POLLUTION PREVENTION AND WATER REUSE AT UTAH DEPARTMENT OF TRANSPORTATION FACILITIES

by

Amanda Stoudt

A thesis submitted in partial fulfillment
of the requirements for the degree

of

MASTER OF SCIENCE

in

Civil and Environmental Engineering

Approved:

Joan E. McLean, M.S. Major Professor	R. Ryan Dupont, Ph.D. Committee Member
Wade Goodridge, Ph.D. Committee Member	Richard S. Inouye, Ph.D. Vice Provost for Graduate Studies

UTAH STATE UNIVERSITY
Logan, Utah

2020

ABSTRACT

Pollution Prevention and Water Reuse at Utah Department of Transportation Facilities

by

Amanda Stoudt, Master of Science

Utah State University, 2020

Major Professor: Joan E. McLean
Department: Civil and Environmental Engineering

The application of road salt is crucial for wintertime public safety but road salt has many negative environmental impacts. Road salt can increase levels of dissolved solids in groundwater and damage vegetation, with these impacts concentrated around salt storage facilities. In Utah, road salt is stored at Utah Department of Transportation (UDOT) facilities and is distributed throughout the winter by salt trucks. After storms, trucks are washed and the wash water is captured in retention ponds. Without data informing pond design and maintenance plans, the ponds suffer from design issues, namely overflow. Because of the environmental impacts of pond overflow and regulation under a Phase I municipal separate stormwater sewer system (MS4) permit, UDOT is required to develop best management practices (BMPs) for salt storage and vehicle wash water containment (UDEQ 2015a).

With the construction of retention ponds to capture salt-laden wash and stormwater, UDOT must also develop guidelines to address the accumulation and disposal of pond water and sediments. Reusing pond water for brine has been implemented by other states, but can be limited by the concentration of toxic elements and oil and grease (O&G). The same pollutants can also limit the disposal of pond sediments.

Through pollution prevention assessments, analysis of water and sediment samples collected from 12 UDOT maintenance stations, and surface water quality modeling, design guidelines and BMPs were developed to help UDOT comply with their MS4 permit. Pond sediments from the maintenance stations tested have O&G concentrations above 1 g/kg, requiring the sediments to be treated before land disposal. To reduce the O&G in pond sediments, oil water separators should be installed upstream of the retention ponds. Pond water analyses and surface water quality modeling indicate the pond water at all eleven maintenance stations can be used for brine without violating aquatic standards. Reusing pond water, diverting stormwater, and implementing vehicle washing standard operating procedures will reduce pond contamination and overflow events at UDOT maintenance stations, effectively reducing permit violations and the environmental footprint of winter maintenance operations in Utah.

(158 pages)

PUBLIC ABSTRACT

Pollution Prevention and Water Reuse at Utah Department of Transportation Facilities

Amanda Stoudt

As stormwater flows over roads, sidewalks, and other impervious surfaces, it picks up pollutants that are deposited on these surfaces. One common pollutant transported by stormwater is road salt. While the application of road salt is crucial for wintertime public safety, road salt has a host of negative environmental impacts. Road salt has been linked to increasing levels of dissolved solids in groundwater, vegetation damage, and behavioral changes in aquatic organisms. Studies have shown that these impacts are concentrated around salt storage facilities. As a result, the United States Environmental Protection Agency issued many state departments of transportation municipal separate storm sewer system (MS4) permits. In Utah, road salt is stored at Utah Department of Transportation (UDOT) maintenance stations, which are regulated by a Phase I MS4 permit. To comply with their MS4 permit, UDOT constructed retention ponds to capture salt-laden stormwater and truck wash water. However, without information and established maintenance and management plans informing pond design, these retention ponds suffer from design issues such as overflow throughout the winter season. Through pollution prevention assessments, pond and tap water analysis, pond sediment analysis, and surface water quality modeling at 11 UDOT maintenance stations, this project provides UDOT with site design guidelines and best management practices to ultimately reduce the impact of UDOT road salt facilities on the environment.

ACKNOWLEDGMENTS

I am extremely grateful and thankful for the following individuals and organizations without which this project would not have been possible:

Professor McLean for her knowledge, guidance, and patience.

Dr. Dupont and Dr. Goodridge for their insight and instruction.

The Utah Department of Transportation for project funding.

Dr. Horsburgh and Levi Manley for their patience and GIS expertise.

Dr. Neilson for her help and expertise in surface water quality modeling.

Brooklyn Morgan, Hunter Payne, Josh Hortin, Seth Tremayne, and Grant Mauk for their help and friendship.

Dr. McNeill and Dr. Dupont for helping me discover my passion for environmental engineering.

Darcie and Celeste for their encouragement, laughter, and friendship.

And finally, Mom, Dad, Claire, and Daniel for their endless support, encouragement, understanding, patience, and love.

CONTENTS

LIST OF TABLES

Table Page

Table Page

LIST OF FIGURES

Figure Page

LIST OF ACRONYMS

ADCP	Acoustic Doppler Current Profiler
APHA	American Public Health Association
BLM	Biotic Ligand Model
BMP	Best Management Practice
BOD	Biological Oxygen Demand
CMA	Calcium Magnesium Acetate
DO	Dissolved Oxygen
DOT	Department of Transportation
EPA	United States Environmental Protection Agency
GC-MS	Gas Chromatography-Mass Spectrometry
ICPMS	Ion Coupled Plasma Mass Spectrometry
INDOT	Indiana Department of Transportation
MCL	Maximum Contaminant Level
MDL	Method Detection Limit
MEP	Maximum Extent Possible
MS4	Municipal Separate Storm Sewer System
NCEI	National Centers for Environmental Information
NOAA	National Oceanic and Atmospheric Administration
NPDES	National Pollutant Discharge Elimination System
ODOT	Oregon Department of Transportation
O&G	Oil and Grease
PAHs	Polyaromatic Hydrocarbons
POTW	Publicly Owned Treatment Works
PW	Pond Water
QC	Quality Control
SOP	Standard Operating Procedure
SWMP	Stormwater Management Plan
TAC	Transportation Association of Canada

TCLP	Toxicity Characteristic Leaching Procedure
TDS	Total Dissolved Solids
TIN	Triangular Irregular Network
TPH	Total Petroleum Hydrocarbons
TRB	Transportation Research Board
TSS	Total Suspended Solids
TW	Tap Water
UDEQ	Utah Department of Environmental Quality
UDOT	Utah Department of Transportation
UDWQ	Utah Division of Water Quality
UPDES	Utah Pollutant Discharge Elimination System
USGS	United States Geological Survey
VDOT	Virginia Department of Transportation
VSS	Volatile Suspended Solids
WTI	Western Transportation Institute
WWTP	Wastewater Treatment Plant

INTRODUCTION

As stormwater flows over roads, sidewalks, and other impervious surfaces, it picks up the particulate matter, chemicals, and debris previously deposited on these surfaces. One of the materials that is becoming increasingly more prevalent in stormwater, due to its increased use, is road salt. Road salt was first applied as an experimental deicing agent in the United States in 1938 (Kelly et al. 2010). Over the years, the application of road salt has increased proportionally with the increase in roads and other impervious surfaces. According to the United States Geological Survey (USGS), 22.7 million metric tons of salt were applied on roadways nationwide in 2015 (Bolen 2017).

While the application of road salt on roads, sidewalks, and parking lots is crucial for wintertime public safety, road salt has been shown to have a host of negative environmental impacts. Findlay and Kelly (2011) report that road salt inhibits the growth of roadside vegetation, impairs the health, reproduction, and behavior of a number of aquatic organisms, and can inhibit spring turnover in lakes. Road salt has also been shown to affect drinking water quality, with sodium hotspots being detected in groundwater near road salt storage facilities (Pieper et al. 2018; Kelly et al. 2019a).

As a result of the environmental impacts of road salt, many state departments of transportation (DOTs) have been issued municipal separate storm sewer (MS4) permits to regulate the discharge of salt laden stormwater from their maintenance facilities. Among the state DOTs to be issued an MS4 permit is the Utah Department of Transportation (UDOT). To comply with their permit, the Utah Department of Environmental Quality (UDEQ) required UDOT to develop best management practices (BMPs) for road salt storage and application and for snow equipment wash water containment (UDEQ 2015a). UDOT satisfied the wash water containment requirement by constructing retention ponds to store the salt truck wash water at all maintenance stations.

Most of the retention ponds, however, were found to have been constructed without knowledge of the required volume needed to contain the truck wash water and stormwater. As a result, a number of ponds often overflow and release highly saline water into the environment. In addition to being highly saline, the pond water could also have high concentrations of trace elements and organics, which pose additional environmental concerns, and pond overflow is a violation of UDOT’s MS4 permit. To reduce the environmental impacts of road salt from UDOT maintenance stations, new best management practices, such as pond water reuse, were developed in this study and pond designs were recommended. Guidelines for pond maintenance and management of pond sediments were also established.

LITERATURE REVIEW

Municipal Separate Storm Sewer System (MS4) Permits

The United States Environmental Protection Agency (EPA) defines stormwater as runoff generated from rain and snowmelt events that flow over land or impervious surfaces (streets, rooftops, etc.) (USEPA 2019a). As stormwater flows across these surfaces, it can transport debris, chemicals, and suspended solids from these surfaces to rivers, lakes, and coastal waters. As a result, stormwater can contribute a large amount of pollution to surface water bodies and groundwater.

Despite being a major source of surface water pollution, stormwater did not gain regulatory attention until 1987. In 1987, Congress passed the Water Quality Act of 1987, which contained three provisions addressing stormwater discharges. Among these provisions was the addition of Section 402(p) to the Clean Water Act. Section 402(p) required the EPA to create a National Pollutant Discharge Elimination System (NPDES) permitting standard for municipal separate storm sewer systems (MS4s) (NACWA 2018).

An MS4 is defined by the EPA as a conveyance or system of conveyances that is owned by a state, city, or other public entity that discharges to waters of the U.S., designed to collect or convey stormwater, not a combined sewer, or part of a wastewater treatment plant (WWTP) or publicly owned treatment works (POTW) (USEPA 2019a). For regulatory purposes, MS4s are categorized as Phase I or Phase II. Phase I MS4s are those located in incorporated areas or counties with populations greater than 100,000 people (NACWA 2018). In contrast, Phase II MS4s are cities, towns, and counties that did not meet the Phase I definition in 1990. Also included in Phase II MS4s are military bases, universities, and other governmental entities (NACWA 2018).

Unlike traditional NPDES permits for POTWs and WWTPs, MS4 permits do not establish water quality-based effluent limits (NACWA 2018). Instead, entities with an MS4 permit must reduce the discharge of pollutants to the maximum extent possible (MEP), also known as the MEP standard (NACWA 2018). To comply with the standard, MS4 permittees must establish BMPs to reduce the amount of pollutants entering or exiting the MS4. BMPs also fall into one of two categories: structural or nonstructural. Structural BMPs include physical structures intended to collect, infiltrate, or convey stormwater, while nonstructural BMPs include practices or actions that directly reduce stormwater pollution or encourage the public to reduce stormwater pollution. Nonstructural BMPs include street sweeping and public education (NACWA 2018).

In addition to BMPs, both Phase I and Phase II MS4s are required to develop stormwater management plans (SWMPs). Phase I MS4 SWMPs must include structural and source control BMPs, illicit discharge detection and elimination programs, and industrial and construction site runoff programs. Phase II MS4 SWMPs must include six minimum control measures describing the permittees' stormwater management program (NACWA 2018). The six minimum control measures are public education and outreach, public involvement and participation, illicit discharge detection and elimination, construction site runoff control, post-construction runoff control, and pollution prevention and good housekeeping (USEPA 2005). While the SWMP requirements differ for Phase I and Phase II MS4s, most SWMPs contain elements from both sets of requirements.

Road Salt

Introduction

A common pollutant transported by stormwater throughout the winter and spring is road salt. Road salt was first applied as an experimental deicing agent in the United States in 1938 (Kelly et al. 2010). Over the years, the application of road salt has increased proportionally with the increase in roads and other impervious surfaces (Kelly et al. 2019a). Today, an average of 23 million metric tons of salt are applied on roadways nationwide every year (Bolen 2017). The application of road salt and its effects on public safety and the environment are discussed in the following sections.

Application of Road Salt

Road salt is applied either before a storm event to prevent ice from forming a bond with the road, known as anti-icing, or after a storm to melt ice that has already formed a bond with the road, also known as de-icing. Liquid chemicals are most commonly used for anti-icing. In anti-icing applications, road salt is applied as a brine solution to ensure the road is completely covered. Applying road salt in the form of brine reduces application rates, quickens post-storm clean up, and reduces material loss from scatter (Fay et al. 2013).

For de-icing applications, road salt is either applied mixed with sand or pre-wetted. Many state DOTs are moving away from using salt and sand mixtures because of air quality concerns and the required post-winter street sweeping to collect all the excess sand. In contrast, pre-wetting road salt before application is becoming more common. Pre-wetting road salt improves the melting action, can lower the effective working temperature of road salt in some cases, and reduces the amount of bounce and scatter of road salt on the road (Fay et al. 2013).

At UDOT facilities, a variety of anti-icing and deicing chemicals are used depending on the road conditions and location. In Weber, Salt Lake, and Utah County urbanized areas, brine and magnesium chloride ($MgCl_2$) are used for anti-icing (UDOT SWMP 2016). Except for some rural areas, traditional road salt is used for deicing throughout the rest of the state. In rural areas, a mixture of sand and salt is used to improve traction since air quality is not a concern in these parts of the state (UDEQ 2015a). In addition to the application of anti-icing and deicing chemicals, snow plowing is also performed at varying frequencies to prevent snow from accumulating more than 2 inches (UDOT SWMP 2016).

Public Safety

Road salt is one of the most effective anti-icing and deicing chemicals available and, as a result, is instrumental in maintaining public safety during the winter. In 2002, over 22% of the total car crashes in the United State were weather-related. Of these crashes, 49% occurred during rain events and 13% during snowfall (Goodwin 2002). Because a large portion of car-related accidents occur in bad weather, numerous studies have examined the crash reduction rates and cost savings associated with the application of road salt and other deicing chemicals using modeling programs. Hanbali et al. (1993) conducted a study on two-lane, two-way highways and freeways in the United States and found an 85% reduction in crashes and an 88% reduction in injury-causing crashes within a few hours of salt application compared to rates on untreated roadways. A similar study conducted by the University of Waterloo using a Before-After (B-A) analysis found that the average collision rate was reduced by over 50% within 12 hours of salt application when compared to the collision rate on unsalted roads (Fu and Usman 2012).

In addition to reducing injuries and vehicle collisions, winter maintenance operations also save the public a substantial amount of money. The Federal Highway Administration (Koch et al. 2002) found that the costs associated with crashes decreased by almost 90% after the application of deicing chemicals. A study conducted by Environment Canada also found significant cost savings were associated with the use of salt. They found that financial savings from the application of salt were \$1,594,412 per fatality, \$26,628 per injury, and \$5,724 for property damage when compared to the costs of fatality, injury, and property damage on untreated roads (values are reported in Canadian dollars) (Environment Canada 2006). Cost savings are not only associated with safety, but also with economic productivity. Hanbali et al. (1993) found that in the first 2 hours after deicing chemical application, road user benefits totaled \$6.50 for every \$1.00 spent on two-lane highways and \$3.50 for every \$1.00 spent on freeways for maintenance.

Environmental Impacts

While the application of road salt to remove snow and ice from roads, sidewalks, and parking lots is crucial for wintertime public safety, road salt has been shown to have a host of negative environmental impacts (Figure 1). One of the most significant impacts is the increased salinization of surface water bodies. The aquatic standard for chloride is 230 mg/L and in many rivers, streams, and lakes in the United States, the ambient chloride concentration is approaching 200 mg/L (Kaushal et al. 2005; Novotny et al. 2008). Increasing chloride concentrations in surface water bodies affects aquatic organisms, plants, lake dynamics, soil, and human health.

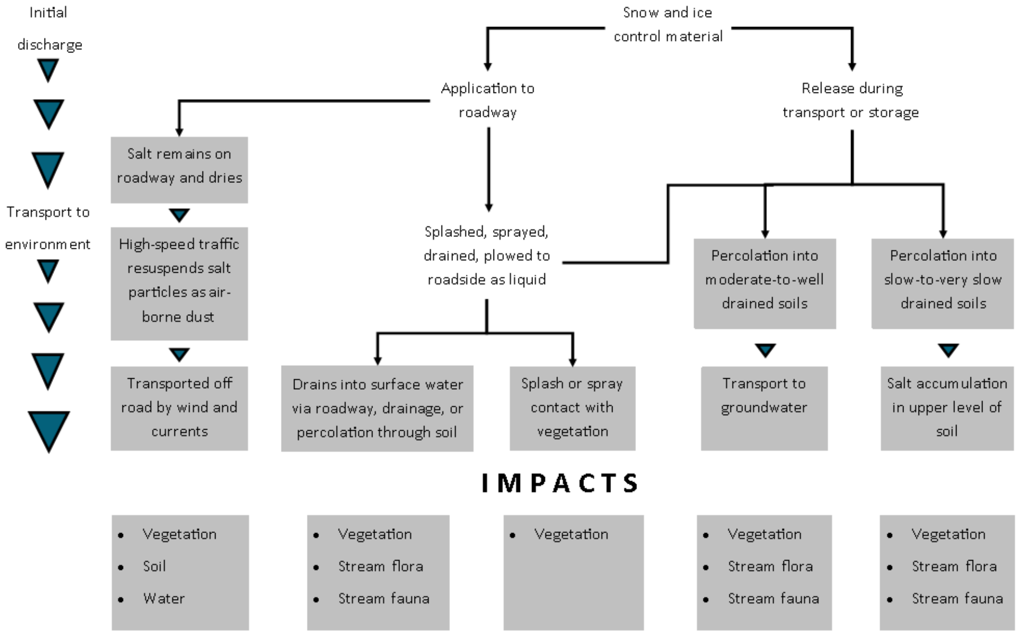


Figure 1. Flow diagram summarizing the main environmental impacts of road salt (adapted from EA Engineering (2009)).

Salt negatively affects aquatic organisms by altering the osmotic balance between the organism and the environment (Findlay and Kelly 2011). If the salt concentration in the environment is lower than that in the organism, as is common in most freshwater systems, the organism must prevent the diffusion of salts out of its body. When the opposite is true, the organism must expend exponentially more energy to keep ions from diffusing into its body. Salt tolerance and threshold concentrations vary widely among species and life stages (Findlay and Kelly 2011). Hart et al. (1991) report that most freshwater macroinvertebrates only survive for short periods of time (approximately 48 hours) in chloride concentrations above 2,000 mg/L, but that freshwater macrophytes begin to die in chloride concentrations above 1,000 mg/L.

During the winter months, many surface water bodies near roads experience peak chloride concentrations as high as 10,000 mg/L (Environment Canada 2010). While peak chloride concentrations in the winter are significantly higher than the toxic concentrations reported by Hart et al. (1991), these peak concentrations are temporary as melting snow and other forms of precipitation dilute the incoming chloride.

The high concentrations of chloride in surface and ground water resulting from road salt application are not only problematic in the winter, but throughout the year. Chloride can be stored in vegetation, soil micropores, groundwater, and organic chlorine compounds (Kelly et al. 2008). Because of this storage, several studies have found summertime chloride concentrations in surface water bodies to be as high as those measured in the winter (Mason et al. 1999; Kelly et al. 2008). Further, the effects of elevated chloride on aquatic organisms are compounded during the summer months because aquatic organisms are in more sensitive life stages and river and stream flow rates may be lower than in winter months (Findlay and Kelly 2011).

The mechanism through which salt affects plants is similar to that of aquatic organisms. Elevated levels of salt in soil generate an osmotic imbalance in plants, which affects the plant’s ability to absorb water, germinate, take in nutrients, flower, seed, and ultimately grow (Siegel 2007). Visible indicators of excess salt in plants include leaf scorch, late coloration, early defoliation, and dying twigs and branches in the crown of the plant (Siegel 2007). According to Wegner et al. (2001), most vegetation damage from road salt application occurs within 60 feet of the road but effects have also been observed up to 660 feet away. In water bodies, increased chloride concentrations can shift native algal populations towards more nuisance organisms (Siegel 2007).

In addition to affecting aquatic organisms and vegetation, road salt also affects lake dynamics. Lakes stratify vertically with warmer water at the surface and colder water at the bottom. The density difference of these two layers is approximately 0.002 g/cm^3, which is the same density difference that would result from adding 2 g/L salt (Findlay and Kelly 2011). This amount of salt is well within the range of average road runoff. As a result, the addition of salt to lakes can increase both their tendency to stratify and the length of time they remain stratified (Findlay and Kelly 2011). Longer periods of stratification can lead to the depletion of dissolved oxygen (DO) in bottom waters, which impacts the ability of aquatic organisms to survive at these depths (Findlay and Kelly 2011).

The impacts of road salt on soil are generally observed within 15 feet of a roadway. The accumulation of sodium in soils can increase alkalinity, moisture retention, and soil density, which reduces permeability (Transportation Research Board (TRB) 1991). An increase in sodium can also mobilize vital nutrients and heavy metals from soil, as high concentrations of sodium is readily exchangeable with calcium, magnesium, potassium, cadmium, and lead (Ramakrishna and Viraraghavan 2005; Findlay and Kelly 2011). As a result of mobilization, the concentrations of these nutrients and metals often increase in ground and surface waters, further compounding the effect of road salt on aquatic environments.

Because of their high solubility, components of road salt can migrate through soil and into groundwater. According to TRB (1991), 10 to 60% of road salt applied to roads enters shallow subsurface waters and accumulates until steady-state conditions are reached. Shallow wells, reservoirs, and low-flow surface waters near roadways or salt storage facilities are the most susceptible to salt and other chemical deicer contamination (TRB 1991). These water bodies also often serve as drinking water supplies. As a result, sodium and chloride concentrations in drinking water have increased with the increased application of road salt. Increased sodium in drinking water poses a health risk for individuals on low sodium diets. As a result, the EPA has established a drinking water limit for sodium of 20 mg/L (USEPA 2003). If the sodium concentration in treated drinking water surpasses 20 mg/L, the public drinking water system is required to report the concentration to the local health authorities (USEPA 2003). In addition, there is a secondary drinking water standard for chloride of 250 mg/L, but chloride exceedances are rare and often temporary.

Salt not only has short-term environmental consequences, but numerous studies have also shown that salt has legacy effects. Because chloride is highly soluble in water, once it enters a water body, it is extremely difficult to remove and is essentially trapped in the environment, cycling between soil, surface water, and groundwater (Environment Canada 2001). Kelly et al. (2008) looked at the sodium retention of a watershed in upstate New York and the effect of winter maintenance BMPs on the surface water chloride concentration. The study found that 35 to 45% of applied road salt is retained in watersheds (Kelly et al. 2008). Salt retention can occur in lakes, reservoirs, wetlands, and groundwater (Novotny et al. 2009; Cooper et al. 2014; Herbert et al. 2015). In addition, summer salt concentrations in streams indicate that salt stored in groundwater is slowly released during periods of low flow and the long-term stabilization of salt concentrations in streams is dependent upon the implementation of BMPs (Kelly et al. 2019b).

Best Management Practices for Road Salt Storage and Application

Salt storage facilities have the greatest potential to impact the environment because of the sheer quantity of salt stored in them. Impacts from road salt decrease as it is applied to roadways because it is spread over a large area and is diluted by snow and ice (OWRC 2012). To prevent environmental contamination from road salt at salt storage facilities, most state DOTs have implemented BMPs for storing, handling, and applying road salt and other de-icing chemicals. In this case, BMPs are defined as any product, technology, program, or operational method that can reduce the potential adverse environmental impacts of snow and ice control operations, while meeting regulatory requirements, saving time, reducing costs, and improving effectiveness (EA Engineering 2009; Fay et al. 2013).

There are a variety of BMPs for the storage and handling of deicing salts and chemicals. One of the most universal BMPs is storing salt on a covered, impermeable surface or requiring salt piles to be covered with tarps (EA Engineering 2009). The Oregon DOT (ODOT) also recommends storing only the required amount of de-icing chemicals needed for one season on-site (ODOT 2014). Effective storage practices save material from being lost to erosion, keep the material workable, and prevent the material from leaving the site as runoff and impacting the surrounding environment (TAC 2013).

For liquid deicers, the most common BMP is installing secondary containment around the storage tanks and liquid transfer point (Fay et al. 2013). Secondary containment should be capable of holding 100-125% of the capacity of the largest tank or 10% of the total tank capacity (Fay et al. 2013). Options for secondary containment include double-walled tanks and containment dikes. According to a survey of state DOTs conducted by Fay et al. (2013), only 22% of the DOTs surveyed store liquid deicers in tanks that have secondary containment.

In addition to salt storage BMPs, many DOTs have BMPs for salt handling. The Indiana and Tennessee DOTs, for example, require the loading and unloading of salt trucks to take place in the covered salt storage areas (EA Engineering 2009; Fay et al. 2013). It is also recommended that smaller loader buckets or side dumping bucket attachments be used in place of large buckets to prevent salt spilling when filling trucks (Fay et al. 2013). Other BMPs include sweeping salt debris back into the covered storage area within 48 hours of a storm and grading entrances to salt storage areas toward the structure to prevent the flow of stormwater out of the storage area (EA Engineering 2009).

Another common source of salt contamination from DOT facilities is runoff from salt truck and snowplow washing. According to a survey conducted by EA Engineering (2009), 93% of the DOTs surveyed wash snow and ice control vehicles and equipment as soon as possible after a storm event. Less than 40% of the survey respondents, however, capture the wash water before it enters the sewer or environment and only 6.5% reuse wash water for brine or pre-wetting salts (EA Engineering 2009-last available data).

To combat salt contamination from wash water runoff, many DOTs have started to implement BMPs for truck washing. One of the most common structural BMPs for containing salt-laden wash water is the use of retention ponds. To be effective at containing runoff without overflowing, retention ponds should be designed to hold the maximum volume of wash water, stormwater, and precipitation, while also considering local evaporation rates (Corson 2003). Further recommendations for retention ponds include lining the retention ponds with a clay or plastic impervious liner and inspecting the ponds annually (Corson 2003; NH DES 2003; Jurries et al. 2013). Many DOTs have also developed non-structural BMPs for vehicle washing. A common practice is to designate specific vehicle washing areas so wash water can be collected and managed appropriately. To further reduce wash water contamination, some DOTs prohibit changing vehicle fluids in wash bays and washing the undercarriages of vehicles (EA Engineering 2009).

Alternatives to Road Salt

In addition to traditional road salt, there are a variety of other inorganic and organic deicers available for use in winter maintenance activities. Magnesium chloride ($MgCl_2$) and calcium chloride ($CaCl_2$) are two of the most commonly used inorganic deicers after traditional road salt. While both salts can be applied in solid form, they are more commonly applied as brine solutions for anti-icing purposes (Ye et al. 2013). Both $MgCl_2$ and $CaCl_2$ are as effective as NaCl, but are more expensive, which limits their widespread use. Unlike NaCl brine, however, $MgCl_2$ leaves a residue on roadways that attracts moisture and creates a slick film on roads. Because $MgCl_2$ residue creates a slick film in the presence of moisture, if a snowstorm is followed by rain, $MgCl_2$ can make roads more dangerous (Ye et al. 2013). In addition, both $MgCl_2$ and $CaCl_2$ have the potential to mobilize more heavy metals from soil than NaCl because chlorides mobilize heavy metals through the formation of chloride complexes and both salts have a higher proportion of chloride anions compared to NaCl (Schuler et al. 2017).

The most commonly used organic deicer is calcium magnesium acetate (CMA).

CMA functions similarly to traditional road salt but requires 50% more by weight to achieve the same results (EA Engineering 2009). Unlike road salt, CMA has negative air quality impacts and performs poorly in thick accumulations of snow and ice and temperatures below 23° F. CMA has a host of negative environmental impacts as well. Acetate is one of the most abundant organic acid metabolites in nature and its biodegradation could lead to anaerobic soil conditions and localized DO depletion in surface water (Defourny 2000).

Other alternatives to road salt include glycol, glycerin, and organically derived or ag-based products. Glycol and glycerin deicers are more commonly used at airports for aircraft deicing than they are on roadways (Ramakrishna and Viraraghavan 2005). While glycols are extremely effective and not acutely toxic, glycol mixtures tend to include 10 to 20% by weight other additives. These additives, which include corrosion and rust inhibitors, thickening agents, and surfactants, however, are extremely toxic and known endocrine disrupters in fish and other aquatic organisms (Kent et al. 1999). As a result, many DOTs do not use glycol-based products for winter road maintenance.

In addition to glycol and glycerin, there are a variety of ag-based organic deicers and additives available for use on roadways. Most of these deicers and additives are the product of the distillation of fermented sugar beet, or molasses waste products (Better Roads 2001). Because of the organic compounds in these deicers, they stick better to roads and, if used as an additive to road salt, help the road salt stick better to the road (Schuler et al. 2017). As a result, using these deicers and additives reduces the quantity of road salt applied per lane mile and, consequently, the amount of salt run-off entering surface and ground water bodies (Fay and Shi 2012). The organic compounds in these ag-based deicers and additives, however, increase the biological oxygen demand (BOD) and phosphorus loading in receiving waters (Fay and Shi 2012). The increased phosphorus loading could lead to phytoplankton and algal blooms in wetlands, lakes and ponds, further reducing DO concentrations and in turn, harming larger aquatic organisms (Schuler et al. 2017). Because of the environmental consequences and high cost, ag-based organic deicers and additives are not widely used by DOTs for winter maintenance operations.

Water Reuse at Department of Transportation Facilities

To reduce the environmental impacts of salt-laden truck wash water, many state DOTs have explored using salt-laden truck wash water for brine make-up water. The feasibility of using salt truck wash water for brine make-up water and pre-wetting salt depends on the quality of the wash water, state reuse limits, and aquatic standards. Several studies have examined the feasibility of wash water reuse at different state DOTs and the results of these studies are summarized in the following paragraphs.

Fitch et al. (2009) investigated the reuse of truck wash water for brine at Virginia Department of Transportation (VDOT) facilities. At VDOT facilities, salt truck wash water and stormwater from around the salt storage shed and brine tanks are collected in retention ponds. To recycle the pond water to produce brine, an ABS-1500 automatic brine generation system was used. The study found that the retention pond water could be reused without pretreatment for brine at both a bench and pilot scale. The total suspended solids (TSS) in the pond water did not affect the brine generation process (Fitch et al.

2009). A cost benefit analysis also indicated that the capital cost of implementing brine generation at VDOT winter maintenance facilities could typically be recovered within 4 years.

A similar study was conducted by Miller et al. (2014) at Ohio Department of Transportation facilities. Initial analysis of the wash water from three facilities indicated that the wash water met disposal guidelines, but several of the heavy metal concentrations, namely copper and zinc, did not meet the reuse limits set by the Ohio Department of Environmental Quality (Miller et al. 2014). The reuse limits are based on the beneficial use of the receiving water bodies and are outlined in water reuse permits (Ullinger et al. 2016). To lower the heavy metals concentration of the pond water, four different proprietary filter media designed to remove metals from wash water were tested. All four media types reduced the heavy metals concentrations below disposal guidelines, which indicates there is a potential for the reuse limits to be met as well (Miller et al. 2014).

At Indiana Department of Transportation (INDOT) facilities, four different brine making systems were evaluated. The four systems included a commercial brine making machine using fresh or recycled truck wash water and a “do-it-yourself” system using fresh or recycled truck wash water (Alleman et al. 2004). The two commercial systems used at INDOT facilities are the Varitech SB600 Salt Brine System and Sprayer Specialties SB-1400 Salt Brine System. The “do-it-yourself” systems included an underground concrete settling tank, oil-water separator, brine manufacturing tank, and a storage tank (Alleman et al. 2004). An analysis of the brine produced from truck wash water at two INDOT facilities revealed that the oil and grease concentration was below the detection limit. The BOD concentration of the finished brine at one facility was below the detection limit and 14 mg/L at the other (Alleman et al. 2004). In addition, both the commercial and “do-it-yourself” systems could produce enough brine using truck wash water to meet the wintertime demand. As a result of this study, INDOT has equipped several of its maintenance stations with equipment to recycle truck wash water into brine (INDOT 2019).

Based on the results achieved by VDOT and INDOT, reusing truck wash water for brine production at UDOT facilities could be feasible. In order for UDOT to reuse the truck wash water currently being collected in retention ponds at each facility, an analysis of the wash water and produced brine will need to be conducted to determine the concentrations of heavy metals and oil and grease. The results of these analyses will determine whether the truck wash water can be used to produce brine.

Utah Department of Transportation MS4 Permit and Current BMPs

Because the State of Utah was granted primacy by the EPA in 1987, UDOT’s MS4 permit falls under the Utah Pollutant Discharge Elimination System (UPDES) Program and is issued by the Utah Department of Environmental Quality (UDEQ), Division of Water Quality (UDWQ) (UDOT MS4 Fact Sheet 2015). According to Section 4.2.6.4.4 of the permit, the operation and maintenance program must include standard operating procedures that ensure vehicle and equipment wash waters are not discharged, either to an MS4 or Waters of the State (UDEQ 2015a). The permit also states the wash water retention ponds must be inspected annually to make sure they are properly maintained.

To comply with their MS4 permit, UDOT has developed BMPs for salt storage, deicer application, and truck washing. The BMPs listed in UDOT's SWMP for salt storage include covering salt piles to prevent stormwater contact and, for facilities that do not have covered salt piles, constructing retention ponds to contain the stormwater runoff from the salt pile. As for the application of deicing chemicals, the SWMP outlines multiple BMPs. Brine and $MgCl_2$ solutions are used for anti-icing in Weber, Salt Lake, and Utah County urbanized areas. Plowing is also performed at varying frequencies to prevent snow from accumulating to more than 2 inches.

Central to these BMPs is applying only the minimum amount of deicing agent necessary to remove ice from the roadways (UDOT SWMP 2016). Minimizing the quantity of deicing chemicals reduces the potential pollutant load to the environment. To minimize the use of deicing chemicals, UDOT uses remote weather information systems to track roadway temperatures and other weather information along all major interstate highways and major rural arterial roadways (UDOT SWMP 2016). These systems provide real-time road conditions to UDOT winter maintenance personnel and ensure the proper deicing chemicals are used and applied in the correct quantities.

Currently, the BMPs outlined in UDOT's SWMP only address the storage and application of anti-icing and deicing chemicals and the containment of salt-laden stormwater in retention ponds. There are no specified design guidelines or BMPs relating to the retention ponds or the sediment that accumulates at the bottom of the retention ponds. Sediment accumulation reduces the storage volume of the retention ponds and can lead to the sorption of heavy metals and oil and grease. Because heavy metals and oil and grease in the pond water are likely to partition out of the water and into the sediment, disposal of pond sediments could be limited by the concentration of heavy metals and oil and grease. Despite the possible complications from sediment accumulation on the bottom of DOT retention ponds, information on how other DOTs manage and dispose of retention pond sediments is not publicly available.

In the absence of BMPs addressing retention pond design and maintenance, most of the retention ponds at UDOT facilities are undersized and not properly maintained. Because of the pond overflow events and accumulation of potentially hazardous sediment, design guidelines and maintenance BMPs for UDOT retention ponds need to be established to prevent the negative impacts of salt-laden stormwater and potentially hazardous sediment on the environment.

PROJECT OBJECTIVES

Main Project Objective: Develop BMPs and pond design guidelines to help reduce UDOT retention pond contamination and overflow events, which will allow UDOT to comply with their MS4 permit while decreasing their environmental impact.

The following objectives were used to accomplish the primary project objective:

Objective 1: Determine BMPs for pond and sediment management. To develop BMPs, pond water, tap water, and sediment samples were collected from 12 UDOT maintenance stations and were analyzed for solids, metals (calcium, magnesium, potassium, and sodium), trace elements (arsenic, cadmium, chromium, copper, iron, nickel, lead, selenium, and zinc), oil and grease (O&G), polyaromatic hydrocarbons (PAHs), and total petroleum hydrocarbons (TPH) to define current conditions. Using the results, several BMPs, including the reuse of pond water for making brine, were evaluated.

Objective 2: Develop pond design guidelines to eliminate overflow and minimize sediment accumulation. Pond design guidelines were established to facilitate the implementation of the BMPs developed in Objective 1, while also considering precipitation, evaporation, and the number of trucks washed at each facility.

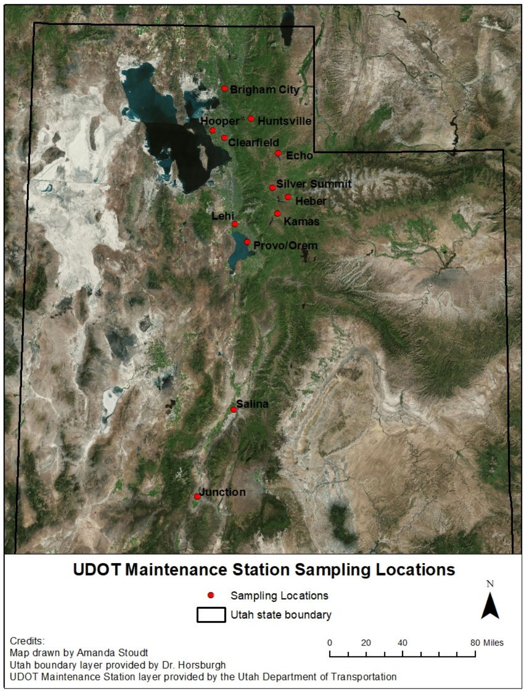
MATERIALS AND METHODS

The following sections outline the materials and methods used in the field and laboratory for sample collection and analysis.

Field Methods

Sampling Locations

Pond water, tap water, and sediment samples were collected from retention ponds at 12 UDOT maintenance stations in the summer of 2018 (Figure 2). The sites were: Kamas, Heber, Lehi, Provo/Orem, Clearfield, Brigham City, Salina, Junction, Silver Summit, Echo, Huntsville, and Hooper. The Provo/Orem maintenance station did not have a conventional retention pond, just a sludge pit, from which sediment samples were collected. The retention ponds at the Kamas and Clearfield maintenance stations had no sediments to collect.



UDOT Maintenance Station Sampling Locations

Credits:
Map drawn by Amanda Stoudt
Utah boundary layer provided by Dr. Horsburgh
UDOT Maintenance Station layer provided by the Utah Department of Transportation

Figure 2. Map of UDOT maintenance station sampling locations.

Pollution Prevention Survey

In order to gain a better understanding of the BMPs and pollution prevention techniques already implemented at UDOT maintenance stations, station supervisors were asked to participate in a pollution prevention survey. Some of the questions asked in the survey included describing the activities that are performed at the maintenance station, waste streams that can enter the retention ponds, and current pond and oil/water separator maintenance. The full pollution prevention survey can be found in Appendix A.

Sample Collection

At each UDOT maintenance station, tap water, pond water and sediment samples were collected. All samples were collected in triplicate with the pond water and sediment samples collected from three different locations around the pond. For quality control, an equipment blank and trip blank were also collected at each maintenance station. Because of the variety of analytical testing performed on each sample, different sample bottles with different pre-treatments were used (Table 1). A copy of the complete sampling trip plan and procedures can be found in Appendix B.

Table 1. Required sample bottles for each sampling trip.

Code	**Parameter**	**Container**	**Volume**	**Number of Bottles**	**Pre-Treatment**	**Preservation**
TSS	Total Suspended Solids	Plastic	1 L	8		
M	Metals	Plastic	250 mL	8	rinsed with 50% HNO_3	0.5 mL HNO_3 for filtered samples; 3 mL HNO_3 for unfiltered samples
O&G	Oil and Grease	Amber Glass	1 L	8	rinsed with 50% HCl	10 mL HCl
O&G MX	Oil and Grease Matrix Spike	Amber Glass	1 L	2	rinsed with 50% HCl	10 mL HCl
Sed.	Sediments	Plastic	1 L	3	rinsed with 50% HNO_3	

The sampling process started with a visual inspection of the pond. Important points noted were the overall condition of the site, appearance of the pond, and other important characteristics (debris, aerator, etc.). After a visual inspection of the site was completed and before samples were collected, a grab sampler (a 1-liter plastic bottle taped to a 5-foot extendable pole) (Figure 2a) was conditioned by completely filling the plastic bottle with retention pond water and emptying it three times. The grab sampler was emptied away from the pond to prevent sediment disruption. A small sample of the pond water at each location around the pond was then collected using the grab sampler and the pH and temperature were measured using a Hanna Instruments HI 9813-5 pH/EC/TDS/°C meter. A small sample of the tap water was also collected, and its pH and temperature were measured.

After the field measurements were completed, pond water samples were collected using the grab sampler and the samples were divided among the necessary bottles (Table 1). Once the pond water samples were collected with care not to disturb the sediments, the same grab sampler was used to collect pond sediments from each location. The bottle was lowered vertically until the bottom of the pond was reached to prevent water from entering the bottle. The bottle was then turned horizontal and drug along the bottom of the pond to collect the sediments. Tap water samples were collected directly from the tap at the wash rack into sample bottles. Before collecting samples, the wash rack or hose was turned on and allowed to run for a few minutes to flush out the line.

Pond Surveying

Of the 11 sites that had retention ponds to sample, nine of the ponds were not designed before construction and therefore, have an unknown volume. At these nine maintenance stations, a survey of each retention pond was conducted so the pond volume could be estimated. Pond volumes were needed for the water and mass balance calculations, specifically to determine the volume of pond overflow and the concentrations of metals and trace elements in the ponds during the winter. To verify the estimation method, two designed ponds (Heber and Salina) were also surveyed.

The surveys were conducted using a theodolite, Philadelphia rod, tape measure (decimal feet), and a pontoon-mounted Teledyne Marine StreamPro acoustic doppler current profiler (ADCP). Because of the irregular shapes of the ponds, surveys were conducted using a polar surveying method. A reference point (salt shed, wash rack, etc.) for the survey was selected and the angle on the theodolite set to 0°. Using 15° increments measured by the theodolite compass, the dry ground elevation was measured using a Philadelphia rod approximately every 10 feet on one side of the pond and then on the other side of the pond in a straight line. All ground elevations were taken in reference to the height of the theodolite.

Because of safety concerns, the surface topography of the bottom of the pond was captured using an ADCP. The ADCP was mounted to a small pontoon boat and pulled across the pond and back again along the same survey lines used for the dry ground survey. The depth data from the ADCP were collected and stored by the accompanying *WinRiver II* software. From the software, the data were imported into Excel along with the survey data collected around the pond. AutoCAD and ArcGIS were then used to estimate the volume of the ponds using triangular irregular networks (TINs) (Figure 3).

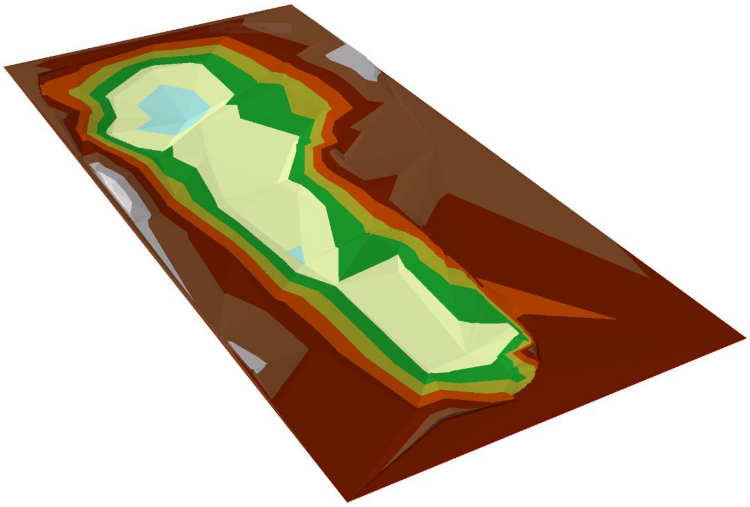


Figure 3. 3D representation of the TIN surfaces used to calculate pond volumes.

Laboratory Methods

The following sections outline the analyses that were performed on the pond and tap water and sediment samples collected from the 12 UDOT maintenance stations. Standard laboratory quality control (QC) procedures were used. These included the generation of standard curves for instrument calibration using authentic standards, continued verification of the standard curve using calibration verification samples, and spiked samples in duplicate to ensure accuracy and precision. Quality control was performed on 10% of samples and fell within specified EPA limits, except as noted in the results section.

Pond and Tap Water Samples

Both the triplicate pond and tap water samples were analyzed for total suspended (TSS), volatile suspended (VSS), and total dissolved (TDS) solids, total and dissolved metals and trace elements, O&G, PAHs, and TPH. A summary of the analysis methods is presented in Table 2. The analyses and methods are discussed further in the following sections.

Table 2. Analyses and methods for pond and tap water samples.

Analysis	Method	Reference
TSS, TDS, & VSS	Gravimetric	APHA Methods 2540 C, 2540 D, and 2540 E
Total and dissolved metals and trace elements	Digestion or filtration and ICPMS	APHA Method 3030E (modified) EPA Method 6020A
O&G	Extraction and gravimetric	EPA Method 1664B (modified)
PAHs	Extraction and GC/MS	EPA Method 1664B (modified) EPA Method 8270E
TPH	Extraction and GC/MS	EPA Method 1664B (modified) EPA Method 8270E

TSS, TDS, and VSS

TSS, VSS, and TDS were measured for the pond and tap water samples from each site according to American Public Health Association (APHA) Method 2540 C, 2540 D, and 2540 E (APHA 1998), respectively. A sample volume of 200 mL was used and samples were analyzed within 1 week of collection.

Total and Dissolved Metals and Trace Elements

The pond and tap water samples from each site were analyzed for total and dissolved metals and trace elements using inductively coupled plasma mass spectrometry (ICPMS) (Agilent 7700x). Polyatomic interferences were minimized through the use of collision cells with helium gas. For dissolved metals, 35 mL of sample were filtered using a 0.45 µm syringe filter. To preserve the filtered and unfiltered samples, 0.5 mL of trace metal grade nitric acid (HNO_3) were added to the filtered sample and 3 mL of HNO_3 were added to the unfiltered sample. The filtered samples were then diluted as necessary and analyzed using ICPMS. To measure total metals, the unfiltered samples were digested using concentrated HNO_3 according to APHA Method 3030E (APHA 1992) using an Environmental Express HotBlock and then analyzed using ICPMS.

Oil and Grease, PAHs, and TPH

To analyze the pond and tap water samples for O&G, PAHs, and TPH, samples were extracted using USEPA Method 1664 (USEPA 2010). Methylene chloride was used as the extraction solvent, instead of hexane, due to the complex matrix of the samples. After extraction, the samples were concentrated using a Caliper Life Sciences TurboVap II. After the sample was concentrated, a 1 mL aliquot was analyzed for PAHs and TPH using an Agilent Technologies 7890A gas chromatography system with an Agilent Technologies 5975C inert XL EI/CI mass spectrometry detector (GC-MS). Samples were run at 310°C through a ResTek 5Sil MS low-polarity capillary column. A phenanthrene d-10 internal standard was used to monitor instrument drift over time. The remaining sample was analyzed gravimetrically for oil and grease according to USEPA Method 1664 (USEPA 2010).

Sediment Samples

The triplicate sediment samples from each site were analyzed for total metals and trace elements, O&G, and TPH. In addition, the Toxicity Characteristic Leaching Procedure (TCLP) (USEPA 1992) was performed on the sediment samples to determine an appropriate disposal method (Table 3).

Table 3. Analyses and methods for sediment samples.

Analysis	Method	Reference
Total metals and trace elements	Digestion and ICPMS	EPA Method 3050B EPA Method 6020A
O&G	Extraction and gravimetric	EPA Method 3545A
TPH	Extraction and GC/MS	EPA Method 3545A EPA Method 8270E
TCLP	Acid extraction	EPA Method 1311 EPA Method 6020A

Sediment Drying

In order to perform the required analyses on the sediment samples, the sediment was dried. Because of the quantity and expected solids content of the pond sediments, a combination of centrifugation and filtration was used to separate the liquid and solid phases of the sediment samples. After filtration, samples were air-dried. Once dry, the sediment was ground using a mortar and pestle and stored for further analysis.

Total Metals

To analyze the sediment samples for total metals, the samples were digested with concentrated trace metal grade HNO_3 and hydrogen peroxide according to USEPA Method 3050B (USEPA 1996) using an Environmental Express HotBlock. After digestion, samples were diluted as necessary and analyzed using ICPMS.

Oil and Grease and TPH

To analyze the sediment samples for O&G and TPH, the samples were first extracted according to USEPA Method 3545a (USEPA 1998), pressurized fluid extraction using a CEM EDGE automated extraction system. A 1:1 methylene chloride acetone solution was used as the extraction solvent. After extraction, a 1 mL aliquot was set aside for TPH analysis using GC-MS. The remaining sample was analyzed gravimetrically for oil and grease according to USEPA Method 1664 (USEPA 2010). Total petroleum hydrocarbons were measured according to USEPA Method 8720E (USEPA 2018). The USEPA definition of TPH from Method 8015C was used, which distinguishes TPH as alkanes from C_{10} to C_{28} or a boiling point range of 170 to 430 °C (USEPA 2007).

Toxicity Characteristic Leaching Procedure

TCLP was performed on the samples according to USEPA Method 1311 (USEPA

1992). This method replicates the mildly acidic conditions found in municipal landfills and is used to classify a waste as hazardous or non-hazardous.

Winter Pond Volume and Brine Concentration Estimation Methods

Not all information needed to determine pond design guidelines and the feasibility of pond water reuse was available. Missing information included:

1. Frequency and volume of overflow from the retention ponds
2. Concentration of metals and trace elements in the water after trucks have been washed, termed the truck wash water
3. Concentration of metals and trace elements in the retention ponds during the winter

In the absence of this information, a water and salt balance were performed on the 11 retention ponds to estimate these variables. The results of the water and mass balances were used to inform site design guidelines and BMPs, specifically the use of pond water for brine make-up water.

The winter concentration of metals and trace elements in the Lehi, Salina, and Echo retention ponds were determined using samples collected in December 2016 (Gelles et al. 2017). These concentrations were used in conjunction with the summer metals and trace elements concentrations, determined as part of this present study, to determine the truck wash water concentrations used in the salt balance.

Water Balance

In order to develop pond design guidelines, a monthly water balance was performed for each of the 11 retention ponds using the inputs and outputs presented in Figure 4. The following sections describe the inputs, outputs, and calculations used in the water balance. A flow chart of the variables used to calculate each component of the water balance is presented in Figure 5.

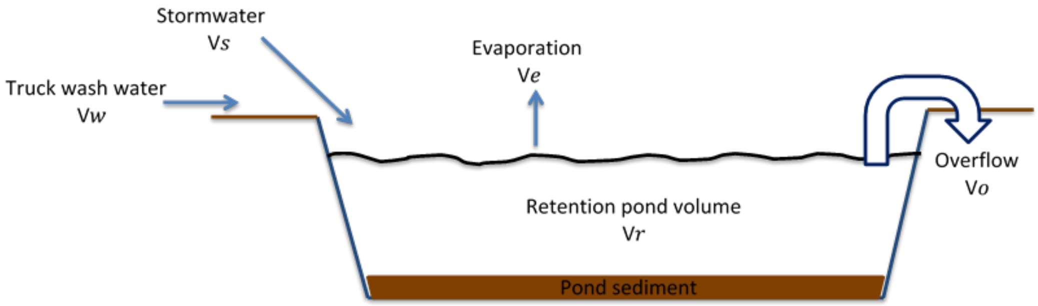


Figure 4. Inputs and outputs used in the water balance for UDOT maintenance station retention ponds.

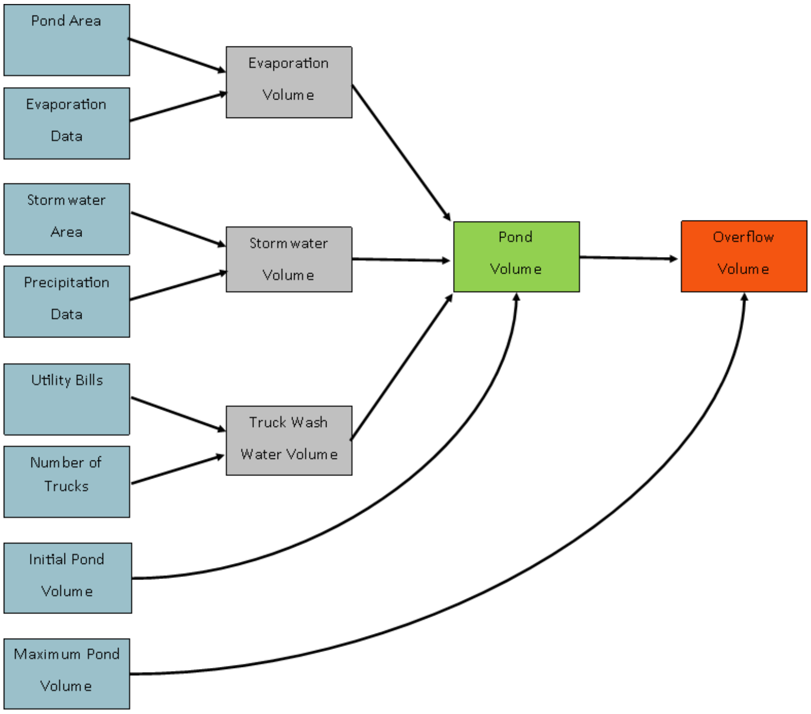


Figure 5. Flow chart showing the variables used to calculate each component of the water balance.

Assumptions

The following assumptions were used in the water balance calculations.

1. Water leaves the pond only through evaporation or overflow.
2. For maintenance stations where utility bills were not available, the monthly truck wash water volume is an average of the volume of truck wash water used at the three maintenance stations for which utility bills were provided.

Pond Area Estimation (Vr)

Using the TIN surfaces described previously, the volume and area of the pond surface at varying water depths were determined using the *Surface Volume* tool in ArcMap. The pond volumes and corresponding areas were then used to generate an equation relating pond area to pond volume (Figure 6). This process was completed for each pond. The resulting equation for each pond was used to calculate the area of the pond surface as the pond volume changes. In turn, the area of the pond surface was used to estimate the volume of water evaporating from the pond each month.

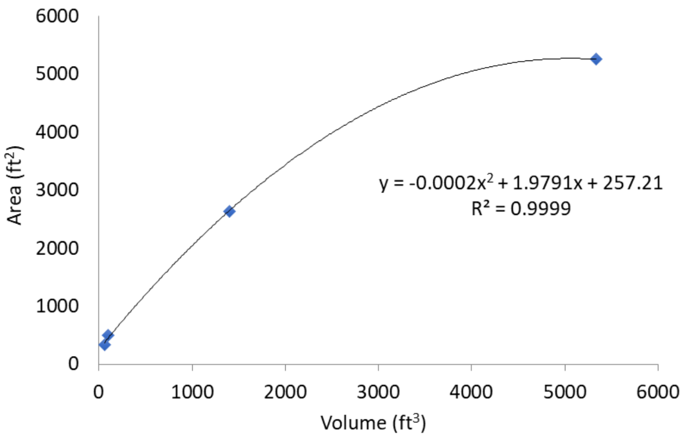


Figure 6. Example of a pond volume curve used to find the equation for pond area.

Stormwater Volume Calculations (V_S)

Average monthly precipitation data for the area surrounding each maintenance station were obtained from the National Oceanic and Atmospheric Administration's

(NOAA) National Centers for Environmental Information (NCEI) (NCEI 2019). To convert the precipitation data to a volume (v_s), the average monthly values were multiplied by the stormwater drainage area. The stormwater area was determined according to the maintenance station SWMPs and at most of the maintenance stations, included the impervious surfaces surrounding the pond, salt shed, wash rack, and brine tanks. The area of these surfaces was determined using ArcGIS through the creation of a polygon feature at each site. The area of the retention pond was also included in the stormwater area since rain and snow fall directly into the pond.

Evaporation Volume Calculation (V_e)

Evaporation data for each site were obtained from the Utah Climate Center (2019). Unlike the precipitation data, the evaporation values were multiplied by the pond area to obtain a volume (v_e). Because the surface area of the pond affects the amount of evaporation from the pond, the volume of the pond from the previous month was used to calculate the pond area. Hence, in the pond area equation, x is the volume of the pond from the previous month (V_{r-1}). In addition, because the ponds are extremely saline, the evaporation volume was multiplied by a factor of 0.7 to account for the difference in evaporation between fresh and saline water (Turk 1970).

Truck Wash Water Volume Calculations (V_w)

The volume of truck wash water used per month at the Salina, Junction, and Silver Summit maintenance stations were obtained from the stations' utility bills (UDOT, personal, communication, 2019). Because the meters at these maintenance stations included the water usage for both the main building and wash rack, a baseline amount of water was subtracted from the monthly water usage to account for the water being used inside the main building. The baseline amount was determined from the June, July, and August utility bills since truck washing does not occur during these months.

To standardize the monthly volume of truck wash water at each maintenance station, the monthly truck wash water volume at each of the three maintenance stations with utility bills was divided by the number of snowplows and salt trucks washed to arrive at the units of gallons per truck. The number of snowplows and salt trucks used at each maintenance station was obtained from a UDOT equipment list (UDOT 2018). The monthly gallons per truck of wash water at the Salina, Junction, and Silver Summit maintenance stations were then averaged. The average monthly volumes of truck wash water were then multiplied by the number of snowplows and salt trucks washed at the remaining eight maintenance stations to calculate the monthly volume of wash water generated at each station.

Pond and Overflow Volume Calculation (V_r and V_o)

Using the input and output volumes described in the previous sections, the retention pond volume was calculated starting in the month of September using Equation 1. Because the ponds were sampled in August, the volume and area of the retention ponds in August were used as the initial conditions in the water balance,

$$V_r = V_w + V_s + V_{r-1} - V_e \tag{1}$$

where V_{r-1} is the volume of the retention pond from the previous month. To prevent V_r from exceeding the maximum pond volume, an *If* statement was used. If V_r was greater than the maximum volume of the pond, V_r defaulted to the maximum pond volume. In the months when the maximum pond volume was exceeded, the volume of overflow (V_o) was calculated using Equation 2. In Equation 2, V_{max} is the maximum volume of the retention pond.

$$V_o = V_w + V_s + V_{r-1} - V_e - V_{max} \tag{2}$$

Mass Balance

To determine the feasibility of reusing pond water for brine make-up water, the winter concentration of the metals and trace elements in the retention ponds were calculated using a mass balance (Figure 7). The winter concentrations of elements in the ponds were then used to determine the blending ratio required to make a 23% salt brine, as sodium, at each maintenance station. For the purpose of the mass balance, truck wash water refers to the water coming off the trucks while they are being washed, not the raw tap water. The following sections describe the variable and calculations used in the mass balance (Figure 8).

Assumptions

The following assumptions were used in the mass balance calculations.

1. All the metals and trace elements enter the pond via the truck wash water. Without a way to estimate both the concentration of metals and trace elements in the wash water and stormwater, the metals and trace elements that potentially enter the pond via stormwater, are accounted for in the concentration of the truck wash water.
2. Elements are only lost with pond overflow.

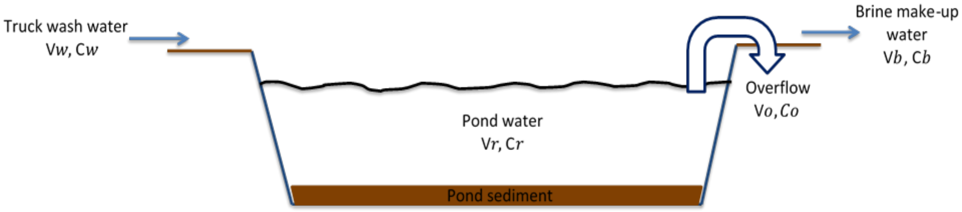


Figure 7. Inputs and outputs used in the mass balance to determine the winter metal and trace element concentrations in UDOT maintenance station retention ponds.

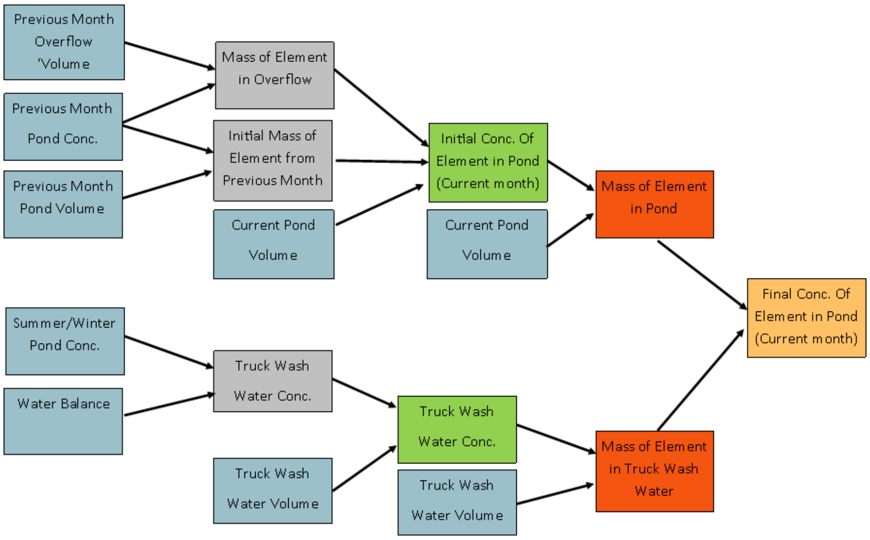


Figure 8. Variables used in the calculations for the mass balance in UDOT retention ponds.

Initial Concentration in the Pond (C_{r_i})

The initial concentration in the pond before the addition of truck wash water was calculated using Equation 3. The highest measured concentration (total or dissolved) of an element in the pond in August was used as the initial condition in the mass balance,

$$C_{r_i} = \frac{\left(C_{r_{f-1}} * V_{r-1}\right) - m_{o-1}}{V_r} \tag{3}$$

where, C_{r_i} is the concentration (mg/L) in the pond before truck wash water addition, $C_{r_{f-1}}$ is the final pond concentration (mg/L) from the previous month, V_{r-1} is the volume (L) of the pond from the previous month, m_{o-1} is the mass (mg) lost from overflow during the previous month, and V_r is the volume (L) of the pond for the current month. Both V_{r-1} and V_r come directly from the water balance described in the previous section. The calculation of $C_{r_{f-1}}$ is discussed in a later section. Like the water balance, the mass balance also starts in September and uses the measured metal and trace element concentrations in the ponds in August as the initial condition.

Concentration in the Truck Wash Water (C_w)

Because data on the concentration of metals and trace elements are not available for the wash water after truck washing, the concentrations of elements in the truck wash water were calculated iteratively. For three maintenance stations, Lehi, Salina, and Echo, the metals and trace element concentrations in the pond in August and December were known. The December metal and trace element concentrations for the Lehi, Salina, and Echo ponds were obtained from a previous study of UDOT retention ponds conducted in December 2017 (Gelles et al. 2017). Using the summer and winter concentrations in conjunction with the monthly water and salt balance calculations, the concentrations in the truck wash water at these three maintenance stations were determined using the *Goal Seek* function in Excel. The concentrations in the truck wash water for the remaining eight maintenance stations were assumed to be the average of the Lehi, Salina, and Echo truck wash water element concentrations. The high concentrations of some of the trace elements in the tap water at several maintenance stations, namely copper and zinc, would not affect the estimation of the winter pond concentrations as these elements either precipitate or sorb to pond sediments and are removed from the water column.

Final Concentration in the Pond ($\mathbf{C_{r_f}}$)

The final concentration of metals or trace elements in the pond was calculated using Equation 4,

$$C_{r_f} = \frac{\left[\left(C_{r_i} * V_r\right) + \left(C_w * V_w\right)\right]}{V_r} \tag{4}$$

where, C_{r_f} is the final concentration (mg/L) in the pond, C_{r_i} is the concentration (mg/L) in the pond before truck wash water addition, V_r is the volume (L) of the pond, c_w is the concentration (mg/L) in the truck wash water, and V_w is the volume (L) of the truck wash water.

Mass Lost in Overflow (m_o)

The mass lost in the overflow was calculated using Equation 5,

$$m_o = C_{r_f} * V_o \tag{5}$$

where, m_o is the mass (mg) of the element lost in the overflow, C_{r_f} is the final concentration (mg/L) in the pond (Equation 4), and V_o is the overflow volume (L) (Equation 2).

Surface Water Quality Modeling

Because portions of the roads serviced by UDOT maintenance stations are immediately adjacent to surface water bodies, surface water quality modeling was performed to determine the proper blending ratio of pond water to tap water for brine making at each site to prevent any adverse effects on surface water quality. The following sections outline the surface water quality modeling procedure used in this study.

Road and Surface Water Body Data

To determine the segments of road that are maintained by each maintenance station and located near surface water bodies, the UDOT *Station Boundary* layer from the UDOT Data Portal (2019) and the National Hydrography Dataset from the USGS (2019a) were used. The datasets were loaded into ArcMap to determine the road segments less than 40 meters (120 feet) from a surface water body and the length of these road segments. Forty meters was used for the distance between the roadway and surface water body because a study conducted by Blomqvist and Johansson (1999) found that deicing salt could be transported 40 meters from roadsides via air and road spray. Google Earth Pro was then used to find the slope of the surface water body along these segments of road. The slope of the surface water body was then used to find the dispersion coefficient.

Stream Flow Data

Stream flow data for the rivers and streams paralleling the road segments of interest were obtained from stream gages operated by the USGS (2019b) and the Utah Division of Water Rights (2019). Only flow measurements for November, December, and January were used to simulate the flow conditions when brine is being applied to the roadways. When available, the stage height, stream width, and stream velocity in November, December, and January were also used. If the stream width was not recorded, the approximate width of the river or stream along the road segment was measured using Google Earth Pro.

Assumptions

The following assumptions were used to model the effect of brine on surface water quality:

1. The brine application rate is 30 gallons/mile per lane with the number of lanes specific to each site and roadway (J. Garahana, UDOT, personal communication, Oct. 16, 2019).
2. The brine is an instantaneous line source, meaning it is only applied once during the time period being modeled and enters

the surface water body along the entire length of the road.

3. The brine acts as a conservative pollutant, therefore reaction and adsorption to sediments and suspended solids are negligible (k and $k_s = 0$).
4. Both dispersion and advection affect the transport of the brine once it enters the surface water body.
5. The surface water body has a constant longitudinal (x) velocity and only one-dimensional (longitudinal) transport is considered.

Modeling Equations

Because both dispersion and advection affect the transport of pollutants in surface water bodies, an analytical solution for the advection dispersion equation for an instantaneous volume source distributed along the length of a surface water body was used (TAMU 2019). The initial concentration at the start of the surface water body (L_1) (m) was estimated using Equation 6,

$$C_i = \frac{M}{A(L_2 - L_1)} \tag{6}$$

where, C_i is the initial concentration (mg/m^3) at L_1, M is the mass of pollutant injected from L_1 to L_2 (mg), L_2 is the length of the surface water body receiving the instantaneous volume source (m), and A is the cross-sectional area of the surface water body (m^2).

The concentration at a distance x (m) along the surface water body at time t (s) was calculated using Equation 7,

$$C(x,t) = \frac{C_i e^{-kt}}{2}\left(erf\,\frac{((x-L_1)-Ut)}{\sqrt{4D_x t}} - erf\,\frac{((x-L_2)-Ut)}{\sqrt{4D_x t}} \right) \tag{7}$$

where C(x,t) (mg/L) is the concentration of the pollutant in the surface water, k is the reaction rate (s^{-1}), U is the longitudinal velocity (m/s), and D_x is the longitudinal dispersion coefficient (m^2/s). Because brine is assumed to act as a conservative pollutant, the reaction rate, k, is 0 as mentioned previously.

The longitudinal dispersion coefficient, D_x, was calculated according to Equation 8 from Appendix B (TAMU 2019).

$$D_x = 0.058\frac{Q}{SB} \tag{8}$$

where Q is the flow rate (m^3/s), S is the slope of the water surface (m/m), and B is the width of the surface water body (m).

Metals and Trace Elements Concentration Calculations

Using the stream gage data and Equations 6, 7, and 8, the transport of the metals and trace elements from the brine were modeled in the target surface water bodies. The location of the maximum concentration in the surface water body was determined using the *Max* function in Microsoft Excel. This location was then used to iteratively calculate what the maximum concentration of the metals and trace elements in the brine could be so the applicable aquatic standards are not exceeded.

Brine Calculations

The following sections outline the procedures used to calculate the concentration of metals and trace elements in the brine made from the tap water or a blend of the tap water and pond water at each maintenance station. The concentrations calculated in this section were compared to the maximum concentrations calculated using the surface water quality model from the previous section to determine if pond water can be used for brine make-up water without concern of violating aquatic standards.

Assumptions

The following assumptions were used to calculate the concentration of metals and trace elements in the brine produced at each maintenance station:

1. Brine is made to be 23% salt (Na) by weight.
2. Calculations are to produce 5,000 gallons of brine, which corresponds to the volume of the brine storage tanks.
3. Morton salt is the rock salt used for calculations involving rock salt

Winter Pond Water Concentrations

To calculate the concentration of the metals and trace elements in the pond water during the winter, the water and mass balances (Equations 1-5) were used. The final pond water concentration in December for each metal and trace element was used as the winter concentration ($c_{rf} = c_w$) for the brine calculations.

Calculations for Brine from Tap Water (TW)

An outline of the variables used in calculations for the production of brine from only tap water is presented in Figure 9.

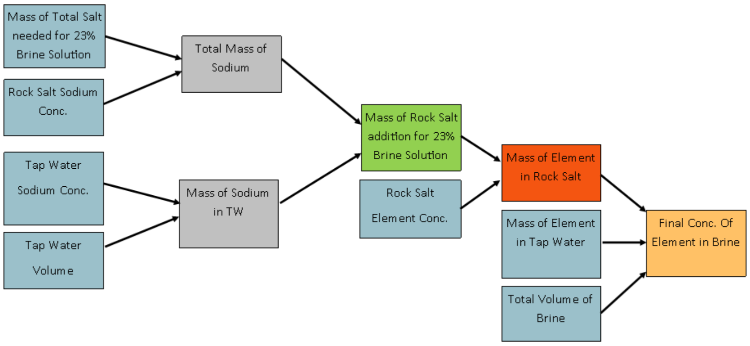


Figure 9. Variables used in the calculations to produce brine from tap water only.

Total Amount of Salt Required for 23% Brine Solution

The total amount of rock salt required to make a 23% brine solution was found using Equation 9,

$$m_{S,T} = \frac{V_T}{12\ gal\ H_2O} \times\ 23\ lb\ salt \qquad (9)$$

where $m_{S,T}$ is the total mass of salt required (lb) to produce a 23% brine solution, and V_T is the total volume of brine being produced (gallons). For the purpose of this study, the volume of brine being produced is constant at 5,000 gallons so the total mass of salt required is 9591 pounds.

Total Mass of Sodium Required for 23% Brine Solution

To find the total required mass of sodium to make a 23% brine solution, Equation 10 was used.

$$m_{Na,T} = C_{RS} \times m_{S,T} \tag{10}$$

where $m_{Na,T}$ is the total required amount of sodium to make a 23% brine solution (mg).

Mass of Elements from the Tap Water

The masses of individual elements in the tap water were calculated using Equation 11,

$$m_{E,TW} = C_{E,TW} V_{TW} \tag{11}$$

where $m_{E,TW}$ is the mass of the element in the tap water (mg), $C_{E,TW}$ is the concentration of the element in the tap water (mg/L), and V_{TW} is the volume of tap water (L).

Mass of Rock Salt Required to Make a 23% Brine Solution

The mass of salt required to be added to the tap water to make a 23% brine solution was calculated using Equation 12,

$$m_{Salt,add} = \frac{m_{Na,T} - m_{Na.TW}}{C_{RS}} \tag{12}$$

where $m_{Salt,add}$ is the mass of salt required to be added to the tap water to make a 23% brine solution (kg) and $m_{Na,TW}$ is the mass of sodium in the tap water calculated from Equation 11 (mg).

Mass of Other Metals and Trace Elements from Added Salt

To calculate the mass of the metals, besides sodium, and trace elements in the rock salt, Equation 13 was used.

$$m_{E,RS} = m_{salt,add} \times C_{RS} \tag{13}$$

where $m_{E,RS}$ is the mass of the element in the rock salt (mg).

Brine Concentration from Using Tap Water Only

The concentrations of the different elements in the final 23% brine solution were calculated using Equation 14,

$$C_{b,TW} = \frac{(m_{E,TW}+m_{E,RS})}{V_{TW}} \tag{14}$$

where $C_{b,TW}$ is the concentration of the element in the brine made with tap water (mg/L or µg/L).

Calculations for Brine Made from Tap Water and Pond Water

An outline of the variables used in calculations for the production of brine from tap water and pond water is presented in Figure 10.

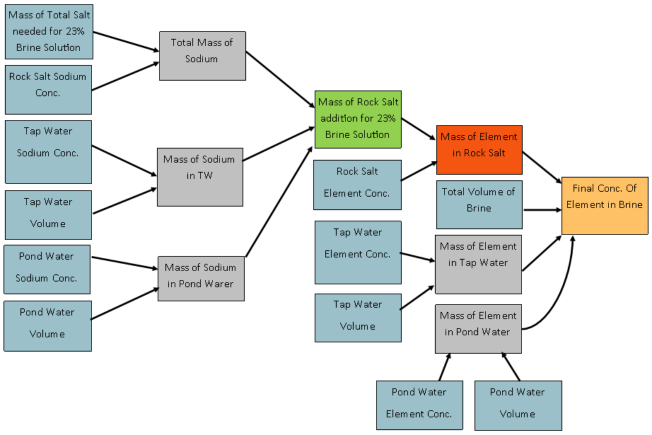


Figure 10. Variables used in the calculations to produce brine from tap water and truck wash water.

Volume of Tap Water and Pond Water

To calculate the volume of tap water (TW) and pond water (PW), a blending ratio must be specified in the form of PW to TW (1:2, 1:3, etc.). Using the blending ratio, the volume of tap water is calculated using Equation 15 and the volume of pond water is calculated using Equation 16,

$$V_{TW} = V_T \frac{r_{TW}}{(r_{TW}+r_{PW})} \tag{15}$$

$$V_{PW} = \frac{V_T}{(r_{TW}+r_{PW})} \tag{16}$$

where V_{TW} is the volume of tap water (L), r_{TW} is the number of parts of tap water in the blending ratio, and r_{PW} is the number of parts of pond water in the blending ratio. In this study, r_{PW} is constant at 1 and r_{TW} can be any integer.

Mass of Elements from the Pond Water

The masses of individual elements in the pond water were calculated using Equation 17,

$$m_{E,PW} = C_W V_{PW} \tag{17}$$

where $m_{E,PW}$ is the mass of the element in the pond water (mg), C_W is the concentration of the element in the pond water (mg/L), and V_{PW} is the volume of pond water (L).

Brine Concentration from Blending Tap Water and Pond Water

The concentrations of the different elements in the final 23% brine solution made from blending pond water and tap water were calculated using Equation 18,

$$C_{b,TW:PW} = \frac{(m_{E,TW}V_{TW}+m_{E,PW}V_{PW}+m_{E,S})}{V_T} \tag{18}$$

where $C_{b,TW:PW}$ is the concentration of the element in the brine made with tap water (mg/L or µg/L) and $m_{E,S}$ is the mass of the element in the added rock salt (mg), found using Equation 19.

$$m_{E,S} = m_{salt,plus} \times C_{RS} \tag{19}$$

where $m_{salt,plus}$ is the mass of rock salt (kg) added to the blend of tap water and pond water. The required mass of additional salt ($m_{salt,plus}$) for the blended brine to be 23% is calculated iteratively until $C_{b,TW}$ - $C_{b, TW:PW}$ = 0 for sodium.

RESULTS AND DISCUSSION

Site Information

When each UDOT maintenance station was visited for sample collection, some basic site information was noted, including pond type, tap water source, primary deicing chemical used at the facility, and inflows to the pond. Table 4 provides a summary of the basic information collected at each site.

Pollution Prevention Survey Responses

The Provo/Orem maintenance station did not have a conventional retention pond, so the pollution prevention survey was not applicable there. At the sites that did provide pollution prevention information, the site supervisor or regional stormwater coordinator answered the survey questions.

At the 11 maintenance stations with a conventional retention pond, the retention pond is positioned to capture truck wash water and runoff from salt and brine storage areas. Because the ponds are only designed to receive these two sources of runoff, the station supervisors were asked if any other waste streams enter the pond and, if so, where the waste stream originates. Seven of the station supervisors reported that no other waste streams enter the retention pond located on site. The remaining four sites reported the retention pond receives additional waste streams other than storm or wash water (Table 4). The ponds at both the Lehi and Brigham City facilities receive decant water from vactor trucks and street sweeping waste. Brigham City and Salina’s ponds also receive the waste from the oil water separator connected to the floor drains inside the main facility. At the Hooper facility, the magnesium chloride tank leaks into the pond.

Table 4. Basic information for the 11 UDOT maintenance stations where pond water samples were collected.

Site Name	Pond Type	Designed	Tap Water Source	Salting Material	Frequency of Overflow Events (per year)	Desire to Use Pond Water for Brine	Routine Pond Maintenance Schedule	Inflows to Pond
Kamas	Concrete	No	Well	NaCl; brine	3 to 4	Yes	Yearly	Stormwater Truck wash water
Heber	Lined	Yes	City	NaCl	None	Yes	None	Stormwater Truck wash water
Lehi	Lined	No	City	NaCl	1 to 2	Yes	None; skimmed with pool net	Stormwater Truck wash water Vactor truck waste
Clearfield	Asphalt	No	City	NaCl; $MgCl_2$	Daily in the winter	Yes	When pond fully evaporates	Stormwater Truck wash water
Brigham City	Asphalt	No	City	NaCl	None	Yes	None	Stormwater Truck wash water Vactor truck waste Oil water separator effluent
Salina	Lined	Yes	City	NaCl; brine	3 to 4	Yes	None	Stormwater Truck wash water Oil water separator effluent
Junction	Asphalt	No	Well	NaCl; brine	1 to 2	No	None	Stormwater Truck wash water
Silver Summit	Asphalt	No	City	NaCl; brine (from pond water)	1 to 2	Yes	Yearly	Stormwater Truck wash water
Echo	Asphalt	No	Well	NaCl	None	No	None	Stormwater Truck wash water
Huntsville	Asphalt	No	Well	NaCl	None	Yes	Yearly	Stormwater Truck wash water
Hooper	Lined	No	City	NaCl; $MgCl_2$	1 to 2	Yes	None	Stormwater Truck wash water Leaking $MgCl_2$ tank

As a follow-up to the previous question, the station supervisors at the four facilities whose ponds receive additional waste streams were asked what procedures were in place to prevent the waste streams from entering the pond. Of the four sites, three had procedures in place to prevent the waste streams from entering the pond. At the Lehi facility, the vactor truck and street sweeping waste is surrounded by concrete jersey barriers to prevent the solid debris from entering the pond. The barriers, however, do not prevent the decant water from reaching the pond. Brigham City does not have any procedures in place regarding the vactor truck and street sweeping waste or to prevent large spills from reaching the floor drains. In Salina, UDOT employees use absorbent pads and granules to clean up large spills before they reach the floor drains.

In addition, the station supervisors were asked about the current procedure for pond maintenance. Seven (64%) of the sites do not have a pond maintenance procedure and the pond on site had never been cleaned (Table 4). Most of the ponds had not been cleaned because either the pond never fully evaporates or is poly lined. For facilities with ponds that never completely evaporate, most of the supervisors said that if the pond does completely dry out, it will be cleaned at that time. A method for cleaning ponds that are poly-lined has yet to be determined since the equipment that would typically be used to clean the pond would damage the liner. Even though most of the surveyed ponds never completely evaporate, two station supervisors perform what maintenance they can. At the Lehi facility, the pond is skimmed with a pool skimmer, and at the Junction facility, the edges of the pond are re-sealed with asphalt when the pond is low. The four sites that do have a procedure for pond maintenance dredge the pond every year when it dries up and if the pond is asphalt, the surface is re-sealed.

Like the previous question, of the 11 sites surveyed, seven reported that the retention pond on site has overflowed (Table 4). Most commonly, truck wash water causes the ponds to overflow in the winter, but monsoon rains and rising groundwater have also caused overflow events in the summer. At two of the facilities (Lehi and Silver Summit), water has been pumped out of the pond and hauled away to prevent the pond from overflowing. According to one of the station supervisors, pumping and hauling the pond water off site for disposal costs approximately $30,000 to remove 1 foot of water.

Based on the responses from the pollution prevention survey, excess waste streams are mostly diverted away from the ponds, reducing contamination and the required pond volume. The retention ponds are also serving their intended purpose of catching salt laden stormwater and truck wash water at most of the facilities. Over half of the ponds, however, have overflowed, which indicates the need for larger capacity ponds or to reuse the truck wash water in some fashion. Not only have over half of the ponds overflowed, at least half also have never been cleaned/maintained. Implementing a pond maintenance procedure will reduce the sediment load in the ponds and improve pond water quality, which would be beneficial for pond water reuse.

Road Salt Analysis

Two granular road salts and one liquid brine ($MgCl_2$) were obtained from the Logan UDOT maintenance station. The two granular salts were Morton salt and Redmond salt. Each granular salt, along with the liquid $MgCl_2$, was analyzed for metals and trace elements. The concentration of the liquid $MgCl_2$ was determined using a density of 1.28 kg/L (DEUSA International 2018). The results are summarized in Table 5.

Table 5. Total metals and trace elements analysis for the primary chemical deicers used by UDOT. All results are reported in units of mg/kg salt.

mg/kg	Morton Salt	Redmond Salt	$MgCl_2$
Na	390,000	350,000	6,600
K	1,000	110	490
Ca	1,200	5,000	990
Mg	1,200	180	72,000
Al	0.05	0.06	0.80
Si	12	23	2.6
Fe	8.0	13	0.86
Mn	0.50	0.70	0.63
As	0.06	0.02	2.8
Se	0.08	0.08	0.39
Cu	0.41	0.62	0.04
Zn	6.7	0.50	0.59
Pb	<0.01	<0.01	0.01
Cd	0.03	0.02	<0.01

The two granular road salts are not a significant source of trace elements of environmental concern (Table 5). As a result, at UDOT facilities that primarily use granular salt, trace elements are not expected to limit pond water reuse, if there are no other sources for these contaminants on site. The $MgCl_2$, however, has elevated levels of aluminum (Al), arsenic (As), and selenium (Se) compared to the three granular salts (Table 5). The concentrations of these three elements in the $MgCl_2$ brine could be of concern at UDOT facilities where $MgCl_2$ is used because the brine could be contributing significant amounts of these elements to the retention pond water. Two of the elements, arsenic and selenium, have aquatic standards which could limit pond water reuse.

Sediment Samples

Sediment samples were collected from 10 maintenance stations. Sediment samples were not collected from two of the conventional retention ponds, Kamas and Clearfield, due to the absence of sediment in the ponds. The Provo/Orem maintenance station did not have a conventional retention pond, but a sludge pit. The sediment from the sludge pit was collected and also tested in triplicate, giving a total of 10 maintenance stations whose sediment was tested.

Total Metals and Trace Elements

Macro Metals

The sediment collected from 10 maintenance stations was analyzed for total metals according to USEPA Method 3050B (USEPA 1996). Table 6 summarizes the concentration ranges of the metals in the pond sediments as well as the ranges found in typical soil (Lindsay 1979). All results are reported in mg/kg of soil on a dry weight basis and the data for the individual UDOT sites can be found in Table C1 (Appendix C).

Table 6. Range of macro metals in soil and the pond sediments from 10 UDOT maintenance stations. Range of metals in soil from Lindsay (1979).

mg/kg	Range of metals in soil	Range of metals in pond sediments
Na	750-7,000	2,500-370,000
Mg	600-6,000	2,600-18,000
Ca	7,000-500,000	5,500-93,000
K	400-3,000	540-5,400

The concentration range of calcium in the pond sediments is within the range of typical soil, but the concentration range of sodium, magnesium, and potassium in the pond sediments exceed the range found in a typical soil. Because the sediment samples were collected in the late summer after the evaporation of most of the pond water, the elevated sodium and magnesium concentrations are most likely from the precipitation and settling of salt crystals from the evaporating pond water. The slightly increased levels of potassium could also be from the addition of road salt to the ponds as the Morton salt has elevated levels of potassium.

Trace Elements

Sediment samples from the retention ponds were also analyzed for trace elements (Table 7). All results are reported in mg/kg of soil on a dry weight basis and the data for the individual UDOT maintenance stations can be found in Table C1 (Appendix C).

Table 7. Range of the trace elements in soil and the retention pond sediments. Range of metals in soil from Lindsay (1979).

mg/kg	Range of metals in soil	Range of metals in pond sediments
As	1.0-50	1.2-15
Cd	0.01-0.7	0.1-1.6
Cr	40-70	50-570
Cu	2-100	8-114
Fe	7,000-550,000	1,600-21,000
Ni	0.2-450	20-370
Pb	2-200	4.5-66
Se	0.1-2	0.2-1.2
Zn	20-300	43-1,100

Most of the trace elements in the pond sediments are within the range of typical soil (Table 7) (Lindsay 1979). The upper concentrations of cadmium, chromium, and zinc, however, are outside of the range for typical soil. These three metals are common components of break dust, which could accumulate on the snowplows and salt trucks and be washed into the pond with the road salt at the end of storm events. The elevated concentrations of these three metals could also be attributed to natural geologic sources that have trace element concentrations outside of the typical range. While the concentration range of cadmium, chromium, and zinc are elevated, this analysis indicates that the trace elements concentration in the sediment is not likely to limit its disposal.

Toxicity Characteristic Leaching Procedure

The toxicity characteristic leaching procedure (TCLP) is used to classify solid waste as hazardous or non-hazardous by simulating leaching conditions that might be found in a landfill. TCLP results dictate the proper disposal method for unclassified solid waste. A solid waste is hazardous if the TCLP extract, after an acid digestion of that extract, has metal concentrations above those listed in Table 8.

The average concentrations of each metal in the digested TCLP extract for the 10 retention pond sediments are reported in Table 8. The TCLP metals in the digested extracts are below the regulatory limits, indicating that the retention pond sediments are not hazardous based on their total metal concentrations in the TCLP extraction, and can be disposed of as a non-hazardous waste, as long as the concentration of organics also meets disposal requirements.

Table 8. Concentration of regulated metals in the digested TCLP extract for the sediment in 10 UDOT retention ponds.

Site Name		Concentration (μg/L)					
		As	Ba	Cd	Cr	Pb	Se
Regulatory Limit		5000	100000	1000	5000	5000	1000
Heber	Mean	17.5	703	12.3	2.06	1.91	1.01
	St. Dev.	1.72	112	2.48	0.71	1.13	0.40
Lehi	Mean	8.35	838	9.58	3.52	1.28	2.48
	St. Dev.	0.66	1.47	1.31	0.52	0.37	1.47
Provo/Orem	Mean	9.49	1213	6.85	2.49	13.24	0.94
	St. Dev.	5.77	311	1.28	0.73	3.16	0.25
Brigham City	Mean	2.76	385	14.1	7.20	3.69	0.33
	St. Dev.	1.00	79.1	8.35	4.31	1.97	0.02
Salina	Mean	4.09	761	8.33	3.85	7.50	11.0
	St. Dev.	1.53	770	8.96	1.90	9.77	17.8
Junction	Mean	14.5	731	8.06	1.29	0.83	0.37
	St. Dev.	10.6	489	5.64	0.57	0.17	0.06
Silver Summit	Mean	4.82	476	6.37	2.35	2.25	0.49
	St. Dev.	1.15	48.1	1.23	2.31	2.28	0.18
Echo	Mean	7.28	728	1.45	1.48	2.92	0.25
	St. Dev.	2.40	86.5	0.73	0.37	1.30	0.06
Huntsville	Mean	9.94	772	11.4	7.99	7.05	0.93
	St. Dev.	5.55	199	5.88	3.34	3.18	0.36
Hooper	Mean	12.2	651	9.05	3.96	13.1	14.9
	St. Dev.	17.9	684	7.87	3.48	19.0	14.3

Oil and Grease and TPH

The pond sediments were also analyzed for O&G and TPH. Standard quality control procedures were used and the results are reported in Table C2 (Appendix C). Data presented in this section were not corrected based on quality control results, but since spike recoveries were within 25% of the expected value, concentrations should not require adjustment.

The O&G concentration (g/kg) ranged from a low at Hooper (3.7 g/kg) to a high at Silver Summit (32 g/kg) (Figure 11). The mean concentration across all sites was 21.0 g/kg and the median was 21.8 g/kg. Most of the sites had similar concentrations of O&G regardless of site management and additional waste streams. TPH concentrations ranged from a low of 92 mg/kg (Hooper) to 2,160 mg/kg (Silver Summit) (Figure 12). Sediment samples were collected from three random locations in each of the ponds. The sediments within a pond were not homogenous as is evident from the large variance associated with the O&G and TPH measurements (Figures 11 and 12). O&G and TPH data for the triplicate samples from each site are reported in Table C3 (Appendix C).

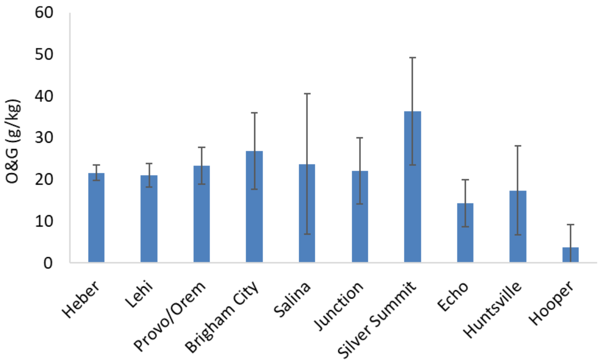


Figure 11. Oil and grease concentration (g/kg) extracted from the pond sediments. Error bars represent a 95% confidence interval.

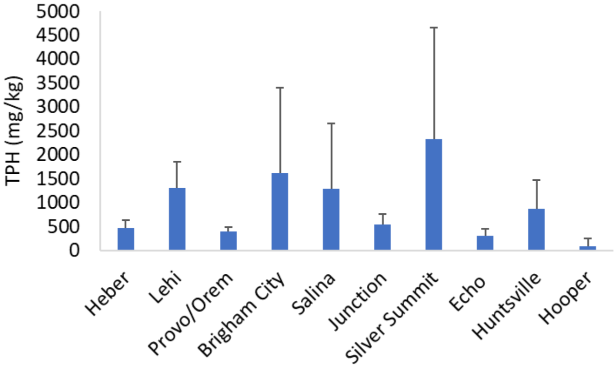


Figure 12. TPH concentration (mg/kg) extracted from the pond sediments. Error bars represent a 95% confidence interval.

Kamas, Silver Summit, and Huntsville remove the sediments annually and Clearfield removes sediments when the pond dries. The other sites have never been dredged. Annual cleaning has not resulted in lower levels of O&G nor TPH associated with the solids. The presence of O&G components was evident with drying of the sediments prior to extraction as shown in Figure 13.

Figure 13. Oil and grease in the dried pond sediment from Brigham City.

There are few regulatory controls associated with O&G that could limit the disposal of these pond sediments. General guidelines from the UDEQ, Division of Environmental Response and Remediation (Utah DERR 2015), related to the disposition of petroleum-contaminated soils, were referenced to evaluate potential actions necessary for pond sediment treatment and disposal. Based on initial screening levels, O&G concentrations in soils below 1 g/kg and TPH less than 500 mg/kg, require no further action. This also roughly corresponds to the level below which landfills accept solids for disposal without further treatment. Tier 1 Screening Criteria for O&G in soils, defining maximum soil concentration limits at sites in which no proximate property or groundwater wells might be impacted, are listed at 10 g/kg and 5,000 mg/kg TPH (Utah DERR 2015). Above the 10 g/kg O&G and 5,000 mg/kg TPH values, further treatment is mandatory to reduce the risk of exposure and impact from contaminated solids, with final soil cleanup levels determined on a site-specific basis based on a risk based corrective action approach (Utah DERR 2015).

In the context of disposal of oil and grease contaminated pond sediments, oil and grease levels above 1 g/kg and TPH above 500 mg/kg would require further treatment, with the sole location in the state accepting such waste being E.T. Technologies Soil Regeneration Facility adjacent to the Salt Lake County Solid Waste Management Facility in Salt Lake County. E.T. Technologies uses a sliding scale to charge for treatment of non-hazardous, petroleum contaminated soils and sludges, based on the TPH content of the material. As of December 1, 2019, the rates are \$20.20/T for < 5,000 mg/kg TPH, \$26.50/T for 5,000 to 10,000 mg/kg TPH, and \$32.50/T for >10,000 mg/kg TPH (E.T. Technologies, Inc. 2019).

Proper management and disposal of pond sludges should then be based on the level of O&G in the samples, along with the corresponding TPH. If an O&G

concentration is below 1 g/kg and/or TPH is below 500 mg/kg, disposal in a Subtitle D landfill should be possible without further treatment. O&G levels above 1 g/kg, and TPH levels above 500 mg/kg would require further treatment prior to disposal and would be charged at the rates stated above based on TPH concentration levels upon arrival at the treatment facility. It should be noted that these costs do not include transportation, the Salt Lake County Health Department fee of $0.40/T, or any special handling that may be required at the E.T. Technology facility based on elevated pH levels above 9, waste consistency issues, etc.

Pond and Tap Water Samples

Pond and tap water samples were collected at 11 UDOT maintenance stations. The Provo/Orem maintenance station did not have a conventional retention pond, so water samples were not collected at this maintenance station.

Field Parameters

Pond water and tap water were analyzed on-site for pH and temperature (Table 9). The pH of the pond and tap water range from 6.9 to 8.5, which is typical for water in Utah (Mesner and Geiger 2005). Electrical conductivity was also measured in the pond water, but the EC readings exceeded the upper limit of the instrument (>6 mS/cm).

Total Suspended, Volatile, and Dissolved Solids

Both the pond and tap water samples were analyzed for TSS, VSS, and TDS. The results for the pond water are presented in Figure 14, with TSS and VSS reported in mg/L and TDS reported in g/L. The method detection limit (MDL) for TSS and VSS is 1 mg/L and 0.01 g/L for TDS. For the equipment and trip blanks, 70% were below the MDL for TSS and VSS. For TDS, 60% of the equipment and trip blanks were below the MDL. The equipment blanks were occasionally above the MDL for both TSS/VSS and TDS due to the inefficiency of decontamination procedures for ponds with high salt and suspended solids concentrations. The average TSS concentration of the equipment blanks was 4.32 mg/L and 3.64 mg/L for VSS. These concentrations are significantly lower than the samples concentrations and therefore, have little affect on the reported sample values. For TDS, the average equipment blank concentration was 0.099 g/L, which again is significantly lower than the sample concentrations and has little affect on the reported sample concentrations.

Table 9. Measured field parameters of the pond and tap water at each of the 11 UDOT maintenance stations. Location A, B, and C designate the three locations around the pond where samples were collected. Tap water was collected directly from the wash rack so only one sample was collected for field parameter measurement.

Site Name	Location	pH	Water Temperature (°C)
Kamas	A	7.1	21
	B	7.3	21
	C	7.3	21
	Tap water	6.9	23
Heber	A	8.0	20
	B	8.2	22
	C	8.2	21
	Tap water	7.6	28
Lehi	A	7.6	19
	B	7.7	19
	C	7.7	19
	Tap water	7.7	28
Clearfield	A	6.9	36
	B	6.9	34
	C	6.9	35
	Tap water	8.0	30
Brigham City	A	8.4	15
	B	8.4	16
	C	8.4	16
	Tap water	7.7	25
Salina	A	7.6	26
	B	7.7	29
	C	7.8	28
	Tap water	7.6	32
Junction	A	7.9	21
	B	7.8	21
	C	7.4	24
	Tap water	7.4	21
Silver Summit	A	7.3	17
	B	8.0	18
	C	7.9	19
	Tap water	8.5	20
Echo	A	7.1	21
	B	7.5	21
	C	7.1	22
	Tap water	8.1	25
Huntsville	A	7.5	27
	B	7.7	27
	C	7.9	26
	Tap water	8.2	25
Hooper	A	7.2	32
	B	7.2	31
	C	7.0	32
	Tap water	8.1	30

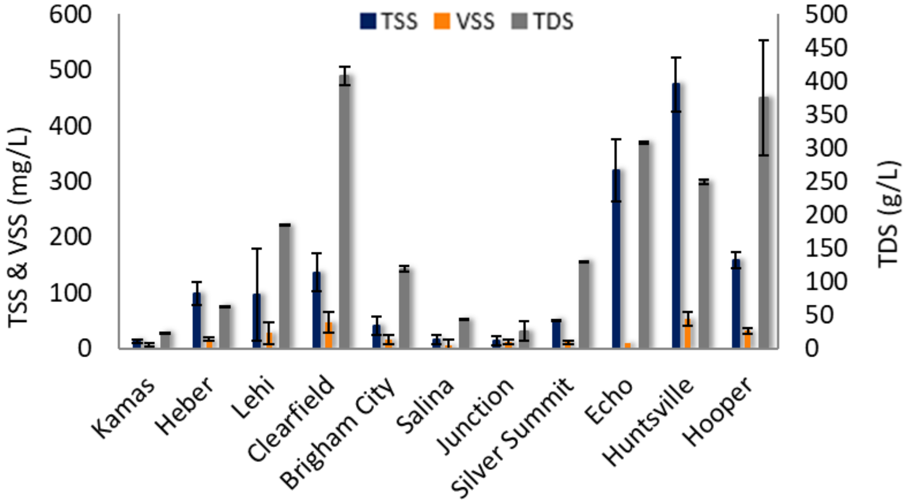


Figure 14. TSS, VSS, and TDS in the pond water samples collected from 11 UDOT facilities. Error bars represent a 95% confidence interval.

The elevated suspended solids concentration in the pond water is likely from the suspension of pond sediments due to the low water level in the ponds at the time of sampling and the precipitation of salts. This could potentially interfere with the pumping and dispensing of brine made with pond water as the solids could damage pump components and clog sprayers and nozzles. Higher pond volumes in the winter when pumping would occur allows for better separation of the solids in the pond, but care should still be taken not to resuspend pond sediments. The VSS in the pond water samples ranges from 6.7 mg/L at Kamas to 53 mg/L at Huntsville Additionally, the VSS concentrations are 3.1 to 87% of the TSS concentration in the pond water. At Junction, where VSS accounts for 87% of the TSS, most of the solids are organic and this is due to the presence of brine shrimp and dead plant material observed in the pond water samples. At Echo, however, the VSS accounts for only 4.6% of the TSS, indicating the solids are primarily inorganic.

Because of the high concentration of salts in the ponds, the TDS concentration is well above typical values for Utah water. While the high TDS concentration is not problematic for pond water reuse, the concentrations of the individual TDS constituents (metals and trace elements) could be of concern and are discussed in the next section.

The concentrations of TSS, VSS, and TDS in the tap water samples are summarized in Figure 15. The tap water at the Kamas maintenance station had an unusually high concentration of TSS because it comes from a groundwater well and is not treated. The highest TDS concentrations were at the Echo (0.99 g/L) and Hooper (0.64 g/L) maintenance stations. At most of the maintenance stations, however, the constituents of TSS and TDS are being introduced into the ponds through other sources, notably through stormwater and washing snowplows and salt trucks.

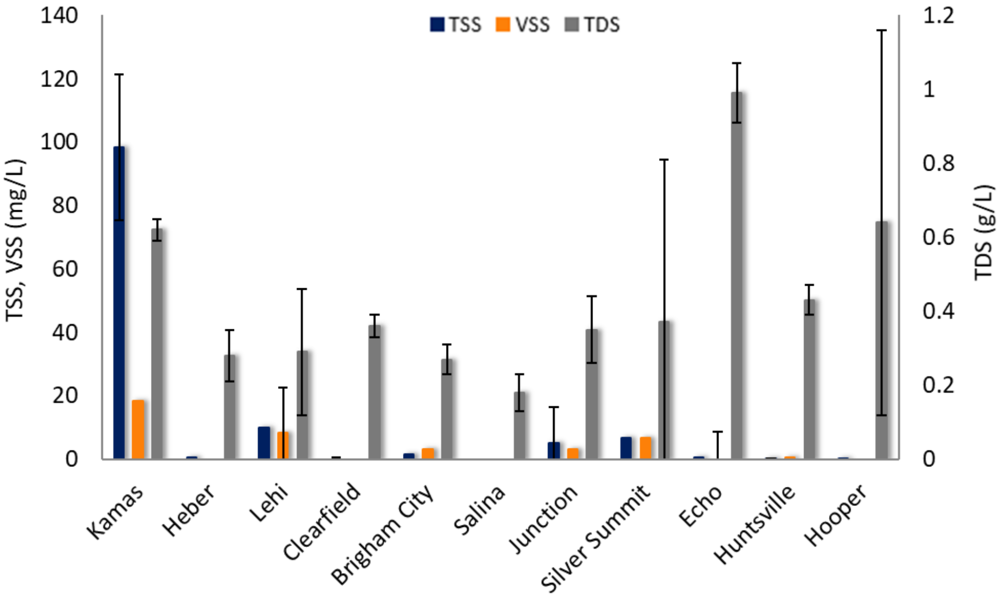


Figure 15. TSS, VSS, and TDS of the tap water samples collected from 11 UDOT facilities. Error bars represent a 95% confidence interval.

Total and Dissolved Metals and Trace Elements

Total and dissolved metals and trace elements were analyzed in the pond and tap water samples by ICPMS. Trip and equipment blanks were below the MDLs for 80% of the samples. For blanks with detectable concentrations, the MDLs were most commonly exceeded for the macro metals, not the trace elements. This again is due to the inefficiency of decontamination procedures. Because of the high salt content of the samples, there was occasional carryover between samples and blanks. The high salt content also created matrix interferences for some of the trace elements, notably copper and selenium. Because of the matrix interferences, the highest measured concentrations for copper and selenium were used in all subsequent data analysis procedures and calculations. Reported data have not been corrected to account for any quality control results or interferences.

Macro Metals

The total concentrations of sodium, magnesium, calcium and potassium were compared in the pond water for the 11 sites (Figure 16 A-D). The sodium concentration of seawater (10.7 g/L) (Nelson 2019) and water from the Great Salt Lake (83.6 g/L) (Nelson 2019) are provided as reference values for the sodium concentration in the ponds (Figure 16A). The data for the individual sites and MDL for each metal can be found in Table C4 for total metals and Table C5 for dissolved metals (Appendix C).

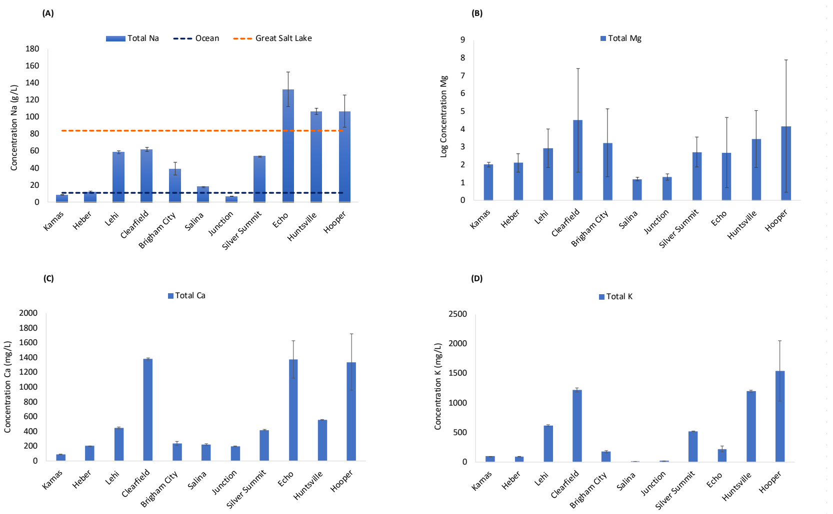


Figure 16. Total sodium (A), magnesium (B), calcium (C), and potassium (D) concentration of the retention pond water collected from 11 UDOT facilities. Error bars represent the 95% confidence interval of triplicate measurements.

The total sodium concentration in 10 of the retention ponds is higher than the sodium concentration in the ocean and three ponds have a total sodium concentration higher than the Great Salt Lake (Figure 16A). The high concentrations are from the influx of road salt in the truck wash water and subsequent evaporation of the ponds during the summer when samples were collected. Total magnesium is also elevated in the Clearfield and Hooper ponds because both sites use $MgCl_2$ as their primary anti-icing and deicing chemical. The total calcium and potassium concentrations are also elevated in these ponds from the addition of salt.

Table 10 presents the percent of the dissolved concentration to the total concentration for each metal at the 11 maintenance stations. A percent followed by an asterisk indicates the dissolved concentration was not significantly different from the total concentration using a t-test with an alpha value of 0.05 and indicates the metal is 100% dissolved.

Table 10. Percent of the dissolved macro metal concentration to the total concentration in the retention ponds at 11 UDOT maintenance stations. A * indicates there is no significant difference between the concentrations using a t-test with α=0.05.

	Na	Mg	K	Ca
Kamas	71.0*	103*	94.0*	94.5*
Heber	186	116*	95.5*	112*
Lehi	96.7*	100*	93.0	96.8*
Clearfield	81.1	80.9	87.5	106*
Brigham City	219*	19.6*	50.8*	45.4*
Salina	84.4*	97.4*	96.7*	92.0*
Junction	109*	89.6*	81.3	70.3
Silver Summit	79.9	86.8	77.6	88.7
Echo	82.8*	91.0*	88.0*	88.6*
Huntsville	92.7*	93.2	90.9	97.1*
Hooper	98.6*	94.4*	90.1*	91.2*

At most of the maintenance stations, the percent of the dissolved to total concentration ranged from 70-100% for these four metals. A percent close to 100 was expected for sodium and potassium, as they are highly soluble in water and do not sorb well to solids. The metals that are significantly less than 100%, such as sodium at Silver Summit or magnesium and calcium at Junction, indicate the precipitation of these metals due to the super saturated conditions in the ponds at the time of sampling.

The metals were also measured in the tap water at the 11 maintenance stations. For sodium, magnesium, calcium, and potassium, the concentration of these metals in the tap water is typical for Utah at all 11 sites (Table 11) (SLC Public Utilities 2019).

Table 11. Concentration ranges for the metals in the tap water from 11 UDOT maintenance stations.

Metal	Concentration (mg/L)	
	Low	High
Na	7.1	220
Mg	6.5	63
Ca	35	130
K	0.8	7.1

The ratios of the total concentration of each metal in the pond water compared to the tap water were calculated (Table 12). Except for calcium at the Kamas maintenance station and magnesium at Junction, the large ratios indicate the pond water has a significantly higher concentration of metals than the tap water. At most of the maintenance stations, a majority of the metals in the pond come from the salt-laden wash water produced from washing snowplows and spreaders after winter storms.

Table 12. Ratio of the total concentration of the macro metals in the pond water to the tap water at 11 UDOT maintenance stations. A * indicates there is no significant difference between the concentrations using a t-test with α=0.05.

	Na	Mg	K	Ca
Kamas	235	4.60	21.9	0.91
Heber	1120	9.44	42.1	3.19
Lehi	1370	39.9	180	10.4
Clearfield	2470	1590	569	17.4
Brigham City	2.00	2.00	1.99	1.73
Salina	2020	2.45	4.21	9.60
Junction	223	1.08*	4.33	2.84
Silver Summit	3650	42.6	154	8.13
Echo	605	7.65	31.3	10.8
Huntsville	3870	142	856	8.60
Hooper	5820	969	873	23.8

Chloride

The chloride concentration of the pond water was not measured, but because there is an aquatic standard for chloride of 230 mg/L (USEPA 2019b), the chloride concentration in the pond water was estimated. The concentration of chloride was estimated using the sodium or magnesium concentration, depending on the primary deicer used at the facility, and the molar relationship of the metal to chloride in the salt (1:1 for sodium; 1:2 for magnesium). The estimated chloride concentration in the ponds at each maintenance station during the summer ranges from 12,000 to 204,000 mg/L. These concentrations exceed the aquatic standard for chloride of 230 mg/L. While maintaining public safety is the utmost priority, the impacts of these high chloride concentrations should be considered in determining the frequency and application rate of deicing chemicals.

Trace Elements

Select trace elements were also measured in the pond and tap water from 11 UDOT maintenance stations. Aquatic standards were used as reference values for the concentrations in the pond and tap water because of the sensitivity of aquatic organisms to trace elements. Even though aquatic standards are not directly applicable to retention ponds, if the concentrations of trace elements in the pond water exceed aquatic standards, aquatic ecosystems could be harmed by pond overflow events and the application of brine made from pond water. The effect of brine application on surface water bodies is explored in a later section. If, however, the trace element concentrations do not exceed aquatic standards, the pond water can be used without concern of harming aquatic ecosystems.

At two of the maintenance stations, Clearfield and Hooper, the concentration of total arsenic exceeds the acute aquatic standard of 340 μg/L (Figure 17A). The elevated arsenic concentrations in these two ponds may be linked to the liquid $MgCl_2$, which has a high concentration of arsenic (Table 5) and is the primary deicer used at these two facilities. The high arsenic concentration in these two ponds should be taken into consideration if the pond water is to be reused for brine. The acute aquatic standard for iron of 1,000 μg/L is only violated in the Huntsville retention pond (Figure 17B).

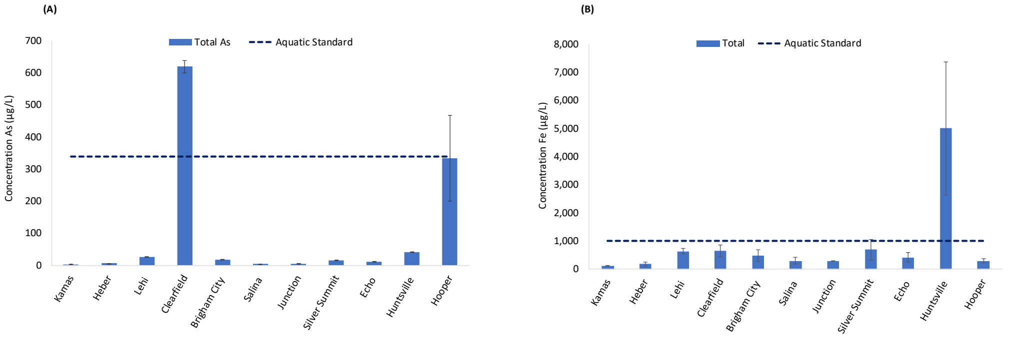


Figure 17. Total arsenic (A) and iron (B) concentrations in the retention pond water collected from 11 UDOT facilities. Error bars represent the 95% confidence interval of triplicate measurements.

The acute aquatic standards for copper (13 µg/L) and selenium (18 µg/L) are exceeded in most of the retention ponds sampled (Figure 18 A and B). The copper aquatic standard is exceeded in eight of the retention ponds, while the selenium standard is higher in seven of the ponds. Both elements were analytically challenging by ICPMS due to the high salt content of the samples. The high salt content of the samples caused matrix interferences that significantly increased the reported concentration of these elements. The ICPMS uses a collision cell to minimize poly atomic interferences, but interferences were still evident. Selenium was also analyzed using hydride generation atomic absorption spectroscopy, that would not have the same interference as ICPMS, but again results were affected by the high salt content of the samples. The results reported here are the highest concentration of these elements recorded using serial dilutions.

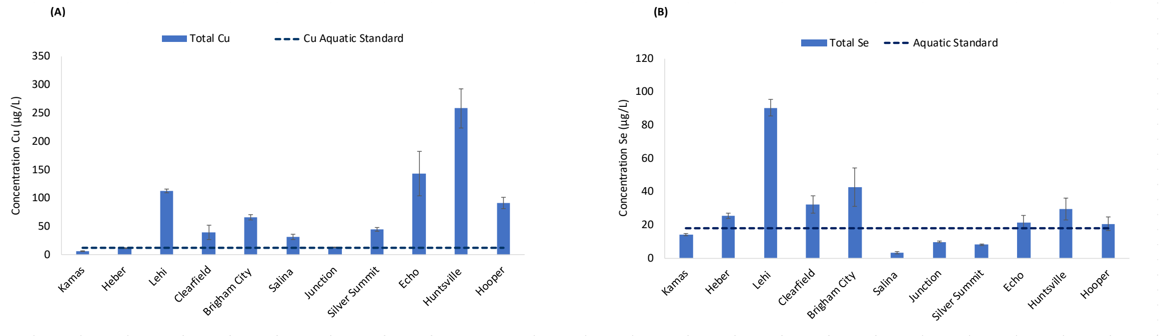


Figure 18. Total copper (A) and selenium (B) concentrations in the retention pond water collected from 11 UDOT facilities. Error bars represent the 95% confidence interval of triplicate measurements.

Other trace metals, cadmium (except for the 95% confidence interval overlapping the aquatic standard at the Brigham City site), chromium, nickel, lead, and zinc, in the pond water are below the applicable aquatic standards (Figure 19 A-E). The percent of the dissolved concentration to the total concentration for the trace elements at the different facilities are presented in Table 13. At most of the maintenance stations, the trace elements are 50-100% dissolved. Iron, however, is notably associated with solids as indicated by the low percentages in Table 13. At three sites, the reported concentration of dissolved selenium is multiple times higher than the total concentration. These results are, again, due to analytical challenges associated with the sample matrix. The samples analyzed for total trace elements were digested with nitric acid, which reduces potential interferences by breaking down solids and organic matter in the sample, while the samples for dissolved trace elements were only filtered.

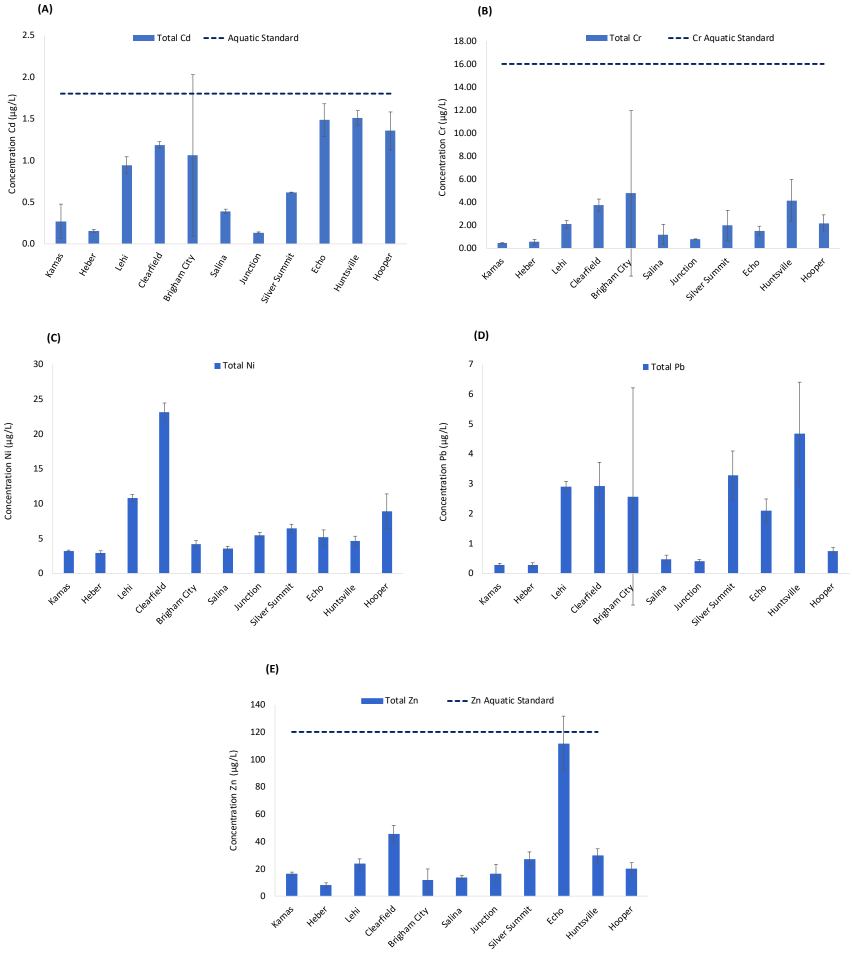


Figure 19. Total cadmium (A), chromium (B), nickel (C), lead (D), and zinc (E) concentrations in the retention pond water collected from 11 UDOT facilities. Error bars represent the 95% confidence interval of triplicate measurements. The dashed lines represent the acute aquatic standard for the given trace element. The aquatic standards for lead and nickel are 65 µg/L and 468 µg/L, respectively.

Table 13. Percent of the dissolved trace element concentration to the total concentration in the retention ponds at 11 UDOT maintenance stations. A * indicates there is no significant difference between the concentrations using a t-test with α=0.05.

	As	Cd	Cr	Cu	Fe	Ni	Pb	Se	Zn
Kamas	1.02*	0.67*	0.50	1.11*	0.50	0.93	0.72*	0.89	0.68
Heber	0.99*	1.98	0.47*	1.81	0.06	0.87*	0.59*	1.31	0.33
Lehi	0.97*	0.89*	0.35	0.80*	0.10	0.94*	0.53	0.55	0.53
Clearfield	1.04*	0.57	0.68	0.46*	0.16	1.00*	0.11	0.96*	0.72*
Brigham City	0.08*	2.23*	0.20*	1.57	0.30	0.47*	0.22*	1.11	0.10*
Salina	1.03*	0.89*	0.21*	0.49	0.11*	0.93*	0.30	5.97	0.64*
Junction	1.12*	0.89*	0.39	0.95	0.12	0.94*	0.21*	0.61	0.28*
Silver Summit	0.80	0.70	0.28*	1.22	0.09*	0.90*	0.21	6.92	0.41
Echo	0.79	0.53	0.47	1.15*	0.03*	0.73	1.04*	5.22	0.92*
Huntsville	0.96*	1.09*	0.09*	0.76*	0.00	0.86*	0.42*	0.89*	0.34
Hooper	1.08*	0.83*	0.99*	1.59*	0.13	0.83*	0.53	1.77*	0.32

The concentration ratios of the trace elements in the pond water compared to the tap water were determined (Table 14).

Table 14. Ratio of the total concentration of trace elements in the pond water to the tap water at 11 UDOT maintenance stations. Dashes indicate the ratio could not be calculated due to a divide by zero error. A * indicates there is no significant difference between the concentrations using a t-test with α=0.05.

	As	Cd	Cr	Cu	Fe	Ni	Pb	Se	Zn
Kamas	1.53	9.00*	0.32	0.06	0.31	0.70	0.11	98.7	0.04
Heber	3.93	6.57	2.09*	0.03	2.24*	0.63*	0.01	187	0.06*
Lehi	18.2	142	3.31	0.35	36.1	4.20	6.80	54.1	0.36
Clearfield	968	50.9	4.99	0.94*	29.5	66.1	1.00*	100	2.09
Brigham City	1.99	1.92*	1.34*	0.89*	1.97	1.95	--	1.92	1.10*
Salina	1.84	9.67	2.22*	2.55	3.33*	13.4	1.13*	20.3	0.24
Junction	1.21*	0.25*	1.08*	0.08*	8.36	2.47	0.11	70.5	0.21
Silver Summit	13.0	--	1.96*	0.06*	5.49*	7.77	0.88*	44.0	0.68*
Echo	33.0	26.2	0.50*	9.66	5.21	1.25*	3.81	16.5	2.60
Huntsville	68.4	41.2	2.76*	20.0	6.36*	2.25*	4.58	--	0.31
Hooper	254	136	1.12*	8.33	0.71*	30.1	3.33	60.51	1.02*

A significant amount of copper and zinc come from the tap water at some of the maintenance stations as indicated by their ratios being less than one (Table 14). At three of the maintenance stations (Kamas, Heber, Lehi), the concentration of total copper in the tap water is significantly higher than that in the pond (Figure 20A). Copper may enter the pond but is removed from the water column as it precipitates and settles into the pond sediments. Like copper, the concentration of total zinc is significantly higher in the tap water than in the pond water at five of the maintenance stations (Figure 20B). Interestingly, the tap water at five of the maintenance stations violates the copper aquatic standard of 13 µg/L. The zinc aquatic standard of 120 µg/L, however, is only exceeded in the tap water at two of the maintenance stations (Kamas and Heber). No other elements in the tap water violate aquatic standards.

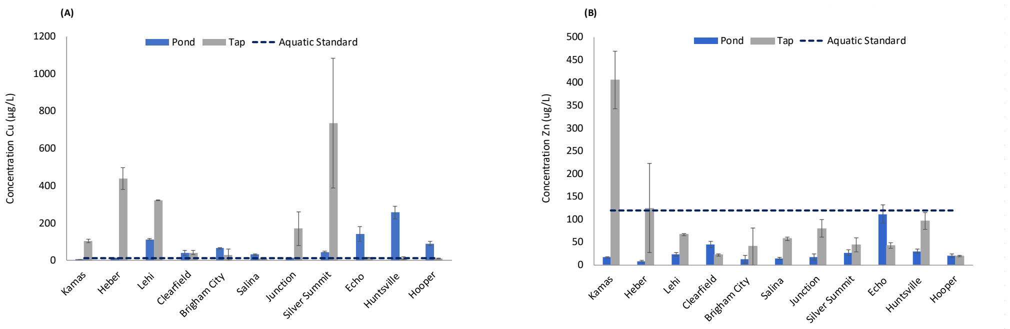


Figure 20. Concentration of total copper (A) and zinc (B) in the pond and tap water collected from 11 UDOT maintenance stations. The acute aquatic standard for copper is 13 µg/L and for zinc is 120 µg/L. Error bars represent the 95% confidence interval of triplicate measurements.

Most of the tap water at these sites is culinary water that meets drinking water maximum contaminant levels (MCLs). However, some elements are harmful to aquatic organisms at lower concentrations than the MCLs. For instance, the drinking water MCL for copper is 1 mg/L and for zinc is 5 mg/L (USEPA 2017), which are concentrations over 1000 times higher than the aquatic standards for these two metals. Because the concentration of total copper and zinc in the tap water at some of the maintenance stations exceeds the acute aquatic standards for these metals, brine produced by these maintenance stations should be analyzed prior to use, regardless of if pond water is being reused or not, to ensure aquatic standards will not be violated in the water bodies adjacent to roadways maintained by these facilities.

While the acute aquatic standard for copper is listed at 13 µg/L, the standard is usually adjusted using the biotic ligand model (BLM) (UDEQ 2017). The BLM adjusts aquatic standards to account for variations in metal toxicity using site specific water chemistry information, including pH, temperature, and certain anion and cation concentrations (Na^+, Mg^{2+}, SO_4^-, Cl^-) (USEPA 2016). Currently, a BLM is only applied for copper, but the EPA is working to develop a BLM for aluminum, zinc, and lead (USEPA 2016). Even though the EPA has not accepted a BLM for zinc, the UDEQ allows the zinc aquatic standard to be modified using a BLM or water effects ratio (UDEQ 2017). Given the hardness and alkalinity of Utah surface and ground waters, the aquatic standards for copper and zinc would be elevated using the BLM. As a result, using the BLM in future calculations for copper and zinc aquatic standards would provide a more realistic estimate of the aquatic impacts of reusing pond water for brine.

Oil and Grease (O&G)

The pond and tap water collected from the retention ponds were also analyzed for O&G. The MDL for oil and grease is 1 mg/L for the pond and tap water samples. Standard quality control procedures were used and the results are reported in Table C6 in Appendix C. The lab and matrix spike recoveries were low. In the pond water and matrix spike samples, a large emulsion layer formed, preventing a large portion of the oil and grease from separating into the solvent layer. Reported data have not been corrected to account for any quality control results, including spike recoveries. The average spike recovery for matrix spike samples was 38%. As such, the concentrations of O&G reported in this section are lower than would be expected with adequate spike recoveries.

The concentration of oil and grease in the pond water ranges from 3.11 mg/L at the Kamas maintenance station to 25.4 mg/L at the Hooper maintenance station (Figure 21). Correcting for the spike recoveries, the range of O&G in the samples could be 8.18 mg/L up to 66.8 mg/L. The discharge of O&G can lead to the formation of an oil layer on surface water bodies. The oil layer can inhibit photosynthesis and oxygen transfer, thereby reducing the concentration of DO in the water (Alade et al. 2011). In addition, oil and grease has a high BOD, which can further reduce the concentration of DO in receiving waters.

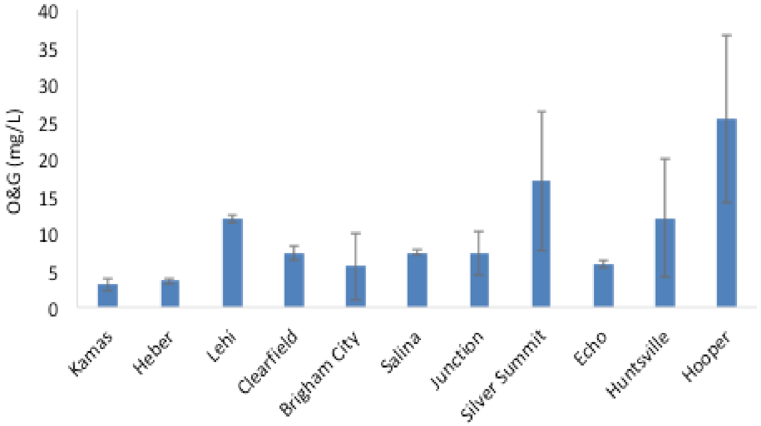


Figure 21. Concentration of oil and grease in the pond water at 11 UDOT maintenance stations. Error bars represent the 95% confidence interval of triplicate measurements.

Despite the possible detrimental environmental effects of O&G, there are currently no quantitative limits for O&G in stormwater discharges in Utah. O&G is commonly regulated via visual inspection. According to UDOT's MS4 permit, stormwater samples do not have to be analytically tested for pollutants, including O&G, only visually inspected (UDEQ 2015b). Before sampling, the ponds were visually inspected and only one pond (Kamas) was found to have a noticeable sheen. While Kamas has the lowest pond water concentration of oil and grease, the pond did not have sediment for the oil and grease to partition into, causing the sheen on the surface. If pollutants are observed in stormwater discharges (floating solids, odor, oil sheen, etc.) from the site, problems associated with pollutant sources and controls must be remedied to prevent further discharge to the MS4 (UDEQ 2015b).

The concentration of O&G in the tap water at 10 of the 11 maintenance stations were below the MDL of 1 mg/L. Kamas was the only station with a detectable O&G concentration in the tap water at 2.6 ± 0.89 mg /L. The water supply at Kamas is well water; the O&G detected may be due to the pump system.

Polyaromatic Hydrocarbons (PAHs) and Total Petroleum Hydrocarbons (TPH)

In addition to being analyzed for O&G, the pond and tap water samples were also analyzed for PAHs and TPH. A complete list of the analyzed PAHs and the raw data for all samples can be found in Table C7 (Appendix C), while the complete data set for TPH is reported in Table C8 (Appendix C).

Most of the water samples did not contain PAHs at concentrations above their detection limit of 0.001 mg/L. The concentrations of PAHs in the pond and tap water samples above 0.001 mg/L are summarized in Table 15. Because most of the water samples did not contain PAHs above 0.001 mg/L, PAHs are not a concern for the reuse of pond water at the sampled UDOT maintenance stations.

Table 15. Concentration of PAHs in the pond and tap water from the Kamas maintenance station, the only station with reportable concentrations of PAHs.

		Concentration (mg/L)		
Site	Water Type	Fluoranthene	Pyrene	1-phenyl-pyrene
Kamas	Pond			0.0024
	Tap	0.0015	0.0013	

The concentration of TPH in the pond water samples ranged from 0.8 mg/L at Kamas to 22 mg/L at Hooper (Figure 22). Both the Brigham City and Salina ponds had a relatively low concentration of TPH, despite receiving effluent from the oil water separators on site. The concentration of TPH was not expected to be high in the water samples due to the chemistry between TPH and water. The compounds that comprise

TPH are non-polar and therefore hydrophobic, which causes them to partition out of aqueous environments. For the tap water samples, the concentration of TPH ranged from <MDL at several of the sites to 2.4 mg/L at the Hooper maintenance station.

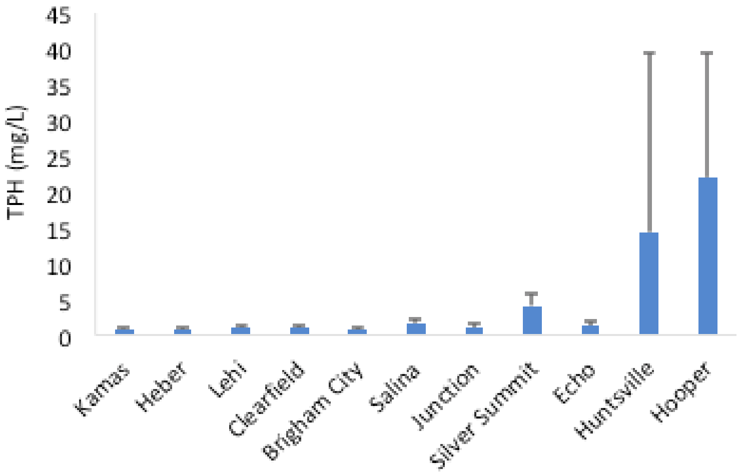


Figure 22. TPH concentration in the pond water at 11 UDOT maintenance stations. Error bars represent the 95% confidence interval of triplicate samples.

Pond Volume Estimation and Brine Calculations

In order to determine the feasibility of pond water reuse for salt brine, the concentration of metals in the pond water during the winter months had to be calculated. This was done using pond volume estimates, water balances, and a salt brine calculation tool. The pond volume estimates were used to develop pond design guidelines, which will help prevent overflow events and MS4 permit violations.

Pond Volume Estimation

Because nine of the 11 retention ponds sampled were either not designed or did not have readily available construction drawings, the volumes of these ponds were unknown. To estimate the volume of these ponds, traditional surveying methods, AutoCAD, and ArcGIS were used. A detailed description of the method can be found in

Appendix D.

To test the methodology described in Appendix D, a case study was performed using the retention ponds at the Heber and Salina UDOT facilities. Because the Heber and Salina retention ponds were engineered, the approximate volumes generated from the survey data were compared to the volumes listed in the design drawings. The volumes of the Heber and Salina retention ponds from the construction drawings and the approximate volumes of the ponds generated from three different surfaces created in ArcMap 10.6.1 are compared in Table 16. The *Spline with Barriers* TIN for the Heber pond is shown in Figure 23A and the Salina pond in Figure 23B.

Table 16. Volumes of the Heber and Salina retention ponds from the construction drawings and three surfaces created in ArcMap 10.6.1.

Method	Heber Pond Volume (ft^3)	Salina Pond Volume (ft^3)
Construction Drawing	36,550	8,021
Spline with Barriers TIN	36,311	8,330
Survey Points TIN	34,823	7,950
Spline with Barriers Raster	37,178	8,340

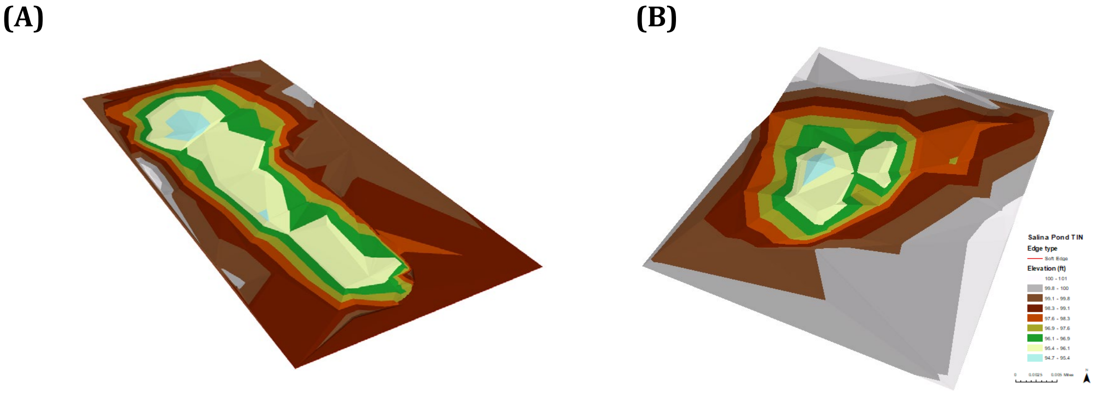


Figure 23. 3D representation of the TIN surface used to calculate the volume of the Heber (A) and Salina (B) retention ponds.

The approximate volume of the Heber retention pond generated from the *Spline with Barriers* TIN was 36,311 ft^3, which results in a 0.7 percent difference when compared with the construction drawing volume. Similarly, the *Spline with Barriers* TIN generated for the Salina retention pond provided an estimated volume of 8,343 ft^3, which is a 3.9 percent difference from the construction drawing volume. These results demonstrate that both the Heber and Salina UDOT retention pond volumes can be approximated accurately using the methodology described in Appendix D.

As a result of the case study, the methodology described in Appendix D was applied to the nine retention ponds with an unknown volume. The estimated volumes for all 11 ponds are presented in Table 17. The estimated pond volumes were used in the following section to complete a water balance on the ponds to determine the concentration of metals and trace elements in the pond water during the winter months.

Table 17. Estimated volumes for 11 UDOT retention ponds using polar surveying, AutoCAD, and ArcGIS. An * indicates the volume is known, not estimated.

Maintenance Station	Volume (ft^3)
Kamas	16,200
Heber	36,600*
Lehi	37,800
Clearfield	7,420
Brigham City	11,300
Salina	8,020*
Junction	5,340
Silver Summit	10,100
Echo	10,700
Huntsville	13,500
Hooper	22,100

Water Balance Results

To inform the development of site design guidelines and BMPs, a monthly water balance was calculated for the 11 conventional retention ponds. The water balance predicted that five of the 11 retention ponds would overflow based on the estimated precipitation, evaporation, and truck wash water volumes. This prediction is similar to the results of the pollution prevention survey, which indicated that seven of the ponds have overflowed. The ponds at the Kamas, Lehi, Clearfield, Salina, and Silver Summit maintenance stations were the five ponds in common between the pollution prevention survey and water balance. The two remaining ponds that have overflowed, Junction and Hooper, were not predicted to overflow based on the water balance, and overflowed for reasons that were not accounted for in the water balance.

The retention pond at the Junction maintenance station has only overflowed once due to a water main break near the station. At the Hooper maintenance station, groundwater pushed the pond lining up and out of the pond, causing the contents of the pond to be released. The events that caused the Junction and Hooper ponds to overflow were isolated events. Under normal conditions, the ponds should not overflow as predicted by the water balance.

For the five ponds predicted to overflow from water balance calculations, Table 18 summarizes their current capacity, estimated overflow volume, estimated required capacity, and the overflow volume as a percentage of the current pond capacity.

Table 18. Current capacity, overflow volume, required capacity, and overflow volume as a percentage of the current total capacity for the five UDOT retention ponds predicted to overflow according to the water balance.

Maintenance Station	Current Pond Capacity (gal)	Estimated Overflow Volume (gal)	Estimated Required Capacity (gal)	Overflow Volume as % of Total Capacity
Kamas	121,000	73,000	194,000	60.3
Lehi	282,000	127,000	409,000	45.0
Clearfield	55,400	200,000	255,000	361
Salina	60,000	56,700	117,000	94.5
Silver Summit	75,400	36,400	112,000	48.3

The water balance indicates that the five UDOT retention ponds that have overflowed are undersized by at least 45%. At the Kamas and Silver Summit facilities, however, a portion of the pond water is already being used to make brine, which is not accounted for in the water balance and would decrease the estimated amount of overflow. Even though these two maintenance stations already use pond water for brine, the ponds still overflow, indicating more pond water should be used for brine production if possible. Additionally, water has been pumped out of both the Lehi and Silver Summit retention ponds to prevent them from overflowing. This was also not included in the water balance and would further decrease the estimated overflow volume.

Of the five ponds predicted to overflow, stormwater is the largest inflow into two of the ponds (Lehi and Clearfield) and truck wash water is the largest inflow for the remaining three ponds (Kamas, Salina, and Silver Summit) (Figure 24). While methods can be implemented to reduce the volume of these inflows, another significant factor linked to the volume of overflow is the evaporation volume. According to the water balance, the Kamas, Lehi, and Clearfield ponds receive more stormwater than can evaporate from the ponds. This was evident during sampling in the beginning of August as the retention ponds at the Kamas and Lehi maintenance stations were virtually full. As a result, water accumulates from year to year, which was likely not accounted for in the original pond designs since the ponds were designed to facilitate complete evaporation.

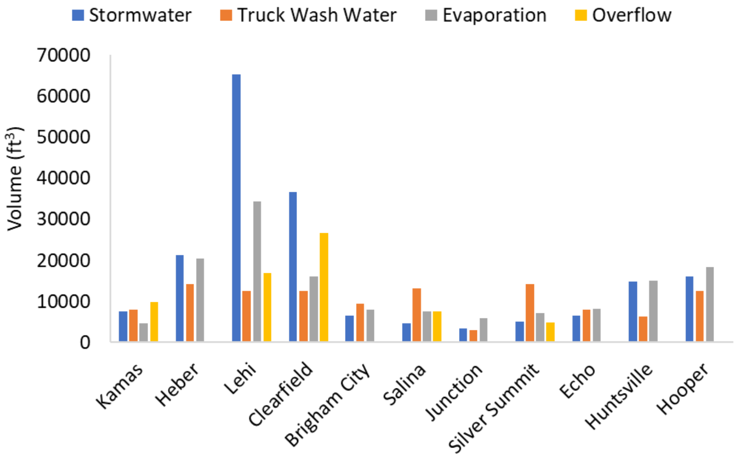


Figure 24. Volume of inflows and outflows for 11 UDOT retention ponds.

While the Kamas and Lehi ponds do not completely evaporate, the pond at the Clearfield maintenance station almost completely evaporates every summer yet is the most undersized pond of the five. The Clearfield maintenance station supervisor reported in the pollution prevention survey that the pond on site overflows almost daily during the winter from the influx of snowmelt and truck wash water. This indicates that the retention ponds are not appropriately designed for either the local evaporation rate or stormwater volume.

Six of the retention ponds samples, however, are appropriately designed for the current local evaporation rates, stormwater volumes, and truck wash water volumes (Figure 24). Table 19 summarizes the maximum pond capacity and the estimated maximum water volume for the six ponds that have not overflowed. Junction and Hooper are included in Table 19 because they do not overflow on a regular basis or from normal activities.

Table 19. Current capacity, estimated maximum water volume, and percent capacity remaining for the six UDOT retention ponds that are not predicted to overflow according to the water balance.

Maintenance Station	Maximum Pond Capacity (gal)	Estimated Maximum Water Volume (gal)	Percent Capacity Remaining (%)
Heber	272,000	173,000	36.4
Brigham City	84,600	84,600	0.0
Junction	40,000	22,200	44.5
Echo	80,100	70,500	12.0
Huntsville	101,000	101,000	0.0
Hooper	165,000	152,000	7.9

Based on the current stormwater volumes, evaporation rates, and truck wash water volumes, the remaining capacity in the ponds that have not overflowed, when full, ranges from 0 to 45%. The Brigham City and Huntsville ponds are right at their maximum capacity when full, which makes the ponds vulnerable to overflowing if input volumes increase or evaporation rates decrease. Pond water reuse for brine make-up water is also not an option for decreasing pond volume at the Brigham City maintenance station because the pond currently receives vactor truck waste (Table 4). At the Huntsville maintenance site, reusing pond water for brine make-up water would free up some of the capacity of the pond, which could prevent future problems with overflow. The Heber, Junction, Echo, and Hooper ponds all have at least 8% of their capacity remaining at the estimated maximum water volume in the pond. This remaining capacity provides a cushion against changing stormwater volumes, truck wash water volumes, and evaporation rates, but again, reuse of pond water for brine production would provide additional protection against pond overflow and future permit violations.

Mass Balance Results

A mass balance was used in conjunction with the water balance to estimate the concentration of metals and trace elements in the pond water during the winter. The highest measured concentration (total or dissolved) of an element in the pond water during the summer was used as the initial pond concentration for the water balance. The measured summer concentrations and estimated winter concentrations of the macro metals in the pond water are presented in Table 20 and the trace elements in Table 21. The winter concentration of the metals and trace elements in the pond water at the Lehi, Salina, and Echo maintenance station were known and used in place of estimated values, indicated by an asterisk in Table 20 and Table 21. Because of the influx of road salt from the truck wash water during the winter, the macro metal concentrations in the pond water increase during the winter, whereas the trace element concentrations decrease from stormwater dilution and sorption to pond sediments.

Table 20. Concentration of macro metals in the pond water during the winter and summer at each UDOT maintenance station. A * indicates the winter concentration was known, not estimated.

	Na (mg/L)		Ca (mg/L)		Mg (mg/L)		K (mg/L)	
	Winter	Summer	Winter	Summer	Winter	Summer	Winter	Summer
Truck Wash Water	22500		393		382		534	
Kamas	10900	8780	135	87.9	148	105	165	97.8
Heber	8760	22500	152	202	147	149	205	93.2
Lehi	17600*	58600	188*	450	354*	828	3823*	617
Clearfield	9950	62100	173	1470	173	31600	235	1220
Brigham City	13600	39300	231	246	246	1700	312	176
Salina	20400*	17800	286*	223	19.4*	15.8	8.49*	12
Junction	12100	7760	215	197	197	20.9	275	22
Silver Summit	19500	53500	328	419	322	522	445	518
Echo	8860*	132000	128*	1380	48.4*	485	21.4*	221
Huntsville	7540	106000	118	554	138	2800	165	1200
Hooper	48600	107000	657	1340	5520	14600	790	1540

Table 21. Concentration of trace elements in the pond water during the winter and summer at each UDOT maintenance station. A * indicates the winter concentration was known, not estimated.

	As (µg/L)		Cu (µg/L)		Pb (µg/L)		Se (µg/L)		Zn (µg/L)	
	Winter	Summer	Winter	Summer	Winter	Summer	Winter	Summer	Winter	Summer
Truck Wash Water	3.00		15.0		5.5		20.3		81.9	
Kamas	3.24	3.32	8.57	7.34	1.09	0.29	13.6	14.2	26.5	16.4
Heber	0.76	6.33	4.55	21.9	2.11	0.28	7.91	25.6	31.4	8.03
Lehi	4.51*	26.2	20.3*	113	< 2.00*	2.9	15.6*	90.4	22.1*	23.6
Clearfield	1.12	642	6.31	39.5	2.42	2.93	8.93	32.3	36.0	45.2
Brigham City	1.60	18.1	9.18	66.1	3.22	2.57	12.4	42.5	47.6	11.7
Salina	3.00*	4.60	20.2*	31.8	< 2.00*	0.47	16.2*	3.19	32.0*	13.8
Junction	1.58	5.49	8.25	13.0	2.85	0.41	11.1	9.64	43.1	16.4
Silver Summit	2.24	15.4	12.9	55.2	4.54	3.29	16.7	8.07	67.1	26.9
Echo	2.00*	11.2	9.44*	164	< 2.00*	2.09	4.69*	21.5	44.1*	112
Huntsville	1.10	41.5	6.76	258	1.62	4.68	6.10	29.6	23.7	29.8
Hooper	134	362	73.0	182	2.60	0.74	16.1	20.6	41.9	20.1

Brine Calculations

Using the water and mass balance equations, the winter concentration of metals and trace elements in the pond water at the 11 UDOT maintenance stations were estimated. The winter pond water concentrations, tap water concentrations, and salt concentrations were then used to calculate the concentrations of metals and trace elements in brine produced from 100% pond water at each maintenance station. Table 20 summarizes the arsenic, copper, lead, selenium, and zinc concentrations in the brine produced with 100% pond water and granular Morton salt at each maintenance station. For the Hooper maintenance station, the reported concentrations are for brine made with Morton salt, even though they currently use $MgCl_2$. The amount of granular Morton salt required to make 5,000 gallons of a 23% brine solution using only pond water ranges from 4,400 lb to 9,340 lb for the nine UDOT maintenance stations (Table 22).

Table 22. Maximum concentration of arsenic, copper, lead, selenium, and zinc in brine made with 100% pond water at the various UDOT maintenance stations.

	Salt required for 23% Brine (lb)	Maximum Concentration in Brine using only Pond Water				
		Arsenic (mg/L)	Copper (mg/L)	Lead (mg/L)	Selenium (mg/L)	Zinc (mg/L)
Kamas	8,430	0.015	0.091	0.001	0.030	1.38
Heber	8,650	0.013	0.090	0.004	0.025	1.42
Lehi	7,720	0.016	0.096	0.004	0.030	1.26
Clearfield	8,530	0.013	0.090	0.004	0.025	1.41
Brigham City	8,140	0.013	0.089	0.005	0.028	1.35
Salina	9,040	0.014	0.093	0.004	0.030	1.22
Junction	8,290	0.014	0.090	0.005	0.027	1.38
Silver Summit	7,500	0.015	0.095	0.004	0.021	1.28
Echo	9,340	0.013	0.097	0.006	0.031	1.44
Huntsville	8,790	0.014	0.093	0.004	0.023	1.44
Hooper*	4,400	0.140	0.116	0.004	0.025	0.750

* Concentrations are for brine made with Morton salt. The Hooper maintenance station, however, currently use $MgCl_2$.

The copper, selenium, and zinc concentrations in the brine produced from 100% pond water exceed the aquatic standards (Table 23) for these elements at each maintenance station (Table 22). Because the concentration of copper, selenium, and zinc in the brine produced with 100% pond water at all maintenance stations exceeds the aquatic standard, surface water quality modeling was used to determine the impact brine made with 100% pond water could have on aquatic ecosystems.

Table 23. Utah acute aquatic standards for arsenic, copper, lead, selenium, and zinc (Utah Office of Administrative Rules 2019).

Metal/Trace Element	Concentration (µg/L)
Arsenic	340
Copper	13
Lead	65
Selenium	18
Zinc	121

Surface Water Quality Modeling Results

To determine the impact of brine made from 100% pond water on aquatic ecosystems, surface water quality modeling was performed. Using the UDOT *Station*

Boundary Layer (UDOT 2019) and the National Hydrography Dataset (USGS 2019a), the surface water bodies within 120 feet of a road maintained by one of the 11 UDOT maintenance stations were identified. Table 24 presents the surface water bodies and the total length that could be impacted by the application of brine produced at the UDOT facility responsible for maintaining the adjacent roadway.

For the Clearfield and Brigham City maintenance stations, pond water could be reused for brine without concern of violating aquatic standards as none of the roads maintained by these maintenance stations are within 120 feet of a surface water body. The Clearfield maintenance station, however, currently uses $MgCl_2$ as its primary anti-icing and deicing chemical so there is no need for them to reuse pond water, other than to reduce pond overflow events. Unlike Clearfield, Brigham City is, however, limited in its pond water reuse, not because of the potential to violate aquatic standards, but because the pond also receives vactor truck waste (Table 4). The Brigham City maintenance station would need to direct the decant water from the vactor waste to another location in order to reuse their pond water for brine.

For the nine maintenance stations with roadways within 120 feet of a surface water body, the stream data for each of the surface water bodies in Table 24 and Equations 6, 7, and 8 were used to model the transport of the metals and trace elements in the brine along the length of the surface water bodies. Arsenic, copper, lead, selenium, and zinc were modeled specifically because these elements have aquatic standards and for copper, selenium, and zinc the aquatic standards are exceeded in the brine produced from 100% pond water at each maintenance station.

Table 24. Surface water bodies, lengths, and river velocity that have the potential to be impacted by the application of brine made with pond water and the UDOT facility responsible for maintaining the adjacent roadway.

Surface Water Body	Length along road (miles)	River Velocity (m/s)	UDOT Facility Responsible for Road Maintenance
Provo River	7.44	0.371	Kamas
South Fork Provo River	1.29	0.561	Kamas
Beaver Creek	6.93	0.402	Kamas
Provo River	0.38	0.371	Heber
American Fork River	16.2	0.274	Lehi
Salina Creek	30.8	0.293	Salina
Ivie Creek	9.38	0.301	Salina
Beaver Creek	0.86	0.414	Junction
East Fork Seveir River	9.50	0.356	Junction
Silver Creek	0.30	0.396	Silver Summit
Echo Creek	39.9	0.171	Echo
Beaver Creek	1.46	0.414	Huntsville
South Fork Ogden River	0.42	0.337	Huntsville
Ogden River	1.10	0.200	Huntsville
Howard Slough	1.25	0.274	Hooper

Figure 25 presents the transport of copper from brine made with 100% pond water as a function of time in the 1.3-miles of the South Fork of the Provo River that can be impacted by road salting activities. The y-axis is the predicated concentration of copper in the river in mg/L, while the x-axis is time in minutes. Each of the colored lines represents a different position along the 1.3-mile section of river.

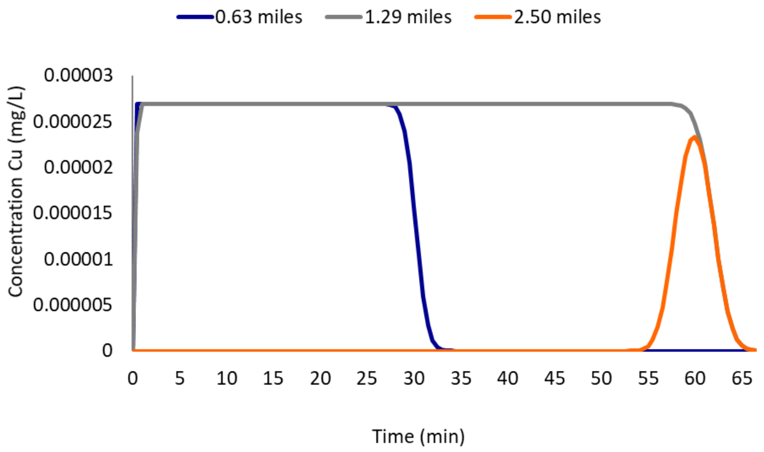


Figure 25. Transport of copper from brine made with 100% pond water in a 1.3-mile section of the South Fork of the Provo River. The different colored lines represent different positions along the section of the river.

Because brine is treated as a distributed source and advection dominates, the concentration of copper is constant along the length of the river immediately after a simulated road salting event. Once all the brine affected water has moved through the brine application zone, the copper concentration abruptly decreases because mass is no longer being added, just advected and dispersed (grey line in Figure 25). The concentration of copper also abruptly drops at locations within the brine application zone as brine affected water moves downstream and is diluted with upstream water not affected by the application of brine (dark blue line in Figure 25). Beyond the brine application zone, the brine acts as an instantaneous point source and moves as a plug downstream. At 2.5 miles downstream, the copper concentration is negligible for 55 minutes until the plug of brine affected water passes this location and the concentration sharply increases (orange line in Figure 25). The copper concentration then immediately decreases as the plug moves downstream and continues to disperse.

For the South Fork of the Provo River, the maximum in stream copper concentration is significantly below the aquatic standard (Figure 25). The concentrations of the other trace elements in the South Fork of the Provo River and the other surface water bodies listed in Table 24 were also significantly below aquatic standards. These results indicate that reusing pond water for brine is feasible at these nine maintenance stations.

The surface water quality model was also used to iteratively calculate the maximum concentration that arsenic, copper, lead, and selenium could be in the brine produced at maintenance station so aquatic standards would not be violated (Table 25).

For the maintenance stations servicing roads along multiple water bodies (Kamas and Huntsville), the lowest concentration in the brine calculated for these multiple water bodies is reported.

Table 25. Maximum concentration of arsenic, copper, lead, selenium, and zinc that can be in the brine produced by each maintenance station to ensure aquatic standards are not violated in adjacent surface water bodies.

	Maximum Allowable Concentration in Brine				
	Arsenic (mg/L)	Copper (mg/L)	Lead (mg/L)	Selenium (mg/L)	Zinc (mg/L)
Kamas	6850	262	1310	363	2440
Heber	5540	212	1059	293	1970
Lehi	3905	149	747	207	1390
Salina	2410	92.0	461	128	858
Junction	695	26.6	133	36.8	247
Silver Summit	1530	58.6	293	81.2	545
Echo	695	26.6	133	36.8	247
Huntsville	695	26.6	133	36.8	247
Hooper	5010	191	957	265	1780

At all nine maintenance stations, the concentrations reported in Table 25 are significantly higher than the concentrations in the brine produced from 100% pond water (Table 22), indicating reusing pond water for brine make-up water is feasible at these maintenance stations. The concentrations in Table 22, however, rely on the estimation of the winter pond concentrations, which were calculated using data from only three maintenance stations and the composition of the granular Morton salt. At maintenance stations that plan to use or are already using pond water for brine make-up water, pond water samples collected during the winter should be analyzed to verify the estimated concentrations used in the brine calculations.

Reusing pond water for brine make-up water is not only feasible at all nine of the maintenance stations, but also preferable compared to making brine with only tap water.

While brine produced from only tap water does not violate aquatic standards (Table 26), reusing pond water for brine reduces virgin salt use, and would help eliminate pond overflow events. Reducing pond overflow events would reduce the input of potentially toxic trace elements into the environment and help UDOT comply with their MS4 permit.

Table 26. Maximum concentration of arsenic, copper, lead, selenium, and zinc in the brine made with 100% tap water.

	Maimum Concentration in Brine using only Tap Water				
	Arsenic (mg/L)	Copper (mg/L)	Lead (mg/L)	Selenium (mg/L)	Zinc (mg/L)
Kamas	0.016	0.198	0.003	0.019	1.95
Heber	0.015	0.534	0.002	0.019	1.67
Lehi	0.015	0.417	0.003	0.020	1.60
Salina	0.016	0.107	0.003	0.019	1.60
Junction	0.018	0.265	0.006	0.019	1.62
Silver Summit	0.014	0.109	0.003	0.020	1.59
Echo	0.015	0.830	0.006	0.019	1.58
Huntsville	0.014	0.107	0.003	0.019	1.64
Hooper	0.015	0.105	0.003	0.019	1.56

The Hooper maintenance station, however, uses liquid $MgCl_2$ as their primary anti-icing agent. Liquid $MgCl_2$ is applied directly to roads without any dilution. Despite the higher arsenic and selenium concentrations in the $MgCl_2$ compared to the Morton salt (Table 5), the concentrations of arsenic and selenium in the $MgCl_2$ do not exceed the maximum allowable concentrations presented in Table 23, indicating $MgCl_2$ is safe to use on roadways maintained by the Hooper maintenance station. The surface water quality modeling and brine calculations (Table 20) also support the reuse of pond water for brine make-up water should the Hooper maintenance station decide to use sodium chloride brine instead of $MgCl_2$.

In addition to modeling the concentration of trace elements in the surface water bodies adjacent to roadways maintained by UDOT, the chloride concentration was also modeled. The aquatic standard for chloride is 230 mg/L (USEPA 2019b). Using the chloride concentration in the brine, which was estimated to be 138,670 mg/L, the chloride concentration in the surface water bodies after brine made from 100% pond water was applied to adjacent roadways would range from 6.9 to 68 mg/L. Because the estimated chloride and trace element concentrations are well below the concentrations required to violate aquatic standards, the application of brine made from pond water should not negatively impact the aquatic life in these surface water bodies either due to trace elements or chloride concentrations.

RECOMMENDATIONS

Based on the results of the water and sediment analyses and the current practices at other state DOTs, the following site design guidelines and BMPs are recommended for implementation at UDOT facilities to help reduce the quantity of pollutants entering the ponds and the potential environmental impact of inadvertent pond water release.

Site Design Guidelines

To help UDOT reduce the environmental footprint of their winter maintenance operations and comply with their MS4 permit, several design guidelines have been developed for the ponds and salt storage sheds at UDOT maintenance stations.

Pond Design Guidelines

Stormwater Diversion Valves

To reduce the volume of the retention ponds designed to capture salt-laden truck wash water and stormwater, the Virginia Department of Transportation (VDOT) has started installing stormwater diversion valves and piping as a part of maintenance station stormwater and wash water containment systems. At these facilities, salt-laden stormwater and truck wash water are directed to a series of drains that are connected to an oil water separator. After the oil water separator, the water either flows to the retention pond or to a detention basin depending on the position of the diversion valve (VDOT 2015). By installing a diversion valve, station supervisors can direct non-impacted stormwater away from the retention pond and into a detention basin or vegetated swale.

For a diversion valve to be effective the areas surrounding salt storage sheds and wash racks must be properly maintained. Before stormwater can be diverted away from the retention pond, all excess salt from the wash rack and around the salt storage shed should be swept back into the shed and properly contained to prevent the contamination of stormwater. The pipes should then be flushed with clean water to remove any salt build up from inside the pipes. Once the areas contributing stormwater are free of salt and the pipes have been flushed, the diversion valve can be switched to divert stormwater away from the pond (VDOT 2015).

While installing a diversion valve and drain system like the ones used by VDOT may not be feasible at existing UDOT facilities, installing stormwater diversion valves where feasible and at new UDOT facilities should be considered to help reduce or prevent pond overflow events. According to the water balance, stormwater is the largest inflow to six of the 11 UDOT retention ponds sampled for this project, and of those six ponds, two have overflowed (Lehi and Clearfield). If the stormwater from the months when salt is not in use and stored properly were diverted away from these two retention ponds, the stormwater volume entering the pond would decrease by 16 to 20% per the water balance. This reduction in stormwater volume would not prevent these two ponds from overflowing, but it would reduce the amount of salt lost through overflow and the environmental impact of salt release. For new UDOT facilities, diverting clean stormwater away from the retention ponds and into detention basins or vegetated swales would decrease the required size of the pond, which would lower excavation, material, and maintenance costs.

Oil Water Separators

Many state DOTs and the Transportation Association of Canada (TAC) suggest oil water separators be installed upstream of retention ponds receiving truck wash water, particularly at maintenance stations that produce brine from pond water (Golub et al.

2008; TAC 2013; Miller et al. 2014). The TAC recommends wash bays be constructed or retrofitted with floor drains that connect to an oil water separator and then to the retention pond (TAC 2013). As with the diversion valves, wash water would need to be contained and directed towards the floor drains.

While the pond water samples collected from the 11 UDOT maintenance stations sampled for this project did not have high concentrations of O&G, the pond sediments had O&G concentrations above the level accepted by municipal landfills. Because O&G is hydrophobic, causing it to partition out of the water column and into the pond sediments, installing oil water separators to treat the truck wash water could potentially decrease the O&G concentration in the pond sediments.

Salt Storage Shed Design Guidelines

While UDOT already follows many of the recommended design principles for pollution prevention at salt storage sheds, several modifications can be made to increase their effectiveness and reduce their environmental impact. Most of the salt storage sheds at UDOT maintenance stations are covered, three-sided structures located on an impermeable surface with a capacity dependent on the amount of salt or sand required by the maintenance station. The Western Transportation Institute (WTI) and TAC recommend, however, that salt storage structures be large enough to store the required amount of materials and facilitate the indoor loading and unloading of materials (TAC 2013; WTI 2015). By loading and unloading materials indoors, salt loss through wind and salt fines left on the ground surface are eliminated (TAC 2013). Spills that occur during loading and unloading are also contained within the structure, which reduces the volume of salt impacted stormwater (WTI 2015).

In addition, the TAC recommends that the structure be positioned to protect the door from the prevailing winter wind (TAC 2013). This prevents precipitation from being carried into the structure by wind and shelters the loading and unloading of materials if the structure cannot support indoor loading and unloading. Salt storage structures should also be located at least 50 feet from surface water bodies (WTI 2015) and graded so drainage is directed away from downstream groundwater wells or salt vulnerable areas (TAC 2013).

Many transportation agencies also recommend that the entire winter maintenance area, meaning the salt storage shed, brine storage tanks, retention pond, and wash bay, be surrounded by a raised berm or curb to contain and direct runoff towards the retention pond (TAC 2013). Not only does a raised berm contain and direct runoff within the winter maintenance area, it also prevents non-salt impacted stormwater from other areas of the site from entering the winter maintenance area and becoming contaminated. This helps reduce the volume of salt contaminated stormwater that requires management. At the two UDOT maintenance stations (Lehi and Clearfield) where the retention pond overflows and the largest volume of inflow is stormwater, installing berms around the winter maintenance area could reduce the frequency of overflow events by reducing the volume of impacted stormwater. To further reduce the volume of stormwater that requires management, the TAC recommends the winter maintenance area be as small as possible (TAC 2013). While the winter maintenance area at existing UDOT maintenance stations would be difficult to reduce without relocating salt sheds, brine tanks, and wash racks, the stations can be retrofitted with berms or curbs to contain salt-laden storm and wash water and prevent non-contaminated stormwater from entering the winter maintenance area.

Street Sweeping and Vactor Truck Waste Decant Basins

Currently at maintenance stations that receive street sweeping and vactor truck waste, the two waste streams are placed in a location that is near the retention pond and graded so that the decant water will flow into the pond. The pond water at these maintenance stations cannot be used for brine make-up water because of the suspected contamination from the decant water as specified by the UDWQ. The results of the surface water quality modeling, however, show that the pond water at the Lehi and Brigham City maintenance stations, which currently receive these waste streams, could be used for brine without violating aquatic standards. This indicates that decant water from vactor truck and street sweeping waste does not contribute significantly to the pollutant load of these two retention ponds.

For maintenance stations receiving vactor truck and street sweeping waste to abide by the current rule and be able to use their pond water for brine, decant basins connected to a sanitary sewer or separate liquid collection tank should be constructed to contain these waste streams. The decant basins should be lined with an impermeable liner and connected to a sanitary sewer or separate liquid collection tank to prevent infiltration of the decant water to groundwater. Complete separation of the solids from the decant water should also be achieved. In addition, the basin should be large enough to promote airflow through the solid portion of the waste so it can be adequately dried.

Constructing decant basins at maintenance stations that receive street sweeping and vactor truck waste could save UDOT a large amount of money from decreased pumping and hauling costs. The Lehi maintenance station, for example, receives street sweeping and vactor truck waste, which prevents the pond water from being reused for brine. In the past, this maintenance station has spent close to $30,000 to have 1 foot of water removed from the pond to prevent it from overflowing (UDOT, personal communication, 2018). Installing a decant basin at the Lehi maintenance station would allow the pond water to be used for brine make-up water and prevent the pond from having to be pumped, saving UDOT money not only in pumping and hauling costs, but also in salt costs.

Best Management Practices

In addition to the site guidelines presented in the previous section, the following BMPs could also be implemented by UDOT as a part of their pollution prevention plan to reduce the environmental impacts of their winter road maintenance operations and comply with their MS4 permit.

Reuse Pond Water for Brine Make-up Water

The results of the pond water testing and surface water quality modeling show that the pond water at all maintenance stations sampled for this project that maintain roadways within 120 ft of a surface water body could be used as brine make-up water. Results also indicate that brine can be made from 100% pond water without violating aquatic standards at all 11 maintenance stations and as such, maintenance stations should use as much pond water as possible for making brine. The Lehi and Brigham City maintenance stations, however, would need to contain their street sweeping and vactor truck waste and prevent it from entering the pond in order for them to use pond water for brine. Using pond water to make brine at all the maintenance stations would reduce the frequency of pond overflow events, while also saving money and conserving resources.

According to the brine calculations, if 5,000 gallons of 23% brine solution were made using 100% pond water at each maintenance station, UDOT could reduce their salt use by 800 to 5,200 pounds or 8.4 to 54 percent (Table 27). Using the most current price for a metric ton of bulk road salt of $54.07 (Bolen 2017), UDOT could save approximately $2.53 to $15.91 per 5,000-gallon spreader per storm at these 11 maintenance stations by using 100% pond water for brine make-up water. UDOT has 564 spreaders (UDOT 2018), so using the average cost saving per spreader of $9.22, they could save over $5,200 in salt per storm by using 100% pond water to make brine. Even using a 1:3 blend of pond water to tap water for brine, UDOT could save over $1,100 per storm.

Table 27. Amount of salt required to make 5,000 gallons of a 23% brine solution using all tap water, all pond water, 1:1 blend of pond water to tap water, or 1:3 blend of pond water to tap water at 11 UDOT maintenance stations.

	Amount of Granular Salt Required for a 23% Brine Solution						
	100% TW (lb)	100% PW (lb)	Percent Reduction	1:1 Ratio of PW:TW (lb)	Percent Reduction	1:3 Ratio of PW:TW (lb)	Percent Reduction
Kamas	9590	8420	12.0	9005	6.1	9300	3.0
Heber	9590	8660	9.8	9120	4.9	9590	2.4
Lehi	9590	7710	20	8650	9.8	9120	4.9
Clearfield	9590	8530	11	9060	5.5	9320	2.8
Brigham City	9590	8140	15	8860	7.6	9230	3.8
Salina	9590	7410	23	8500	11	9050	5.7
Junction	9590	8300	14	8950	6.7	9270	3.4
Silver Summit	9590	7510	22	8550	11	9070	5.4
Echo	9570	8650	9.9	9110	5.1	9340	2.6
Huntsville	9590	8790	8.4	9190	4.2	9390	2.1
Hooper	9590	4400	54	7000	27	8290	14

In addition to saving salt and money, reusing pond water for brine make-up water would reduce the environmental impacts associated with pond overflow events. If 5,000 gallons of brine made using 100% pond water was used per spreader per storm, two to five storms requiring winter maintenance would be needed to use the entire overflow volume from the five ponds that currently overflow (Table 28). Using a 1:3 blend of pond water to tap water to make brine, five to 20 storms would be required to use the entire pond overflow volume.

Table 28. Number of storms required to use 100% of the pond overflow volume through making brine with 100% PW or 1:3 blend of pond water to tap water.

		Number of Storms to use Pond Overflow Volume	
	Number of Spreaders	100% PW	1:3 Blend of PW:TW
Kamas	5	3	12
Lehi	8	4	13
Clearfield	8	5	20
Salina	8	2	6
Silver Summit	6	2	5

At the Clearfield maintenance station, pond water reuse would reduce the volume of overflow significantly but cannot be relied upon to eliminate pond overflow events, unless brine is made using 100% pond water. The Clearfield maintenance station would also have to evaluate their winter road maintenance strategy to determine if using NaCl brine is feasible, as they currently use $MgCl_2$ as their primary deicer. The Salina and Silver Summit maintenance stations, however, could reasonably use the entire overflow volume from their ponds for brine since only five or six storms would be needed to use the entire overflow volume.

Implement a Standard Operating Procedure for Equipment and Vehicle Washing

To reduce pollution from vehicle wash water, many other state DOTs have implemented standard operating procedures (SOPs) for equipment and vehicle washing with the goal of conserving water and reducing oil and grease contamination. These SOPs recommend not washing the undercarriages of vehicles at wash bays draining to retention ponds to reduce the concentration of oil and grease in the pond. The undercarriages of vehicles should instead be washed inside where floor drains are connected to a sanitary sewer. If washing the undercarriage of vehicles inside is not feasible, as mentioned previously, oil water separators should be installed under wash bays so wash water can be treated for oil and grease before it enters the retention ponds. At UDOT maintenance stations, not washing the undercarriage of equipment and vehicles would reduce the oil and grease contamination of the pond sediments and subsequent disposal costs. Washing leaking vehicles and changing vehicle fluids in wash bays is also prohibited in most SOPs. Additionally, the use of high-pressure systems is recommended to conserve water, which reduces the volume of contaminated wash water. Using dry cleanup techniques as much as possible, such as sweeping excess salt out of truck beds and back into the storage pile before washing, are also recommended to reduce the contamination of truck wash water and material loss.

Yard Maintenance

To reduce the amount of pollutants, such as debris, plastic, and sediment, that can enter the retention ponds at UDOT maintenance stations, the maintenance yard, or at least the area immediately surrounding the retention pond and wash bay, should be swept frequently. This will reduce the amount of pollutants entering the pond, namely sediment, which requires hauling, treatment, and disposal. Salt spills should also be swept up as soon as possible to prevent the loss of material and contamination of stormwater.

Pond Maintenance

While the frequency of pond maintenance does not affect the concentrations of metals, trace elements, and oil and grease in the pond water and sediment at UDOT maintenance stations, annual maintenance of the retention ponds will allow for higher quality brine to be produced from the pond water and prevent unnecessary environmental contamination. In the summer months when most of the ponds completely evaporate, the accumulated sediment should be removed and the liner checked for leaks. If the retention pond at a maintenance station does not completely evaporate, the remaining water can be pumped to a brine storage tank and stored until winter when it can be used for brine. If storage is not feasible, the remaining pond water can be pumped and hauled to a waste disposal site. Cleaning the ponds annually will reduce the suspended solids concentration in the pond water, decreasing the wear and tear on pumps and equipment used for making and applying brine. Annual maintenance will also ensure that asphalt ponds are not leaking and contributing to soil and ground water contamination.

Salt Storage

To prevent salt pollution, in addition to being kept in a three-sided structure without leaks, salt should be stored at least 10 feet from the door or open side of the structure to prevent material loss from wind and precipitation (WTI 2015). At the conclusion of the winter maintenance season, if salt and other winter maintenance materials are stored in a three-sided structure, the front side of the salt pile should be covered with a tarp and secured with sandbags. This prevents the loss of material through wind and the contamination of stormwater.

Data Collection and Management

In order for UDOT maintenance station retention ponds to be adequately designed for the complete containment of salt laden truck wash water and stormwater, data on the volume of truck wash water and stormwater flowing to the retention ponds needs to be collected. This could be accomplished through metering the wash racks and determining the precise area of the maintenance station that contributes stormwater to the pond. The volume of pond water removed from the pond and used for brine should also be recorded so the water balances for the individual ponds can be better estimated. It would also be beneficial to measure the concentration of metals, trace elements, and O&G in the truck wash water so the mass balance and winter pond water concentrations can be better estimated.

CONCLUSIONS

Pond water, tap water, and sediment samples were collected from 12 UDOT maintenance stations to aid in the development of site design guidelines and pollution prevention BMPs. The samples were analyzed for suspended, dissolved, and volatile solids, metals, trace elements, O&G, and TPH. While the pond and tap water samples were rather benign, other than the high salt concentration of the pond water, the pond sediments were found to require treatment prior to disposal in local landfills because of their O&G concentration. This limits the disposal of pond sediments to one landfill in the state of Utah. Pond maintenance was also found to have no effect on the O&G concentration in the pond sediments.

Using the water quality analyses and surface water quality modeling, the maximum allowable concentration of metals and trace elements that could be in brine produced from pond water were determined. The required blending ratio of pond water to tap water for the production of brine that would not violate aquatic standards was then calculated using a brine calculation worksheet. All the maintenance stations with conventional retention ponds could use 100% pond water to make brine and still be below the concentrations that would violate aquatic standards. The two maintenance stations that use liquid $MgCl_2$ (Clearfield and Hooper) could also reuse their pond water to make brine, despite the high arsenic and selenium concentrations in the raw $MgCl_2$.

Based on the results of the surface water quality modeling and brine calculations, pond water reuse for brine production was recommended as a best management practice for UDOT maintenance stations. Annual pond maintenance, vehicle washing SOPs, and yard maintenance were also recommended BMPs to reduce pond pollution and increase the quality and ease of brine making at these maintenance stations. At maintenance stations that receive street sweeping and vactor truck waste, decant basins should be installed so the pond water can be used for brine make-up water. Oil water separators should also be installed upstream of the pond to reduce the amount of oil and grease entering the pond, which could decrease the level of treatment required for the pond sediments. Installing curbs around the winter maintenance areas and stormwater diversion valves were recommended design guidelines to decrease the contamination and volume of stormwater entering the retention ponds. Reducing stormwater flows should reduce the frequency of overflow events. Implementing these design guidelines and BMPs as a part of their pollution prevention program should help UDOT reduce the environmental footprint of their winter road maintenance operations and comply with their MS4 permit.

ENGINEERING SIGNIFICANCE

While the application of road salt is critical for wintertime public safety, the impacts of road salt on vegetation, aquatic organisms, and drinking water necessitate change. This study addresses pollution prevention and water reuse at UDOT facilities to minimize the environmental and economic impacts of their winter road maintenance operations. BMPs, including pond water reuse, and retention pond design guidelines were developed to reduce the contamination and overflow of UDOT retention ponds. By reusing pond water and preventing pond contamination and overflow, UDOT can significantly reduce their salt and pond water pumping, treatment, and disposal costs. These BMPs and site design guidelines can also be applied by other state DOTs to minimize the environmental and economic footprint of their winter maintenance operations.

REFERENCES

Alade, A., Jameel, A., Muyubi, S., Karim, M., and Alam, M. (2011). "Removal of Oil and Grease as Emerging Pollutants of Concern (EPC) in Wastewater Streams." *IIUM Engineering Journal,* 12(4), 161-169.

Alleman, J., Partridge, B., and Yeung, L. (2004). Innovative Environmental Management of Winter Salt Runoff Problems at INDOT Yards, < https://docs.lib.purdue.edu/cgi/viewcontent.cgi?article=1601&context=jtrp> (accessed 20 June 2018).

American Public Health Association (APHA) (1992). Method 3030E, Standard Methods for the Examination of Water and Wastewater, <http://standardmethods.org/> (accessed 20 August 2018).

American Public Health Association (APHA) (1998). *Standard Methods for the Examination of Water and Wastewater,* 20(2), 55-59.

Better Roads (2001)**. "**Agricultural Byproduct Deicers are Here to Stay." *Better Roads*, 72(7), 47-49.

Blomqvist, G. and Johansson, E. (1999). "Airborne spreading and deposition of de-icing salt—a case study." *The Science of the Total Environment*, 235, 161-168.

Bolen, W. (2017). 2015 Minerals Yearbook, < https://s3-us-west-2.amazonaws.com/prd-wret/assets/palladium/production/mineral-pubs/salt/myb1-2015-salt.pdf> (accessed 10 April 2019).

Cooper, C., Mayer, P., and Faulkner, B. (2014). "Effects of road salts on groundwater and surface water dynamics of sodium and chloride in an urban restored stream." *Biogeochemistry*, 121(1), 149–166.

Corson, L. (2003). Development of a Database and System for Analyzing the Actual and Potential Impacts on the Environment of Existing and Planning INDOT Sites, <https://docs.lib.purdue.edu/cgi/viewcontent.cgi?article=1530&context=jtrp> (accessed 9 April 2019).

Defourny, C. (2000). "Environmental risk assessment of deicing salts." *World salt Symposium*, 2, 67–77.

EA Engineering (2009). Compendium of Best Management Practices for Environmental Compliance and Stewardship at Highway Transportation Maintenance Facilities, < http://onlinepubs.trb.org/onlinepubs/nchrp/docs/nchrp25-25(46)_FR.pdf> (accessed 17 March 2018).

DEUSA International GmbH (2018). Solution of Magnesium Chloride, <http://deusa.de/phocadownload/products/Magnesium_chloride_solution/spezifikation_magnesiumchloridloesung-ees_30.pdf> (accessed 13 March 2019).

Environment Canada, Ecoplans Ltd. (2001). List of Canadian Programs, Initiatives, and Guidelines Related to Road Salts, <http://www.ec.gc.ca/noop/roadsalt/en/list.htm> (accessed 15 April 2019).

Environment Canada (EC) (2006). Winter Road Maintenance Activities and the Use of Road Salts in Canada: A Compendium of Costs and Benefits Indicators, <http://www.ec.gc.ca/nopp/roadsalt/reports/en/winter.cfm> (accessed 29 March 2019).

Environment Canada (EC) (2010). Risk management strategy for road salts, <http://www.ec.gc.ca/nopp/roadsalt/reports/en/rms.cfm> (accessed 7 March 2019).

E.T. Technologies, Inc. (2019). Rates, < http://etsrs.com/rates/> (accessed 19 December 2019).

Fay, L. and Shi, X. (2012). “Environmental Impacts of Chemicals for Snow and Ice Control: State of the Knowledge.” *Water, Air & Soil Pollution*, 223(5), 2751-2770.

Fay, L. Shi, X, and Huang, J. (2013). Strategies to mitigate the impacts of chloride-based deicers to the environment, <https://www.in.gov/indot/files/Strategies_to_Mitigate_the_Impacts_of_Chloride_Deicers.pdf > (accessed 4 April 2018).

Findlay, S. and Kelly, V. (2011). “Emerging indirect and long-term road salt effects on ecosystems.” *Annals of the New York Academy of Sciences, The Year in Ecology and Conservation Biology*, 1223, 58-68.

Fitch, M., Oyanedel-Craver, V., Bartfelt-Hunt, S., Fuller, M., and Smith, J. (2009). “Salt-Water Recycling for Brine Production at Road-Salt-Storage Facilities.” *Environmental Progress and Sustainable Energy*, 28(4), 565-575.

Fu, L. and Usman, T. (2012). Safety Impacts of Using Deicing Salt, <https://www.researchgate.net/publication/274720669_The_Safety_Impacts_of_Using_De-icing_Salt_Report_prepared_for_Salt_Institute> (accessed 25 October 2019).

Gelles, L., Goodridge, W., Maguire, M., Wood, S., Sweat, T., Fletcher, E., Torgersen, T., Johnson, J., Espinoza, J., McLean, J., Stewart, J., and Guy, T. (2017). "Summary of Water Quality Analysis of UDOT Maintenance Site Detention and Retention Ponds Report." *UDOT Report #2.*

Golub, R., Dresnack, R., Konon, W., Meegoda, J., and Marhaba, T (2008). Salt Runoff Collection System, <https://transportation.njit.edu/nctip/final_report/SaltRunoffCollectionSystems.pdf > (accessed 23 April 2019).

Goodwin, L. (2002). Analysis Weather-Related Crashes on U.S. Highways, < https://ops.fhwa.dot.gov/weather/best_practices/CrashAnalysis2001.pdf> (accessed 12 May 2019).

Hanbali, R. and Kuemmel, D. (1993). "Traffic Volume Reduction Due to Winter Storm Conditions." *Transportation Research Record: Journal of the Transportation Research Board*, 1387, 159-164.

Hart, B., Bailey, P., Edwards, R., Hortle, K., James, K., McMahon, A., Meredith, C., and Swadling, K. (1991). "A Review of the Salt Sensitivity of the Australian Freshwater Biota." *Hydrobiologia,* 210, 105-144.

Herbert, E., Boon, P., Burgin, A., Neubauer, S., Franklin, R., and Ardón, M. (2015). "A global perspective on wetland salinization: ecological consequences of a growing threat to freshwater wetlands." *Ecosphere*, 6(10).

Indiana Department of Transportation (INDOT) (2019). INDOT SWQMP Annual Report April 2018-April 2019, <https://www.in.gov/indot/files/SWQMP%20Annual%20Report%202018-2019.pdf> (accessed 21 October 2019).

Jurries, D. and Ratliff, K. (2013). Industrial Stormwater Best Management Practices Manual, < https://www.oregon.gov/deq/FilterDocs/IndBMP021413.pdf> (accessed 21 March 2019).

Kaushal, S., Groffman, P., Likens, G., Belt, K., Stack, W., Kelly, V., Band, L., and Fisher, G. (2005). "Increased salinization of fresh water in the northeastern United States." *Proceedings of the National Academy of Sciences,* 102(38), 13517-13520.

Kelly, V., Lovett, G., Findlay, S., Strayer, D., Burns, D., and Likens, G. (2008). "Long-Term Sodium Chloride Retention in a Rural Watershed: Legacy Effects of Road Salt on Streamwater Concentration." *Environmental Science and Technology,* 42(2), 410-415.

Kelly, V., Findlay, S., Schlesinger, W., Menking, K., Chatrchyan, A. (2010). Road salt:

moving toward the solution, <https://www.caryinstitute.org/sites/default/files/public/reprints/report_road_salt_2010.pdf> (accessed 2 May 2019).

Kelly, V., Findlay, S., Weathers, K. (2019a). Road salt: the problem, the solution, and how to get there, <https://www.caryinstitute.org/news-insights/road-salt-problem-solution-and-how-get-there-report> (accessed 3 May 2019).

Kelly, V., Findlay, S., Hamilton, S., Lovett, G., and Weathers, K. (2019b). "Seasonal and Long-Term Dynamics in Stream Water Sodium Chloride Concentrations and the Effectiveness of Road Salt Best Management Practices." *Water, Air, and Soil Pollution,* 230(13).

Kent, R., Andersen, D., Caux, P., and Teed, S. (1999). "Canadian water quality guidelines for glycols—an ecotoxicological review of glycols and associated aircraft anti-icing and deicing fluids." *Environmental Toxicology*, 14, 481–522.

Koch, G., Brongers, M.,Thompson, N., Virmani, Y., and Payer, J. (2002). Corrosion Costs and Preventative Strategies in the United States, < http://impact.nace.org/documents/ccsupp.pdf> (accessed 20 March 2019).

Lindsay, W. L. (1979). *Chemical Equilibria in Soils*. The Blackburn Press, New Jersey.

Mason, C., Norton, S., Fernandez, I., and Katz, L. (1999). "Deconstruction of the Chemical Effect of Road Salt on Stream Water Chemistry." *Journal of Environmental Quality,* 28(1), 82-91.

Mesner, N. and Geiger, J. (2005). Understanding Your Watershed: pH, <https://extension.usu.edu/waterquality/files-ou/Publications/pH.pdf> (accessed 17 November 2019).

Miller, C., Schneider, W., Kennedy, M., and Sullivan, S. (2014). Snow Removal Wastewater Disposal Alternatives, < http://www.dot.state.oh.us/Divisions/Planning/SPR/Research/reportsandplans/Reports/2014/Environmental/134629_FR.pdf> (accessed 21 June 2018).

National Association of Clean Water Agencies (NACWA) (2018). MS4 Stormwater Permitting Guide, < http://www.nacwa.org/docs/default-source/news-publications/White-Papers/2018-03-07permittingguide.pdf?sfvrsn=4> (accessed 3 April 2019).

National Oceanic and Atmospheric Administration National Centers for Environmental Information (NOAA NCEI) (2019). Climate Data Online, <https://www.ncdc.noaa.gov/cdo-web/results> (accessed 24 June 2019).

Nelson, D. (2019). Natural Composition of Fresh Water, <http://www.waterencyclopedia.com/En-Ge/Fresh-Water-Natural-Composition-of.html> (accessed 2 April 2019).

New Hampshire Department of Environmental Services (NH DES) (2003). Wastewater Discharges from Vehicle Washing, <https://www.des.nh.gov/organization/commissioner/pip/factsheets/dwgb/documents/dwgb-22-10.pdf> (accessed 18 May 2019).

Novotny, E., Murphy, D., and Stefan, H. (2008). "Increase of urban lake salinity by road deicing salt." *Science of the Total Environment,* 406, 131-144.

Novotny, E., Sander, A., Mohseni, O., and Stefan, H. (2009). "Chloride ion transport and mass balance in a metropolitan area using road salt." *Water Resources Research*, 45(12).

Ohio Water Resources Council (OWRC) (2012). Recommendations for Salt Storage, Guidance for Protecting Ohio's Water Resources, <http://www.ohiodnr.com/Portals/23/pdf/Draft%20OWRC%20Salt%20Storage%20Guidance.pdf> (accessed 24 April 2019).

Oregon Department of Transportation (ODOT) (2014). Water Quality and Habitat Guide Best Management Practices, <https://www.oregon.gov/ODOT/Maintenance/Documents/blue_book.pdf> (accessed 3 April 2019).

Pieper, K., Tang, M., Jones, C., Weiss, S., Greene, A., Mohsin, H., Parks, J., Edwards, M. (2018). "Impact of road salt on drinking water quality and infrastructure corrosion in private wells." *Environmental Science and Technology*, 52, 4078-14087.

Ramakrishna, D. and Viraraghavan, T. (2005). "Environmental Impact of Chemical Deicers—A Review." *Water, Air, and Soil Pollution,* 166, 49-63.

Salt Lake City (SLC) Public Utilities (2019). Salt Lake City Department of Public Utilities Water Quality Report 2019, <http://www.slcdocs.com/utilities/CCR.pdf> (accessed 17 November 2019).

Schuler, M., Hintz, W., Jones, D., Lind, L., Mattes, B., Stoler, A., Sudol, K., and Relyea, R. (2017). "How common road salts and organic additives alter freshwater food webs: in search of safer alternatives." *Journal of Applied Ecology*, 54, 1353-1361.

Siegel, L (2007). Hazard Identification for Human and Ecological Effects of Sodium Chloride Road Salt, <http://www.rebuildingi93.com/documents/environmental/Chloride-TMDL-

Toxicological-Evaluation.pdf> (accessed 7 May 2019).

Texas A&M University (TAMU) (2019). Solutions to the Advective Reacting Diffusion Equation, <https://ceprofs.civil.tamu.edu/ssocolofsky/cven489/Downloads/Book/Ap2.pdf> (accessed 6 September 2019).

Transportation Association of Canada (TAC) (2013a). 1.0- Salt Management Plans, <http://tac-atc.ca/sites/tac-atc.ca/files/site/doc/resources/roadsalt-1.pdf> (accessed 5 December 2018).

Transportation Association of Canada (2013b). 7.0- Design and Operation of Road Maintenance Yards, <https://www.tac-atc.ca/sites/tac-atc.ca/files/site/doc/resources/roadsalt-7.pdf> (accessed 5 December 2018).

Transportation Research Board (TRB) (1991). Highway Deicing: Comparing Salt and Calcium Magnesium Acetate, < https://www.nap.edu/catalog/11405/highway-deicing-comparing-salt-and-calcium-magnesium-acetate-comparing-salt> (accessed 12 March 2019).

Turk, L.J. (1970). "Evaporation of Brine: A Field Study on the Bonneville Salt Flats, Utah." *Water Resources Research*, 6(4), 1209-1215.

Ullinger, H., Kennedy, M., Schneider, W., and Miller, C. (2016). "Exploratory Disposal and Reuse Feasibility Analysis of Winter Maintenance Wash Water." *PLoS ONE,* 11(2).

United States Environmental Protection Agency (USEPA) (1992). Method 1311: Toxicity Characteristic Leaching Procedure, < https://www.epa.gov/hw-sw846/sw-846-test-method-1311-toxicity-characteristic-leaching-procedure> (accessed 23 January 2019).

United States Environmental Protection Agency (USEPA) (1996). Method 3050B: Acid Digestion of Sediments, Sludges, and Soils, < https://www.epa.gov/esam/epa-method-3050b-acid-digestion-sediments-sludges-and-soils> (accessed 8 August 2018).

United States Environmental Protection Agency (USEPA) (1998a). "Method 3545A: Pressurized Fluid Extraction (PFE), < https://www.epa.gov/esam/method-3545a-sw-846-pressurized-fluid-extraction-pfe> (accessed 2 February 2019).

United States Environmental Protection Agency (USEPA) (1998b). Method 6020A: Inductively Coupled Plasma Mass Spectrometry, <https://www.epa.gov/esam/epa-method-6020b-sw-846-inductively-coupled-plasma-mass-spectrometry> (accessed 3 August 2018).

United States Environmental Protection Agency (USEPA) (2003). Drinking Water Advisory: Consumer Acceptability Advice and Health Effects Analysis on Sodium, < https://www.epa.gov/sites/production/files/2014-09/documents/support_cc1_sodium_dwreport.pdf> (accessed 12 April 2019).

United States Environmental Protection Agency (USEPA) (2005). Stormwater Phase II Final Rule: Small MS4 Stormwater Program Overview, <https://www3.epa.gov/npdes/pubs/fact2-0.pdf> (accessed 23 March 2019).

United States Environmental Protection Agency (USEPA) (2007). Method 8015C: Nonhalogenated Organics by Gas Chromatography, < https://www.epa.gov/hw-sw846/sw-846-test-method-8015c-nonhalogenated-organics-gas-chromatography> (accessed 16 May 2019).

United State Environmental Protection Agency (USEPA) (2010). Method 1664, Revision B: n-Hexane Extractable Material (HEM; Oil and Grease) and Silica Gel Treated n-Hexane Extractable Material (SGT-HEM; Non-polar Material) by Extraction and Gravimetry, < https://www.epa.gov/sites/production/files/2015-08/documents/method_1664b_2010.pdf> (accessed 2 August 2018).

United States Environmental Protection Agency (USEPS) (2016). Biotic Ligand Model and Copper Criteria, < https://www.epa.gov/sites/production/files/2016-03/documents/biotic_ligand_model_and_copper_criteria_for_web_mar2016_508c.pdf> (accessed 11 November 2019).

United States Environmental Protection Agency (USEPA) (2017). Secondary Drinking Water Standards: Guidance for Nuisance Chemicals, <https://www.epa.gov/dwstandardsregulations/secondary-drinking-water-standards-guidance-nuisance-chemicals> (accessed 30 October 2019).

United State Environmental Protection Agency (USEPA) (2018). Method 8270E: Semivolatile Organic Compounds by Gas Chromatography/Mass Spectrometry, <https://www.epa.gov/hw-sw846/sw-846-test-method-8270e-semivolatile-organic-compounds-gas-chromatographymass-spectrometry> (accessed 16 May 2019).

United States Environmental Protection Agency (USEPA) (2019a). NPDES Stormwater Program, < https://www.epa.gov/npdes/npdes-stormwater-program> (accessed 1 May 2019.

United States Environmental Protection Agency (USEPA) (2019b). National Recommended Water Quality Criteria—Aquatic Life Criteria Table, < https://www.epa.gov/wqc/national-recommended-water-quality-criteria-aquatic-life-criteria-table#table> (accessed 15 November 2019).

United States Geological Survey (USGS) (2019a). National Hydrography Dataset. < https://www.usgs.gov/core-science-systems/ngp/national-hydrography/national-hydrography-dataset?qt-science_support_page_related_con=0#qt-science_support_page_related_con> (accessed 12 September 2019).

United States Geological Survey (USGS) (2019b). National Water Information System, <https://waterdata.usgs.gov/ut/nwis/current/?type=flow> (accessed 25 June 2019).

Utah Climate Center (UCC) (2019). Climate Data, <https://climate.usu.edu/mapGUI/mapGUI.php> (accessed 24 June 2019).

Utah Department of Environmental Quality (UDEQ) (2015a). Utah Department of Transportation (UDOT) MS4 Permit No. UTS000003, <https://documents.deq.utah.gov/water-quality/permits/updes/DWQ-2015-013429.pdf> (accessed 12 June 2018).

Utah Department of Environmental Quality (UDEQ) (2015b). Fact Sheet/Statement of Basis MS4 Renewal Permit, UPDES Permit Number: UTS000003, <https://documents.deq.utah.gov/water-quality/permits/updes/DWQ-2015-016747.pdf> (accessed 12 June 2019).

Utah Department of Environmental Quality (UDEQ) (2017). Water Quality Standards Ongoing Review Topics Workplan, <https://documents.deq.utah.gov/water-quality/standards-technical-services/triennial-review/DWQ-2017-001045.pdf> (accessed 17 November 2019).

Utah Department of Transportation (UDOT) (2016). “Stormwater Management Program (SWMP) Plan.”

Utah Department of Transportation (UDOT) (2018). Central Equipment List, <https://docs.google.com/spreadsheets/d/ 1RRlQ48CGygqM2BpvI9117d-kUlzhm6_xdd31G3ur3ZE/edit - gid=205612916> (accessed 20 September 2019).

Utah Department of Transportation (UDOT) (2019). Station Boundary Layer, < http://data-uplan.opendata.arcgis.com/datasets/station-boundary> (accessed 12 September 2019).

Utah Division of Environmental Remediation and Response (DERR) (2015). *Guidelines for Utah's Corrective Action Process for Leaking Underground Storage Tank Sites*. Third Edition, Final Draft. Utah Department of Environmental Quality, Leaking Underground Storage Tank Program. <https://documents.deq.utah.gov/environmental-response-and-remediation/ust-

lust/leaking-underground-storage-tanks-remedial-assistance/guidelines-for-utahs-corrective-action-process-for-lust-sites.pdf>

Utah Division of Water Rights (UDWR) (2019). GAGEVIEW Stream Gage Records Viewer, <https://www.waterrights.utah.gov/cgi-bin/gageview.exe?Startup> (accessed 25 June 2019).

Utah Office of Administrative Rules (2019). Rule R317-2. Standards of Quality for Water of the State, *Utah Administrative Code*, < https://rules.utah.gov/publicat/code/r317/r317-002.htm#T12> (accessed 26 September 2019).

Virginia Department of Transportation (VDOT)(2015). Waste Management and Pollution Prevention Guide, <https://www.virginiadot.org/business/resources/const/P2_Waste_Management_Guides.pdf> (accessed 4 February 2019).

Wegner W. and Yaggi, M. (2001). "Environmental impacts of road salt and alternatives in the New York City Watershed." *Stormwater,* 2(5).

Western Transportation Institute (WTI)(2015). "Manual of Environmental Best Practices for Snow and Ice Control." *Development of a Snow and Ice Control Environmental Best Practices Manual,* < www.clearroads.org>.

Ye, Z., Shi, X., Veneziano, D., and Fay, L. (2013). Evaluating the Effectiveness of Winter Chemicals on Reducing Crashes in Idaho, <https://apps.itd.idaho.gov/apps/research/Completed/RP201.pdf> (accessed 29 March 2019).

APPENDICES

APPENDIX A: UDOT POLLUTION PREVENTION SURVEY

1. What activities are performed at this location (maintenance, painting, etc.)?

2. a. Besides stormwater/wash water, are there any other waste streams that can enter the pond?

   b. If so, what are the sources of these waste streams?

3. Are there any sources of contamination from outside the UDOT facility?

4. What is the current procedure for pond maintenance (how often is it dredged, pumped, etc.)?

5. How often does the pond overflow and what causes it to overflow?

6. Is there an oil/water separator on site? If so, where is it located and how often is it maintained?

7. How is the truck wash water handled or disposed of (sewer, drains to pond, etc.)?

8. Miscellaneous:

APPENDIX B: UDOT SAMPLING TRIP PLAN

The following document describes equipment and information you will need and procedures you must follow during your sampling trips.

Equipment List:

- Clipboard
- Field notes and blank paper
- Chain of custody form
- Pollution prevention survey
- Differential leveling form
- Water depth form
- Camera or camera phone
- Sharpies (black and silver)
- Coolers
- Ice or icepacks (ensure temperature < 6°C)
- pH/conductivity meter
    - pH and EC calibration solutions
    - Batteries
- Sample containers (variable per visit)
    - 1 L plastic (sediment, TSS)
    - 1 L Amber glass
    - 1 250 mL plastic (metals)
- DDW
    - Squeeze bottle
    - 4L plastic container of DDW (for field blank and rinsing)
- Grab sampler
- Duct tape (in case of sampling apparatus failure)
- ADCP StreamPro
    - Batteries
    - Rope
    - Boat for mounting ADCP
    - Computer with *WinRiver II*
- Surveying equipment
    - Tripod
    - Theodolite
    - Philadelphia rod
    - 100' and 300’ measuring tape
    - Compass
    - Plumb bob (2)
    - Chalk
- Kimwipes and trash bag
- Snacks/lunch/food and drinking water
- Phones for emergency
- Sunscreen

Overnight Travel:

- Nitric acid
- Syringes
- Syringe filters
- Pasteur pipette and bulb
- Sample containers
    - 1 L amber glass with HCl preservative (Oil & Grease)
    - 500 mL plastic with HNO3 preservative (metals)
    - 125 mL plastic (filtered metals)
    - 1 L plastic (sediment, TSS)

Safety Equipment:

- Gloves (disposable, nitrile, large and small)
- Safety vest
- Safety glasses
- Flashlights

Safety Considerations:

- Don't compromise safety. Evaluate the banks/ponds.
- Everyone should be within sight of at least one other person.
- If sample bottles/vials contain preservative be sure to avoid contact with preservative and tightly seal caps. If minor skin contact occurs, rinse with copious amounts of water.
- Everyone handling samples should wear gloves.
- Minimum of two people need to go on a sampling trip. No one can sample alone.

Site Identification:

Site #	Location
S1	Logan
S2	Kamas
S3	Heber
S4	Lehi
S5	Provo/Orem
S6	Clearfield
S7	Brigham City
S8	Salina
S9	Junction
S10	Silver Summit
S11	Echo
S12	Huntsville
S13	Hooper

Parameter Identification:

Code	Water Quality Parameter	Sample	Volume	Preservative*
TSS	Total Suspended Solids	Plastic Bottle	250 mL	No
M	Metals	Plastic Bottle	250 mL	Added in lab
Sed.	Pond sediment	Plastic Bottle	1 L	No
O&G	Oil & Grease	Amber glass	1 L	No
MX	Oil & Grease Matrix Spike	Amber glass	1 L	No

**Preservative will only be added if we cannot get the samples back to the lab within 8 hours.*

Sample Identification:

Each sample must have a unique identifier. An example of a sample ID is as follows:

102016 S1 TSS A

- Date= 102016 (October 20th, 2016)
- Location ID=S1 (Site #1) see table above.
- Parameter ID= TSS (Total Suspended Solids)
- Sequential Letter
    - Pond #1
        - A= Field sample # 1
        - B= Field sample # 2
        - C= Field sample # 3
    - Other
        - D= DDW water blank
        - E= Truck Wash-water #1
        - F= Truck Wash-water #2
        - G= Truck Wash-water #3
        - H= Trip blank
        - MX= Matrix spike (O&G)

List of Samples for a Site Visit:

#	Sample ID	Parameter	Container	Volume	Time Sampled
Retention Pond					
1		TSS #1	Plastic	1 L	
2		TSS #2	Plastic	1 L	
3		TSS #3	Plastic	1 L	
4		Metals #1	Plastic	250 ml	
5		Metals #2	Plastic	250 ml	
6		Metals #3	Plastic	250 ml	
7		Oil and Grease #1	Amber Glass	1 L	
8		Oil and Grease #2	Amber Glass	1 L	
9		Oil and Grease #3	Amber Glass	1 L	
10		Oil and Grease MX #1	Amber Glass	1 L	
11		Oil and Grease MX #2	Amber Glass	1 L	
12		Sediments #1	Plastic	1 L	
13		Sediments #2	Plastic	1 L	
14		Sediments #3	Plastic	1 L	
DDW Field Blanks					
15		TSS Field Blank	Plastic	1 L	
16		Metals Field Blank	Plastic	250 ml	
17		Oil & Grease Field Blank	Amber Glass	1 L	
If Available: Truck Wash Water					
18		TSS WW #1	Plastic	1 L	
19		TSS WW #2	Plastic	1 L	
20		TSS WW #3	Plastic	1 L	
21		Metals WW #1	Plastic	250 ml	
22		Metals WW #2	Plastic	250 ml	
23		Metals WW #3	Plastic	250 ml	
24		Oil and Grease WW #1	Amber Glass	1 L	
25		Oil and Grease WW #2	Amber Glass	1 L	
26		Oil and Grease WW #3	Amber Glass	1 L	
Trip Blanks					
27		TSS Trip Blank	Plastic	1 L	
28		Metals Trip Blank	Plastic	250 ml	
29		Oil & Grease Trip Blank	Amber Glass	1 L	

Before Sampling:

1. Obtain permission for site access by calling site manager.
    a. Find out if there are more than one ponds to sample, where they get their water to wash trucks.
    b. Find out if the pond is lined/unlined/asphalt/etc.
2. Coordinate with UWRL if someone will be there for pre and post trip visit.
    a. If not, make plans for sample preservation and refrigeration.
3. Check weather for hazardous conditions (lightning, wind, snow, flash flood warning).
    a. If too hazardous, reschedule your sampling trip.
4. Be sure coolers and grab sampler are clean/decontaminated.
5. Determine if trip will take > 8 hours to get samples to lab. If so, add preservative to samples (HNO_3 for Metals, HCl for Oil & Grease).
6. Prepare Supplies for Trip
    a. Freeze icepacks.
    b. Pre-fill out Chain of Custody form.
    c. Obtain and acid wash sample bottles.
    d. Check if number of bottles matches chain of custody form.
7. Lab Preparation
    a. Prepare filters for TSS in UWRL.
    b. Ensure there is adequate space in walk-in for samples.
8. Vehicle
    a. Check to see if vehicle is in good operating condition (has wiper fluid, tires okay, etc.).
    b. Check to see if there is enough gas for trip.
    c. Driver (okay to drive, enough seats in car and room for coolers).

Arriving on location:

1. Park somewhere safe.
2. Put on and wear PPE (personal protective equipment).
3. Assess the location and weather.
    a. Are there any weather hazards?
    b. Are there any location hazards? Is it safe to walk down to the retention/detention pond? Are the edges steep and unconsolidated?
4. Determine safest place to take samples.
5. Make observations/Take pictures
    a. What does the site look like?
    b. What does the surface of the water look like?
    c. Is there a visible sheen to the water?
    d. Are there particles or clumps in the water? Describe them. (Take pictures)

Sampling Procedure:

Begin your sampling process by taking field parameters. Field parameters are those that you measure on the site. Usually these include those you can measure with a probe (pH, conductivity). These can also include visual observations.

Remember: Do not disturb the location where sample is to be taken with discarded rinse water.
Field Parameters:

1. Take an initial grab sample for field parameters and pour into the kit's intermediate container.
2. Wash pH meter probe with DDW (squeeze bottle).
3. Calibrate meter for pH and conductivity. Pay attention to water temperature and calibrate based on the values on the calibration packet.
4. Wash pH probe with DDW between each calibration.
5. After calibration, wash meter probe with DDW.
6. Take temperature of the sample by pressing °C. Record in field notes.
7. Switch meter to pH and record value in field notes.
8. Switch meter to mS/cm for conductivity and record value in field notes.
9. Switch meter to ppm for TDS and record value in field notes
10. Rinse meter probe with DDW.
11. Discard sample water.
12. Wash out intermediate container with DDW.

TSS: (Plastic)

1. Wear disposable nitrile gloves.
2. Avoid contamination by holding bottles on the outside. Be careful not to touch the inside of bottles or caps.
3. Approach the bank of the detention/retention pond carefully, safely, and with caution.
4. You must first condition the grab sampler by filling it with the retention/detention pond water.
    a. Dip the sampler into the pond and completely fill the sampler container so that no external contamination goes into sample bottles.
5. Repeat this process three times
6. Use the grab sampler to reach out 7-8 feet out into the deepest point of the pond.
7. Fill the device by slowly submerging the sampler into the water at a consistent depth with minimum disturbance.
    a. Do not take samples near the bottom or skim the water surface. Take samples at a consistent depth below the surface.
    b. Contamination can occur due to agitation of bottom sediments or surface floating debris.
8. Transfer sample water carefully to an appropriately labeled 1 L plastic sample bottle. Only fill to the neck of the bottle.
9. Carefully tighten cap and be careful to avoid contamination.
10. Take two more TSS samples at two different locations around the pond.

Metals: (Plastic)

1. Wear disposable nitrile gloves.
2. If preservative has already been added, be very careful. The acid may burn your skin if exposed.
3. Avoid contamination by holding bottles by outside. Be careful not to touch the inside of bottles or caps.
4. Approach the bank of the detention/retention pond carefully, safely, and with caution.

5. Use the grab sampler to reach out 7-8 feet out into the deepest point of the pond.
6. Fill the device by slowly submerging the sampler into the water with minimum disturbance.
    a. Do not take samples near the bottom or skim the water surface. Take samples at a consistent depth below the surface.
    b. Contamination can occur due to agitation of bottom sediments or surface floating debris.
7. Transfer sample water carefully to the 1 L sample bottle. Only fill to the neck of the bottle to leave room for acid preservative.
8. Carefully tighten cap and be careful to avoid contamination.
9. Take two more metals samples at two different locations around the pond.

Oil & Grease: (Amber glass)

1. Avoid filling the sample containers near a running motor or any type of exhaust system because discharged fumes and vapors may contaminate the samples.
2. Avoid exposing the containers to gasoline or other organic vapors before and after sampling (do not store in an automobile trunk for a long time).
3. Approach the bank of the detention/retention pond carefully, safely, and with caution.
4. Use the grab sampler to reach out 7-8 feet out into the deepest point of the pond.
5. Fill the device by slowly submerging the sampler into the water with minimum disturbance.
    a. Do not take samples near the bottom or skim the water surface. Take samples at a consistent depth below the surface.
    b. Contamination can occur due to agitation of bottom sediments or surface floating debris.
6. Transfer sample water carefully to the 1 L sample bottle. Only fill to the neck of the bottle to leave room for preservative.
7. Carefully tighten cap and be careful to avoid contamination.
8. Take two more oil and grease samples at two different locations around the pond.

Sediment: (Plastic)

1. Wear disposable nitrile gloves.
2. Avoid contamination by holding bottles on the outside. Be careful not to touch the inside of bottles or caps.
3. Approach the bank of the detention/retention pond carefully, safely, and with caution.
4. You must first condition the grab sampler by filling it with the retention/detention pond water.
    a. Dip the sampler into the pond and completely fill the sampler container so that no external contamination goes into sample bottles.
5. Repeat this process three times
6. Use the grab sampler to reach out 7-8 feet out into the deepest point of the pond.
7. Fill the device by slowly submerging the sampler into the water and running it along the bottom.
8. Transfer sediment and sample water carefully to an appropriately labeled 1 L plastic sample bottle. Only fill to the neck of the bottle.
9. Carefully tighten cap and be careful to avoid contamination.

10. Take two more sediment samples at two different locations around the pond.

Field blanks: (variable)

1. Field Blanks are used to evaluate the potential for contamination of a sample by site contaminants from a source not associated with the sample collected (i.e. air-borne dust, etc.).
2. DDW water is taken into the field in a sealed container. The DDW is then poured into the sample container and the chemical preservative is added if appropriate.
3. Often it is a good idea to sample these **first** to avoid contamination of other water.
4. Refer to the procedures for TSS, Metals, and Oil & Grease, except use the lab's DDW water you brought with you to fill the sample containers. Be sure to avoid contamination of other water.

Water used to wash trucks:

1. This will likely be from a tap or some sort of hose. Let the water run for a few minutes and refer to procedures for TSS, metals, and oil and grease. Do not cross contaminate any intermediate sample containers.

Before you leave the site:

- Check Chain of Custody form and the coolers to see if you have all the samples and they are appropriately marked.
- Collect all your equipment and any debris you may have discarded.

On return:

- Immediately drop off samples at the lab and give them the chain of custody form.
- Fill out the lab-book of the samples you dropped off.
- Label the samples with the lab's labeling system.

Within a week of sampling trip:

- Perform TSS analysis.
- Perform Oil & Grease analysis

APPENDIX C: SITE DATA

Table C1. Metals and trace elements data for the sediment samples collected from 11 UDOT maintenance stations.

Site Name & Number	Sample Name	Concentration (mg/kg)													
		Weight (g)	23 Na [He]	24 Mg [He]	39 K [He]	44 Ca [He]	52 Cr [He]	56 Fe [He]	60 Ni [He]	63 Cu [He]	66 Zn [He]	75 As [He]	78 Se [H2]	1 Cd [No Gas	8 Pb [No Gas
Heber (S3)	UDOT sed 18885	0.4818	10035	11955	4161	50934	30.6	18310	19.1	49.0	632	19.0	0.68	0.88	53.3
	UDOT sed 18886	0.4809	11728	15824	6103	52922	31.2	18409	21.7	56.2	347	10.8	0.68	0.79	28.4
	UDOT sed 18887	0.4832	10813	15635	5422	54915	28.3	18764	21.8	54.2	287	10.1	0.83	0.93	27.6
	Mean		10859	14472	5229	52924	30.1	18494	20.9	53.2	422	13.3	0.73	0.87	36.5
	St. Dev.		847	2181	985	1991	1.54	239	1.52	3.73	184	4.94	0.09	0.07	14.6
Lehi (S4)	UDOT sed 181264	0.5023	25752	17798	5186	95690	42.2	14336	22.1	73.0	371	13.6	1.09	0.95	40.2
	UDOT sed 181265	0.491	17485	18534	5998	94369	39.9	16467	23.4	94.3	329	13.7	1.27	1.26	46.9
	UDOT sed 181266	0.5034	16498	17481	4877	87962	49.1	15590	23.6	106	404	18.0	1.16	1.22	49.6
	Mean		19911	17938	5354	92673	43.7	15464	23.0	91.2	368	15.1	1.18	1.14	45.5
	St. Dev.		5082	540	579	4133	4.81	1071	0.80	16.9	37.8	2.52	0.09	0.17	4.85
Provo/Orem (S5)	UDOT sed 181267	0.5033	7669	15826	1997	87910	38.4	11776	22.7	109	1218	7.21	0.78	1.47	63.1
	UDOT sed 181268	0.4995	5045	17097	2112	92302	41.6	13527	22.2	123	1322	7.65	0.82	1.61	67.9
	UDOT sed 181269	0.4987	4672	15450	1975	87508	44.7	12832	20.1	109	917	7.53	0.66	1.27	66.3
	Mean		5796	16124	2028	89240	41.6	12712	21.7	114	1153	7.46	0.76	1.45	65.8
	St. Dev.		1633	863	73.6	2660	3.16	881	1.38	8.08	210	0.23	0.08	0.17	2.46
Brigham City (S7)	UDOT sed 181293	0.4979	4981	14531	1808	40098	18.8	9120	14.9	29.2	393	5.69	0.22	0.49	18.0
	UDOT sed 181294	0.4966	5538	11720	1530	27296	30.3	9290	16.2	46.8	358	6.30	0.26	0.88	17.8
	UDOT sed 181295	0.5041	4592	9730	1805	29012	30.1	15878	14.7	50.0	310	7.59	0.26	0.65	22.4
	Mean		5037	11994	1714	32135	26.4	11429	15.3	42.0	354	6.53	0.25	0.67	19.4
	St. Dev.		475	2412	159	6949	6.56	3853	0.81	11.2	41.7	0.97	0.02	0.19	2.55
Salina (S8)	UDOT sed 181427	0.4981	4306	21562	3393	90654	12.1	9183	14.0	23.7	137	5.45	0.40	0.72	11.4
	UDOT sed 181428	0.506	1433	12194	2253	55247	10.1	6524	8.82	14.8	43.4	1.99	0.18	0.11	4.74
	UDOT sed 181429	0.5003	9504	15491	3188	70818	15.9	9854	15.2	45.6	232	7.46	0.61	1.38	15.7
	Mean		5081	16415	2945	72240	12.7	8520	12.7	28.0	137	4.96	0.40	0.74	10.6
	St. Dev.		4091	4752	608	17747	2.95	1761	3.39	15.8	94.3	2.77	0.22	0.64	5.54
Junction (S9)	UDOT sed 181390	0.4973	5218	15655	5148	43797	22.0	15791	23.6	28.6	106	4.15	0.43	0.43	19.3
	UDOT sed 181391	0.5004	17466	16797	4846	23271	28.0	23043	45.3	45.5	155	4.58	0.60	0.91	24.8
	UDOT sed 181392	0.5033	15468	16710	4957	23723	28.4	25328	42.8	42.6	136	4.54	0.57	0.78	24.6
	Mean		12717	16387	4984	30264	26.1	21387	37.3	38.9	132	4.42	0.53	0.71	22.9
	St. Dev.		6571	636	153	11722	3.59	4979	11.9	9.04	24.6	0.23	0.09	0.25	3.14
Silver Summit (S10)	UDOT sed 181580	0.5001	3519	15887	2829	67097	72.6	16534	22.4	62.9	289	19.3	0.36	0.48	24.8
	UDOT sed 181581	0.4995	2052	20541	2102	70380	52.2	12058	17.8	44.4	269	13.7	0.28	0.37	19.2
	UDOT sed 181582	0.4991	1803	11280	1322	71789	45.5	11291	14.7	61.1	328	8.10	0.23	0.76	27.2
	Mean		2458	15903	2085	69755	56.8	13294	18.3	56.1	295	13.7	0.29	0.54	23.7
	St. Dev.		927	4630	754	2408	14.1	2831	3.87	10.2	30.00	5.61	0.07	0.20	4.09

Site Name & Number	Sample Name	Concentration (mg/kg)													
		Weight (g)	23 Na [He]	24 Mg [He]	39 K [He]	44 Ca [He]	52 Cr [He]	56 Fe [He]	60 Ni [He]	63 Cu [He]	66 Zn [He]	75 As [He]	78 Se [H2]	1 Cd [No Gas	8 Pb [No Gas
Echo (S11)	UDOT sed 181554	0.5019	4065	8159	1385	40675	17.6	9788	10.8	23.7	84.5	4.42	0.26	0.32	9.67
	UDOT sed 181555	0.5022	5705	13939	2250	63789	33.0	13438	17.1	44.2	211	8.64	0.50	0.73	20.6
	UDOT sed 181556	0.5031	8935	14590	2296	69042	39.5	16121	20.4	59.2	273	10.5	0.63	0.93	24.7
	Mean		6235	12229	1977	57836	30.0	13116	16.13	42	190	7.85	0.46	0.66	18.3
	St. Dev.		2478	3540	513	15091	11.2	3179	4.89	18	96.0	3.11	0.19	0.31	7.78
Huntsville (S12)	UDOT sed 182195	0.5002	3129	8507	1439	18003	18.0	10817	9.90	24.5	144	5.23	0.17	0.25	12.6
	UDOT sed 182196	0.4994	8410	10783	1792	21466	23.7	14459	13.3	32.6	164	7.30	0.20	3.59	15.1
	UDOT sed 182197	0.4998	10304	17297	3371	27131	28.8	20511	22.5	65.2	230	14.5	0.39	0.94	27.5
	Mean		7281	12195	2201	22200	23.5	15262	15.2	40.8	179	9.00	0.25	1.59	18.4
	St. Dev.		3719	4562	1029	4608	5.39	4897	6.54	21.5	45.0	4.86	0.12	1.77	7.97
Hooper (S13)	UDOT sed 182392	0.5022	424134	558	259	1006	1.04	322	0.40	1.49	6.11	0.30	0.44	0.02	0.69
	UDOT sed 182393	0.5028	285402	6951	1273	14708	14.2	4377	6.45	20.7	122	4.29	0.38	0.28	12.2
	UDOT sed 182394	0.5016	410686	269	69.8	797	0.27	29.9	0.09	0.21	0.81	0.06	0.16	0.01	0.09
	Mean		373407	2593	534	5504	5.18	1577	2.31	7.47	43.1	1.55	0.33	0.10	4.33
	St. Dev.		76511	3777	647	7972	7.85	2430	3.59	11.5	68.7	2.37	0.15	0.15	6.83

Table C2. Quality control results for the TPH analysis of sediment samples.

Instrument and Lab Spikes

Sample	TPH (ug/mL)	Spike Recovery (%)
Blank 1	0.6	
TPH Lab spk 1	87.0	86.4
Blank 2	0.4	
TPH Lab spk 2	98.4	98.1
Blank 3	0.0	
Blank 5	0.0	
18886 A	23.4	
18886 TPH spk 1	116.9	93.5
18886 TPH spk 2	264.8	241
181264 A	45.8	
181264 A TPH spk 1	117.5	71.7
181264 A TPH spk 2	160.2	114
181429 A	140.8	
181429 TPH spk 1	184.8	44.0
181429 TPH spk 2	392.5	252
181582 A	59.2	
181582 TPH spk A	118.5	59.3
181582 TPH spk B	392.5	333

Edge Spikes

Sample	TPH (ug/mL)	Spike Recovery (%)
181391	40.4	
181391 spk	75.1	121.6
181556	24.3	
181556 spk	42.4	63.6
182196	41.0	
182196 spk	76.7	124.9
182393	14.8	
182393 spk	37.2	78.2

Table C3. Oil and grease and TPH data for the sediment samples collected from 10 UDOT maintenance stations.

Site Name		Oil and Grease (g/kg)	TPH (mg/kg)
Heber		20.4	315
		20.9	452
		23.4	608
	Mean	21.6	459
	95% CI	1.83	165
Lehi		18.5	867
		22.0	1267
		23.0	1804
	Mean	21.0	1312
	95% CI	2.80	532
Prove/Orem		24.8	358
		26.2	490
		19.0	339
	Mean	23.3	396
	95% CI	4.34	93.6
Brigham/Orem		26.6	684
		35.0	3443
		18.8	734
	Mean	26.8	1620
	95% CI	9.17	1786
Junction		14.0	334
		25.6	707
		26.7	580
	Mean	22.1	540
	95% CI	7.98	214
Salina		28.4	1034
		7.10	245
		35.7	2605
	Mean	23.7	1295
	95% CI	16.8	1359
Echo		8.70	172
		15.75	310
		18.35	425
	Mean	14.3	302
	95% CI	5.65	143
Silver Summit		48.8	3514
		33.4	1832
		26.6	1144
	Mean	36.3	2164
	95% CI	12.9	1379
Huntsville		10.9	450
		13.0	717
		28.3	1458
	Mean	17.4	875
	95% CI	10.6	591
Hooper		1.1	13.6
		9.3	260
		0.7	5.04
	Mean	3.70	92.8
	95% CI	5.49	164

Table C4. Total metals and trace elements data for the pond and tap water collected from 11 UDOT maintenance stations.

			23 Na [He]	24 Mg [He]	27 Al [He]	39 K [He]	44 Ca [He]	52 Cr [He]	55 Mn [He]	56 Fe [He]	63 Cu [He]	66 Zn [He]	75 As [He]	78 Se [H2]	1 Cd [No Ga	8 Pb [No Ga	8 U [No Gas
		Top Limit	**100**	**100**	**4000**	**100**	**100**	**200**	**300**	**2000**	**500**	**400**	**200**	**100**	**100**	**100**	**100**
		MRL *	**0.40**	**0.10**	**10.00**	**0.25**	**0.20**	**0.10**	**0.50**	**5.00**	**0.63**	**2.00**	**0.25**	**0.13**	**0.13**	**0.25**	**0.25**
Site Name & Numb	Sample ID	UWRL Log Number	Conc. [mg/l]	Conc. [mg/l]	Conc. [ug/l]	Conc. [mg/l]	Conc. [mg/l]	Conc. [ug/l]	Conc. [ug/l]	Conc. [ug/l]	Conc. [ug/l]	Conc. [ug/l]	Conc. [ug/l]	Conc. [ug/l]	Conc. [ug/l]	Conc. [ug/l]	Conc. [ug/l]
Kamas (S2)	080118 S2 M A	UDOT dig 18920	8691.00	101.20	61.33	97.30	86.60	0.49	127.43	134.27	6.95	16.15	3.34	14.23	0.48	0.33	
	080118 S2 M B	UDOT dig 18921	8987.00	101.70	49.52	97.20	88.20	0.40	119.18	111.47	6.16	17.57	3.24	13.48	0.16	0.27	
	080118 S2 M C	UDOT dig 18922	8667.00	103.50	47.04	98.90	89.00	0.48	125.39	125.38	6.71	15.51	3.21	14.74	0.17	0.28	
		Mean	8781.67	102.13	52.63	97.80	87.93	0.46	124.00	123.71	6.61	16.41	3.26	14.15	0.27	0.29	
		St. Dev.	178.23	1.21	7.64	0.95	1.22	0.05	4.30	11.49	0.41	1.05	0.07	0.63	0.18	0.03	
	080118 S2 M D	UDOT dig 18923	18.10	0.50	19.78	0.03	0.05	0.23	1.30	40.28	1.19	8.72	0.12	0.00	0.00	0.40	
	080118 S2 M E	UDOT dig 18924	37.69	22.56	175.60	4.31	97.50	1.10	9.80	297.55	97.22	354.36	2.05	0.15	0.02	2.18	
	080118 S2 M F	UDOT dig 18925	38.02	22.55	287.32	4.47	96.80	1.60	15.23	514.90	113.20	465.00	2.26	0.15	0.03	3.16	
	080118 S2 M G	UDOT dig 18926	36.37	21.57	216.24	4.60	95.20	1.55	12.62	390.32	100.90	398.80	2.08	0.13	0.04	2.77	
		Mean	37.36	22.23	226.39	4.46	96.50	1.42	12.55	400.92	103.77	406.05	2.13	0.14	0.03	2.70	
		St. Dev.	0.87	0.57	56.55	0.15	1.18	0.28	2.72	109.06	8.37	55.68	0.11	0.01	0.01	0.49	
	080118 S2 M H	UDOT dig 18927	6.70	12.00	3.44	0.01	0.05	0.06	0.08	6.67	0.48	3.90	0.07	0.00	0.00	0.06	
Heber (S3)	073018 S3 M A	UDOT dig 18888	11600.00	128.00	262.86	95.08	202.60	0.75	281.30	253.01	11.79	9.84	6.53	24.05	0.17	0.36	
	073018 S3 M B	UDOT dig 18889	12920.00	128.40	103.81	91.29	201.80	0.40	272.79	139.13	12.26	7.27	6.16	26.05	0.15	0.27	
	073018 S3 M C	UDOT dig 18890	11300.00	128.50	133.10	93.07	202.60	0.50	278.75	161.92	12.31	6.99	6.31	26.77	0.14	0.22	
		Mean	11940.00	128.30	166.59	93.15	202.33	0.55	277.61	184.69	12.12	8.03	6.33	25.62	0.15	0.28	
		St. Dev.	861.86	0.26	84.65	1.90	0.46	0.18	4.37	60.26	0.29	1.57	0.19	1.41	0.02	0.07	
	073018 S3 M D	UDOT dig 18891	39.10	2.50	4.64	0.03	0.05	0.48	0.18	9.98	0.42	3.98	0.06	0.01	0.00	0.07	
	073018 S3 M E	UDOT dig 18892	10.40	13.35	5.43	2.12	61.81	0.36	1.07	105.12	431.35	89.17	1.59	0.16	0.02	22.75	
	073018 S3 M F	UDOT dig 18893	10.88	14.02	7.47	2.28	64.90	0.18	0.51	43.10	393.99	61.94	1.68	0.13	0.02	20.86	
	073018 S3 M G	UDOT dig 18894	10.71	13.41	5.50	2.24	63.30	0.25	0.96	99.27	493.30	223.21	1.57	0.12	0.03	23.88	
		Mean	10.66	13.59	6.13	2.21	63.34	0.26	0.85	82.50	439.55	124.77	1.61	0.14	0.02	22.50	
		St. Dev.	0.24	0.37	1.16	0.08	1.55	0.09	0.30	34.24	50.16	86.33	0.06	0.02	0.01	1.53	
	073018 S3 M H	UDOT dig 18895	16.00	1.90	1.86	0.02	0.06	0.37	0.10	8.17	0.58	4.61	0.07	0.00	0.00	0.07	
Lehi (S4)	080618 S4 M A	UDOT dig 181238	59840.00	818.90	512.28	615.00	440.30	2.25	171.12	614.56	109.57	21.03	25.06	87.30	0.87	2.78	
	080618 S4 M B	UDOT dig 181239	58990.00	837.30	515.86	627.40	459.80	1.75	278.30	568.90	115.30	22.21	26.76	95.50	0.92	2.84	
	080618 S4 M C	UDOT dig 181240	56740.00	818.70	642.40	607.70	451.20	2.26	364.40	742.16	113.66	27.63	26.65	88.30	1.04	3.08	
		Mean	58523.33	824.97	556.85	616.70	450.43	2.09	271.27	641.87	112.84	23.62	26.16	90.37	0.94	2.90	
		St. Dev.	1601.82	10.68	74.11	9.96	9.77	0.29	96.83	89.80	2.95	3.52	0.95	4.47	0.09	0.16	
	080618 S4 M D	UDOT dig 181241	110.80	0.10	3.66	0.02	0.07	0.09	0.16	9.33	0.27	4.40	0.04	1.70	0.00	0.07	
	080618 S4 M E	UDOT dig 181242	42.57	20.78	8.62	3.45	43.67	0.64	0.70	23.75	325.02	66.22	1.46	1.73	0.01	0.49	
	080618 S4 M F	UDOT dig 181243	43.02	20.58	3.03	3.42	43.23	0.63	0.46	12.12	323.54	68.51	1.39	1.61	0.01	0.36	
	080618 S4 M G	UDOT dig 181244	42.56	20.63	3.94	3.38	42.81	0.62	0.51	17.41	319.67	64.17	1.46	1.67	0.00	0.43	
		Mean	42.72	20.66	5.20	3.42	43.24	0.63	0.56	17.76	322.74	66.30	1.44	1.67	0.01	0.43	
		St. Dev.	0.26	0.10	3.00	0.04	0.43	0.01	0.13	5.82	2.76	2.17	0.04	0.06	0.01	0.07	
	080618 S4 M H	UDOT dig 181245	3.26	1.97	4.65	0.09	0.15	0.29	0.33	22.12	0.50	4.11	0.07	0.00	0.00	0.03	

Clearfield (S6)	080718 S6 M A	UDOT dig 181296	62720.00	32080.00	285.88	1200.00	1377.00	3.61	2159.50	563.50	52.55	42.10	613.60	27.30	1.21	2.14	
	080718 S6 M B	UDOT dig 181297	63840.00	31930.00	312.57	1209.00	1391.00	3.40	2183.70	522.84	35.99	41.45	606.80	33.50	1.15	3.22	
	080718 S6 M C	UDOT dig 181298	59740.00	30780.00	465.39	1256.00	1375.00	4.26	2261.30	862.71	30.09	52.18	637.80	36.20	1.20	3.44	
		Mean	62100.00	31596.67	354.61	1221.67	1381.00	3.76	2201.50	649.68	39.54	45.24	619.40	32.33	1.19	2.93	
		St. Dev.	2119.15	711.22	96.86	30.07	8.72	0.45	53.18	185.60	11.64	6.02	16.29	4.56	0.03	0.70	
	080718 S6 M D	UDOT dig 181299	0.43	0.19	4.95	0.03	0.06	0.14	0.14	12.38	0.39	4.93	0.04	0.00	0.00	0.09	
	080718 S6 M E	UDOT dig 181300	23.86	19.15	4.09	2.10	78.65	0.73	1.74	13.66	37.26	23.34	0.60	0.29	0.02	2.88	
	080718 S6 M F	UDOT dig 181301	25.18	19.74	11.50	2.14	79.01	0.80	2.01	30.21	35.78	20.55	0.64	0.31	0.03	2.98	
	080718 S6 M G	UDOT dig 181302	26.41	20.69	4.49	2.20	81.05	0.73	1.56	22.17	52.57	21.07	0.68	0.37	0.02	2.95	
		Mean	25.15	19.86	6.69	2.15	79.57	0.75	1.77	22.01	41.87	21.65	0.64	0.32	0.02	2.94	
		St. Dev.	1.28	0.78	4.17	0.05	1.29	0.04	0.23	8.28	9.30	1.48	0.04	0.04	0.01	0.05	
	080718 S6 M H	UDOT dig 181303	1.32	0.93	7.64	0.05	0.15	0.12	0.32	16.18	0.46	4.69	0.06	0.01	0.05	0.18	
Brigham City (S7)	080718 S7 M A	UDOT dig 181270	43060.00	1743.00	350.71	166.20	222.70	0.76	63.32	345.36	67.46	7.58	17.95	48.30	0.62	1.08	
	080718 S7 M C	UDOT dig 181272	35450.00	1662.00	302.67	186.60	248.50	12.10	60.25	459.23	62.32	8.67	17.60	32.90	1.87	1.04	
		Mean	39255.00	1702.50	326.69	176.40	235.60	6.43	61.79	402.30	64.89	8.13	17.78	40.60	1.25	1.06	
		St. Dev.	5381.08	57.28	33.97	14.42	18.24	8.02	2.17	80.52	3.63	0.77	0.25	10.89	0.88	0.03	
	080718 S7 M D	UDOT dig 181273	10.47	25.46	28.02	1.17	51.81	0.39	4.98	65.15	45.30	41.09	0.78	0.25	0.01	1.09	
	080718 S7 M E	UDOT dig 181274	0.41	0.23	3.76	0.02	0.10	0.11	0.16	9.86	0.44	4.39	0.04	0.00	0.01	0.68	
	080718 S7 M F	UDOT dig 181275	10.52	25.79	34.99	1.19	52.69	0.47	6.08	121.13	45.58	76.57	0.78	0.31	0.01	0.79	
		Mean	10.50	25.63	31.51	1.18	52.25	0.43	5.53	93.14	45.44	58.83	0.78	0.28	0.01	0.94	
		St. Dev.	5.82	14.66	16.39	0.67	30.11	0.19	3.15	55.64	25.98	36.09	0.43	0.16	0.00	0.21	
Salina (S8)	081418 S8 M A	dig UDOT 181394	17780.13	16.60	124.75	12.01	230.28	1.18	329.34	283.55	26.95	13.48	4.58	2.78	0.36	0.33	0.35
	081418 S8 M B	dig UDOT 181395	17271.06	15.23	108.80	11.94	213.32	0.43	316.98	193.68	33.62	12.39	4.46	2.94	0.40	0.55	0.30
	081418 S8 M C	dig UDOT 181396	18237.62	15.58	304.26	12.48	224.21	1.98	347.43	412.50	34.91	15.42	4.77	3.84	0.40	0.53	0.31
		Mean	17762.94	15.80	179.27	12.14	222.60	1.20	331.25	296.58	31.83	13.76	4.60	3.19	0.39	0.47	0.32
		St. Dev.	483.51	0.71	108.54	0.29	8.59	0.78	15.31	109.99	4.27	1.53	0.16	0.57	0.02	0.12	0.03
	081418 S8 M D	dig UDOT 181397	77.93	0.11	44.83	0.09	0.98	0.37	2.08	33.62	0.94	5.56	0.01	0.01	0.01	0.22	0.04
	081418 S8 M E	dig UDOT 181398	9.13	6.76	17.55	3.04	24.38	0.43	1.71	42.26	11.85	57.97	2.61	0.16	0.01	0.31	0.90
	081418 S8 M F	dig UDOT 181399	8.60	6.22	49.18	2.80	22.40	0.59	2.41	72.84	12.15	54.06	2.42	0.12	0.02	0.31	0.89
	081418 S8 M G	dig UDOT 181400	8.60	6.36	109.90	2.82	22.79	0.60	5.71	151.99	13.39	60.02	2.46	0.19	0.09	0.63	0.94
		Mean	8.78	6.45	58.88	2.89	23.19	0.54	3.28	89.03	12.46	57.35	2.50	0.16	0.04	0.42	0.91
		St. Dev.	0.31	0.28	46.93	0.13	1.05	0.10	2.14	56.63	0.82	3.03	0.10	0.04	0.04	0.18	0.03
	081418 S8 M H	dig UDOT 181401	0.08	0.02	19.17	0.03	0.06	0.08	0.36	22.89	0.49	2.68	-0.04	0.00	0.00	0.19	0.00
Junction (S9)	081518 S9 M A	UDOT 181368	6560.00	21.20	265.65	22.42	199.86	0.76	592.73	288.93	12.87	19.97	5.04	9.88	0.14	0.44	0.73
	081518 S9 M B	UDOT 181369	6750.00	20.51	233.23	22.12	194.64	0.81	564.61	281.40	13.03	12.87	4.77	9.40	0.13	0.38	0.68
	081518 S9 M C	UDOT 181370	13474.25	45.36	262.02	42.62	260.79	2.48	1496.86	1108.54	21.54	18.15	12.61	24.43	0.29	1.23	0.48
		Mean	6655.00	20.86	249.44	22.27	197.25	0.79	578.67	285.17	12.95	16.42	4.91	9.64	0.14	0.41	0.71
		St. Dev.	134.35	0.49	22.92	0.21	3.69	0.04	19.88	5.32	0.11	5.02	0.19	0.34	0.01	0.04	0.04
	081518 S9 M D	UDOT dig 181371	0.03	0.00	4.71	0.01	0.03	0.10	0.16	14.44	0.42	3.42	-0.01	-0.02	0.00	0.07	0.14
	081518 S9 M E	UDOT dig 181372	29.94	19.13	21.74	5.08	69.68	0.66	0.53	26.93	126.42	65.05	4.06	0.14	0.01	3.27	4.35
	081518 S9 M F	UDOT dig 181373	30.03	19.67	11.38	5.26	69.98	0.82	0.68	55.90	124.60	75.81	4.15	0.14	1.60	2.83	4.35
	081518 S9 M G	UDOT dig 181374	29.52	18.88	4.77	5.08	68.95	0.71	0.43	19.56	262.98	98.95	3.96	0.13	0.01	4.81	4.31
		Mean	29.83	19.23	12.63	5.14	69.54	0.73	0.55	34.13	171.33	79.94	4.06	0.14	0.54	3.64	4.34
		St. Dev.	0.27	0.40	8.55	0.10	0.53	0.08	0.13	19.21	79.37	17.32	0.10	0.01	0.92	1.04	0.02
Silver Summit (S10	082018 S10 M A	dig UDOT 181557	53988.09	528.69	343.63	522.02	420.88	1.30	209.21	512.40	42.88	21.19	15.18	8.06	0.61	2.96	0.92
	082018 S10 M B	dig UDOT 181558	53129.67	516.81	320.92	512.70	412.09	1.27	216.62	511.29	44.32	30.07	14.95	7.67	0.62	2.80	0.95
	082018 S10 M C	dig UDOT 181559	53478.74	521.45	745.31	519.76	422.63	3.34	240.20	1062.80	48.64	29.55	16.09	8.47	0.62	4.12	0.99
		Mean	53532.17	522.32	469.95	518.16	418.53	1.97	222.01	695.50	45.28	26.94	15.41	8.07	0.62	3.29	0.95
		St. Dev.	431.70	5.99	238.74	4.86	5.65	1.19	16.18	318.09	3.00	4.98	0.60	0.40	0.01	0.72	0.04
	082018 S10 M D	dig UDOT 181560	0.41	0.12	84.28	0.07	0.09	0.43	2.17	105.10	0.86	4.44	-0.01	0.01	0.00	0.15	0.08
	082018 S10 M E	dig UDOT 181561	14.33	12.06	58.89	3.29	50.45	0.34	0.76	59.55	649.82	40.76	1.20	0.20	0.00	3.79	1.04
	082018 S10 M F	dig UDOT 181562	14.89	12.42	101.70	3.46	52.80	2.02	6.46	164.11	466.04	27.17	1.33	0.20	0.00	3.99	1.03
	082018 S10 M G	dig UDOT 181563	14.77	12.28	83.47	3.32	51.20	0.65	2.07	156.33	1018.70	51.76	1.03	0.15	0.00	3.44	0.99
		Mean	14.66	12.25	81.35	3.36	51.48	1.00	3.10	126.66	711.52	39.90	1.19	0.18	0.00	3.74	1.02
		St. Dev.	0.29	0.18	21.48	0.09	1.20	0.89	2.99	58.25	281.45	12.32	0.15	0.03	0.00	0.28	0.03

Echo (S11)	082018 S11 M A	dig UDOT 181530A	120968.32	445.60	525.70	203.70	1288.14	2.04	711.58	646.62	87.34	110.50	11.16	21.72	1.54	1.88	3.76
	082018 S11 M A	dig UDOT 181530B	144185.74	530.38	612.32	243.04	1510.38	2.12	826.88	730.22	118.10	121.08	12.86	28.14	1.58	2.08	4.00
	082018 S11 M B	dig UDOT 181531A	137368.06	515.54	118.74	238.30	1506.40	1.62	811.42	301.06	99.62	113.80	11.96	19.76	1.52	1.68	3.96
	082018 S11 M B	dig UDOT 181531B	121792.14	449.02	102.96	204.20	1256.58	1.30	695.30	263.38	86.00	97.90	10.18	18.52	1.38	1.62	3.30
	082018 S11 M C	dig UDOT 181532A	97267.82	310.80	83.90	124.44	881.88	0.72	484.60	193.80	47.10	74.68	7.44	14.10	1.08	2.32	2.34
	082018 S11 M C	dig UDOT 181532B	172102.00	656.04	195.12	311.00	1821.38	1.18	991.58	396.92	101.34	151.34	13.66	26.48	1.82	2.98	4.76
		Mean	132280.68	484.56	273.12	220.78	1377.46	1.50	753.56	422.00	89.92	111.55	11.21	21.45	1.49	2.09	3.69
		St. Dev.	25366.23	114.40	233.89	61.30	316.08	0.54	169.04	218.15	23.98	25.40	2.22	5.21	0.25	0.51	0.81
	082018 S11 M D	dig UDOT 181533	0.86	0.04	31.58	0.05	0.06	0.15	0.63	51.61	0.60	2.40	-0.02	0.00	0.00	0.09	0.02
	082018 S11 M E	dig UDOT 181534	207.76	60.25	28.82	6.44	119.12	1.51	0.91	81.70	14.41	39.88	0.33	1.23	0.03	0.45	4.93
	082018 S11 M F	dig UDOT 181535	244.96	71.06	27.67	8.15	146.10	1.80	1.09	75.15	15.81	49.11	0.39	1.38	0.07	0.67	5.05
	082018 S11 M G	dig UDOT 181536	202.98	58.72	26.83	6.56	117.39	5.63	1.07	85.98	14.10	39.78	0.30	1.30	0.07	0.53	4.98
		Mean	218.57	63.34	27.77	7.05	127.54	2.98	1.02	80.94	14.77	42.92	0.34	1.30	0.06	0.55	4.99
		St. Dev.	22.98	6.73	1.00	0.95	16.10	2.30	0.10	5.45	0.91	5.36	0.05	0.08	0.02	0.11	0.06
	082018 S11 M H	dig UDOT 181537	0.27	0.06	21.54	0.03	0.11	0.13	0.29	30.15	1.15	5.52	-0.02	0.00	0.01	0.07	0.00
Huntsville (S12)	090618 S12 M A	dig UDOT 182169	103373.36	2762.29	1991.25	1185.12	554.84	3.16	640.45	3533.87	291.68	26.67	40.88	33.95	1.42	3.47	1.43
	090618 S12 M B	dig UDOT 182170	105913.59	2831.54	2382.63	1218.62	556.84	3.34	655.47	4110.87	249.44	27.78	42.25	31.95	1.57	4.17	1.73
	090618 S12 M C	dig UDOT 182171	110162.31	2807.87	4497.28	1193.24	549.87	5.99	785.90	7406.22	233.41	35.01	41.41	22.88	1.54	6.39	1.88
		Mean	106483.09	2800.57	2957.05	1198.99	553.85	4.16	693.94	5016.99	258.18	29.82	41.51	29.59	1.51	4.68	1.68
		St. Dev.	3430.12	35.20	1348.15	17.48	3.59	1.58	79.99	2089.15	30.10	4.53	0.69	5.90	0.08	1.52	0.23
	090618 S12 M D	dig UDOT 182172	0.34	0.15	136.82	0.17	0.23	0.39	2.24	133.76	5.26	12.74	0.10		0.01	1.08	0.00
	090618 S12 M E	dig UDOT 182173	26.90	18.98	44.50	1.38	63.88	1.37	5.52	323.64	10.69	90.47	0.58		0.04	1.11	0.54
	090618 S12 M F	dig UDOT 182174	27.37	19.85	10.24	1.40	62.97	2.22	16.77	943.27	20.04	83.31	0.55		0.03	0.68	0.68
	090618 S12 M G	dig UDOT 182175	28.34	20.34	165.19	1.42	66.44	0.94	31.90	1097.98	8.07	115.02	0.69		0.04	1.27	0.60
		Mean	27.54	19.72	73.31	1.40	64.43	1.51	18.06	788.30	12.93	96.27	0.61		0.04	1.02	0.61
		St. Dev.	0.73	0.69	81.39	0.02	1.80	0.65	13.24	409.77	6.29	16.63	0.07		0.01	0.31	0.07
	090618 S12 M H	dig UDOT 182176	0.20	0.04	34.36	0.03	0.06	0.13	0.44	35.10	1.26	3.55	-0.01		0.00	0.12	0.00
Hooper (S13)	091818 S13 M A	dig UDOT 182366A	98304.98	9881.86	232.30	1029.86	972.10	1.46	1016.28	342.58	95.78	13.82	202.98	18.92	1.36	0.78	1.72
	091818 S13 M A	dig UDOT 182366B	128882.18	14005.94	317.08	1509.10	1413.78	1.88	1361.14	451.46	72.46	21.72	300.46	24.00	1.76	0.96	2.36
	091818 S13 M B	dig UDOT 182367A	105181.92	11487.00	151.54	1213.78	1152.90	3.10	1153.04	266.54	52.76	17.06	255.38	22.22	1.30	0.76	2.02
	091818 S13 M B	dig UDOT 182367B	117736.32	12343.28	165.26	1378.12	1285.88	3.44	1270.50	288.52	54.10	19.26	290.76	16.82	1.38	0.76	2.06
	091818 S13 M C	dig UDOT 182368A	64554.00	12154.38	55.68	1314.40	969.92	0.98	746.04	138.34	28.36	19.24	284.54	13.42	0.88	0.48	1.62
	091818 S13 M C	dig UDOT 182368B	125169.76	27726.72	149.40	2793.18	2239.18	2.14	1514.48	303.12	42.72	29.74	668.10	28.06	1.46	0.72	3.36
		Mean	106638.19	14599.86	178.54	1539.74	1338.96	2.17	1176.91	298.43	57.70	20.14	333.70	20.57	1.36	0.74	2.19
		St. Dev.	23681.32	6567.94	88.24	634.85	474.17	0.95	271.54	102.11	23.62	5.40	167.58	5.26	0.28	0.15	0.63
	091818 S13 M D	dig UDOT 182369	0.13	0.05	13.39	0.03	0.10	0.20	0.25	18.09	0.65	6.02	-0.04	0.00	0.00	0.09	0.00
	091818 S13 M E	dig UDOT 182370	18.75	15.37	121.10	1.79	56.42	1.52	2.52	680.25	13.01	20.93	1.34	0.39	0.02	0.45	1.48
	091818 S13 M F	dig UDOT 182371	18.34	15.08	24.44	1.76	56.75	3.07	0.91	489.47	11.08	18.65	1.40	0.35	0.00	0.12	1.52
	091818 S13 M G	dig UDOT 182372	17.87	14.77	42.16	1.74	55.71	1.19	0.98	98.54	8.83	19.46	1.20	0.28	0.01	0.10	1.46
		Mean	18.32	15.07	62.57	1.76	56.29	1.93	1.47	422.75	10.97	19.68	1.31	0.34	0.01	0.22	1.49
		St. Dev.	0.44	0.30	51.46	0.03	0.53	1.00	0.91	296.54	2.09	1.16	0.10	0.06	0.01	0.20	0.03
	091818 S13 M H	dig UDOT 182373	0.14	0.07	72.83	0.05	0.10	0.41	3.25	82.41	0.65	7.24	-0.03	-0.01	0.00	0.08	0.00

Table C5. Dissolved metals and trace elements data for the pond and tap water collected from 11 UDOT maintenance stations.

			23 Na [He]	24 Mg [He]	39 K [He]	44 Ca [He]	52 Cr [He]	55 Mn [He]	56 Fe [He]	63 Cu [He]	66 Zn [He]	75 As [He]	Se	1 Cd [No Ga	8 Pb [No Gas
		Top Limit	**100**	**100**	**100**	**100**	**200**	**300**	**2000**	**500**	**400**	**200**		**100**	**100**
		MRL *	**0.40**	**0.10**	**0.25**	**0.20**	**0.10**	**0.50**	**10.00**	**0.63**	**2.00**	**0.25**		**0.13**	**0.25**
Site Name & N	Sample ID	Sample Name	Conc. [mg/l]	Conc. [mg/l]	Conc. [mg/l]	Conc. [mg/l]	Conc. [ug/l]	Conc. [ug/l]	Conc. [ug/l]	Conc. [ug/l]	Conc. [ug/l]	Conc. [ug/l]	Conc. [ug/l]	Conc. [ug/l]	Conc. [ug/l]
Kamas (S2)	080118 S2 M A	UDOT filt 18920	7197.00	117.80	101.90	92.30	0.22	118.92	61.28	5.62	10.88	3.39	13.04	0.21	0.21
	080118 S2 M B	UDOT filt 18921	4736.00	93.10	79.30	73.70	0.23	114.93	59.87	10.98	11.89	3.31	12.18	0.17	0.25
	080118 S2 M C	UDOT filt 18922	6780.00	103.90	94.50	83.30	0.24	116.54	64.02	5.43	10.61	3.27	12.50	0.16	0.17
		Mean	6237.67	104.93	91.90	83.10	0.23	116.80	61.72	7.34	11.13	3.32	12.57	0.18	0.21
		St. Dev.	1317.09	12.38	11.52	9.30	0.01	2.01	2.11	3.15	0.67	0.06	0.43	0.03	0.04
	080118 S2 M D	UDOT filt 18923	35.20	5.30	-0.01	0.03	0.01	0.20	0.07	-0.02	51.90	0.01	0.00	0.00	0.00
	080118 S2 M E	UDOT filt 18924	34.44	20.23	3.74	91.92	0.11	8.76	4.00	30.57	270.54	1.69	0.21	0.00	0.03
	080118 S2 M F	UDOT filt 18925	33.57	19.69	3.65	88.85	0.09	3.68	4.00	23.94	271.32	1.70	0.27	0.01	0.03
	080118 S2 M G	UDOT filt 18926	34.72	20.46	3.79	97.45	0.10	3.99	4.32	26.72	288.90	1.63	0.24	0.02	0.03
		Mean	34.24	20.13	3.73	92.74	0.10	5.48	4.11	27.08	276.92	1.67	0.24	0.01	0.03
		St. Dev.	0.60	0.40	0.07	4.36	0.01	2.85	0.18	3.33	10.38	0.04	0.03	0.01	0.00
	080118 S2 M H	UDOT filt 18927	32.60	7.30	0.00	0.04	0.01	0.02	0.39	0.03	48.40	0.02	0.03	0.00	0.11
Heber (S3)	073018 S3 M A	UDOT filt 18888	24310.00	126.40	73.40	186.10	0.27	299.01	13.40	19.88	385.00	6.28	33.38	0.28	0.22
	073018 S3 M B	UDOT filt 18889	22450.00	162.80	97.90	248.50	0.25	285.31	9.33	23.26	2740.00	6.25	33.44	0.32	0.14
	073018 S3 M C	UDOT filt 18890	20870.00	159.00	95.60	242.90	0.25	287.20	9.94	22.61	2260.00	6.28	34.01	0.31	0.14
		Mean	22543.33	149.40	88.97	225.83	0.26	290.51	10.89	21.92	1795.00	6.27	33.61	0.30	0.17
		St. Dev.	1721.90	20.01	13.53	34.52	0.01	7.42	2.20	1.79	1244.46	0.02	0.35	0.02	0.05
	073018 S3 M D	UDOT filt 18891	52.30	4.50	0.00	0.04	0.01	0.07	0.64	-0.02	2310.00	0.02	0.01	0.00	0.01
	073018 S3 M E	UDOT filt 18892	9.79	12.64	1.93	57.58	0.08	0.33	1029.00	384.55	91.44	1.88	0.24	0.02	15.83
	073018 S3 M F	UDOT filt 18893	10.07	12.66	1.94	58.24	0.10	0.34	6430.00	341.38	51.65	1.92	0.25	0.01	13.00
	073018 S3 M G	UDOT filt 18894	9.37	11.76	1.80	55.19	0.08	0.71	0.82	422.93	166.04	1.72	0.22	0.02	14.36
		Mean	9.74	12.35	1.89	57.00	0.09	0.46	2486.61	382.95	103.04	1.84	0.24	0.02	14.40
		St. Dev.	0.35	0.51	0.08	1.60	0.01	0.22	3453.56	40.80	58.07	0.11	0.02	0.01	1.42
	073018 S3 M H	UDOT filt 18895	28.80	4.70	0.00	0.06	0.01	51.00	7879.00	0.26	427.00	0.01	-0.01	0.00	0.02
Lehi (S4)	080618 S4 M A	UDOT filt 181238	58020.00	843.30	568.80	433.00	0.84	167.23	77.18	75.06	16.18	25.88	54.30	0.84	1.84
	080618 S4 M B	UDOT filt 181239	55720.00	841.80	579.50	444.70	0.67	149.74	60.14	98.78	10.97	24.86	48.40	0.87	1.51
	080618 S4 M C	UDOT filt 181240	56050.00	799.10	571.70	429.70	0.65	147.78	62.56	96.66	10.65	25.22	46.00	0.82	1.30
		Mean	56596.67	828.07	573.33	435.80	0.72	154.92	66.63	90.17	12.60	25.32	49.57	0.84	1.55
		St. Dev.	1243.64	25.10	5.53	7.88	0.10	10.71	9.22	13.13	3.10	0.52	4.27	0.03	0.27
	080618 S4 M D	UDOT filt 181241	1.04	0.70	0.03	0.03	0.05	0.11	7.39	0.17	1.34	0.05	0.07	0.02	0.07
	080618 S4 M E	UDOT filt 181242	42.18	20.64	3.44	43.49	0.55	0.47	1.90	320.04	72.26	1.72	2.48	0.00	0.15
	080618 S4 M F	UDOT filt 181243	42.65	20.74	3.42	43.40	2.84	0.61	25.26	329.88	73.48	1.65	2.59	0.00	0.20
	080618 S4 M G	UDOT filt 181244	44.26	21.45	3.52	44.31	0.53	0.41	3.62	320.12	73.07	1.72	2.46	0.01	0.13
		Mean	43.03	20.94	3.46	43.73	1.31	0.50	10.26	323.35	72.94	1.70	2.51	0.00	0.16
		St. Dev.	1.09	0.44	0.05	0.50	1.33	0.10	13.02	5.66	0.62	0.04	0.07	0.01	0.04
	080618 S4 M H	UDOT filt 181245	23.20	0.02	0.02	0.04	0.02	0.19	1.48	0.35	0.61	0.02	0.01	0.00	0.05

Clearfield (S6)	080718 S6 M A	UDOT filt 181296	50370.00	25920.00	1098.00	1506.00	2.43	2130.00	92.72	5.22	28.24	599.40	16.88	0.71	0.43
	080718 S6 M B	UDOT filt 181297	49080.00	24390.00	1042.00	1420.00	2.30	2165.30	91.69	24.79	29.51	605.30	27.46	0.77	0.30
	080718 S6 M C	UDOT filt 181298	51690.00	26400.00	1067.00	1468.00	2.96	2202.00	137.08	24.20	39.56	722.48	48.76	0.56	0.24
		Mean	50380.00	25570.00	1069.00	1464.67	2.56	2165.77	107.16	18.07	32.44	642.39	31.03	0.68	0.32
		St. Dev.	1305.03	1049.71	28.05	43.10	0.35	36.00	25.91	11.13	6.20	69.42	16.24	0.11	0.10
	080718 S6 M D	UDOT filt 181299	39.10	14.90	0.01	0.05	0.01	0.04	0.18	0.06	0.46	0.03	0.02	0.00	0.01
	080718 S6 M E	UDOT filt 181300	25.29	21.10	2.31	89.11	0.63	0.16	0.70	40.86	21.04	0.72	0.38	0.01	2.37
	080718 S6 M F	UDOT filt 181301	23.95	19.12	2.09	78.95	0.68	0.14	0.60	35.13	19.18	0.76	0.44	0.01	2.14
	080718 S6 M G	UDOT filt 181302	24.11	19.26	2.13	80.55	0.65	0.15	0.45	51.87	20.13	0.74	0.43	0.01	2.58
		Mean	24.45	19.83	2.18	82.87	0.65	0.15	0.58	42.62	20.12	0.74	0.42	0.01	2.36
		St. Dev.	0.73	1.10	0.12	5.46	0.03	0.01	0.13	8.51	0.93	0.02	0.03	0.00	0.22
	080718 S6 M H	UDOT filt 181303	18.20	6.30	0.00	0.13	0.02	0.11	3.26	0.28	1.01	0.01	0.00	0.00	0.03
Brigham City (	080718 S7 M A	UDOT filt 181270	36220.00	1655.00	178.00	243.40	0.26	43.56	11.58	53.12	0.25	16.90	15.00	0.53	0.34
	080718 S7 M B	UDOT filt 181271	36350.00	1691.00	182.90	247.30	0.28	43.02	16.10	52.83	6.70	17.11	11.00	0.53	0.58
	080718 S7 M C	UDOT filt 181272	37780.00	1668.00	184.20	248.30	0.24	40.67	11.27	54.60	0.32	17.26	9.20	0.53	0.33
		Mean	36783.33	1671.33	181.70	246.33	0.26	42.42	12.98	53.52	2.42	17.09	11.73	0.53	0.42
		St. Dev.	865.58	18.23	3.27	2.59	0.02	1.54	2.70	0.95	3.70	0.18	2.97	0.00	0.14
	080718 S7 M D	UDOT filt 181273	10.41	25.77	1.17	51.59	0.32	0.50	12.89	42.51	41.43	0.79	0.34	0.00	0.14
	080718 S7 M D	UDOT filt 181273	25.84	18.30	1.27	61.98	0.17	4.49	17.53	1.84	74.75	0.48	0.20	0.04	0.02
	080718 S7 M E	UDOT filt 181274	34.10	0.90	0.01	0.05	0.01	0.06	0.62	0.08	0.30	0.02	0.01	0.00	0.01
	080718 S7 M F	UDOT filt 181275	10.42	25.71	1.15	51.02	0.23	0.25	3.68	42.47	38.65	0.75	0.39	0.00	0.10
	080718 S7 M G	UDOT filt 181276	10.14	25.11	1.13	50.02	0.22	0.18	0.89	41.39	34.28	0.71	0.37	0.01	0.16
		Mean	10.28	25.41	1.14	50.52	0.23	0.22	2.29	41.93	36.47	0.73	0.38	0.01	0.13
		St. Dev.	0.20	0.42	0.01	0.71	0.01	0.05	1.97	0.76	3.09	0.03	0.01	0.01	0.04
Salina (S8)	081418 S8 M A	UDOT filt 181401	14610.00	15.65	11.16	210.20	0.22	299.00	30.13	14.06	11.79	4.60	14.85	0.29	0.14
	081418 S8 M B	UDOT filt 181402	13750.00	16.09	12.41	207.60	0.27	276.20	33.17	16.22	7.82	4.91	21.44	0.37	0.17
	081418 S8 M C	UDOT filt 181404	16640.00	14.44	11.64	196.80	0.27	295.36	31.82	16.20	6.66	4.66	20.82	0.37	0.12
		Mean	15000.00	15.39	11.74	204.87	0.25	290.19	31.71	15.49	8.76	4.72	19.04	0.34	0.14
		St. Dev.	1483.95	0.85	0.63	7.11	0.03	12.25	1.52	1.24	2.69	0.16	3.64	0.05	0.03
	081418 S8 M D	UDOT filt 181405	33.80	1.00	0.01	0.05	0.09	0.32	19.86	0.40	1179.80	0.02	0.02	0.16	0.14
	081418 S8 M E	UDOT filt 181406	8.42	5.80	2.60	21.05	0.31	0.66	6.86	9.14	41.43	2.74	0.25	0.02	0.29
	081418 S8 M F	UDOT filt 181407	8.42	5.75	2.59	20.97	1.75	2.63	94.04	12.47	47.63	2.92	0.25	0.02	0.66
	081418 S8 M G	UDOT filt 181408	8.14	5.64	2.51	20.74	0.30	0.54	8.33	8.59	43.01	2.73	0.23	0.01	0.21
		Mean	8.33	5.73	2.57	20.92	0.79	1.28	36.41	10.07	44.02	2.80	0.24	0.02	0.39
		St. Dev.	0.16	0.08	0.05	0.16	0.83	1.17	49.91	2.10	3.22	0.11	0.01	0.01	0.24
	081418 S8 M H	UDOT filt 181410	12.10	1.80	0.00	0.08	0.10	0.74	15.75	0.18	2.34	0.03	0.04	0.01	0.06
Junction (S9)	081518 S9 M A	UDOT filt 181368	7846.00	19.07	18.13	139.20	0.30	300.50	21.24	12.29	6.68	5.50	5.48	0.11	0.09
	081518 S9 M B	UDOT filt 181369	6634.00	18.30	18.07	138.30	0.32	320.10	46.04	12.43	2.60	5.48	6.28	0.13	0.08
	081518 S9 M C	UDOT filt 181370	26000.00	39.46	38.25	252.40	2.13	1539.80	568.24	18.76	3.52	12.68	23.85	0.27	0.53
		Mean	7240.00	18.69	18.10	138.75	0.31	310.30	33.64	12.36	4.64	5.49	5.88	0.12	0.09
		St. Dev.	857.01	0.54	0.04	0.64	0.01	13.86	17.54	0.10	2.88	0.01	0.57	0.01	0.01
	081518 S9 M D	UDOT filt 181371	32.20	2.80	0.00	0.05	0.01	0.10	1.07	0.29	4.78	0.00	0.00	0.04	0.23
	081518 S9 M E	UDOT filt 181372	27.59	17.99	4.61	67.95	0.62	0.37	1.39	109.69	78.90	4.93	0.26	0.01	3.42
	081518 S9 M F	UDOT filt 181373	28.32	18.33	4.72	68.72	0.60	0.48	1.68	106.22	90.37	4.85	0.24	0.01	1.81
	081518 S9 M G	UDOT filt 181374	28.14	18.35	4.79	68.41	0.59	0.26	1.17	255.09	124.03	4.71	0.22	0.01	3.94
		Mean	28.02	18.22	4.71	68.36	0.60	0.37	1.41	157.00	97.77	4.83	0.24	0.01	3.06
		St. Dev.	0.38	0.20	0.09	0.39	0.02	0.11	0.26	84.97	23.46	0.11	0.02	0.00	1.11

Silver Summit	082018 S10 M A	UDOT filt 181557	45300.00	450.20	406.00	369.20	0.61	209.20	73.09	56.98	13.61	12.20	56.10	0.40	0.75
	082018 S10 M B	UDOT filt 181558	41070.00	457.90	400.30	371.80	0.54	214.84	56.44	58.09	9.47	12.61	59.60	0.47	0.62
	082018 S10 M C	UDOT filt 181559	41920.00	452.20	399.80	372.50	0.50	216.39	67.28	50.38	9.91	12.37	51.70	0.43	0.71
		Mean	42763.33	453.43	402.03	371.17	0.55	213.48	65.60	55.15	11.00	12.39	55.80	0.43	0.69
		St. Dev.	2237.55	4.00	3.44	1.74	0.06	3.78	8.45	4.17	2.27	0.21	3.96	0.04	0.07
	082018 S10 M D	UDOT filt 181560	78.00	-0.04	-0.02	-0.05	-0.01	-0.37	-2.07	0.00	-7.60	-0.02	-0.01	0.00	-0.02
	082018 S10 M E	UDOT filt 181561	14.91	11.76	3.25	50.30	0.23	0.38	9.17	541.10	235.61	1.40	0.25	0.12	2.86
	082018 S10 M F	UDOT filt 181562	13.96	11.70	3.28	49.90	0.30	2.67	15.89	354.59	112.40	1.36	0.23	0.06	1.25
	082018 S10 M G	UDOT filt 181563	13.91	11.49	3.35	49.13	0.20	0.43	1.67	859.50	86.32	1.11	0.24	0.06	1.60
		Mean	14.26	11.65	3.29	49.78	0.24	1.16	8.91	585.06	144.78	1.29	0.24	0.08	1.90
		St. Dev.	0.56	0.14	0.05	0.59	0.05	1.31	7.11	255.31	79.74	0.16	0.01	0.03	0.85
Echo (S11)	082018 S11 M A	UDOT filt 181530	115450.00	436.60	192.50	1206.00	0.66	715.80	12.40	156.43	105.13	9.32	109.60	0.70	2.24
	082018 S11 M B	UDOT filt 181531	105830.00	449.40	196.30	1263.00	0.69	714.10	11.91	169.86	103.16	8.60	118.20	0.82	2.19
	082018 S11 M C	UDOT filt 181532	107160.00	436.60	194.00	1191.00	0.78	699.20	11.36	166.02	100.85	8.72	107.90	0.86	2.09
		Mean	109480.00	440.87	194.27	1220.00	0.71	709.70	11.89	164.10	103.05	8.88	111.90	0.79	2.17
		St. Dev.	5212.76	7.39	1.91	37.99	0.06	9.13	0.52	6.92	2.14	0.39	5.52	0.08	0.08
	082018 S11 M D	UDOT filt 181533	3.07	0.03	0.01	0.08	0.01	75.00	21943.00	0.24	3.96	0.01	0.00	0.00	0.04
	082018 S11 M E	UDOT filt 181534	188.80	49.40	5.83	105.70	1.21	0.63	21.23	10.37	40.28	0.43	2.03	0.04	0.32
	082018 S11 M F	UDOT filt 181535	186.20	49.08	5.82	105.00	1.19	0.69	22.19	10.17	41.79	0.41	1.93	0.04	0.26
	082018 S11 M G	UDOT filt 181536	187.00	49.64	5.94	104.80	1.23	0.67	21.07	10.65	42.97	0.46	1.87	0.03	0.24
		Mean	187.33	49.37	5.86	105.17	1.21	0.66	21.50	10.40	41.68	0.43	1.94	0.04	0.27
		St. Dev.	1.33	0.28	0.07	0.47	0.02	0.03	0.61	0.24	1.35	0.03	0.08	0.01	0.04
	082018 S11 M H	UDOT filt 181537	0.12	0.01	0.00	0.04	0.02	0.10	1.80	0.32	1.92	0.02	0.00	0.00	0.12
Huntsville (S12	090618 S12 M A	filt UDOT 182169	97926.17	2523.26	1051.56	524.16	0.37	422.31	25.25	211.91	10.45	39.21	26.75	1.67	1.76
	090618 S12 M B	filt UDOT 182170	98963.91	2646.50	1114.55	544.08	0.37	410.00	21.40	166.13	10.70	38.47	23.74	1.70	1.97
	090618 S12 M C	filt UDOT 182171	99185.84	2660.70	1104.83	544.92	0.41	436.31	22.03	208.56	9.02	42.39	28.82	1.58	2.15
		Mean	98691.97	2610.15	1090.31	537.72	0.38	422.87	22.89	195.53	10.06	40.02	26.44	1.65	1.96
		St. Dev.	672.42	75.59	33.91	11.75	0.02	13.16	2.07	25.52	0.91	2.08	2.55	0.06	0.20
	090618 S12 M D	UDOT F 182172	0.05	0.02	0.01	0.05	0.01	0.41	1.68	0.25	1.21	0.03	0.01	0.01	0.06
	090618 S12 M E	UDOT F 182173	24.47	17.32	1.22	57.82	0.17	4.15	11.06	1.39	73.59	0.43	0.19	0.04	0.01
	090618 S12 M F	UDOT F 182174	24.85	17.99	1.24	56.22	0.06	12.73	7.39	4.49	58.47	0.40	0.14	0.03	0.02
	090618 S12 M G	UDOT F 182175	113.76	21.85	2.15	63.04	0.06	30.39	7.77	0.86	69.83	0.44	0.19	0.03	0.02
		Mean	54.36	19.05	1.54	59.03	0.10	15.76	8.74	2.25	67.30	0.42	0.17	0.03	0.02
		St. Dev.	51.44	2.45	0.53	3.57	0.06	13.38	2.02	1.96	7.87	0.02	0.03	0.01	0.01
	090618 S12 M H	UDOT F 182176	0.25	0.04	0.01	0.08	0.01	0.42	1.43	0.55	6.03	0.01	0.01	0.01	0.04
	091818 S13 M A	filt UDOT 182366	112684.74	11142.42	1102.14	1103.30	0.52	1189.98	28.85	211.77	5.05	259.62	30.84	1.20	0.46
Hooper (S13)	091818 S13 M B	filt UDOT 182367	110258.81	11052.44	1118.46	1103.79	5.23	1681.09	51.51	206.57	5.80	370.10	32.45	1.07	0.35
	091818 S13 M C	filt UDOT 182368	92490.85	19166.99	1940.91	1456.08	0.71	1135.97	39.13	128.65	8.21	455.95	46.21	1.10	0.37
		Mean	105144.80	13787.28	1387.17	1221.06	2.15	1335.68	39.83	182.33	6.35	361.89	36.50	1.12	0.39
		St. Dev.	11025.57	4659.18	479.62	203.54	2.67	300.35	11.35	46.56	1.65	98.42	8.45	0.07	0.06
	091818 S13 M D	UDOT F 182369	0.16	0.05	0.01	0.16	0.01	0.10	0.85	0.49	-0.34	0.04	0.02	0.01	0.03
	091818 S13 M E	UDOT F 182370	16.70	13.26	1.56	50.45	0.95	0.35	3.47	5.29	12.18	1.33	0.48	0.01	0.06
	091818 S13 M F	UDOT F 182371	16.59	13.47	1.55	50.01	0.95	0.16	1.00	6.22	13.42	1.40	0.46	0.01	0.02
	091818 S13 M G	UDOT F 182372	16.70	13.54	1.59	51.37	0.96	0.21	0.91	4.99	12.38	1.43	0.50	0.01	0.01
		Mean	16.66	13.42	1.57	50.61	0.95	0.24	1.79	5.50	12.66	1.39	0.48	0.01	0.03
		St. Dev.	0.06	0.15	0.02	0.69	0.01	0.10	1.45	0.64	0.67	0.05	0.02	0.00	0.03
	091818 S13 M H	UDOT F 182373	0.17	0.04	0.01	0.10	0.00	0.67	0.66	0.09	0.53	0.02	0.00	0.01	0.00

Table C6. Quality control results for the oil and grease analysis of the water samples.

Site	Sample	O&G (mg/L)	Calculated Spike Concentration (mg/L)	Spike Recovery (%)
Lehi	O&G A	11.54		
	MX 1	20.74	39.50	23.3
	MX 2	21.58	39.23	25.6
Brigham City	O&G C	0.93		
	MX 1	13.95	37.20	35.0
	MX 2	13.97	37.25	35.0
Salina	O&G A	7.83		
	MX 1	34.87	37.69	71.7
	MX 2	15.07	37.67	19.2
Silver Summit	O&G C	26.80		
	MX 1	37.86	36.94	29.9
	MX 2	40.00	37.21	35.5
Huntsville	O&G B	6.52		
	MX 1	27.35	37.73	55.2
	MX 2	36.25	39.19	75.9
Hooper	O&G C	16.31		
	MX 1	19.50	37.15	8.6
	MX 2	31.43	36.98	40.9
	Lab Blank 1	0.00		
	Lab spk 1	7.08	40.4	17.5
	Lab Blank 2	1.04		
	Lab spk 2	18.38	38.7	44.8

Table C7. PAH data for the pond and tap water collected from 11 UDOT maintenance stations.

Site	Date-Site #	Sample Type	Sample Code	UWRL Log #	Sample Volume (L)	1,3,5 - Trimethyl benzene	Napthalene	Naphthalene, 1-methyl-	Naphthalene, 2-methyl-	Acenaphthylene	Acenaphthene	Dibenzofuran	Fluorene	Phenanthrene	Anthracene	Fluoranthene	Pyrene	Benzo(a)anthracene	Chrysene	Benzo[k]fluoranthene	Benzo[b]fluoranthene	Benzo(a)pyrene	Indeno[1,2,3-cd]pyrene	Pyrene, 1-phenyl-	Benzo[b]triphenylene	Dibenz(ah)anthracene	Benzo(ghi)perylene
Kamas	08/01/2018 S2	O&G	A	18928	1.04		<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001		
			B	18929	1.05		<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001		
			C	18930	1.03		<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	**0.00235**	<0.001		
			Mean St. Dev.																					**0.00235**			
			D	18931	1.03		<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001		
			E	18932	1.02		<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	**0.001605**	**0.0013**	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001		
			F	18933	1.02		<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	**0.001630**	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001		
			G	18934	1.04		<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	**0.001568**	**0.0012618**	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001		
			Mean St. Dev.													**0.001601**	**0.001281**										
			H	18935	1.03		<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001		
Heber	07/30/2018 S3	O&G	A	18904	1.04		<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001		
			B	18905	1.03		<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001		
			C	18906	1.03		<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001		
			Mean St. Dev.																								
			D	18907	1.04		<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001		
			E	18908	1.01		<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001		
			F	18909	1.01		<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001		
			G	18910	1.03		<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001		
			Mean St. Dev.																								
			H	18911	1.00		<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001		
Lehi	08/06/2018 S4	O&G	A	181254	1.04	<0.0002	<0.0002		<0.0002	<0.0002	<0.0002		<0.0002	<0.0002	<0.0002	<0.0002	<0.0002	<0.0002	<0.0002	<0.0002	<0.0002	<0.0002	<0.0002	<0.0002	<0.0002		
			B	181255	1.06	<0.0002	<0.0002		<0.0002	<0.0002	<0.0002		<0.0002	<0.0002	<0.0002	<0.0002	<0.0002	<0.0002	<0.0002	<0.0002	<0.0002	<0.0002	<0.0002	<0.0002	<0.0002		
			C	181256	1.03	<0.0002	<0.0002		<0.0002	<0.0002	<0.0002		<0.0002	<0.0002	<0.0002	<0.0002	<0.0002	<0.0002	<0.0002	<0.0002	<0.0002	**0.000230388**	<0.0002	<0.0002	<0.0002		
			Mean St. Dev.																			**0.000230388**					
			D	181257	1.04	<0.0002	<0.0002		<0.0002	<0.0002	<0.0002		<0.0002	<0.0002	<0.0002	<0.0002	<0.0002	<0.0002	<0.0002	<0.0002	<0.0002	<0.0002	<0.0002	<0.0002	<0.0002		
			E	181258	1.04	<0.0002	<0.0002		<0.0002	<0.0002	<0.0002		<0.0002	<0.0002	<0.0002	<0.0002	<0.0002	<0.0002	<0.0002	<0.0002	<0.0002	<0.0002	<0.0002	<0.0002	<0.0002		
			F	181259	1.04	<0.0002	<0.0002		<0.0002	<0.0002	<0.0002		<0.0002	<0.0002	<0.0002	<0.0002	<0.0002	<0.0002	<0.0002	<0.0002	<0.0002	<0.0002	<0.0002	<0.0002	<0.0002		
			G	181260	1.04	<0.0002	<0.0002		<0.0002	<0.0002	<0.0002		<0.0002	<0.0002	<0.0002	<0.0002	<0.0002	<0.0002	<0.0002	<0.0002	<0.0002	<0.0002	<0.0002	<0.0002	<0.0002		
			Mean St. Dev.																								
			H	181261	1.08	<0.0002	<0.0002		<0.0002	<0.0002	<0.0002		<0.0002	<0.0002	<0.0002	<0.0002	<0.0002	<0.0002	<0.0002	<0.0002	<0.0002	<0.0002	<0.0002	<0.0002	<0.0002		
			MX 1	181262	1.01	<0.0002	<0.0002		<0.0002	<0.0002	<0.0002		<0.0002	<0.0002	<0.0002	<0.0002	<0.0002	<0.0002	<0.0002	<0.0002	<0.0002	<0.0002	**0.00052**	**0.00029**	**0.00023**		
			MX 2	181263	1.02	<0.0002	<0.0002		<0.0002	<0.0002	<0.0002		<0.0002	<0.0002	<0.0002	<0.0002	<0.0002	<0.0002	<0.0002	**0.000291087**	<0.0002	**0.00036**	**0.00093**	**0.00040**	**0.00041**		
Clearfield	08/07/2018 S6	O&G	A	181312	1.02	<0.0002	<0.0002		<0.0002	<0.0002	<0.0002		<0.0002	<0.0002	<0.0002	<0.0002	<0.0002	<0.0002	<0.0002	<0.0002	<0.0002	<0.0002	<0.0002	<0.0002	<0.0002		
			B	181313	1.04	<0.0002	<0.0002		<0.0002	<0.0002	<0.0002		<0.0002	<0.0002	<0.0002	<0.0002	<0.0002	<0.0002	<0.0002	<0.0002	<0.0002	<0.0002	<0.0002	<0.0002	<0.0002		
			C	181314	1.01	<0.0002	<0.0002		<0.0002	<0.0002	<0.0002		<0.0002	<0.0002	<0.0002	<0.0002	<0.0002	<0.0002	<0.0002	<0.0002	<0.0002	<0.0002	<0.0002	<0.0002	<0.0002		
			Mean St. Dev.																								
			D	181315	1.1	<0.0002	<0.0002		<0.0002	<0.0002	<0.0002		<0.0002	<0.0002	<0.0002	<0.0002	<0.0002	<0.0002	<0.0002	<0.0002	<0.0002	<0.0002	<0.0002	<0.0002	<0.0002		
			E	181316	1.02	<0.0002	<0.0002		<0.0002	<0.0002	<0.0002		<0.0002	<0.0002	<0.0002	<0.0002	<0.0002	<0.0002	<0.0002	<0.0002	<0.0002	<0.0002	<0.0002	<0.0002	<0.0002		
			F	181317	1.03	<0.0002	<0.0002		<0.0002	<0.0002	<0.0002		<0.0002	<0.0002	<0.0002	<0.0002	<0.0002	<0.0002	<0.0002	<0.0002	<0.0002	<0.0002	<0.0002	<0.0002	<0.0002		
			G	181318	1.05	<0.0002	<0.0002		<0.0002	<0.0002	<0.0002		<0.0002	<0.0002	<0.0002	<0.0002	<0.0002	<0.0002	<0.0002	<0.0002	<0.0002	<0.0002	<0.0002	<0.0002	<0.0002		
			Mean St. Dev.																								
			H	181319	1.05	<0.0002	<0.0002		<0.0002	<0.0002	<0.0002		<0.0002	<0.0002	<0.0002	<0.0002	<0.0002	<0.0002	<0.0002	<0.0002	<0.0002	<0.0002	<0.0002	<0.0002	<0.0002		
Brigham City	08/07/2018 S6	O&G	A	181284	1.05	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001			<0.001	<0.001
			B	181285	1.08	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001		<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001			<0.001	<0.001
			C	181286	1.07	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001				<0.001	
			Mean St. Dev.																								
			D	181287	1.05	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001		<0.001	<0.001	<0.001							<0.001	
			F	181289	1.05	<0.001	<0.001	<0.001				<0.001		<0.001	<0.001												
			G	181290	1.05	<0.001	<0.001	<0.001	<0.001		<0.001	<0.001	<0.001	<0.001	<0.001												
			Mean St. Dev.																								
			MX 1	181291	1.08	<0.001	<0.001	<0.001	<0.001		<0.001	<0.001	<0.001	<0.001	<0.001					<0.001		<0.001	<0.001			<0.001	<0.001
			MX 2	181292	1.07	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001			<0.001	<0.001				<0.001

Salina	08/14/2018 S8	O&G	A	181417	1.02	<0.001	<0.001	<0.001	<0.001	<0.001		<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001			<0.001	<0.001			<0.001	<0.001
			B	181418	1.05	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001			<0.001	<0.001	<0.000	<0.001				<0.001	
			C	181419	1.07	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001						<0.001			<0.001	<0.001
			Mean																								
			St. Dev.																								
			D	181420	1.05	<0.001	<0.001		<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001												
			E	181421	1.03	<0.001	<0.001	<0.001	<0.001			<0.001		<0.001	<0.001					<0.001	<0.001	<0.001					
			F	181422	1.04	<0.001	<0.001	<0.001				<0.001	<0.001	<0.001	<0.001		<0.001										
			G	181423	1.03	<0.001	<0.001	<0.001	<0.001	<0.001		<0.001		<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001					
			Mean																								
			St. Dev.																								
			H	181424	1.05	<0.001	<0.001	<0.001	<0.001			<0.001		<0.001	<0.001								<0.001			<0.001	<0.001
			MX 1	181425	1.06		<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001				<0.001
			MX 2	181426	1.06	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001						
Junction	08/15/2018 S9	O&G	A	181382	1.04	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001					<0.001
			B	181383	1.03	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001			<0.001	<0.001	<0.001	<0.001	<0.001	<0.001			<0.001	<0.001
			C	181384	1.03	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	**0.00045**	<0.001	<0.001	**0.00053**	**0.00009**	<0.001	<0.001			<0.001	<0.001
			Mean														**0.00045**			**0.00053**	**0.00009**						
			St. Dev.																								
			D	181385	1.06		<0.001	<0.001				<0.001		<0.001	<0.001		<0.001										
			E	181386	1.05	<0.001	<0.001	<0.001	<0.001	<0.001		<0.001		<0.001	<0.001	<0.001	<0.001										<0.001
			F	181387	1		<0.001	<0.001	<0.001			<0.001		<0.001	<0.001												
			G	181388	1.05	<0.001	<0.001	<0.001	<0.001			<0.001		<0.001	<0.001	<0.001	<0.001										
			Mean																								
			St. Dev.																								
Silver Summit	8/20/2018 S10	O&G	A	181571	1.07	<0.001	<0.001		<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001		<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001			<0.001	<0.001
			B	181572	1.08	<0.001	<0.001		<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001				<0.001	
			C	181573	1.04	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001			<0.001	<0.001
			Mean																								
			St. Dev.																								
			D	181574	1.04	<0.001	<0.001	<0.001	<0.001	<0.001		<0.001		<0.001	<0.001	<0.001											
			E	181575	1.05		<0.001	<0.001	<0.001	<0.001		<0.001	<0.001	<0.001	<0.001												
			F	181576	1.05	<0.001	<0.001	<0.001	<0.001			<0.001		<0.001	<0.001												
			G	181577	1.02	<0.001	<0.001	<0.001	<0.001			<0.001		<0.001	<0.001			<0.001	<0.001	<0.001	<0.001		<0.001			<0.001	<0.001
			Mean																								
			St. Dev.																								
			MX 1	181578	1.08	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001		<0.001	<0.001	<0.001	<0.001	<0.001	<0.001		<0.001			<0.001	<0.001
			MX 2	181579	1.07	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001			<0.001	<0.001
Echo	8/20/2018 S11	O&G	A	181546	1.1	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001			<0.001		<0.001		<0.001			<0.001	<0.001
			B	181547	1.07	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001			<0.001		<0.001						<0.001	
			C	181548	1.1	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001		<0.001	<0.001	<0.001		<0.001	<0.001			<0.001	<0.001
			Mean																								
			St. Dev.																								
			D	181549	1.09	<0.001	<0.001	<0.001			<0.001	<0.001		<0.001	<0.001												
			E	181550	1.02	<0.001	<0.001	<0.001				<0.001		<0.001	<0.001												
			F	181551	1.03	<0.001		<0.001				<0.001		<0.001	<0.001												
			G	181552	1.07		<0.001	<0.001	<0.001	<0.001		<0.001		<0.001	<0.001												
			Mean																								
			St. Dev.																								
			H	181553	1.05	<0.001	<0.001	<0.001				<0.001		<0.001	<0.001												
Huntsville	09/06/2018 S12	O&G	A	182177	1.06	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001		<0.001		<0.001		<0.001				<0.001
			B	182178	1.07	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001		<0.001		<0.001	<0.001	<0.001			<0.001	<0.001
			C	182179	1.06	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001			<0.001	<0.001
			Mean																								
			St. Dev.																								
			D	182180	1.02	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001				<0.001	<0.001
			E	182181	1.04	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001			<0.001	<0.001			<0.001	<0.001
			F	182182	1.03		<0.001	<0.001				<0.001		<0.001	<0.001												
			G	182183	1.02		<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001				<0.001	<0.001
			Mean																								
			St. Dev.																								
			H	182184	1.03		<0.001	<0.001				<0.001		<0.001	<0.001							<0.001					
			MX 1	182185	1.02	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001		<0.001		<0.001			<0.001					
			MX 2	182186	1.02	<0.001	<0.001	<0.001				<0.001		<0.001	<0.001		<0.001			<0.001	<0.001						
Hooper	09/18/2018 S13	O&G	A	182374	1.07	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001				<0.001
			B	182375	1.08	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001		<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001			<0.001	<0.001
			C	182376	1.08	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001			<0.001	<0.001
			Mean																								
			St. Dev.																								
			D	182377	1.09	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001		<0.001			<0.001	<0.001
			E	182378	1.1	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001		<0.001	<0.001			<0.001	<0.001
			F	182379	1.04	<0.001	<0.001	<0.001	<0.001	<0.001		<0.001	<0.001	<0.001	<0.001		<0.001										
			G	182380	1.06	<0.001	<0.001	<0.001	<0.001	<0.001		<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001			<0.001	<0.001
			Mean																								
			St. Dev.																								
			H	182381	1.05	<0.001	<0.001	<0.001	<0.001		<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001		<0.001	<0.001	<0.001			<0.001	<0.001
			MX 1	182382	1.03	<0.001	<0.001	<0.001	<0.001			<0.001		<0.001	<0.001					<0.001	<0.001	<0.001					
			MX 2	182383	1.03	<0.001	<0.001	<0.001				<0.001		<0.001	<0.001												

Table C8. O&G and TPH data for the pond and tap water collected from 11 UDOT maintenance stations.

Site	Sample	Sample ID	Sample Volume (L)	O&G (mg/L)	TPH (ug/mL)
Kamas	A	18928	1.04	2.88	68.6
	B	18929	1.05	1.90	98.0
	C	18930	1.03	3.89	87.9
	D	18931	1.03	0.00	4.17
	E	18932	1.02	1.97	18.4
	F	18933	1.02	3.90	15.5
	G	18934	1.04	1.92	18.4
	H	18935	1.03	0.00	1.68
Heber	A	18904	1.04	3.83	45.2
	B	18905	1.03	3.89	59.6
	C	18906	1.03	2.92	95.8
	D	18907	1.04	0.958	4.77
	E	18908	1.01	0.993	11.6
	F	18909	1.01	0.989	7.77
	G	18910	1.03	0.000	8.90
	H	18911	1	1.00	2.05
Lehi	A	181254	1.04	11.5	116
	B	181255	1.06	11.3	81.2
	C	181256	1.03	12.6	137
	D	181257	1.04	0.00	-2.4
	E	181258	1.04	0.00	-2.5
	F	181259	1.04	0.00	-2.2
	G	181260	1.04	0.00	-1.1
	H	181261	1.08	0.00	-2.6
Clearfield	A	181312	1.02	7.82	79.7
	B	181313	1.04	6.71	125.7
	C	181314	1.01	6.92	92.6
	D	181315	1.1	0.00	0.3
	E	181316	1.02	0.00	-2.5
	F	181317	1.03	0.00	3.3
	G	181318	1.05	0.00	-0.8
	H	181319	1.05	0.00	0.5
Brigham City	A	181284	1.05	7.63	103.1
	B	181285	1.08	7.39	77.1
	C	181286	1.07	0.934	14.0
	D	181287	1.05	0.948	6.1
	F	181289	1.05	0.953	2.6
	G	181290	1.05	0.954	1.8
Salina	A	181417	1.02	7.83	146.1
	B	181418	1.05	6.70	226.4
	C	181419	1.07	7.51	160.0
	D	181420	1.05	0.00	7.5
	E	181421	1.03	0.00	3.6
	F	181422	1.04	2.88	54.6
	G	181423	1.03	9.71	242.1
	H	181424	1.05	0.00	8.4

Site	Sample	Sample ID	Sample Volume (L)	O&G (mg/L)	TPH (ug/mL)
Junction	A	181382	1.04	8.62	163
	B	181383	1.03	8.72	80.5
	C	181384	1.03	3.90	39.5
	D	181385	1.06	0.00	4.3
	E	181386	1.05	0.95	17.6
	F	181387	1	0.94	6.4
	G	181388	1.05	0.95	10.1
Silver Summit	A	181571	1.07	11.20	419
	B	181572	1.08	12.93	308
	C	181573	1.04	26.80	582
	D	181574	1.04	0.00	6.7
	E	181575	1.05	0.00	3.8
	F	181576	1.05	0.00	2.0
	G	181577	1.02	0.00	5.4
Echo	A	181546	1.1	6.34	195
	B	181547	1.07	5.59	97.3
	C	181548	1.1	5.45	129
	D	181549	1.09	0.921	5.3
	E	181550	1.02	0.00	3.1
	F	181551	1.03	0.00	1.7
	G	181552	1.07	0.00	6.9
	H	181553	1.05	0.956	3.8
Huntsville	A	182177	1.06	9.46	195
	B	182178	1.07	6.52	138
	C	182179	1.06	20.2	4242
	D	182180	1.02	0.00	4677
	E	182181	1.04	13.7	475
	F	182182	1.03	0.00	3.4
	G	182183	1.02	0.00	34.9
	H	182184	1.03	0.00	5.6
Hooper	A	182374	1.07	36.3	960
	B	182375	1.08	24.0	1959
	C	182376	1.08	16.3	4205
	D	182377	1.09	0.00	427
	E	182378	1.1	6.61	555
	F	182379	1.04	3.82	10.6
	G	182380	1.06	0.00	219
	H	182381	1.05	0.00	109

APPENDIX D: ARCGIS METHODOLOGY FOR APPROXIMATING THE VOLUME OF UDOT RETENTION PONDS

Data Transformation and Projection

The survey data collected in the field was converted to XYZ coordinates using a local coordinate system in AutoCad (Figure 1). The origin of the local coordinate system was set to the left and below all the survey data to avoid negative numbers (Figure 1). To convert the XYZ coordinates from the local coordinate system to a coordinate system recognized by ArcGIS software, the latitude and longitude of the reference point were obtained from Google Earth. This was done by visually identifying the reference point in Google Earth and then clicking on the reference point.

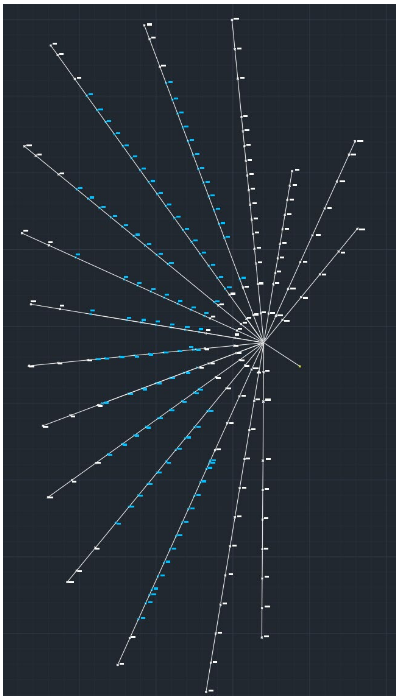


Figure D1. AutoCAD representation of the collected survey points. The blue points indicate the survey points were submerged in water, while white represents points on dry ground. North is "up" or the top of the figure.

Using the latitude and longitude of the reference point and Microsoft Excel, the XY survey coordinates were transformed into latitude and longitude in the WGS 1984 coordinate system using Equation 1 and Equation 2. Survey points were transformed to the WGS 1984 coordinate system even though they were measured in feet, because the *Display XY Data…* command requires the points to be in a geographic coordinate system (ESRI, 2018).

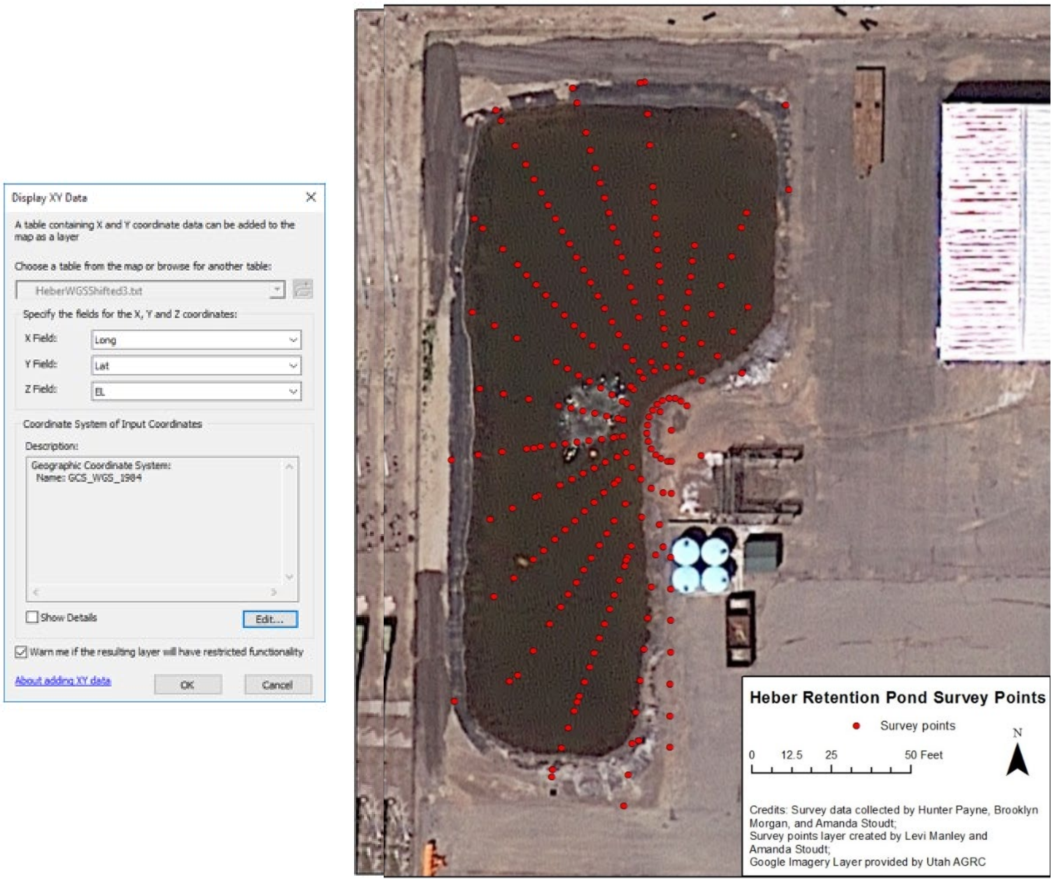
$$Y_{RP} - (Y_{SP} \times \frac{1\,mile}{5280\,ft} \times \frac{1°\,latitude}{69.172\,miles}) \qquad (1)$$

$$X_{RP} - (X_{SP} \times \frac{1\,mile}{5280\,ft} \times \frac{1°\,longitude}{69.172\,miles}) \qquad (2)$$

In equations 1 and 2, Y_{RP} is the latitude of reference point in WGS 1984 coordinate system, X_{RP} is the longitude of reference point in WGS 1984 coordinate system, Y_{SP} is the y coordinate of the survey point in the local coordinate system, and X_{SP} is the x coordinate of the survey point in the local coordinate system.

The Z coordinate representing elevation was left in the local coordinate system which had a reference plane of 100 ft. corresponding to the height of the pond edge or maximum water level. The reference point and the points beyond the edge of the pond were assigned an elevation above 100 ft so they would not be included in the volume calculation.

The resulting latitude, longitude, and Z values of the survey points were then exported to a text file and added to an ArcMap 10.6.1 document. Using the *Display XY Data…* command in ArcMap (Figure 2, left), the survey points were added to the map as a .txt Events layer in the WGS 1984 coordinate system as shown in Figure 2.



Display XY Data

A table containing X and Y coordinate data can be added to the map as a layer

Choose a table from the map or browse for another table:

HeberWGSShifted3.txt

Specify the fields for the X, Y and Z coordinates:

X Field: Long

Y Field: Lat

Z Field: EL

Coordinate System of Input Coordinates

Description:

Geographic Coordinate System:
Name: GCS_WGS_1984

☐ Show Details

☑ Warn me if the resulting layer will have restricted functionality

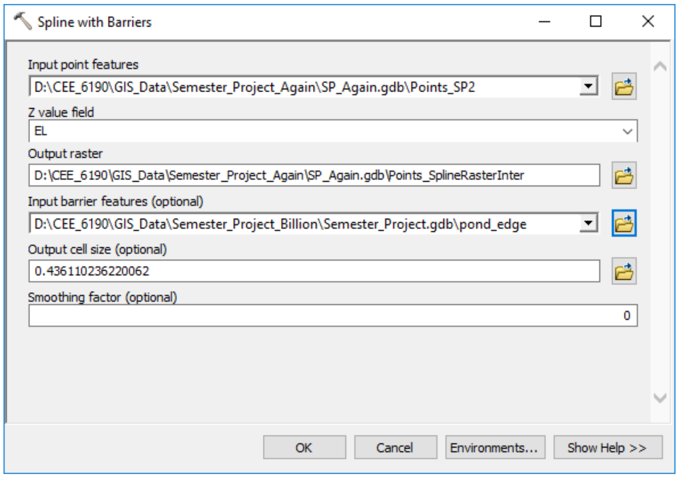
Credits: Survey data collected by Hunter Payne, Brooklyn Morgan, and Amanda Stoudt;
Survey points layer created by Levi Manley and Amanda Stoudt;
Google Imagery Layer provided by Utah AGRC

Figure D2. Display XY Data command window in ArcMap showing properties used for importing the survey points (left) and the resulting ArcMap layer (right).

The .txt events layer was then exported into a geodatabase as a feature class and simultaneously projected into the UTM 1983 StatePlane Utah North FIPS 4301 (Intl Feet) coordinate system using the *Export Data…* command. The resulting feature class was then added to the map as a layer. A feature class delineating the pond edge was also created by digitizing the outline of the pond on the Google imagery layer provided by the Utah Automated Geographic Reference Center (AGRC).

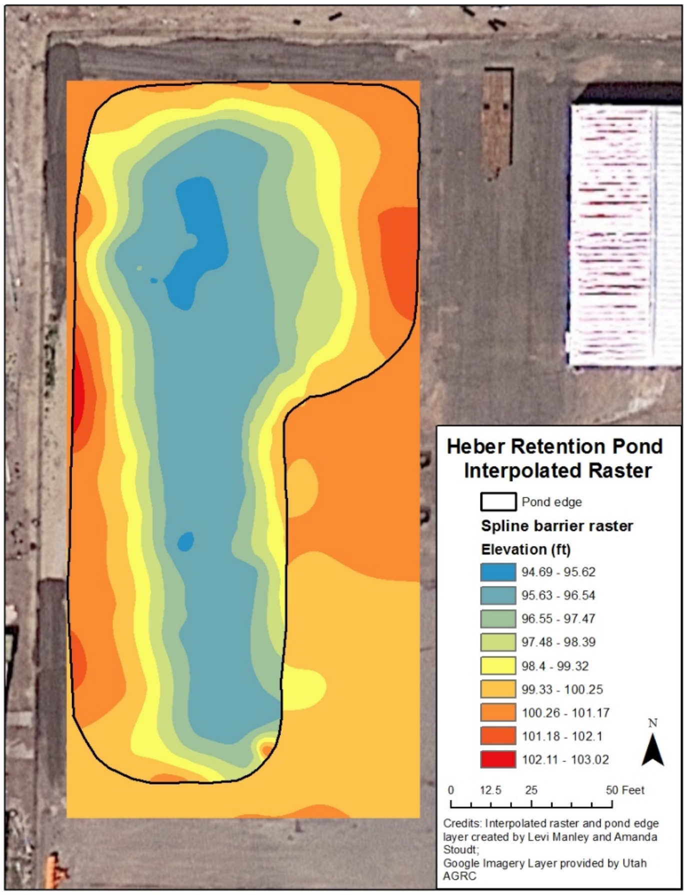
Data Points to Raster

To incorporate the elevation of the survey points into the map, a raster was created to hold the elevation information for each survey point and to interpolate the elevation between survey points. Because the pond edge feature class could be used to delineate the boundary for the interpolated raster, the *Spline with Barriers* raster interpolation tool was used. The pond edge feature class and survey points feature class created in the previous step were used as inputs in the *Spline with Barriers* raster interpolation tool (Figure 3). The elevation of the survey points was selected for the Z field and the interpolated raster was saved in the project geodatabase. For the output cell size, the default cell size was used, which was calculated from the shortest height or width of the extent of the input feature in the output spatial reference, divided by 250 (ArcGIS for Desktop, 2016). Figure 4 shows the resulting interpolated spline with barrier raster.



Input point features
D:\CEE_6190\GIS_Data\Semester_Project_Again\SP_Again.gdb\Points_SP2
Z value field
EL
Output raster
D:\CEE_6190\GIS_Data\Semester_Project_Again\SP_Again.gdb\Points_SplineRasterInter
Input barrier features (optional)
D:\CEE_6190\GIS_Data\Semester_Project_Billion\Semester_Project.gdb\pond_edge
Output cell size (optional)
0.436110236220062
Smoothing factor (optional)
0

Figure D3. *Spline with Barriers* tool window with the selected parameters used to create an interpolated spline with barriers raster of the retention pond.

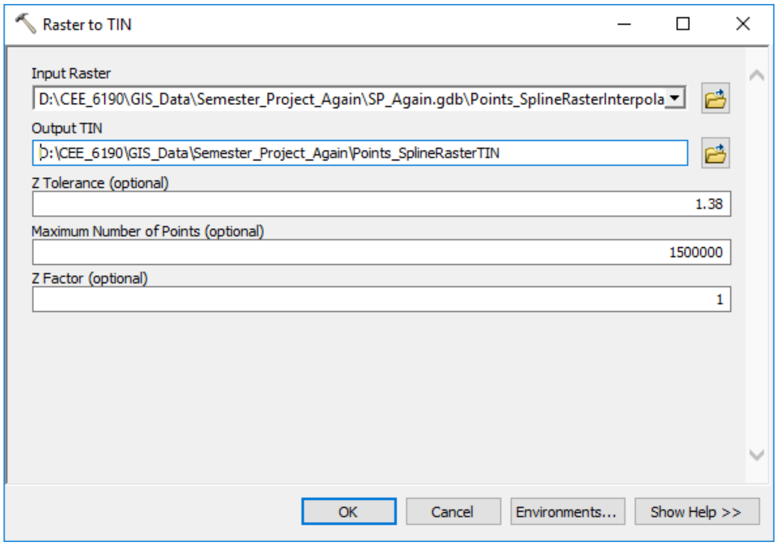


Credits: Interpolated raster and pond edge layer created by Levi Manley and Amanda Stoudt;
Google Imagery Layer provided by Utah AGRC

Figure D4. Interpolated spline with barriers raster of the retention pond generated using the *Spline with Barriers* raster interpolation tool.

Raster to TIN

A TIN represents surface topography with triangulated vertices. The *Raster to TIN* tool creates a TIN from the raster grid cells containing the elevation data for the pond surface. The raster was converted to a TIN because values between TIN nodes are interpolated, whereas data represented by a raster is limited by the raster cell size. Given the minimal survey data collected in the field, the interpolation used in the creation of the TIN provides more data points, increasing the precision and smoothness of the surface. The input for the *Raster to TIN* tool was the spline with barriers raster created from the survey points. The TIN was output to the project geodatabase. The default values for the Z Tolerance, Maximum Number of Points, and Z Factor were used. Figure 5 shows the *Raster to TIN* tool window with the settings explained above. The resulting TIN representing the interior surface of the retention pond is presented in Figure 6.



Input Raster
D:\CEE_6190\GIS_Data\Semester_Project_Again\SP_Again.gdb\Points_SplineRasterInterpola

Output TIN
D:\CEE_6190\GIS_Data\Semester_Project_Again\Points_SplineRasterTIN

Z Tolerance (optional)
1.38

Maximum Number of Points (optional)
1500000

Z Factor (optional)
1

Figure D5. *Raster to TIN* tool window with the selected inputs used to generate a TIN for the retention pond.

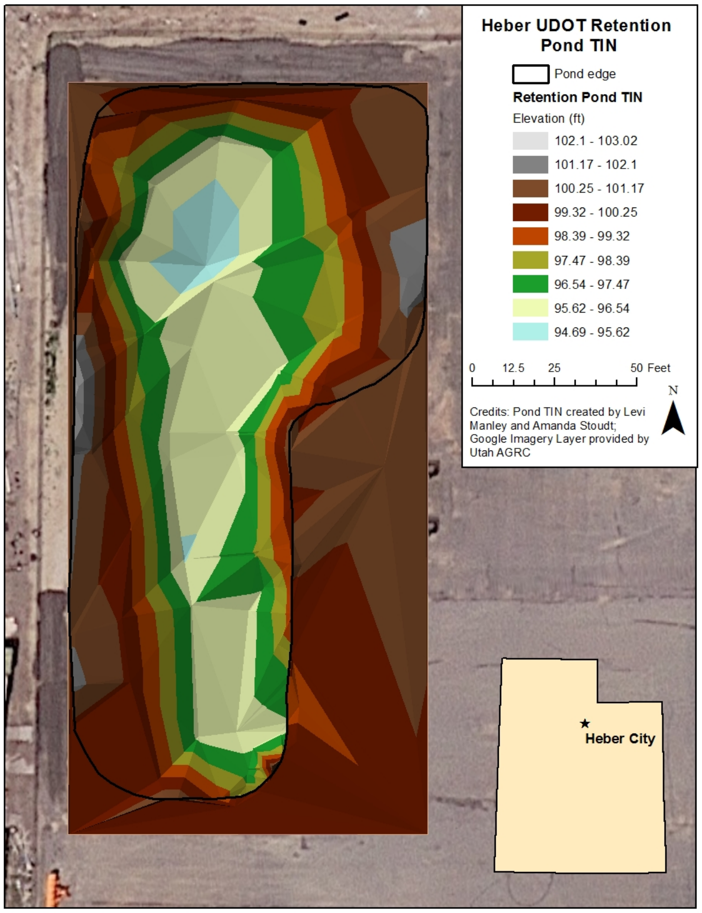


Figure D6. TIN surface representing the interior topography of the Heber retention pond.

Surface Volume Calculation

The TIN created in the previous step was used to estimate the volume of the retention pond. To calculate the volume of the TIN, the *Surface Volume* tool was used. The TIN was used for the input and the table output was saved to the project database. The Reference Plane field was set to BELOW and given a value of 100 to correspond with the edge of the pond, which was used to establish the Z coordinate of the survey points. All the other fields were left as the default value. The volume of the surface is stored in the output table and can be viewed by right clicking on the output table in the table of contents in ArcMap and selecting *Open Attribute Table.*

References

ArcGIS for Desktop, 2016. Point to raster. Accessed on April 24, 2019.

ESRI, 2018. How to: Import XY data tables to ArcMap and convert the data to a shapefile or feature class at ArcMap 10.1 and later versions. Accessed on April 24, 2019