FINAL

Pond Operational Strategy Report
Pond Optimization Study 2

Submitted to:
Wastren Advantage, Inc.
1571 Shyville Road
Piketon, Ohio 45661

Submitted by:
Amec Foster Wheeler Environment & Infrastructure, Inc.
San Diego, California

January 2017
Amec Foster Wheeler Project No. 1655500023

amec foster wheeler

January 2017
Amec Foster Wheeler Project 1655500023

Dave Sablosky
Wastren Advantage, Inc.
Project Manager
1571 Shyville Road
Piketon, Ohio 45661

Re: Paradox Valley Unit Salinity Control Project: Final Pond Operational Strategy Report for Study 2, PVU Salinity Control Project, Paradox Valley, Colorado

Dear Mr. Sablosky:

This report fulfills the deliverable for the Paradox Valley Unit Evaporation Ponds Study 2: Pond Operational Strategy Final Report. We have received comments for Reclamation, received their approval for their resolution, and present this final version.

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

Amec Foster Wheeler Environment & Infrastructure, Inc.
9210 Sky Park Court, Suite 200
San Diego, California
Tel: (858) 300-4300
Fax: (858) 300-4301 www.amecfw.com

This page intentionally left blank

amec foster wheeler

EXECUTIVE SUMMARY

The Pond Operational Strategy Report details the optimal operational strategy of the solar evaporation pond series that can be used for the disposal of the brine produced by the United States Bureau of Reclamation's (Reclamation) Paradox Valley Unit (PVU). The report reviews the assumptions that have led to the size and configuration of the pond series, and describes the byproducts that these ponds will produce. An overview theory of pond function and management is presented that describes the rationale for overall pond operation. Specific operational strategies for each portion of the pond series are described, with the rationale for why these strategies are optimal for the project goals. Harvest, transport, and storage operations are covered for both solid salts and bittern fluids, as well as a brief description of staffing requirements for the operation of the pond series for the production of salts.

This page intentionally left blank

TABLE OF CONTENTS

LIST OF FIGURES

This page intentionally left blank

ACRONYMS AND ABBREVIATIONS

%	percent
AF	acre feet
Amec Foster Wheeler	Amec Foster Wheeler Environment & Infrastructure, Inc.
ET	evapotranspiration
gpm	gallons per minute
H_2S	hydrogen sulfide
Mg	magnesium
$MgCl_2$	magnesium chloride
NaCl	sodium chloride, halite
ppm	parts per million
PVU	Paradox Valley Unit
Reclamation	Bureau of Reclamation
SG	specific gravity

This page intentionally left blank

1.0 Introduction

The Bureau of Reclamation's (Reclamation) 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 of salt per year from entering the Colorado River system. The current collection well field is capable of producing 400 gpm. Reclamation's 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 Pond Optimization Study investigates site location, sizing, layout and configuration strategies, and operational strategies, for an evaporation pond or ponds. This report presents the strategy for pond operation.

Amec Foster Wheeler Environment & Infrastructure, Inc. (Amec Foster Wheeler) is conducting studies for three other aspects of the evaporation ponds. These studies include the management of hydrogen sulfide (H_2S), the nature and quantity of byproducts that the ponds will produce, and the ecological risk associated with the development and operation of the ponds. The results of these studies are integrated with the pond optimization study. This report is to detail the operational strategies for such ponds in order to optimize a potentially marketable by-product, and to minimize operational costs. Other reports associated with the pond optimization study include Site Selection Strategy Report (Amec Foster Wheeler 2016b) and Pond Design Strategy Report (Amec Foster Wheeler 2016a).

The end goal for all of these studies is to provide Reclamation with the information needed to determine if using evaporation ponds will provide an economically viable and environmentally suitable solution for the disposal of the brine recovered by the PVU.

The operational strategies presented here are only for the operations conducted at the ponds site. This report does not consider operational strategies at the pumping station associated with the production wells.

As there are three different sites under consideration for the potential development of evaporation ponds, the operational strategies described here are necessarily generic. The site-specific layout of the ponds on the selected site would require a unique operational protocol to be developed for that site.

1.1 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; located with all Figures at the end of this report). 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.

2.0 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 2016a). A summary of important parameters of pond design that affect operation are shown here.

2.1 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.

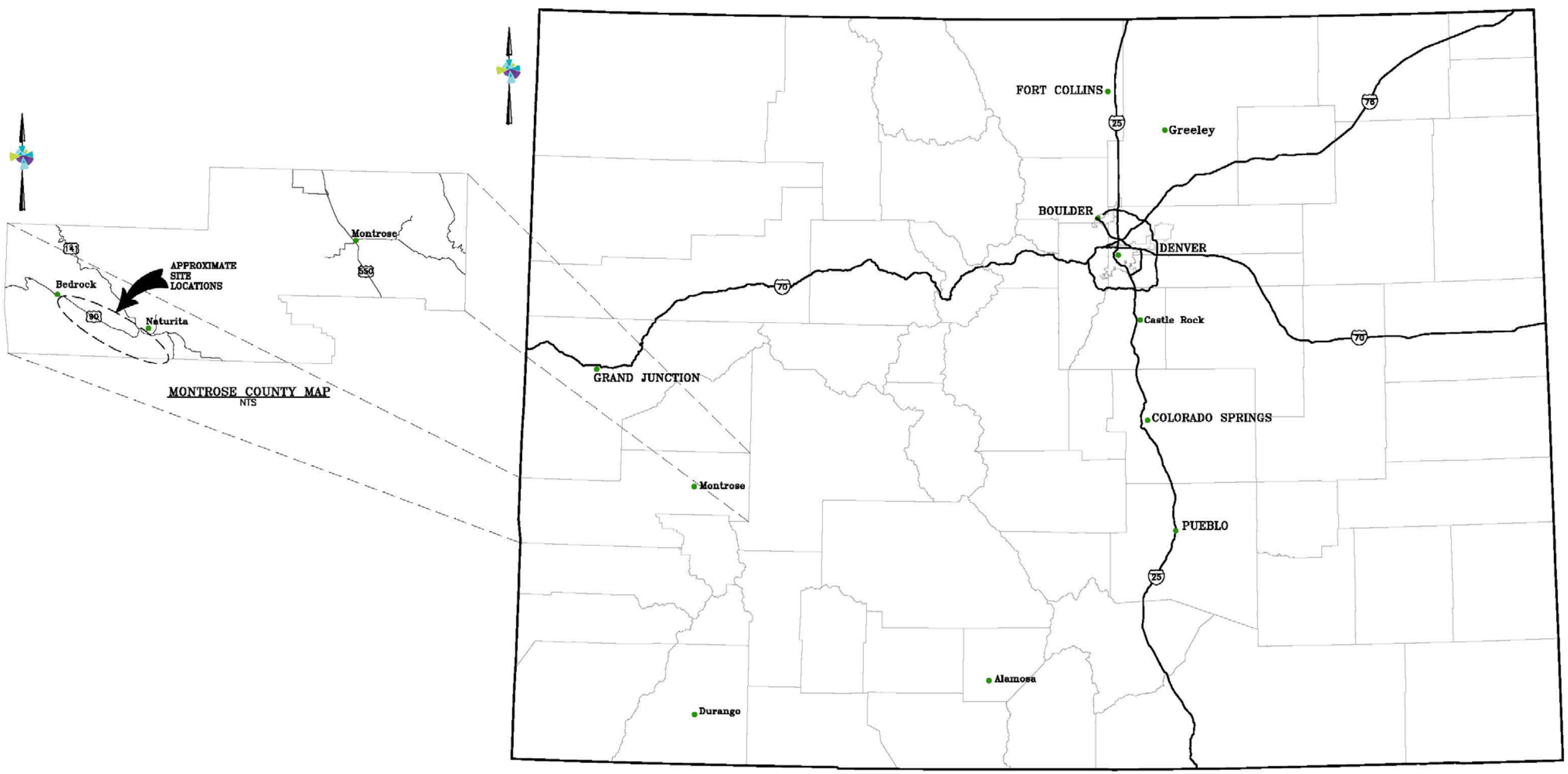
- The rate of flow into the system, which will be relatively constant, is 300 gpm of brine.
- The input brine has specific gravity (SG) of 1.1725 as reported from the hoh-PAK laboratory analysis.
- Evaporation rates were calculated based on local climate data analyzed from 1993-2015, and on pan evaporation data produced by Reclamation at the PVU facility as described in the Feasibility and Cost Analysis, Findings and Recommendations Report (Amec Foster Wheeler 2016c) (Byproducts Report). 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. This requirement is described in the Byproducts Report (Amec Foster Wheeler 2016c). 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 the Byproducts Report (Amec Foster Wheeler 2016c). These assumptions do not maximize the quantity of salt made in the crystallizers, nor do they minimize the amount of bittern solids generated.



MONTROSE COUNTY MAP
NTS

COLORADO STATE MAP
NTS

amec foster wheeler	CLIENT	BUREAU OF RECLAMATION	ISSUED DATE 05/12/2016
DRN BY MGC / DSN BY RBR / CHK BY ALM / APR BY ALM	PROJECT	PARADOX VALLEY UNIT EVAPORATION PONDS	PROJECT No. 1655500023
	TITLE	OVERALL MAP	FIGURE No. 1 / REV 0

S:\Projects\1655500023-Paradox Valley Unit\9.0 CADD\9.2 Figures\Overall Map.dwg-5/12/2016 12:51 PM

This page intentionally left blank

Finally, we assume that the H_2S 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.

We note here that there is a range of acreages that *could* be developed depending on the type of salt that is desired. If bittern products are determined to be more desirable, the proposed designs would allow for operational strategies to be modified to achieve the desired results. The salt model presented in the Pond Design Strategy Report (Amec Foster Wheeler 2016a) allows for exploring modifications to both design and operation based on a range of physical and byproduct outcome assumptions.

2.1.1 Volume

The volume of brine delivered to the pond system will average 300 gpm, totaling 1.33 acre-feet (AF) per day, and 483.94 AF per year. This volume, minus evaporation and plus precipitation, must be accommodated in the pond system. These calculations were developed for the Pond Design Strategy Report (Amec Foster Wheeler 2016a), and resulted in the provision of a deep surge pond capable of storing 180 AF of water to accommodate continual delivery of 300 gpm during periods of minimal or negative gross evaporation. There will be some amount of evaporation from the surge pond, but it was designed primarily to accommodate continual delivery of brine during the winter with conditions of both low evaporation and high precipitation.

2.1.2 Chemistry

The chemistry of the brine is detailed in the Byproducts Report (Amec Foster Wheeler 2016c). The chemistry data, together with the climate and evaporation data, determines what kinds of byproducts can be generated. It is the operational strategy, however, that allows for those products to be produced efficiently. That operational strategy is the subject of this report.

2.2 Byproducts Desired

2.2.1 Solid Salts

The only significant type of solid salt which will be produced by these evaporation ponds is halite, or crystals of sodium chloride (NaCl). The operational strategy for the ponds is designed to allow for this salt to be produced with a purity acceptable for use as a road de-icing agent. Such purity relies on precipitation of bittern solids in the bittern ponds rather than in the crystallizer ponds. Those specifications can vary from jurisdiction to jurisdiction, and the minimums are set in ASTM D-632. More details regarding the nature of the salt byproducts which may be produced by solar evaporation of PVU brine are in the Byproducts Report (Amec Foster Wheeler 2016c).

2.2.2 Bitterns

Bitterns are liquid salts high in magnesium chloride ($MgCl_2$) that have utility for road de-icing as well as for the suppression of dust on unpaved roadways. The operational strategies for the pond sequence is designed to produce bitterns with a concentration acceptable for road standards as is described in the Byproducts Report (Amec Foster Wheeler 2016c). Magnesium chloride liquid in a concentration of approximately 30% $MgCl_2$ is used as a major ingredient in several liquid deicers in Colorado and the surrounding Rocky Mountain states. The other ingredients in these liquid deicers are various forms of corrosion inhibitors. Bittern will be removed from the crystallizers at a specific gravity of 1.26. It will then have to be concentrated by a factor of up to 16 in the bittern concentrator pond in order to be marketable as $MgCl_2$ liquid for deicing purposes. The main compositional requirement for bitterns in Colorado is for 30% $MgCl_2$; other requirements include maximum allowable amounts of several trace metals such as barium and strontium.

3.0 Overall Theory of Solar Evaporation Pond Management

The operational activities of the ponds can be divided into three main periods -- storage, transition, and salt production.

3.1 Storage

The storage period is during the time of the year when net evaporation is essentially zero. This is estimated to be from approximately September 15 to February 1. During this 135-day period, well brine in a pond setting will evaporate approximately 4.8 inches (based on reported evapotranspiration [ET] with a pan to pond conversion factor) and will receive approximately 5.9 inches of rain (based on data from Bedrock). Therefore, the ponds gain approximately 1.1 inches of water due to precipitation and the stored pond brine will lose density to rain. The ponds serve as passive storage reservoirs at a functional standstill. A total of 180 AF may be stored from the production wells in the winter. The 39 acre concentrator with an average 1.5 foot (18 inches) depth will store about 60 AF. The remaining 120 AF would need to be stored in the surge pond. The concentrator pond will enter the winter passive storage period with a relatively shallow depth containing a brine near a saturated SG. Starting the storage period with a shallow depth in the concentrator allows for volume additions from well production as needed as well as from precipitation. If the concentrator is drawn down to an even smaller pool volume at the end of the summer, there would be additional capacity for storage. This capacity would buffer against a longer cold period, higher than average precipitation, or increased brine delivery. No delivery out of the surge pond or the concentrator takes place during this time period.

3.2 Transition

Starting in the spring, ponds would enter the transition period. For this period, the operational strategy is to distribute the stored brine such that it can be effectively evaporated during the upcoming warmer weather. This is also when the ponds experience nearly zero positive evaporation volume loss. Using data from Bedrock (described in the Pond Design Strategy Report, Amec Foster Wheeler 2016a), the evaporation over this period is a net of about 1.3 inches. This is approximately between February 1st and March 15th (45 days). However, it could be extended to facilitate management of the high volume of stored brine which will need to be distributed. The ponds will continue to function as passive storage, but the brine would begin to concentrate as it flows through the concentrator and into the crystallizers. The concentrator pond would also begin to discharge winter-stored, saturated brine to the four crystallizer ponds, each of which holds about 70 AF. The concentrator brine would then be replaced with the winter stored well brine in the surge pond along with fresh brine pumped from the production wells. Production would be approximately 60 AF during this time. A low volume of the relatively light brine from the production wells and the surge pond storage would then flow through the concentrator and into the crystallizer. The total amount of brine being transferred includes the brine stored in the surge and concentrator ponds, and the additional 60 AF produced during this period by the production wells.

3.3 Salt Production

The volume of brine transferred during the transition period is about two-thirds the expected annual evaporation from the concentrator. The salt model indicates the crystallizers would be functioning at full salt saturation after the end of the transition period. At this point, the ponds enter the salt production period, which extends from about March 15th to September 15th. The remaining one third of the brine to be evaporated will be delivered during this phase. The concentrator would be operating continuously, discharging saturated brine to the crystallizers as the target density is reached. The surge pond would be essentially dry, having been drained of stored brine during the transition period. Production from the wells would be balanced by evaporation over the combined areas of the concentrator and crystallizers. The crystallizers would have had about 12 inches of light brine delivered during the transition period on top of the existing salt deposit formed in previous years. It is assumed that all four crystallizer ponds would be in operation during any given year, although only one would be harvested each year. This throughput amounts to about 200 AF of brine flooded over about 220 crystallizer acres. The combination of initially light brine and the continual output of saturated brine from the concentrator will form salts in the crystallizers during this high evaporation salt production period.

Towards the end of summer, total evaporation will have greatly exceeded inflows from the production wells through the concentrator. When salt harvest is planned, one crystallizer pond will be drained in December for harvest, and refilled in February. The continual flooding in the crystallizers will have served the purpose of providing for evaporation off the entire functioning crystallizer surface area, which is the area needed for evaporation balance. The concentrator will have been drawn down during the summer from any excessive depth produced by delivery during the transition period. Such a drawdown will prevent saturation during the high evaporation rates of the summer months, although some deposition of salt at the discharge point of the concentrator is expected during times of high evaporation. The surge pond will be dry, or will have formed a nominal salt bed from any residual volume.

3.4 Summary

Seeing the operational strategy in these three stages allows for understanding the aspects of the management of brine behavior even though the ponds are not in balance for evaporation and brine delivery during any one day or month. The storage period accommodates well brine in the surge pond during the winter months when precipitation and delivery exceeds evaporation. During the transition period, flows will distribute the stored brine into the concentrator and crystallizers. The pond series as designed accommodates full flows from the production wells and produces salt during the period of high evaporation.

This operational strategy underscores the importance of the surge pond. It stores produced brine during the storage period, and allows for a seasonally suitable rate of brine delivery during the transition period, delivering the brine to the concentrator and crystallizers in preparation for the summer months. During the salt production period the surge pond would be virtually dry since the surface area of the surge pond is not needed for concentrator acreage. However, during the salt production period the surge pond does provide buffer capacity in the event of rain or a period of decreased evaporation.

4.0 Specific Operational Strategies of Pond Sequence

The flow of brine from the point of delivery to the bittern ponds, as well as product harvesting and shipping operations, is shown in the schematic in Figure 2. Each step of flow management is described in this section.

4.1 Treatment for Hydrogen Sulfide

When the brine is delivered to the pond location through a pipeline, it will first be subjected to treatment to remove H_2S. This prevents hazardous exposure both for workers associated with the pond operation and salt removal, and for wildlife. The brine produced at the PVU contains dissolved H_2S at concentrations of approximately 50 to 125 parts per million (ppm). If the brine is exposed to the atmosphere, H_2S readily volatilizes out of the brine and into the air. Concentrations in the air above the brine surface could exceed 500 ppm without treatment. This compound produces noxious odors, creates a corrosive environment, is flammable and can be explosive, and can be toxic if volatilized and inhaled at high concentrations.

Treatment will be conducted at the pond site location since the treatment strategy would produce precipitates which could cause issues with plugging. The proposed strategy is to utilize a sodium hypochlorite oxidation system with reducing agents added afterwards to ensure there is no residual chlorine in the ponds. The addition of ferric chloride helps settle precipitated solids settle in the surge pond. The addition of caustic or lime returns the pH to neutral following the addition of the precipitating agents. A process flow diagram for this system is shown as Figure 3. More detailed information on the hydrogen sulfide treatment can be found in the Engineering Evaluation, Pre-design, and Cost Analysis Report (Amec Foster Wheeler 2016d). Only treated brine, then, will be released to the open evaporation ponds.

4.2 Management of Incoming Flow

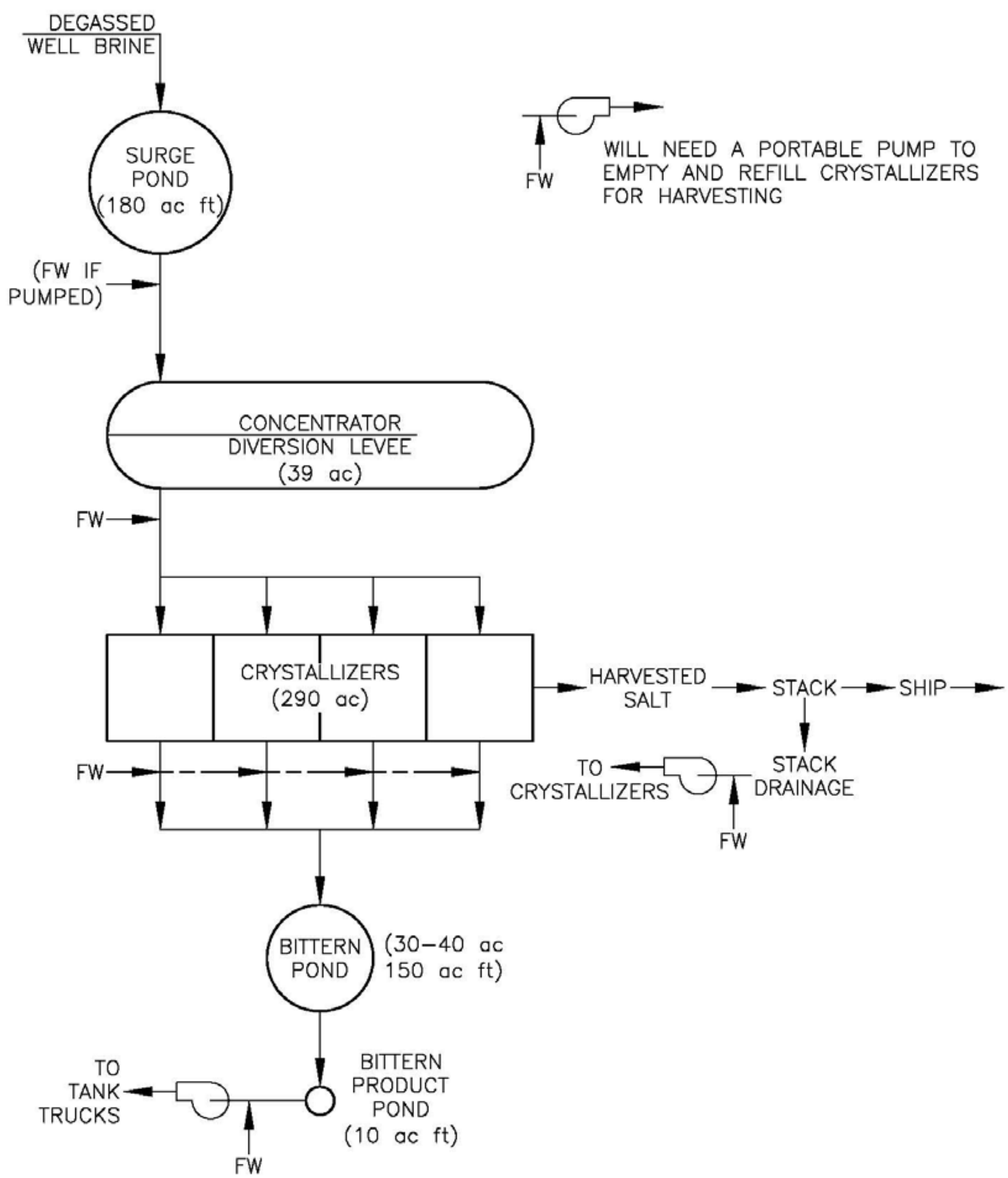
Brine will be released from the H_2S treatment system to the surge pond at the proposed 300 gpm pumping rate. As the surge pond is expected to be downslope of the H_2S treatment facility, discharge would be by gravity.

Flow out of a surge pond into the concentrator pond will range from 200 to 500 gpm depending on the month. This flow can be pumped or moved by gravity, depending on the relative position in the landscape of the surge and concentrator ponds. Five to ten gpm of fresh water (shown as FW in Figure 2) will be needed during periods of brine transfer, as explained in Section 4.6. The SG of this brine will be about 1.17, the same as the SG of the brine from the PVU wells.

4.3 Management of the Concentrator

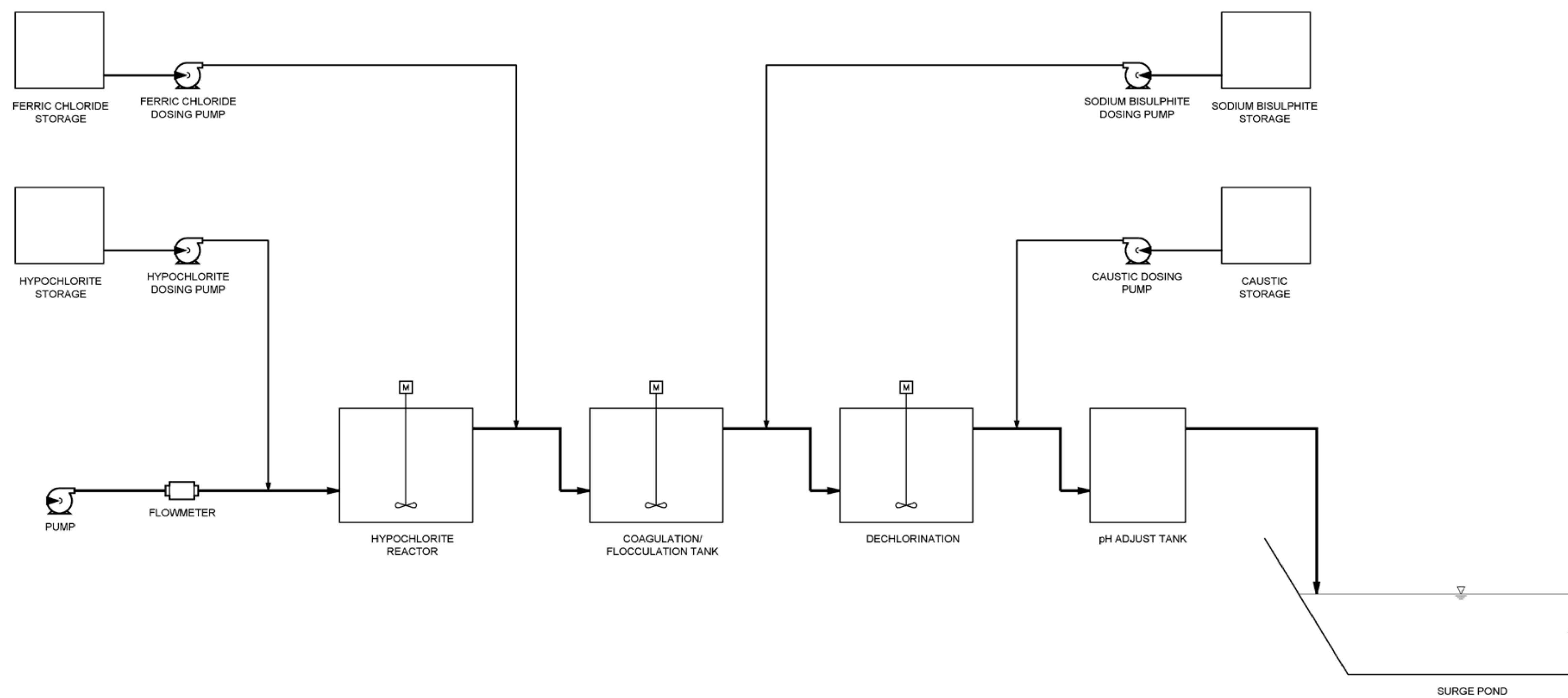
The next pond in the sequence is the concentrator pond. The function of the concentrator is to evaporate the well brine to the point where solid sodium chloride, or halite (NaCl), starts to precipitate (“salting point”).

The working depth of this type of pond is normally about 18 inches during the summer. Most of the sites under consideration have more than a 1% slope, which could result in ponds without a uniform depth. If pond bottoms must be sloped, the goal is to have no more than 24 inches of depth at the deep end and approximately 12 inches at the shallow end.



amec foster wheeler	CHK BY	CLIENT: BUREAU OF RECLAMATION	ISSUED DATE: 06/22/2016	
	APR BY	PROJECT: PARADOX VALLEY UNIT EVAPORATION PONDS	PROJECT No.: 1655500023	
	DRN BY MGC	TITLE: PARADOX POND SCHEMATIC	FIGURE No.: 2	REV: 0
	DSN BY JP			

This page intentionally left blank



CAUTION: THIS PLAN MAY BE REDUCED 0 25mm 50mm ORIGINAL SCALE

NO.	REVISION	DATE	APRVD

DRAWN	C.P.F.	JULY 2016
DESIGNED	V.A.F.	JULY 2016
CHECKED	–	–
REVIEWED	–	–

AMEC FOSTER WHEELER
1239 MAIN AVENUE
DURANGO, CO 81301
PHONE: (970) 764-4070

amec foster wheeler

PROCESS FLOW DIAGRAM
SURFACE TREATMENT FACILITY
PROCESS FLOW DIAGRAM

WASTREN ADVANTAGE
USBR PARADOX VALLEY UNIT, FIREBAUGH, CA

DATE:	JULY 2016
SCALE:	N.T.S.
SHEET:	– OF – SHEETS
PROJ No: 1655500023.0001.0004	Figure 3

This page intentionally left blank

The flow of the brine through the single shallow concentrator pond is a passive process. Brine is introduced into the pond at a concentration similar to that at which it was delivered from the H_2S treatment facility. The flow rate will allow the depth in the concentrator to reach a maximum of 24 inches. The depth could be shallower in some places depending on the slope on which the pond is constructed. As the brine flows through the pond it is guided by a diversion levee to assure maximum exposure to the air and sunlight. The slowly moving brine evaporates, concentrating it to the “salting point”. The laboratory results indicate that this point is reached at a SG of 1.1986.

Management of the concentrator pond consists of monitoring the appearance of the brine at the point where it would be discharged from the concentrator to the crystallizers. The general practice is to observe whether solid salt has formed near the discharge point. If salt crystals are forming, the “salting point” has been reached.

In the early spring, a slow discharge flow is started as soon as salt is observed to be forming at the outlet of the concentrator. However, a SG measurement would be needed at this time because flow has not commenced and salt may form in other places until flow starts. If the area in the concentrator where salt is forming expands beyond the outlet, a higher flow rate may be delivered from the concentrator. The rate of that flow would depend upon how much additional brine could be accommodated in a crystallizer. A maximum flow rate of approximately 245 gpm during the hottest months of the summer is possible.

There are always balance issues between the concentrator and the crystallizers which will determine the rate of brine transfer. During the hot months, the concentrator will work faster than the crystallizers. This will result in salt being deposited in a larger area in the concentrator during the hot months, not just at the discharge point. As the temperature cools later in the year, unsaturated brine upstream of the discharge location may be fed at a faster rate into the crystallizer. This faster flow of initially unsaturated brine will dissolve the precipitated salt which had formed during the summer months at the discharge region of the concentrator so the brine that ultimately flows into the crystallizer is fully saturated.

Management of the movement of saturated brine from the concentrator to a crystallizer is one of the two main control points in the system. Proper operation of this control point minimizes the amount of calcium and sulfate contamination in the salt forming in the crystallizers. Development of the knowledge necessary to manage this transfer is one of the critical skills required from a pond operator.

4.4 Management of Crystallizers

The function of the crystallizer ponds is to precipitate NaCl from the brine. The design proposed for this project assumes four separate crystallizer ponds. Each pond is fed in parallel from the concentrator through a distribution pipe or ditch. The working depth of the crystallizer is normally about 18 inches in the summer. Most of the sites under consideration have more than a 1% slope. In order to minimize construction costs, the pond bottoms may be sloped. Design will specify that brine depth will be between 12 and 24 inches.

Fluid depth in the crystallizers is managed by moving brine into the ponds in a quantity sufficient to maintain the target operating depth in the pond. It is important to monitor the crystallizer inlet areas to make sure new salt is being made in those areas, indicating that saturated brine is being delivered from the concentrator pond. Absence of new salt formation is an indication the incoming brine is not saturated, in which case the delivery rate should be reduced.

Transfer of brine from the crystallizers is the second important operating control point in the pond system. This transfer occurs when the brine in the crystallizer has reached the bittern point. The bittern point is an arbitrary SG chosen to control the amount of magnesium contained in the precipitated salt to meet product quality standards. As determined from the brine testing done to date, SG = 1.261 is the level at which brine should be removed from the crystallizer in order to produce solid salt of the target quality.

Once the brine in a crystallizer has reached this SG, it should be moved to the bittern pond. The crystallizer is then isolated so it receives no inflow and all the brine in that crystallizer is pumped from the pond's sump area into the bittern pond. The transfer rate could be as high as 5,000 gpm during this process. Once this is done, the crystallizer can be refilled from the concentrator pond. During pump operation, a freshwater feed of 5-10 gpm is necessary to prevent precipitation of material in the transfer pipes.

Each crystallizer is fed in parallel, and the bittern point in each is managed to get the type of salt desired. As discussed below in Section 5.2.2, management of this second control point may be altered if salt of a different quality is desired.

4.5 Management of Bittern Ponds

Bitterns are delivered from the crystallizer into a separate pair of ponds designed to hold bittern material. The initial bittern concentrator pond has a surface area of about 24 acres and an annual brine input volume of 30.7 AF/year. This volume converts to about 19 gpm on average, but it will be moved in discrete volumes as dictated by evaporation rate and by sampled SG in the crystallizers and the bittern pond.

The bittern in the bittern concentrator pond will continue to concentrate during the warm months. The evaporating liquid in the pond will tend to stratify, with the heavier, more concentrated brine sinking to the bottom. When the concentrated brine near the bottom has reached marketable concentration (about 30% $MgCl_2$) as determined by sampling material suctioned from the bottom of the pond, it is pumped from the bottom of the bittern concentrator pond to the bittern product storage pond.

The formation of bittern solids is expected as the bittern concentrates. These solids can be removed to a disposal area once every few years. The solids have a more slushy composition than does NaCl, and the volume is far less. Removal is typically done with a backhoe or dragline, using care to protect the pond's liner. These slushy salts can be placed with the other solid salts in a storage area, but should be isolated from the storage of marketable salt to avoid contamination. The bittern solids will be stored for the long term in a permitted salt storage facility, as they do not have any marketable value.

Additional discussion of the management and disposal of bitterns can be found in Section 5.3.

4.6 Requirement for Fresh Water

Availability of 5 -10 gpm of fresh water will be needed wherever a brine transfer is done, especially transfer of more saturated brines using a pump. The fresh water would be utilized whenever brine transfer is in progress. It helps move the brine from the surge pond to the concentrator, from the concentrator to the crystallizer, or from the crystallizer to the bittern pond. This fresh water would be injected into the brine flow as it leaves the point of discharge from a pond, or injected into a pump suction. The small amount of fresh water injected into the brine stream is quickly evaporated once the brine reaches the next pond, and it prevents pumps, pipes and ditches from being plugged by precipitated salt. The flow rate for fresh water is independent of the flow rate and the concentration of the brine being transferred.

The pond design provides for a fresh water (FW) feed pipe at all brine transfer locations, as shown in Figure 2. The fresh water would be delivered from a storage tank on site, which is in turn filled from a pipeline that pumps water from the Dolores River for this purpose. The discharge from the tank would operate by gravity, and the flow rate can be controlled with a valve at each usage point.

5.0 Harvest Strategies

5.1 Harvest Timing and Temporary Salt Storage

Once equilibrium operation is reached, about 2.8 inches of salt will be deposited each year in the crystallizers. Each crystallizer will be initially controlled to build a salt deposit to a depth of about 24 inches before the first harvest would take place. The first 24 inches (two feet) of salt will remain in the crystallizer indefinitely as a protective layer above the liner to prevent damage to the liner during harvest, as described below.

The annual deposition of 2.8 inches of salt is not an efficient amount of salt to harvest. Therefore, it will be more economical to harvest when the layer of deposition above the protective 24 inch protective bed is approximately 11-12 inches thick, or about once every four years. The early years will be managed such that a harvest rotation is set up. The rotation will have one of the four crystallizers harvested each year. This rotation will ensure harvest efficiency and allow a routine operation each year, rather than trying to organize a harvest of all the ponds every four years.

Harvest timing is based on climate patterns. December and January are the driest months during the winter period and should be used for harvesting. New salt would not be in production due to the low evaporation rates, and rain amounts are minimal during these two months. This is the ideal time to harvest salt so the crystallizers would not be disturbed during warmer and drier weather when salt is being produced.

As previously stated, the crystallizer ponds would be harvested one at a time. After the ninth full year of operation, when the initial 24 inches of protective salt has been deposited, a partial harvest of three of the ponds may be done in successive years in order to set up the rotation. The next year, the 13^{th} year, the fourth pond would be the harvest target with the full 11-12 inches of deposited salt removed. After that, the rotation can continue, harvesting 11-12 inches from a single pond each year.

Prior to harvest, the remaining brine from the pond being harvested would be drained into an adjacent pond(s) using a transfer pump. Brine in each crystallizer collects in a sump area designed into each crystallizer pond, and is pumped from the sump. Harvesting will be done with heavy equipment such as a Cat 12M3 motor grader, a wheeled loader, and trucks. The grader would be used to loosen the salt and windrow it. The loader would be used to move salt from a windrow and load it onto trucks. The trucks would then haul it from the crystallizer and place it in a storage location stockpile. Salt to be potentially sold into the deicing market will need to be drained for about three months after harvesting and before shipping in order to meet moisture requirements. Rain falling on the salt in the stockpile will assist in cleaning the salt. The drained brine will be discharged back into the crystallizers for re-use in the system. When drainage is complete, the salt can be removed either for sale, to an off-site permanent storage facility, or can remain in the on-site storage stockpile area for future sale of for long-term storage. (Section 5.2).

When the harvest in a pond is complete, the remaining salt bottom would be groomed and the pond refilled with saturated brine. The harvesting operation would then move on to the next pond the following year. The amount of salt harvested from each pond would be about 142,000 tons.

Each pond will be lined to reduce or eliminate seepage. Whether the crystallizers are lined with clay or plastic, the liner will need protection from harvesting equipment and other operation and maintenance activities. A typical protection system may consist of a layer of soil both to add weight-bearing capacity and to protect the liner from abrasive and sharp cornered salt crystals. In addition, the liner should be protected by at least 24 inches of deposited salt. This protective salt would be considered a base which would never be removed until the ponds were decommissioned and the liner and salt layer removed to a permitted landfill. Both the pond bottoms and ramps for the entry and exit of equipment will be protected in this fashion.

5.2 Permanent Disposition of Solid Salt

5.2.1 Solid Salt for De-Icing

Once the required level of drainage and salt quality is achieved, the product salt can be shipped directly from the stockpile. A Cat 938M wheel loader (or the equivalent) and heavy hauling trucks would be used for loading and hauling the material .The haul trucks would take the salt to a final sale or transport point, or to a designated storage/disposal area.

Any salt harvested but not sold can be kept in the same stockpile and storage/disposal areas. Simple stockpile management aimed at isolating marketable salt from other salts such as non-marketable solid salts (Section 5.2.2) or bittern solids (Section 4.5) should be implemented.

5.2.2 Salt Not Made for Deicing

There is a possibility that not all the salt made in the crystallizers will be able to be sold. If there is a time when the market does not support sale of deicing salt, the produced salt would not have to meet quality goals. One or more crystallizers could be used to make this lower quality salt. In this case, the bittern can be allowed to become more concentrated in the crystallizer before being removed to the bittern pond. This practice will increase the amount of salt made, decrease the initial amount of bittern generated, and increase the concentration of bittern initially placed in bittern storage.

The mixed use of crystallizers – some to make marketable salt, and some not – is easy to manage. The operational control point from each crystallizer discharge would be managed for a different SG bittern point.

5.3 Management and Disposal of Bitterns

Management of the point at which brine is removed from a crystallizer was described previously (Section 4.4). At the concentration level defining a bittern, the brine must be removed from the crystallizer as described in Section 4.4.

The bittern will be removed to a bittern concentrator pond for further evaporation, and then pumped to a bittern product storage pond in preparation for sale and shipping. The same pump used to transfer bittern from the bittern concentrator pond to the product pond could also be used to load trucks with bittern product.

If liquid bittern product is never sold, or if only a portion of the bittern product goes to a market, the bittern pond would eventually fill and would have to be evacuated so it can continue to be used. If bittern is stored in place, the bittern pond would have to be permitted as a landfill.

There will also be bittern solids produced in the bittern concentrator pond. These bittern solids will include halite as well as potassium chloride, sodium sulfate, and potassium sulfate. These salts would be removed from the bittern ponds using an excavator or a dredge, and stockpiled for disposal. Disposal options include an existing permitted landfill or a dedicated salt storage facility associated with the evaporation ponds. The quantity of bittern solids can be modified by changing the discharge specific gravity point from the crystallizers. Any such change would affect the quality of the solid salt produced in the crystallizers.

6.0 Protocols, Staffing, and Equipment

If the evaporation pond option is selected by Reclamation as the preferred alternative, details of personnel requirements and qualifications, operating protocols, and equipment lists will be developed. For the purposes of this report, we briefly describe each category separately.

6.1 Staffing

Most of the pond operation can be done with one person over the long term who either will be hired from another solar salt production facility, or who will be trained by an experienced pond operator or industry specialist. Occasionally a second person will be needed for more labor-intensive work. This second person could also be trained as the vacation relief for the full time operator. In the early learning years, additional personnel may be needed to assure that all components of the pond system are operating correctly, and to trouble-shoot infrastructure elements as required.

6.2 Operating Protocols

A detailed set of operational protocols will be developed for the operation of the ponds once they have been built. These protocols will be developed by an experienced pond operator or industry specialist, and will take the form of a checklist and a series of decision trees for each of the operational control points described above in Sections 4.3 and 4.4.

6.3 Equipment Needs

As described above, there are several kinds of portable equipment that will be required to operate the evaporation pond system. These include:

- Transfer pumps. A large portable pump will be needed for draining the crystallizers prior to harvest and refilling after harvest, and for transferring brine into the bittern concentrator pond. A smaller pump will be needed to transfer bittern from the bittern concentrator pond to the bittern storage pond, and from bittern storage to transport.
- Backhoe or some other equipment will be needed at different times for maintenance and operational tasks.
- Cat 12M3 motor grader used to loosen the salt and windrow it.
- Equipment for harvesting solid salt products. For harvest of the crystallizers, a loader such as a Cat 938M wheel loader would be used to move salt from a windrow and load it into a truck. For bittern solids, an excavator with a dredge attachment would be appropriate.
- Trucks for transporting salt from the crystallizer for placement in a stockpile.
- Vehicles for the operators such as a pickup truck to carry supplies and equipment.

7.0 Conclusions

The operation of the solar evaporation ponds is done by an individual or a team well versed in the processes that produce salt products of different qualities. The operational activities consist largely of the management of the transfer of brine from one stage of evaporation to another, and in the harvest and storage of the salt products. Besides the ponds and water distribution and transfer piping, there is minimal infrastructure required to operate solar ponds. Stationary pumps with the capability for a freshwater feed, transfer pumps with the same capability, sampling equipment, and the vehicles and heavy equipment required for repairs and maintenance constitute the only operational materials. For harvest activities, management of a permanent salt bed in each crystallizer pond is critical to the protection of a liner. The transfers of harvested salt to stockpile locations as well as to haul vehicles for delivery for sale or for long-term disposal in a storage facility must be properly managed.

There are no operational obstacles to the production of solid and bittern salts from the PVU brines.

8.0 References

Amec Foster Wheeler. 2016a. Pond Optimization Design Strategy Report For Paradox Valley Unit Evaporation Ponds. Report to Wastren Advantage, Inc. October 2016.

Amec Foster Wheeler. 2016b. Site Selection Report. Pond Optimization Study 2. For Paradox Valley Unit Evaporation Ponds. Report to Wastren Advantage, Inc. submitted to United States Bureau of Reclamation. August 2016.

Amec Foster Wheeler. 2016c. Feasibility and Cost Analysis; Findings and Recommendation Report for Paradox Valley Unit Evaporation Ponds. Report to Wastren Advantage, Inc. October 2016.

Amec Foster Wheeler 2016d. Paradox Valley Unit Salinity Control Investigations. Study 1 – Hydrogen Sulfide Management. Bedrock, Colorado. Engineering Evaluation, Pre-design, and Cost Analysis Report. Report to Wastren Advantage, Inc. submitted to United States Bureau of Reclamation. August 2016. October 2016.

This page intentionally left blank