory pigments (Gilchrist 1954). *Artemia* also manage the detrimental effects of extreme salinity, desiccation, and heat through a suite of internally produced proteins, enzymes, and polysaccharides that protect cell structure and function (Feder and Hofmann 1999, Gajardo and Beardmore 2012). Finally, dormant cysts are produced to endure periods of hostile environmental conditions that exceed the ability of free-swimming age classes to survive.

Numerous studies demonstrate the ability of *Artemia* to survive very high salinities. *Artemia* from U.S. origin (defined at the time as *A. salina* and possibly from GSL) survived in salinities of 285 g/L under laboratory conditions in Croghan (1958a, b, c). Other *Artemia* species and populations may have higher ultimate thresholds, such as 310 g/L for *A. urmiana* and *A. parthenogenetica* (Mohammadi et al. 2009) and 340 g/L for populations in some solar evaporation ponds (Clegg and Trotman 2002). The GSLBSC has observed live *Artemia* periodically in the North Arm at salinities exceeding 260 g/L.

However, these lower and upper salinity tolerance values are misleading from an ecological perspective. The intermediate salinity hypothesis put forward by Herbst (2001) dictates that a population will be limited by interspecies interactions such as predation and competition at the lower end of the salinity range, and physiological stress at the upper, resulting in an optimum that is narrower than the strict physiological survival range. For the GSL *Artemia* population, this optimum is much narrower—evidence from field data and literature reviews sets this optimal salinity range at 120 to 160 g/L.

The ecological limitations supporting the 120 g/L lower limit have been abundantly documented in GSL. The corixid *Trichocorixa verticalis* will prey effectively on *Artemia* (Céspedes et al. 2007, Wurtsbaugh 1992). Wurtsbaugh and Berry (1990) measured a multi-year precipitous decline in South Arm *Artemia* and increase in *T. verticalis* in the 1980s, when salinities declined from 100 g/L to 50 g/L. Similar removal of *Artemia* and other zooplankton by *T. verticalis* has been noted in seasonal zooplankton dynamics in Farmington Bay (Marden and Richards 2017). The strong predatory effect makes the salinity tolerance of *T. verticalis* the clearest criteria for setting the lower optimal salinity range for GSL *Artemia*, and this is generally considered to be 90 g/L. However, the closely related *T. reticulata* survived in *Artemia*-producing evaporation ponds until 100 g/L (Herbst 2006). Furthermore, the salinity of the South Arm typically declines by 20 g/L during spring runoff, suggesting that this safety buffer should be applied to the 100 g/L corixid threshold for a lower optimal salinity range of 120 g/L.

Interspecific competition and phytoplankton assemblage shifts are additional factors. Filter-feeding rotifers and copepods that may compete with *Artemia* were also observed in Wurtsbaugh and Berry (1990). In other years, lower salinities have corresponded with shifts in GSL phytoplankton assemblages that may have been unfavorable to the *Artemia* population. A period of rising lake volume in the mid- to late-1990s lowered South Arm salinities to 76 g/L, and the phytoplankton assemblage shifted from dominance by *Dunaliella* to primarily centric and pennate diatoms (Stephens 1998), then co-dominance by diatoms and chlorophytes (GSLBSC unpublished) or perhaps cyanobacteria (Belovsky et al. 2011). Stephens (1998) hypothesized that the pennate diatoms may have been too large for the nauplii to consume, and *Artemia* cyst production was so poor during several of those years that the brine shrimp cyst harvest could not be opened on the South Arm in 1999.

GSLBSC monitoring data and published studies demonstrate that the upper salinity bound for GSL *Artemia* is far lower than the near-saturation range of the short-term survival studies cited herein. Osmoregulation becomes increasingly expensive from a metabolic standpoint as salinities increase, reducing energy available for reproduction and growth, and thereby reducing individual and population fitness well before the upper short-term survival salinity is reached. Following 13 years of continuous *Artemia* population monitoring on the South Arm and periodic measurements of the North Arm, a marked decline was revealed in *Artemia* densities above 160 g/L (Figure 5). A GSLBSC microcosm test produced similar results, with the survival of the test specimens declining sharply in treatments above 160 g/L by Day 22 (Figure 6). Other studies have demonstrated reduced survival (Dana and Lenz 1986, Wear and Haslett 1986, Triantaphyllidis et al. 1995) and reproduction (Dana and Lenz 1986, Browne and Wanigasekara 2000, Abatzopoulos et al. 2003) in the 150 to 170 g/L range for various *Artemia* populations. Decleir et al. (1980) determined the critical oxygen tension for *Artemia* occurred at 170 g/L, suggesting increasing oxygen stress at salinities above this. The convergence of results strongly suggests that the 160 g/L upper salinity bound would be protective of the GSL *Artemia* population and prevent the longer-term detrimental impacts of reduced fitness and reproduction that the short-term survival studies are unable to address.

The 120 g/L to 160 g/L optimal salinity range for GSL *Artemia* attempts to incorporate the complicated ecological processes and physiological stresses that underpin the intermediate salinity hypothesis and, by doing so, that protect the *Artemia* population. Salinities below 120 g/L risk predation, interspecific competition, and phytoplankton changes that have demonstrably harmed the *Artemia* population in the past. Salinities greater than 160 g/L risk increased metabolic costs, oxygen stress, and reduced reproduction that accumulate into long-term population impacts that are often missed by acute survival trials. The salinity range between provides the highest likelihood of a healthy *Artemia* population according to substantial information available from GSL and other *Artemia* biotopes.

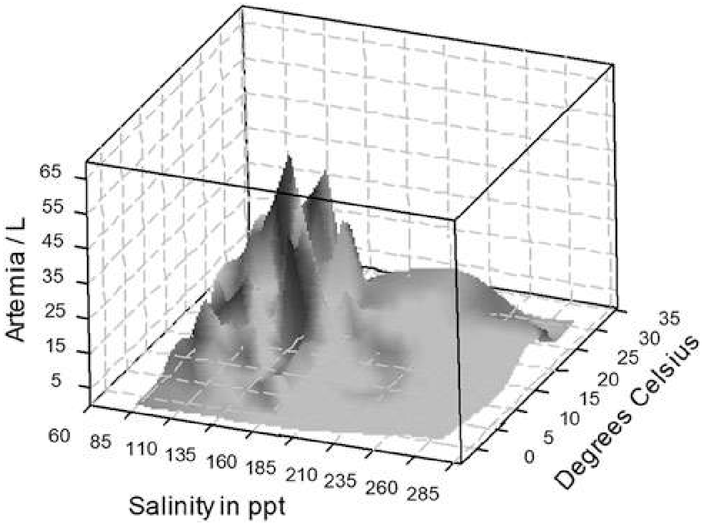


Figure 5. GSL *Artemia* Population Densities across Salinity and Temperature from GSLBSC Monitoring of the South and North Arms

The surface graph represents several thousand individual samples across 20 years.

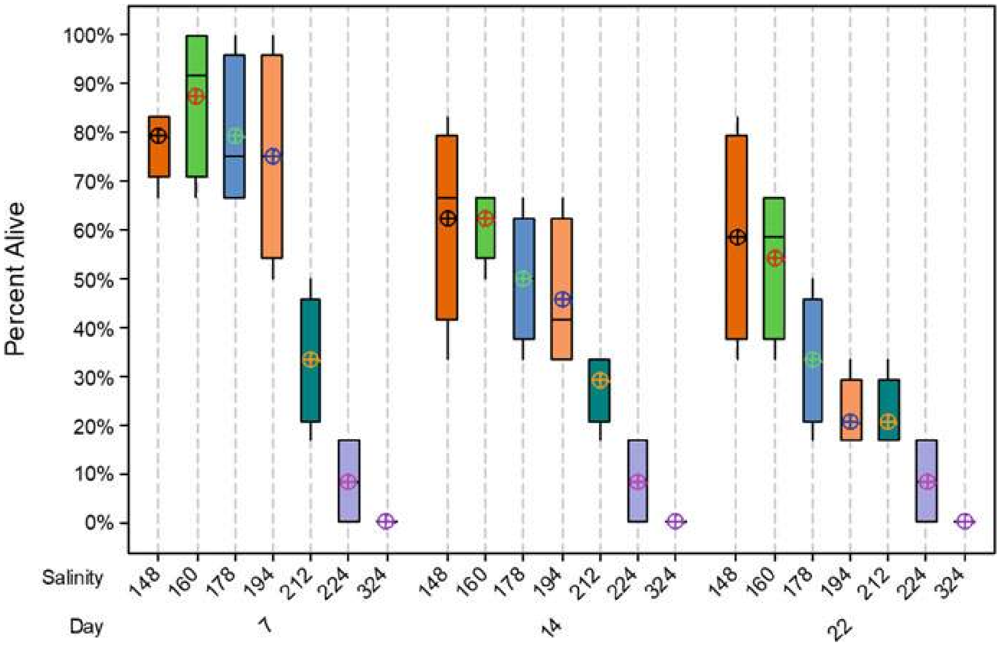


Figure 6. Microcosm Test Measuring GSL *Artemia* Survival across Salinity Treatments over a 22-day Course of Study

3.5 Corixids

Trichocorixa verticalis, also known as corixids or waterboatman, have a significant role in the foodweb of GSL. They exert predatory pressure upon *Artemia* and other zooplankton and serve as an important food source for birds at GSL (Belovsky et al. 2011, Céspedes et al. 2007, Marden and Richards 2017, Mellison 2000, Wurtsbaugh and Berry 1990, Wurtsbaugh 1992). They are most commonly found in the wetlands, littoral zones, and estuarine areas near freshwater inflows to GSL (Marden and Richards 2017, Mellison 2000). They were also observed in the open water of the South Arm (Gilbert Bay) during the high-water levels and lower salinities of the mid-1980s (Wurtsbaugh and Berry 1990, Wurtsbaugh 1992). The potential of *T. verticalis* to influence a trophic cascade in GSL make it important to consider the influence of lake salinity upon *T. verticalis.*

Salinity does appear to be a significant factor in the distribution of *T. verticalis* at GSL (Mellison 2000); however, their densities in GSL cannot be explained by any single environmental factor (Belovsky et al. 2011). Suitable prey, substrate type, water salinity and temperature, and the ability of *T. verticalis* to adapt all play a role in where they may be found (Mellison 2000, Keltz 1979). Each of these factors, as summarized here, make *T. verticalis* ideally suited to the highly dynamic and saline environment of GSL:

- The predatory role of *T. verticalis* is well-documented and has been described in this document. *T. verticalis* have been found to have a strong top-down control on *Artemia* juveniles and other zooplankton of GSL and other similar saline water bodies (Belovsky et al. 2011, Keltz 1979, Marden and Richards 2017, Wurtsbaugh and Berry 1990, Wurtsbaugh 1992) but are not likely the only explanation for observed brine shrimp population declines in the 1990s (Mellison 2000).

- Mellison (2000) found *T. verticalis* to prefer rock habitats over mud and vegetation habitats in Farmington Bay. Keltz (1979) found *T. verticalis* in high salt waters with silt substrates but they preferred floating algae habitats when available; this was posited as a means to avoid predation by birds, fish, and other invertebrates. Wurtsbaugh and Berry (1990) found *T. verticalis* in the open waters of the South Arm.

- *T. verticalis*' well-developed capability for osmoregulation and to hypo-regulate in saline water (Tones and Hammer 1975) provide them with a competitive advantage in the saline waters of GSL. *T. verticalis* have been found to thrive at salinities of between 2 and 6 percent salinity (Hammer et al. 1990, Mellison 2000) and have a maximum salinity tolerance of 9.0 percent (Hammer 1986). Lab experiments by Keltz (1979) found that salinities of 5.5 to 7.0 percent were lethal to all *T. verticalis* instars, with mortality most rapid at 7.0 percent salinity. Mellison (2000) found a sharp decline in *T. verticalis* numbers above 6.0 percent and few at 9.0 percent salinity. These salinity tolerance thresholds are also consistent with where and when they have been observed by others at GSL (Belovsky et al. 2011, Hayes 1971, Marden and Richards 2017, Wurtsbaugh and Berry 1990, Wurtsbaugh 1992).

- Keltz's laboratory studies (1979) found that *T. verticalis* generally had less tolerance for higher salinities at higher water temperatures but that the summer generation of *T. verticalis* was more tolerant of higher water salinity and temperature than the winter generation. This may help, in part, explain discrepancies in observations by Hayes (1971) and Mellison (2000) noting that *T. verticalis* at GSL are most frequently located in shallow waters where water temperatures are highest.

- Corixid eggs can survive hypersaline and frozen waters and desiccated conditions (Keltz 1979) and, thus, can survive the fluctuating water levels of GSL. *T. verticalis* typically exhibit two generations in a calendar year that often coincide with generations of *Artemia* in GSL. Overwintering corixid eggs typically hatch in the spring (April to May) and summer eggs hatch in the late summer (July to August) (Keltz 1979, Wurtsbaugh 1992).

- Uniquely among the zooplankton of GSL, *T. verticalis* can both swim, even to depths of 3.6 meters (m) (Wurtsbaugh and Berry 1990), and fly (Keltz 1979) to find suitable habitat and prey. Keltz (1979) found that while juvenile *T. verticalis* could only escape a stressed environment by swimming, adult *T. verticalis* could also fly to habitat they found more tolerable. Hayes (1971) similarly found that *T. verticalis* could fly between the more saline waters of Farmington Bay and surrounding brackish waters to find suitable prey.

3.6 Birds

Contributed by Brian Tavernia

Internationally and locally, the management of salinity is seen as important to supplying high-quality habitat for waterbirds, shorebirds, and waterfowl (Ma et al. 2010, Sorenson et al. 2018). Salinity directly and indirectly affects bird survival and reproduction. Direct effects may include increased energy cost associated with salt regulation (Gutiérrez et al. 2011, Gutiérrez et al. 2012), reduced immune response (Gutiérrez et al. 2013), weight loss due to saltwater intake (Hannam et al. 2003), and reduced feather insulation (Rubega and Robinson 1997, Jehl et al. 2012). Regarding indirect effects, salinity changes may affect plant cover, composition, and invertebrate food resources important to birds (Ma et al. 2010). For example, high salinity in shoreline, remnant, and playa wetlands associated with saline lakes promotes bare ground and mudflat areas favored by shorebirds (Sorenson et al. 2018).

Focusing on indirect effects is one possible approach to managing salinity for birds. Under this approach, salinity goals are based on the salinity tolerance limits and responses of cover and food habitat resources for birds. Thus, the underlying assumption is that, if one meets the salinity needs of habitat resources, one also meets birds' salinity needs. This approach does not address direct effects or the possibility of interactions between direct and indirect effects, and these omissions may have potentially detrimental effects on birds.

The following hypothetical example (Figure 7) conceptually illustrates the importance of accounting for direct effects. A bird species depends on an aquatic invertebrate as a primary food resource while at GSL, and its ability to capture and consume the invertebrate increases as invertebrates become more abundant. If one were managing salinity indirectly, the salinity management goal might be to maximize the abundance of the aquatic invertebrate

(Figure 7). However, as the invertebrate becomes more abundant with increasing salinity, the direct energetic cost (basal metabolic rate) of dealing with an additional salt load also increases. Such energetic costs might be due to physiological (e.g., salt glands) or behavioral (e.g., frequent trips to freshwater) responses by the birds. Thus, management considering direct and indirect effects would lead to an intermediate salinity goal different from the goal based on indirect effects only (Figure 7).

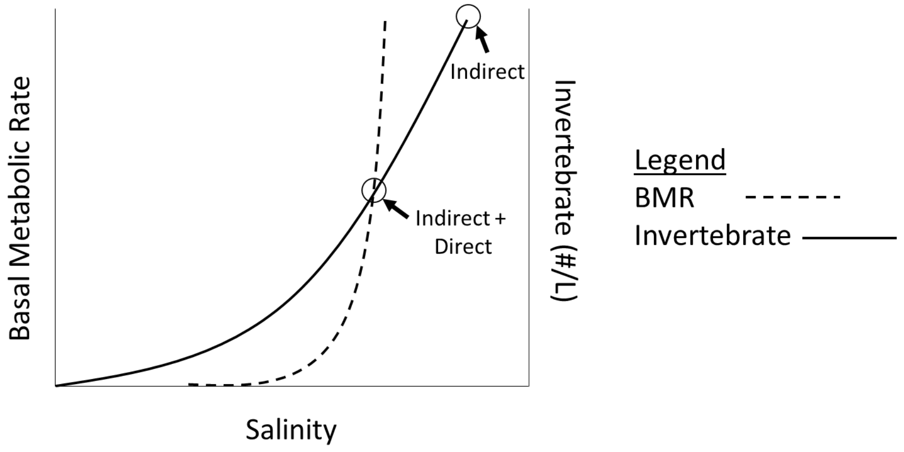


Figure 7. Hypothetical Effects of Salinity on Bird Basal Metabolic Rate and Aquatic Invertebrate Density.
This graphic illustrates the setting of salinity management goals based solely on indirect effects (invertebrate density) versus setting salinity management goals based on indirect and direct (basal metabolic rate) effects.

While it is ideal to consider both direct and indirect effects, data may be lacking to address immediately both effect categories when setting salinity management goals. In this case, indirect effects can be used to set salinity goals in the near term, and these goals can be updated as new research provides necessary data and information to address and incorporate direct effects.

3.7 Fish

Fish are often assumed to be completely absent in GSL (Utah.com 2021) because of its salinity. This assumption, however, does not account for the historical variability of salinity in the South Arm or the lower salinities found in Bear River Bay and Farmington Bay as a result of freshwater inflows. Fish can survive and have been observed in areas of the lake with salinities as high as 4 percent but more frequently when salinities are less than 1 percent:

- Fish were observed on one occasion in the South Arm in 1986 when lake water levels were at their historical high and salinities were less than 5.5 percent. Rainwater killifish (*Lucania parva*), only about 1 inch in length, were observed in the South Arm near Stansbury Island where the salinity was approximately 4 percent. They were thought to have been introduced by inflows from the Timpie Springs Waterfowl Management Area and had found the salinity in the South Arm tolerable enough to breed (Associated Press 1986).

- More recent studies in Willard Spur of Bear River Bay (Penne 2012a; Penne 2012b; Moore 2011) confirmed that several species of fish were present including common carp (*Cyprinus carpio*), Utah chub (*Gila atraria*), black bullhead (*Ameiurus melas*), yellow perch (*Perca flavescens*), black crappie (*Poxomis nigromaculatus*), channel catfish (*Ictaluris punctatis*), and gizzard shad (*Dorosoma cepedianum*). Willard Spur's location above an approximate elevation of 4201.8 feet (NVGD 29) has made it largely a freshwater ecosystem since 2002 (CH2M HILL 2016). All fish species were found to be present in the Willard Bay outflow channel on the eastern side of Willard Spur (salinities of less than 5 g/L [Ostermiller and Hooker

2015]) with only the common carp and Utah chub found in the main body of Willard Spur (salinities of less than 10 g/L [Ostermiller and Hooker 2015]).

- The Utah Division of Wildlife Resources completed a fish survey in Bear River Bay, Willard Spur, and Farmington Bay in 2020 (unpublished data, Edwards 2021). Common carp, Utah chub, channel catfish, gizzard shad, and black bullhead were found downstream of the Bear River Migratory Bird Refuge in Bear River Bay. Common carp, Utah chub, channel catfish, gizzard shad, black bullhead, Striper X White Bass, and black crappie were found in Willard Spur. Only common carp and Utah chub were found in the open water of Farmington Bay. All fish were found at estimated salinities of less than 22 g/L, with the vast majority of fish found at estimated salinities of less than 5 g/L (unpublished data, Edwards 2021).

3.8 Vegetation

Contributed by Heidi Hoven

Vegetation (or lack thereof) in and along GSL's shoreline is best characterized by soil salinity as influenced by salt deposited by Lake Bonneville and GSL flooding events and subsequent leaching by freshwater flows and precipitation. Shorebird mudflat habitat is associated with water flowing through GSL bays such as Farmington Bay and Bear River Bay as well as wetlands associated with GSL along its fringes. Although the lake is in a probable long-term decline, separating the lake level further and further from its shoreline, the salt deposits it has left behind will influence vegetation for the long term as well. Salt is a key component to controlling the vegetative species and abundance in wetlands of the lake. Exceptions to the influence of salt on wetland habitat are, of course, where managed wetlands have flushed salts from the system or along the upper reaches of tributaries and drainages onto the lake's shores. The following characterizes soil salinities in the various shorebird habitat niches around the lake (as described by Sorensen et al. 2020, with soil salinity ranges added from other literature):

- Unvegetated mudflat zone: 5 to 20% soil salinity (Flowers 1955; and Vest 1962) as summarized in Bradbury and Parrott (2020)
- Pickleweed zone: 3 to 6.5% soil salinity (sodium chloride dominant, Flowers and Evans 1966)
- Saltgrass zone: up to 2.5% soil salinity (sodium chloride dominant, Flowers and Evans 1966)
- Sedges and alkali bulrush zone: 30 to 60 mmhos at 30 to 40 centimeters (cm) in the sediment, only intermittently flooded (Kadlec 1982)

However, shorebirds are not only queuing in on plant cover. Water depth and available macroinvertebrates as described by Sorensen et al. (2020) are important additional factors that define shorebird habitat of Great Salt Lake.

Habitat for waterfowl and wading birds is somewhat different, in that they are also accessing open waters. The following characterizes sediment or water salinities in these preferred habitats:

- Dominated by hardstem bulrush, cattail, alkali bulrush or Phragmites continuously flooded during the growing season: 4 to 16 mmhos at 30 to 40 cm in the sediment (Kadlec 1982)
- Dominated by salt grass, alkali bulrush, (Phragmites, or cattail to a lesser extent) only intermittently flooded: 30 to 60 mmhos at 30 to 40 cm in the sediment (Kadlec 1982)

- Sago pondweed optimum range: Cl- and SO_4 dominated waters is 3 to 6 g/L and 2 to 15 g/L, respectively (Jensen 1940; Stewart and Kantrud 1972; and Millar 1976 in: Kantrud 1990) (water column salinity)

- Ruppia-dominated communities' optimum range in SO_4- dominated waters: greater than 26 g/L (water column salinity) (Stewart and Kantrud 1972; in: Kantrud 1990)

3.9 Mineral Extraction

Contributed by Tom Tripp

There are multiple mineral extractors currently operating on GSL with only one extractor operating on the North Arm. All mineral extractors on the lake bring lake water into a solar evaporative system and increase the concentration to some level of saturation where salts will be precipitated. For some extractors, their desired solar evaporation will only go to a point where sodium chloride is being precipitated to the pond floor. The other extraction companies, including US Magnesium, will go beyond that first precipitation targeting different salts or concentrated brines.

The extracted minerals are derived from the dissolved ionic species that naturally exist in GSL water. A company's production capacity is in part limited by "solar evaporation capacity" that is partially defined by evaporative area and the summertime climatic conditions. The other component of solar evaporation capacity is the inlet brine concentration—the dissolved mineral content in the lake water. Lower than "normal" mineral concentrations in the starting brine result in lower than normal production capacity, given a fixed evaporative pond area and normal weather patterns.

For production capacity, a mineral extractor will prefer the maximum available concentration, but there are some limitations on that maximum based on systems available to protect the solar ponding pumping equipment. Pumping saturated brine requires the ability to deal with ongoing salt precipitation. Saturated brines will coat all wetted components of the pumping system. The usual protection method is to "desalt" pumps and pipelines by periodically flushing them with unsaturated water or brines. Failure to flush pumps will result in problems with pump impeller imbalances that will lead to early bearing failures and other physical damage to pumps. Most of the inlets pumping areas for GSL mineral extraction are remote with only limited water resources. (There are some exceptions where flush water may be available to mineral extractors.) This salt coating problem is a key consideration when trying to determine an optimum inlet brine concentration.

In US Magnesium's situation on the South Arm, the preferred salinity for inlet brine for the lake is just short of sodium chloride saturation or about 0.8 to 0.9% magnesium. Compass Minerals' operation on the North Arm also prefers salinities just short of sodium chloride saturation, or near 2% potassium. In these cases, lake brine (lake water) can be brought into the solar evaporation ponds without a need to do water flushing to desalt pumps. The current lake water magnesium and potassium content is about half of that preferred target concentration.

In summary, extractors generally prefer the highest concentration they can handle. Lower salinities or concentrations can limit production unless the "solar evaporative capacity" is increased by adding additional evaporation area (additional mineral leases) and pumping capacity to maintain production. Note that a declining lake to very low levels is also an important factor requiring significant investment to maintain production.

Salinities indicated in the GSL Salinity Matrix (Appendix A) as green generally illustrate ideal conditions, where production has been maintained and further investments in infrastructure have not been required. Salinities indicated by yellow illustrate salinities that have occurred since 2011 and that have required mineral extractors to make additional investments or reductions in production. Salinities indicated by orange illustrate salinities that may require extractors to make new investments or result in reductions in production. Salinities indicated by red illustrate salinities that are unprecedented for the mineral extractors and likely represent significant impacts to their operation.

4. Conclusions

The SAC developed the GSL Salinity Matrix (Figure 1 and Appendix A) to illustrate the important influence salinity has upon the wide variety of uses of GSL. The matrix illustrates our current understanding of how each use can adapt and has adapted to change. GSL is a harsh environment; however, the organisms that use GSL are adapted to that environment. The matrix illustrates how the uses are tightly interwoven; they are closely dependent upon each other and upon the lake's water level and salinity. A change in one element of the ecosystem has a rippling effect throughout the system. An adaptation of one trophic level likely requires an adaptation in others. The complexity of these interdependencies is what has made GSL such a unique, thriving, and resilient ecosystem and benefit to industry, recreational users and the communities within its watershed. As a result, the matrix also illustrates that the salinity of GSL cannot be managed to a singular value or threshold. The lake's salinity is very dynamic and has varied, does vary, and will vary spatially and temporally.

However, even as GSL adapts to change, the Salinity Matrix also illustrates how an induced change(s), intentional or unintentional, upon the system could have consequential impacts. Changes that happen too quickly or at too large of scale, or that make up a new long-term trajectory can inflict costs to the system. The potential for these impacts is what must be understood to enable well-informed decisions. The GSL Salinity Matrix will provide decision-makers with an important illustration, not to predict how GSL's salinity will change, but to illustrate the potential consequences of a salinity change.

5. Recommendations

The SAC voted unanimously to recommend that a salinity range of 120 to 160 g/L is most protective of the beneficial uses in the South Arm.

The SAC makes the following recommendations to further advance development of the GSL Salinity Matrix:

1. Cross-reference the GSL Salinity Matrix with the GSL Aquatic Life Use Resident Taxa Summary prepared with the Utah Division of Water Quality and U.S. Environmental Protection Agency in 2016 (Horsely Witten Group 2016).

2. Expand upon the current review of literature describing how salinity influences the various uses of GSL. The intent is to continue to improve the accuracy and deepen our understanding of the potential consequences of changing lake salinity.

3. Compare the GSL Salinity Matrix to results from the Division of Wildlife Resources' ecological model of GSL. Are similar patterns observed in the results of the model for changing lake salinity?

4. Compare results of forecasted changes in the water and salt balance of GSL to the GSL Salinity Matrix.

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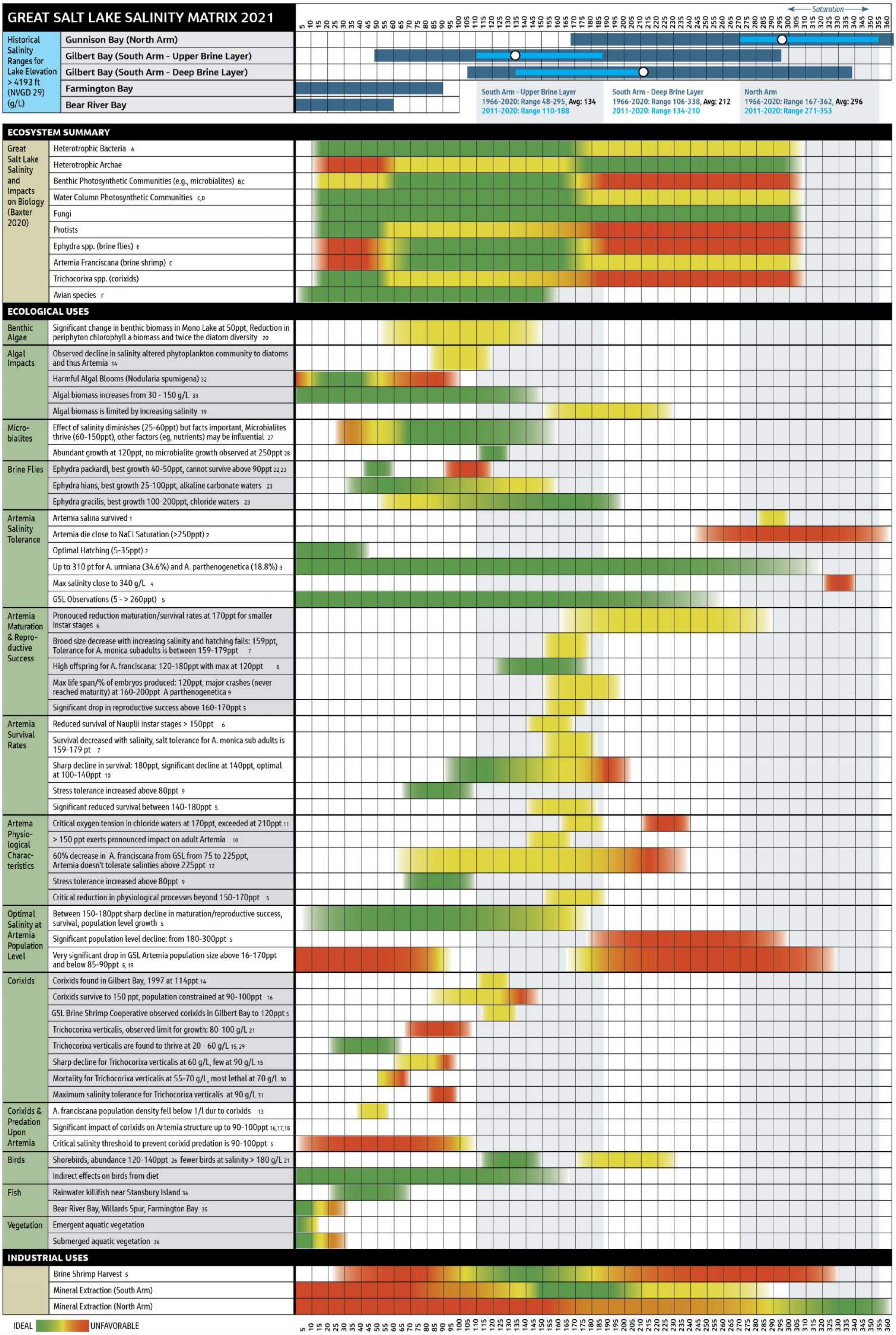
Attachment A

GREAT SALT LAKE SALINITY MATRIX 2021



Historical Salinity Ranges for Lake Elevation > 4193 ft (NVGD 29) (g/L)

- **Gunnison Bay (North Arm)**
- **Gilbert Bay (South Arm - Upper Brine Layer)**
- **Gilbert Bay (South Arm - Deep Brine Layer)**
- **Farmington Bay**
- **Bear River Bay**

South Arm - Upper Brine Layer
1966-2020: Range 48-295, Avg: 134
2011-2020: Range 110-188

South Arm - Deep Brine Layer
1966-2020: Range 106-338, Avg: 212
2011-2020: Range 134-210

North Arm
1966-2020: Range 167-362, Avg: 296
2011-2020: Range 271-353

ECOSYSTEM SUMMARY

Great Salt Lake Salinity and Impacts on Biology (Baxter 2020)

- Heterotrophic Bacteria A
- Heterotrophic Archae
- Benthic Photosynthetic Communities (e.g., microbialites) B,C
- Water Column Photosynthetic Communities C,D
- Fungi
- Protists
- Ephydra spp. (brine flies) E
- Artemia Franciscana (brine shrimp) C
- Trichocorixa spp. (corixids)
- Avian species F

ECOLOGICAL USES

Benthic Algae

- Significant change in benthic biomass in Mono Lake at 50ppt, Reduction in periphyton chlorophyll a biomass and twice the diatom diversity 20

Algal Impacts

- Observed decline in salinity altered phytoplankton community to diatoms and thus Artemia 14
- Harmful Algal Blooms (Nodularia spumigena) 32
- Algal biomass increases from 30 - 150 g/L 33
- Algal biomass is limited by increasing salinity 19

Micro-bialites

- Effect of salinity diminishes (25-60ppt) but facts important, Microbialites thrive (60-150ppt), other factors (eg, nutrients) may be influential 27
- Abundant growth at 120ppt, no microbialite growth observed at 250ppt 28

Brine Flies

- Ephydra packardi, best growth 40-50ppt, cannot survive above 90ppt 22,23
- Ephydra hians, best growth 25-100ppt, alkaline carbonate waters 23
- Ephydra gracilis, best growth 100-200ppt, chloride waters 23

Artemia Salinity Tolerance

- Artemia salina survived 1
- Artemia die close to NaCl Saturation (>250ppt) 2
- Optimal Hatching (5-35ppt) 2
- Up to 310 pt for A. urmiana (34.6%) and A. parthenogenetica (18.8%) 3
- Max salinity close to 340 g/L 4
- GSL Observations (5 - > 260ppt) 5

Artemia Maturation & Repro-ductive Success

- Pronouced reduction maturation/survival rates at 170ppt for smaller instar stages 6
- Brood size decrease with increasing salinity and hatching fails: 159ppt, Tolerance for A. monica subadults is between 159-179ppt 7
- High offspring for A. franciscana: 120-180ppt with max at 120ppt 8
- Max life span/% of embryos produced: 120ppt, major crashes (never reached maturity) at 160-200ppt A parthenogenetica 9
- Significant drop in reproductive success above 160-170ppt 5

Artemia Survival Rates

- Reduced survival of Nauplii instar stages > 150ppt 6
- Survival decreased with salinity, salt tolerance for A. monica sub adults is 159-179 pt 7
- Sharp decline in survival: 180ppt, significant decline at 140ppt, optimal at 100-140ppt 10
- Stress tolerance increased above 80ppt 9
- Significant reduced survival between 140-180ppt 5

Artema Physio-logical Charac-teristics

- Critical oxygen tension in chloride waters at 170ppt, exceeded at 210ppt 11
- > 150 ppt exerts pronounced impact on adult Artemia 10
- 60% decrease in A. franciscana from GSL from 75 to 225ppt, Artemia doesn't tolerate salinities above 225ppt 12
- Stress tolerance increased above 80ppt 9
- Critical reduction in physiological processes beyond 150-170ppt 5

Optimal Salinity at Artemia Population Level

- Between 150-180ppt sharp decline in maturation/reproductive success, survival, population level growth 5
- Significant population level decline: from 180-300ppt 5
- Very significant drop in GSL Artemia population size above 16-170ppt and below 85-90ppt 5,19

Corixids

- Corixids found in Gilbert Bay, 1997 at 114ppt 14
- Corixids survive to 150 ppt, population constrained at 90-100ppt 16
- GSL Brine Shrimp Cooperative observed corixids in Gilbert Bay to 120ppt 5
- Trichocorixa verticalis, observed limit for growth: 80-100 g/L 21
- Trichocorixa verticalis are found to thrive at 20 - 60 g/L 15,29
- Sharp decline for Trichocorixa verticalis at 60 g/L, few at 90 g/L 15
- Mortality for Trichocorixa verticalis at 55-70 g/L, most lethal at 70 g/L 30
- Maximum salinity tolerance for Trichocorixa verticalis at 90 g/L 31

Corixids & Predation Upon Artemia

- A. franciscana population density fell below 1/l dur to corixids 13
- Significant impact of corixids on Artemia structure up to 90-100ppt 16,17,18
- Critical salinity threshold to prevent corixid predation is 90-100ppt 5

Birds

- Shorebirds, abundance 120-140ppt 26 fewer birds at salinity > 180 g/L 21
- Indirect effects on birds from diet

Fish

- Rainwater killifish near Stansbury Island 34
- Bear River Bay, Willards Spur, Farmington Bay 35

Vegetation

- Emergent aquatic vegetation
- Submerged aquatic vegetation 36

INDUSTRIAL USES

- Brine Shrimp Harvest 5
- Mineral Extraction (South Arm)
- Mineral Extraction (North Arm)

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1 Croghan 1957
2 Sorgeloos et al , 1986, Lavens and Sorgeloos 1996
3 Mohammadi et al 2009
4 Gonzalo and Beardmore 2012
5 Bosteels 2012
6 Wear et al. 1986
7 Dana and Lenz 1986
8 Browne & Wanigasekera 2000
9 Abatzopoulos et al 2003
10 Triantaphyllidis et al 1995
11 Decleir et al 1980
12 Barnes and Wurtsbaugh 2015
13 Wurtsbaugh and Berry 1990
14 Stephens 1998
15 Mellison 2000
16 Herbst 2006
17 DeMeutter et al 2010
18 Tanner et al 2014
19 Belovsky et al 2011
20 Herbst and Blinn 1998
21 Herbst 2006
22 Ping 1921
23 Herbst 1999
24 Por 1980
25 Harbst 2001
26 Warnock et al 2002
27 Anderson et al 2020
28 Lindsay et al 2017
29 Hammer et al 1990
30 Kertz 1979
31 Hammer 1986
32 Jacobs 2018
33 Belovsky 2005
34 Associated Press 1986
35 Penne 2012, Edwards 2021
36 Steward and Kantrud 1972, Kantrud 1990

A. Includes potentially harmful cyanobacterial blooms, but only at the 10-50 ppt salinity range
B. Microbialite-associated
C. Includes both bacterial and eukaryotic photosynthesizers
D. Dunaliella salina and Tetracystis spp are prevalent in the north arm, no evidence of other eukaryotic algae, so diversity is limited.
E. Predation by Trichocorixa spp. at lower salinities
F. Avian diets are particular to the species and will be tied to the success of their food source, which is controlled by salinity. The high salinities provide little in food source, but much in protection (e.g. American White Pelican colony on Gunnison island), which is tied to lake level and not salinity.

All data cited in: Baxter, B.K and Butler, J.K., Eds. Great Salt Lake Biology: A Terminal Lake in a Time of Change. Springer, Cham, 2020.

GSL SALINITY ADVISORY COMMITTEE

Appendix D. Upland Trench Conveyance Concept

General Notes:

1. New intake trench to extend to lake bottom elevation of 4185.0 (NGVD 29)

2. Extent of current US Magnesium lease area

3. New pumping station required, located above OHWM

4. Pressurized pipe to extend from pump station, under Rambo Bridge, and discharge along topographical ridge @ elevation 4203.0 (NGVD 29)

5. Open channel conveyance, approx 40 ft bottom width

6. Proposed pump station required to pump around topographical high point. Additional pump stations along alignment have not been evaluated, but likely needed.

7. Approximately 25 miles from Pump Station 1 to Existing Point of Diversion/Pump Station

Legend

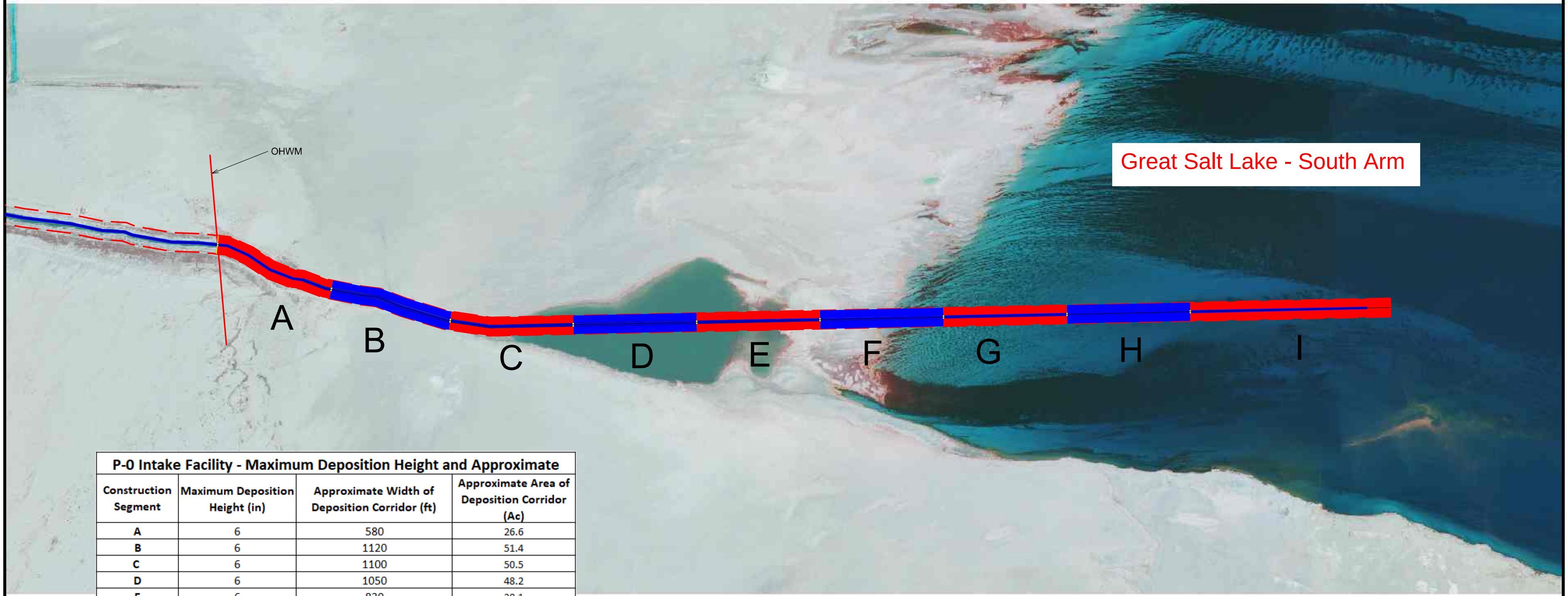
—	Bathymetric Contour
🟨	US Mag Lease Area

1 inch = 3,000 feet

Upland Trench Conveyance Concept

PRELIMINARY

Appendix E. Deposition Depth Tables and Exhibits

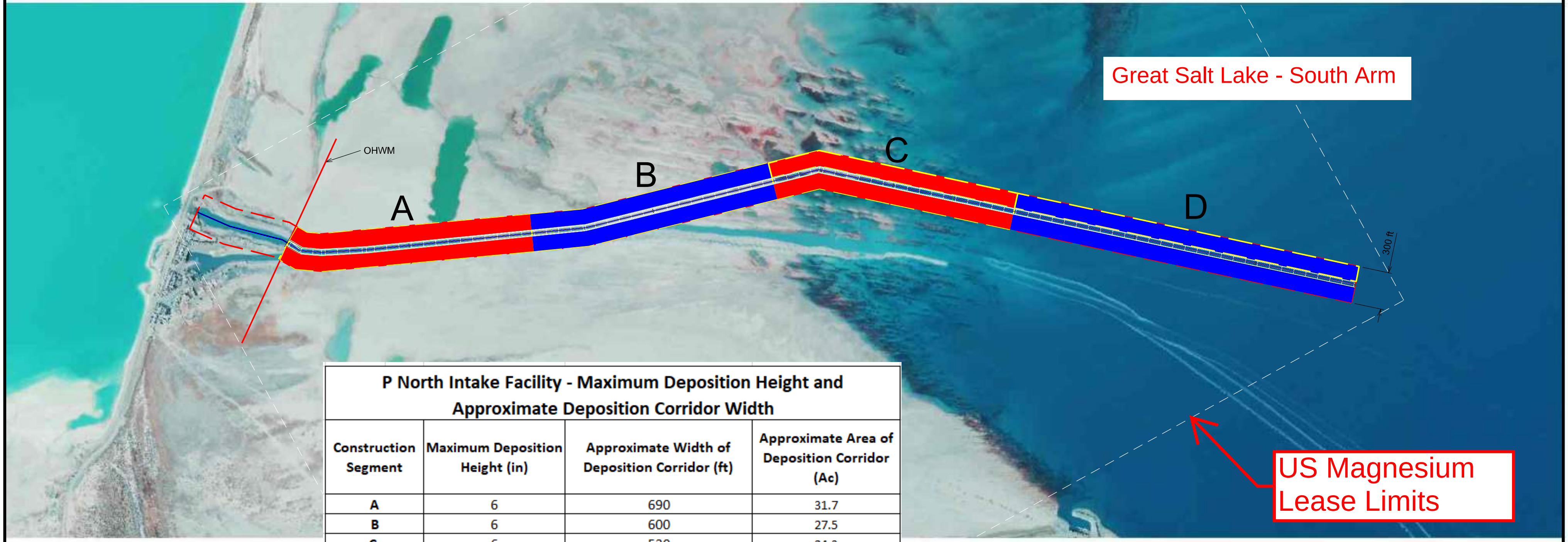


P-0 Intake Facility - Maximum Deposition Height and Approximate

Construction Segment	Maximum Deposition Height (in)	Approximate Width of Deposition Corridor (ft)	Approximate Area of Deposition Corridor (Ac)
A	6	580	26.6
B	6	1120	51.4
C	6	1100	50.5
D	6	1050	48.2
E	6	830	38.1
F	6	625	28.7
G	6	555	25.5
H	6	390	17.9
I	6	228	10.5

P-0 Construction Segments

P-0 Intake Facility



P North Intake Facility - Maximum Deposition Height and Approximate Deposition Corridor Width

Construction Segment	Maximum Deposition Height (in)	Approximate Width of Deposition Corridor (ft)	Approximate Area of Deposition Corridor (Ac)
A	6	690	31.7
B	6	600	27.5
C	6	530	24.3
D	6	220	10.1

P North Construction Segments

P North Intake Facility

Appendix F. USACE Technical Note TN-19-1

ERDC TN-19-1
February 2019

Thin Layer Placement: Technical Definition for U.S. Army Corps of Engineers Applications

By Jacob. F. Berkowitz, Candice Piercy, Tim Welp, and Christine VanZomeren

PURPOSE: The following document provides a technical definition of thin layer placement (TLP) activities for U.S. Army Corps of Engineers (USACE) applications. A discussion of the development, history, and examples of TLP applications are also provided.

BACKGROUND: Sediments are routinely intentionally placed into the environment to achieve beneficial outcomes, including beach nourishment, wetland creation, and other activities (Landin et al. 1989; USACE 2015; National Research Council 1995). Many publications and reports document the beneficial use of sediment, including dredged materials, to support infrastructure and enhance ecological outcomes (Yozzo et al. 2004; USEPA and USACE 2007; Faulkner and Poach 1996). Recently, increasing interest has focused on the placement of dredged sediments in thin layers; this provides opportunities for sediment management, beneficial use of dredged material, and ecological restoration or enhancement (Wilbur et al. 2007; Smith and Niles 2016; Berkowitz et al. 2017). Several terms associated with TLP appear in literature (Table 1), highlighting the need for further discussion of the topic and a definition specific to USACE applications.

Table 1. Terms associated with TLP within available literature

Term	Source
Artificial sediment enhancement	La Peyre et al. 2009
Thin layer placement	USACE, others
Thin layer deposition	Ford et al. 1999
Sediment subsidy	Mendelssohn and Kuhn, 2003
Sediment slurry application/addition/amendment	Schrift et al. 2008
Sediment enrichment	Slocum et al. 2005
Thin layer sediment renourishment	Croft et al. 2008
Thin layer disposal	USACE, others
Marsh Nourishment	CPRA 2018

BENEFITS OF TLP: In the late 1970s, practitioners began investigating potential benefits of thin layer sediment applications (Reimold et al. 1978). The application of thin layers of sediment may have advantages over traditional, thicker sediment placement applications in a variety of environments where thicker layers of sediment pose potential challenges to natural resources, infrastructure, navigation, or other assets. For example, a number of reports document the benefits of thin layer sediment applications such as increased marsh elevation, improved soil stability, and enhancement of wetland functions while maintaining characteristic plant communities (Figure 1) (DeLaune et al. 1990; Mendelssohn and Kuhn 2003). Several studies document the benefits of TLP applications to marsh vegetation, with common wetland plants (e.g., *Spartina alterniflora*) displaying the capacity for rapid recovery following the deposition of a 0 – 30 cm thick layer of sediment. In some cases, the placement of thicker layers of sediment may smother established marsh vegetation, highlighting the benefits of using TLP in some contexts, compared to traditional placement approaches (Riemold et al. 1978). Ray (2007) provides a review of TLP projects conducted in coastal wetlands; however, thin layer applications have occurred in other contexts including open water placement.

Figure 1. Thin Layer Placement (TLP) of sediment in marsh environments (left) are designed to increase marsh elevation and prevent subsidence, while allowing vegetation to recover (right). Photo credits: Tim Welp (left) and Christine VanZomeren (right).

Open water applications, including TLP on bay bottoms, maintain sediment supplies within the system while enhancing benthic communities (Parson et al., 2015). For example, Wilbur (2007) reported that open water TLP applications resulted in enhanced benthic recovery following dredged material placement at a water depth of approximately 20 m. Others applied TLP to provide supplementary sediment in support of existing infrastructure. This approach was utilized as part of the Mouth of the Columbia River (MCR) Regional Sediment Management Plan, in which the TLP addressed littoral sediment needs by placing sediments to reduce scour along jetties, while avoiding potential negative impacts to navigation safety (e.g., mound elevations) and smothering of biological resources (e.g., fish and crabs) (Figure 2; Portland State University 2016; Roegner and Fields 2014). Alternatively, the practice of capping contaminated sediments with a relatively thin layer of clean dredged material in shallow water at a thickness on the order of the mixing depth of benthic activity may also be referred to as thin layer placement or thin layer capping (Merritt et al. 2010). The use of TLP achieved project objectives while avoiding potential negative impacts to benthic species associated with thicker sediment deposition techniques.

Figure 2. Benthic sled images of fish, worms, and crab emerging from sediment following an open water TLP application within the littoral zone (reproduced from Roegner and Fields 2014).

TLP CHALLENGES: While TLP has proven useful in wetland, subtidal, and open water contexts across the U.S., the wide variety of application methods and project objectives complicate defining the TLP concept (Table 2). Additionally, the ability to obtain a specific TLP thickness or target elevation remains limited by placement technique, equipment, project objectives, and other factors. Specifically, the thickness of material placed by a dredge is a function of the type of dredge equipment being used, how it is being operated, placement site conditions, and dredged material physical characteristics (e.g., dispersion or consolidation potential).

Table 2. Examples of TLP project locations, application methods, habitats, and placement depths. Note that TLP applications utilized discreet thicknesses ranging from 0–36 cm, or an unspecified target elevation based upon project objectives. *

Location	Application method or equipment	Receiving habitat	Depth (cm)	Citation
Barataria Basin, LA	Manual spreading	Marsh	2–5	DeLaune et al. 1990
Bayou Lafourche, LA	Low pressure discharge	Marsh	13–36	Schrift et al. 2008
Blackwater NWR, MD	High pressure discharge	Marsh	Target elevation	Nemerson 2007
Blackwater NWR, MD	High pressure discharge	Shallow open water	Target elevation	Nemerson 2007
Coos Bay, OR	Mechanical spreading	Diked marsh	Target elevation	Cornu and Sadros 2002
Delaware Day, NJ	High pressure discharge	Diked marsh	Target elevation	Weinstein and Weishar 2002

Location	Application method or equipment	Receiving habitat	Depth (cm)	Citation
Fortescue, NJ	Low pressure discharge	Marsh	Target elevation	Dredging Today 2016
Galveston Bay, TX	Hydraulic cutterhead dredge	Open water; subtidal	7.5–20	Sallese 2012
Masonboro Island, NC	Low pressure discharge	Marsh	0–10	Croft et al. 2006
Mississippi Sound, MS	Hydraulic cutterhead dredge	Open water; subtidal	15	Wilber et al. 2007
Mobile Bay, AL	Spill barge	Open water; subtidal	< 30	USACE 2014
Narrow River, RI	Mechanical spreading	Marsh	10–15	USFWS 2014a
Pepper Creek, DE	High pressure discharge	Marsh	0–20	Wilson 2013
Portland, OR	Hopper dredge	Open water; subtidal	5–6.8	Roegner and Fields 2015
Sachuest Point, RI	Mechanical spreading	Marsh	2.5–30	Center for Ecosystem Restoration 2015
Seal Beach, CA	High pressure discharge	Marsh	25	USFWS 2014b
Venice, LA	High pressure discharge	Marsh	2.3 ± 0.5	Ford et al. 1999
Venice, LA	High pressure discharge	Shallow open water	11.6 ± 1.1	Ford et al. 1999
Venice, LA	Low pressure discharge	Marsh	0–30	Mendelssohn and Kuhn 2003
Vermillion Parish, LA	Low pressure discharge	Marsh	0–20	Graham and Mendelssohn 2013

* Hydraulic low pressure discharge (modified after Cahoon and Cowan, 1987) consists of an open-ended discharge pipe that is generally equipped with a diffuser (or spreader plate); a device placed to slow the velocity of slurry to provide better control over point placement and/or reduce impacts to wetland surfaces or in the water column. Hydraulic high pressure discharge involves the use of a contraction section at the pipeline outlet (typically a nozzle) that increases the slurry's exit velocity such that the resultant jetting action propels the slurry in an arc-shaped pattern (some literature sources refer to high pressure discharge applications as “rainbowing”; see Figure 1).

The engineering behavior and physical characteristics of dredged material vary with grain size distribution, organic matter content, mineralogy, and bulk density. In situ sediment is mixed with water in varying proportions, depending on the type of dredging equipment used. For example, mechanical dredges (e.g., clamshell bucket and backhoe) excavate material with near in situ density, while hydraulic pipeline dredging (e.g., cutterhead dredges) typically generate a dredged material slurry with solids content of approximately 15% by weight. During placement activities, a mechanically dredged, unconsolidated, fine-grained material being released from a dump scow in open water could result in a sediment layer thickness of less than 30 cm, representing a TLP application. However, that same barge filled with a sand-dominated sediment could result in >200 cm thick layers of material placed over them same area, eliminating such applications from the TLP by concept. Further, a hydraulically dredged sediment slurry will separate during placement, depositing coarse grained sediment in the immediate vicinity of the discharge point, while the fine-grained sediment spreads and flows further distances (Kungchum et al. 2017).

Therefore, the deposition layer thickness remains a function of hydraulic sorting processes, including the distance from the discharge location, duration of discharge and quantity of sediment, site topography or containment structure(s), and the density of the deposited material. These factors, along with the variety of project objectives, placement environments, and application techniques, pose challenges to establishing a concise, comprehensive TLP definition. As a result, a review of existing literature was conducted to identify key components defining TLP and synthesize those components related to USACE applications.

DEFINING TLP: Defining TLP promotes clarity for practitioners and the public regarding sediment applications. Additionally, the development of a comprehensive definition provides an opportunity to distinguish TLP from other sediment placement practices, since TLP includes unique application thicknesses, placement techniques, and outcomes (Wilbur 1992; Ray 2007). However, a number of TLP definitions appear in the literature, resulting in confusion regarding the classification and communication of the application, potential benefits, and limitations of this technique. For example, Wilbur (1992) defined TLP as follows:

> "Any disposal of dredged material involving the purposeful, planned placement of material at thicknesses that are generally believed to either greatly reduce the immediate impacts to biota or greatly hasten the recruitment of native biota to the material without transforming the habitat's ecological function."

This definition contains several valuable elements, including the fact that TLP activities should remain purposeful and consider potential impacts and benefits to natural resources. However, as written, the definition specifies that TLP applications involve dredged material, potentially excluding other source materials. Additionally, the usage of the term "disposal" has declined in recent years as the scientific community and the public increasingly view dredged materials as a beneficial resource.

LaPeyre et al. (2006) provides the following definition for TLP activities in a marsh nourishment centric context:

> "A relatively new restoration strategy that can refer to either the direct placement of a thin-layer of sediment through spray or hydraulic dredging or from the "spilling" of a thin-layer of sediment over marsh that is adjacent to an uncontained restoration project."

This definition also includes several important components, including the potential of TLP to support restoration. However, the definition limits TLP applicability to a particular technique (e.g., spray application) and purpose (e.g., marsh restoration).

The USACE Engineer Research and Development Center (ERDC) Dredging Operations Technical Support (DOTS) program has conducted several TLP-related activities, including the development of a website highlighting TLP concepts, pilot projects, and associated literature (*http://tlp.el.erdc.dren.mil/*). That resource contains the following definition:

"Thin Layer Placement broadly encompasses the purposeful placement of sediment or dredged material in a manner that produces a specific layer thickness or ground surface elevation necessary to achieving the overall project objectives. In TLP projects, the layer thickness typically ranges from a few centimeters to some fraction of a meter, depending upon the variation in ground surface or water levels at the site, and the functional objectives the placement is intended to achieve."

This definition contains many of the positive elements identified by Wilbur (1992), Ray (2007), LePeyre (2006) and others. Additionally, it incorporates the concept of a target elevation as opposed to the sole criterion of a placed thickness.

The following list highlights important components of a comprehensive TLP definition:

- TLP sediment applications should be purposeful.
- TLP sediments should not be limited to dredged material sources.
- TLP projects can support infrastructure objectives.
- TLP activities should be environmentally acceptable.
- TLP projects provide opportunities to create, maintain, enhance, and/or restore ecological function.
- The TLP definition should not specify particular layer thickness or application techniques.
- The term "disposal" should not be incorporated into the TLP definition.

Based on these factors and the previously completed work on the topic, a TLP definition was developed for USACE applications (provided below). This definition incorporates the desirable qualities of prior studies, while making the definition more inclusive and comprehensive to support the wide array of TLP projects being conducted (e.g., open water and marine placement activities). Additionally, the TLP definition may require periodic updates based upon new scientific information and/or advances in TLP practices. Further sub-categorization to address specific types of TLP activities (e.g., marsh vs. open water applications) may be required. Note that the definition is designed to be comprehensive, and intentionally does not specify a threshold thickness. This allows for flexibility based upon habitat (e.g., marsh surface, open water) and project objective (e.g., increase elevation, supplement sediment supply). For example, during marsh nourishment, TLP thickness thresholds are typically dictated by the capacity for vegetation to penetrate the applied sediment layer (Berkowitz et al. 2017). Similarly, in open water settings, TLP thickness may be limited by the ability of benthic organisms to avoid permanent burial (Roegner and Fields 2014). As a result, practitioners should determine and document specific TLP thickness thresholds based upon project specific objectives and site conditions.

TLP DEFINITION: Purposeful placement of thin layers of sediment (e.g., dredged material) in an environmentally acceptable manner to achieve a target elevation or thickness. Thin layer placement projects may include efforts to support infrastructure and/or create, maintain, enhance, or restore ecological function.

SUMMARY: This technical note (TN) current report provides background information regarding TLP, a brief discussion of TLP benefits, and reviews previously published definitions of TLP.

Based on those findings, a more inclusive, updated TLP definition is presented to support USACE applications.

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