



Final

**FEASIBILITY AND COST ANALYSIS
FINDINGS AND RECOMMENDATION REPORT
PARADOX VALLEY UNIT BYPRODUCTS DISPOSAL STUDY**

**Submitted to:
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**Submitted by:
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January 2017

Amec Foster Wheeler Project No. 1655500023

January 2017

Dave Sablosky
Wastren Advantage, Inc.
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Piketon, Ohio 45661

Re: Final Feasibility, Cost Analysis, Findings, and Recommendation Report for Paradox Valley Unit Byproducts Disposal Study

Dear Dave:

The report included here satisfies the deliverable for the Paradox Valley Unit Evaporation Ponds Study 3: Final Feasibility, Cost Analysis, Findings, and Recommendations for Byproducts Disposal Report. As agreed with you and with Reclamation, this is a single combined report for the Byproducts Disposal Study that includes all elements anticipated from the Feasibility and Cost Analysis study, and the Findings and Recommendations report. This is a final version including all the information collected for Study 3 combined into a single report. It also includes the responses to the final comment matrix submitted by Reclamation.

If you have any questions or concerns regarding this report, please contact Carla Scheidlinger at 858-300-4311 or by email at carla.scheidlinger@amecfw.com.

Respectfully submitted,

Amec Foster Wheeler Environment & Infrastructure, Inc.



Carla Scheidlinger
Project Manager

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ACRONYMS AND ABBREVIATIONS

Amec Foster Wheeler	Amec Foster Wheeler Environment & Infrastructure, Inc.
Ca	Calcium
Ca SO ₄	Calcium sulfate
CD	Certificate of Designation
CDPHE	Colorado Department of Public Health and Environment
DOT	Department of Transportation
EDOP	Engineering Design and Operations Plan
F	Fahrenheit
gpm	Gallons per minute
h-P	hoh-Pak
K	potassium
M	million
Mg	Magnesium
Mg SO ₄	Magnesium sulfate
MgCl	Magnesium chloride
Na	Sodium
NaCl	Sodium chloride
NORM	Naturally Occurring Radioactive Material
ppm	Parts per million
PVU	Paradox Valley Unit
Reclamation	Bureau of Reclamation
SG	Specific gravity
SO ₄	Sulfate
USGS	United States Geological Survey

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1.0 BACKGROUND AND INTRODUCTION

1.1 Statement of Problem

The Bureau of Reclamation's Paradox Valley Unit (PVU) is a component of the Colorado River Basin Salinity Control Program, a multi-works program to control the salinity of Colorado River water delivered to users in the United States and Mexico. The PVU currently intercepts 200 gallons per minute (gpm) of 260,000 mg/l brine and diverts it to a 16,000' deep injection well for disposal. The injection rate has been curtailed during the 20 year life of the well due mainly to induced seismic activity associated with the injection process. At the current rate, Reclamation prevents approximately 100,000 tons per year from entering the Colorado River system. The current collection well field is capable of producing 400 gpm. However salinity control benefits may decrease when pumping in excess of 300 gpm. Therefore, for purposes of this study, the goal is to control up to 170,000 tons per year, or 300 gpm. Due to current and future limitations of the injection well, and long term salinity control considerations at Paradox, Reclamation is currently evaluating alternative methods of brine disposal of this produced brine. One of the long-term strategies being considered for brine disposal is diverting the brine to an evaporation pond or series of ponds. The Byproducts Disposal Study investigates the nature of the solid salts that would be produced in such an evaporation pond complex, the nature of the liquid magnesium chloride rich brine that remains, and evaluates preferred methods for their disposal or sale. This report presents and discusses the Feasibility and Cost Analysis for such disposal, and presents Findings and Recommendations regarding byproducts and their disposal or sale.

Amec Foster Wheeler is conducting studies for three other aspects of the evaporation ponds. These studies include the management of hydrogen sulfide (H₂S), the siting, design, and operation of the ponds, and the ecological risk associated with the development and operation of the ponds. The results of these studies are integrated as appropriate with the byproduct disposal study.

This report is to present the cost and feasibility analyses of potential byproducts produced by the PVU brines in evaporation ponds. These analyses lead to findings and recommendations that address the ultimate disposal or sale of the salt products. The nature of the salts that will be produced is described, the various issues associated with both sale and storage of those products are discussed, and recommendations based on these findings are made.

This evaluation was conducted without the benefit of a pilot-scale project in the field. Absent such a project, these conclusions must be taken as preliminary. They are the result of the best available data from initial brine analyses and laboratory evaporation studies, and of responsible peer-reviewed models. In the experience of the industry professionals involved in this work, however, any final conclusions would require the development of an on-site field pilot project.

1.2 Location

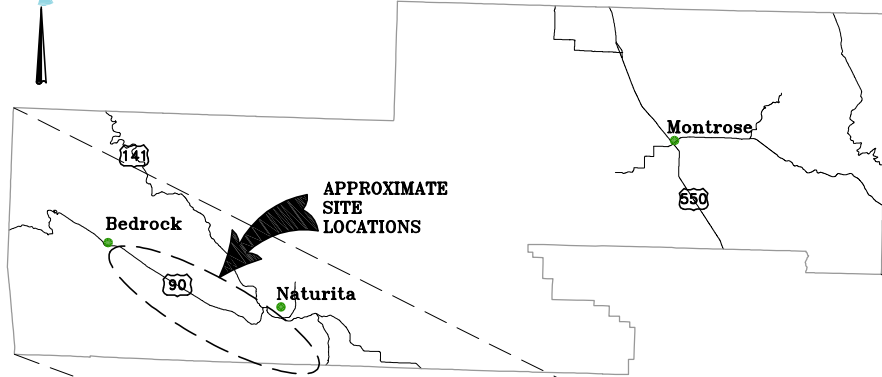
The PVU is located near Bedrock, Colorado in the Paradox Valley of Montrose County, about 10 miles east of the Colorado-Utah state line (Figure 1). The well sites are located adjacent to the Dolores River, which flows from south to north through the valley. The elevation of the well sites

is about 5000 feet. The Broad Canyon and Reams 80 Pond Landfills, which are discussed in the disposal section of this report (Section 11.3), are located approximately 25 miles from the production well sites, to the south of the town of Naturita.

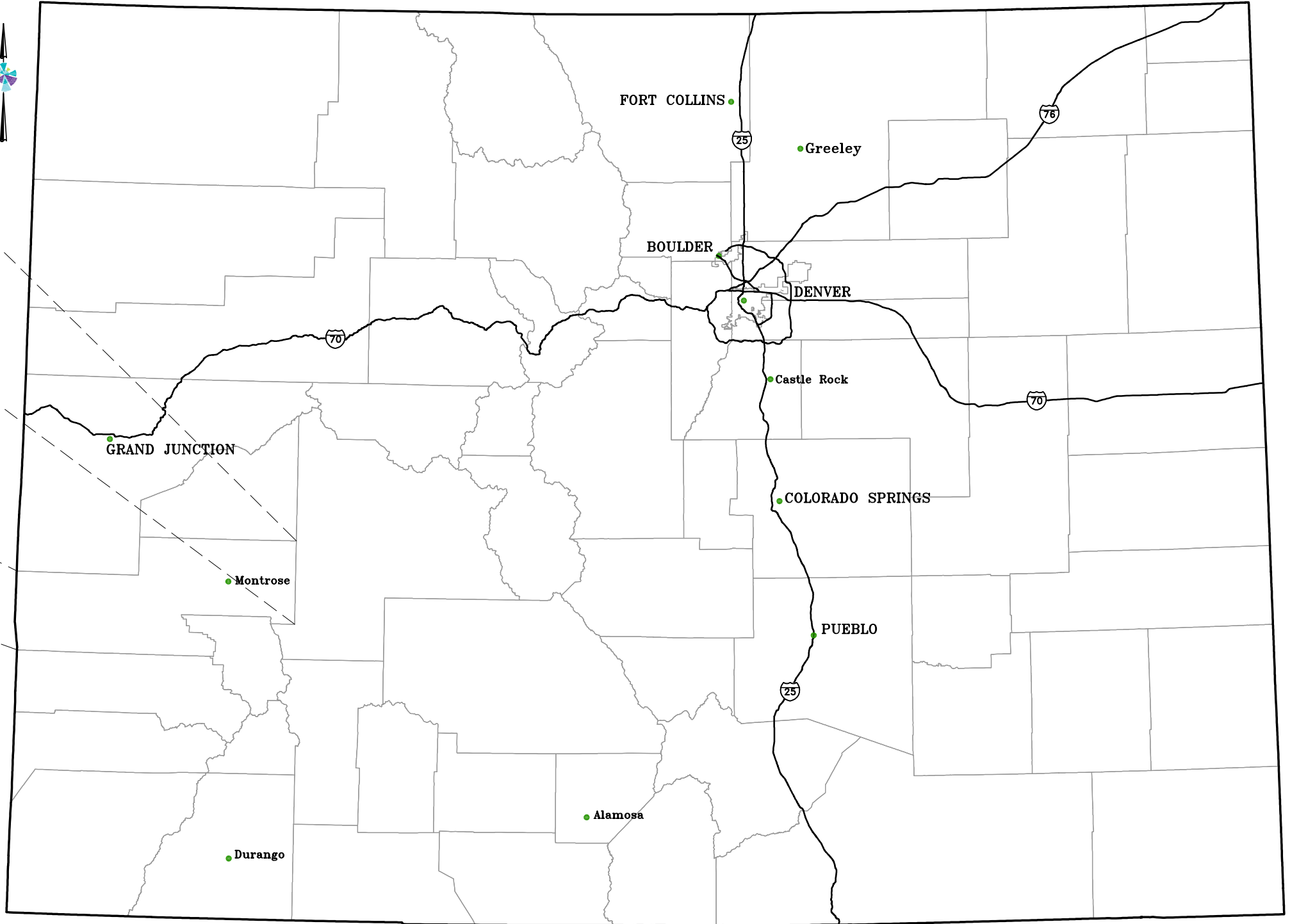
1.3 Organization of Report

This report will first describe the nature of the evaporation ponds that will produce salt products, and will touch on the operational parameters that contribute to the production of salt products. Details of the nature of the brine itself are discussed, along with the nature of the products that are predicted to be produced from evaporation under different environmental conditions. The quality and quantity of the potential products will then be described, and the harvesting strategies required to collect those products from the ponds will be discussed briefly. Detailed operational strategies will be the subject of a separate report (Amec Foster Wheeler 2016a). The report then evaluates the potential disposition of those products, evaluating the potential markets, prices which suppliers have paid for the products in the past, and our professional judgement about the viability of entering these markets with PVU-generated products. The report also evaluates the disposal options for products that may not reach a market, and recommends which disposition option(s) should be considered. The costs for implementing these disposition options are discussed. Overall recommendations are made for how decisions may be made regarding the sale or disposition of the salt products in the future.

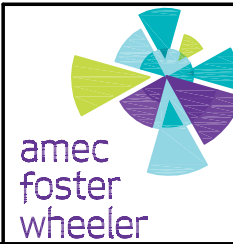
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MONTROSE COUNTY MAP
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COLORADO STATE MAP
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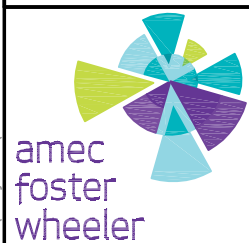
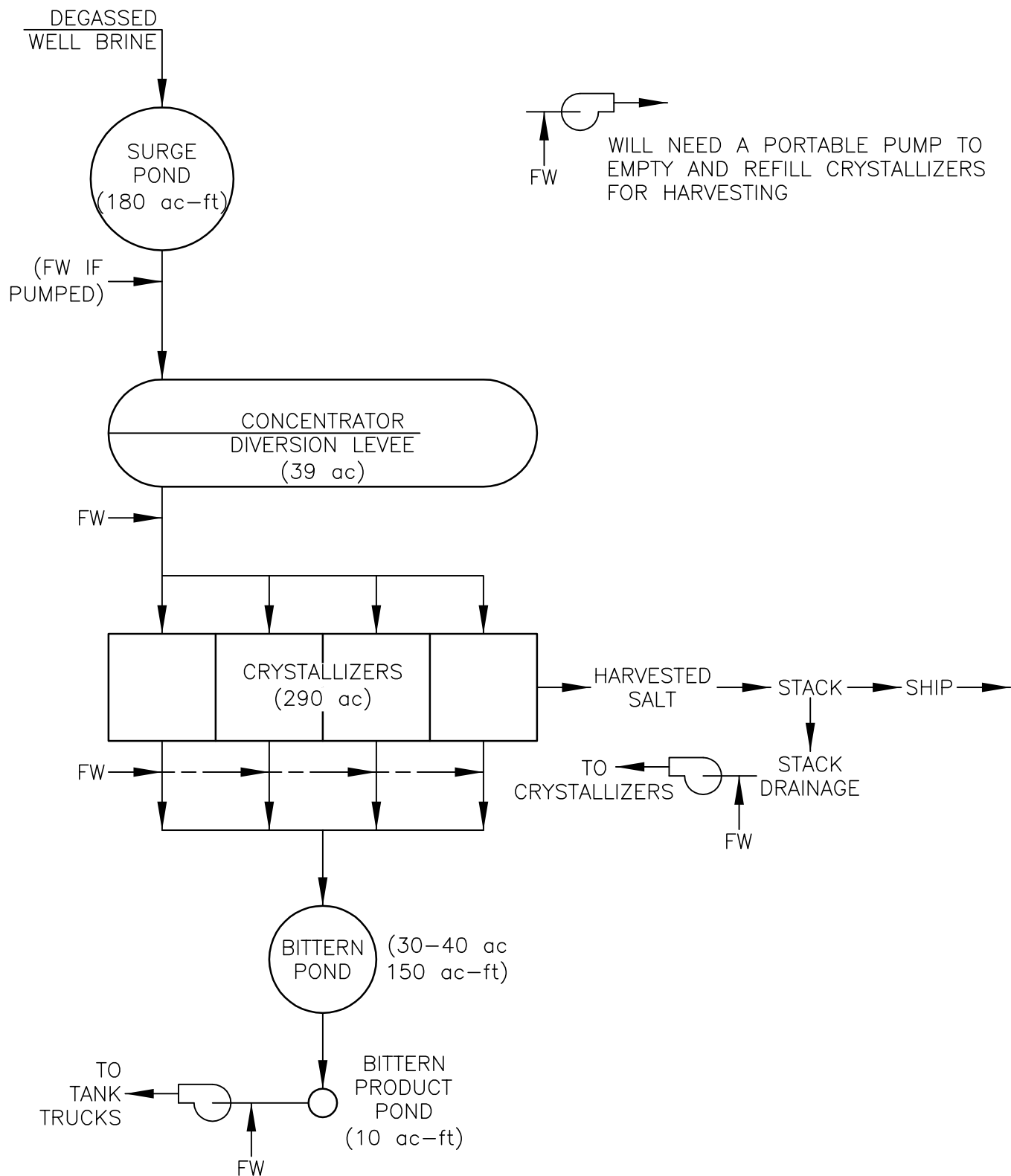
2.0 POND SERIES CONCEPT

The pond series (Figure 2) is designed to accommodate a continual flow rate of 300 gpm, and for optimizing evaporation during the periods of time when evaporation exceeds precipitation. It includes an initial surge pond to accommodate flows during periods of low evaporation; 39 acres acting as a concentrator to bring the brine to a state of saturation, and a total of 290 acres of ponds serving as crystallizers where solid salts will be deposited. A bittern concentration pond of 24 acres allows for bittern liquids to attain the concentration required for road deicing use, and a final bittern storage pond accommodating up to 10 AF of fluid confines the final liquid product prior to sale or disposal. Ponds were determined using a model that is described in the Pond Design Strategy Report (Amec Foster Wheeler 2016b) and which is also considered in Appendix D.

The pond series can be operated with some flexibility depending on climate and weather parameters, or on what byproducts are desired. Details of the operational strategies that produce the salt products discussed here are in the Operational Strategies report (Amec Foster Wheeler 2016a). In this report, the ponds are identified as in Figure 2, and their operation is assumed to have the potential to produce the products described here. The points at which a freshwater feed is needed for brine transfers are shown in Figure 2 as FW.

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3.0 ASSUMPTIONS

There are several assumptions that were used to determine the size and footprint of the ponds, and these assumptions are detailed in the Pond Design Strategy Report (Amec Foster Wheeler 2016b). A summary of important parameters of pond design that affect operation are shown here.

3.1 Inputs and Pond Sizes

Amec Foster Wheeler has made the following assumptions about the inputs to the system, which are based on the chemistry analyses of the brine and of the operational goals of the project.

- The rate of flow into the system will be relatively constant at 300 gpm of brine.
- The input brine has specific gravity (SG) of 1.1725 as reported from the hoh-PAK laboratory analysis.
- Evaporation rates were calculated based on local climate data analyzed from 1993-2015, and on pan evaporation data produced by Reclamation at the PVU facility. Pertinent parameters are:
 - A pan to pond coefficient of 0.73.
 - Well brine evaporation discount factor of 0.72.
 - Saturated brine evaporation discount factor of 0.76.

Based on the data, the pond series is designed for a surge pond to accommodate flows during periods of low evaporation; 39 acres acting as a concentrator, and of a total of 290 acres of ponds serving as crystallizers. Refinements for the evaporation rates included assumptions that across the concentrator an average discount factor (the factor by which evaporation is different from that of pure water) of 0.74 is appropriate, and across the crystallizers, which are fed in parallel, an average discount factor of 0.66 is appropriate.

Assumptions are also made for bittern production. These assumptions are:

- The bittern point is set at SG = 1.2610 in order to produce a product with the required maximum concentration of magnesium (Mg) for deicing salt as described in Section 4.3. The SG point was arrived at by interpolation of the laboratory results.
- With the bittern at SG = 1.2610, the evaporation discount factor is 0.55.
- A total of about 63 gallons (gal) of every 1,000 gal of brine fed from the concentrators to the crystallizers will result in the initial bittern. After bittern concentration, about 4 gal of concentrated bittern would remain.
- The size of the bittern concentrator pond is 24 acres.

These assumptions are derived from calculations that result in all the solid salt being made conforming to salt deicing quality standards, as described in Section 4.2.4. These assumptions do not maximize the quantity of salt made in the crystallizers, nor do they minimize the amount of bittern solids generated.

Finally, it is assumed that the H₂S in the brine will be removed such that operators can work in the area without any undue risk to health or to being exposed to noxious odors.

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4.0 BYPRODUCTS

The byproducts that will be possible to produce from the evaporation ponds are a function of the nature of the produced brine, and of the manner in which the pond series is operated. In order to determine what the brine could produce, this project began with a series of evaporation tests.

4.1 Evaporation Tests

A sample of well brine from Paradox Valley was sent to hoh-PAK (h-P) Labs in Louisiana for testing. This laboratory is highly experienced in testing saline brines and related salts. h-P is audited yearly by the salt industry to certify its results, and has been utilized several times to do the type of testing discussed below.

The intent of the testing was to determine the phase chemistry of the brine as it evaporates. The testing follows both the brine and the precipitated salts as brine concentration increases. Testing was done for evaporation under both warm and cold season conditions. The results allows prediction of the quality of salts produced. Using evaporation and precipitation data from the area, this information also allows modeling a series of ponds that will produce these salts in the area of the Paradox Valley and predict the quantities produced.

Refer to Appendix A for the associated Excel Spreadsheet describing the test results and analysis of the h-P data. Appendix B shows pictures of the salt formed during the evaporation tests.

4.1.1 Procedure

Well brine was placed in a shallow evaporation dish and placed in a climate-controlled box. The box was kept at 120°F. A fan maintained air movement above the surface of the brine, and provided for exchange of outside air. The temperature was set to speed the progress of laboratory work, and was not meant to duplicate atmospheric conditions in the field at the PVU site. Note that the phase chemistry of saline brines of these concentrations is not temperature dependent in this temperature range. A similar test was done at 12°F to determine if the phase chemistry was different at that temperature.

Brine in the evaporation dish and precipitated salts were gathered and both brine and solid salts were tested at intervals during the procedure. The intervals varied and depended on when enough salt was made for testing. The test procedure followed the ASTM E-534 protocol used worldwide by salt producers and users.

The brine was tested for calcium (Ca), magnesium (Mg), sulfate (SO₄), potassium (K), specific gravity (SG) and pH. Direct sodium (Na) measurement was attempted in several samples. However, since the required dilution to measure the Na was 20,000:1, any small error was greatly magnified. This led to unreliable results and the measurement was discontinued. Trace chemicals such as barium and zinc were not measured.

Specific gravity and potassium were measured as a way to track the concentration path of the brine. Specific gravity is easy to measure in the lab and in the field; however, great accuracy is

needed to use this metric to detect small changes in concentration, and specific gravity data are therefore more difficult to interpret. Potassium will not precipitate at the concentrations investigated, and is therefore a good way to measure percent evaporation. As concentration of K in the brine increases as a direct result of evaporation, that concentration allows for an accurate calculation of the amount of water evaporated from the brine.

Testing of the precipitated crystals was done to measure water insolubles (dirt), Ca, Mg, and SO₄. Calculations were then made to determine the solid phase mineral makeup of the crystals. Again, trace chemicals were not measured.

The salt crystals were sent to the lab at TestAmerica for the detection of radionuclides. This was done to determine if the salts would constitute hazardous waste if they are permanently disposed of in a landfill facility. The results are in Section 12.4.1.

4.1.2 Brine Results

The initial brine analysis is shown at a K concentration of 4846 parts per million (ppm) (SG = 1.1725). Sodium chloride (NaCl) saturation was reached at a K level of 5523 ppm (SG=1.1986). At that point, 12% of the original brine had evaporated.

Thereafter, precipitated crystals were removed from the brine when there was an amount sufficient for testing. When the crystals were removed, a sample of the brine was also taken for analysis. The percent evaporation, based on K concentration, is shown for each sampling. A final brine sample was taken at 91% evaporation. The amount of solid salt at this brine point was too small to test. These results are shown in Table A-1 in Appendix A.

The brine did evaporate to dryness under laboratory conditions at 120°F. A further test was made by h-P to simulate ambient temperatures in the upper 80's F (day simulation) and in the 50's F and 60's F (night simulation). This sample also evaporated to dryness under the laboratory conditions.

The graphs in Appendix A illustrate the results of the testing. The "Summer Brine Phase Chemistry-K" graph shows K as a tracer for concentration, and the "Summer Brine Phase Chemistry-SG" graph shows SG used for the same purpose. (Note that K is a much more definitive measure of concentration for doing this kind of analysis.) Data in black are laboratory results. Data in green are calculated from the laboratory results. Calcium is depicted on the graphs as ten times the lab value in order for the line to be more easily visible. Any line or part of a line shown on the graphs that slopes downward from left to right shows definitive precipitation of that element.

An upward sloping line may or may not indicate precipitation. Sulfate is precipitating with Ca, but as there is stoichiometrically more SO₄ than Ca, the SO₄ line does not show a downward trend. The percent evaporation based upon SO₄ was also computed. Note that the SO₄ numbers are much lower than the K numbers. This indicates that SO₄ is precipitating.

4.1.3 Laboratory Salt Results

Knowledge of saline brine chemistry and the use of stoichiometric relationships allow for calculations of the type of minerals precipitating from the brine. Given the lab measurement of Ca, Mg and SO_4 in the collected salts, a calculation of the minerals precipitated was made. These results are shown in cells describing the crystals in Appendix A, Tables A-1 through A-3 and in Table 1 below for the tests done at 120°F.

The first crystals that formed in an amount large enough to test were formed between K=5523 ppm and K=7573 ppm. This range is from the point where NaCl (halite) first started to precipitate at 12% of initial brine evaporation, to 36% of initial brine evaporation. Note again that, due to testing methods explained above, the percentage of NaCl was calculated by subtracting the amounts of Ca and Mg salts, and the insolubles, from 100 per ASTM E-534. So these first crystals were 97.60% NaCl, 2.2% CaSO_4 , 0.14% magnesium chloride (MgCl_2) and 0.07% magnesium sulfate (Mg SO_4).

Four samples of crystals were gathered for testing. The results for salt crystal composition are shown in Appendix A Table A3; photos of the crystals collected are in Appendix B (Figure B2 and B2). The average NaCl composition across all samples was 98.63%. This does not mean that the statistical average NaCl content was 98.63%, as the sample sizes were different, and lab conditions don't really allow for weighted averages. However, note that the NaCl content of each sample doesn't vary substantially. Therefore the statistical average would actually be close to 98.63%.

As the CaSO_4 (gypsum) precipitates during the evaporation process, the amount of gypsum decreases. This is entirely in keeping with the known progress of other similar saline brines.

The amount of MgSO_4 and MgCl_2 shown in the results generally increases as the percent of the brine that is evaporated increases. The precipitation of gypsum and the precipitation of Mg salts are fundamentally different. Gypsum is co-precipitating with NaCl *before* the solid sample is collected from the brine. Mg salts only precipitate *after* the crystals are removed from the brine.

These evaporated brines exhibit a high surface tension and stick tenaciously to the surface of the precipitated crystals. No matter how well the collected crystals are drained before testing, a small amount of brine will remain on the crystals. If the brine on the crystal surface dries before testing, the magnesium minerals will precipitate on the surface of the NaCl crystals. Although they appear in the analysis as constituents of the halite, they are not actually part of the halite crystal but rather a film of a different material adhering to those crystals. If the brine does not dry before testing, the mineral ions are in the brine and show up in the testing. In either event, the Mg minerals are calculated. In a commercial salt production facility, the brine adhering to the salt crystals is washed off before going to a stockpile, resulting in a salt that is very low in Mg.

Table 1.
Salt Products Produced in Laboratory Evaporation Tests

	1st Crystals	2nd Crystals	3rd Crystals	4th Crystals
	%	%	%	%
CaSO ₄	2.20	0.71	0.54	0.57
MgSO ₄	0.07	0.00	0.13	0.37
MgCl ₂	0.14	0.13	0.19	0.41
Insolubles	0.004	0.001	0.001	0.001
NaCl (by diff)	97.59	99.16	99.15	98.65

Under laboratory conditions, these brines, then, produce a preponderance of halite, with only trace amounts of gypsum and Mg salts under laboratory conditions. MgCl₂ can be produced in greater quantity in the ponds under the climatic conditions of Paradox Valley than can be produced under laboratory conditions.

The tests performed at 12°F give essentially the same results as shown above (See Appendix A, Winter Brine Analysis). As the overwhelming preponderance of salt will be made at warmer temperatures, Table 1 indicates in generally accurate terms the nature of the product that will be formed year round.

4.2 Potential End Products

The solid salt byproducts described above can be treated in a variety of ways to produce final products. These potential products, how they are produced, and the potential for their market disposition, are described in the following sections.

4.2.1 Food Grade Salt

Strictly speaking, the quality requirements for food grade salt revolve more around good manufacturing process than around product purity. In order to produce food grade salt, the production facility must have a *documented and inspected* process to eliminate metal particles from the salt, a *documented and inspected* process to keep contaminants such as rodent droppings out of the salt, and other management requirements. However, in effect, the American consumer has associated food grade with high purity as well. In addition, there are also a number of granule size screening ranges to be considered in a food grade product. Therefore, a food grade product from PVU would have to meet all of the criteria for purity, granule size range and contamination. Food grade salt is packaged in a variety of ways and some products require additives such as iodine. Production of food grade salt would involve a high level of capital expenditure, business development and organization, and cost. Based on the professional experience of the team, production of this material is not recommended.

4.2.2 Processed Salt

A second category of products uses salt from a stockpile that has been washed a second time, dried to near zero moisture, screened to meet granule size requirements, and packaged in a

variety of ways – bulk, bulk bags, bags, etc. Some deicing locations that have very low temperatures want a bagged, dried salt. Furthermore, some of these processed products require additives prior to being used for purposes such as seafood processing salt. Water softening salt is a big user of processed salt. This kind of production would also involve a high level of capital expenditure, business organization, and cost. Based on the professional experience of the team, production of this material is not recommended.

4.2.3 Chlor-alkali Salt

A third category of products is salt sold in bulk directly from a stockpile. The salt in the stockpile has typically been harvested from a crystallizer pond, washed and drained. One use for this salt is feedstock for chlor-alkali facilities. The chlor-alkali process is an industrial process for the electrolysis of NaCl. It is the technology used to produce chlorine and sodium hydroxide (caustic soda), which are commodity chemicals required by industry. The chemical industry is the largest consumer of salt worldwide, using about 60% of the total production. This industry converts the salt mainly into chlorine, caustic soda and soda ash (Sedivy 2008).

The production process for chlor-alkali facilities has been changing over the last couple of decades. The newer processes require high quality salt. Salt made from PVU brine for this use would have to be washed, and otherwise treated to assure adequate purity. The general purity of NaCl from solar salt production anticipated by the chlor-alkali is 99.8%. Laboratory testing would have to be done at the outset, however, to determine whether washing, which is an expensive process, would even produce a product of the necessary quality. Based on the professional experience of the team, production of this material is not recommended.

4.2.4 Deicing Salt

Salt used for deicing is applied to road surfaces to melt snow and ice and to improve the safety of the roads for vehicle passage. This is the most feasible product for production at the PVU facility.

In the United States, deicing salt must meet both a quality and granule size range specification. Those specifications can vary from jurisdiction to jurisdiction, and the minimums are set in ASTM D-632. Typical specifications are shown in Tables 2 and 3.

Table 2.
Salt Type Specifications for Deicing Use

Component	Specification (%)	Lab Results (%)
NaCl db* (min)	97.9	98.6
Ca+Mg (max)	0.7	0.4
SO ₄ (max)	0.5	0.8**
Insolubles (max)	0.05	0.002
Moisture (max)	2.0	Not known

Notes:

*db denotes "dry basis". The NaCl content is stated without moisture

** Actual percent of SO₄ can only be determined with a pilot pond test.

Table 3.
Salt Crystal Size Specifications for Deicing Use

USS Mesh	% Passing
3/8	90-100
4	20-90
8	10-60
30	0-15

Some suppliers report providing a product with a lower percentage of SO_4 and a higher allowance for Ca and Mg (Central Salt 2012), so the final product would have to be evaluated by the entity marketing it. Some shipping destinations will require a Yellow Prussiate of Soda (YPS) additive. This is inexpensive and easily applied at the time of shipment. YPS keeps salt stockpiles from freezing in very cold situations, and could be added at the PVU production site.

Based on lab testing, salt produced from PVU brine can meet the quality requirements for this kind of use. It is not possible to know much about meeting the size requirements until salt can be made in a pilot size pond. As salt crystal size is climate dependent, it is expected, based on salt produced in similar climates, that the produced PVU salt would also meet crystal size specifications. Some minimal screening to remove lumps and fine particles would probably be necessary to produce a marketable quality of salt. Although most producers subject harvested solar salt to processes of washing, drying and screening (Compass Minerals 2014), these processes would not be needed if road deicing salt is to be the only use. This process does not require much capital or operating costs. Normal stockpile stack drainage should take care of the moisture specification. A sample deicing salt specification that would be applicable to salt is in Appendix C.

4.3 Bitterns

The point at which a brine is considered to be “bittern” can be designated in different ways and for different purposes. The bittern point in the salt industry is determined by quality considerations for the main product, which is generally NaCl. If a process focuses on producing a marketable bittern product without regard to the salt product, then a different bittern point could be designated to achieve that result. Leaving the brine in a crystallizer for longer than would be done for the production of NaCl, for example, could lead to a more valuable bittern product, as less desirable compounds would precipitate out and remain in the crystallizer.

Bittern is generally thought of as a liquid product that is high in Mg content. Such products can be sold to Mg metal producers as a raw material feed, used in some formulations for road deicing, and applied to dirt roads as a dust suppressant to satisfy government mandated particulate matter regulations.

Although h-P was able to take the PVU brine to complete dryness in the lab, this result was obtained in dishes that had a very shallow level of brine in them. In field conditions, especially if bittern production was a goal, bittern would be produced. The bittern would consist of both bittern fluids and bittern solids (Section 5.2).

Magnesium chloride ($MgCl_2$) is a common component of a variety of commercial preparations of road deicers. Per personal correspondence with Tyler Weldon (Colorado DOT Staff Maintenance Engineer, July 14, 2016), Colorado uses the Pacific Northwest Snowfighters (PNS) specifications as their standards. Other surrounding states also use these specifications. Table 4 below shows the Mg content specification for a variety of Mg-based products used on roads. Colorado uses FreezeGard 0®, Ice Ban®, and Caliber M1000®. The required percent $MgCl_2$ for the list and for Colorado products ranges between 26 and 30%. Other specifications, however, may have trace mineral maximums, which are shown in Table 5. In addition, corrosion inhibition requires additives.

Table 4.
Specifications for Products Approved by PNS for Road Use

Pacific Northwest Snow Fighters (PNS) Qualified Product List – PRODUCTS

Date of Listing: April 4, 2016

Category 1 – Corrosion Inhibited Liquid Magnesium Chloride

Product Name	Manufacturer	Corrosion Rate % Effectiveness	% $MgCl_2$ Concentration	Date Approved
Iceban 200	Earth Friendly Chem.	8.4	26%	8/15/2002
Caliber M1000 AP	Envirotech Services Inc.	20.8	28%	8/2/2004
Meltdown with Shield AP	Envirotech Services Inc.	25.9	30%	8/2/2004
Hydro-Melt Green	Cargill	24.3	28.5%	8/1/2005
Meltdown APEX with Shield AP	Envirotech Services Inc.	25.1	30%	1/25/2006
FreezGard CI Plus	Compass Minerals	12.2	30%	8/28/2006
Ice B'Gone II HF	Sears Ecological Appl.	28.6	25%	8/9/2007
FreezGard LITE CI Plus	Compass	12.3	27%	6/13/2001
HydroMelt Liquid Deicer	Cargill	28.0	28.6%	8/15/2011
FreezGard CI Plus Sub zero	Compass	14.1	27.5%	10/11/2011
Ice Ban 305	GMCO Corporation	25.3	26.6%	1/10/2013
FreezGard 0 CCI	GMCO Corporation	21.2	30.0%	1/10/2013
Meltdown Apex	Envirotech Services Inc.	22.4	30.0%	4/16/2014
Meltdown Inhibited	Envirotech Services Inc.	24.1	30.0%	4/29/2014
ProMelt MAG 20 INH	Innovative Surface Solutions	25.2	30.0%	7/13/2015
ProMelt Ultra 1000 INH	Innovative Surface Solutions	28.2	27.0%	7/31/2015
NexGen Torch	GMCO Corporation	25.0	30.0%	12/17/2015

Note: Iceban 200 was formerly Iceban Performance Plus M

Table 5.
Trace Element Limits for Road De-Icing Bittern Products (PNS)

Element	Concentration limit (ppm)*
Arsenic	5
Barium	10
Cadmium	0.2
Chromium	0.5
Copper	0.2
Lead	1
Mercury	0.05
Selenium	5
Zinc	10
Total cyanide	0.2
Total phosphorus (1% solution)	25
pH (1:4 solution)	6 to 9
Sulfate (% by weight)	2

*Unless otherwise indicated

5.0 DETERMINATION OF PRODUCT QUANTITIES AND QUALITIES

Amec Foster Wheeler used a non-proprietary model to determine the quantity and quality of salts that could be produced on an annual basis at the PVU site. This model was also informed by the professional judgement and experience of the Amec Foster Wheeler consultant team. Appendix D is a summary of the results of that model using one of several assumptions or scenarios that was selected to optimize the quality of solid salt produced that would be suitable for sale for road deicing use. A discussion of the evaporation data and how it informs the model is in Appendix E. The Excel spreadsheet that produced the tables shown in Appendix C is also provided as a separate file to allow the user to manipulate the assumptions to produce different scenarios for consideration. This report uses the assumptions shown in the tables and discussion of Appendix D. Pond sizing was also done using these assumptions (Amec Foster Wheeler 2016 b). Amec Foster Wheeler emphasizes that the quantities and qualities of products discussed here cannot be known definitively unless a pilot pond series is designed and operated for at least a year. The team also stresses there are multiple operational parameters and assumptions which would affect ultimate pond design and operation. For this project, the team selected the scenario shown in Appendix D.

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6.0 QUANTITY OF END PRODUCTS

6.1 Solid Halite Salt

Calculation of the total quantity of marketable halite that would be expected to be produced by the PVU project each year is based on the assumption of a constant production rate of 300 gpm of brine at a constant chemical composition, and on the operation of the ponds to discharge brine from the concentrator and crystallizers at a defined SG. The current quantity assumed at this time is 137,000 tons of solid halite. This total does not include the mass of the bitterns, which include both liquids and solids, and which are described separately in Section 5.2.

6.2 Bittern

The salt model that was produced to arrive at the pond design (Amec Foster Wheeler 2016b) predicts that after 94% of the well brine produced annually evaporates in the concentrator and crystallizers, about 30.7 AF would remain as a “dilute” bittern with an MgCl_2 concentration of about 2.7%. This would need to evaporate to a concentration of 30% MgCl_2 to be marketable.

The model cannot make especially accurate predictions about the quantity of marketable MgCl_2 that could be recovered from the ponds, as much of the ultimate results depend on operational parameters and on a field knowledge of the nature of the solid salts that will precipitate from the bittern fluid as bittern salts. A pilot pond test would be required to make accurate volume and mass determinations. The brine solution at the point of discharge from the crystallizer ponds is saturated in halite and mixed Na, Ca and K- SO_4 compounds. It is also highly saturated in polyhalite -- $\text{K}_2\text{MgCa}_2\text{-4}(\text{SO}_4)\cdot 2\text{H}_2\text{O}$ (per a PHREEQC analysis). It is not, however, close to saturation in any other Mg compound. Therefore, the discharged brine will continue to precipitate halite and other salts. These bittern salts have little or no value, and they must be removed from the bittern as it continues to concentrate. This process is discussed in the Operational Strategy Report (Amec Foster Wheeler 2016a). This continued precipitation will entrain some of the remaining bittern brine in the voids of the crystal mass.

The residual brine will be enriched in Mg by the relative loss of other compounds including the K, but the recoverable volume could be small. To determine the volume of final MgCl_2 that could be recovered, as well as the exact nature of the bittern solids, it will be necessary to construct and operate pilot ponds as discussed above.

Based on the models presented, the best prediction that can be made at this time is for about 3,456 tons (643,254 gal) of concentrated MgCl_2 would be produced per year. The inventory of salts present in the bittern is shown in the table in Appendix F.

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7.0 MARKETABILITY

The principal goal of the PVU project is for the on-going and continual removal of salt from the groundwater system. In evaporation ponds, the products produced from this brine are halite salt, and MgCl_2 bittern liquid. Both the produced halite salt and MgCl_2 bittern liquid would require some level of processing to meet market requirements. Marketability of each kind of product is discussed below.

7.1 Food Grade, Processed, and Chlor-alkali Salt

To make the salt products suitable for the various end users, the application of advanced technologies in salt production and processing are necessary to facilitate profitable production of high quality solar salt for human consumption, exports, and the chlor-alkali industry (Sedivy 2008). In the professional opinion of the team, the development of an operation for the production, storage, transport, and marketing of food grade, processed, or chlor-alkali salt should not be considered.

7.2 De-icing Salt

For deicing salt, the PVU brine can produce an acceptable product. The issue of whether a remotely located producer such as the PVU, or a more local distributor/applicator would be able to enter the existing market given the transportation hurdle is an important consideration, and it is addressed below in Section 9.0. Cost and pricing data for this product is also addressed in this report, in Section 10.0.

7.3 Bittern

7.3.1 Metal production

It is unlikely that bittern produced by the PVU project could be sold to Mg metal producers, given transportation costs and market supply factors. The Mg metal producer closest to the PVU is in the Salt Lake City area. They have a captive system and produce all their own brine at a low cost, and do not require any inputs from other sources. The only time on record when they purchased brine from an outside source was in 1983 when the Great Salt Lake flooded and the facility's in-house brine system was inundated. Once they reactivated their system, they stopped buying the product from other sources.

7.3.2 Road Dust Control and De-icing

The other two uses for biterterns are for road de-icing and dust suppression products. The nature of the biterterns needed to supply this market is discussed in Section 4.3. Biterterns produced from PVU brine could be marketed for these purposes.

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8.0 END USERS

Road salt products and $MgCl_2$ preparations are by far the most widely used chemical methods of deicing roadways because of their ease of use, effectiveness, and relatively low cost compared to alternative de-icing methods. Driven by an increased public expectation for safe and clear roads, and fueled by relatively low costs, many states have steadily increased their use of road salt and $MgCl_2$ over the last 30 years.

Figure 3 is a map showing the salt producing locations in North America. It can be seen that the main producers are in Utah, Kansas, Oklahoma and New Mexico. Kansas is the top salt producing state in the US, and its salt is derived from mines. The closest producer to PVU is located in Moab, UT. A major source of solar salt is at the Great Salt Lake, production facilities along the shore of the lake.


Per the United States Geological Survey (USGS) Mineral Commodity Summary for Salt, in 2015 47.2 million tons of salt was produced and used in the United States (USGS 2015). A total of 23.2 million additional tons were imported, and 0.8 million tons produced domestically were exported. The amount imported tends to vary with the needs for winter deicing. Of the 69.5 million tons used in the United States in 2015, 46% or 32.4 million tons was used for road deicing. Compass Minerals (2014) estimates that 37 million tons per year are used in North America, based on average winter weather conditions. Most of the deicing salt sold in the Midwest and East is produced from underground mines. In the West, however, deicing salt is produced in solar ponds. The 137,000 tons of solid salt produced by the PVU project, then, is a very small fraction (0.45%) of the salt used annually in the United States for deicing, and would be unlikely to dramatically affect the competitive climate for solid salt in this country. The salt could, however, prove to be a valuable resource for deicing salt providers who sell such a product in the region. Reclamation could consider offering the products to suppliers who would pay more than the disposal costs.

Potential purchasers of deicing salt produced by PVU are most likely to be State Departments of Transportation (DOT), counties, larger cities, other producers that can more cheaply serve their customers from PVU products, and independent distributors and spreaders. Compass Minerals (2014) reports that their principal customers are states, provinces, counties, and maintenance contractors that purchase material in bulk, untreated, for ice control on public roadways. Compass Minerals (2014) also reports that highway deicing salt in North America is sold primarily through an annual tendered bid contract process with governmental entities, as well as through some longer-term contracts, with price, product quality and delivery capabilities as the primary competitive based market factors.

The solid salt can be used in different ways for deicing. The salt can be spread as is, mixed with sand, used with wetting agents or anticorrosion additives, or as an ingredient in a liquid product. Much of the deicing salt is purchased and transported during the summer to be stockpiled at the point of use prior to the onset of winter. If the upcoming winter has many snowfalls and all the stockpiled salt is used, spot deliveries would be made from a supplier during the winter. As noted above, tonnages of salt purchased vary significantly from year to year due to differences in the frequency and intensity of winter storms.

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 amec foster wheeler	CLIENT		BUREAU OF RECLAMATION		ISSUED DATE		06/22/2016		
	DRN BY	PROJECT	PARADOX VALLEY UNIT EVAPORATION PONDS			PROJECT No.		1655500023	
	MOC								
	DSN BY								
	RBR								
CHK BY	TITLE	MAJOR SALT DEPOSITS AND DRY PRODUCTION SITES IN NORTH AMERICA			FIGURE No.		REV		
ALM	3				0				
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The use of deicing salt varies somewhat from state to state. Also, states change their salt policies from time to time. Following is an overview of current salt usage policies by state. The states analyzed are those within a reasonable transportation distance from Paradox.

Colorado

Given competition from Utah, Kansas and New Mexico, Colorado is likely to be the major market – at least initially – for PVU byproducts. Although there are no salt producers in Colorado, Colorado Department of Transportation (CDOT) uses a variety of salt-related products to treat Colorado highways during winter storms. All of the products contain salt with added corrosion inhibitors used to prevent or remove the build-up of ice and snow on roads and minimize the impact on vehicles. The two major types currently used are salt complexes and sand mixtures. An example of a salt complex is Ice Slicer®, a proprietary product of Redmond Minerals. It is a mined product that Redmond describes as a blend of complex chlorides (Na, Mg, Ca, K) with an anticaking additive and a red color. The other type is a sand or sand/salt mixture, which is mainly used in the high elevations and the eastern plains where more extreme cold temperatures exist and more traction is needed. Sand Slicer®, for example, is sand with some $MgCl_2$ or other similar chemicals mixed in. Table 6 lists the actual usage in the State of Colorado for the winter of 2013/14. Some of the listed products are proprietary, and others are mixed by the State from ingredients acquired separately. Although there is some use of unblended solid salt (as road salt and the salt component of the salt-sand mix), salt does not form a large part of the deicing materials used in Colorado.

A more important constituent of Colorado's road deicing arsenal is $MgCl_2$. This product is used alone (liquid de-icers, salt brine) and as an ingredient in a number of mixtures. With few exceptions, these products are manufactured or pre-mixed materials that incorporate proprietary additions for corrosion control or for other performance enhancements. Many of these are produced by Redmond Minerals from their salt mine located in central Utah, or by Envirotech with offices in Colorado.

In Colorado, an important avenue for selling byproduct material is the $MgCl_2$ market. The product required as a raw material is a 30% $MgCl_2$ liquid. Envirotech is one of the major suppliers of $MgCl_2$ products in the region. They have expressed interest in purchasing $MgCl_2$ from the PVU project as long as it meets their specifications (Jonathon Nelson, pers. comm. August 9, 2016). A sample $MgCl_2$ specification for the products they sell is in Table 7. As the laboratory data from h-P did not include concentration of the initial bittern fluids, it is not possible to evaluate the characteristics of the final bittern. It will be possible to attain the target 30% concentration of $MgCl_2$, but the amount of sulfates and other constituents is not known. Information in Section 6.2 shows that 3,456 tons (643,254 gal) of concentrated $MgCl_2$ could be produced per year. Depending on the price offered in any year, sale in Colorado might be possible.

Table 6.
Usage of Road De-Icing Materials in Colorado in 2013

Description	Quantity	UOM	Total Cost	cost/unit delivered	Producer (if known)
Calcium Chloride	1.025	TON	\$415.54	\$405.40	
Calcium Chloride	9.18875	TON	\$6,116.63	\$665.67	
SALT, ROAD	162.98	TON	\$25,490.39	\$156.41	
Abrasive Non-Sanding	7,749.11	TON	\$64,066.83	\$8.27	
Abrasive Non-Mixed for Sanding	2,808.50	TON	\$44,667.83	\$15.90	
SALT-SAND MIX	18,306.94	TON	\$550,970.86	\$30.10	
Liquid Deicer	254,308.10	GLL	\$165,553.71	\$0.65	
ICE SLICER RS	40,345.34	TON	\$3,974,021.61	\$98.50	Redmond Minerals
LIQUID DEICER SPECIAL (Liquid+Salt-Sand)	5,144.50	TON	\$98,044.40	\$19.06	
Caliber 1000	14,400.00	GLL	\$11,784.00	\$0.82	Envirotech
APEX, LIQUID DEICER	8,822,724.70	GLL	\$7,323,932.29	\$0.83	Envirotech
SAND/SLICER	163,606.12	TON	\$4,555,557.25	\$27.84	
ICE SLICER SB	8	TON	\$861.46	\$107.68	Redmond Minerals
RAPID THAW	23.25	TON	\$2,495.21	\$107.32	GMCO
CALIBER M-2000	15,726.00	GLL	\$15,557.06	\$0.99	Envirotech
ICE BAN 305	2,654,557.00	GLL	\$2,075,344.02	\$0.78	Earth Friendly Chemicals
LIQUID DEICER SPECIAL (PRE-MIX)	3,774.03	TON	\$63,006.97	\$16.69	
Salt Brine, Gallon	600,264.60	GLL	\$326,849.50	\$0.54	
Solar Qwicksalt	1,167.25	TON	\$100,058.24	\$85.72	
Ice-Melt, Snow, Ice, Sidewalk, -25F	4.875	TON	\$3,892.00	\$798.36	
SOS-TM, LIQUID DEICER, MAG CHLORIDE 26%	24,156.00	GLL	\$29,112.58	\$1.21	Envirotech
			\$19,492,798.38		

Source: CDOT 2014. This information is for CODOT only and does not include cities, counties or municipalities.

Table 7.
Specifications for MgCl₂ used in Envirotech's Products

CHEMICAL PROPERTIES

Chemical Composition	Typical Analysis (%)	Range (%)
Magnesium Chloride	30.0	29.0-31.0
Sulfates	2.50	1.50 – 3.50

TYPICAL ANALYSIS

Testing per Pacific Northwest States Methods (ppm)

Constituent	Detected Level	Constituent	Detected Level
Phosphorus	< 2500	Chromium	<1.0
Cyanide	< 0.20	Cadmium	< 0.20
Arsenic	< 5.00	Barium	< 100.0
Copper	< 1.00	Selenium	< 5.0
Lead	< 1.00	Zinc	< 10.00
Mercury	< 0.05		

Utah

There are 73 road maintenance stations in Utah, and all of them have on-site salt storage (Report UT-14.02). Salt is used as-is for deicing, or is made into a liquid product by mixing it with water. Salt from the PVU ponds could be used in this way. In 2014, UDOT reported use of 194,000 cubic yards of solid salt (183,330 tons), as well as 1.8 million gallons of liquid brine (Deseret 2014). Utah also used Quiksalt®, which is a proprietary product of Compass Minerals. We note that the PVU project would be pumping 158,000,000 gallons/year. It is over 99% NaCl salt with added MgCl₂ and anticaking agents. The major salt producers in Utah include Compass Minerals, Redmond Minerals, Cargill and Morton. Most of the produced salt comes from the evaporation facilities at the Great Salt Lake. In addition, there is a mine in Redmond and a solar operation in Moab.

Wyoming

The state's main product used for deicing is a salt/sand mixture. Data from 2014 shows that Wyoming used 4,860 tons of salt at \$73.98/ton; 1209 gallons of salt brine at \$.21/gallon, and 225,583 gallons of MgCl₂ at \$.84/gallon (Clear Roads 2015). There are no salt producers in Wyoming, although there are salt storage facilities throughout the state.

Idaho

Idaho uses salt on its roads for deicing, but does not produce any salt in the state. In 2014, Idaho used 104,000 tons of solid salt at \$58/ton, 4,409,000 gallons of salt brine at \$.07-\$.11/gallon, and 7,798 tons of MgCl₂ at \$152/ton (1,450,000 gallons at \$0.82/gallon)(Clear Roads 2015).

Nebraska

Nebraska uses both salt and sand for road deicing. There are no salt producers in Nebraska. The only area that is a potential customer for PVU salt is the western part of the state, due to the proximity of large amounts of salt available from neighboring Kansas.

Kansas

Kansas is the largest salt producing state in the United States. Kansas is therefore not a likely market for PVU salt. Kansas salt has a large presence in Eastern Colorado.

New Mexico

There are significant salt producers in the southeast part of the state. In 2012, the State contracted for 15,960 tons of salt to be delivered to 86 sites.

In summary, Colorado and possibly parts of Utah and Wyoming remain the most likely end users for PVU salt. The salt would most likely be marketed not directly to the state DOTs, but to one or more of the companies or suppliers listed above. Magnesium chloride is probably the most valuable product; it is not known at this time, however, how much of a suitable product the PVU ponds could produce.

9.0 POTENTIAL DIRECT BUYERS

The salt producers map shown in Figure 2 indicates the locations of production sites. It was noted in Section 6 that there are large salt producers in Utah, Kansas and New Mexico. These producers typically have satellite distribution facilities strategically located near the places of use of their customers. In addition, local distribution companies buy salt from the major producers. If PVU salt would provide a lower delivered cost to certain deicing locations, sales could be made to these companies. If they can expand market share by utilizing PVU salt, they would likely look at that opportunity.

Amec Foster Wheeler has contacted several direct buyers or producers that have indicated interest in obtaining further information about the PVU salt if it is produced. These buyers are shown in Table 8.

Table 8.
Direct Buyers and Producers Contacted by Amec Foster Wheeler

Company Name	Person Contacted	Phone	Email
A1 Salt	Mark C. Chick	314-428-4804	mark@markchick.com
Envirotech	Jonathan Nelson	720-641-8415	jnelson@envirotechservices.com
Morton	www.emaks.com	312-807-2000	NA
Nutrecycle LLC	Ken McKay	563-370-2970	KEN@nutrecycle.com
Custom Pool LLC	Jack Anderson	618-538-9985	Jack@customizedpools.com

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10.0 TRANSPORT OF SALT PRODUCTS

Due to salt's relatively low production cost, transportation and handling costs tend to be a significant component of the total delivered cost making logistics management and customer service key competitive factors in the industry. The high relative cost associated with transportation tends to favor the supply of salt by producers located nearest to the customers.

This section addresses those costs, and draws some conclusions about the potential for overcoming them based on the ability to provide the product at essentially no production cost to the acquiring entity.

10.1 Harvesting and Loading Considerations for Solid Salt

Compass Minerals (2014) notes that prices for salt used in highway deicing and consumer and industrial products in the U.S. have increased at an historical average of approximately 3% per year, although there have been recent fluctuations which have been above and below this average. As the crystallizer ponds are expected to be managed in parallel, there will always be one of the four ponds that has a sufficient depth of deposited salt to be readily harvested during the winter months of each year. Transportation of the salt from the evaporation pond site to any point of distribution or storage will involve the use of trucks. Even though the Landfill site is adjacent to the Broad Canyon Landfill, the seasonality of harvest makes a conveyor belt system less cost-effective than trucking.

A total of about 137,000 tons of solid salt will be produced each year. When a crystallizer is ready for harvest, the salt crop will be between 11 and 12 inches thick. In its undisturbed state, the salt bulk density is about 90 lb/ft³. Once disturbed, the bulk density is reduced to about 70 lb/ft³. The disturbed bulk density was used when soliciting quotes from trucking companies for the cost of moving the salt.

Bids for road salt are made on an "as delivered" basis. The information obtainable for costs therefore includes the delivery charges. From a single supplier to a single client the prices vary based on point of delivery. In order to determine in generalities the cost of loading and shipping the salt, some assumptions were made.

Without a special permit, the maximum load for trucks operating on paved roads in Montrose County is 85,000 lbs. Use of a truck and pup (a standard dump truck pulling a dump trailer) gives the best load hauling potential, with the lightest truck weight. A truck and pup can carry about 25 tons. Given the proposed salt production rate, approximately 5,480 truck loads per year would be required. With a special permit, the maximum gross weight of a load could be increased to about 110,000 lbs, allowing for a net load of about 35 tons.. This would reduce the number of truck loads required to approximately 3,914 trucks per year.

For local hauls, the assumption is the cost for such hauling would be approximately \$0.14 per ton-mile (USDA 2014). Table 9 shows the cost per ton to transport the salt from each of the proposed pond sites (Amec Foster Wheeler 2016) to the Broad Canyon Landfill or to Reams 80 Ponds. It also shows the total cost to dispose of 137,000 tons of salt per year at the Broad Canyon Landfill or to Reams 80 Ponds, including the transport cost and the receiving cost of \$10 per ton

(pers. comm. J. E. Stover of Broad Canyon Landfill to Carla Scheidlinger, March 24, 2016; pers. comm. Reams July 6, 2016). Other transport costs shown in Table 9 include for delivery to a rail siding at Grand Junction, CO using the interstate highway system through Moab, UT, which is a distance of approximately 170 miles; and to Glenwood Springs, CO along the same route, a distance of about 256 miles.

Trucking may not be the preferable method of delivery once the material has left the local region. Salt can shipped over a greater distance by train, or barges on the major river systems. Barges can be eliminated for the purpose of this discussion. There is a cost to transferring salt from a truck to a train, however. Salt must be first stockpiled near a train siding, then loaded into cars. For the purposes of presenting conceptual costs, this report assumes that these costs would be the same on a per ton basis as the cost assumed for loading to the trucks.

Finally, the cost to harvest the salt, transport it by truck to Grand Junction, load it onto a rail car, and ship it to Denver (a rail distance of 273 miles) is also shown in Table 9.

Table 9.
Transport and Disposal Costs for Salt from Three Locations

	Paradox NW	BLM	Landfill
Transport Cost (per ton) to Broad Canyon Landfill or Reams 80 Ponds	\$5.04	\$3.50	\$0.28
Annual Cost to Dispose at Broad Canyon Landfill or Reams 80 Ponds	\$2,060,480	\$1,849,500	\$1,408,360
Transport Cost (per ton) to Grand Junction, CO	\$24.80	\$25.92	\$29.00
Annual Transport Cost to Grand Junction	\$3,397,600	\$3,551,040	\$3,973,000
Transport Cost (per ton) to Glenwood Springs, CO	\$35.84	\$36.96	\$40.04
Annual Transport Cost to Glenwood Springs, CO	\$ 4,910,080	\$5,063,520	\$5,485,480
Transport Cost (per ton) to Denver, CO	\$34	\$35	\$38
Annual Transport Cost to Denver, CO	\$4,656,630	\$4,810,070	\$5,232,030

10.2 Harvesting and Loading Considerations for Bittern (MgCl₂ Liquid)

The bittern is produced from the bittern concentrator by pumping the concentrated liquid from the sump that is designed into the bottom of the pond, where it has settled. The fluid is then shipped by road, most likely to a facility such as Envirotech that would use it as a raw ingredient for their proprietary de-icing products.

The trucking costs are assumed to be the same as for solid salts, by the ton. The point of delivery, however, would most likely be at Glenwood Springs, CO. Table 10 shows the cost per ton, and per gallon, for delivery from each of the potential pond sites, shipped over the same route through Moab, UT as was assumed for the solid salt.

Table 10.
Transport Costs for Bittern (MgCl₂ Liquid)

Location	Miles to Glenwood Springs, CO	Cost/ton (\$)	Cost/gal (\$)	Annual Transport Cost
Landfill	286	\$40.04	\$0.22	\$138,378
BLM	264	\$36.96	\$0.20	\$127,734
Paradox NW	256	\$35.84	\$0.19	\$123,863

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11.0 PRICE OF SALT PRODUCTS

11.1 Solid Salt for Road Deicing

State and local governments spend over \$2.3 billion to control snow and ice annually. The market minimum volume is relatively stable during any given year, as salt contracts often involve an 80% delivery acceptance rate, guaranteeing demand from state and local agencies (Balakrishnan 2015). Spot prices for road de-icing salt are extremely variable from year to year, however, as supply and demand are difficult to predict. From the demand side, the timing, intensity, and distribution of snowstorm events plays heavily into the need for repeated application of salt to roads. Although salt producers can store some amount of salt at their own facilities, they typically produce only what they expect to be able to sell. When unexpectedly severe weather is widespread, salt prices may increase dramatically in response to underproduction from mines and evaporation facilities. As the price of salt is usually presented “as delivered”, the cost of fuel can also drive up the delivered price of salt, although the price to the producer would presumably remain stable, with the transportation costs driving up the delivered price.

In 2015, for example, Michigan’s MDOT (MDOT 2015) reported that the winter season average cost of road salt for the state and local road agencies was \$65.81 per ton delivered, an increase of about 46 percent over the 2013-2014 average of \$44.99 per ton. This was the result of legitimate market conditions caused by that winter’s harsh weather. Road salt suppliers and government agencies depleted existing inventories at the end of the previous winter, which was one of the harshest on record. Suppliers consequently had less road salt to supply for this season while agencies were simultaneously purchasing above-average amounts in order to restock. In addition, due to heavy market demand, fewer road-salt suppliers were willing to bid for supply contracts. New Mexico contracted for salt in August 2015 for delivery to various points in the state through August 2017 for a price per ton ranging from \$62 to \$132 delivered, underscoring the importance of the point of delivery in the determination of price (New Mexico 2015).

Given that solid salt can be delivered to Denver by truck and rail for under \$40/ton, it could be that the salt can at least be offered to suppliers for no cost and have that transaction be an economical disposal solution for Reclamation. Also given that the cost to transport it for deposit at Broad Canyon or Reams 80 Ponds is at least \$1 per ton, and possibly as much as \$6 per ton (plus the \$10/cu yd, or \$10.58/ton, disposal fee), it could even be in Reclamation’s interest to pay a small amount to a supplier to remove and transport the salt.

11.2 Liquid Bittern Salt

The liquid bittern, when evaporated to a concentration of 30% MgCl_2 , could be among the valuable products that the project could produce. As discussed in Section 5.2, the amount of concentrated MgCl_2 that the project would be able to produce is difficult to calculate from the knowledge available at this time. The model predicts approximately 643,000 gallons of this material each year, which translates to approximately 3,456 tons per year. Envirotech Services sells 250,000-300,000 tons of MgCl_2 each year, much of it in Colorado (pers. comm. with Jonathan Nelson, August 8, 2016). The PVU project could therefore supply a small portion of Envirotech’s market.

Given the price that Colorado pays for this product as shown in Table 6, the revenue to Reclamation could be up to \$466,000 per year, taking into account the cost of transport from the PVU area to Envirotech at Redmond, UT and assuming that Envirotech would pay PVU 75 percent the market price shown in Table 6.

11.3 Sale and Disposal Options

In order to remove any perception that government funding for this project was allowing for unfair competition in the market for salt products, the salt products would be made equally available to all interested suppliers for bidding. There are several scenarios in which salt could be disposed to suppliers.

A solid salt or MgCl_2 product supplier could offer to purchase raw, unprocessed salt products from Reclamation for a price that would be greater than or equal to the cost of transport and storage of the salt in the Broad Canyon or Reams 80 Ponds Landfill, or to the cost of handling and long-term storage at an on-site facility. Such a scenario would allow Reclamation to realize annual project costs that would be below the projected costs of operation and maintenance by putting salt disposal costs into the income column of a balance sheet.

If there is no opportunity for the sale of salt during any given year, Reclamation could offer the salt products to interested suppliers at no cost, thus reducing the need to store or transport the salt. This option would also reduce annual operation and maintenance costs by removing transport and storage costs from the annual budget.

A final option would be to offer to pay interested suppliers to remove the salt. If what a supplier bid for this service was equal to or lower than the costs to Reclamation for transport, handling, and disposal of the salt, Reclamation would also reduce annual operation and maintenance costs.

As discussed in Section 11.1, the prices and demands for salt products are variable and unpredictable. Given the value of the MgCl_2 products, some cost recovery from that product is likely on a regular basis. For the solid salts, sale and disposal options as discussed here should be evaluated on a year-by-year basis.

12.0 STORAGE OF SOLID SALT

If sale of the solid salt is not considered a viable option, or if sales in any year are less than the total production volume of salt due to market factors beyond the control of the project, there will need to be provision for the storage, either long-term or short-term, of the salt. The salt could either be disposed of at an existing landfill site, or it could be stored at an independent facility developed in association with the evaporation ponds. If both the landfill and evaporation pond facility are operated by Reclamation, it may be possible to operate the landfill as both a landfill and temporary storage facility. This stockpile of salt could be available to meet peak salt demands.

12.1 Type of Waste

12.1.1 Evaporation Ponds

The evaporation ponds themselves will not be regulated as impoundments. The ponds will be regulated by Colorado Department of Public Health and Environment (CDPHE), who determined that the salts contained in the ponds would be considered "environmental media", not solid waste.

The Ponds will require a single liner (compacted clay or synthetic liner) with a percolation rate equal to or less than 10^{-6} cm/s, so no discharge permit would be necessary.

For pond closure, the liner would need to be removed and disposed of in a landfill; and subgrade soils would need to be demonstrated to be clean.

Finally, the ponds would need to be fenced, for security purposes.

12.1.2 Naturally Occurring Radioactive Material (NORM) in Solid Salt Products

In order to get information on radionuclide content of the material, solid salt samples were shipped from h-P where the crystals had been created to TestAmerica for analysis. The results (TestAmerica 2016; provided as Appendix G) showed that the concentrations in the salt crystals are far below average background concentrations found in Colorado for both Uranium and Thorium, and that the solid salt would be considered non-hazardous solid waste (Jim Grice, Radioactive Materials Unit, CDPHE, pers. comm. via email, August 19, 2016)). This means that the material could be disposed of in a permitted landfill. It could also potentially be stored in a dedicated storage facility developed associated with the pond site.

The salt was also tested for Radium by laboratories contracted by Reclamation. Results for Radium 226 and Radium 228 were at or below the detection limits for the analysis (United States Bureau of Reclamation 2016; also as Appendix H).

12.2 Methods and Issues for Handling

The solid halite salt would be harvested from the crystallizers using a loader as described in the Pond Operational Strategy report (Amec Foster Wheeler 2016a). It would be stockpiled close to the crystallizer pond complex and any remaining brine allowed to drain back into the crystallizers.

Any precipitation falling on the stored salt would percolate through it and create a salt brine that would be collected to be similarly delivered back to the pond complex. When the salt had been sufficiently drained, it would be loaded onto trucks either for sale or for delivery to a disposal area.

During the time it is stacked, the salt would not produce any fugitive dust. In the extensive experience of the consultant, there are no salt evaporation storage sites where fugitive dust is an issue. A salt stack quickly forms a crust that wind cannot disturb. If fugitive dust were to be a problem, spraying the surface of any new salt with a single application of water would create a crust. However, the salt comes to the stack with a moisture content. Evaporation of that moisture naturally forms a crust. Once delivered to a storage facility and compacted or distributed, the salt can be trafficked over with trucks. A soil cap would not be necessary, either during the time the stack awaits loading at the pond or when it is placed in an active on-site storage facility. When the storage facility is retired, closure requirements would include re-grading the salt to a condition of stable slopes, then capping with an engineered cover of composite liner system with a leak detection systems. Leachate would be managed thorough monitoring, collection, and pumping back into the ponds.

As part of the expert panel discussions (CRB 2015), capping and closing a full bittern pond, and creating a new bittern pond from time to time was considered. If bittern solids were removed from time to time and stored in a contained landfill, a single bittern storage pond could be operated on a more continual basis. However, if only a portion of the bittern liquid can be sold, bittern liquid will also build up over time and would eventually require long-term management.

The costs associated with the construction of a dedicated salt disposal facility at the pond site location are presented in The Design Strategy report (Amec Foster Wheeler 2016b). The economic viability of storing salts on location vs. transporting and disposing of them at a landfill would need to be evaluated when the final site selection for a pond series is made.

12.3 Disposal Sites

12.3.1 Broad Canyon Landfill

The most readily available existing option for solid salt storage is in the existing landfill at Broad Canyon, in southern Montrose County, CO. This Montrose County landfill is fully permitted, and includes a permitted expansion area. CDPHE has indicated that this disposal option has the fewest concerns of the disposal options presented (pers. comm. August 24, 2016). Broad Canyon Landfill is located approximately 25 miles from the PVU facilities at the Dolores River, and is operated by J.E. Stover & Associates. The landfill management has tentatively agreed to receive all of the salt waste produced over the proposed 50-year life of the evaporation pond project (J.E. Stover, pers. comm.). Their disposal fees are \$10/cu yd. The volume of salt to be landfilled is approximately 159,000 cu yd. per year. The cost estimate for disposing of all the salt at this facility, therefore, is approximately \$1.6 million per year in 2016 dollars. This amount includes a solid waste user fee payable to the State of Colorado. Disposal of salt into a landfill would also require paying for the cost of transportation to the landfill, as shown in Table 8. Since this landfill is in use, no road upgrades will be necessary for its use by the PVU project.

12.3.2 Reams Construction 80 Ponds Landfill

The 80 Ponds Landfill is owned by Reams Construction. This facility is located on Hwy. 141, 4.5 miles southeast of Naturita, Colorado. It is approximately 23 miles from the PVU facilities at the Dolores River. The cells that are currently being used are permitted to receive non-hazardous oil and gas production and extraction waste consisting of soil and water only. The permitted ponds have an HDPE liner.

Dianna Reams, the owner of Reams Construction, indicates that they have the room to expand, and are willing to open an additional cell to receive PVU salt (pers. comm. July 6, 2016). They have reviewed the lab results from the salt, and state that \$10/cu. yd. would be the cost for deposition at their facility. This location would present comparable costs to those at the Broad Canyon landfill. Since this landfill is in use, no road upgrades will be necessary for its use by the PVU project.

12.4 Independent Salt Storage Facility Associated with the Ponds

The nature of the solid salt produced by this project would qualify it as a non-hazardous solid waste. A storage facility for the salt would therefore be characterized as a solid waste disposal site, with the associated permitting issues. Each of the three sites under consideration for the PVU evaporation ponds has the area available for the construction of a storage facility. The issues associated with the development of such a facility are reviewed here.

12.4.1 Permitting Issues

Anyone operating a facility for solid waste disposal where processing, treatment, or final disposal of solid waste is performed must obtain a Certificate of Designation (CD).^{1,2} In effect, the CD is the permit.³ “The Solid Wastes Disposal Sites and Facilities Act (solid waste act) (C.R.S. § 30-20-100, et seq.) defines a dual-jurisdictional relationship between the department and the local governing authority for siting, permitting, and regulating a solid waste site and facility. Roles and responsibilities in the solid waste act provide for the department to regulate the design, operations, monitoring, closure and post-closure of a solid waste site and facility. Land use decisions are left to the local governing authority. The Colorado Department of Public Health and Environment (CDPHE) works with the local governing authority to evaluate the proposed solid waste site and facility. While the statute does not prohibit a local governing authority from conducting its own technical review of the engineering design and operations plan for permitting

¹ Section 9 Waste Impoundments: Permitting, Operation, Monitoring, Closure and Post-Closure Care According to the Regulations Pertaining to Solid Waste Sites and Facilities, 6, C.C. R. 1007-2, Part 1 Final Guidance, November 2014. https://www.colorado.gov/pacific/sites/default/files/HM_sw-sect-9-waste-impoundment-guide.pdf

² “Certificate of Designation” as used in the regulations means a document issued by the local governing body having jurisdiction to a person authorizing the use of land for a solid wastes disposal site and facility pursuant to the Solid Wastes Disposal Sites and Facilities Act, Colorado Revised Statutes (C.R.S.) Title 30, Article 20, Parts 1 and 10 (solid waste act). The “Certificate of Designation,” which incorporates all information as may be required by the Colorado Department of Public Health and Environment (CDPHE) and the local governing body having jurisdiction, is then issued by the local governing body having jurisdiction if the department’s Hazardous Materials and Waste Management Division has determined that the minimum standards have been met. https://www.colorado.gov/pacific/sites/default/files/HM_sw-sect-9-waste-impoundment-guide.pdf

³ Section 9 Waste Impoundments, p 8.

a solid waste site and facility, most local jurisdictions defer to the department's expertise for this review and determination."⁴

For the purposes of this project, facilities *potentially* requiring a permit include the evaporation ponds, temporary or interim salt storage locations, and ultimate landfill or disposal locations. Table 11 summarizes the permitting requirements, and indicates which agency is responsible for the permits.

Table 11.
Regulation of Salt Storage for PVU Project

Phase	Regulatory Agency	Determination and/or Permitting Requirement
Evaporation Ponds	CDPHE Solid Waste	Ponds have been determined to be "environmental media." Permit is not required.
	CDPHE Water Quality	Permit is not required as long as there is no expectation that surface water will be impacted. Liner design is prescriptive: double liner system.
	CDPHE Hazardous Waste	Not hazardous
	CDPHE Air Quality	TBD
Temporary or Interim Salt Storage Locations	CDPHE Water Quality	Permit is not required as long as there is no expectation that surface water will be impacted. Liner design is prescriptive: double liner system.
	CDPHE Hazardous Waste	Not hazardous
	CDPHE Air Quality	Could petition for a daily cover waiver. Depends on the fugitive dust permit. An emissions permit may be necessary. Based on salt composition, unlikely to be necessary.
Ultimate Landfill or Salt Disposal Location	CDPHE Solid Waste	Permit is required
	CDPHE Hazardous Waste	Not hazardous

Given the information in Table 11, permits for the operation of the ponds and of a temporary storage facility would not be required, as the material is not hazardous. The presence of Naturally Occurring Radioactive Material (NORM) in the salt has been determined to be below the threshold of concern (TestAmerica 2016). Temporary storage would be for stockpiling salt for delivery to a sale point rather than for holding it for any extended period of time; no permits would be required for this storage either. If the project elects to use an existing landfill such as Broad Canyon or Reams 80 Ponds, those locations would be permitted separately from the PVU project.

⁴ Section 9 Waste Impoundments.

Permits would only be required to develop a new landfill or storage facility for ultimate salt disposal at the evaporation ponds site. The permitting process is summarized here.

12.4.2 Application Submission Process

Prior to beginning the CD/ Engineering Design and Operations Plan (EDOP) application process, an organizational meeting should be scheduled with the interested parties and CDPHE. There is no charge from CDPHE for this meeting.

Figure 3 illustrates the sequence of events required for the CD application process for an independently developed and operated ultimate disposal facility. The CD application (which is a standard form) and EDOP should be completed in accordance with Montrose County Special Use Permitting and/or County Engineer. There may be a fee from Montrose County for reviewing the application, which will be determined at that time; in the context of the entire project, it would be nominal.

The CD application review and approval process begins with the submittal of an EDOP with a minimum of two (2) hard copies and one (1) electronic copy. Montrose County must forward one (1) hard copy and one (1) electronic copy of the CD application and EDOP to the CDPHE for review along with a request for recommendation of approval or disapproval.

Submittal of the application by Montrose County to CDPHE begins a Completeness Review which may take up to 30 days. At the end of this period they will notify Montrose County in writing of the completeness status. Incomplete applications and EDOPs will be returned. Complete CD applications and EDOP notifications will be accompanied by a “30 Hour Billable Time Notification Waiver/Cease Work Notice” to be signed and returned by the applicant to CDPHE. This finalizes this phase of the application and begins a 150-day Technical Review, also conducted by CDPHE.

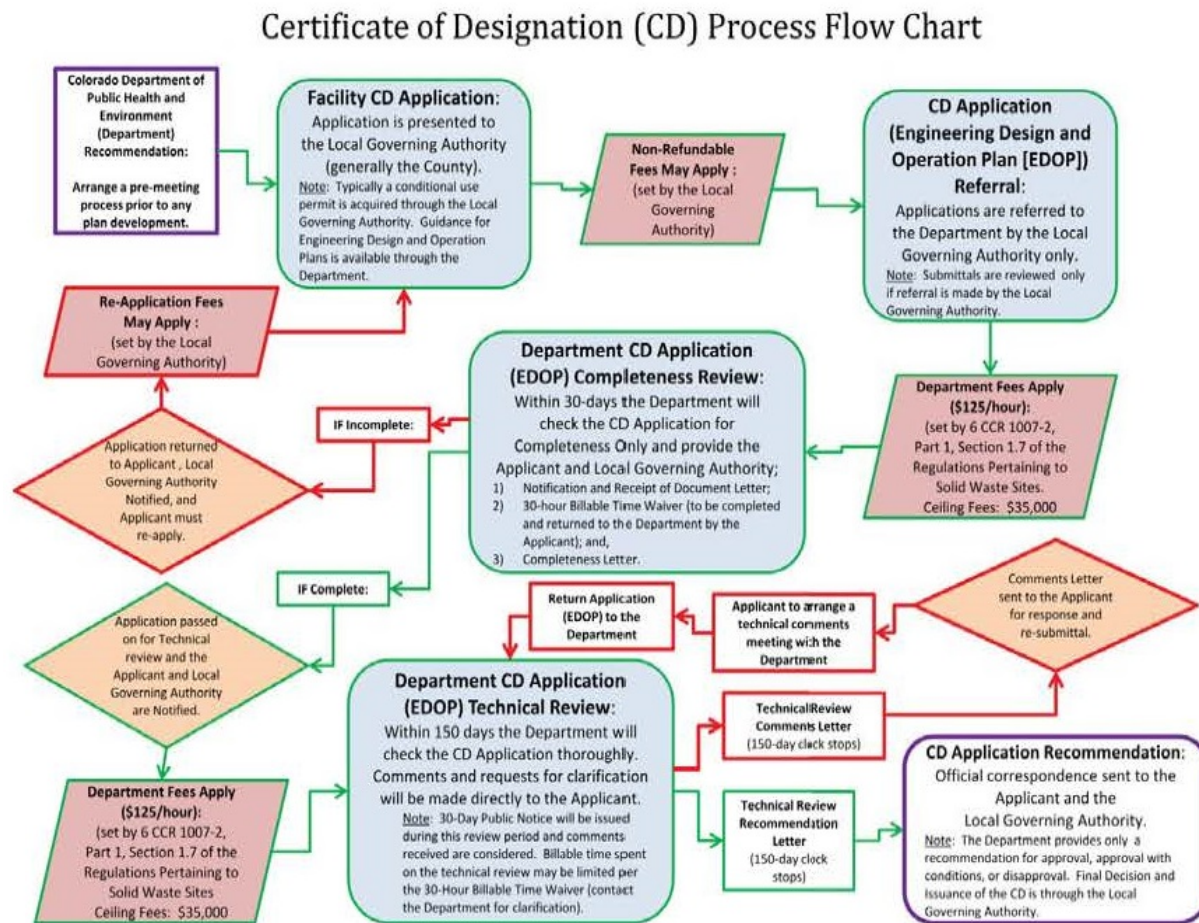
At some point toward the end of the Technical Review, Montrose County must provide at least 30 days for public review and comment of the CD application. A public hearing must be held prior to the issuing of the CD. A public notice must be published in local newspapers at least 10 days, but no more than 30 days, prior to the hearing. The public notice must also be posted in at least one conspicuous location at the offices of Montrose County and in at least one location at the proposed site. Notices must be posted at least 30 days prior to the public hearing and continue through the day of the hearing.

If CDPHE is unable to complete the technical review in this timeframe, they may refer it to a consultant, which will extend the response time. Montrose County would have the right to decline up to two recommended consultants, at which point CDPHE will complete the review as time allows.

It should be anticipated that the permitting process will take at least 6 months (pers. comm. CDPHE August 24, 2016).

Figure 4 below illustrates the process.

Figure 4. Flowchart for the Completion of a Certificate of Designation



Source: Section 9 Waste Impoundments: Permitting, Operation, Monitoring, Closure and Post-Closure Care According to the Regulations Pertaining to Solid Waste Sites and Facilities, 6, C.C. R. 1007-2, Part 1 Final Guidance, November 2014.
https://www.colorado.gov/pacific/sites/default/files/HM_sw-sect-9-waste-impoundment-guide.pdf

12.4.3 Application Content

The application consists of eight sections and supporting appendices, tables, and figures. Additional content may be submitted.

- Introduction
- Location Restrictions
- Geologic and Hydrogeologic Conditions
- Design Requirements
- Operations
- Closure Plan Requirements
- Post-Closure Plan Requirements

- Final Engineering and Hydrogeologic Approvals

12.4.4 Financial Assurance

Owners must provide proof of sufficiency of financial assurance to CDPHE for payment to a third party to close the facility and conduct post-closure care, until such time that CDPHE determines that proof is no longer necessary.⁵ Methods for establishing financial assurance are numerous and include instruments such as a surety bond, establishment of a trust, letter of credit, insurance, and others. An extensive list of options is provided in 6 CCR 1007-2 Part 1, Section 1.8.

12.4.5 Siting Approval

In addition to a CD or EDOP, an applicant for a solid waste site and facility will need to go through the local land use process to get siting approval. The local land use approval process is independent of the Hazardous Materials and Waste Management Division's review process. The local land use process may come prior to, during, or after the Hazardous Materials and Waste Management Division's review.⁶ It is necessary to determine if more information about this process exists.

12.4.6 Application Fees

All facilities and solid waste disposal sites are subject to document review fees and activity fees. The CD Application and EDOP Review fees are listed in Table 12 below. Additional fees are documented in 6 CCR 1007-2 Part 1, Section 1.7.2.

Fees due at the time of the application submittal include:

- CD/EDOP application fees
- Montrose County document review fees (may be applicable)

12.4.7 Additional Fees

Additional CDPHE fees that are likely to apply later:

- Financial Assurance review fees
- Financial Assurance 5-year review fees
- Monitoring Reports
- Closure plan modification fees
- Post-closure plan modification fees

⁵ 6 CCR 1007-2, p. 44.

⁶ Section 9 Waste Impoundments, p.9.

Table 12.
Fees Applicable to Solid Waste Disposal Permitting

Applicable Document Review and Activity Fees Schedule		
Task	Fee Ceiling	Description
Certificate of Designation Application	\$35,000	Accrues at \$125/hour.
Financial Assurance – Annual	\$3,000	Fee to review the documents. Not submitted in with initial application. Required annually, and adjusted for inflation.
Financial Assurance – 5 yr	\$5,000	Paid every 5 years when the estimate is revised.
Monitoring Reports (e.g., groundwater landfill gas, remediation)	\$3,000	Annual monitoring report, \$3,000 max
General Correspondence	\$500	Usually captured in some other category
Special Requests	\$10,000	Ad hoc
Corrective Actions	\$10,000	If required
Closure Plan modifications	\$5,000	If submitted
Post-closure plan modification fees	\$5,000	If submitted
Post-closure fees	\$1,000	Paid annually for 30 years

12.4.8 Post-Closure fees

The facilities would be subject to an unattended surface impoundment post-closure fee of \$1,000 per year, to be paid annually as regulated under Part 9 (Surface Impoundment Facilities) for a minimum of thirty (30) years..⁷ These fees are due to the Treasurer of the State of Colorado for the duration of the post-closure care period to reimburse CDPHE for costs incurred in tracking, compliance monitoring, compliance assistance, plan review, enforcement, and other recurring activities that are reasonable and necessary to ensure compliance with these regulations.⁸

12.5 Storage of Bittern Salts

The storage of bittern salts (mixed salts resulting from the concentration of bittern liquid) would be done only if no market was deemed feasible. Bittern solids, as discussed in Section 5.2, would be stored either in an existing landfill or in a separately permitted facility, as these mixed salts would have no commercial value. The mass of the bittern salts, which are solid salts that precipitate out of the bittern as it is concentrating to 30% MgCl, is predicted to be approximately 8,200 tons per year. This is just the mass of the solid material, however; with entrained fluids, if such fluids are not extracted for sale as bitterns, the annual mass would be 11,600 tons (including MgCl₂ and other bittern solids). The cost of transport and disposal of such salts can be found in Table 9.

⁷ 6 CCR 1007-2 Part 1, Section 3.6.3, p. 88.

⁸ 6 CCR 1007-2, p. 39.

12.5.1 Construction Cost Estimates

Construction costs associated with the development of a dedicated storage facility for salt products is considered in the Design Strategy Report (Amec Foster Wheeler 2016b).

12.5.2 Management of Disposal Facility

A dedicated storage facility would be managed by a third party, such as a landfill operator who would be retained by the project for this purpose. Costs associated with such management are beyond the scope of this report.

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13.0 RECOMMENDATIONS

Based on the information presented herein, the findings and present recommendations for the disposal of the PVU salt are summarized. It is important to recognize that the exact quantity and quality of solid salt and bittern products resulting from operation of the evaporation ponds cannot be known exactly without the construction and operation of a series of pilot ponds. In addition, operational strategies can differ depending on the quality and quantity of any specific salt product that is preferred. The calculations summarized in this report represent the best effort of the modelers and the authors to present a likely scenario for pond operation and for salt production.

13.1 Salt products anticipated

13.1.1 Finding

The only practical marketable solid salt product that our studies indicate could be produced by the proposed PVU evaporation ponds is road de-icing salt. This is because of the high costs for producing and handling food grade salt, processed salt, or chlor-alkali salt. There is also the potential for the production of bittern $MgCl_2$ as a liquid product. The quantity of marketable bittern would be rather low if the solid salt road deicing quality specification is met. If the goal is to produce high quality road salt, the brine is moved earlier into the bittern pond. In that case, more salts are left in the bittern that will then precipitate in the bittern pond and reduce its value.

13.1.2 Recommendation

Amec Foster Wheeler recommends that the evaporation ponds be sized, designed, and operated for the production of solid salt of a suitable quality for de-icing use, and of bittern $MgCl_2$ in a concentration suitable for road deicing use. The design and operation reports follow this recommendation.

13.2 Marketability

13.2.1 Finding

The market for road deicing salt would need to be relatively local, as the cost of transportation is the largest factor in determining a price. The states most likely to utilize road salt are Colorado, Wyoming, and parts of Utah, as these states and regions use the product, are relatively close to the Paradox Valley, and do not have major supplies of salt produced closer in distance than the PVU. DOTs purchase salt from suppliers that may or may not be the entities that produce the salt. Multiple contracts are awarded each year for salt supply, and bidding is highly competitive.

Although suppliers will be eager to protect their own markets, there may be markets that can be exploited by suppliers using PVU salt, especially during years of unusually high or unpredictable demand, since PVU salt will be produced continuously and not in response to market forces. Suppliers that we have contacted for both solid salt and liquid bittern products have indicated interest, as long as the product produced meets their quality specification.

13.2.2 Recommendation

Reclamation should develop relationships with several road salt suppliers, including those such as Cargill, Morton, and Compass that produce salt themselves. Marketing to the producers of brand-name de-icing products such as Envirotech could be done as well. Marketing directly to state DOTs is not recommended. If the solid salt produced at the PVU can be transported at a competitive cost, it could be an attractive commodity. It is not recommended that Reclamation charge for the salt, at least initially, but rather make it available to suppliers who can bid for removing it at no cost. If markets in the future indicate that the salt could be more valuable than anticipated at this time, Reclamation could attempt to partially recoup costs of production by marketing the salt to the suppliers at a competitive cost. The same strategy should pertain for bittern fluids. If the produced fluids are of sufficient quality and quantity to attract the interest of supplier and of the manufacturers of proprietary mixtures, sales could be reasonably anticipated.

13.3 Storage

13.3.1 Findings

As the PVU project will produce salt at a continuous rate, and without regard to market forces or prices, it is highly likely that in some years, there will be a need to remove the salt from the crystallizer ponds to a storage facility for disposal. That facility could either be an existing site, such as the Broad Canyon or Reams 80 Ponds Landfill, or a newly developed solid waste facility developed by Reclamation specifically for this project.

The calculated cost for transportation and payment of fees to the Broad Canyon Landfill or to the Reams 80 Ponds facility is shown in Table 9. From all sites except for Landfill, the annual projected cost is over \$2M per year. Therefore, development and operation of an independent storage facility is preferred. The permitting process for such a facility is neither extremely difficult, time-consuming, nor relatively expensive. The costs of the construction of a near-site storage facility are presented in the Design Strategy report (Amec Foster Wheeler 2016b). Operational costs have not been developed for such a facility, but the operation should be done by a third party with the appropriate skills and licenses (if applicable).

Regardless of the ability to sell the marketable salt products, there will be a need to dispose of some bittern solids that do not have market value.

13.3.2 Recommendations

Unless the pond complex is sited quite close to the existing Broad Canyon Landfill, it is recommended that the PVU pursue the development of an independent storage facility adjacent to the ponds, and operated for the exclusive use of the brine evaporation project. Costs are being developed for the construction and operation of such a facility. Costs are unlikely to exceed the \$100M+ cost of transporting the solid salt over a 50 year period to the Broad Canyon or Reams 80 Ponds Landfill.

14.0 REFERENCES

- Amec Foster Wheeler. 2016a. Operational Strategies Report. Pond Optimization Study 2. Paradox Valley Unit. Report submitted to United States Bureau of Reclamation. September 2016.
- Amec Foster Wheeler. 2016b. Pond Design Strategy Report. Pond Optimization Study 2. Paradox Valley Unit. Report submitted to United States Bureau of Reclamation. September 2016.
- ASTM D-632. Standard Specification for Sodium Chloride. Copyright © ASTM International, 100 Barr Harbor Drive, PO Box C700, West Conshohocken, PA 19428-2959. United States. www.astm.org
- Balakrishnan, A. 2015. "Road salt: Winter's \$2.3 billion game changer," Cary Institute of Ecosystem Studies, 20-Feb-2015. [Online]. Available at: <http://www.caryinstitute.org/newsroom/road-saltwinters-23-billion-game-changer>.
- CDOT. 2014. CDOT's Winter Maintenance Strategy. PowerPoint Presentation prepared by Colorado Department of Transportation. January 2014.
- Clear Roads. 2015. Clear Roads 2015 Technical Advisory Committee Spring Meeting: Minutes. March 17-19, 2015. Coeur d'Alene, ID
- Consultant Review Board (CRB). 2015. Report from the Consultant Review Board on Paradox Valley Unit—Colorado Salinity. March 17-19, 2015. Grand Junction, Colorado. Report Submitted to Bureau of Reclamation. July 2015.
- Deseret News. 2014. <http://www.deseretnews.com/article/865616406/UDOT-uses-salt-and-brine-solution-to-clear-roads-more-efficiently.html?pg=all>
- Michigan Department of Transportation (MDOT). 2015. Road Salt 2014-2015 Winter Season Pricing Report. State of Michigan Department of Attorney General.
- NCHRP 25-25(04). 2005. Final Report Environmental Stewardship Practices, Procedures, and Policies for Highway Construction and Maintenance v1.0. Updated November 2005. Chapter 8.
- New Mexico, State of, General Services Department. 2015. Price Agreement Number 60-805-15-13305.
- RTI. 2014. Measuring North Carolina Railroad Company's Impact on North Carolina. A report prepared for the North Carolina Railroad Company. September 25, 2014.
- Salt Institute. 2014. Alexandria, VA. Map and Information on website at www.saltinstitute.org
- Sedivy. 2008. Economy of Salt in Chloralkali Manufacture. National Salt Conference 2008, Gandhidham

TestAmerica. 2016. Analytical Report. TestAmerica Job ID: 160-18103-1. Client Project/Site: PVU
- Radionuclide Testing. Performed for Amec Foster Wheeler. July 31, 2016.

United States Bureau of Reclamation. 2016. Paradox Valley Unit Brine Solids Testing for Landfill
Disposal. Report dated November 22, 2016.

USDA United States Department of Agriculture Cooperative Extension. Feb 2014. Cost Factors
in Harvesting and Transporting Woody Biomass.
<http://articles.extension.org/pages/70339/cost-factors-in-harvesting-and-transporting-woody-biomass>

United States Geological Survey (USGS). 2016. Mineral Commodity Summary for Salt. Prepared
by: Wallace P. Bolen [(703) 648-7727, wbolen@usgs.gov]

Utah Department of Transportation Project. 2014. Deicer Usage on Concrete and Asphalt
Pavements in Utah. Report UT-14.02. Prepared for Utah Department of Transportation.
Prepared by Brigham Young University, Department of Civil and Environmental
Engineering.

APPENDIX A

SALT COMPOSITION TABLES

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Paradox Valley Brine Laboratory Data

NOTE: Data in **black** are laboratory results. Data in **green** are calculated from the laboratory results.

Table A1. Analysis of brine after sequential crystal deposition at summer temperature conditions.

Summer Brine Analysis (120°F)											
Spl. No.	Identification	Ca ppm	Ca X10	Mg ppm	SO ₄ ppm	K ⁺⁺ ppm	Na ⁺ ppm	SG	pH	% Evap K	% Evap SO ₄
0930316	Initial Brine	1,780	17,800	1,652	6,378	4,846	95,340	1.1725	7.20		
0400416	Brine At Initial NaCl Cryst	1,520	15,200	1,993	6,419	5,523	---	1.1986	7.22	0.12	0.01
0950316	Brine After 1st Crystals	1,160	11,600	2,855	7,119	7,573	119,020	1.2105	7.21	0.36	0.10
1060316	Brine After 2nd Crystals	860	8,600	3,852	7,983	10,388	---	1.2131	7.31	0.53	0.20
1210316	Brine After 3rd Crystals	720	7,200	5,710	10,370	14,188	---	1.2230	7.31	0.66	0.38
0060416	Brine After 4th Crystals	480	4,800	16,040	26,336	40,810	---	1.2436	7.20	0.88	0.76
0410416	Final Brine	280	2,800	35,310	52,096	55,850	---	1.2745	6.72	0.91	0.88

Table A2. Evaluation of crystals produced under summer temperature conditions.

Summer Salt Analysis (120°F)							
Spl. No.	Identification	Water Insoluble %	Ca %	Mg %	SO ₄ %	Calc Na %	Calc NaCl %
0940316	1st Crystals	0.004	0.648	0.049	1.610	38.35	97.59
1050316	2nd Crystals	0.001	0.210	0.033	0.486	38.97	99.16
1200316	3rd Crystals	0.001	0.158	0.074	0.481	38.96	99.15
0050416	4th Crystals	< 0.001	0.168	0.180	0.701	38.77	98.65
		0.002	0.296	0.084	0.820		

Table A3. Composition of crystals produced under summer temperature conditions.

	1st Crystals %	2nd Crystals %	3rd Crystals %	4th Crystals %	
CaSO₄	2.20	0.71	0.54	0.57	
residual SO ₄	0.06	-0.02	0.10	0.30	
MgSO₄	0.07	0.00	0.13	0.37	
residual Mg	0.03		0.05	0.10	
MgCl₂	0.14	0.13	0.19	0.41	
Total	2.41	0.84	0.85	1.35	Avg NaCl
NaCl	97.59	99.16	99.15	98.65	98.63
Na	38.35	38.97	38.96	38.77	

Tables A4 and A5. Specifications for salt used for deicing compared to laboratory results.

Deicing chemical specs vs results		
	Spec	Lab Results
NaCl _{db} (min)	97.9	98.6
Ca+Mg (max)	0.7	0.4
SO ₄ (max)	0.5	0.8
Insolubles (max)	0.05	0.002
Moisture (max)	2.0	?

Deicing Salt Size Specs	
USS Mesh	% Passing
3/8	90-100
4	20-90
8	10-60
30	0-15

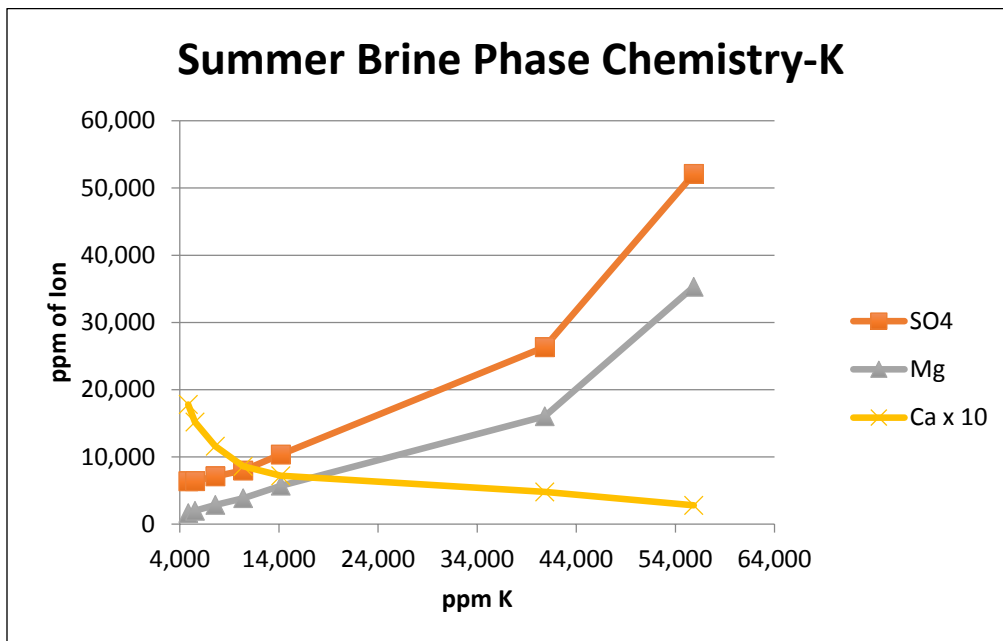


Figure A1. Phase chemistry of PVU brine based on analysis of K during the summer evaporation sequence.

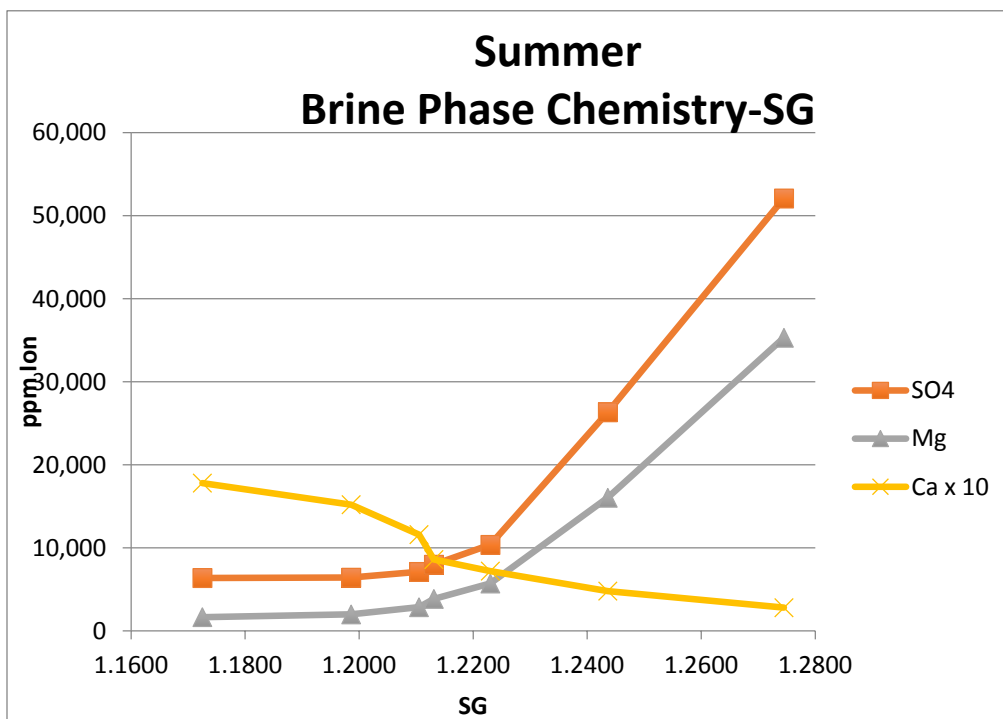


Figure A2. Phase chemistry of PVU brine based on analysis of SG during the summer evaporation sequence.

Table A6. Analysis of brine after sequential crystal deposition at winter temperature conditions.

Winter Brine Analysis (12°F)									
Spl. No.	Identification	Ca	Ca	Mg	SO ₄	K ⁺	SG	pH	% Evap
		ppm	X10	ppm	ppm	ppm			K
	Initial Brine	1,780	17,800	1,652	6,378	4,846	1.1725	7.20	
0040516	Brine After 1st Crystals	1,120	11200	2,673	6,666	7,333	1.2105	7.16	0.34
0350516	Brine After 2nd Crystals	840	8400	4,447	9,176	11,898	1.2142	7.26	0.59
0120616	Brine After 3rd Crystals	520	5200	8,967	15,514	23,960	1.2255	7.35	0.80
0220616	Brine After 4th Crystals	120	1200	21,311	31,356	53,125	1.2545	7.09	0.91

Table A7. Evaluation of crystals produced under winter temperature conditions.

Winter Salt Analysis (12°F)						
Spl. No.	Identification	Water	Ca	Mg	SO ₄	Calc
		Insoluble				Na
		%	%	%	%	%
0030516	1st Crystals	0.022	0.720	0.034	1.778	38.27
0340516	2nd Crystals	0.006	0.320	0.015	0.691	38.85
0110616	3rd Crystals	< 0.001	0.184	0.088	0.568	38.91
0210616	4th Crystals	< 0.001	0.188	0.194	1.144	38.68
		0.014	0.353	0.083	1.045	

Table A8. Composition of crystals produced under winter temperature conditions.

	1st Crystals	2nd Crystals	3rd Crystals	4th Crystals	
	%	%	%	%	
CaSO₄	2.45	1.09	0.63	0.64	
residual SO ₄	0.05	0.00	0.13	0.69	
MgSO₄	0.06	0.00	0.16	0.87	
residual Mg	0.02	0.02	0.06	0.02	
MgCl₂	0.08	0.06	0.22	0.07	
Total	2.62	1.15	1.00	1.58	Avg NaCl
NaCl	97.38	98.85	99.00	98.42	98.41
Na	38.27	38.85	38.91	38.68	

Table A9. Specifications for salt used for deicing compared to laboratory results.

Deicing chemical specs vs results		
	Spec	Lab Results
NaCl _{db} (min)	97.9	98.4
Ca+Mg (max)	0.7	0.4
SO ₄ (max)	0.5	1.0
Insolubles (max)	0.05	0.014
Moisture (max)	2.0	?

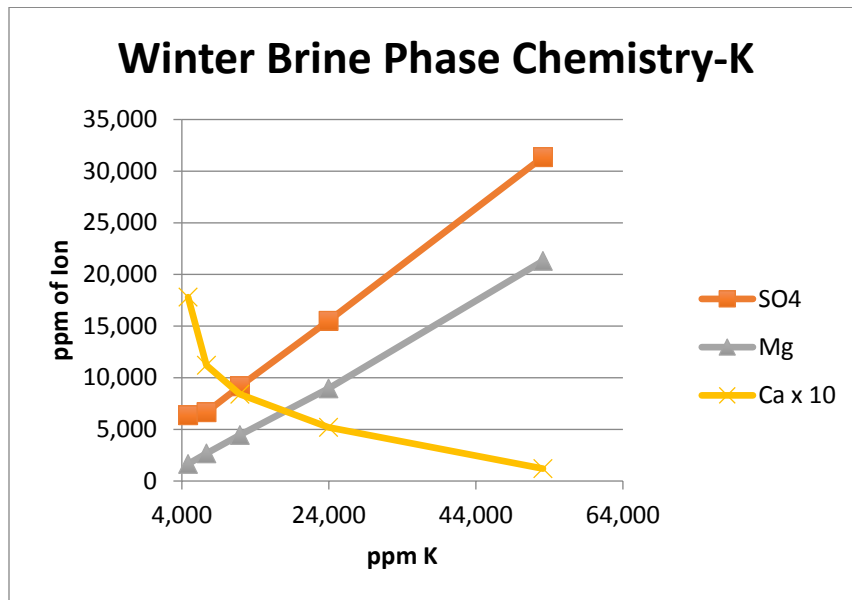


Figure A3. Phase chemistry of PVU brine based on analysis of K during the winter evaporation sequence.

APPENDIX B

SALT CRYSTAL PHOTOGRAPHS

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Figure B-1
First Crystals

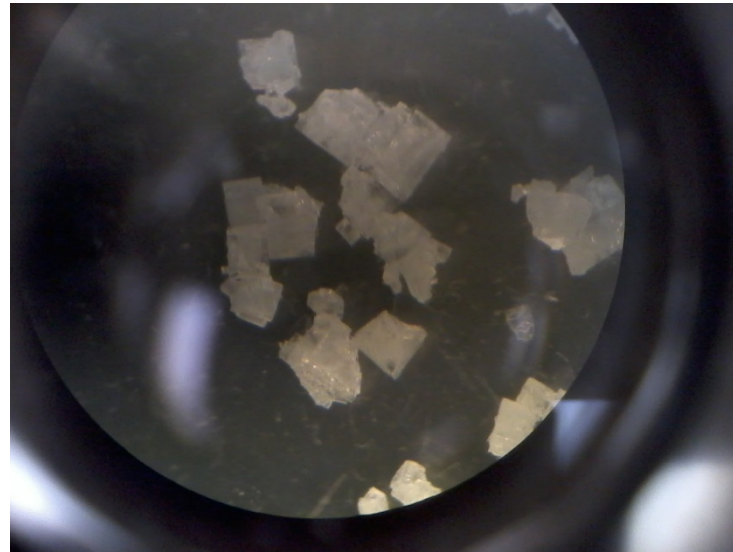


Figure B-2
Second Crystals



Figure B-3
Winter Crystals

APPENDIX C

BULK DE-ICING SPECIFICATION

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**PARADOX VALLEY
BUREAU OF RECLAMATION
DRAFT SPECIFICATION
*Bulk Deicing Salt***

DESCRIPTION:

Bulk Deicing Salt is a coarse screened, white crystalline sodium chloride, produced by solar evaporation of brine. The salt crystals are drained of excess moisture and screened to size.

Component	Typical
Sodium Chloride (dry basis) ¹	97.9%
Calcium & Magnesium (as Ca)	0.7%
Sulfate (as SO ₄)	0.5%
Water Insolubles	.05%
Surface Moisture	0.2.0%
Yellow Prussiate of Soda ²	As needed

EXPECTED CHEMICAL ANALYSIS:

¹By difference of impurities

²Sodium ferrocyanide decahydrate

COMPLIANCE:

Bulk Deicing Salt is not approved for human or animal consumption. It is intended for use only as a chemical deicer on roadways and thoroughfares. This salt complies fully with ASTM specifications.

EXPECTED SIEVE ANALYSIS:

USS Mesh	Opening Inches	Typical %	Specification
3/8"	0.375	93	90-100
4	0.187	67	20-90
8	0.0937	30	10-60
30	0.0232	0.5	0-15

ADDITIVES:

Bulk Deicing Salt may contain yellow prussiate of soda, which is added to improve caking resistance.

BULK DENSITY:

APPLICATIONS:

Bulk Deicing Salt is intended for use as an ice and snow removal agent on highways and other roadways.

Parameter	Typical	Specification
Pounds per cubic foot	75	71-79

PACKAGING AND SHIPPING:

Bulk Deicing Salt is available only in bulk form.

METHODS OF ANALYSIS:

Methods of analysis and product performance evaluation are taken from the ASTM designations D 632 and E 534.

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APPENDIX D

USE OF SALT PRODUCTION MODEL

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Appendix D to Byproducts Report Use of the Salt Model

I. Introduction

This information is presented to assist in the use and interpretation of the salt model that was developed by John Chesnut of Amec Foster Wheeler for the PVU Evaporation Pond Optimization project. The model itself is provided as a spreadsheet in an Excel file (MinVerse Model PVU) that can be used to explore various options regarding the design and operation of the evaporation ponds. The parameters of the model are described here, with instructions on how user-controlled parameters can be varied to produce different results depending on the desired salt outcome. The discussion is aimed at the relatively sophisticated user of Excel. Minimal effort has been made to simplify the discussion; it should be used by individuals familiar with Excel functions.

A screenshot view of the first tab of the spreadsheet, "Model", is shown in Figure D1. Selected portions of that page are referred to in the discussion below.

Figure D1. Salt model running the “Cl at Pyles” scenario.

(Green Cells are user adjustable)				Yellow Cells are calculated and should not be touched										Scenario lookup	
Scenario	CL at Pyles	conversion to PPT												3	
Flow	300 GPM	>	596,884	Cubic Meter/year											2
Sp gr	1.1725 Units	>	699,846	Metric Tons	Restore default										
K	0.004846 g/L	>	0.004133049	ppT	Run selected scenario										
Mg	0.001652 g/L	>	0.001408955	ppT											
Cl	0.13970381 g/L	>	0.119150371	ppT											
Reference ET	63.0	inch per annum													
Rain	16.0	inch per annum													
Sp Gr at Sat	1.1986 Units			>	0.132839004	CL									
K at Sat	0.005523 g/L	>	0.004607876	ppT	1.114885357	K									
Sp GR at Bit	1.261 Units														
Intermediate	1168.15	mm	Concentrator	ppm											Total Evap Mass
Concentrator		Mass	Tons	Conc	Evap	Salt	Cramer Rule Solution	Hectare	Acres						
Evap Factor	0.74	K	699,846	1	0.45803	1	627,729	Metric Mass							
Evap in mm	458	Cl	2,892	0.0046	0	0	157,451	Sq Meters	15.75	38.89	72,117				
Evap in Inches	18.0326	Mg	83,387	0.1328	0	0.6067	-	Metric Ton							
			986.05				-	Entrain							
Main Stage		Mass	Tons	Conc	Evap	Salt	Cramer Rule Solution								
Evap factor	0.66	K	627,729	1	0.36458	1	78,835	Metric Mass							
Evap in mm	365	K	2,892.50	0.0367	0	0	1,164,571	Sq Meters	116.46	287.65	424,575				
		Cl	83,386.9	0.1010	0	0.6067	124,319	Metric Ton							
							31,079.86	Entrain Mass							
Bittern		Mass	Tons	Conc	Evap	Salt	Cramer Rule Solution								
Evap Factor	0.55	K	47,755	1	0.23608	1	29,698	Metric Mass							
Evap in mm	236	K	1,752.16	0.05900	0	0	59,406	Sq Meters	5.94	14.67					
		Cl	4,823.27	0.08003	0	0.6067	4,033	Metric Ton							
							1,008.20	Entrain							
		Sq At Main	1.261												
		Bittern mass	47,755.15												
		Bittern Volume	37,884.21												
		bittern Evap	0.2360803				160,471.70	Sq Meters	16.05	39.64					
		Acrefeet bittern	30.71												
Summary	Concentrator		39	Acre											
	Crystallizer		288	Acre											
	Footprint		327	Acre											
	Halite Metric Ton		124,319	Halite Metric Ton											
	US TON	1.10231	137,039	Halite Tons											
	Halite Efficiency		432	Tons/Area											
	Bittern Wet Mass		47,755.15	Metric ton											
	Area at Steady state Evap		39.64	acres											

II. Design of the model.

The concentrator and crystallizer stages are solved by a system of three simultaneous equations in the form:

$$\text{Mass} = \text{Brine Mass} - (\text{Evaporation Mass} + \text{Salt Mass})$$

The three equations solve for total mass, chloride (Cl) mass and Potassium (K) mass simultaneously. No provision is made for leakage, as it was assumed that ponds will be competently lined.

The segment solutions are provided using the Excel Formula

$$=\text{INDEX}(\text{MMULT}(\text{MINVERSE}(\text{Variable Matrix}), \text{Mass Matrix}), \text{"index number"})$$

The formula calculates the inverse matrix of a variables array (3x3) using the MINVERSE function. The inverse matrix is solved using the MMULT – matrix product function. The solution is stored in a 1x3 array. The two inputs are the Mass Matrix and the inverse of the Variable matrix. The index function (1,2,3) calls the individual solution values of the each element of the MMULT solution array.

The solution appears in the following form (Figure D2) on the spreadsheet.

Figure D2. Solution for salt produced from PVU brine

	Tons	Conc	Evap	Salt	Cramer Rule Solution	
Mass	47,755	1	0.23608	1	29,698	Metric Mass
K	1,752.16	0.05900	0	0	59,406	Sq Meters
Cl	4,823.27	0.08003	0	0.6067	4,033	Metric Ton

Mass is calculated in metric tons, and can be converted to US tons using the conversion tables provided in the Constants tab of the spreadsheet. The variable array uses % values for Concentration/Meter values (or % of a cubic meter) for evaporation, and % values for the constituent parts of the salt mass. The solution is presented in Metric tons, sq meters of surface area, and metric tons of salt formed.

Entrainment Mass is factored from a default 25% mass of the salt mass formed. The Entrainment mass factor is found on the "Constants" tab, and could be adjusted.

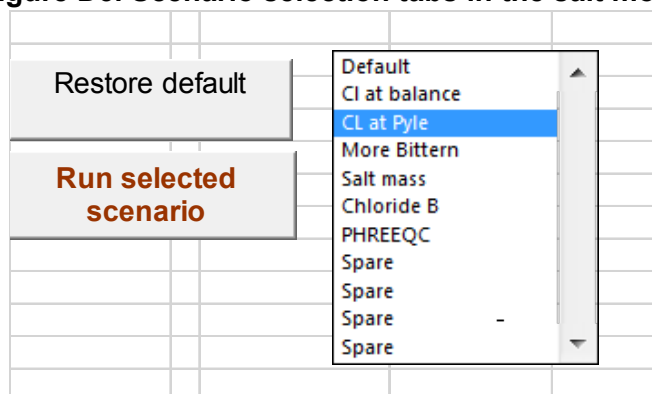
The solution is provided as input to the next matrix element, and entrainment mass is subtracted.

III. Use of the model

Only green cells in the model are user adjustable. All other cells are dependents on the green cell parameters --- DO NOT TOUCH OR MODIFY yellow cells. These are not protected in the design of the model. Entering values in yellow cells will BREAK THE MODEL, and the spreadsheet must be restored from a saved copy. For this reason, it is recommended that an unmodified version of the model be saved and that any versions that may be modified be saved with a new name.

The Cramer rule solutions are live formulas, and any change in the green cells will update all solution values. Several "canned" alternative parameters are provided in the control form list (box on the right of Figure D3 below). These alternatives must be loaded by pressing the "Run Selected scenario" button. The button overwrites any user changes to green cells. The "Restore default" simply rewrites the default scenario, and restores the model to the default solution.

Figure D3. Scenario selection tabs in the salt model



The model does not make a "sense" check on altered parameters. Therefore, entering values that are out of scale (such as bittern Specific Gravity (SG) showing as less than crystallizer SG) will cause irrational answers. Restoring the default parameters will bring the model back to "sense".

The Scenario tab stores the "canned solutions" accessed through the control form. "Spare" columns are provided for users to edit and save their own adjustments, and may be named so that they can be identified in the future.

The Chemistry tab provides the model with SG (Sp Gr) and bittern concentration through a simple linear trend calculation of the K and Sp Gr data. The tab stores data from the hoPak results (and other analysis), but is only accessed for the SG and concentration of K data.

The Constants tab is accessed for the Entrainment Fraction parameter, default value is 25% by mass. The evaporation factor for Class A Pan to open pond conversion, default value 0.73 is also stored on this page. Other values are presented for reference.

The Rain tab stores a sequence of ET and Rain data for Co Ag Met stations, and the synthetic 22 year series that was created by combining Olathe and YellowJacket station data. A button on the Rain tab calls a macro that steps through the ET and Rain values and writes the results to the "Results Tab"

The Results tab writes the acreage solutions for concentrators, crystallizers, and bittern ponds from the Macro called on the Rain tab. It writes results based on the scenario (or user adjustments) made on the Model. If unedited adjustments are left on the Model, the results of calling the Rain macro will vary.

IV. Parameters of the PVU salt pond model

Parameters used for the model developed specifically for the PVU project are described below. The parameter list as it appears in the spreadsheet model is shown as Figure D4.

Flow: Average flow is shown in gallons per minute (GPM), and is used to calculate volume and mass delivered on a 24 hours per day/7 days per week/365 days per year basis. No provision was made for downtime, but a modified flow rate would change the total volume delivered in line with expected downtime.

Specific Gravity (Sp Gr) of well brine. This parameter is used to calculate the total mass of solids from volume, and the ion concentration in parts per thousand (ppt) from concentrations reported in mg/L of K, Mg, Cl – (Potassium, Magnesium, Chloride). These concentrations are those that were reported by brine chemical analysis which were assumed to be in mg/L units. Chloride, which was not present in the 2016 hohPak analysis, is calculated separately from a forced cation-anion molar balance, and added back in.

ET and Rain. These parameters are expressed in inches per year (as per Colorado Agricultural Meteorology - Co Ag Met data). Default values represent the 1st quartile measure of a synthetic 22 data series based on Olathe and Yellow Jacket weather stations. A more thorough discussion of ET, Rain, and the synthetic model is described in a separate memo which is included as Appendix E. The PVU model has a macro that steps through the available annual data to provide a range of annual solutions.

Saturation Sp. Gr. This parameter is used to calculate ppt concentration of the tracer Potassium (K) at saturation based on its reported value in g/L. This in turn determines the default concentration factor, which is the relative volume change of the saturated brine as it evaporates. Since the concentration factor is the product of two variables with some uncertainty, the error in the factor is the product of the variable errors. The default value (1.1986) is from the hohPak summer series. Alternatively, a PHREEQC simulation reports a higher value (1.207) when halite saturation index reaches 0.

K at Saturation. This parameter is the K concentration (g/L) reported at halite saturation. The default value (0.004846) is the concentration reported by the summer hohPak series. Alternatively, a PHREEQC simulation reports a higher value (0.006013496) when halite saturation index reaches 0.

Sp Gr at Bittern. Bittern point was selected for production of maximum halite purity as determined from consultant John Pyles's professional experience. Bittern point is used to provide a K concentration based on a simple linear regression of Sp Gr to K in the hohPak data series.

Figure D4. Parameter list, with default values, in the salt model

Scenario	CL at Pyles			conversion to PPT	
Flow	300	GPM	>	596,884	Cubic Meter/year
Sp gr	1.1725	Units	>	699,846	Metric Tons
K	0.004846	g/L	>	0.004133049	ppT
Mg	0.001652	g/L	>	0.001408955	ppT
Cl	0.13970381	g/L	>	0.119150371	ppT
Reference ET	63.0	inch per annum			
Rain	16.0	inch per annum			
Sp Gr at Sat	1.1986	Units			
K at Sat	0.005523	g/L	>	0.004607876	ppT
Sp GR at Bit	1.261	Units			

Evaporation factors relative to fresh water

The model provides three evaporation factors for brine (Figure D5). Evaporation follows the formula

$$\text{Inches} = [(\text{ET} * \text{Pan-to-Pond Factor} * \text{Concentration Factor}) - \text{Rain}]$$

For this reason, the effect of rain, especially on higher gravity brines, is very important. Rainfall is highly variable annually, and this factor may require adjustment in order to manage brines effectively for the desired product.

The Pan-to-Pond factor default value is 0.73 and is taken from reference for western Colorado. (NOAA technical report TR33, Farnsworth, R.K., E.S. Thompson, and E.L. Peck (1982). "Evaporation Atlas for the Contiguous 48 United States," NOAA Technical Report NWS 33, Washington, D.C.) This value is affected by site elevation (due to the effect of partial pressure) and ambient humidity.

The default concentrator factor is the midpoint of the Well Brine (0.72) and the Saturated Brine (0.76) factors recorded in the continuing pan tests undertaken at Bedrock. It is assumed that a serpentine concentrator pathway produced by a concentrator pond constructed with a baffle will perform, on average, at the mean value.

The crystallizer evaporation value reflects the same logic: use of a midpoint performance value (0.66) of Saturated and Bittern brines.

Bittern evaporation is calculated with a 0.55 factor relative to fresh water. High magnesium bittern are hygroscopic and absorb water from the atmosphere. It is not anticipated that the pond bitterns are at magnesium saturation when released from the crystallizer, or drained from stockpiled salt.

Figure D5. Evaporation rates used at different stages of the pond sequence

Concentrator		
Evap Factor	0.74	
Evap in mm	458 mm	
Evap in Inches	18.0326 inch	
Main Stage		
Evap factor	0.66	
Evap in mm	365 mm	
Bittern		
Evap Factor	0.55	
Evap in mm	236 mm	

Concentration factor for ions

Three factors of concentration are user adjustable (Figure D6).

- 1) Chloride concentration on exit of the crystallizers.
- 2) Residual potassium
- 3) Residual chloride

The residual mass check are values that check for “sense” in the bittern point, which is set to maximize purity of the halite stage, and avoid halite contamination in the magnesium bittern. The values are based on concentration breakpoints set by John Pyles, converted to ppt values, as no laboratory produced check analysis is available in the hoh-Pak data, and no data on chloride has been developed.

Figure D6. Concentration factors in the salt model

	Main Stage	
	Tons	Conc
Mass	627,729	1
K	2,892.50	0.0367
Cl	83,386.9	0.1010
	Residual check	
	Tons	Conc
Mass	47,755	1
K	1,752.16	0.05900
Cl	4,823.27	0.08003

V. Changing parameters and changing results

As the user alters any of the parameters described, the final results will change. This can be useful if the final end products are to be modified. For example, if the production of Mg bittern is desired, changing the Sp Gr for bittern as in Figure 3 will produce different solutions for management of the crystallizers. If a colder, warmer, wetter, or drier year is predicted, modifying the climate data as in Figure D4 will produce different results for management of the brine to obtain the desired result.

APPENDIX E

ESTIMATION OF EVAPORATION AND PRECIPITATION

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Appendix E

Estimation of Evaporation and Precipitation

Design area of a solar pond series is dependent on rate of evaporation and precipitation falling on the operating ponds. Evaporation and especially precipitation are variable year-over-year. A pond system should be designed to accommodate this uncertainty and variability. Other sources of uncertain estimates include the interaction of evaporation rate and brine density, small changes in input brine density, and arbitrary bittern points.

Evaporation, precipitation and weather data has been collected at the Paradox site beginning in May 2015. A CoAgMet weather station has been in operation at Bedrock (site brk01) since late 2013. A network of CoAgMet stations with long-term weather data operates regionally, with online databank beginning in 1993. The information is available at: http://ccc.atmos.colostate.edu/cgi-bin/stationsum_form.pl

The data series can be cross-correlated to extend the expected evaporation performance of the PVU solar ponds, and estimate inter-annual variation in rates. The local PVU evaporation pan and precipitation data series are virtually equivalent to the CoAgMet Bedrock data series (Figures E1 and E2). The ET calculated using the 1982 Kimberly-Penman equation matches the PVU Class A pan series more precisely in the 2016 season than the alternative ASCE Standardized reference evapotranspiration (also reported) for unanalyzed reasons. This close agreement between these two independent data series give strong confidence that the larger CoAgMet data set can be used to describe PVU evaporation and precipitation performance.

Weather data collected at nearby network sites since 1993 can be used to estimate the climatic variance at the Paradox site. The nearby "Olathe 1" site shows strong resemblance to the 2014-16 CoAgMet Bedrock series for evaporation (Table E1). Mean annual Reference ET at Olathe 1 over the 22 years of data collection (some data missing, and values interpolated) is 61.28 inches (St Dev = 2.19 inches). Equivalent 2014-2015 values for Bedrock station are 61.18 and 60.34. Linear correlation (using the 2 available data points indicate that RFET at Bedrock = 1.044* Olathe. The Olathe site is semi-irrigated and the Bedrock station is dryland, so the overage at Bedrock in respect to Olathe can be anticipated. In summary, a synthetic Bedrock data series can be developed by taking using 104% of the Olathe measure.

Table E1. Olathe and Bedrock ET Data

	Reference ET Total Inches	
	Olathe	Bedrock
2014	60.03	61.18
2015	55.73	60.34
22 year Mean	61.28	(est) 63.7

The low standard deviation in the Olathe dataset indicates that on an inter-annual basis the variation in Reference ET is minor. ET is inversely correlated with precipitation; wet, rainy years have lower evaporation.

Precipitation data has much higher variance. Precipitation accumulation is highly idiosyncratic to sites; that is, correlation between yearly and monthly data among the nearby CoAgMet network

sites is relatively low. Variation between yearly cumulative totals across the long-term data collection sequence is also high.

The effective pond evaporation is determined by

$$[\text{ReferenceET} * \text{Pan-to-Pond factor} * \text{Brine Concentration factor}] - \text{Precipitation}$$

Consequently, high variation in precipitation (and season of the precipitation) affects the pond performance strongly. Additionally, as the brine concentration factor falls from an anticipated 0.75 to 0.55 across the pond series, the relative impact of precipitation variance increases dramatically.

Comparison of 2014-6 Bedrock precipitation data to long-term medians and same year comparisons of other CoAgMet sites shows Bedrock has higher base precipitation in the 2014-15 sequence. Empirically, in 2014-5, Bedrock cumulative precipitation was 110% of the same-year YellowJacket data.

Rescaling the long-term median at Yellow Jacket to this empirical correction yields a model Bedrock median cumulative precipitation of 13.2 inches. Inter-annual standard deviation in the YellowJacket data is 2.8 inches.

A synthetic data series based on the simple linear corrections to Olathe ET and Yellow Jacket precipitation was constructed and tested against default conditions in the design spreadsheet (Figure E5). The results show that the default design based on 2015 empirical data is highly conservative – 2015 Reference ET was slightly reduced, and precipitation was likely significantly higher than normal.

Scaled 22 year median values for ET are 63.5 inches with 12.7 inches of rain. Sizing design elements against the 22-year median values reduces crystallizer acreage from 345 to 240 acres using the spreadsheet's otherwise default parameters. Using the 1st quartile values (63.2 inches, 15.8 inches) generates a 327 acre crystallizer, and 62 acre concentrator.

Several factors buffer design requirements: 1) Wet years are typically followed by normal or dry years, allowing a pond system to catch up with evaporation. 2) A surge pond design provides extra concentrator area that can be used to bring a slowly evaporating brine to saturation. 3) The bittern point is chosen to maximize quality over quantity of the halite deposit, so extra brine can be released to the bittern pond to form a low quality halite-bittern mixed deposit.

Figure E1: 2015 Precipitation Data for PVU and Bedrock CoAgMet

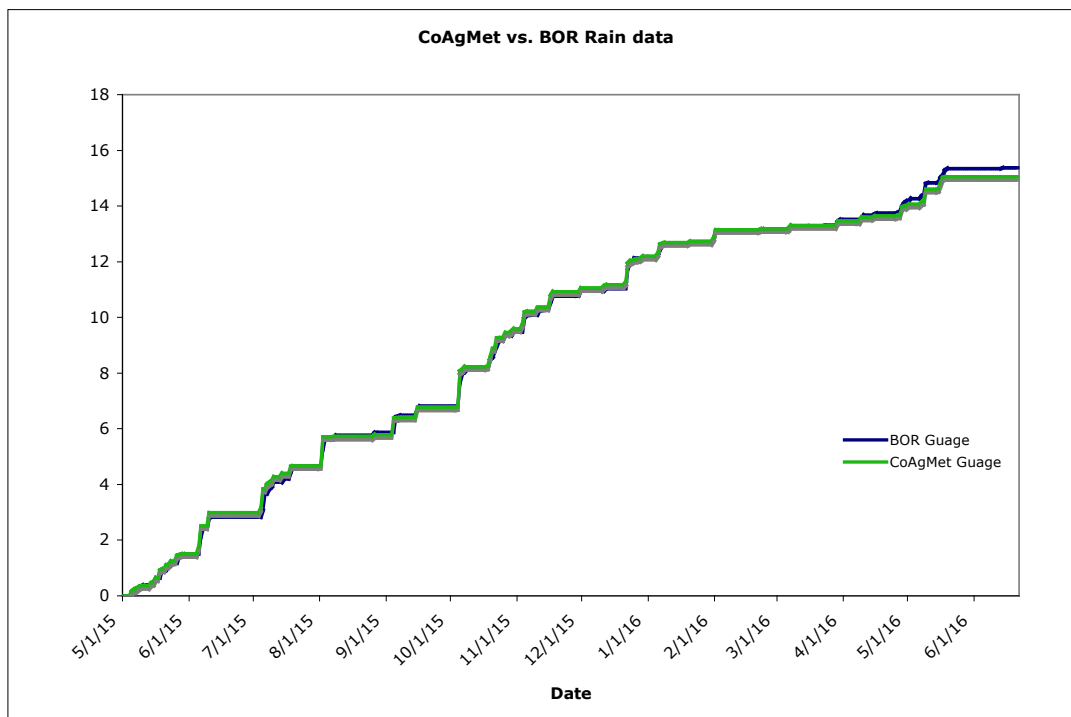


Figure E2: 2014-6 Reference ET and PVU Class A evaporation data series

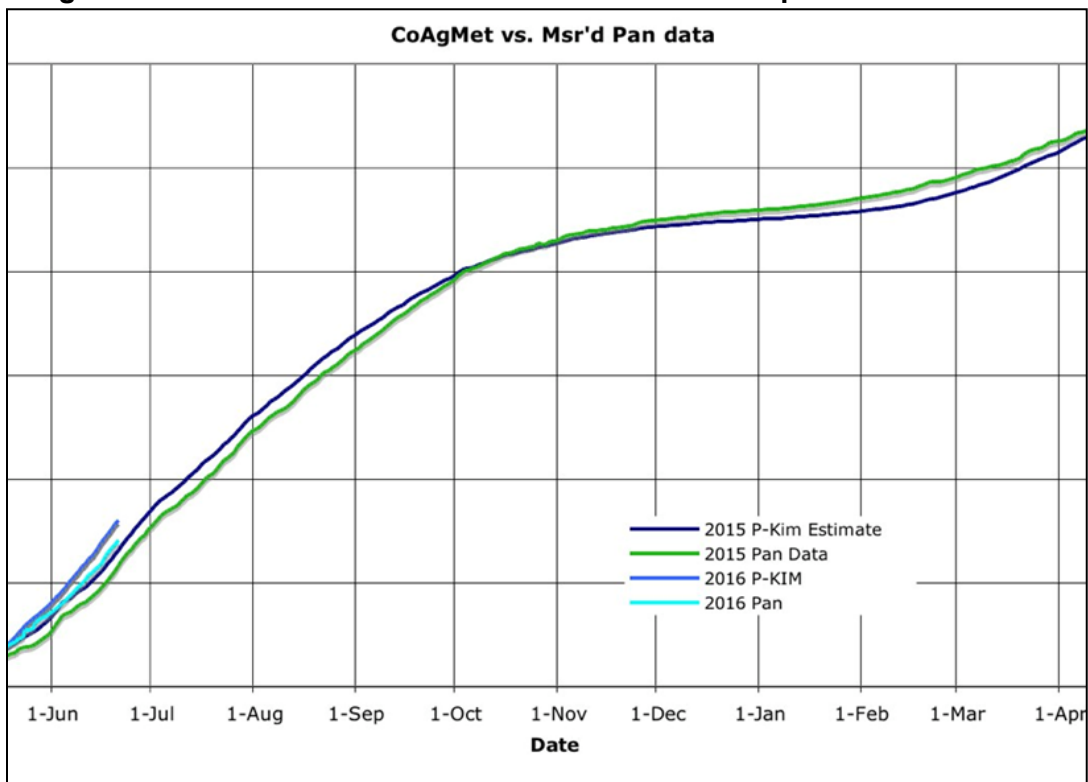


Figure E3: Cumulative precipitation Bedrock and long-term (22 year) median values

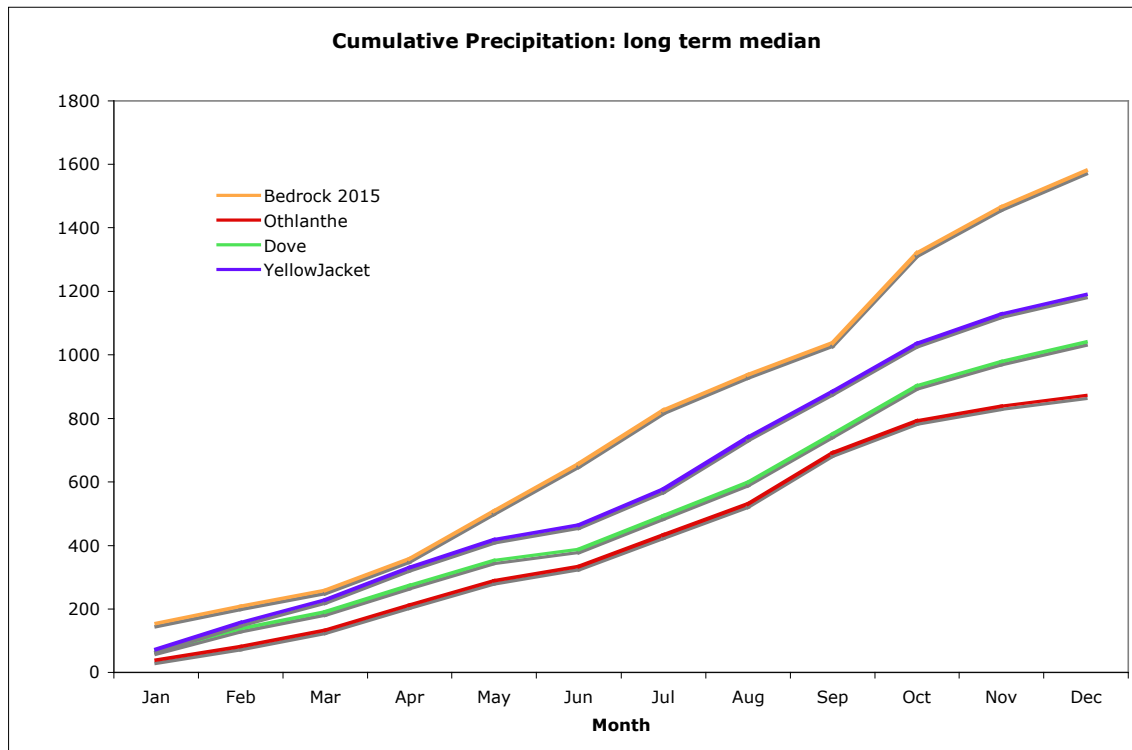


Figure E4: Model Cumulative precipitation (based on 1.10 correction of Yellow Jacket CoAgMet median).

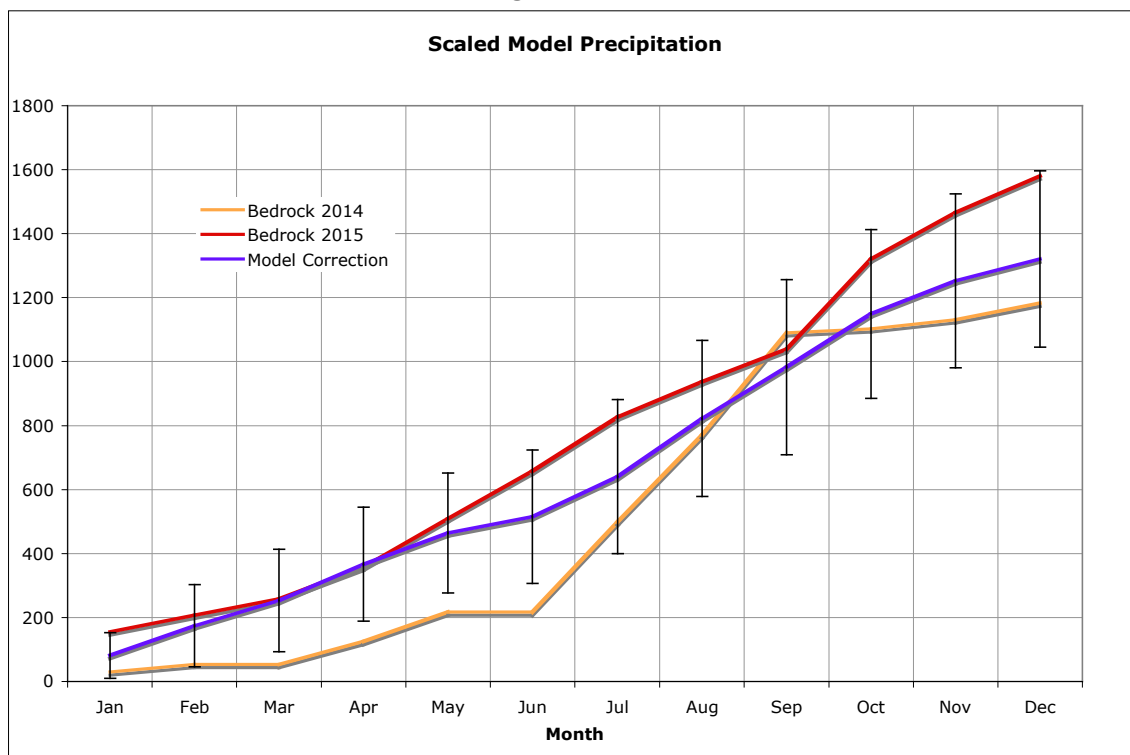
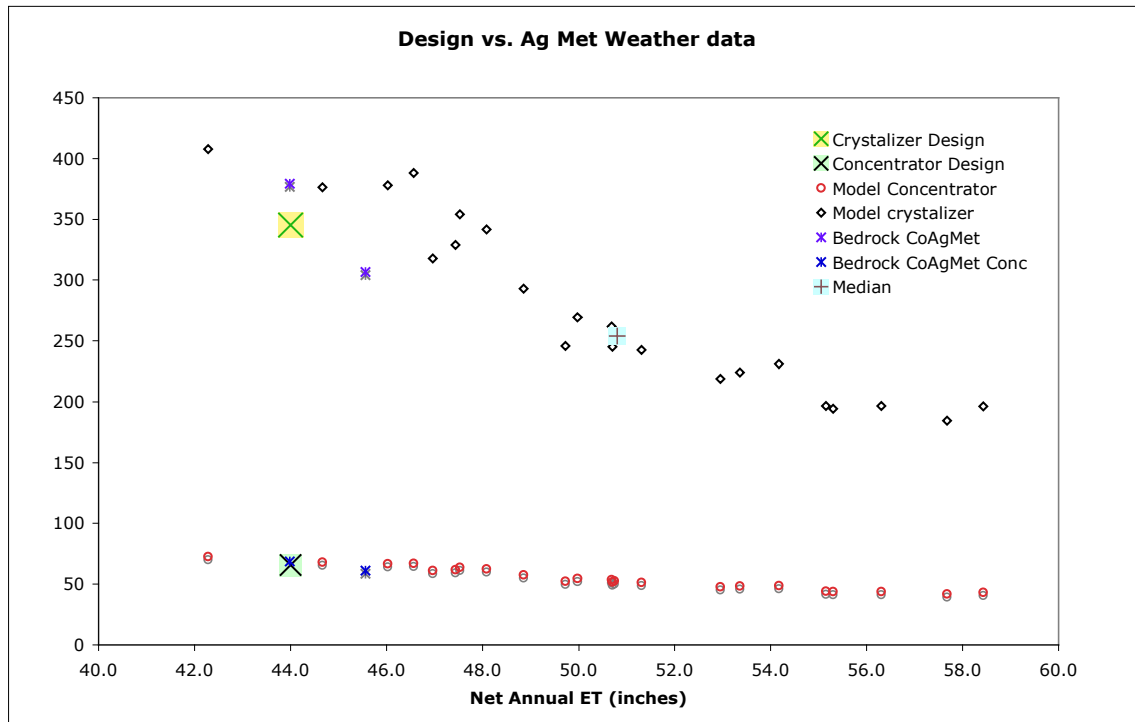


Figure E5: Design element sizing for a "model" annual ET and Precipitation. Note Net ET is defined as Reference ET – Precipitation (used only to scale axis).



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APPENDIX F

ION MASS DELIVERED TO BITTERN STAGE

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Ion mass delivered to Bittern Stage

Assumptions

Sp Gr	1.261	Check	1.00052492	29,656
volume correct	1.15417			
Metric Mass	29640			

Ion	Mole	Weight	gram Kilo	Fraction	Corrected	Total Metric Ton
Cl	6.818	35.453	241.718554	0.191687989	0.16608298	4,923
Na	2.787	22.98977	64.072489	0.050810856	0.04402372	1,305
Mg	1.617	24.305	39.301185	0.031166681	0.02700354	800
K	1.75	39.0983	68.422025	0.054260131	0.04701225	1,393
SO ₄	0.4396	96.0576	42.226921	0.033486852	0.0290138	860
Ca	0.01017	40.06	0.4074102	0.000323085	0.00027993	8
Water	55.51	18.0152	1000.02375	0.793040247	0.6871087	20,366

Hypothetical salts	Mole		Weight		gram/kg	weight percent	corrected	Metric Ton
NaCl	2.65	2.65	58.44	154.714056	0.122691559	0.10630285	3,151	
MgCl ₂	1.62	3.234	95.21	153.95457	0.12208927	0.10578101	3,135	
KCl	1.15	1.15	74.55	85.7325	0.067987708	0.05890615	1,746	
Subtotal Cl		7.0314					-	
NaSO ₄	0.14		142.04	19.828784	0.01572465	0.01362421	404	
K ₂ SO ₄	0.30	0.6	174.25	104.55	0.082910389	0.07183551	2,129	
							-	
Water	55.51		18.0152	1000.02375	0.793040247	0.6871087	20,366	

Check 1.04355842 30,931

	Bittern Mass		
	MgCl ₂	other salts	water
			(after 16x conc)
metric tons	3,135	7,430	1,273
US tons	3,456	8,190	1,403
gallons	643,254		

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APPENDIX G

RADIONUCLIDE TESTING REPORT

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TestAmerica

THE LEADER IN ENVIRONMENTAL TESTING

ANALYTICAL REPORT

TestAmerica Laboratories, Inc.

TestAmerica St. Louis
13715 Rider Trail North
Earth City, MO 63045
Tel: (314)298-8566

TestAmerica Job ID: 160-18103-1

Client Project/Site: PVU - Radionuclide Testing

For:

AMEC Foster Wheeler E & I, Inc
9210 Sky Park Court
Suite 100
San Diego, California 92123

Attn: Carla Scheidlinger

Elizabeth M. Hoerchler

Authorized for release by:
7/31/2016 6:16:21 PM

Elizabeth Hoerchler, Project Mgmt. Assistant
(314)298-8566

elizabeth.hoerchler@testamericainc.com

LINKS

Review your project
results through

TotalAccess

Have a Question?



Visit us at:

www.testamericainc.com

This report has been electronically signed and authorized by the signatory. Electronic signature is intended to be the legally binding equivalent of a traditionally handwritten signature.

Results relate only to the items tested and the sample(s) as received by the laboratory.

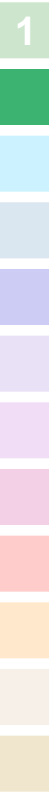


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Case Narrative

Client: AMEC Foster Wheeler E & I, Inc
Project/Site: PVU - Radionuclide Testing

TestAmerica Job ID: 160-18103-1

Job ID: 160-18103-1

Laboratory: TestAmerica St. Louis

Narrative

CASE NARRATIVE

Client: AMEC Foster Wheeler E & I, Inc

Project: PVU - Radionuclide Testing

Report Number: 160-18103-1

With the exceptions noted as flags or footnotes, standard analytical protocols were followed in the analysis of the samples and no problems were encountered or anomalies observed. In addition all laboratory quality control samples were within established control limits, with any exceptions noted below. Each sample was analyzed to achieve the lowest possible reporting limit within the constraints of the method. In some cases, due to interference or analytes present at high concentrations, samples were diluted. For diluted samples, the reporting limits are adjusted relative to the dilution required.

TestAmerica St. Louis attests to the validity of the laboratory data generated by TestAmerica facilities reported herein. All analyses performed by TestAmerica facilities were done using established laboratory SOPs that incorporate QA/QC procedures described in the application methods. TestAmerica's operations groups have reviewed the data for compliance with the laboratory QA/QC plan, and data have been found to be compliant with laboratory protocols unless otherwise noted below.

The test results in this report meet all NELAP requirements for parameters for which accreditation is required or available. Any exceptions to NELAP requirements are noted in this report. Pursuant to NELAP, this report may not be reproduced, except in full, without the written approval of the laboratory.

Calculations are performed before rounding to avoid round-off errors in calculated results.

All holding times were met and proper preservation noted for the methods performed on these samples, unless otherwise detailed in the individual sections below.

All solid sample results for Chemistry analyses are reported on an "as received" basis unless otherwise indicated by the presence of a % solids value in the method header. All soil/sediment sample results for radiochemistry analyses are based upon sample as dried and disaggregated with the exception of tritium, carbon-14, and iodine-129 by gamma spectroscopy unless requested as wet weight by the client.

This laboratory report is confidential and is intended for the sole use of TestAmerica and its client.

RECEIPT

The samples were received on 07/08/2016; the samples arrived in good condition, properly preserved. The temperature of the coolers at receipt was 21.0° C.

ISOTOPIC THORIUM (ALPHA SPECTROMETRY)

Sample PVU-SALT-20160701 (160-18103-1) was analyzed for Isotopic Thorium (Alpha Spectrometry) in accordance with DOE. The samples were prepared on 07/19/2016 and analyzed on 07/28/2016.

The following sample in batch 160-261169 consists of a salt matrix and is non homogeneous: PVU-SALT-20160701 (160-18103-1).

No additional analytical or quality issues were noted, other than those described above or in the Definitions/Glossary page.

ISOTOPIC URANIUM (ALPHA SPECTROMETRY)

Sample PVU-SALT-20160701 (160-18103-1) was analyzed for Isotopic Uranium (Alpha Spectrometry) in accordance with DOE A01R_U. The samples were prepared on 07/19/2016 and analyzed on 07/27/2016.

Case Narrative

Client: AMEC Foster Wheeler E & I, Inc
Project/Site: PVU - Radionuclide Testing

TestAmerica Job ID: 160-18103-1

Job ID: 160-18103-1 (Continued)

Laboratory: TestAmerica St. Louis (Continued)

The following sample in batch 160-261171 consists of a salt matrix and is non homogeneous: PVU-SALT-20160701 (160-18103-1).

No analytical or quality issues were noted, other than those described above or in the Definitions/Glossary page.

Earth City, MO 63045-1205
phone 314.298.8566 fax 314.298.8757

Regulatory Program:

☐ DW ☐ NPDES ☐ RCRA ☐ Other:

TestAmerica Laboratories, Inc.

Client Contact Amec Foster Wheeler 9210 Sky Park Court, Suite 200 San Diego, CA 92123 (858) 300-4300 Phone (858) 300-4301 FAX Project Name: Evaporation Pond Solid Waste Evaluation Site: Paradox Valley Unit P O # N/A - Quote #16005417		Project Manager: Carla Scheidlinger Tel/Fax: (858) 300 4311 Analysis Turnaround Time <input type="checkbox"/> CALENDAR DAYS <input checked="" type="checkbox"/> WORKING DAYS TAT if different from Below 20 <input type="checkbox"/> 2 weeks <input type="checkbox"/> 1 week <input type="checkbox"/> 2 days <input type="checkbox"/> 1 day		Site Contact: Hallie Simpson Lab Contact: Mike Franks Date: 07/01/2016 Carrier:		COC No: 1 of 1 COCs Sampler: David Lowry For Lab Use Only: Walk-in Client: Lab Sampling: Job / SDG No.:					
Sample Identification PVU-SALT-20160701		Sample Date: 7/1/2016 Time: 12:00 Type: G Matrix: S # of Cont: 1		Filtered Sample (Y/N) Y		Isotopic Thorium (Method A-01-R, Alpha Spectrometry) Y		Isotopic Uranium (Method A-01-R, Alpha Spectrometry) Y		Sample Specific Notes:	
Preservation Used: 1= Ice, 2= HCl; 3= H2SO4; 4=HNO3; 5=NaOH; 6= Other None Possible Hazard Identification: Are any samples from a listed EPA Hazardous Waste? Please List any EPA Waste Codes for the sample in the Comments Section if the lab is to dispose of the sample. <input type="checkbox"/> Non-Hazard <input type="checkbox"/> Flammable <input type="checkbox"/> Skin Irritant <input type="checkbox"/> Poison B <input type="checkbox"/> Unknown											
Special Instructions/QC Requirements & Comments:											
Please email results to: carla.scheidlinger@amecflw.com											
Custody Seals Intact: <input checked="" type="checkbox"/> Yes <input type="checkbox"/> No Relinquished by: David Lowry		Custody Seal No.: N/A Company: hoh-PAK		Cooler Temp. (°C): Obs'd:		Corrd:		Therm ID No.:		Date/Time: 7.8.16 1300	
Relinquished by:		Company:		Received by:		Company:		Date/Time:		Date/Time:	
Relinquished by:		Company:		Received in Laboratory by:		Company:		Date/Time:		Date/Time:	

Form No. CA-C-WI-002, Rev. 4.9, dated 2/2/2016

Login Sample Receipt Checklist

Client: AMEC Foster Wheeler E & I, Inc

Job Number: 160-18103-1

Login Number: 18103

List Source: TestAmerica St. Louis

List Number: 1

Creator: Clarke, Jill C

Question	Answer	Comment
Radioactivity wasn't checked or is \leq background as measured by a survey meter.	True	
The cooler's custody seal, if present, is intact.	N/A	
Sample custody seals, if present, are intact.	N/A	
The cooler or samples do not appear to have been compromised or tampered with.	True	
Samples were received on ice.	True	
Cooler Temperature is acceptable.	True	
Cooler Temperature is recorded.	True	
COC is present.	True	
COC is filled out in ink and legible.	True	
COC is filled out with all pertinent information.	True	
Is the Field Sampler's name present on COC?	True	
There are no discrepancies between the containers received and the COC.	True	
Samples are received within Holding Time (excluding tests with immediate HTs)	True	
Sample containers have legible labels.	True	
Containers are not broken or leaking.	True	
Sample collection date/times are provided.	True	
Appropriate sample containers are used.	True	
Sample bottles are completely filled.	True	
Sample Preservation Verified.	True	
There is sufficient vol. for all requested analyses, incl. any requested MS/MSDs	True	
Containers requiring zero headspace have no headspace or bubble is $<6\text{mm}$ (1/4").	N/A	
Multiphasic samples are not present.	True	
Samples do not require splitting or compositing.	True	
Residual Chlorine Checked.	N/A	

Definitions/Glossary

Client: AMEC Foster Wheeler E & I, Inc
Project/Site: PVU - Radionuclide Testing

TestAmerica Job ID: 160-18103-1

Qualifiers

Rad

Qualifier	Qualifier Description
U	Result is less than the sample detection limit.

Glossary

Abbreviation	These commonly used abbreviations may or may not be present in this report.
α	Listed under the "D" column to designate that the result is reported on a dry weight basis
%R	Percent Recovery
CFL	Contains Free Liquid
CNF	Contains no Free Liquid
DER	Duplicate error ratio (normalized absolute difference)
Dil Fac	Dilution Factor
DL, RA, RE, IN	Indicates a Dilution, Re-analysis, Re-extraction, or additional Initial metals/anion analysis of the sample
DLC	Decision level concentration
MDA	Minimum detectable activity
EDL	Estimated Detection Limit
MDC	Minimum detectable concentration
MDL	Method Detection Limit
ML	Minimum Level (Dioxin)
NC	Not Calculated
ND	Not detected at the reporting limit (or MDL or EDL if shown)
PQL	Practical Quantitation Limit
QC	Quality Control
RER	Relative error ratio
RL	Reporting Limit or Requested Limit (Radiochemistry)
RPD	Relative Percent Difference, a measure of the relative difference between two points
TEF	Toxicity Equivalent Factor (Dioxin)
TEQ	Toxicity Equivalent Quotient (Dioxin)

Method Summary

Client: AMEC Foster Wheeler E & I, Inc
Project/Site: PVU - Radionuclide Testing

TestAmerica Job ID: 160-18103-1

Method	Method Description	Protocol	Laboratory
A-01-R	Isotopic Thorium (Alpha Spectrometry)	DOE	TAL SL
A-01-R	Isotopic Uranium (Alpha Spectrometry)	DOE	TAL SL

Protocol References:

DOE = U.S. Department of Energy

Laboratory References:

TAL SL = TestAmerica St. Louis, 13715 Rider Trail North, Earth City, MO 63045, TEL (314)298-8566

Sample Summary

Client: AMEC Foster Wheeler E & I, Inc
Project/Site: PVU - Radionuclide Testing

TestAmerica Job ID: 160-18103-1

Lab Sample ID	Client Sample ID	Matrix	Collected	Received
160-18103-1	PVU-SALT-20160701	Solid	07/01/16 12:00	07/08/16 13:00

Client Sample Results

Client: AMEC Foster Wheeler E & I, Inc
Project/Site: PVU - Radionuclide Testing

TestAmerica Job ID: 160-18103-1

Client Sample ID: PVU-SALT-20160701

Lab Sample ID: 160-18103-1

Date Collected: 07/01/16 12:00

Matrix: Solid

Date Received: 07/08/16 13:00

Method: A-01-R - Isotopic Thorium (Alpha Spectrometry)

Analyte	Result	Qualifier	Count Uncert. (2σ+/-)	Total Uncert. (2σ+/-)	RL	MDC	Unit	Prepared	Analyzed	Dil Fac
Thorium-228	0.0561	U	0.0601	0.0603	1.00	0.0932	pCi/g	07/19/16 13:35	07/28/16 10:17	1
Thorium-230	0.0653		0.0494	0.0497	1.00	0.0483	pCi/g	07/19/16 13:35	07/28/16 10:17	1
Thorium-232	0.0150	U	0.0247	0.0247	1.00	0.0416	pCi/g	07/19/16 13:35	07/28/16 10:17	1
Tracer	%Yield	Qualifier	Limits					Prepared	Analyzed	Dil Fac
Thorium-229	83.2		30 - 110					07/19/16 13:35	07/28/16 10:17	1

Method: A-01-R - Isotopic Uranium (Alpha Spectrometry)

Analyte	Result	Qualifier	Count Uncert. (2σ+/-)	Total Uncert. (2σ+/-)	RL	MDC	Unit	Prepared	Analyzed	Dil Fac
Uranium-233/234	0.738		0.226	0.234	1.00	0.0967	pCi/g	07/19/16 13:35	07/27/16 13:57	1
Uranium-235/236	0.0211	U	0.0423	0.0423	1.00	0.0634	pCi/g	07/19/16 13:35	07/27/16 13:57	1
Uranium-238	0.217		0.122	0.124	1.00	0.0772	pCi/g	07/19/16 13:35	07/27/16 13:57	1
Tracer	%Yield	Qualifier	Limits					Prepared	Analyzed	Dil Fac
Uranium-232	57.4		30 - 110					07/19/16 13:35	07/27/16 13:57	1

QC Sample Results

Client: AMEC Foster Wheeler E & I, Inc
Project/Site: PVU - Radionuclide Testing

TestAmerica Job ID: 160-18103-1

Method: A-01-R - Isotopic Thorium (Alpha Spectrometry)

Lab Sample ID: MB 160-261169/1-A

Matrix: Solid

Analysis Batch: 262493

Client Sample ID: Method Blank

Prep Type: Total/NA

Prep Batch: 261169

Analyte	MB Result	MB Qualifier	Count Uncert. (2σ+/-)	Total Uncert. (2σ+/-)	RL	MDC	Unit	Prepared	Analyzed	Dil Fac
Thorium-228	0.1019	U	0.0803	0.0808	1.00	0.110	pCi/g	07/19/16 13:35	07/28/16 10:17	1
Thorium-230	0.1489		0.0781	0.0790	1.00	0.0485	pCi/g	07/19/16 13:35	07/28/16 10:17	1
Thorium-232	0.02989	U	0.0345	0.0346	1.00	0.0299	pCi/g	07/19/16 13:35	07/28/16 10:17	1
Tracer	MB %Yield	MB Qualifier	Limits					Prepared	Analyzed	Dil Fac
Thorium-229	76.6		30 - 110					07/19/16 13:35	07/28/16 10:17	1

Lab Sample ID: LCS 160-261169/2-A

Matrix: Solid

Analysis Batch: 262494

Client Sample ID: Lab Control Sample

Prep Type: Total/NA

Prep Batch: 261169

Analyte		Spike Added	LCS Result	LCS Qual	Total Uncert. (2σ+/-)	RL	MDC	Unit	%Rec	%Rec. Limits
Thorium-230		24.5	26.88		2.62	1.00	0.0797	pCi/g	110	81 - 118
Tracer	LCS %Yield	LCS Qualifier	Limits							
Thorium-229	85.7		30 - 110							

Method: A-01-R - Isotopic Uranium (Alpha Spectrometry)

Lab Sample ID: MB 160-261171/1-A

Matrix: Solid

Analysis Batch: 262304

Client Sample ID: Method Blank

Prep Type: Total/NA

Prep Batch: 261171

Analyte	MB Result	MB Qualifier	Count Uncert. (2σ+/-)	Total Uncert. (2σ+/-)	RL	MDC	Unit	Prepared	Analyzed	Dil Fac
Uranium-233/234	0.004573	U	0.0391	0.0391	1.00	0.112	pCi/g	07/19/16 13:35	07/27/16 13:57	1
Uranium-235/236	-0.004268	U	0.00854	0.00854	1.00	0.104	pCi/g	07/19/16 13:35	07/27/16 13:57	1
Uranium-238	0.06959	U	0.0733	0.0736	1.00	0.0831	pCi/g	07/19/16 13:35	07/27/16 13:57	1
Tracer	MB %Yield	MB Qualifier	Limits					Prepared	Analyzed	Dil Fac
Uranium-232	55.5		30 - 110					07/19/16 13:35	07/27/16 13:57	1

Lab Sample ID: LCS 160-261171/2-A

Matrix: Solid

Analysis Batch: 262305

Client Sample ID: Lab Control Sample

Prep Type: Total/NA

Prep Batch: 261171

Analyte		Spike Added	LCS Result	LCS Qual	Total Uncert. (2σ+/-)	RL	MDC	Unit	%Rec	%Rec. Limits
Uranium-233/234		6.37	5.934		0.738	1.00	0.0710	pCi/g	93	84 - 120
Uranium-238		6.51	6.188		0.761	1.00	0.0567	pCi/g	95	82 - 122
Tracer	LCS %Yield	LCS Qualifier	Limits							
Uranium-232	82.2		30 - 110							

TestAmerica St. Louis

QC Association Summary

Client: AMEC Foster Wheeler E & I, Inc
Project/Site: PVU - Radionuclide Testing

TestAmerica Job ID: 160-18103-1

Rad

Prep Batch: 261169

Lab Sample ID	Client Sample ID	Prep Type	Matrix	Method	Prep Batch
160-18103-1	PVU-SALT-20160701	Total/NA	Solid	ExtChrom	
MB 160-261169/1-A	Method Blank	Total/NA	Solid	ExtChrom	
LCS 160-261169/2-A	Lab Control Sample	Total/NA	Solid	ExtChrom	

Prep Batch: 261171

Lab Sample ID	Client Sample ID	Prep Type	Matrix	Method	Prep Batch
160-18103-1	PVU-SALT-20160701	Total/NA	Solid	ExtChrom	
MB 160-261171/1-A	Method Blank	Total/NA	Solid	ExtChrom	
LCS 160-261171/2-A	Lab Control Sample	Total/NA	Solid	ExtChrom	

Tracer/Carrier Summary

Client: AMEC Foster Wheeler E & I, Inc
Project/Site: PVU - Radionuclide Testing

TestAmerica Job ID: 160-18103-1

Method: A-01-R - Isotopic Thorium (Alpha Spectrometry)

Matrix: Solid

Prep Type: Total/NA

		Percent Yield (Acceptance Limits)	
Lab Sample ID	Client Sample ID	Th-229 (30-110)	
160-18103-1	PVU-SALT-20160701	83.2	
LCS 160-261169/2-A	Lab Control Sample	85.7	
MB 160-261169/1-A	Method Blank	76.6	
Tracer/Carrier Legend			
Th-229 = Thorium-229			

Method: A-01-R - Isotopic Uranium (Alpha Spectrometry)

Matrix: Solid

Prep Type: Total/NA

		Percent Yield (Acceptance Limits)	
Lab Sample ID	Client Sample ID	U-232 (30-110)	
160-18103-1	PVU-SALT-20160701	57.4	
LCS 160-261171/2-A	Lab Control Sample	82.2	
MB 160-261171/1-A	Method Blank	55.5	
Tracer/Carrier Legend			
U-232 = Uranium-232			

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APPENDIX H

BRINE SOLIDS TESTING FOR LANDFILL DISPOSAL

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**Paradox Valley Unit
Brine Solids Testing for Landfill Disposal
November 22, 2016**

In May 2016 brine from the U.S. Bureau of Reclamation's (Reclamation) Paradox Valley Unit was tested in a small-scale crystallizer by Saltworks in Vancouver, BC. A sample of the solids (11% moisture content) was sent to the Reclamation Technical Service Center in June 2016. At the request of Reclamation's Western Colorado Area Office, samples were sent to Huffman Laboratories, Inc. in Golden, CO, for analysis in September 2016. Solids samples were analyzed by Huffman Laboratories, Inc. for thorium and uranium. Solids samples were analyzed by Hazen Research, Inc. for radium. Results are shown below.

Thorium and Uranium (Huffman Lab No. 171216)

Lab

Huffman Labs
4630 Indiana St
Golden CO 80403
303-278-4455
chemistry@huffmanlabs.com

Instrumentation

Perkin Elmer NexIon 300D ICP-MS. Th232 and U235 as U238 masses. Detection limits were 0.01 ug/L for both Th and U in clean sample matrices. Terbium was utilized as the internal standard.

Standard Operating Procedures

HHL SOP ICPMS-01 Rev#2, HHL QA-01 Rev#2

Sample Preparation

Samples were digested in triplicate at nominal 100, 200, and 300 mg sample to a final weight of 200 g after a nitric, perchloric, hydrofluoric, and boric acid digestion (proprietary digestion method).

Results

Thorium ($\mu\text{g/g}$)	Uranium ($\mu\text{g/g}$)
<0.1	<0.1



RECLAMATION

Managing Water in the West

Radium (Hazen Project No. 12081)



Hazen Research, Inc.
4801 Indiana Street
Golden, CO 80403 USA
Tel: (303) 279-4501
Fax: (303) 278-1528

DATE November 17, 2016
HRI PROJECT 12081
HRI SERIES NO. 1082/16
DATE REC'D 9/8/2016
CUST P.O. # None Rec'd

Huffman Hazen
Sandy Kanapilly

REPORT OF ANALYSIS

SAMPLE NO: 1082/16-1

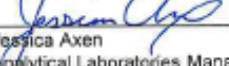
SAMPLE IDENTIFICATION: HHL 171216-01

PARAMETER	RESULT	DETECTION LIMIT	METHOD	ANALYSIS DATE	ANALYST
Radium-226 (+-Precision*), pCi/g	0.0(+/-0.5)	0.5	SM 7500-Ra B (Modified)	9/23/2016 @ 1305	LD/AN
Radium-228 (+-Precision*), pCi/g	1.1(+/-1.2)	1.2	EPA Ra-05 (Modified)	10/06/2016 @ 0822	JR

Certification ID's: CO/EPA CO00008; CT PH-0152; KS E-10265; NJ CO008; NYSELAP (NELAC Certified) 11417; RI LA000284;
WI 998376610; TX T104704256-15-6;

*Variability of the radioactive decay process (counting error) at the 95% confidence level, 1.96 sigma.

Results reported herein relate only to discrete samples submitted by the client.
Hazen Research, Inc. does not warrant that the results are representative of
anything other than the samples that were received in the laboratory.

By: 
Jessica Axen
Analytical Laboratories Manager

CODES: (T) = Total (D) = Dissolved (S) = Suspended (R) = Total Recoverable
(PD) = Potentially Dissolved < = Less Than

