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Cardno ENTRIX

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Mr. Ed Hickey
Utah Department of Environmental Quality
Division of Water Quality
195 North 1950 West
Salt Lake City, UT 84116
(801) 536-4350

June 4, 2013

Re: Groundwater Discharge Permit Application
Magnum NGLs Storage Project - Brine Evaporation Pond

Dear Mr. Hickey:

Magnum NGLs Solution Mining, LLC (Magnum) and Cardno ENTRIX are pleased to submit the following information in support of Magnum's Groundwater Discharge Permit Application. Materials included in the application package were previously reviewed and approved by Utah Division of Water Quality (DWQ) and Utah Division of Water Rights (DWR) staff as part of DWQ Underground Injection Control Permit UTU-27-AP-9232389, DWQ Construction Permit for the Magnum Gas Storage LLC evaporation ponds, and DWR Dam Permit UT53584. The interpretations provided herein were prepared by, or reviewed by, a Licensed Professional Engineer in the State of Utah.

We thank you and your staff for your time and feedback. We believe the information contained within this application and supporting materials provides the information necessary to deem the application complete for issuance. Should you have any questions or comments regarding this application, please do not hesitate to contact Tiffany James (801.993.7001) with Magnum or myself (801.363.0116).

Sincerely,

R. Jeffrey Davis, PE
Senior Consultant
Cardno ENTRIX
(801)-363-0116
jeffrey.davis@cardno.com

David P. Kelly, P.G.
Senior Project Scientist
Cardno ENTRIX
813 664 4500
david.p.kelly@cardno.com

RJD: kab

Enc: 1. Groundwater Discharge Permit Application Checklist
2. Groundwater Discharge Permit Application
3. Groundwater Discharge Permit Application Attachment

cc:

PROFESSIONAL ENGINEER
6/4/13
No. 189690-2202
R. JEFFREY DAVIS
STATE OF UTAH

Groundwater Discharge Permit Application Package Checklist			
Item #		Part A - General Facility Information	Item Location
X	1	Administrative Information	*Utah Groundwater Discharge Permit Application* form and Section 1 and Figure 1-1 of the *Groundwater Discharge Permit Application*
X	2	Owner/Operator Information	*Utah Groundwater Discharge Permit Application* form
X	3	Facility Classification	*Utah Groundwater Discharge Permit Application* form
X	4	Type of Facility	*Utah Groundwater Discharge Permit Application* form
X	5	SIC/NAICS Codes	*Utah Groundwater Discharge Permit Application* form
X	6	Projected Facility Life	*Utah Groundwater Discharge Permit Application* form and Figure 2-2 of the *Groundwater Discharge Permit Application Attachment*
X	7	Principal Processes Used	*Utah Groundwater Discharge Permit Application* form and the *Groundwater Discharge Permit Application Attachment*
X	8	Existing Permits	*Utah Groundwater Discharge Permit Application* form and Section 1-2 of the *Groundwater Discharge Permit Application Attachment*
X	9	Well Locations / UAC 309-600 Regs.	Section 2.1, Appendix B, Appendix E of the *Groundwater Discharge Permit Application Attachment*
Item #		Part B - General Discharge Information	Item Location
X	1	Location	*Utah Groundwater Discharge Permit Application* form
X	2	Type of Fluid to be Dsicharged	*Utah Groundwater Discharge Permit Application* form
X	3	Discharge Volumes	*Utah Groundwater Discharge Permit Application* form and Section 2-2 of the *Groundwater Discharge Permit Application Attachment*
X	4	Potential Discharge Volumes	*Utah Groundwater Discharge Permit Application* form
X	5	Means of Discharge	*Utah Groundwater Discharge Permit Application* form
X	6	Flows, Sources of Pollution, and Treatment Technologies	Figure 2-1 of the *Groundwater Discharge Permit Application Attachment*
X	7	Discharge Effluent Characteristics	Section 2.3 of the *Groundwater Discharge Permit Application Attachment*
X	8	Hydrogeologic Reports	Section 2.4 of the *Groundwater Discharge Permit Application Attachment*
X	9	Groundwater Discharge Control Plan	Section 2.5 of the *Groundwater Discharge Permit Application Attachment*
x	10	Compliance Monitoring Plan	Appendix G. Groundwater Monitoring and Protection Plan
X	11	Closure and Post Closure Plan	Section 2.6.4 of the *Groundwater Discharge Permit Application Attachment*
X	12	Contingency and Corrective Action Plans	Section 2.6.5 of the *Groundwater Discharge Permit Application Attachment*

MAIL TO:
Division of Water Quality
Utah Department of Environmental Quality
Salt Lake City, Utah 84114-4870

Application No.:____________________
Date Received:____________________
(leave both lines blank)

UTAH GROUND WATER DISCHARGE PERMIT APPLICATION

Part A - General Facility Information

Please read and follow carefully the instructions on this application form. Please type or print, except for signatures. This application is to be submitted by the owner or operator of a facility having one or more discharges to groundwater. The application must be signed by an official facility representative who is: the owner, sole proprietor for a sole proprietorship, a general partner, an executive officer of at least the level of vice president for a corporation, or an authorized representative of such executive officer having overall responsibility for the operation of the facility.

1. **Administrative Information.** Enter the information requested in the space provided below, including the name, title and telephone number of an agent at the facility who can answer questions regarding this application.

Facility Name: Magnum NGLs Storage Project

Mail Address: 3165 East Millrock Drive, Suite 330 Holladay, UT 84121
(Number & Street, Box and/or Route, City, State, Zip Code)

Facility Legal Location* County: Millard

Township	Range	Section	Allotment
15 South	6 West	19	SE¼
15 South	6 West	30	NE¼, S of NW¼, W of SE¼, SW¼
15 South	6 West	31	W of NE¼, NW¼, W of SE¼, SW¼
15 South	7 West	22	SESE of the SE¼
15 South	7 West	23	SESE and S of the SW¼
15 South	7 West	26	NW¼
15 South	7 West	27	NENE of the NE¼

Lat. 39 ° 29' 36.21" "N.Long. -112 ° 36' 42.54" "W

*Note: Figure 1-1 of the *Groundwater Discharge Permit Application Attachment* shows the location of the facility on a USGS topographic basemap.

Contact's Name: Tiffany James Phone No.:(801) 993-7001
Title: Vice President of Project Development and Government Affairs

2. **Owner/Operator Information.** Enter the information requested below, including the name, title, and phone number of the official representative signing the application.

Owner

Name: Magnum NGLs Solution Mining, LLC Phone No.:(801) 993-7001
Mail Address: 3165 East Millrock Drive, Suite 330 Holladay, UT 84121
(Number & Street, Box and/or Route, City, State, Zip Code)

Operator

Name: Same as Owner Phone No.:(____) n/a
(If different than Owner's above)

Mail Address: n/a
(Number & Street, Box and/or Route, City, State, Zip Code)

Official Representative

Name: Craig Broussard Phone No.:(801) 993-7001

Title: Chief Executive Officer

3. Facility Classification (check one)

- [x] New Facility
- [ ] Existing Facility
- [ ] Modification of Existing Facility

4. Type of Facility (check one)

- [ ] Industrial
- [x] Mining
- [ ] Municipal
- [ ] Agricultural Operation
- [x] Other, please describe: Subsurface natural gas liquids storage facility

5. SIC/NAICS Codes: 2123 - Nonmetallic mineral mining and quarrying

Enter Principal 3 Digit Code Numbers Used in Census & Other Government Reports

6. Projected Facility Life: minimum of 25 years

7. Identify principal processes used, or services performed by the facility. Include the principal products produced, and raw materials used by the facility:

The Magnum NGLs Storage Facility will store natural gas liquids in solution-mined caverns within a subsurface salt deposit. The attached *Groundwater Discharge Permit Application Attachment* contains additional information.

8. List all existing or pending Federal, State, and Local government environmental permits:

	Permit	Permit Number
[ ]	NPDES or UPDES (discharges to surface water)	
[ ]	CAFO (concentrated animal feeding operation)	
[X]	UIC (underground injection of fluids)	UTU-27-AP-9232389
[ ]	RCRA (hazardous waste)	
[ ]	PDS (air emissions from proposed sources)	
[]	Construction Permit (wastewater treatment)	
[ ]	Solid Waste Permit (sanitary landfills, incinerators)	
[ ]	Septic Tank/Drainfield	
[X]	Other, specify Section 1.2 of the attached *Groundwater Discharge Permit Application Attachment* provides additional detail.	

9. Name, location (Lat. 39 ° 29' 36.21" N,Long. -112 ° 36' 42.54" W) and description of: each well/spring (existing, abandoned, or proposed), water usage(past, present, or future); water bodies; drainages; well-head protection areas; drinking water source protection zones according to UAC 309-600; topography; and man-made structures within one mile radius of the point(s) of discharge site. Provide existing well logs (include total depth and variations in water depths).

Name	Location	Description	Status	Usage
MH-1	39°29'36.21' N, -112°36'42.54' W	Water Well	Active	water for solution mining

Section 2.1, Appendix B, and Appendix E (well log) of the attached *Groundwater Discharge Permit Application Attachment* provides a more detailed discussion, table, and map to satisfy the requirements set forth in UAC 309-600.

The above information must be included on a plat map and attached to the application.

Part B - General Discharge Information

Complete the following information for each point of discharge to ground water. If more than one discharge point exists, photocopy and complete this Part B form for each discharge point.

1. **Location** (if different than Facility Location in Part A): Facility location is as described in Part A of this application.
   T.__________, R.__________, Sec.__________, __________1/4 of __________1/4,
   Lat.__________°__________'__________"N.Long.__________°__________'__________"W

2. **Type of fluid to be Discharged or Potentially Discharged**
   (check as applicable)

   Discharges (fluids discharged to the ground)

   [ ] Sanitary Wastewater: wastewater from restrooms, toilets, showers and the like
   [ ] Cooling Water: non-contact cooling water, non contact of raw materials, intermediate, final, or waste products
   [ ] Process Wastewater: wastewater used in or generated by an industrial process
   [] Mine Water: water from dewatering operations at mines
   [X] Other, specify: brine (sodium chloride) from solution mining operations associated with the development of subsurface salt storage caverns

   Potential Discharges (leachates or other fluids that may discharge to the ground)

   [ ] Solid Waste Leachates: leachates from solid waste impoundments or landfills
   [ ] Milling/Mining Leachates: tailings impoundments, mine leaching operations, etc.
   [ ] Storage Pile Leachates: leachates from storage piles of raw materials, product, or wastes
   [ ] Potential Underground Tank Leakage: tanks not regulated by UST or RCRA only
   [X] Other, specify: Same as discharges listed above

3. **Discharge Volumes**
   For each type of discharge checked in #2 above, list the volumes of wastewater discharged to the ground or ground water. Volumes of wastewater should be measured or calculated from water usage. If it is necessary to estimate volumes, enclose the number in parentheses. Average daily volume means the average per operating day: ex. For a discharge of 1,000,000 gallons per year from a facility operating 200 days, the average daily volume is 5,000 gallons.

Discharge Type:	Daily Discharge Volume	all in units of
Brine associated with solution mining	3,000 (maximum)	gallons per minute

4. **Potential Discharge Volumes**
   For each type of potential discharge checked in #2 above, list the maximum volume of fluid that could be discharged to the ground considering such factors as: liner hydraulic conductivity and operating head conditions, leak detection system sensitivity, leachate collection system efficiency, etc. Attach calculation and raw data used to determine said potential discharge.

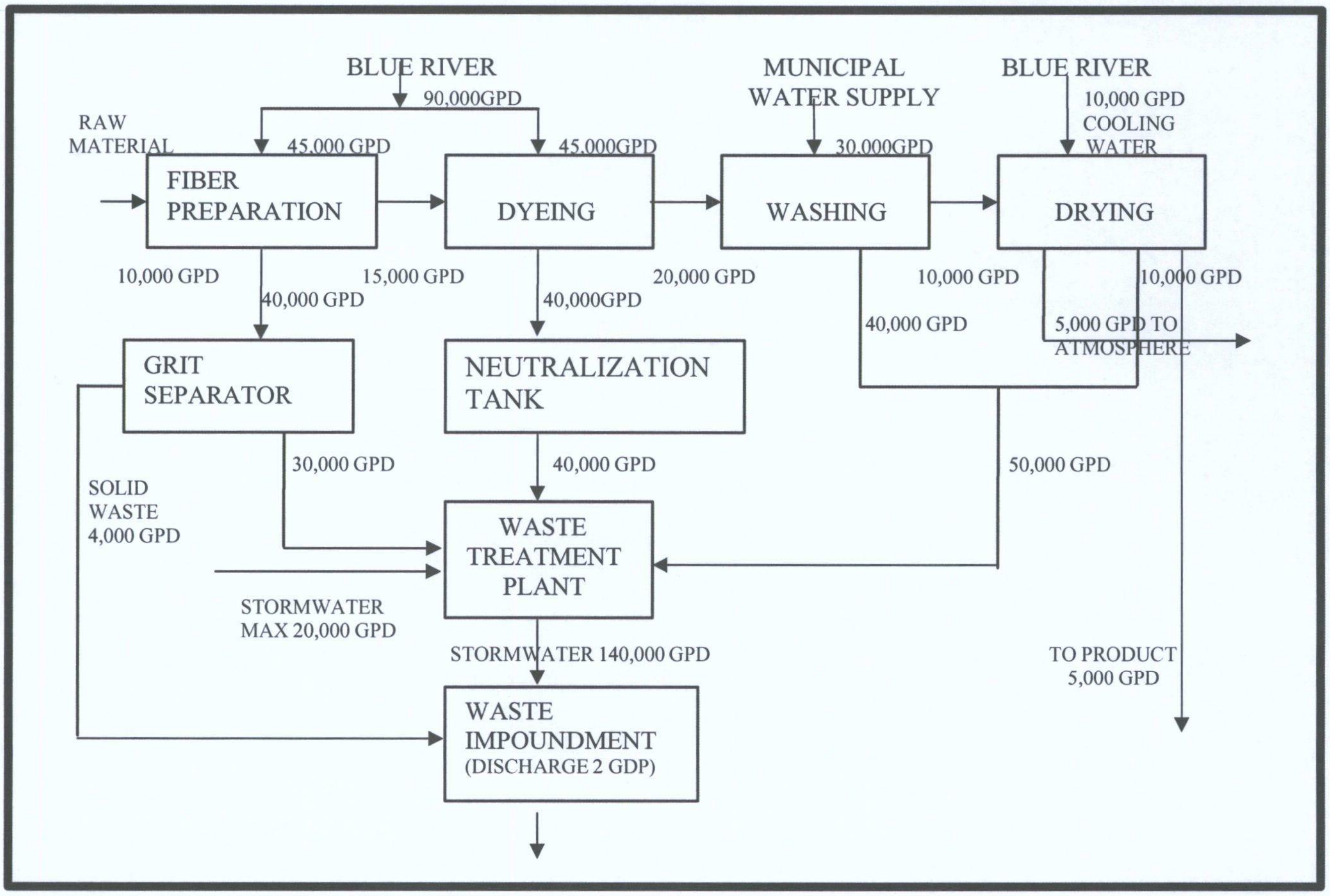
Discharge Type:	Daily Discharge Volume	all in units of
Brine associated with solution mining	0.24 (maximum)	gallons per minute

5. **Means of Discharge or Potential Discharge** (check one or more as applicable)

[] lagoon, pit, or surface impoundment (fluids) [ ] industrial drainfield
[ ] land application or land treatment
[ ] underground storage tank
[ ] discharge to an ephemeral drainage (dry wash, etc.)
[ ] percolation/infiltration basin
[ ] storage pile
[ ] mine heap or dump leach
[ ] landfill (industrial or solid wastes)
[ ] mine tailings pond
[X] other, specify Brine evaporation pond

6. **Flows, Sources of Pollution, and Treatment Technologies**

Flows. Attach a line drawing showing: 1) water flow through the facility to the ground water discharge point, and 2) sources of fluids, wastes, or solids which accumulate at the potential ground water discharge point. Indicate sources of intake materials or water, operations contributing wastes or wastewater to the effluent, and wastewater treatment units. Construct a water balance on the line drawing by showing average flows between intakes, operations, treatment units, and wastewater outfalls. If a water balance cannot be determined, provide a pictorial description of the nature and amount of any sources of water and any collection or treatment measures. See the following example.



7. **Discharge Effluent Characteristics**

Established and Proposed Ground Water Quality Standards - Identify wastewater or leachate characteristics by providing the type, source, chemical, physical, radiological, and toxic characteristics of wastewater or leachate to be discharged or potentially discharged to ground water (with lab analytical data if possible). This should include the discharge rate or combination of discharges, and the expected concentrations of any pollutant (mg/l). If more than one discharge point is used, information for each point must be provided.

Hazardous Substances - Review the present hazardous substances found in the Clean Water Act, if applicable. List those substances found or believed present in the discharge or potential discharge.

Part C - Accompanying Reports and Plans

The following reports and plans should be prepared by or under the direction of a professional engineer or other ground water professional. Since ground water permits cover a large variety of discharge activities, the appropriate details and requirements of the following reports and plans will be covered in the pre-design meeting(s). For further instruction refer to the Ground Water Permit Application Guidance Document.

8. Hydrogeologic Report

Provide a Geologic Description, with references used, that includes as appropriate:

Structural Geology – regional and local, particularly faults, fractures, joints and bedding plane joints;
Stratigraphy – geologic formations and thickness, soil types and thickness, depth to bedrock;
Topography – provide a USGS MAP (7 ½ minute series) which clearly identifies legal site location boundaries, indicated 100 year flood plain area and applicable flood control or drainage barriers and surrounding land uses.

Provide a Hydrologic Description, with references used, that includes:
Ground water – depths, flow directions and gradients. Well logs should be included if available. Include name of aquifer, saturated thickness, flow directions, porosity, hydraulic conductivity, and other flow characteristics, hydraulic connection with other aquifers or surface sources, recharge information, water in storage, usage, and the projected aerial extent of the aquifer. Should include projected ground water area of influence affected by the discharge. Provide hydraulic gradient map indicating equal potential head contours and ground water flow lines. Obtain water elevations of nearby wells at the time of the hydrologic investigation. Collect and analyze ground water samples from the uppermost aquifer which underlies the discharge point(s). Historic data can be used if the applicant can demonstrate it meets the requirements contained within this section. Collection points should be hydraulically up and downgradient and within a one-mile radius of the discharge point(s). Ground water analysis should include each element listed in Ground Water Discharge Permit Application, Part B7.
NOTE Failure to analyze for background concentrations of any contaminant of concern in the discharge or potential discharge may result in the Executive Secretary's presumptive determination that zero concentration exist in the background ground water quality.
Sample Collection and Analysis Quality assurance – sample collection and Preservation must meet the requirements of the EPA RCRA Technical Enforcement Guidance Document, OSWER-9959.1, 1986 [UAC R317-6-6.3(I,6)]. Sample analysis must be performed by State of Utah certified laboratories and be certified for each of the parameters of concern. Analytical methods should be selected from the following sources [UAC R317-6-6.3L]: (Standard Methods for the Examination of Water and Wastewater, 20th Ed.,1998; EPA, Methods for Chemical Analysis of Water and Wastes, 1983; Techniques of Water Resources Investigation of the U.S. Geological Survey, 1998, Book 9; EPA Methods published pursuant to 40 CFR Parts 141, 142, 264 (including Appendix IX), and 270. Analytical methods selected should also include minimum detection limits below both the Ground Water Quality Standards and the anticipated ground water protection levels. Data shall be presented in accordance of accepted hydrogeolgic standards and practice.

Provide Agricultural Description, with references used, that includes:
If agricultural crops are grown within legal boundaries of the site the discussion must include: types of crops produced; soil types present; irrigation system; location of livestock confinement areas (existing or abandoned).

Note on Protection Levels:

After the applicant has defined the quality of the fluid to be discharged (Ground Water Discharge Permit Application, Part B), characterized by the local hydrogeologic conditions and determined background ground water quality (Hydrogeologic Report), the Executive Secretary will determine the applicable ground water class, based on: 1) the location of the discharge point within an area of formally classified ground water, or the background value of total dissolved solids. Accordingly, the Executive Secretary will determine applicable protection levels for each pollutant of concern, based on background concentrations and in accordance with UAC R317-6-4.

9. **Ground Water Discharge Control Plan:**
Select a compliance monitoring method and demonstrate an adequate discharge control system. Listed are some of the Discharge Control Options available.

No Discharge – prevent any discharge of fluids to the ground water by lining the discharge point with multiple synthetic and clay liners. Such a system would be designed, constructed, and operated to prevent any release of fluids during both the active life and any post-closure period required.

Earthen Liner – control the volume and rate of effluent seepage by lining the discharge point with a low permeability earthen liner (e.g. clay). Then demonstrate that the receiving ground water, at a point as close as practical to the discharge point, does not or will not exceed the applicable class TDS limits and protection levels* set by the Executive Secretary. This demonstration should also be based on numerical or analytical saturated or unsaturated ground water flow and contaminant transport simulations.

Effluent Pretreatment – demonstrate that the quality of the raw or treated effluent at the point of discharge or potential discharge does not or will not exceed the applicable ground water class TDS limits and protection levels* set by the Executive Secretary.

Contaminant Transport/Attenuation – demonstrate that due to subsurface contaminant transport mechanisms at the site, raw or treated effluent does not or will not cause the receiving ground water, at a point as close as possible to the discharge point, to exceed the applicable class TDS limits and protection levels* set by the Executive Secretary.

Other Methods – demonstrate by some other method, acceptable to the Executive Secretary, that the ground water class TDS limits and protection levels* will be met by the receiving ground water at a point as close as practical to the discharge point.

*If the applicant has or will apply for an alternate concentration limit (ACL), the ACL may apply instead of the class TDS limits and protection levels.

Submit a complete set of engineering plans and specifications relating to the construction, modification, and operation of the discharge point or system. Construction Permits for the following types of facilities will satisfy these requirements. They include: municipal waste lagoons; municipal sludge storage and on-site sludge disposal; land application of wastewater effluent; heap leach facilities; other process wastewater treatment equipment or systems.

Facilities such as storage piles, surface impoundments and landfills must submit engineering plans and specifications for the initial construction or any modification of the facility. This will include the design data and description of the leachate detection, collection and removal system design and construction. Provide provisions for run on and run-off control.

10. **Compliance Monitoring Plan:**

The applicant should demonstrate that the method of compliance monitoring selected meets the following requirements:

Ground Water Monitoring – that the monitoring wells, springs, drains, etc., meet all of the following criteria: is completed exclusively in the same uppermost aquifer that underlies the discharge point(s) and is intercepted by the upgradient background monitoring well; is located hydrologically downgradient of the discharge point(s); designed, constructed, and operated for optimal detection (this will require a hydrogeologic characterization of the area circumscribed by the background sampling point, discharge point and compliance monitoring points); is not located within the radius of influence of any beneficial use public or private water supply; sampling parameters, collection, preservation, and analysis should be the same as background sampling point; ground water flow direction and gradient, background quality at the site, and the quality of the ground water at the compliance monitoring point.

Source Monitoring – must provide early warning of a potential violation of ground water protection levels, and/or class TDS limits and be as or more reliable, effective, and determinate than a viable ground water monitoring network.

Vadose Zone Monitoring Requirements – Should be: used in conjunction with source monitoring; include sampling for all the parameters required for background ground water quality monitoring; the application, design, construction, operation, and maintenance of the monitoring system should conform with the guidelines found in: Vadose Zone Monitoring for Hazardous Waste Sites; June 1983, KT-82-018(R).

Leak Detection Monitoring Requirements – Should not allow any leakage to escape undetected that may cause the receiving ground water the exceed applicable ground water protection levels during the active life and any required post-closure care period of the discharge point. This demonstration may be accomplished through the use of numeric or analytic, saturated or unsaturated, ground water flow or contaminant transport simulations, using actual filed data or conservative assumptions. Provide plans for daily observation or continuous monitoring of the observation sump or other monitoring point and for the reporting of any fluid detected and chemical analysis thereof.

Specific Requirements for Other Methods – Demonstrate that: the method is as or more reliable, effective, and determinate than a viable ground water monitoring well network at detecting any violation of ground water protection levels or class TDS limits, that may be caused by the discharge or potential discharge; the method will provide early warning of a potential violation of ground water protection levels or class TDS limits and meets or exceeds the requirements for vadose zone or leak detection monitoring.

Monitoring well construction and ground water sampling should conform to A Guide to the Selection of Materials for Monitoring Well Construction. Sample collection and preservation, should conform to the EPA RCRA Technical Enforcement Guidance Document, OSWER-9950.1, September, 1986. Sample analysis must be performed by State-certified laboratories by methods outlined in UAC R317-6-6.3L. Analytical methods used should have minimum detection levels which meet or are less than both the ground water quality standards and the anticipated protection levels.

11. **Closure and Post Closure Plan:** The purpose of this plan is to prevent ground water contamination after cessation of the discharge or potential discharge and to monitor the discharge or potential discharge point after closure, as necessary. This plan has to include discussion on: liquids or products, soils and sludges; remediation process; the monitoring of the discharge or potential discharge point(s) after closure of the activity.

12. **Contingency and Corrective Action Plans:** The purpose of this Contingency plan is to outline definitive actions to bring a discharge or potential discharge facility into compliance with the regulations or the permit, should a violation occur. This applies to both new and existing facilities. For existing facilities that may have caused any violations of the Ground Water Quality Standards or class TDS limits as a result of discharges prior to the issuance of the permit, a plan to correct or remedy any contaminated ground water must be included.

    Contingency Plan – This plan should address: cessation of discharge until the cause of the violation can be repaired or corrected; facility remediation to correct the discharge or violation.

    Corrective Action Plan – for existing facilities that have already violated Ground Water Quality Standards, this plan should include: a characterization of contaminated ground water; facility remediation proposed or ongoing including timetable for work completion; ground water remediation.

Certification

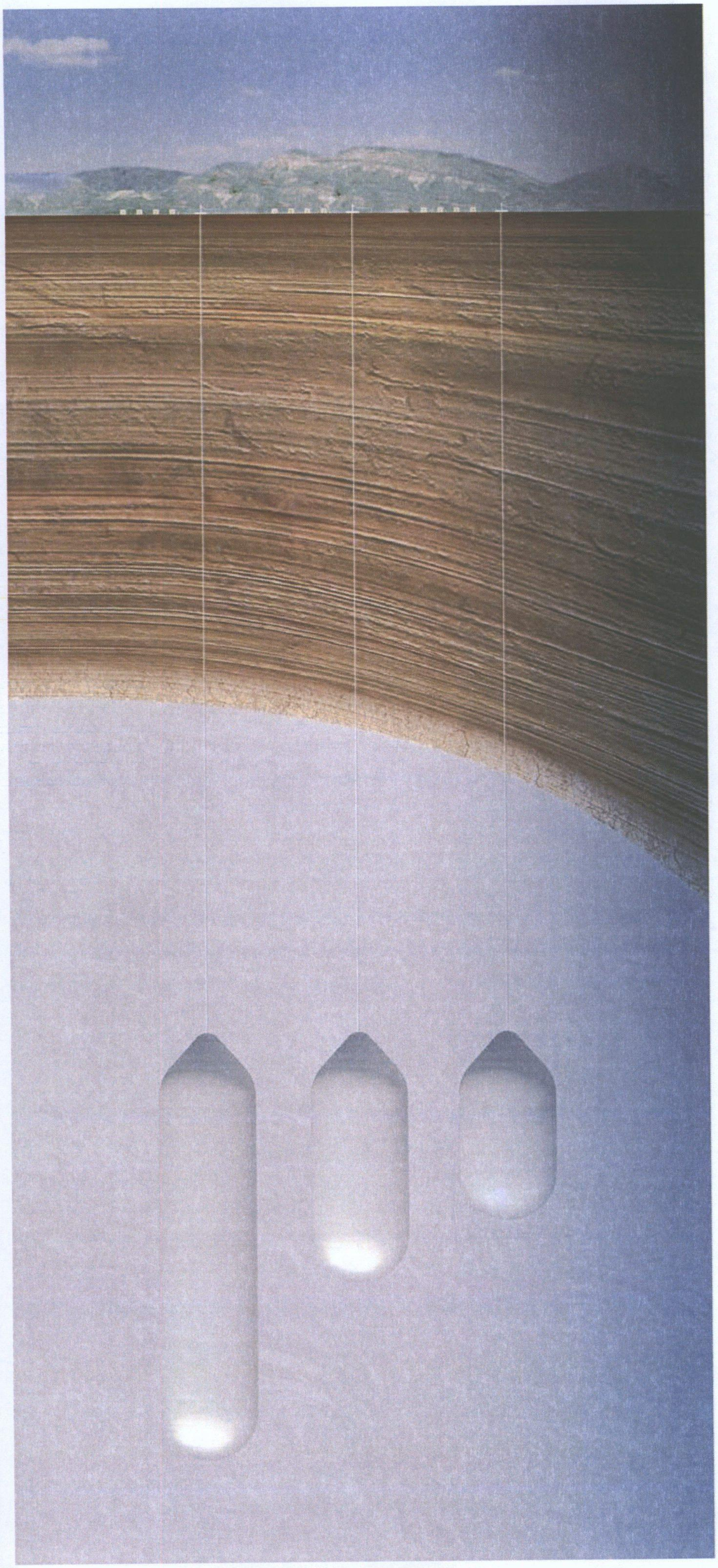
I certify under penalty of law that this document and all attachments were prepared under my direction or supervision in accordance with a system designed to assure that qualified personnel properly gather and evaluate the information submitted. Based on my inquiry of the person or persons who manage the system or those persons directly responsible for gathering the information, the information submitted is, to the best of my knowledge and belief, true, accurate, and complete. I am aware that there are significant penalties for submitting false information, including the possibility of fine and imprisonment for knowing violations.

TIFFANY A. JAMES VP PROJECT DEVELOPMENT
NAME & OFFICIAL TITLE (type or print)

801.719.9131/801.993.7001
PHONE NO. (area code & no.)

[signature]
SIGNATURE

June 4, 2013
DATE SIGNED



Groundwater Discharge Permit Application Attachment

Magnum NGLs Storage Project- Brine Evaporation Pond

MAGNUM

NGLs

Groundwater Discharge Permit Application Attachment

Magnum NGLs Storage Project - Brine Evaporation Pond

June 4, 2013

Prepared For:

Magnum NGLs Solution Mining, LLC
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R. JEFFREY DAVIS
STATE OF UTAH

Prepared by:

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Tables

Figures

Section 1

Introduction

Magnum NGLs Solution Mining, LLC (Magnum) is constructing a Natural Gas Liquids Storage Facility (Project) in Millard County, Utah approximately 10 miles north of Delta. The Project entails solution mining storage caverns in a subsurface salt deposit for the purpose of storing propane and butane. The resulting brine from the solution mining process will be stored in an above ground, 159-acre earthen pond for evaporation. The Project lies within an approximately 750-acre site located on Utah School and Institutional Trust Lands Administration (SITLA) lands (**Figure 1-1**). **Table 1-1** provides the legal location of the Project.

Table 1-1: Legal Locations of Project Facilities (SLB&M)

Township	Range	Section	Allotment
15 South	6 West	19	SE¼
15 South	6 West	30	NE¼, S of NW¼, W of SE¼, SW¼
15 South	6 West	31	W of NE¼, NW¼, W of SE¼, SW¼
15 South	7 West	22	SESE of the SE¼
15 South	7 West	23	SESE and S of the SW¼
15 South	7 West	26	NW¼
15 South	7 West	27	NENE of the NE¼

1.1 Brine Evaporation Pond Description

As a component of the Project, Magnum plans to construct a brine evaporation pond in the S½NW¼, SW¼NE¼, W½SE¼ and SW¼ of Section 30, Township 15 South, Range 6 West. Figures 1-2 through 1-4 depict the brine evaporation pond design. It is important to note that DWQ has approved a construction permit for a three pond scenario (Ponds 1, 2, and 3). This application only pertains to Pond 1.

Pond 1 has a disturbance area of approximately 159 acres. The brine evaporation pond will be constructed using a combination of excavation into the ground surface and the construction of elevated berms. Berms would have an external height of up to 45 feet above the ground level, with internal excavation depths up to 20 feet, depending on undisturbed land contours. The pond will be approximately 42 feet deep. Berms would be constructed with 2H:1V exterior slopes, 2.5H:1V interior slopes, and a 22-foot wide platform on top to allow berm/pond maintenance. During brine evaporation, a minimum of 3 feet of freeboard would be maintained in the pond to allow adequate storage area for incidental precipitation. The pond would be constructed with a compacted subgrade and double lining system with a proactive leak detection system to ensure adequate protection of the groundwater and the environment. A full description of the leak detection system is provided in Section 2.6.

The brine evaporation pond will be lined with a synthetic double liner system. The primary liner will consist of 80-mil HDPE geomembrane liner covering the full upstream embankment and basin of the pond. No horizontal joints will be allowed on the interior slopes. Horizontal joints and welds will be made a minimum distance of 5 feet onto the pond floor from the inside toe of the pond slopes, thus eliminating stress on the horizontal joints. The liner will be hot wedge welded to ensure continuous uninterrupted watertight containment.

The secondary liner will consist of 60-mil HDPE geomembrane drain liner with 130-mil high raised studs supporting the primary liner. The studs create an unpressurized drainage space between the liners. The drainage gap allows fluid to flow freely to a collection sump where it can be removed and pumped back into the pond. The liner will be hot wedge welded to ensure continuous uninterrupted watertight containment. **Figures 1-2**, **1-3**, and **1-4** provide pond location and engineering design details.

Magnum's brine evaporation pond engineering plans and specifications were previously reviewed and approved by the DWQ and Utah Division of Water Rights (DWRi). Refer to Section 1.2 below for a listing of pertinent permits.

1.2 Existing Environmental Permits

Magnum has received the following environmental permits or construction approvals for the Magnum NGLs Storage Project:

a. Division of Oil, Gas, and Mining (DOGM) Permit to Drill 43027500020000 (Cavern Well 5), issued 5/6/13;
b. DOGM Permit to Drill 43027500030000 (Cavern Well 6), issued 5/6/13;
c. DWRi Dam Impoundment Permit UT53584, issued 9/20/11 and renewed on 7/12/12;
d. DWQ Construction Permit for the Magnum Gas Storage Evaporation Ponds, issued 9/7/11 and renewed 8/7/12;
e. DWQ Underground Injection Control Permit (UIC) UTU-27-AP-9232389, last modified and approved 1/8/13; and
g. Millard County Conditional Use Permit, Z-2010-008, issued 3-28-11.

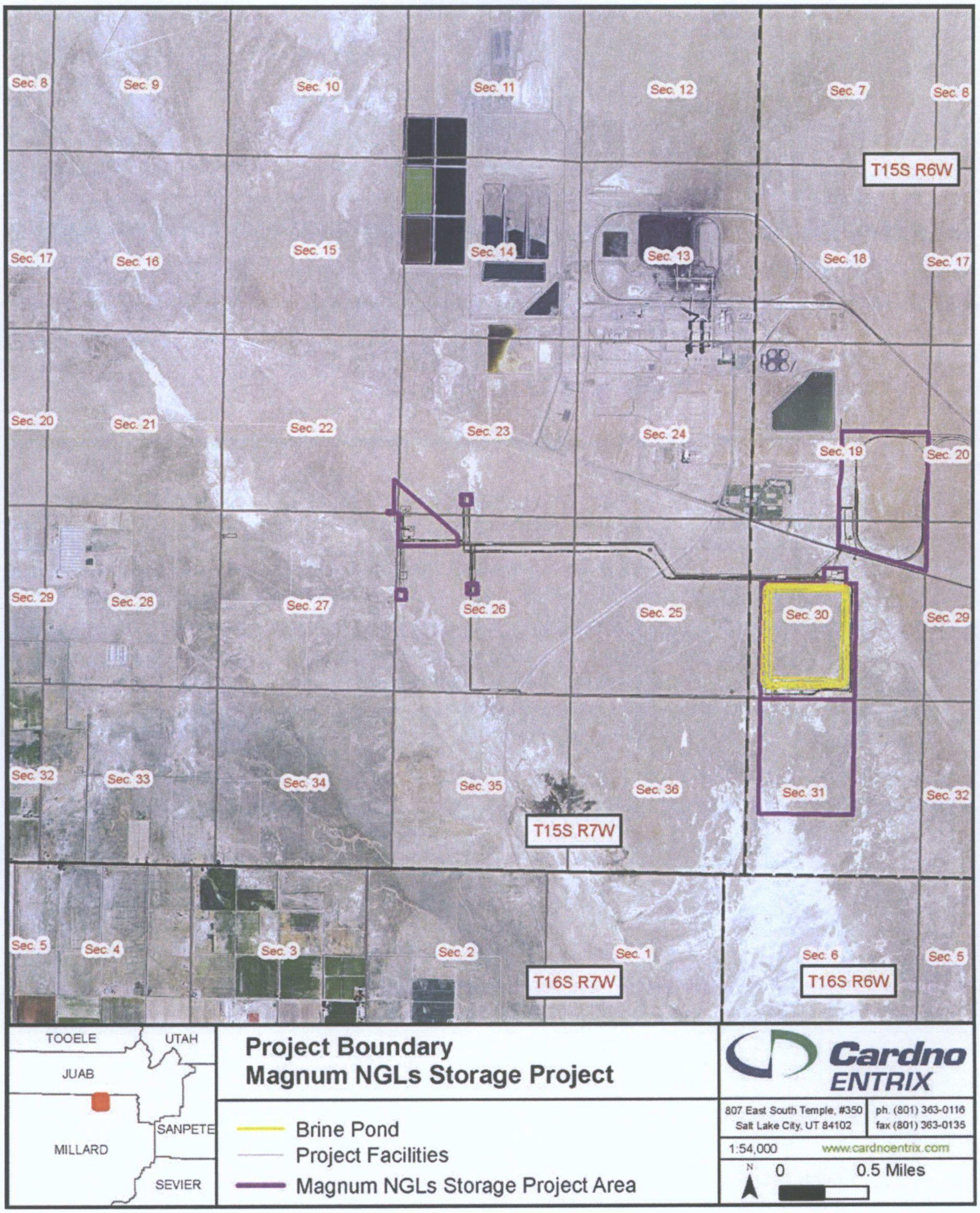


Figure 1-1 Project Boundary

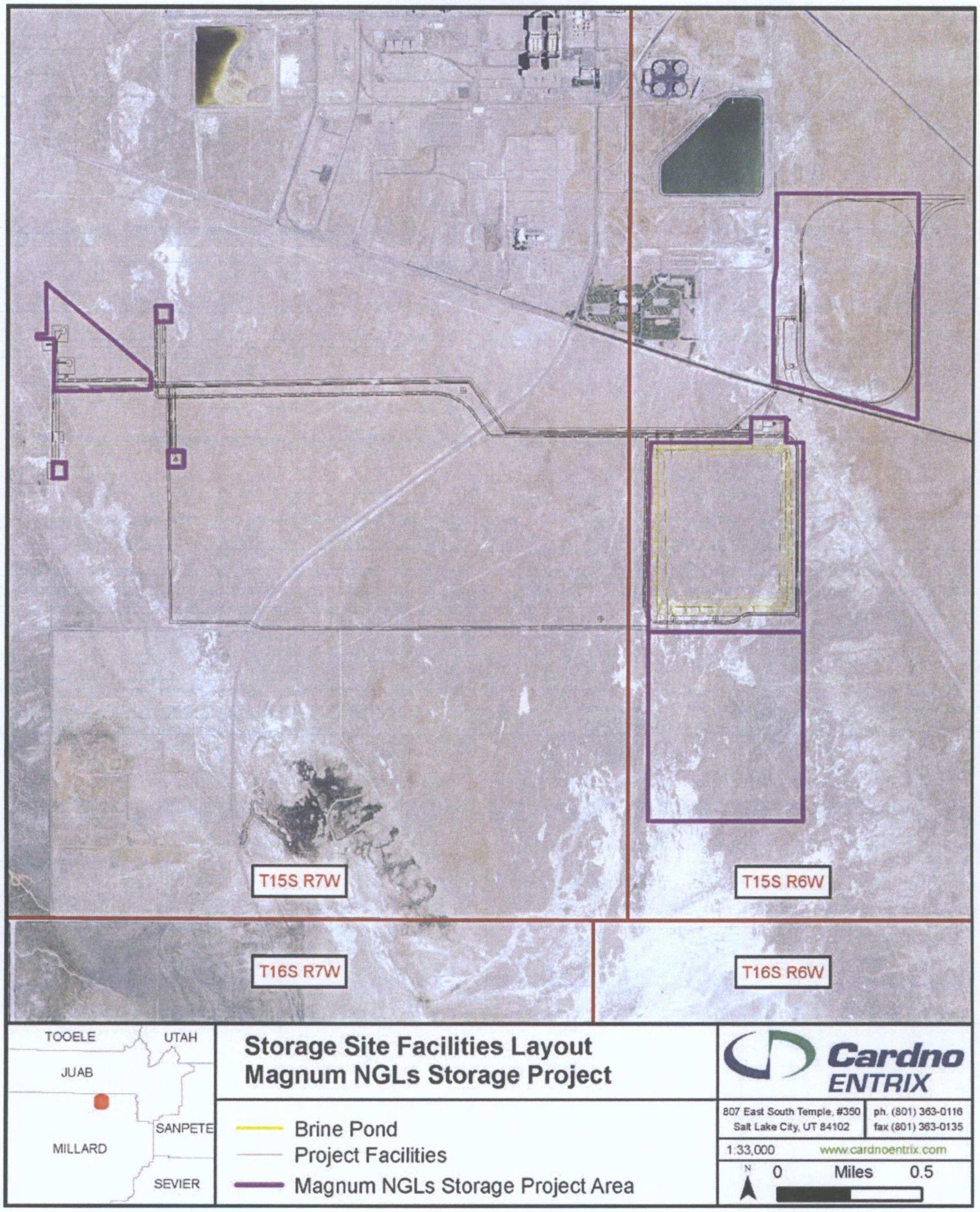


Figure 1-2 Magnum NGLs Storage Project Layout

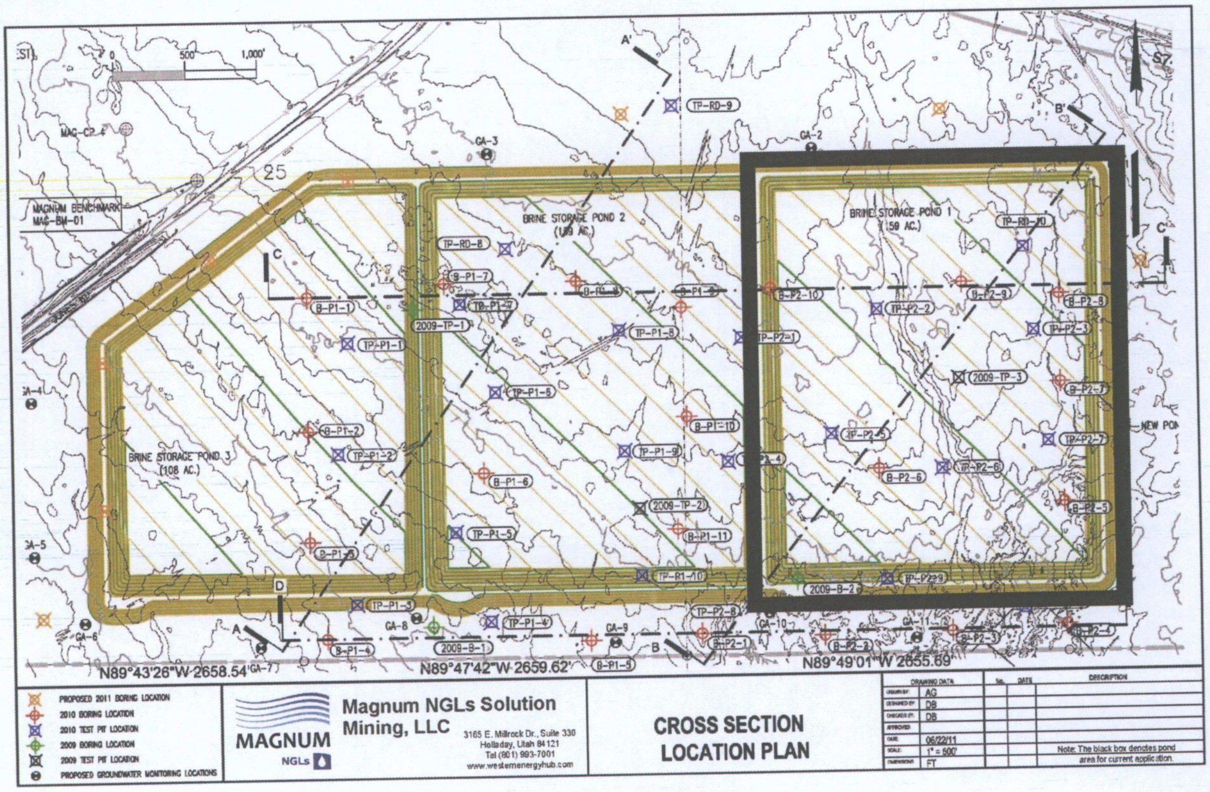


Figure 1-3: Brine Evaporation Ponds

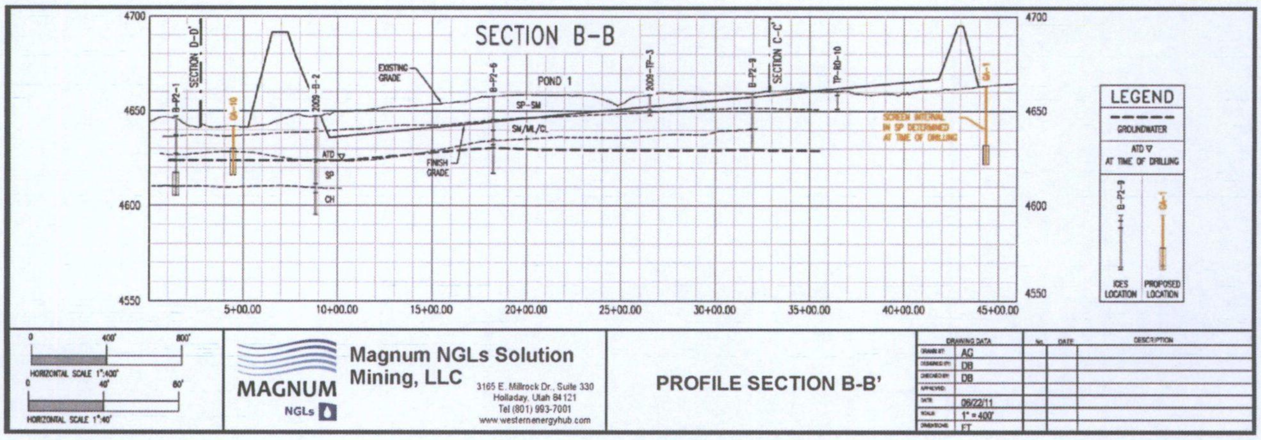


Figure 1-4: Brine Evaporation Pond Profile Section

Section 2

Application Requirements

2.1 Water Rights, Surface Water and Wells

A search of the DWRi database was performed to search for descriptions of each well/spring (existing, abandoned, or proposed), and existing well logs (include total depth and variations in water depths) within 1 mile of the brine evaporation ponds. Appendix A provides a table detailing water wells and rights within 1 mile of the brine evaporation pond.

In addition, Magnum's UIC Permit application for the Project contains comprehensive lists and figures providing water usage (past, present, or future); water bodies; drainages; well-head protection areas; drinking water source protection zones according to UAC 309-600; topography; and man-made structures within a one mile radius of the point of discharge (Magnum Solution Mining, 2011). **Figure 2-1** depicts a copy of the radius map from Magnum's UIC permit application.

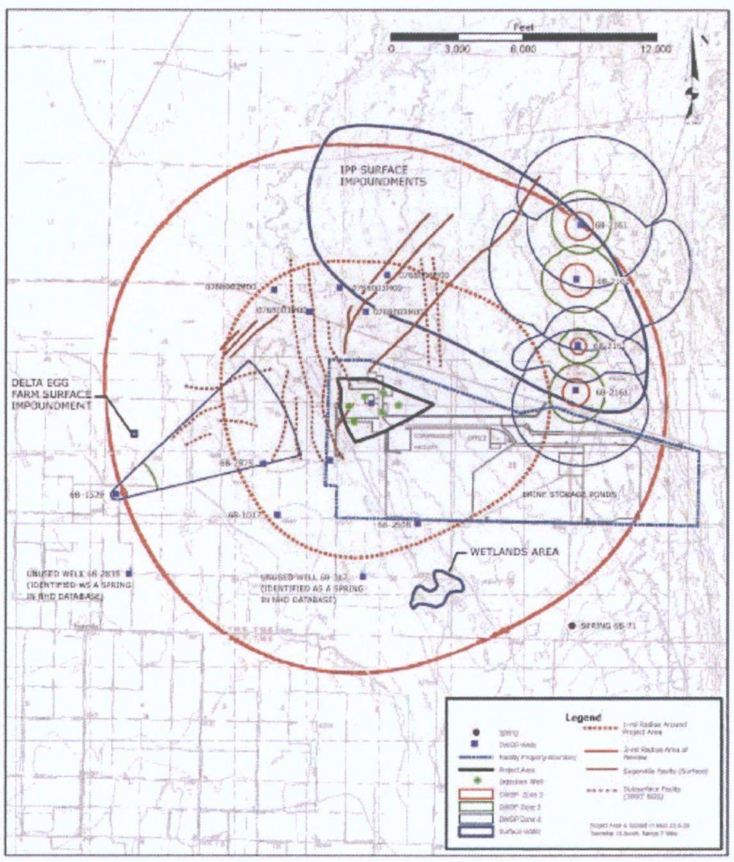


Figure 2-1: UIC Well Radius Map

2.2 Flows, Sources of Pollution, and Treatment Technologies

Flow to the brine evaporation pond will come from solution mining underground storage caverns within a subsurface, homogeneous salt deposit that is approximately one mile thick. The brine evaporation pond is designed with a zero-discharge dual liner system and leak detection system that is described in Sections 1.1 and 2.4. It is not anticipated that there will be any sources of pollution entering the system, therefore, treatment technologies are not necessary. **Figure 2-2** shows the brine flow through the facility. **Table 2-1** shows pond geometry and expected volume.

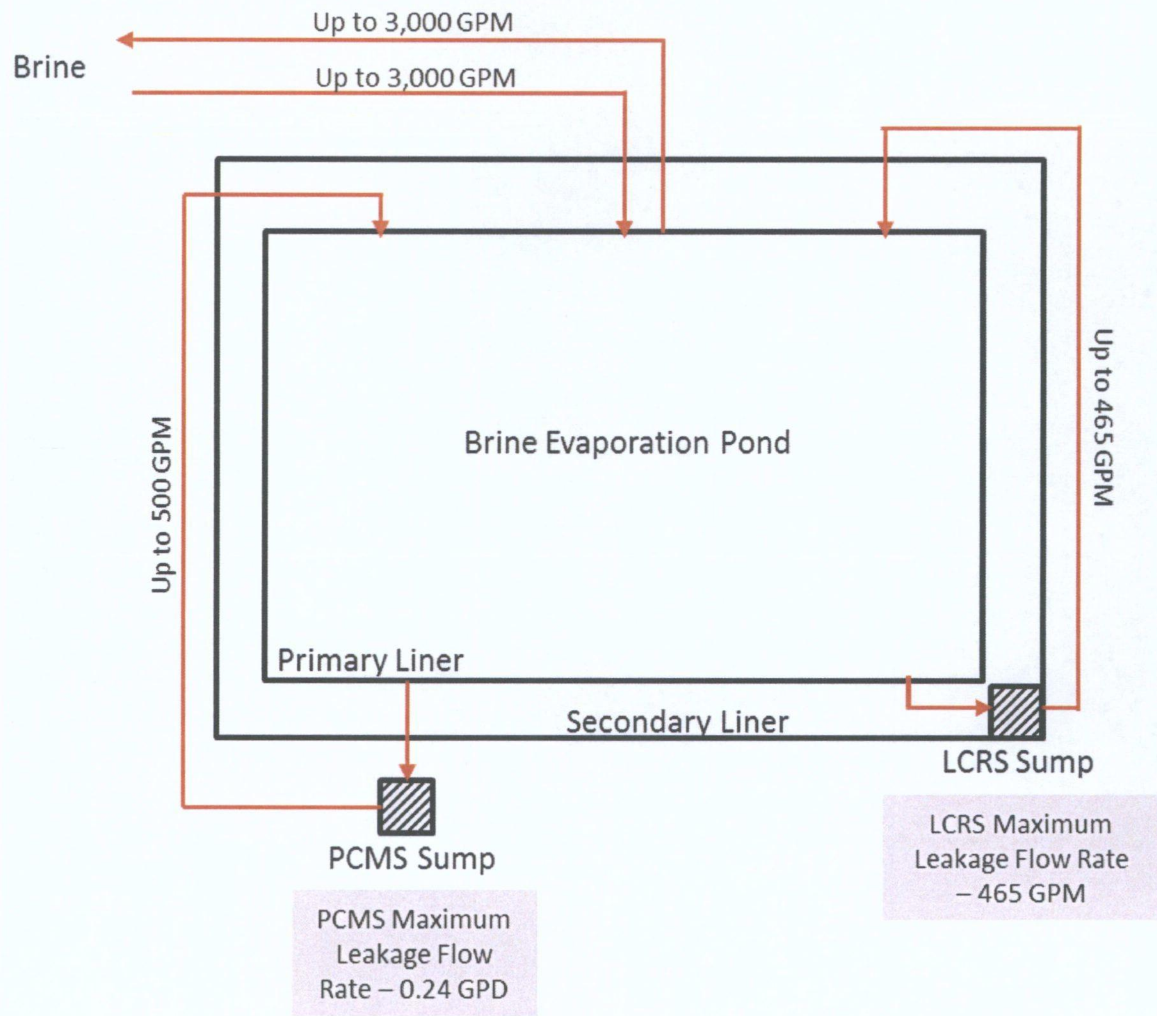


Figure 2-2: Brine Flow through Facility

Table 2-1: Predicted Volume of Brine

Evaporation Pond 1 Design Specifications Construction Specifications	
Length (at top of berm)	2,961 ft.
Width (at top of berm)	2,340 ft.
Total area (at top of berm)	159 acres
Pond depth	42 ft.
Slope	2.5:1
Pond top berm elevation	45 ft.
Total area at pond floor	133 acres
Total area at design water surface elevation	157 acres
Volumetric Calculations	
Total volume of pond at design water surface elevation of 43 ft.	5,712.29 ac-ft
Total volume of Pond at maximum water surface elevation	6,085 ac-ft

2.3 Discharge Effluent Characteristics

The brine evaporation pond will contain highly saturated brines that are a by-product of the solution mining process. Saturated brines will be approximately 98% sodium chloride. As the pond has been designed as a zero-discharge system, no discharges are anticipated from the brine evaporation ponds.

2.4 Environmental Setting

The environmental setting of Magnum's brine evaporation pond is described in the following sections

2.4.1 Geologic Description

The mountains that surround the basin of the Sevier Desert are composed of a variety of consolidated sedimentary, metamorphic and igneous rock. The basin is underlain by deposits that consist primarily of semi-consolidated and unconsolidated sediments of Tertiary and Quaternary age. The basin-fill includes sand, silt, clay and gravel deposited as alluvial fans, stream alluvium, mudflows, lacustrine (lake) sediments and deltas. The basin fill also contains scattered basalt flows and tuffs of late Tertiary and Quaternary age. Tertiary and Quaternary basin-fill deposits are over 7,000 feet thick. Oligocene and Miocene basin-fill sediments contained evaporite deposits. Through time, evaporites in the area flowed to form a salt dome.

The brine evaporation pond is situated overtop of the subsurface salt deposit in the Sevier - Black Rock Desert in the Basin and Range physiographic province of Utah. The profile at the site consists of three units. The upper unit is comprised of fine-grained glacial lacustrine deposits consisting of deep-water calcareous silts and may contain younger alluvium up to 10 feet thick. The upper unit is underlain by pre-Lake Bonneville alluvium consisting of sand and sandy gravel beds, of which 5 feet is exposed. The complete thickness of this unit is unknown. The lower unit consists of alluvium, silt and sandy silt deposited in large low-gradient alluvial fans, river terraces, and abandoned river channels on the river delta. This unit ranges up to 30 feet in thickness. Topography at the project site is relatively flat with minor relief. Appendix D provides maps of the regional geology of the Project area. **Table 2-2** provides the symbols and descriptions for the maps. The DWQ currently has a geologic description on file as Part B.3.4 and B.4 of Magnum's UIC Permit (UTU-27-AP-9232389) application for the Project.

Table 2-2: Symbols and Geologic Descriptions

Symbol	Description
Q	Quaternary surficial deposit (undivided); on cross sections only
Qal_2	Alluvium, middle and lower Holocene -- Tan and gray silt and sandy silt in large low-gradient alluvial fans
Qes	Eolian sand – Wind-blown sand; mostly silty fine-grained quartz sand
Qed	Eolian dunes – Chiefly barchan, parabolic, dome and transverse sand dunes that are active and not stabilized by vegetation; mostly tan, well-sorted, finegrained quartz sand
Qpm	Playa mud – Laminated, silty fine sand, silt, and clayey silt infused with various salts, gypsum, and calcium carbonate
Qdf	Underflow fan deposit – Thin-bedded to laminated, calcareous silt with minor interbedded very fine sand in thin beds that were deposited into the Lake Bonneville deltas of the Sevier River
Qlf	Fine-grained lake deposits – Grayish-tan, tan and light gray, calcareous silts that are deep-water sediments of Lake Bonneville
QTif	Fine-grained lacustrine deposits of Sevier Desert – Brown and light olive gray, calcareous, lacustrine silt and silty clay with minor sand; off shore to deepwater sediments. Pliocene to middle Pleistocene in age
Tvs	Tertiary volcanic and sedimentary units, undivided – on cross section only
Tbf	Tertiary basin-fill, undivided – Alluvium, mudflow and lacustrine deposits of sand, silt, clay and gravel – on cross section only
Ts	"Salt" structure, Miocene and upper Oligocene – Halite, anhydrite, gypsum and minor detrital sand and clay – on cross-section only

2.4.2 Hydrologic Description

The principal regional groundwater system is the unconsolidated basin-fill deposits that formed from erosion of the surrounding mountains and was laid down by streams, lakes, and mudflows. These regional deposits consist of interbedded and lenticular deposits of clay, silt, sand, gravel and boulders. The regional depositional processes created alternating and interfingering layers and lenses with regional horizontal and vertical heterogeneity. Differences in sorting and grain size influence local permeability and storage capacity, which can vary greatly depending on the nature of local depositional processes. Sediments are generally coarser near the mountain front and grade finer towards the valley centers. Stream channel deposits are coarser and better sorted than alluvial fan and mudflow deposits that generally occur at the base of steep drainages. Vast lakes that occupied the valleys many thousands of years ago deposited interbedded clay and fine-grained sands. Rivers flowing into these lakes formed coarse-grained delta deposits near the ancient lake shore, such as near the mouth of Leamington Canyon.

Aquifers in the area have been clearly defined using data collected during the installation of multiple wells constructed in the region around the Magnum site, including Magnum's MH-1 Test Well (constructed in 2009). The unconfined water table aquifer is located above the shallow artesian aquifer and is generally confined to the upper 50 to 150 feet, the shallow artesian aquifer to depths of about 150 to 700 feet, and the deep artesian aquifer between about 700 to 1,400 feet (the bottom of historically drilled wells). A previously undefined deeper confined aquifer (defined as the basement aquifer) is located at depths greater than 1,400 feet. **Figure 2-3** provides a diagram of the hydrostratigraphic units in the vicinity of the Project. The

DWQ currently has a complete hydrologic description on file as Part B.5 of Magnum's UIC Permit.

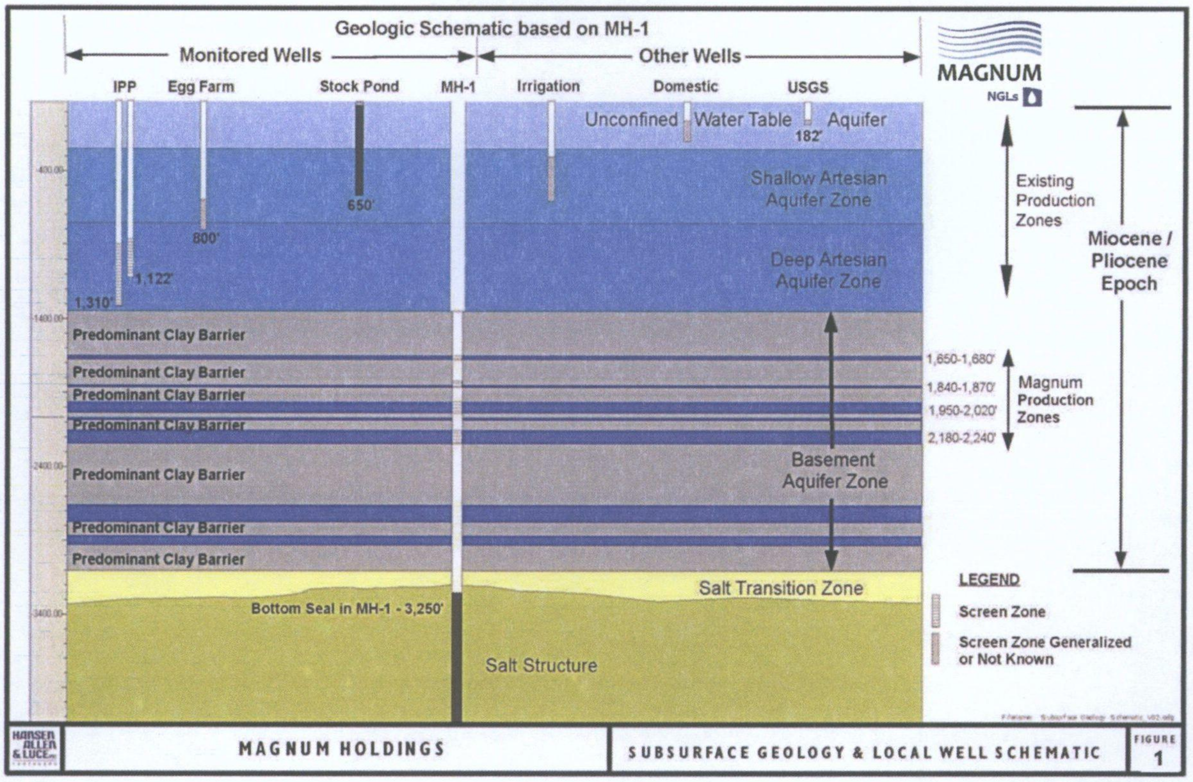


Figure 2-3: Hydrostratigraphic Framework of the Project Area (Cardno ENTRIX, 2011)

2.4.2.1 Recharge, Discharge and Groundwater Flow Direction

Recharge to the principal groundwater aquifer system (basin-fill deposits) in the Sevier Desert occurs by stream infiltration along mountain fronts, subsurface inflow from consolidated rocks of mountain areas, subsurface inflow from adjoining basins, precipitation on basalt outcrops, and seepage from rivers, canals, reservoirs and unconsumed irrigation. Prime recharge areas for the unconfined water table aquifer occur mostly near the mountain fronts in the Project region. Ultimately, some of the water that recharges the water table aquifer flows downgradient and provides recharge into the underlying artesian aquifers. **Figure 2-4** shows a schematic block diagram showing the basin-fill groundwater system in the Sevier Desert.

Groundwater generally flows from recharge areas near the mountains on the northeast and east of the Sevier Desert toward discharge areas in the central and western parts of the area. Groundwater flow direction is perpendicular to the potentiometric contours and is shown on the Regional Geology Maps in Appendix D for the shallow artesian aquifer and the deep artesian aquifer. As indicated earlier, no data is available to verify flow direction in the shallow unconfined water table aquifer. As a general rule however, unconfined flows typically move in a direction perpendicular to the topographic contour, or in the same direction as the ground surface slope.

Groundwater discharge occurs by evapotranspiration, subsurface outflow to adjoining basins, discharge to springs (largely to Clear Lake Springs, located about 20 miles south of Delta City), and to wells. Snyder (1998) identifies a large groundwater discharge area due to evapotranspiration generally to the west and south of the Project area.

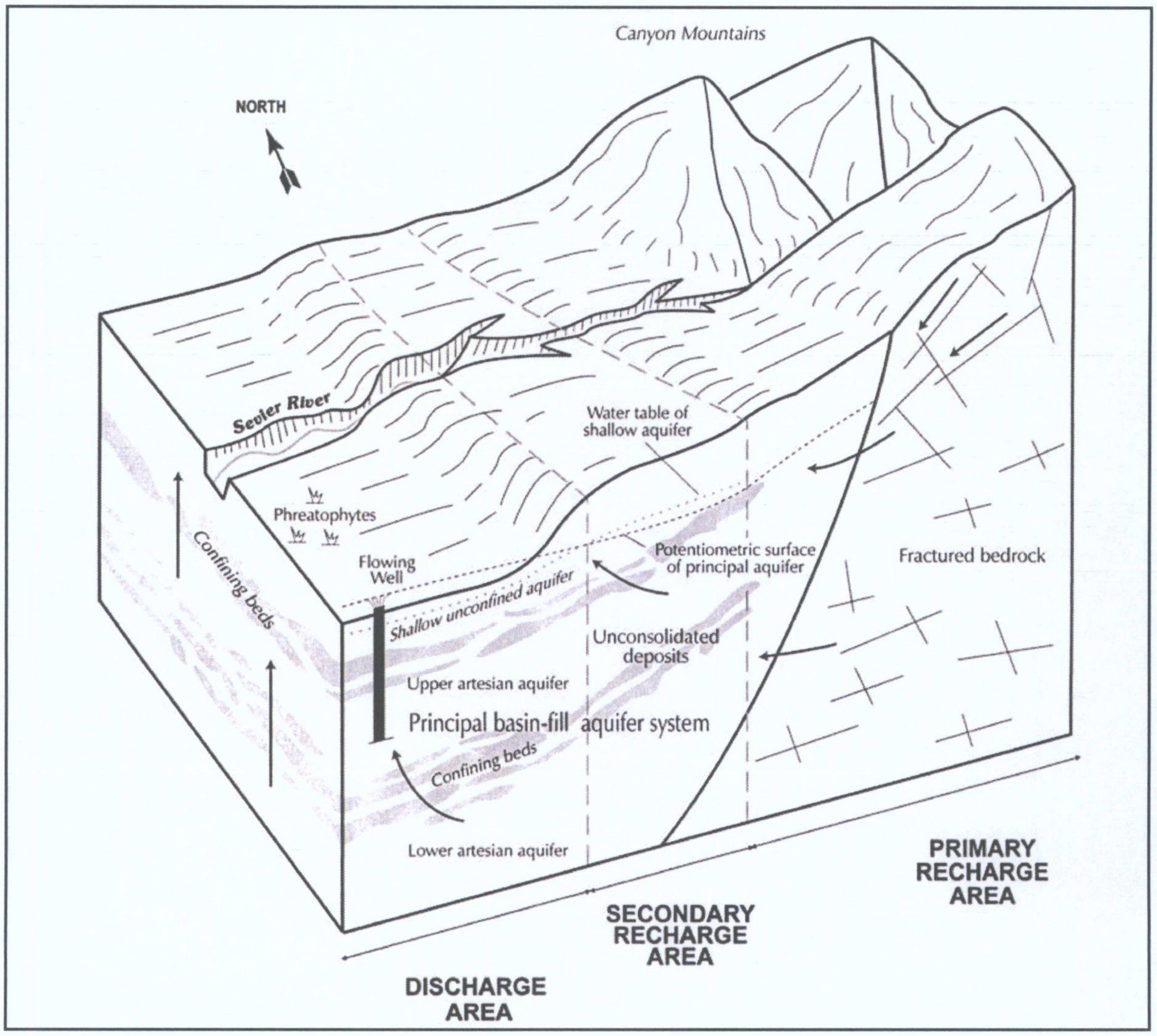


Figure 2-4: Basin-Fill Groundwater System in the Sevier Desert (from Snyder 1998)

2.4.2.2 Surface and Groundwater Quality

As part of Magnum's MH-1 Test Well start-up, testing and evaluation process groundwater quality data was collected and submitted to the DWQ. Three other locations were also tested. **Figure 2-5** depicts the testing locations and **Table 2-3** provides a summary of results.

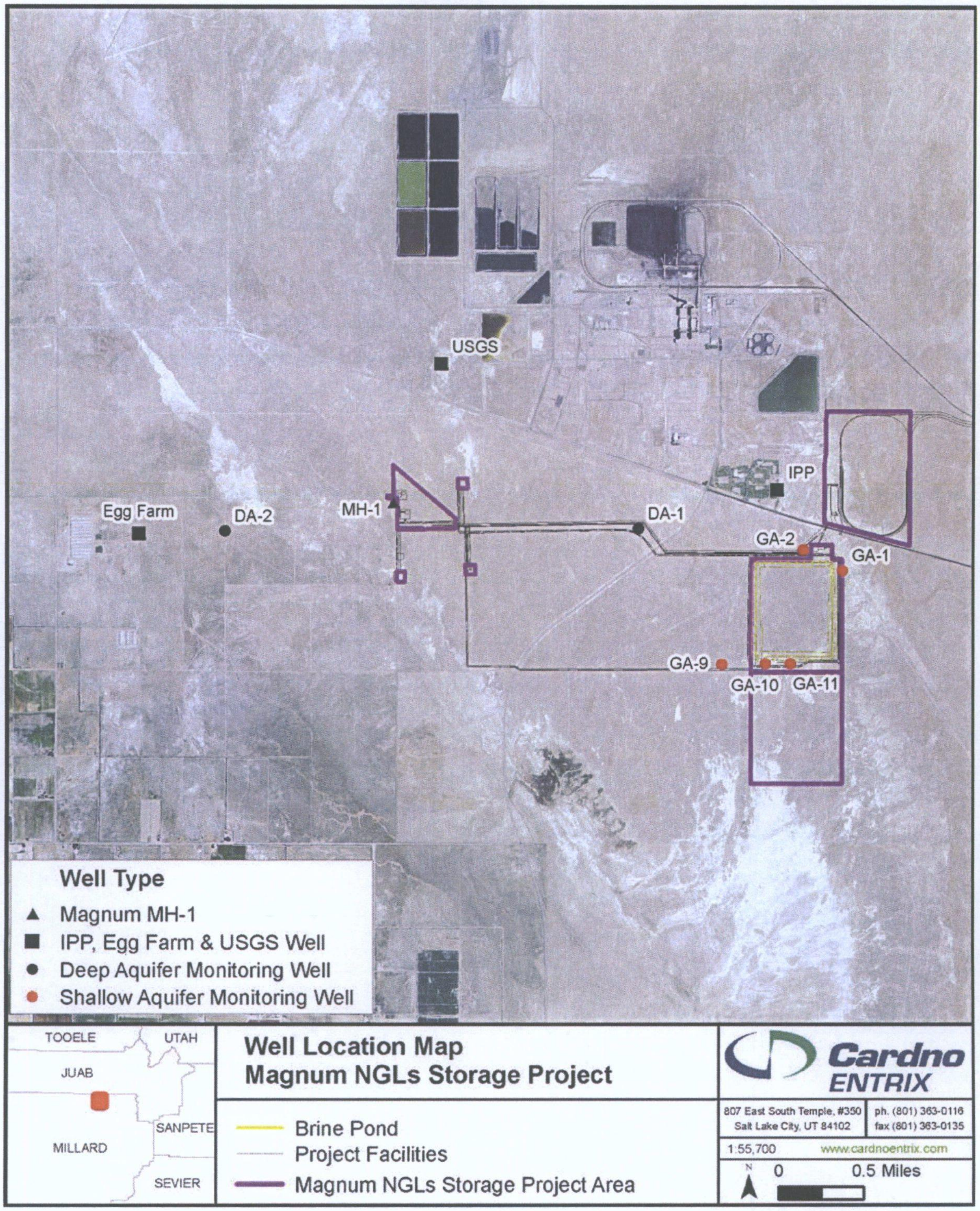


Figure 2-5: Water Quality Sampling Locations

Table 2-3: Groundwater Quality Data

Parameter	Unit	Well			
		MH-1	Delta Egg Farm	IPP	Stock Pond
Bromide	mg/L	0.1	0.05	0.05	0.2
Chloride	mg/L	210	64	37	298
Conductivity	umhos/cm	1250	565	410	1930
Fluoride	mg/L	0.9	0.6	0.4	2
Nitrate	mg/L	ND	ND	0.4	ND
Nitrite	mg/L	ND	ND	ND	ND
pH	pH Units	7.8	7.9	707	8.3
Sulfate	mg/L	163	66	27	158
TDS	mg/L	731	328	249	1140
Arsenic	mg/L	0.0355	0.0545	0.0146	0.156
Calcium	mg/L	23.5	16.6	15.2	16.5
Iron	mg/L	0.08	0.14	ND	3.81
Magnesium	mg/L	8.8	7.0	9.2	13.2
Potassium	mg/L	2.7	1.6	3.5	9.0
Silica	mg/L	33.5	22.4	38.5	42.8
Sodium	mg/L	193	74.6	48	363

2.5 Agricultural Description

No agricultural crops are grown in the legal boundaries of the site. The area is currently used for livestock grazing.

2.6 Groundwater Discharge Control Plan

In designing the evaporation pond, Magnum worked extensively with federal, state, and local regulatory agencies to design a zero discharge pond system that incorporates four stages of leak protection and detection, including a 1) double liner, 2) a leak collection recovery system, 3) a process component monitoring system, and 4) a monitoring well network. Potential groundwater discharge will be controlled first though the double lining of the pond and then through the engineered design of the Leak Collection Recovery System (LCRS) and the Process Component Monitoring System (PCMS) as described in the following sections.

The LCRS is a secondary, protective engineering control that provides a rapid system for detection of leaks through the primary lining system. The LCRS will consist of an open-space drainage layer between the primary and secondary lining systems. This system is designed to provide drainage of liquids that leak through the upper lining system to sumps located at low points within the pond floor. Probes will be placed in the sumps to detect the presence of liquids. Liquids that enter the sumps can also be tested for the presence of high concentrations of brine indicating leak(s) in the primary lining system. Additionally, a 4-inch diameter perforated polyethylene (CPE) piping will be positioned along the toe of the west and south earthen embankments to increase lateral flow. Any solution reporting to the sump can be pumped and returned to the brine pond surface creating a closed system.

The design of the LCRS sump is based on a projected maximum leakage flow rate that was calculated by AMEC (2011) and based on studies by Giroud and Bonaparte (1989). The purpose of calculating a maximum leakage flow rate is to determine a worst case scenario value for leakage from the primary liner. Then this value is used to design a sump and recovery/return system that can manage leakage up to that maximum rate. The maximum leakage flow rate for the primary liner was calculated at 465gpm (AMEC 2011).

The PCMS is a tertiary, protective engineering control that will consist of a series of shallow trenches containing 4-inch diameter perforated and corrugated CPE piping below the secondary liner. The CPE piping will allow any liquids permeating the secondary liner to flow into an additional sump located near the LCRS sump. To limit the amount of fine sediment flowing into the system CPE piping will be surrounded by coarse sand and sleeved with a 3-oz/yd^2 non-woven geotextile sock. The PCMS is located at the upstream toeslope of each earthen embankment and three diagonal runs across along the base of the pond. Any solution reporting to the sump will also be pumped and returned to the brine pond surface.

The design of the PCMS sump is also based on a projected maximum leakage flow rate that was calculated by AMEC (2011) and based on studies by Giroud and Bonaparte (1989). Again, the purpose of calculating a maximum leakage flow rate is to determine a worst case scenario value for leakage from the secondary liner in order to design a sump and recovery/return system that can manage leakage up to that maximum rate. The maximum leakage flow rate for the secondary liner was calculated at 0.24 gallons per day (AMEC 2011). This low rate can be attributed to the low hydraulic head that results from using a dual liner system. It should be noted that 0.24 gallons per day is well below the current maximum allowable leakage rate of 200 gallons per acre per day that was established by EPA and accepted in Utah (Koerner and Koerner 2009). As the PCMS leakage rate is the only potential discharge source, it is used as the reportable rate for the pond.

2.7 Compliance Monitoring Plan

Magnum has developed a comprehensive Groundwater Monitoring, Mitigation and Protection Plan and Brine Evaporation Pond Management Plan as part of the permitting process for the Project. A brief description is provided in the following sections.

2.7.1 Groundwater Monitoring

Groundwater monitoring of the brine evaporation pond will consist of two components: a monthly physical leak inspection; and, the collection and analysis of data from the Project monitoring well network.

The first component will entail physical inspections of the pond impoundment and operational components, including monitoring for leakage at the sumps. The physical inspection will be completed on a monthly basis to confirm the integrity of the pond berms and identify any associated ground failures like fissures that could adversely affect integrity of the engineered design. This inspection will also include an examination of monitoring equipment including leak detection and pump initialization sensors installed within the sumps. In addition, the equipment will be inspected and tested semi-annually to confirm proper operation. Non-functioning units will be immediately repaired or replaced.

The second component will entail collecting data from five groundwater monitoring wells in the vicinity of the pond. The monitoring well network will consist of five shallow water monitoring wells that will be installed both upgradient and downgradient of the brine evaporation pond as described below.

2.7.2 Source and Vadose Zone Monitoring

Source and vadose zone monitoring will be accomplished by shallow water table aquifer monitoring. A total of five wells will be installed in the vicinity of the pond to establish baseline water quality conditions and to verify that the double liner, LCRS and PCMS is properly operating. These monitoring wells will provide a fourth tier verification of overall system integrity. Two monitoring wells (GA-1 and GA-2) will be installed up-gradient of the brine evaporation pond. Three monitoring wells will be installed immediately adjacent to the pond embankment and down-gradient from the sump where the down-gradient direction is outside the pond footprint (GA-9, GA-10, and GA-11).

All monitoring wells will be equipped with dedicated pumps that will provide quick and reliable groundwater samples from the wells. Groundwater sample analysis and reporting will be based on acceptable water quality as regulated by Class II groundwater discharge standards and listed in Table 1 of RS-317-6-2 of the DWQ groundwater rules.

2.7.3 Leak Detection Monitoring

Monitoring for leakage at the brine evaporation pond sump will be accomplished monthly. The sump will be equipped with a water detection sensor and a conductivity meter to identify whether the water is highly saturated with brines or relatively clean. A high conductivity (greater than two orders of magnitude above conductivity levels established as base water quality conditions for the site) would indicate a leak from the brine pond. A low conductivity reading (less than one order of magnitude above conductivity levels established as base water quality conditions for the site) will help clarify if an outside water source, perhaps from the anchor trench, etc. had found a flow path to the sump.

2.7.4 Closure and Post-Closure Plan

Final reclamation of the brine evaporation pond will take place as soon as the brine evaporation is complete and it is determined that no further cavern leaching will take place. Magnum is investigating two potential reclamation options; the first will include in-situ capping of the evaporites present in the pond, while the second will include mining and selling the pond evaporates (98% sodium chloride).

If the first option is selected, the salt will be shaped into a low dome that follows the general contours of the surrounding topography within the pond area. An impermeable plastic sheet with welded seams will be affixed over the salt. Earthen materials from pond berms will be spread over the plastic-covered salt, using the inside berm materials first and saving the outer-most materials, which would be least affected by brine evaporation, for use as top dressing. Earthen materials will be spread to a depth of at least four feet, which will settle over time to an average depth of three feet. A soil depth of 3 feet exceeds the State of Utah requirement for landfills and mine operations reclamation.

The second option will involve mining and selling the salts and removing the liner system from the pond floor. Then, similar to the first option, the pond berms would be folded back into the pond and the pond footprint would be re-contoured and re-vegetated with a final cover depth of at least three feet.

2.7.5 Contingency and Corrective Action Plan

If sump sensors indicate the presence of saturated brine or high conductivity water (greater than two orders of magnitude above conductivity levels established as baseline water quality conditions for the site), samples will be collected and analyzed by a qualified third-party technician and a state-certified laboratory. If an immediate resample confirms the presence of a leak, the DWQ and the DWRi will be immediately notified. Additional emergency sumps will be brought in if needed to assimilate any quantity of leakage water above the design capacity of the LCRS and PCMS systems in the event of a liner failure. Any leaks would be identified and appropriate actions would be undertaken to repair the leak. The leaking pond will not be utilized for any additional discharge until the leak has been repaired to the satisfaction of the appropriate State regulatory agency.

References

AMEC, 2011. Evaporation Ponds Final Design Report. Technical Memorandum.

Giroud, J.P. and R. Bonaparte, 1989. Leakage Through Liners Constructed with Geomembranes, Part I: Geomembrane Liners. *Geotextiles and Geomembranes*, 8(1): 27-67.

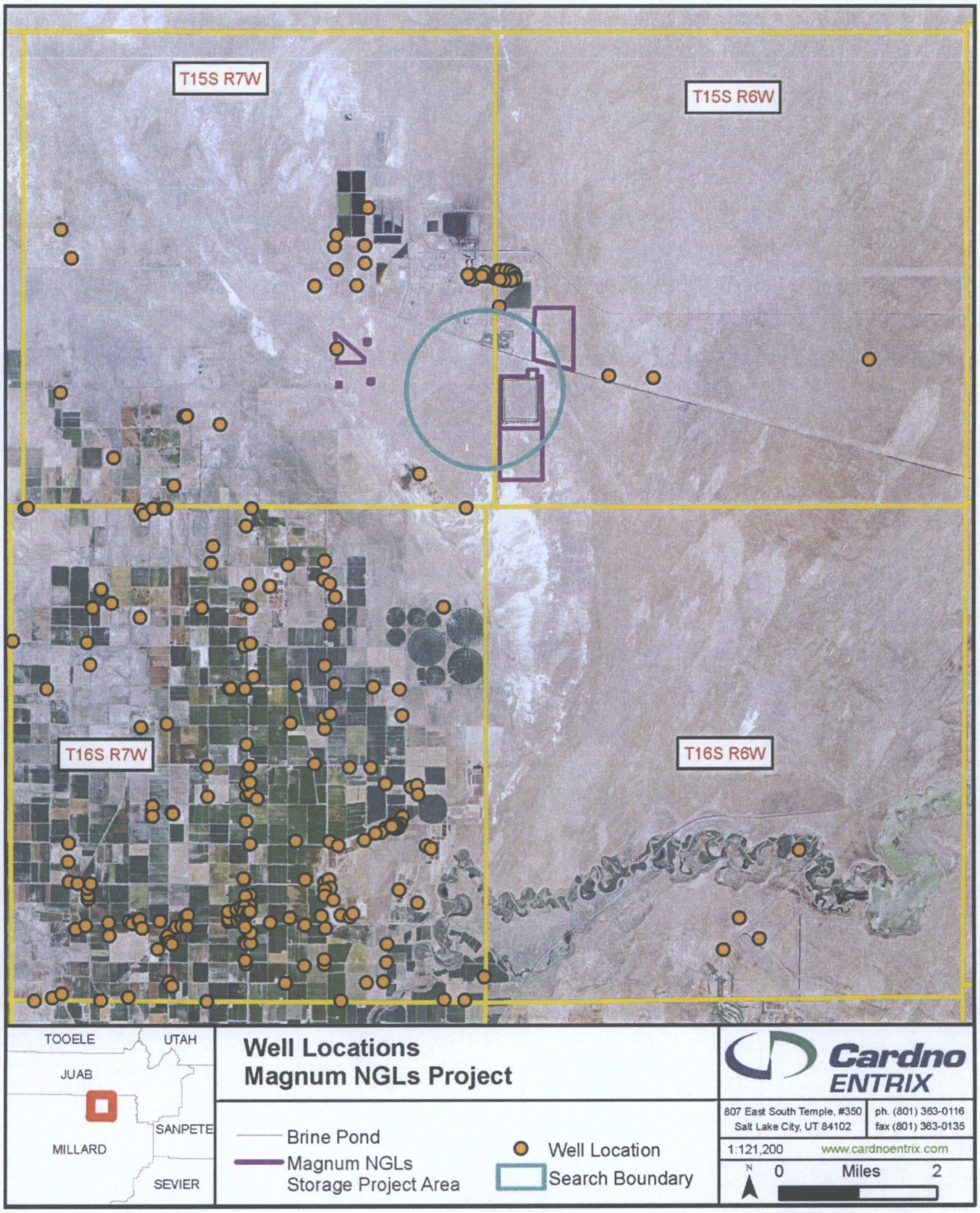
Koerner, Robert M. and Jamie R. Koerner, 2009. Survey of U.S. State Regulations on Allowable Leakage Rates in Liquid Impoundments and Wastewater Ponds. GRI White Paper #15. http://www.geosynthetic-institute.org/papers/paper15.pdf.

Magnum Gas Storage, 2011. Groundwater Monitoring, Mitigation, and Protection Plan. Prepared by Magnum Gas Storage, LLC in conjunction with Hansen, Allen and Luce to satisfy regulatory requirements for several permits.

Magnum Solution Mining, 2011. Utah DWQ Underground Injection Control Permit Modification Application Package. Submitted to Utah DWQ on November, 15, 2011.

Appendix A

Water Rights/Sources Map



Well Locations
Magnum NGLs Project

Appendix B

Water Rights/Sources Summary Table

Water Rights/Sources Summary Table

Water Right/Source Summary Within 1 Mile of Brine Evaporation Ponds

WRNUM	Priority	Location	Owner	CFS	ACFT	Depth (ft)	Dia (in)	Perf Intervals	Source
Irrigation									
68-50	19360723	N2202 E264 SW 36 15S 7W SL	Chelsey and Black, LC	3.000	0.000	420	6	n/a	Underground Water
68-50	19360723	N2423 E390 SW 36 15S 7W SL	Chelsey and Black, LC	3.000	0.000	n/a	n/a	n/a	Underground Waters
68-50	19360723	N2014 E732 SW 36 15S 7W SL	Chelsey and Black, LC	3.000	0.000	n/a	n/a	n/a	Underground Waters
68-50	19360723	N2015 E732 SW 36 15S 7W SL	Chelsey and Black, LC	3.000	0.000	n/a	n/a	n/a	Underground Waters
68-50	19360723	N1672 E1062 SW 36 15S 7W SL	Chelsey and Black, LC	3.000	0.000	n/a	n/a	n/a	Underground Waters
68-50	19360723	N1669 E1070 SW 36 15S 7W SL	Chelsey and Black, LC	3.000	0.000	n/a	n/a	n/a	Underground Waters
68-50	19360723	N1065 E1371 SW 36 15S 7W SL	Chelsey and Black, LC	3.000	0.000	n/a	n/a	n/a	Underground Waters
68-50	19360723	N608 E1767 SW 36 15S 7W SL	Chelsey and Black, LC	3.000	0.000	n/a	n/a	n/a	Underground Water
68-428	19850627	N700 E150 SW 19 15S 6W SL	IPA	2.775	0.000	n/a	n/a	n/a	Underground Water
68-428	19850627	N1470 E150 SW 19 15S 6W SL	IPA	2.775	0.000	n/a	n/a	n/a	Underground Water
68-428	19850627	S1170 E150 NW 19 15S 6W SL	IPA	2.775	0.000	n/a	n/a	n/a	Underground Water
68-428	19850627	S2485 E217 NW 19 15S 6W SL	IPA	2.775	0.000	n/a	n/a	n/a	Underground Water
68-780	19331100	N2216 W2398 S4 36 15S 7W SL	John A. Elder	0.089	0.000	n/a	n/a	n/a	Underground Waters
68-2161	19790921	N600 E150 SW 19 15S 6W SL	IPA	0.00	44.000	n/a	n/a	n/a	Underground Waters
68-2161	19790921	N1470 E150 SW 19 15S 6W SL	IPA	0.00	44.000	n/a	n/a	n/a	Underground Waters
68-2161	19790921	S2490 E150 NW 19 15S 6W SL	IPA	0.00	44.000	n/a	n/a	n/a	Underground Waters
Stock									
68-780	19331100	N2216 W2398 S4 36 15S 7W SL	John A. Elder	0.089	0.000	n/a	n/a	n/a	Underground Water
68-2508	19831209	S85 E462 N4 35 15S 7W SL	Neil R. Dutson	0.007	0.000	n/a	n/a	n/a	Underground Water
Other									
68-264	19800326	N600 E150 SW 19 15S 6W SL	IPA	0.000	289.64	n/a	n/a	n/a	Underground Water
68-264	19800326	S2490 E150 NW 19 15S 6W SL	IPA	0.000	289.64	n/a	n/a	n/a	Underground Water
68-356	19850627	N700 E150 SW 19 15S 6W SL	IPA	3.500	0.000	n/a	n/a	n/a	Underground Water
68-356	19850627	N1470 E150 SW 19 15S 6W SL	IPA	3.500	0.000	n/a	n/a	n/a	Underground Water
68-356	19850627	S1170 E150 NW 19 15S 6W SL	IPA	3.500	0.000	n/a	n/a	n/a	Underground Water
68-356	19850627	S2485 E217 NW 19 15S 6W SL	IPA	3.500	0.000	n/a	n/a	n/a	Underground Water
68-410	19821018	N1470 E150 SW 19 15S 6W SL	IPA	3.000	0.000	n/a	n/a	n/a	Five Underground Waters
68-410	19821018	S1170 E150 NW 19 15S 6W SL	IPA	3.000	0.000	n/a	n/a	n/a	Five Underground Waters

68-428	19850627	N700 E150 SW 19 15S 6W SL	IPA	2.775	0.000	n/a	n/a	n/a	Underground Water
68-428	19850627	N1470 E150 SW 19 15S 6W SL	IPA	2.775	0.000	n/a	n/a	n/a	Underground Water
68-428	19850627	S1170 E150 NW 19 15S 6W SL	IPA	2.775	0.000	n/a	n/a	n/a	Underground Water
68-428	19850627	S2485 E217 NW 19 15S 6W SL	IPA	2.775	0.000	n/a	n/a	n/a	Underground Water
68-2161	19790921	N600 E150 SW 19 15S 6W SL	IPA	0.000	44.000	n/a	n/a	n/a	Underground Waters
68-2161	19790921	N1470 E150 SW 19 15S 6W SL	IPA	0.000	44.000	n/a	n/a	n/a	Underground Waters
68-2161	19790921	S2490 E150 NW 19 15S 6W SL	IPA	0.000	44.000	n/a	n/a	n/a	Underground Waters
68-2161	19790921	S1170 E150 NW 19 15S 6W SL	IPA	0.000	44.000	n/a	n/a	n/a	Underground Waters
68-2168	19790921	N1470 E150 SW 19 15S 6W SL	IPA	0.000	435.00	n/a	n/a	n/a	Underground Waters
68-2168	19790921	S1170 E150 NW 19 15S 6W SL	IPA	0.000	435.00	n/a	n/a	n/a	Underground Waters
68-2173	19791004	N600 E150 SW 19 15S 6W SL	IPA	0.000	205.60	n/a	n/a	n/a	Underground Water
68-2173	19791004	N1470 E150 SW 19 15S 6W SL	IPA	0.000	205.60	n/a	n/a	n/a	Underground Water
68-2173	19791004	S2490 E150 NW 19 15S 6W SL	IPA	0.000	205.60	n/a	n/a	n/a	Underground Water
68-2173	19791004	S1170 E150 NW 19 15S 6W SL	IPA	0.000	205.60	n/a	n/a	n/a	Underground Water
68-2182	19791019	N600 E150 SW 19 15S 6W SL	IPA	0.000	44.400	n/a	n/a	n/a	Underground Water
68-2182	19791019	N1470 E150 SW 19 15S 6W SL	IPA	0.000	44.400	n/a	n/a	n/a	Underground Water
68-2182	19791019	S2490 E150 NW 19 15S 6W SL	IPA	0.000	44.400	n/a	n/a	n/a	Underground Water
68-2182	19791019	S1170 E150 NW 19 15S 6W SL	IPA	0.000	44.400	n/a	n/a	n/a	Underground Water
68-2430	19821018	N1470 E150 SW 19 15S 6W SL	IPA	3.540	0.000	n/a	n/a	n/a	Five Underground Waters
68-2430	19821018	S1170 E150 NW 19 15S 6W SL	IPA	3.540	0.000	n/a	n/a	n/a	Five Underground Waters
68-2432	19600107	N700 E150 SW 19 15S 6W SL	IPA	1.722	400.00	n/a	n/a	n/a	Underground Water
68-2432	19600107	S2485 E217 NW 19 15S 6W SL	IPA	1.722	400.00	n/a	n/a	n/a	Underground Water
68-2432	19821018	N700 E150 SW 19 15S 6W SL	IPA	2.100	0.000	n/a	n/a	n/a	Underground Waters (5)
68-2432	19821018	S2485 E217 NW 19 15S 6W SL	IPA	2.100	0.000	n/a	n/a	n/a	Underground Waters (5)
Power									
68-2161	19790921	N600 E150 SW 19 15S 6W SL	IPA	0.000	44.000	n/a	n/a	n/a	Underground Waters
68-2161	19790921	N1470 E150 SW 19 15S 6W SL	IPA	0.000	44.000	n/a	n/a	n/a	Underground Waters
68-2161	19790921	S2490 E150 NW 19 15S 6W SL	IPA	0.000	44.000	n/a	n/a	n/a	Underground Waters
68-2161	19790921	S1170 E150 NW 19 15S 6W SL	IPA	0.000	44.000	n/a	n/a	n/a	Underground Waters
68-2166	19790921	N600 E150 SW 19 15S 6W SL	IPA	0.000	362.50	n/a	n/a	n/a	Underground Waters (5)
68-2166	19790921	S2490 E150 NW 19 15S 6W SL	IPA	0.000	362.50	n/a	n/a	n/a	Underground Waters (5)
68-2168	19791003	N1470 E150 SW 19 15S 6W SL	IPA	0.000	435.00	n/a	n/a	n/a	Underground Water
68-2168	19791003	S1170 E150 NW 19 15S 6W SL	IPA	0.000	435.00	n/a	n/a	n/a	Underground Water
68-2168	19791003	N600 E150 SW 19 15S 6W SL	IPA	0.000	435.00	n/a	n/a	n/a	Underground Water (5)
68-2168	19791003	S2490 E150 NW 19 15S 6W SL	IPA	0.000	435.00	n/a	n/a	n/a	Underground Water (5)
68-2169	19791003	N600 E150 SW 19 15S 6W SL	IPA	0.000	322.51	n/a	n/a	n/a	Underground Waters (5)
68-2169	19791003	S2490 E150 NW 19 15S 6W SL	IPA	0.000	322.51	n/a	n/a	n/a	Underground Waters (5)
68-2170	19791003	N600 E150 SW 19 15S 6W SL	IPA	0.000	435.00	n/a	n/a	n/a	Underground Waters (5)
68-2170	19791003	S2490 E150 NW 19 15S 6W SL	IPA	0.000	435.00	n/a	n/a	n/a	Underground Waters (5)

68-2173	19791004	N600 E150 SW 19 15S 6W SL	IPA	0.000	205.60	n/a	n/a	n/a	Underground Water
68-2173	19791004	N1470 E150 SW 19 15S 6W SL	IPA	0.000	205.60	n/a	n/a	n/a	Underground Water
68-2173	19791004	S2490 E150 NW 19 15S 6W SL	IPA	0.000	205.60	n/a	n/a	n/a	Underground Water
68-2173	19791004	S1170 E150 NW 19 15S 6W SL	IPA	0.000	205.60	n/a	n/a	n/a	Underground Water
68-2173	19791004	N600 E150 SW 19 15S 6W SL	IPA	0.000	205.00	n/a	n/a	n/a	Underground Waters (5)
68-2173	19791004	N1470 E150 SW 19 15S 6W SL	IPA	0.000	205.00	n/a	n/a	n/a	Underground Waters (5)
68-2180	19791003	N600 E150 SW 19 15S 6W SL	IPA	0.000	388.00	n/a	n/a	n/a	Underground Waters (5)
68-2180	19791003	S2490 E150 NW 19 15S 6W SL	IPA	0.000	388.00	n/a	n/a	n/a	Underground Waters (5)
68-2181	19791003	N600 E150 SW 19 15S 6W SL	IPA	0.000	579.84	n/a	n/a	n/a	Underground Waters (5)
68-2181	19791003	S2490 E150 NW 19 15S 6W SL	IPA	0.000	579.84	n/a	n/a	n/a	Underground Waters (5)
68-2182	19791019	N600 E150 SW 19 15S 6W SL	IPA	0.000	44.400	n/a	n/a	n/a	Underground Water
68-2182	19791019	N1470 E150 SW 19 15S 6W SL	IPA	0.000	44.400	n/a	n/a	n/a	Underground Water
68-2182	19791019	S2490 E150 NW 19 15S 6W SL	IPA	0.000	44.400	n/a	n/a	n/a	Underground Water
68-2182	19791019	S1170 E150 NW 19 15S 6W SL	IPA	0.000	44.400	n/a	n/a	n/a	Underground Water
68-2182	19791019	N600 E150 SW 19 15S 6W SL	IPA	0.000	250.00	n/a	n/a	n/a	Underground Waters (5)
68-2182	19791019	S2490 E150 NW 19 15S 6W SL	IPA	0.000	250.00	n/a	n/a	n/a	Underground Waters (5)
68-2227	19800227	N600 E150 SW 19 15S 6W SL	IPA	0.000	605.42	n/a	n/a	n/a	Underground Waters (5)
68-2227	19800227	S2490 E150 NW 19 15S 6W SL	IPA	0.000	605.42	n/a	n/a	n/a	Underground Waters (5)
Undefined									
68-2717	19850627	N700 E150 SW 19 15S 6W SL	C+ Land and Cattle Co	0.725	0.000	n/a	n/a	n/a	Underground Water
68-2717	19850627	N1470 E150 SW 19 15S 6W SL	C+ Land and Cattle Co	0.725	0.000	n/a	n/a	n/a	Underground Water
68-2717	19850627	S1170 E150 NW 19 15S 6W SL	C+ Land and Cattle Co	0.725	0.000	n/a	n/a	n/a	Underground Water
68-2717	19850627	S2485 E217 NW 19 15S 6W SL	C+ Land and Cattle Co	0.725	0.000	n/a	n/a	n/a	Underground Water

Appendix C

Leakage Rate Calculations

go to problem statement input values solution contact help references

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Leakage Rate Through Geomembrane Liner - Design Calculator

Problem Statement

This calculator computes the rate of leakage through defects in a geomembrane underlain by a very permeable medium. A geonet sandwiched between two geomembranes in a double liner system is one application of this calculator. The rate of leakage through a geomembrane liner due to geomembrane permeability is negligible compared to the rate of leakage through defects in the geomembrane. Hence, only leakage through defects will be considered. As proposed by Giroud (1984), Bernoulli's equation (shown and used below) for free flow through an orifice can be used to evaluate the rate of leakage through a defect in a geomembrane underlain by a very permeable medium. This free flow condition occurs when the underlain porous medium has a average opening size that is greater than the diameter of the geomembrane defect. This free flow condition is valid if the hydraulic conductivity of the underlain media (gravel, geonet, eg.) in contact with the geomembrane is greater than 10^{-1} to 1 m/s if a = 0.1 cm^2 (10^{-5} m^2) and greater than 1 to 10 m/s if a = 1 cm^2 (10^{-4} m^2). A typical geonet/geocomposite has a hydraulic conductivity of 10^{-1} to 1 m/s, therefore, this leakage rate calculation is valid for geonet, only when the defect size in the geomembrane is less than or equal to 0.1 cm^2.

$$Q = 0.6 * a * \sqrt{2gh}$$

Q	Leakage rate (m^3/s)
A	Considered geomembrane surface area (m^2)
n	Number of defects in the geomembrane area
a	Area of a single defect (m^2)
g	Acceleration of gravity (m/s^2)
h	Hydraulic head on top of the geomembrane (m)

Note that Bernoulli's equation often overestimates the leakage rate, especially in landfills, even absurd leakage rates are possible, e.g. the calculated rate through a defect in a geomembrane may be greater than the impingement rate above the geomembrane. Giroud et al. (1997) has extended this equation to include impeded flow. Design equations in this case are more complex and requires iteration for calculating the leakage rate. Design charts are available in the above referenced paper.

Studies by Giroud and Bonaparte (1989) have shown that for geomembrane liners installed, with strict construction quality assurance, could have one to two defects per acre (4000 m^2) with a typical defect diameter of 2 mm (i.e., a defect area of 3.14 * 10^{-6} m^2).

Typical for liner performance evaluation one defect per acre (4000 m^2) is considered with a defect area of 0.1 cm^2 (equivalent to defect diameter of 3.5 mm), for a conservative design a defect area of 1 cm^2 (equivalent defect diameter of 11 mm) can be considered (Giroud et al., 1994)

Input Values

Geometry

Hydraulic head on liner (h)	13.1	m
Considered geomembrane surface area (A)	628143	m^2

Defect Properties

Number of defects (n)	2	
Area of defect (a)	1.00E-5	m^2

Leakage Rate Calculation

Solution

Leakage rate per unit area	3.1E-010	$(m^3/s)/m^2$
	2.6E+002	lphd (liter per hectare per day) 1 $(m^3/s)/m^2$ = 8.64E11 lphd
	2.8E+001	gpad (gallons per acre per day) 1 lphd =0.1056 gpad

Additional Assistance

If you would like to have Advanced Geotech Systems provide material specifications that meet your performance criteria, please fill in the following fields and click the submit button. All information is kept strictly confidential.

Name *

Company

Email Address *

Phone

Project Reference

Comments

*required fields

Submit Design Results

References

J.P. Giroud, "Impermeability: The Myth and a Rational Approach", Proceedings of the International Conference on Geomembranes, Denver, USA, 1:157-162, 1984.

J.P. Giroud and R. Bonaparte, "Leakage Through Liners Constructed with Geomembranes, Part I:

Geomembrane Liners", Geotextiles and Geomembranes, 8, 1: 27-67, 1989.

J.P. Giroud, K. Badu-Tweneboah & K.L. Soderman, "Evaluation of Landfill Liners" , Fifth International Conference on Geotextiles, Geomembranes and Related Products, Singapore, 5-9 September 1994.

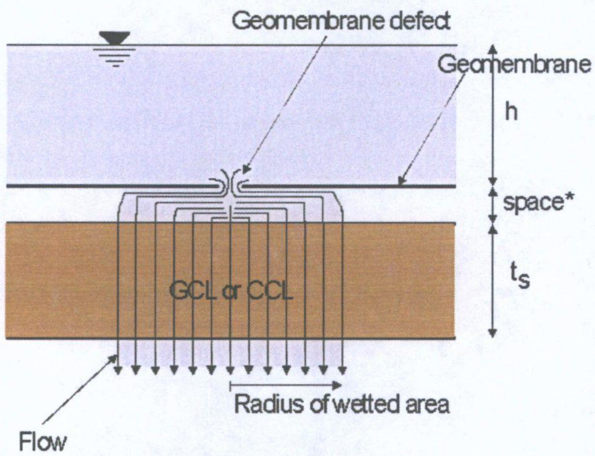
J.P. Giroud, M.V. Khire, and K.L. Soderman, " Liquid Migration Through Defects in a Geomembrane Overlain and Underlain by Permeable Media" ,Geosynthetics International, Vol. 4, Nos. 3-4, pp.293-321, 1997.

landfilldesign.com
Design Calculator
Leakage Rate Through a Composite Liner

Problem Statement

This calculator computes the rate of leakage through defects in a composite liner, i.e. geomembrane/CCL or geomembrane/GCL. The thickness of a CCL is between 0.3 to 1.5 m whereas the thickness of a hydrated GCL depends on the compressive stress applied during hydration. Typical values are between 5 and 10 mm; or in the order of 100 times less than the thickness of a CCL. Field evaluation, sponsered by USEPA, of leakage rate for double-lined landfills indicates that GM/GCL composite liners outperform GM/CCL liners (Othman et al.,1998.)

The rate of leakage through a geomembrane liner due to geomembrane permeability is negligible compared to the rate of leakage through defects in the geomembrane (Giroud and Bonaparte 1989.) Hence, only leakage through defects will be considered. If there is a defect in the geomembrane, the liquid first passes through the defect, then it flows laterally some distance between the geomembrane and the low-permeability soil, and, finally it infiltrates in the low permeability soil.



* Space exaggerated to show interface flow

Flow between geomembrane and low-permeability soil is called interface flow, and is highly dependent upon the quality of contact between the two components (Bonaparte et al., 1989.) Contact conditions are defined as follows:

- **Good contact conditions** correspond to a geomembrane installed, with as few wrinkles as possible, on top of a low-permeability soil layer that has been adequately compacted and has a smooth surface.
- **Poor contact conditions** correspond to a geomembrane that has been installed with a certain number of wrinkles, and/or placed on a low-permeability soil that has not been well compacted and does not appear smooth.

Table 1

	Contact quality factor (C_{qo}) (circular, square, rectangular)	Contact quality factor ($C_{q\infty}$) (infinite length)
Good contact	0.21	0.52
Poor contact	1.15	1.22

The Help model provides guidance for estimating the defect densities (Schroeder et al., 1994). Some useful information on the Help model is given in the Technical Note on Using HELP Model (ver 3.07). There are mainly two types of defects, manufacturing defects and installation defects. Typical geomembranes may have about 0.5 to 1 (1 to 2 per hectare) pinholes per acre from manufacturing defects (Pinholes are defects with a diameter equal or smaller than the geomembrane thickness. The density of installation defects is a function of the quality of installation, testing, materials, surface preparation, equipment, and QA/QC program. Representative installation defect densities as a function of the quality of installation are given in Table 2 for landfills being built today with the state of the art in materials, equipment and QA/QC.

Table 2

Installation quality	Defect density (number per acre)	Frequency (percent)
Excellent	Up to 1	10
Good	1 to 4	40
Fair	4 to 10	40
Poor	10 to 20*	10

*Higher defect densities have been reported for older landfills with poor installation operations and materials; however, these high densities are not characteristic of modern practice.

Studies by Giroud and Bonaparte (1989) have shown that for geomembrane liners installed, with strict construction quality assurance, could have one to two defects per acre (4000 m^2) with a typical defect diameter of 2 mm (i.e., a defect area of $3.14 * 10^{-6}$ m^2).

Typical for liner performance evaluation one defect per acre (4000 m^2) is considered with a defect area of 0.1 cm^2 (equivalent to defect diameter of 3.5 mm), for a conservative design a defect area of 1 cm^2 (equivalent defect diameter of 11 mm) can be considered (Giroud et al., 1994)

Problem Solution

Different geomembrane defect shapes will be considered:

Circular defect with diameter of d

$$\frac{Q}{A}=n\cdot 0.976\,C_{qo}\cdot[1+0.1\cdot(h/t_s)^{0.95}]\cdot d^{0.2}\cdot h^{0.9}\cdot k_s^{0.74}$$

Square defect with side length b

$$\frac{Q}{A}=n\cdot C_{qo}\cdot[1+0.1\cdot(h/t_s)^{0.95}]\cdot b^{0.2}\cdot h^{0.9}\cdot k_s^{0.74}$$

Infinitely long defect with width of b

$$\frac{Q^*}{A}=n\cdot C_{q\infty}\cdot[1+0.2\cdot(h/t_s)^{0.95}]\cdot b^{0.1}\cdot h^{0.45}\cdot k_s^{0.87}$$

Rectangular defect with width of b and length of B

$$\frac{Q}{A}=n\cdot C_{qo}\cdot[1+0.1\cdot(h/t_s)^{0.95}]\cdot b^{0.2}\cdot h^{0.9}\cdot k_s^{0.74}$$
$$+n\cdot C_{q\infty}\cdot[1+0.2\cdot(h/t_s)^{0.95}]\cdot(B-b)\cdot b^{0.1}\cdot h^{0.45}\cdot k_s^{0.87}$$

Q	Leakage rate through the considered geomembrane defect (m^3/s)
Q*	Leakage rate per unit length of geomembrane defect ($m^3/s.m$)
A	Considered geomembrane area (m^2)
n	Number of defects per considered geomembrane area (A)
Co or $C_{q\infty}$	Contact quality factor (see above table 1)
h	Hydraulic head on top of the geomembrane (m)
t_s	Thickness of the low-permeability soil component of the composite liner (m)
d	Diameter of circular defect (m)
b	Width of defect (m)
B	Length of rectangular defect (m)

Limitation of the equations presented (Giroud et al. 1997):

- If the effect is circular, the defect diameter should be no less than 0.5 mm and not greater than 25 mm. In the case of the defects that are not circular, it is proposed to use these limitations for the defect width.
- The liquid head on top of the geomembrane should be equal to or less than 3 m.

Input Values

Geometry of circular defect

Considered geomembrane area (A)	628143	m^2
Hydraulic head on top of the geomembrane (m)	.0033	m
Thickness of the low-permeability soil (m)	.3	> m
Permeability of the low-permeability soil (m/s)	.00000000033	m/s

Properties of circular defect

Contact (good or poor)	Good	
Number of defects (n)	2	
Diameter of defect (d)	0.00356825	m

Geometry of square defect

Considered geomembrane area (A)	4000	m^2
Hydraulic head on top of the geomembrane (m)	0.3	m
Thickness of the low-permeability soil (m)	2	m
Permeability of the low-permeability soil (m/s)	1.00E-7	m/s

Properties of square defect

Contact (good or poor)	Good	
Number of defects (n)	1	
Side length of defect (d)	0.0002	m

Geometry of Infinitely Long Defect

Considered geomembrane area (A)	4000	m^2
Hydraulic head on top of the geomembrane (m)	0.3	m
Thickness of the low-permeability soil (m)	2	m
Permeability of the low-permeability soil (m/s)	1.00E-7	m/s

Properties of Infinitely Long Defect

Contact (good or poor)	Good	
Number of defects (n)	1	
Width of defect (b)	0.0002	m

Geometry of Rectangular Defect

Considered geomembrane area (A)	4000	m^2
Hydraulic head on top of the geomembrane (m)	0.3	m
Thickness of the low-permeability soil (m)	2	m
Permeability of the low-permeability soil (m/s)	1.00E-7	m/s

Properties of Rectangular Defect

Contact (good or poor)	Good	
Number of defects (n)	1	
Width of defect (b)	0.002	m
Length of defect (B)	0.01	m

Calculate

Solution

Circular Defect

Leakage Rate	1.191E-016	$(m^3/s)/m^2$
	0.0002	lphd (liter per hectare per day)
		1 $(m^3/s)/m^2 = 8.64 \cdot 10^{11}$ lphd
	0.00001	gpad (gallons per acre per day)
		1 lphd =0.1056 gpad

Square Defect

Leakage Rate	2.172E-011	$(m^3/s)/m^2$
	86.4000	lphd (liter per hectare per day)
		1 $(m^3/s)/m^2 = 8.64 \cdot 10^{11}$ lphd
	1.98178	
		1 lphd =0.1056 gpad

Infinitely Long Defect

Leakage Rate per unit length	1.094E-011	$(m^3/s)/m^2.m$
	86.4000	lphd/m (liter per hectare per day per meter)
		1 $(m^3/s)/m^2 = 8.64 \cdot 10^{11}$ lphd
	0.99825	gpad/ft (gallons per acre per day per feet)
		1 lphd =0.1056 gpad

Rectangular Defect

Leakage Rate	3.469E-011	$(m^3/s)/m^2.m$
	86.4000	lphd (liter per hectare per day)
		1 $(m^3/s)/m^2 = 8.64 \cdot 10^{11}$ lphd
	3.16541	gpad (gallons per acre per day)
		1 lphd =0.1056 gpad

Assistance

References

R. Bonaparte, J.P.Giroud, and B.A. Gross,"Rates of Leakage through Landfill Liners", Proceedings of Geosynthetics '89, Vol. 1, IFAI, San Diego, California, USA, February 1989, pp. 18-29, 1989.

J.P. Giroud and R. Bonaparte, "Leakage Through Liners Constructed with Geomembranes, Part I", Geomembrane Liners, Geotextiles and Geomembranes, 8, 1: 27-67, 1989.

J.P. Giroud, K. Badu-Tweneboah & K.L. Soderman,"Evaluation of Landfill Liners", Fifth International Conference on Geotextiles, Geomembranes and Related Products, Singapore, 5-9 September 1994.

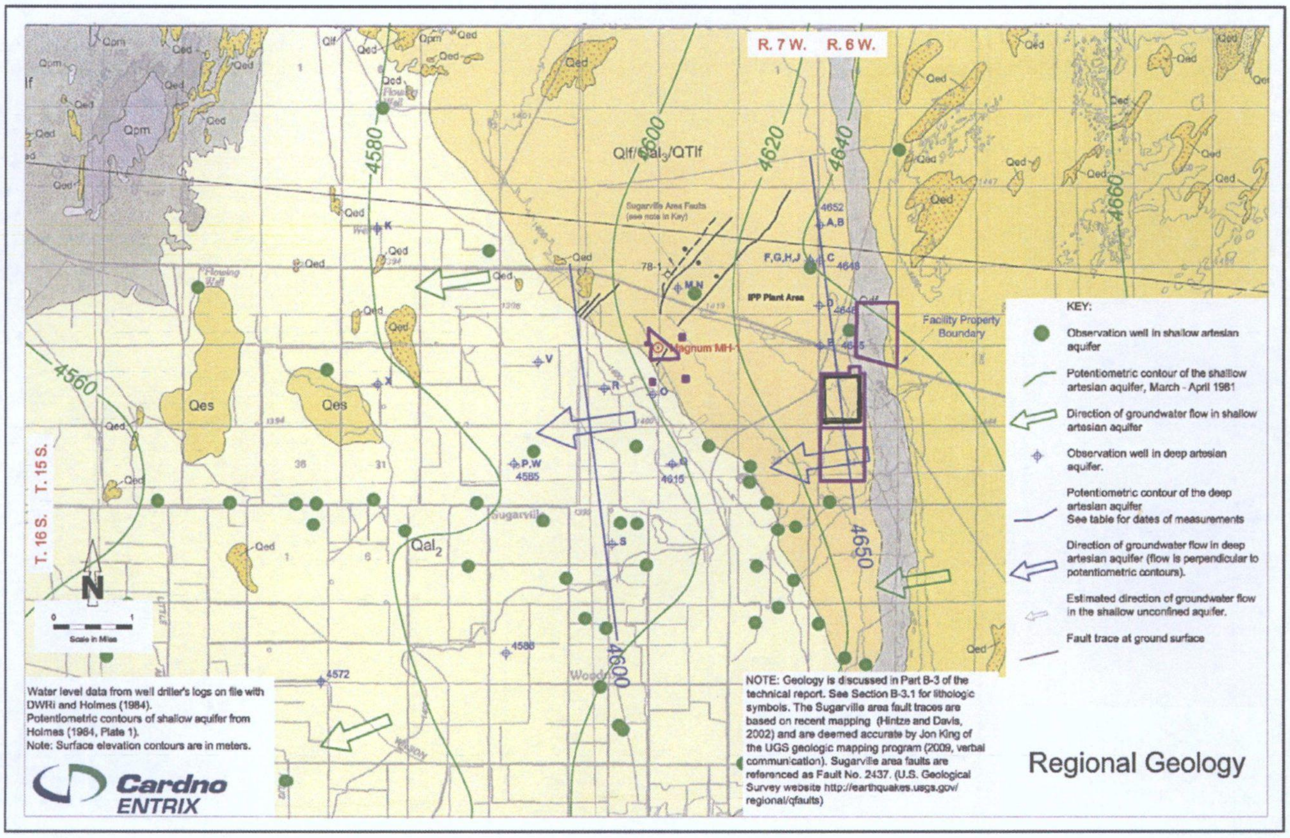
P.R. Schroeder, T.S. Dozier, P.A. Zappi, B.M. McEnroe, J.W. Sjostrom, and R.L. Peton, " The Hydrologic Evaluation of Landfill Performance (HELP) Model:Engineering Documentation for Version 3", EPA/600/R-94/168b, US. Environmental Protection Agency, Risk Reduction Engineering Laboratory, Cincinnati, OH.(1994)

J.P. Giroud,"Equations for Calculating the Rate of Liquid Migration Through Composite Liners Due to Geomembrane Defects", Geosynthetics International, Vol. 4, Nos. 3-4, pp.335-348, 1997.

M.A. Othman, R. Bonaparte, B.A. Gross, and D. Warren, "Evaluation of Liquids Management Data for Double-Lined Landfills" Draft Document Prepared for the U.S. Environmental Protection Agency, National Risk Management Laboratory, Cincinnati, Ohio, 1998.

Appendix D

Geologic Maps


R. 7 W.
R. 6 W.
T. 15 S.
T. 16 S.
Qlf/Qal1/QTlf
Sugarville Area Faults (see note in Key)
IPP Plant Area
Magnum MH-1
Facility Property Boundary
Qes
Qal2
Sugarville
4560
4580
4600
4620
4640
4660
4650
4652
4648
4645
4615
4585
4586
4572
N
0
1
Scale in Miles
KEY:
Observation well in shallow artesian aquifer
Potentiometric contour of the shallow artesian aquifer, March - April 1981
Direction of groundwater flow in shallow artesian aquifer
Observation well in deep artesian aquifer.
Potentiometric contour of the deep artesian aquifer
See table for dates of measurements
Direction of groundwater flow in deep artesian aquifer (flow is perpendicular to potentiometric contours).
Estimated direction of groundwater flow in the shallow unconfined aquifer.
Fault trace at ground surface
Water level data from well driller's logs on file with DWRi and Holmes (1984).
Potentiometric contours of shallow aquifer from Holmes (1984, Plate 1).
Note: Surface elevation contours are in meters.
Cardno ENTRIX
NOTE: Geology is discussed in Part B-3 of the technical report. See Section B-3.1 for lithologic symbols. The Sugarville area fault traces are based on recent mapping (Hintze and Davis, 2002) and are deemed accurate by Jon King of the UGS geologic mapping program (2009, verbal communication). Sugarville area faults are referenced as Fault No. 2437. (U.S. Geological Survey website http://earthquakes.usgs.gov/regional/qfaults)
Regional Geology

Appendix E

Well Logs

Well Logs on File with Division of Water Quality as part of UIC Permit UTU-27-AP-9232389 and Submitted Digital Copy with this Application

Appendix F

Brine Evaporation Ponds Engineering Plans and Specifications

Brine Evaporation Pond Engineering Plans and Specification on File with Division of Water Quality as part of Construction Permit for the Magnum Gas Storage LLC Evaporation Ponds and Submitted Digital Copy with this Application

Appendix G

Groundwater Monitoring Mitigation and Protection Plan

Appendix R
Groundwater Monitoring, Mitigation and Protection Plan

Implementation Plan

Appendix R

Groundwater Monitoring, Mitigation and Protection Plan

April 2011 • Final
(Revised November 2011)

FERC Docket No. (CP10-22-000)
(PF09-3-000)

Prepared by
MAGNUM GAS STORAGE, LLC

Table of Contents

Tables

Attachments

Section 1

Introduction

This Groundwater Monitoring, Mitigation and Protection Plan (Plan) has been developed for the Magnum Gas Storage Project (Project) located approximately 10 miles north of Delta, Utah. The Plan has been segregated into two basic areas involving the monitoring of the Sevier Desert Basin groundwater system which will be the source for water production to support the solution mining of storage caverns and the monitoring of the water table aquifer for potential impacts from the brine evaporation ponds. Magnum has developed this Plan at the request of the agencies to provide an adaptive monitoring and mitigation strategy to identify and respond to conditions that may be encountered during operations.

1.1 Groundwater Source

Magnum will be producing water for the solution mining process from the Sevier Desert Basin groundwater system. Data collected from the MH-1 test well indicates the aquifer system includes a water table aquifer zone, a shallow artesian aquifer, a deep artesian aquifer and a newly defined basement artesian aquifer. This newly defined aquifer is located approximately 1,400 feet below ground surface (bgs) and appears to be separated from overlying aquifers by as much as 250 feet of clays. While little is known about the basement artesian aquifer, previous data from the Argonaut test well confirms the MH-1 test well data. Figure A-1 depicts the Sevier Desert Basin Groundwater system as defined by the MH-1 and Argonaut test well data.

1.2 Projected Groundwater Use

Existing groundwater data indicates that water production in the vicinity of the Project has been historically limited to the shallow artesian and deep artesian aquifers. Magnum will be producing water from the basement artesian aquifer to complete the solution mining process. The solution mining process for each cavern will use approximately 10,000 acre feet of water over the course of 2 years. Magnum will be solution mining caverns sequentially rather than simultaneously to reduce the amount of annual groundwater usage during the creation of caverns 1 and 2.

1.3 Jurisdiction and Regulation

The State Engineer has the jurisdiction and legal authority to administer water rights within the State of Utah, as well as the obligation to monitor, regulate and enforce water usage. To support water production for the Project, Magnum has leased existing water rights from current water right holders and has obtained temporary water right point of diversion changes from the State Division of Water Rights (DWRi). While the DWRi does not currently differentiate between the shallow, deep, or basement artesian aquifers for the allocation of water rights usage, Magnum has chosen to produce water from the basement artesian aquifer to mitigate any potential groundwater impacts to the upper aquifers from the project. Magnum recognizes that there are significant penalties associated with the violation of Utah water law. Magnum is obligated under temporary water right Orders from the State Engineer to record and report all water right usage on an annual basis.

Section 2

Groundwater System Monitoring Locations, Installation Procedures, and Baseline Testing

2.1 Basement Artesian Aquifer Monitoring Points

Magnum will monitor water levels in the basement artesian aquifer from all five MH (MH-1 through MH-5) water production wells as they are installed and two newly installed observation monitoring wells (DA-1 and DA-2). The proposed locations of all seven wells are listed below and depicted on Figure A-2. All water production and observation well locations been approved by the State Engineer.

1) MH-1: Lat 39°29'38.56"N Long 112°36'44.73"W
2) MH-2: Lat 39°29'43.83"N Long 112°36'13.57"W
3) MH-3: Lat 39°29'43.10"N Long 112°36'27.76"W
4) MH-4: Lat 39°29'17.96"N Long 112°36'8.17"W
5) MH-5: Lat 39°29'16.05"N Long 112°36'41.25"W
6) DA-1: Lat 39°29'29.42"N Long 112°35'4.23"W
7) DA-2: Lat 39°29'33.22"N Long 112°37'51.38"W

The purpose of monitoring is to confirm that the basement artesian aquifer has sufficient water resources to support the annual production of water for the Project. In order to confirm and manage potential impacts each well will be designed and equipped to monitor water levels at the well head. It is anticipated that the MH water production wells will reflect dynamic water level data during cycles of pumping and recovery and the observation wells will reflect the overarching influence of the MH water production wells on the aquifer system.

Schematics of the MH-1 test well and future MH water production wells (MH-2 thru MH-5) are shown in Figures A-3 and A-4 respectively. Figure A-3 shows basement artesian aquifer perforations located between 1,650 feet and 2,240 feet. The MH-1 test well is currently equipped with a 100 HP motor and has a tested capacity of 1,100 gpm. During Project operations MH-1 will be converted to a water production well and equipped with an *in-situ* or equivalent pressure transducer installed within a monitoring tube located within the well casing which will provide direct measurements of water levels within the basement artesian aquifer. Installed transducers will be calibrated at well installation and quarterly thereafter as outlined in Section 3.

Future water Production wells MH-2 thru MH-5 will be constructed and equipped as shown in Figure A-4. The wells will be completed within selected zones located at the stratigraphic equivalents of the aquifers produced between 1,650 feet and 2,250 feet in the MH-1 test well. The completed intervals in each additional water production well will be isolated from all shallower groundwater zones above 1,400 feet. This isolation will be achieved through the identification of clay aquitards during drilling operations, followed by the installation of grout or bentonite seals between the well casing and outer well boring throughout the identified clay zone. For comparison, the clay aquitard identified in the MH-1 test well below 1,400 feet and the top of the shallowest completed production interval was approximately 245 feet thick.

Each MH water production well will also include PVC water level transducer tubes installed in the well annulus between the bore hole and the casing above the isolating grout seal (see Figure A-4). These transducer tubes will allow monitoring of real time data showing potential impacts on groundwater levels in the shallow and deep artesian aquifers from pumping of the basement artesian aquifer below the grout seals. The grout seals installed in the well annulus will ensure that the water level monitoring equipment (*in-situ* or equivalent) is accurately recording potentiometric levels for the isolated aquifers.

In addition to the MH water production wells, Magnum will install two dedicated observation wells (DA-1 and DA-2). As depicted in Figure A-5, the location of DA-1 well is between Magnum's MH water production wells and the Intermountain Power Plant (IPP) groundwater well field. Also, the location of the second observation well (DA-2) is between Magnum's MH water production wells and the Delta Egg Farm well to the west. The observation wells will be completed and instrumented to measure the water levels of each aquifer. Due to the small diameter of the observation wells they will not be equipped to obtain water samples from each aquifer. A schematic depicting observation wells DA-1 and DA-2 is provided in Figure A-6.

2.2 Existing Shallow and Deep Artesian Aquifer Monitoring Wells

In addition to the five MH water production wells and two observation wells, Magnum will collect data from three existing off-site groundwater monitoring wells. The three wells are located within a two mile radius near the Intermountain Power Project (IPP) and the Delta Egg Farm (see Figure A-3).

The three well locations are:

1) USGS well: Lat 39°30'20.46"N, Long 112°36'21.70"W
2) IPP well: Lat 39°29'44.59"N, Long 112°34'13.60"W
3) Delta Egg Farm well: Lat 39°29'26.57"N, Long 112°38'25.16"W

The Utah State Water Rights database indicates that the USGS well is installed to a depth of 183 feet, the IPP well is installed to a depth of 1,350 feet, and the Delta Egg Farm well is installed to a depth of 800 feet. The IPP well currently collects groundwater level data and Magnum, with permission from the landowners, installed *in-situ* pressure transducers at the IPP and Delta Egg Farm wells in 2009. The automatic data loggers attached to the IPP and Delta Egg farm transducers are currently set to collect water level measurements on an hourly basis and have been downloaded periodically to date to establish a continuous record since 2009.

Magnum will collect water level data from these three wells to establish three additional independent monitoring points within the shallow and deep artesian aquifers, subject to continued cooperation by the well owners.

2.3 Establishing Baseline Aquifer Conditions

Baseline aquifer conditions will be recorded as each new water well is installed. As part of well construction and development a step drawdown and constant rate pump test will be conducted on each well constructed. This testing procedure will help in the evaluation of aquifer conditions at the well site, help determine the production potential for the specific well, provide added monitoring and evaluation opportunities between wells constructed, and help refine our understanding of the regional hydrogeology. Data collected will be shared with the State as part of the drilling reporting process and with USGS in an effort to assist them in understanding more about the regional hydrogeology. This testing is independent from the following monitoring plan which follows well completion and testing. The data and results that will be provided at a minimum include:

- All aquifer pump tests (water production wells MH-2 through MH-5), and drawdown calculations for all nearby wells (including interference effects between Magnum's own water supply wells) assuming the maximum proposed pumping rate;
- The measured/calculated aquifer parameters for each water supply well (hydraulic conductivity, transmissivity, storage coefficient, etc.);
- The details on each well completion (depth, diameter, screened intervals), and electric logs annotated with Magnum's stratigraphic and hydrogeologic interpretations;
- All data obtained that substantiates the isolated nature of the basement artesian aquifer.

Section 3

Groundwater System Monitoring Program and Reporting

3.1 Monitoring Program

The monitoring program is outlined in Table 3-1. During the initial 3 months of operation transducers will collect/measure water levels from MH wells hourly in order to provide a clear record of aquifer response to pumping. During this period, conditions are anticipated to stabilize to a point where daily measurements can be implemented thereafter. Daily measurements are being proposed for all other wells with the exception of the USGS well that has a fixed schedule dictated by the USGS.

Data from monitoring wells will be collected and analyzed on an ongoing basis of operations and reviewed by a professional engineer/hydrogeologist. Data from all monitoring wells will be downloaded and analyzed monthly for the first year, as required by the FERC. After the first year, data will be downloaded and analyzed quarterly throughout operations. The functionality of transducers will also be verified at least quarterly through a check using a water level tape. Adjustments to transducer settings will be made accordingly.

Table 3-1 Monitoring Program

Well	Aquifer	Data Collection at Operational Startup (< 3 months)	Data Collection during Operations (> 3 months)	Data Analysis and Reporting (< 1 year)	Data Analysis and Reporting (> 1 year)
MH-1 – MH-5 Water Production Wells	Basement Artesian	Hourly	Daily	Monthly	Quarterly
	Deep Artesian	Hourly	Daily	Monthly	Quarterly
	Shallow Artesian	Hourly	Daily	Monthly	Quarterly
DA Observation Wells (2)	Deep & Shallow Artesian	Daily	Daily	Monthly	Quarterly
USGS	Water Table	Per USGS Schedule	Per USGS Schedule	Per USGS Schedule	Per USGS Schedule
IPP	Deep Artesian	Daily	Daily	Monthly	Quarterly
Delta Egg Farm	Shallow Artesian	Daily	Daily	Monthly	Quarterly

3.2 Additional Water Sampling Program

Table 3-2 identifies the parameters of an additional water sampling program proposed by Magnum. The purpose of this program will be to aid in the understanding of local aquifers and to provide a knowledge base regarding the potential interaction between aquifers. Basic parameters including TDS, conductivity, temperature, pH, dissolved chlorides, and the basic Cations-Anions will help identify general water quality conditions within the aquifer. The initial sample for Tritium, Deuterium, Oxygen 18, Carbon 14, Helium 4, and the Noble Gases (oxygen

18 and deuterium) will help provide a definition of the age and potential (but general) source of water. Quarterly monitoring of Magnum water production wells MH-1 through MH-5 will be completed for conductivity, temperature, pH, and dissolved chlorides.

Table 3-2 Water Sampling Program

Well	Frequency	Parameters*
MH-1 – MH-5 Water Production Wells	One Time During Pump Testing	TDS, Conductivity, Temp, pH, Dissolved Chloride, Basic Cations-Anions, Tritium, Deuterium, Oxygen 18, Carbon 14, Helium 4, Noble Gases
	Quarterly During Operation	Conductivity, Temp, pH, Dissolved Chloride
IPP	One Time	Tritium, Deuterium, Oxygen 18, Carbon 14, Helium 4, Noble Gases
Delta Egg Farm	One Time	Tritium, Deuterium, Oxygen 18, Carbon 14, Helium 4, Noble Gases
USGS	n/a	n/a

*Basic Anions-Cations include Calcium, Magnesium, Sodium, Potassium, Bicarbonate, Carbonate, Chloride, Sulfate, Stable Isotopes include Oxygen 18 and Dueterium analyses

Generally speaking age dating data will help define conditions within the aquifers. Tritium indicates whether the water source has been exposed to atmospheric conditions since the atomic testing period of the 1950's and is therefore a simple indicator as to whether the water is older or younger than 55 years. Deuterium and Oxygen 18 provide an indicator of climatic conditions that originated at the time of recharge. Data evaluated to date has been interpreted to mean that water found within the basement artesian aquifer was recharged from an area higher in elevation than the shallow or deep artesian aquifers, or that it recharged during an earlier time period and has traveled farther to get to the well.

Carbon 14, Helium 4 and the Noble Gas Thermometry will help define whether the water is geologically recent or more ancient (Paleozoic). Paleozoic water may indicate naturally slow aquifer discharge rates, a long travel time for recharge water, or an unlikely scenario that the basement artesian aquifer water is stagnant with little to no recharge or discharge. If the basement artesian aquifer is stagnant because of limited discharge, recharge would be stimulated through water withdrawals by Magnum through one of two main sources. First, some vertically downward recharge would be induced through the clay aquitard separating the deep artesian and basement artesian aquifers due to the head differential created by pumping. This head differential is the difference in pressure heads between the basement artesian aquifer and the deep artesian aquifer. Because of the tight nature of the aquitard the downward recharge rate will be limited, but it would continue until pressure heads equalize between the aquifers, thus mitigating the withdrawal. Second, if natural discharge is limited, recharge areas will be full and spilling to shallower aquifer systems. Under this second scenario withdrawals from the basement artesian aquifer would reduce heads in recharge areas thus reducing spillage and inducing recharge. The scenario that the basement artesian aquifer is stagnant is unlikely due to the presence of higher artesian pressures within the basement artesian aquifer noted during the drilling of the MH-1 test well.

Data from this sampling program would be used to evaluate the interrelationships with Groundwater hydrogeology during operations by a registered professional engineer/hydrogeologist specializing in water resources. Age dating data and influences between aquifer zones will be analyzed and evaluated by a certified laboratory and qualified professional.

3.3 Reporting

Magnum will prepare and submit the results of the monitoring program to the FERC on a monthly basis for the first year of solution mining and then quarterly thereafter. In addition, Magnum will prepare and submit an annual "Water Rights and Water Usage Summary and Analysis" to the State Engineer during the first quarter of the year. This report will include the following summary information and be the basis for ongoing State approvals for the leased temporary water rights:

- Temporary Water Rights granted during the previous year;
- Water usage location for the previous year, indicating whether the water was used by the owner or used by Magnum;
- Water volume used by Magnum for the previous year;
- Graphed water level data from monitored wells;
- Temporary Change Applications granted by the State Engineer to Magnum for the current year;
- Water usage location associated with those Temporary Change Applications for the current year;
- Water volume anticipated to be used by Magnum for the current year; and
- Other information as required in the Temporary Water Right Orders.

Upon request, Magnum will cooperate with the State Division of Water Rights (State Engineer) in providing any information available should the State desire to develop a Groundwater Management Plan for the Sevier Desert Basin based on the annual data collected, analyzed and submitted. Copies of all monthly, quarterly and annual reports will be submitted to the State Engineer, the FERC, Millard County and the USGS.

Section 4

Groundwater Monitoring Triggers Prompting Further Investigation or Corrective Action

Significant efforts have been expended by Magnum to investigate the hydrologic and geologic resources of the project site. Included in these efforts were extensive seismic testing and evaluations and the drilling of the MH-1 test well. Well MH-1 test well confirmed and refined data evaluated during the seismic work. Well drilling data clearly showed the currently developed aquifers above 1,400 feet are underlain by 250 feet of significant clay. The data also showed another aquifer below this clay which is now called the basement artesian aquifer. The basement artesian aquifer lying below 1,400 feet consists of small interbedded sands and small gravels separated by thick clay zones.

Based on basement artesian aquifer testing completed at the MH-1 test well, evidence suggests the basement artesian aquifer is recharging, and there are adequate resources to meet project water demands. Additional age dating analyses have also confirmed this conclusion. Additional monitoring data collected during Project operations will be used to verify the aquifer's response to water production.

There are two components to monitoring that are required under this Plan. First, is the monitoring and continued evaluation of the basement artesian aquifer. Second, is the monitoring of impacts to existing well systems within the shallow and deep artesian aquifers. The first component involving the characterization of the basement artesian aquifer includes the monitoring of water levels within Magnum's well field and is discussed in Section 6.1. This data is needed to confirm and expand our knowledge regarding the characteristics of the basement artesian aquifer and verify the projected aquifer response to development.

The second monitoring component implemented to protect existing water users involves the review and evaluation of water levels within the shallow and deep artesian aquifers at adjacent off-site monitoring locations, namely IPP, Delta Egg Farm, and observation wells. This second monitoring component is discussed in Section 6.2. The data will help refine and evaluate off-site regional impacts currently projected to be non-existent or negligible. Because there are two basic conditions that need to be monitored, the Plan has been prepared to consider these two components separately.

4.1 Basement Artesian Aquifer

Water levels within the basement, deep and shallow artesian aquifers will be monitored continuously at Magnum water production wells MH-2 thru MH-5. Existing test well MH-1 will monitor water levels within the basement artesian aquifer only since the well was not constructed or equipped to monitor levels within the upper aquifers. Although only basement artesian aquifer data is needed to complete the goals of this section, data from the deep and shallow aquifers will be collected in Magnum's water production wells to help refine the characteristics of the overlying clay layer isolating the basement artesian aquifer.

The data from Magnum's water production wells will be recorded at least hourly by Magnum and evaluated at least monthly for at least the first year of project construction by a licensed Groundwater engineer/hydrogeologist, unless a more frequent review is prompted by anomalies seen within the data sets. The purpose of this quarterly review will be to determine the condition and response of the basement artesian aquifer in response to Magnum's pumping activities. The monthly Hydrologic Reviews will be submitted to the FERC. After the first year, Magnum may request approval to provide quarterly reports if the data demonstrates minimal impact on the basement artesian aquifer. At a minimum the hydrogeologic reviews will include the following activities:

- Plot available flow and water level data for each Magnum well;
- Review water level changes at each well, including a check for data inflection points or other unexpected changes to water level(s) that might suggest changed basement artesian aquifer conditions;
- Download and review the Palmer Drought Index for correlation with recorded water levels to evaluate whether any noted changes might be climatic in nature. The presence or absence of any correlation between the data sets will be noted;
- Review the flow history at each Magnum well and correlate changes in pumping to noted changes in water level data, thus evaluating the potential cause and degree of water level changes;
- Review and analyze water quality data for changes. Age dating data collected from the upper aquifer(s) will be used to evaluate potential changes in source water which would occur if pumping induced a recharge into an adjoining aquifer zone;
- Review flow and water level data for Magnum water production wells, evaluating the stability and health of each individual well. Stability and health considerations shall include the review of flow and drawdown to identify:
  - Unexpected changes to local basement artesian aquifer water levels. Seasonal and climatic induced variations will occur naturally in the data both locally and regionally. Unexpected changes will however demonstrate themselves through deviations in the data that are uncharacteristic or inconsistent with other observed trends or variations;
  - Water level stability preventing long term aquifer mining. Long term declining trends exceeding the timeline for naturally occurring cyclic variations will be noted;
  - Well specific capacity. Changes in the ratio of instantaneous flow over pumped drawdown will be effectively used to monitor overall water production well efficiency. Decreases in this ratio demonstrate that increased drawdowns are required to withdraw the same amount of water. This condition indicates a need for a review of well equipment and conditions;
- Develop groundwater potentiometric contour mapping for the basement artesian aquifer;
- Develop and review "change in groundwater level" site mapping showing total change in groundwater levels in the basement artesian aquifer since project inception.

Magnum's well field monitoring per the above identified plan will categorize the basement artesian aquifer into one of the following basic scenarios:

Scenario I – Healthy aquifer conditions. During extended production pumping, well drawdowns stabilize, and quickly recover following pump shutdown. Conditions following pump shutdown can be evaluated not only at the end of cavern leaching, but also during the periods of time the water wells are shut down for cavern workovers or maintenance, thus giving a check of conditions over time. Under normal pump testing procedures it is common for 95% of water level recovery to occur within 24 to 48 hours. This condition will confirm healthy aquifer conditions consistent with pump testing completed to date.

Scenario II – Aquifer capacity is less than the short term withdrawals. During extended production pumping, well drawdowns do not fully stabilize but continue to drop at a rate less than or equal to 5% of the total drawdown per month. Under this scenario, pumping exceeds basement artesian aquifer capacity, but the aquifer is able to recover following the termination of pumping. As with Scenario I, water level recovery will be monitored during and after cavern leaching, and during the periods of time the water water production wells are shut down for cavern workovers or maintenance. Scenario II will be considered applicable if the 95% recovery level is achieved within 30 days after pumping has ceased. If this scenario occurs, it will provide valuable information related to the overall recharge potential for the basement artesian aquifer.

Scenario III – Little aquifer capacity is demonstrated. During extended production pumping, drawdowns do not stabilize, nor is the 95% recovery level achieved within 30 days following the termination of pumping or any extended cavern maintenance period. Under this scenario, pumping significantly exceeds basement artesian aquifer capacity, but the aquifer is able to recover over an extended period of time. As with Scenario II, Scenario III will provide valuable information related to the overall potential capacity of the aquifer. The mitigation plan outlined below will be implemented.

Scenario IV – Little to no aquifer recharge is found. During extended production pumping, drawdowns do not stabilize, nor do water levels within the basement artesian aquifer recover within 2 years following the termination of pumping. Under this scenario there would appear to be little to no aquifer recharge. It is strongly believed by Dr. David Hansen and other professionals which are familiar this the Magnum project that this scenario is highly unlikely as discussed in a meeting with Magnum, the BLM, and USGS on June 29, 2010. In that meeting USGS indicated that recent investigations have determined that there is water moving through deep carbonate rocks from the Sevier Desert Area toward Fish Springs located to the north-northwest. By the conservation of mass, this groundwater movement requires recharge to deep aquifers. The mitigation plan outlined below will be implemented.

Mitigation for each of these scenarios is as follows:

Scenario I – Healthy aquifer conditions. Pumping conditions indicate that basement artesian aquifer transmissivity and storativity are adequate to meet pumping demands. No action or mitigation is required.

Scenario II – Aquifer capacity is less than the short term withdrawals. Recharge is sufficient to replenish the aquifer during periods of non-pumping following cavern leaching. No action or mitigation is required other than continued monitoring with rest periods between cavern leaching sufficient to allow recharge. Coordination with the State Engineer on an annual basis during the temporary water right renew process will also ensure protection of the basement artesian aquifer under this condition.

Scenario III – Little aquifer capacity is demonstrated. Under this scenario mitigation plans would be implemented to modify the water development plan wherein water pumped from the basement artesian aquifer will be reduced to match recharge potentials, while at the same time developing water from the deep and/or shallow artesian aquifers to balance demand. If required, development of the upper aquifers will occur on a well by well basis, starting with the deep artesian aquifer, then if needed, into the shallow artesian aquifer, the aquifers from which the water rights are currently utilized. In other words, if the recharge/discharge balance within the basement artesian aquifer cannot be achieved in one well, then a second well will be drilled into the upper aquifers, and so on until the needed balance is achieved. This scenario will be coordinated through the State Engineer and implemented with his approval.

Scenario IV – Little to no aquifer recharge is found. Withdrawals from the basement artesian aquifer will be substantially reduced or terminated to match any recharge noted. Groundwater withdrawals will be moved one well at a time to the deep and/or shallow artesian aquifers as outlined in Scenario III. It should be noted that regardless of existing recharge under this scenario, recharge to this zone will be induced from the deep artesian aquifer as a result of the pressure head gradient created between the overlying aquifers and the basement artesian aquifer. This induced recharge will naturally mitigate the impact over time. The mitigation of impacts under this scenario will be coordinated through the State Engineer and implemented with his approval and carefully monitored for results.

4.2 Shallow and Deep Artesian Aquifers

Studies completed for the Project indicate the basement artesian aquifer is isolated from the overlying shallow and deep artesian aquifers by 250 feet of clay, impacts to these aquifers by Magnum's pumping will be small or negligible. The following plan will be implemented to verify the engineers' conclusions, and provide mitigation under the conditions identified.

The second component of monitoring and mitigation involves the analysis and related actions should pumping impacts be felt regionally in the shallow or deep artesian aquifers. This will be accomplished through the monitoring and analysis of water levels within the shallow and deep artesian aquifers located above 1,400 feet bgs, at the two closest existing off-site wells (IPP and Delta Egg Farm) to the project site and the new observation monitoring wells to be installed by Magnum. In previous plans for constructing the caverns Magnum considered constructing the first two caverns simultaneously. Magnum has revised the cavern construction plans and now commits to constructing the caverns sequentially. This commitment to sequential cavern construction will significantly reduce the rate of groundwater use (groundwater pumping) during the initial phase of construction and the potential for adverse impacts to groundwater levels in the aquifers at the site.

These two monitoring wells, including the IPP and Delta Egg Farm wells, will be recorded on a frequency of at least daily. During the first year of operation, data from each of the four wells will be collected and reviewed by a licensed Groundwater engineer/hydrogeologist on a monthly basis. If no anomalies are apparent in the data, Magnum will request the reviews be completed on a quarterly basis, otherwise, monthly reviews will continue until the anomalies are resolved. The purpose of these reviews will be to determine whether there are any declining trends in observed off-site water levels that may be attributable to Magnum pumping activities. At a minimum the hydrogeologic reviews will include the following activities:

- Plot available flow and water level data for the IPP and Delta Egg Farm off-site wells, and the new observation monitoring wells.
- Review water level changes at each off-site well, including a check for data inflection points or other unexpected changes to water level(s) that might suggest changed local aquifer conditions.
- Review the Palmer Drought Index for correlation with recorded water levels to evaluate whether any noted changes in the off-site wells might be climatic in nature. The presence or absence of any correlation between the data sets will be noted.
- Review the flow history at each off-site well and correlate changes in pumping to noted changes in water level data, thus evaluating the potential cause and degree of water level changes.
- Develop groundwater potentiometric contour mapping for the shallow and deep artesian aquifers.
- Develop and review “change in groundwater level” site mapping showing total change in groundwater levels in the aquifers since project inception for comparison against the limiting criteria set for each phase of investigation identified below.

If declining trends are observed in the off-site wells, Magnum will pursue additional investigation following the hydrologic review methodology as discussed above for each of the following phases that represent increasing levels of impact and response:

Phase I – Historical water levels within the shallow and deep artesian aquifers at each off-site monitoring well will be reviewed for short and long term trends. Short term trends lasting less than 12 months will initially be attributed to seasonal impacts upon the Groundwater system. Long term trends exceeding 12 months will be noted for further investigation including the possible identification of impacts from Magnum pumping.

Phase II – Changes in water levels within the shallow and deep artesian aquifers in the observation monitoring wells installed by Magnum of greater than 6 feet below the historic low recorded level will initiate an internal review of pumping and monitoring data and prompt a re-evaluation of aquifer characteristics. This review will include an investigation of pumping volumes and patterns, and whether the observed impacts are the result of external causes (third party pumping, seasonal trends, weather, etc.), or Magnum pumping. Under this scenario, Magnum will employ a professional engineer/hydrogeologist to review the data on a monthly basis and provide well management strategies to control impacts.

Phase III – Changes in water levels within the shallow and deep artesian aquifers in off-site monitoring wells, specifically the IPP and Delta Egg Farm wells, of greater than 6 feet below the historic low recorded level will initiate a discussion of the observed data with the owner of the off-site well, and will prompt further investigation to determine whether the observed impacts are the result of external causes (third party pumping, seasonal variation, weather, etc.), or Magnum pumping. Under this scenario, Magnum will employ a professional engineer/hydrogeologist to review the data on a monthly basis and provide well management strategies to control impacts, and will coordinate with the off-site well owner through the investigation process.

Phase IV – Changes in water levels within the shallow and deep artesian aquifers in off-site monitoring wells of greater than 12 feet below the historic low recorded level will initiate a detailed internal review by Magnum management and professional engineer/hydrogeologist to determine the cause of the declining water level. Once Magnum's internal review is complete, Magnum will then meet with the owner of the off-site well, Magnum's professional engineer/hydrogeologist, and the State Engineer to review and coordinate any needed action.

Included within the above phases is a commitment that Magnum will cooperate with local well owners and/or the State Engineer in investigating groundwater issues that arise that are believed to be the direct result of the Magnum project.

Section 5

Groundwater System Implementation of Corrective Actions

Magnum will implement corrective actions based upon the outcome of the hydrologic reviews by a professional engineer/hydrogeologist, and according to the criteria identified in Section 4. Magnum will also comply with requirements imposed by the State Engineer including operational changes as required. In the State of Utah the State Engineer has ultimate authority for defining impacts to the groundwater system and the statutory authority to impose mitigation of those impacts. Magnum will file with the Secretary of the Commission a copy of all correspondence with the State Engineer regarding corrective actions Magnum will implement if declining water level trends are observed in the off-site wells.

It is Magnum's intent to extract water from the basement artesian aquifer. Should it be concluded at any time that the basement artesian aquifer cannot provide the full flow or volume required for solution mining, water will be produced from the deep and/or shallow artesian aquifers. In this event, the FERC will be consulted prior to implementation and the parameters of this Plan will be maintained.

Section 6

Brine Evaporation Pond Water Table Aquifer Monitoring Program

Magnum has developed a water table aquifer monitoring program for the purpose of monitoring and mitigating potential impacts to the water table aquifer in relation to the brine evaporation ponds. The plan includes a basic pond design and monitoring systems that use best available technology and products for protection of the environment. The final design was approved jointly by the Utah Division of Water Rights (DWRi) and Utah Division of Water Quality (DWQ).

6.1 Brine Evaporation Pond Liner System Design

The brine evaporation ponds have been designed as a zero-discharge system. The individual brine evaporation ponds design includes a double lining system that has a Leak Collection and Recovery System (LCRS) and Process Component Monitoring System (PCMS). The double lining system will consist of a top (primary) high density polyethylene (HDPE) geomembrane liner, a bottom (secondary) HDPE geomembrane liner with 130-mil high raised studs. The LCRS is consists of the interstitial space between the primary and secondary liners that allows any potential leakage to drain to a sump. The PCMS consisting of an engineered sloped grade and underlying network of piping that collects any potential leakage of brine from under the secondary liner in a separate sump. Sumps will be located at the southwest corner of each pond. 500 gpm pumps will be used to transfer any liquids collected back into the ponds. The LCRS and PCMS are discussed in further detail in Sections 6.4 and 6.6. Figures A-6 through A-12 depict the brine evaporation pond design to include details on the LCRS, PCMS and groundwater monitoring wells.

Double liner systems are most commonly applied to hazardous waste and ore leaching (acid and cyanide) facilities. The design incorporates the most current advancements in engineering, materials and construction techniques to prevent leakage. Magnum's design engineer for the brine evaporation ponds has successfully implemented this design at ore leaching facilities in Nevada, Alaska, Arizona and at international locations in Turkey, Russia, and Indonesia. Figure A-13 illustrates a typical double liner system.

6.2 Brine Evaporation Pond Liner System Construction

The proposed construction methods will incorporate design standards that take into consideration differential settlement and the potential effect that differential settlement will have on the liner system. To ensure that differential settlement is minimized the liner system will be installed on an engineered foundation. The foundation preparations will include ripping and compacting of native soils and fill prior to installation of the liner system. The standard compaction rate will be 95 percent of the maximum dry density.

6.3 Primary Lining System

The primary liner will consist of 80-mil HDPE geomembrane liner covering the full upstream embankment and basin of the pond. No horizontal joints will be allowed on the interior slopes. Horizontal joints and welds will be made a minimum distance of 5 feet onto the pond floor from the inside toe of the pond slopes, thus eliminating stress on the horizontal joints. The liner will be hot wedge welded to ensure continuous uninterrupted watertight containment.

6.4 Secondary Lining System

The secondary liner will consist of 60-mil HDPE geomembrane drain liner with 130-mil high raised studs supporting the primary liner. The studs create an unpressurized drainage space between the liners. The drainage gap allows fluid to flow freely to a collection sump where it can be removed and pumped back into the pond. The liner will be hot wedge welded to ensure continuous uninterrupted watertight containment.

6.5 Leak Collection Recovery System (LCRS)

The LCRS provides a rapid system for detection of leaks through the primary lining system. The LCRS will consist of an open-space drainage layer between the primary and secondary lining systems. This system is designed to provide drainage of liquids that leak through the upper lining system to sumps located at low points within the pond floor. Probes will be placed in the sumps to detect the presence of liquids. Liquids that enter the sumps can also be tested for the presence of high concentrations of brine indicating leak(s) in the primary lining system. Additionally, a 4-inch diameter perforated polyethylene (CPE) piping will be positioned along the toe of the west and south earthen embankments to increase lateral flow. Any solution reporting to the sump can be pumped and returned to the brine pond surface creating a closed system (see Figure A-10).

6.6 LCRS Leakage Flow Rate

The LCRS maximum leakage flow rate was calculated by AMEC (2011) and based on studies by Giroud and Bonaparte (1989) to provide an assumed value for primary liner system leakage. The rate demonstrates a worst case scenario value for leakage of the primary liner. A maximum leakage flow rate for Pond 1 was calculated at 465gpm, Pond 2 at 484gpm, and Pond 3 at 410gpm (AMEC 2011). These values are based on the maximum operating levels of the brine evaporation ponds and the sump design is planned to handle the maximum leakage flow rate.

6.7 Process Component Monitoring System (PCMS)

The PCMS will consist of a series of shallow trenches containing 4-inch diameter perforated and corrugated CPE piping below the secondary liner. The CPE piping will allow any liquids permeating the secondary liner to flow into an additional sump located near the LCRS sump. To limit the amount of fine sediment flowing into the system the CPE piping will be surrounded by coarse sand and sleeved with a 3-oz/yd^2 non-woven geotextile sock. The PCMS is located at the upstream towslope of each earthen embankment and three diagonal runs across along the base of the ponds. Any solution reporting to the sump will also be pumped and returned to the brine pond surface (see Figure A-8).

6.8 PCMS Leakage Flow Rate

The PCMS leakage flow rate was calculated by AMEC (2011) based on studies by Giroud and Bonaparte (1989). The rate demonstrates a worst case scenario value for leakage of the secondary liner. The leakage rate of approximately 0.024 gallons per day for Ponds 1 and 2 and 0.16 gallons per day for Pond 3 was calculated. This low rate was attributable to the low hydraulic head value from the engineering of the dual liner system. These values are well below the current maximum allowable leakage rate established by EPA and accepted in Utah of 200 gallons per acre per day (Koerner and Koerner 2009).

Section 7

Water Table Aquifer Monitoring

7.1 Brine Evaporation Pond Monitoring

Monitoring of the brine evaporation ponds consist of two aspects. The first will include a monthly physical inspection of the pond impoundment and operational components. The second will include monitoring for leakage at the sumps. The physical inspection will be completed on a monthly basis to confirm the integrity of the pond berms and identify any associated ground failures like fissures that could adversely affect integrity of the engineered design. This inspection will also include an examination of monitoring equipment including leak detection and pump initialization sensors installed within the sumps. Equipment will also be inspected and tested semi-annually to confirm proper operation. Non-functioning units will be immediately repaired or replaced. To ensure the personal safety while working along the perimeter of the crest of pond embankments, personnel will be required to wear a personal flotation device.

Monitoring for leakage at the sumps will be accomplished monthly. Each of the sumps will be equipped with a water detection sensor and a conductivity meter to identify whether the water is highly saturated with brines or relatively clean. A high conductivity (greater than two orders of magnitude above conductivity levels established as base water quality conditions for the site) would indicate a leak from the brine pond. A low conductivity reading (less than one order of magnitude above conductivity levels established as base water quality conditions for the site) will help clarify if an outside water source, perhaps from the anchor trench, etc. had found a flow path to the sump.

If sensors indicate the presence of saturated brine or high conductivity water (greater than two orders of magnitude above conductivity levels established as base water quality conditions for the site), samples will be collected and analyzed by a qualified third-party technician and a state-certified laboratory. If an immediate resample confirms the presence of a leak, the DWQ and the DWRi will be immediately notified. The leaking pond will not be utilized until the leak has been repaired to the satisfaction of the appropriate State regulatory agency. Sample water will be disposed of in a brine evaporation pond with no detectable leak. If necessary, brine from the leaking pond will be transferred to another pond.

7.2 Water Table Aquifer Monitoring

Water table aquifer monitoring wells will be installed as outlined below to identify base water quality conditions for the pond site and document and verify that the double liner and LCRS is properly operating. These monitoring wells will help provide a third tier verification of overall system integrity. Monitoring wells will be equipped with designated pumps that will provide quick and reliable samples from the wells.

Three baseline monitoring wells (GA-1, GA-2 and GA-3) will be installed up-gradient of the brine evaporation ponds. Eight monitoring wells will also be installed immediately adjacent to the pond embankment and down-gradient from each sump where the down-gradient direction is outside the pond footprint (GA-4 through GA-11). The location of these wells are depicted in Figure A-2 and Figures A-6 through A-9.

After construction, Magnum will provide well completion data (e.g., well logs, casing depth, diameter, screen interval) for each of the water table aquifer monitoring wells along with the initial baseline water quality analytical results. Up-gradient and down-gradient wells will then be monitored for water quality variations including conductivity and sodium chloride on a monthly basis using field analysis techniques with an applicable detection limit for a period of two years and then quarterly thereafter. Once a year, samples will be collected and analyzed for these same parameters by a qualified third-party technician and state-certified laboratory.

Up-gradient and down-gradient wells will be monitored for water quality variations including conductivity and Sodium Chloride according to the schedule shown in Table 7-1. Sodium chloride will be used as the testing parameter since brines created during the cavern creation process are approximately 98% sodium chloride. Since the brine evaporation ponds contain highly saturated brines, the appropriate parameters to be monitored include conductivity and sodium chloride. During the baseline period each parameter will be monitored monthly (or as otherwise required by the DWQ) to obtain two full years of data which may show and document seasonal variation. Since the brine evaporation ponds are designed with a double liner system, monitoring after the baseline period will be conducted on a quarterly (or as otherwise required by the DWQ) basis. Operational monitoring will revert to a monthly basis should the LCRS indicate that the primary liner has been breached, or at the direction of the regulatory agency following the verification of a leak in a sump that shows concentrated brines indicated by the PCMS.

Table 7-1 Brine Evaporation Pond Shallow Groundwater Monitoring Schedule

Well	Parameter	Baseline Frequency (0-24 Months)	Operational Frequency (> 24 Months)*
Up-gradient	Conductivity	Monthly	Quarterly
	Sodium Chloride	Monthly	Quarterly
Down-gradient	Conductivity	Monthly	Quarterly
	Sodium Chloride	Monthly	Quarterly

*Sampling reverts to quarterly should the drainage capacity of the liner is exceeded, or at the direction of the regulatory agency.

Up-gradient and down-gradient wells will be monitored for water quality variations including conductivity and dissolved chloride on a monthly basis using field analysis techniques with an applicable detection limit for a period of two years and then quarterly thereafter. Samples would will be collected quarterly and analyzed for these same parameters by a qualified third-party technician and State-certified laboratory. In the event that saturated brine or high conductivity water (greater than two orders of magnitude above conductivity levels established as base water quality conditions for the site) is found within the brine evaporation pond sumps, the DWQ and the DWRi will be immediately notified. Similarly, if conductivity or dissolved chloride levels in the down-gradient monitoring well exceed background samples by more than a magnitude of two, the DWQ and the DWRI will be immediately notified.

Section 8

Water Table Aquifer Reporting

Data collected will be summarized and evaluated annually. A report of the results will be submitted to the FERC, DWQ and DWRi within the first quarter of the year. In addition, Magnum will file with the same agencies a report detailing the presence of any leaks. Magnum will also file with the FERC a follow-up report on the specific measures approved by the State regulatory agency to investigate and repair the leak.

Section 9

References

AMEC. 2011. Evaporation Ponds Final Design Report. Technical Memorandum.

Giroud, J.P. and R. Bonaparte. 1989. Leakage Through Liners Constructed with Geomembranes, Part I: Geomembrane Liners. *Geotextiles and Geomembranes*, 8(1): 27-67.

Koerner, Robert M. and Jamie R. Koerner. 2009. Survey of U.S. State Regulations on Allowable Leakage Rates in Liquid Impoundments and Wastewater Ponds. GRI White Paper #15. http://www.geosynthetic-institute.org/papers/paper15.pdf.

Attachment A

Figures

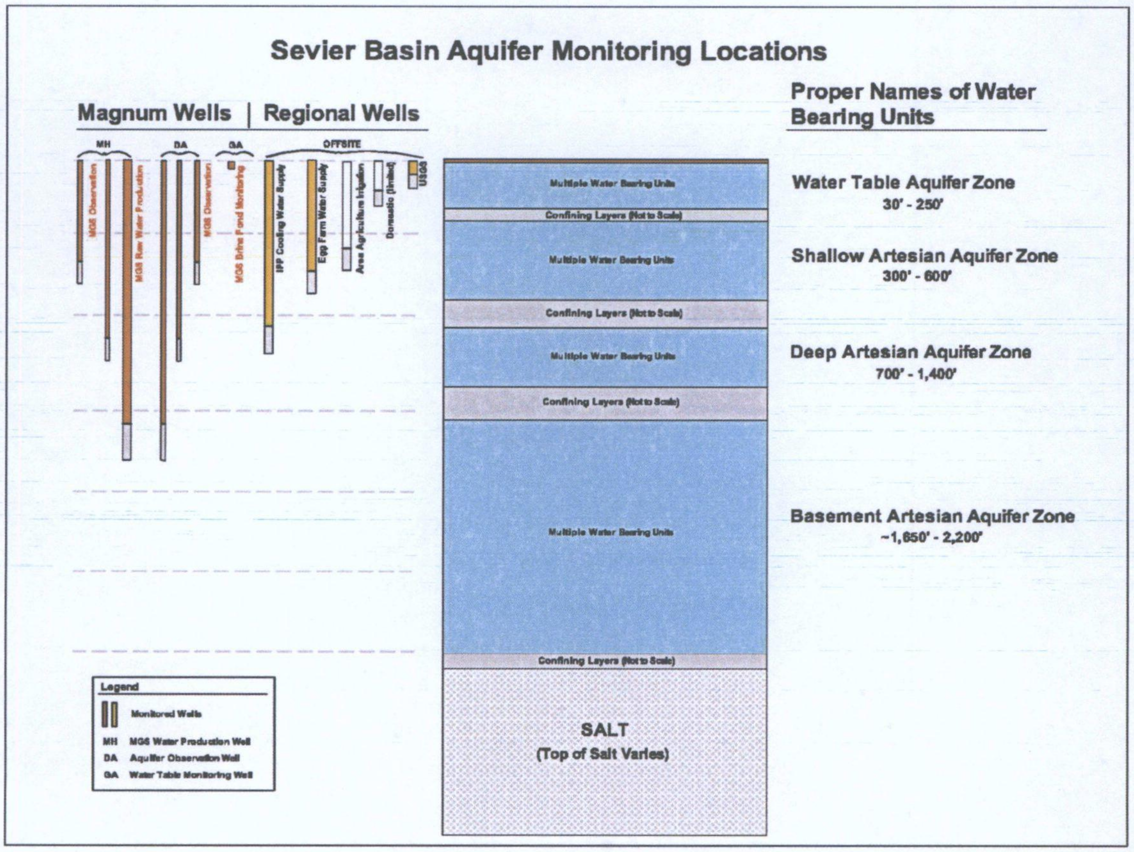


Figure A-1 Sevier Basin Aquifers and Monitoring Locations

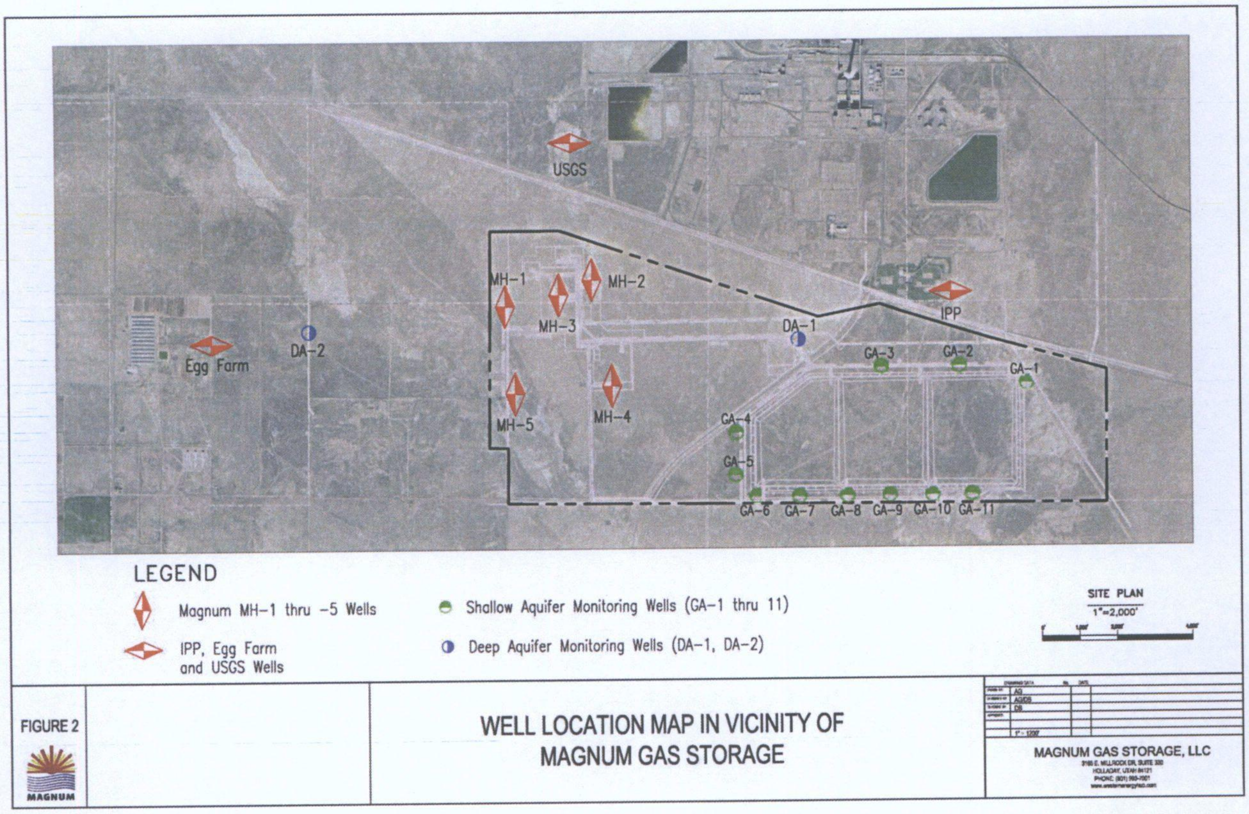


Figure A-2 Well Location Map

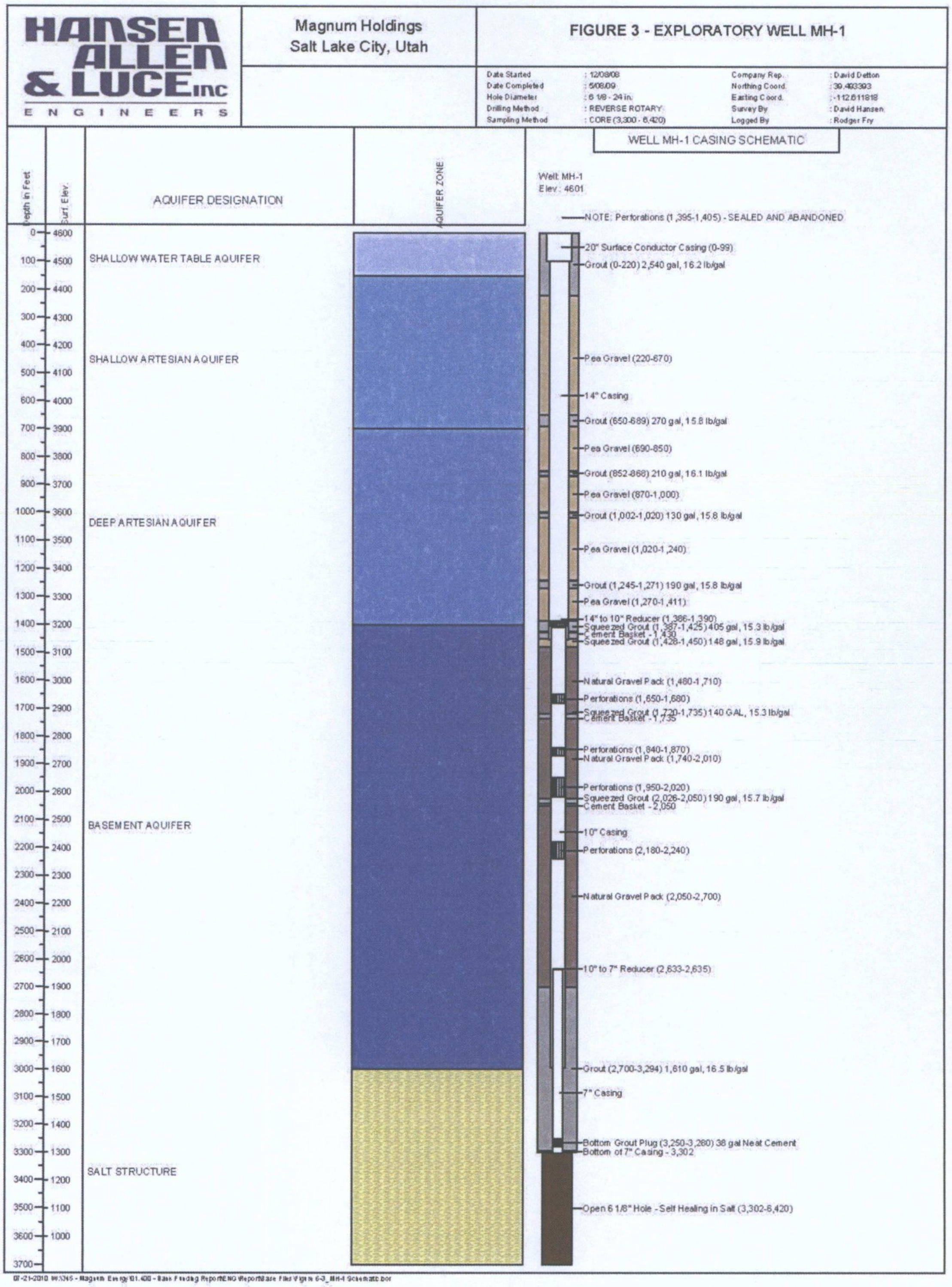


Figure A-3 Test Well MH-1

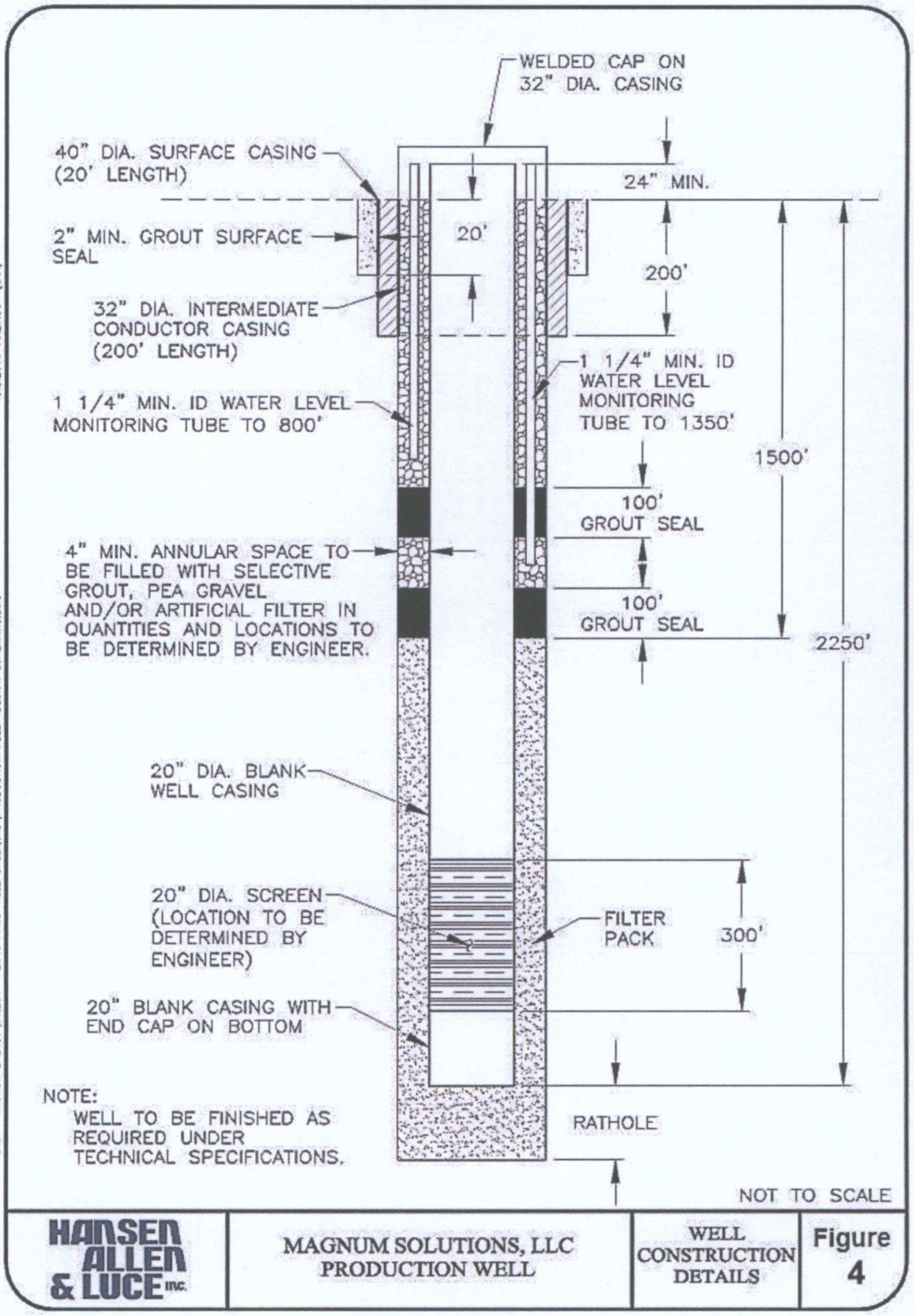


Figure A-4 MH Supply Well Details

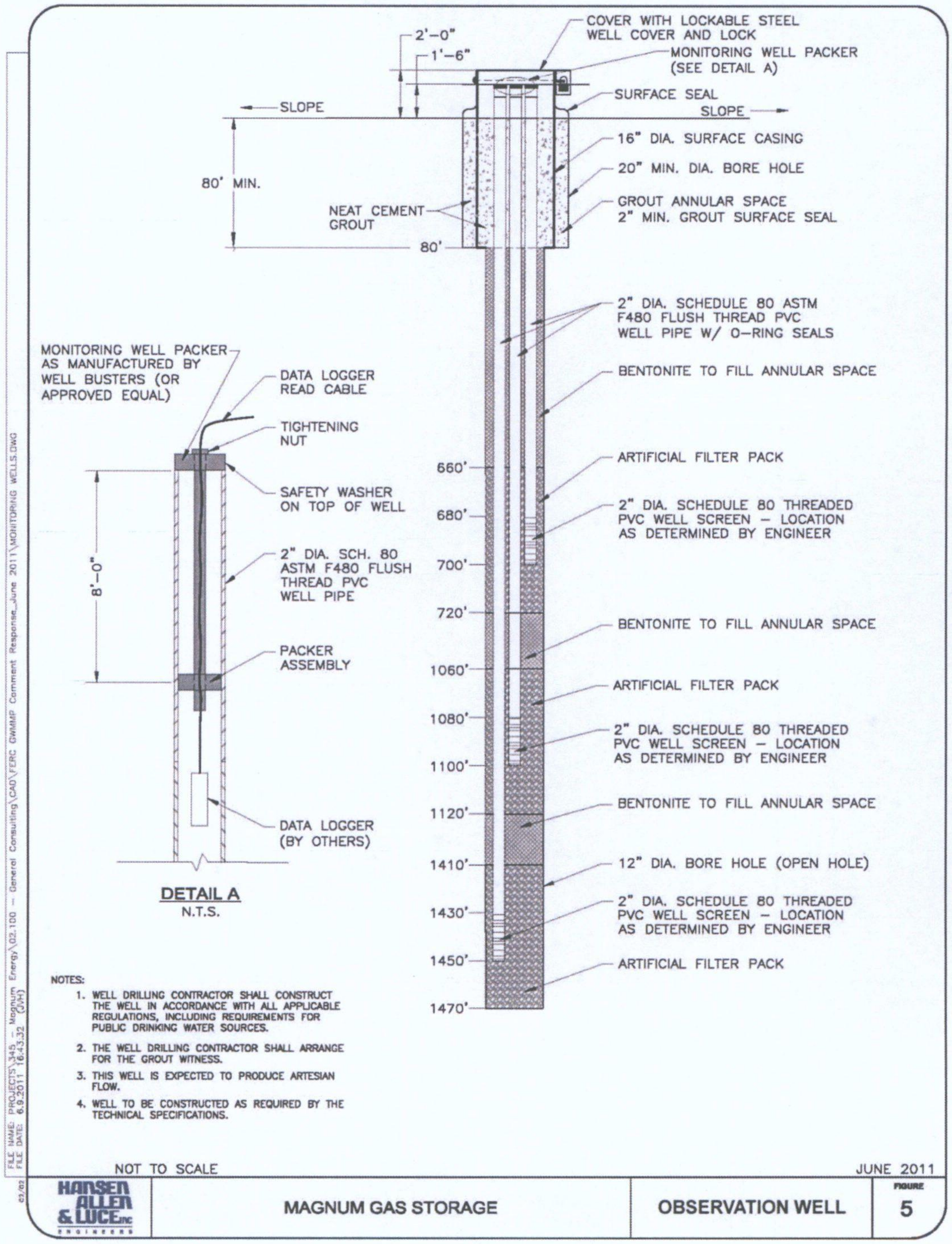


Figure A-5 Observation Well Details

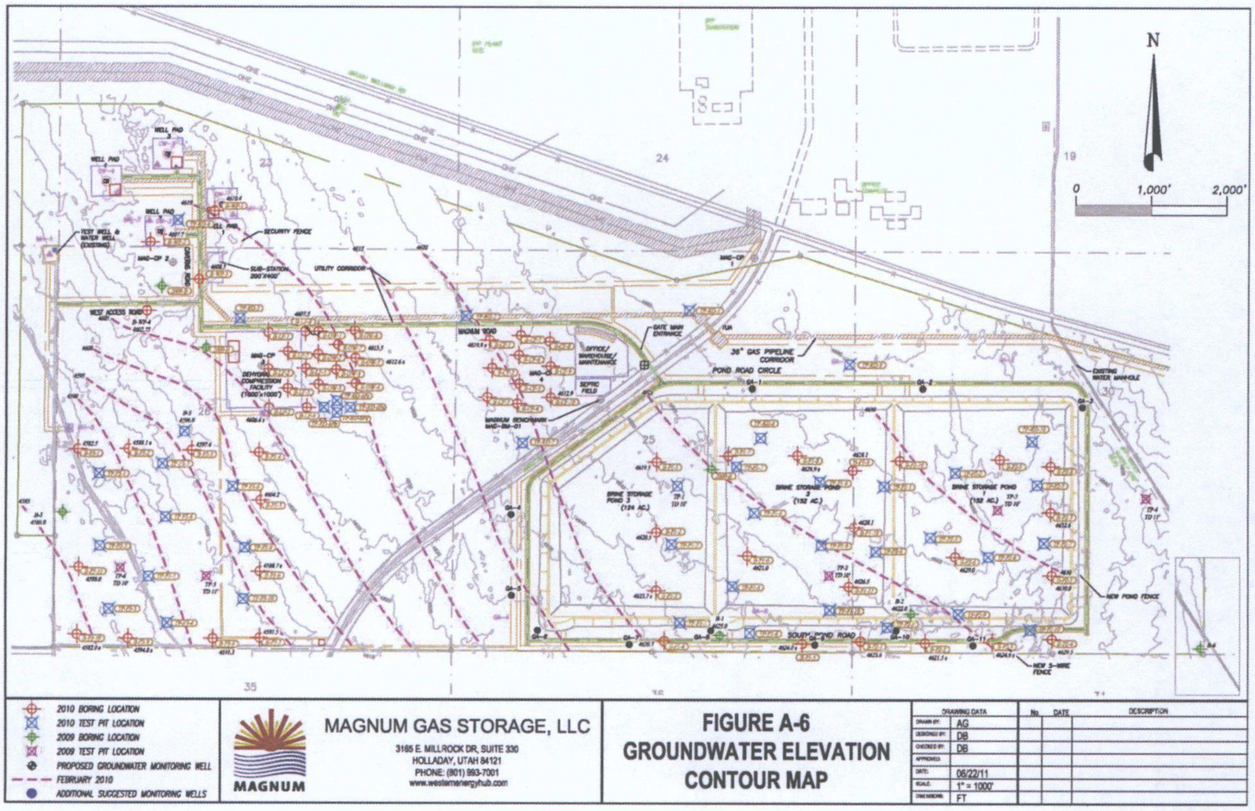


Figure A-6 Groundwater Elevation Contour Map

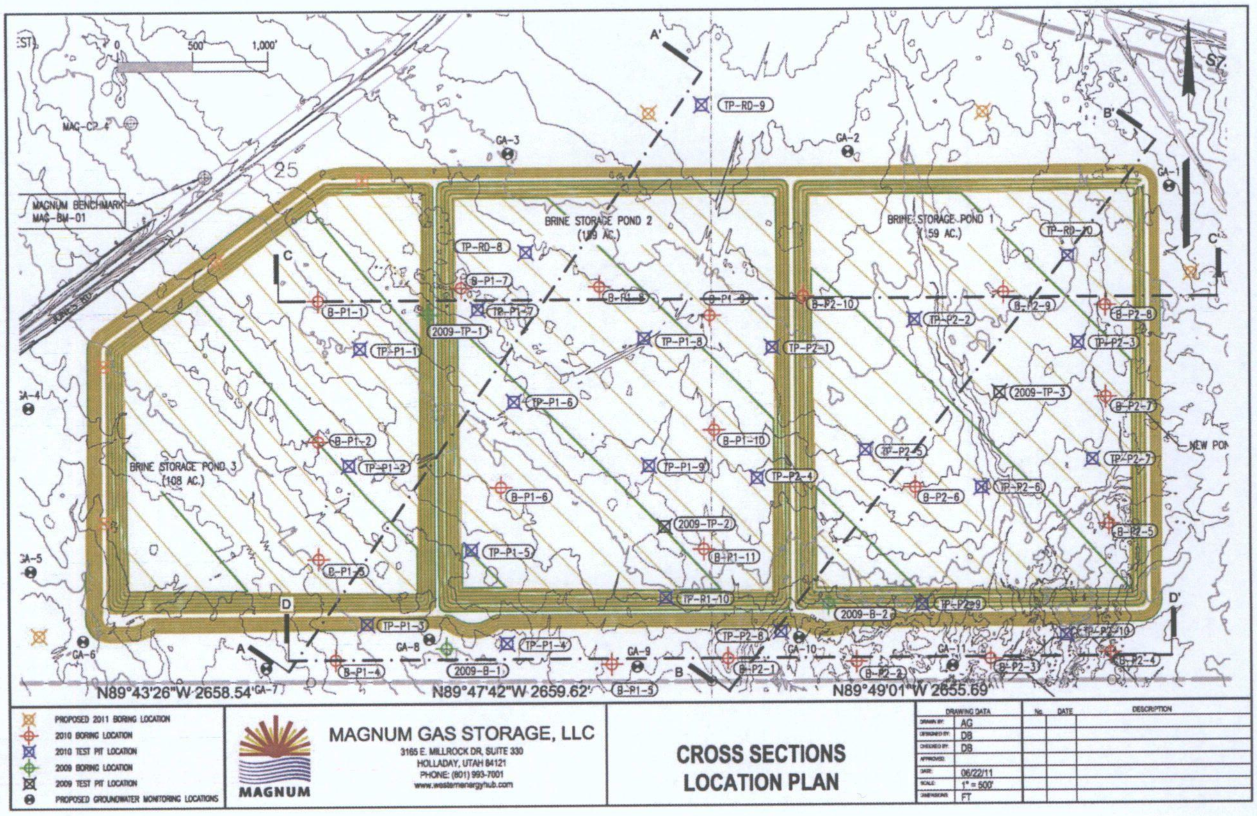


Figure A-7 Cross Sections Location Plan

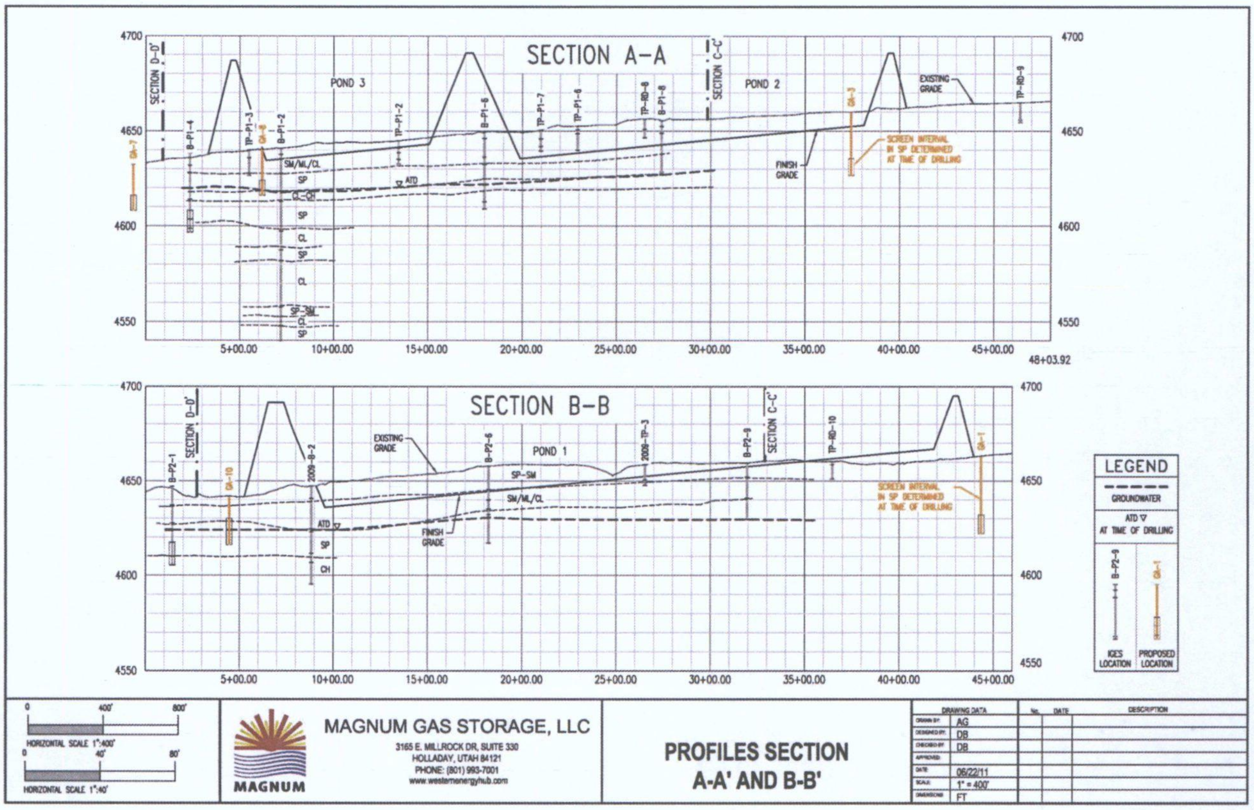


Figure A-8 Profiles Section A-A' and B-B'

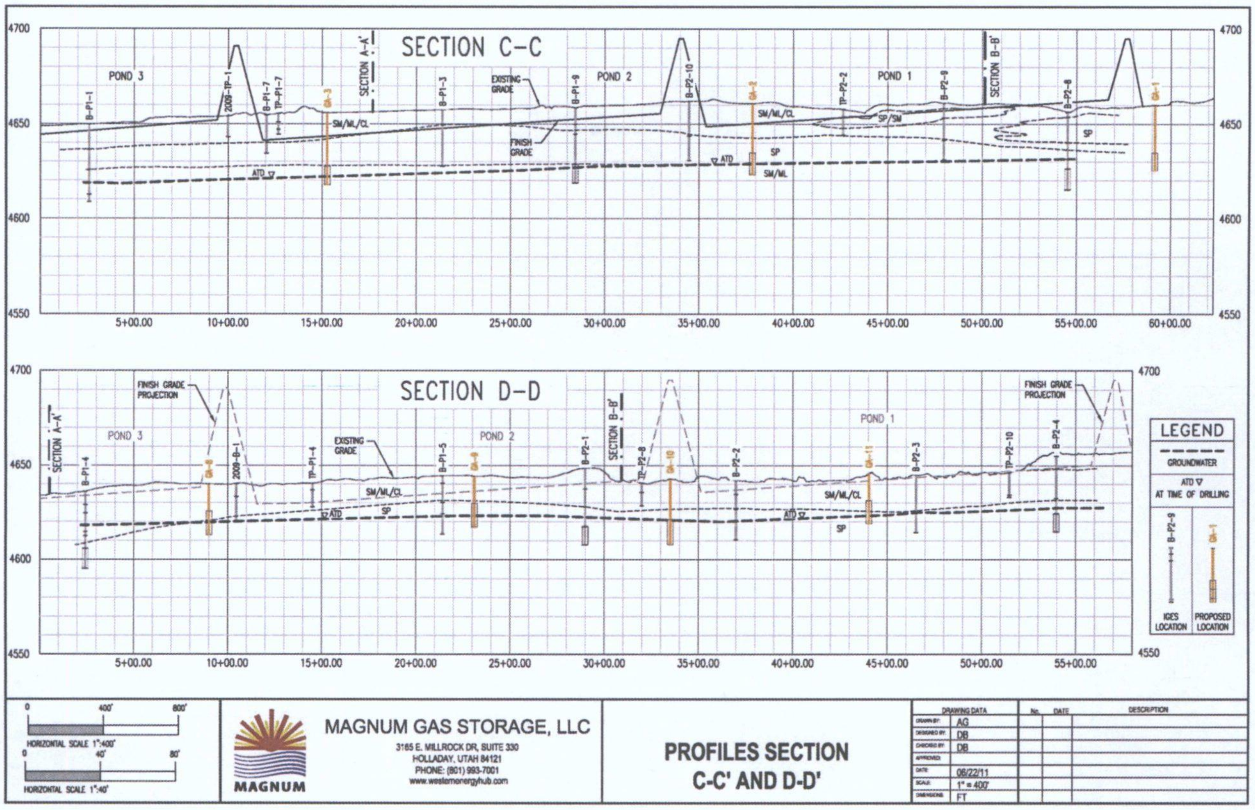


Figure A-9 Profiles Section C-C' and D-D'

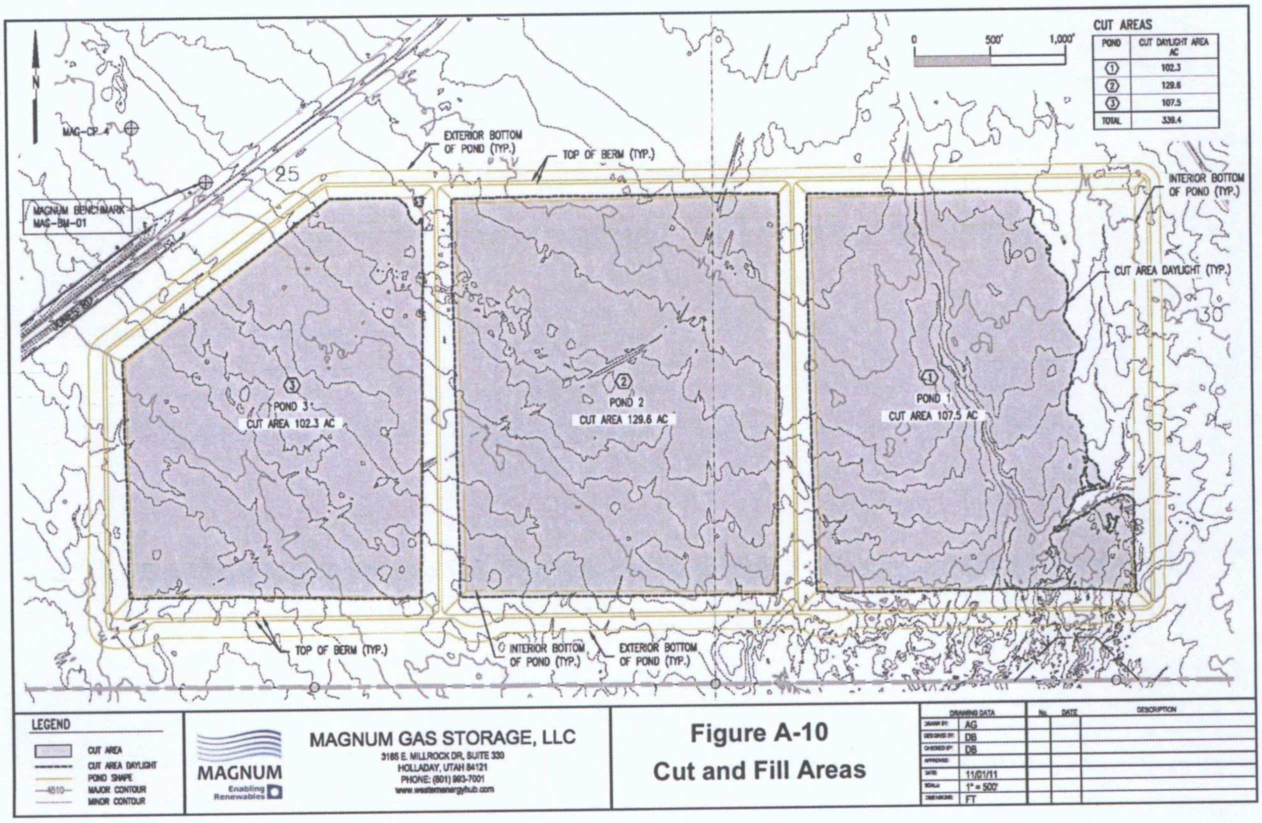


Figure A-10 Cut and Fill Areas

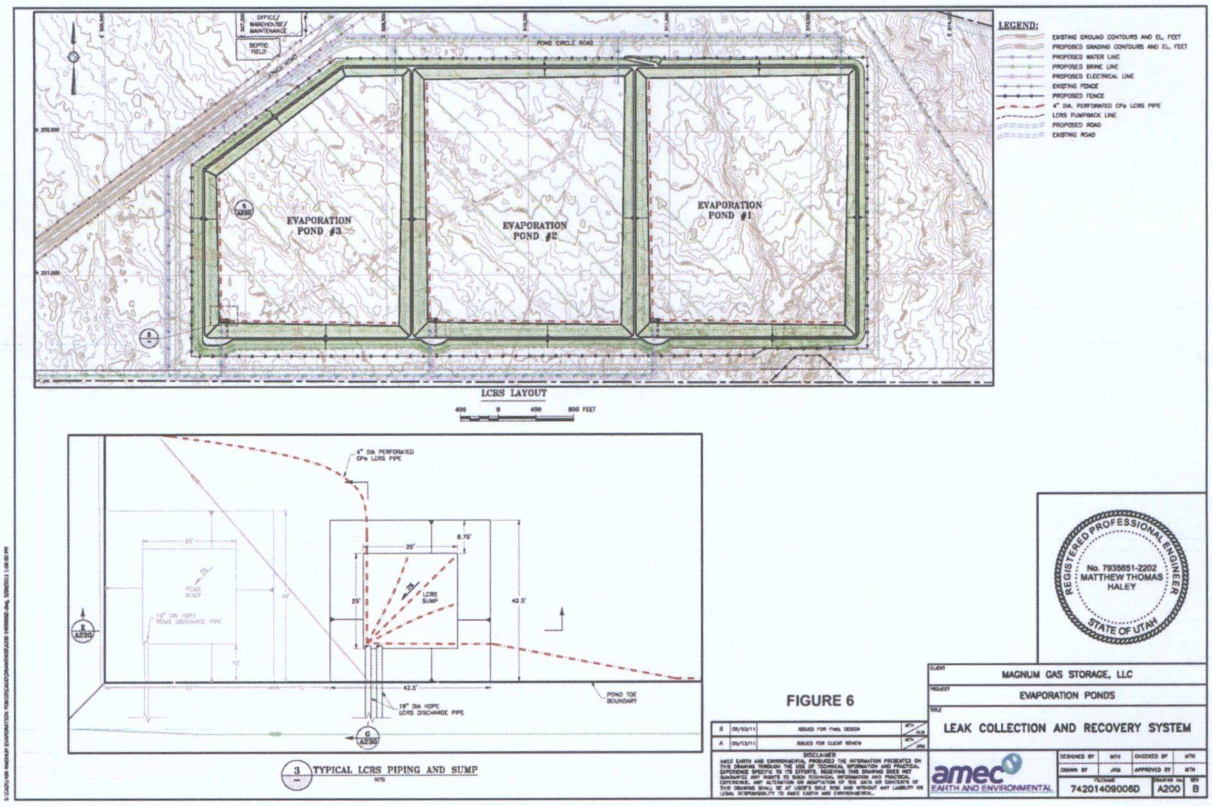


Figure A-11 Leak Collection and Recovery System

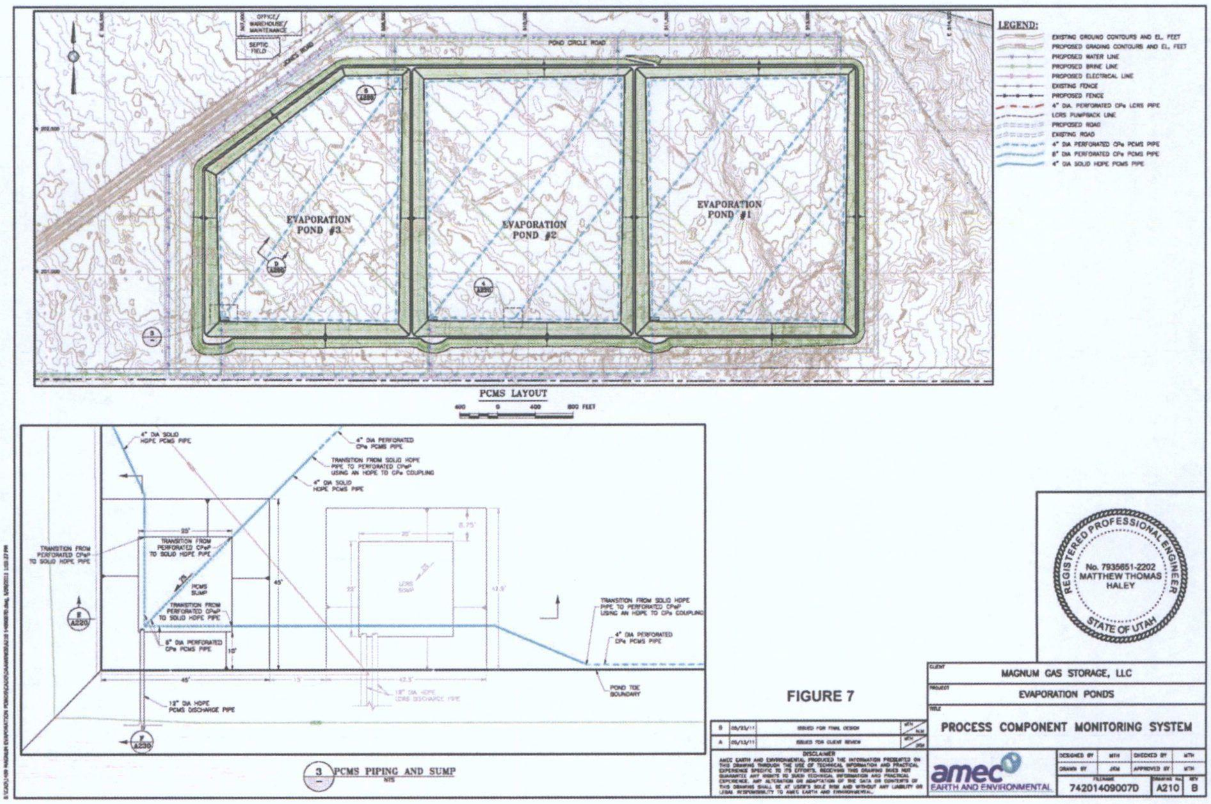


Figure A-12 Process Component Monitoring System

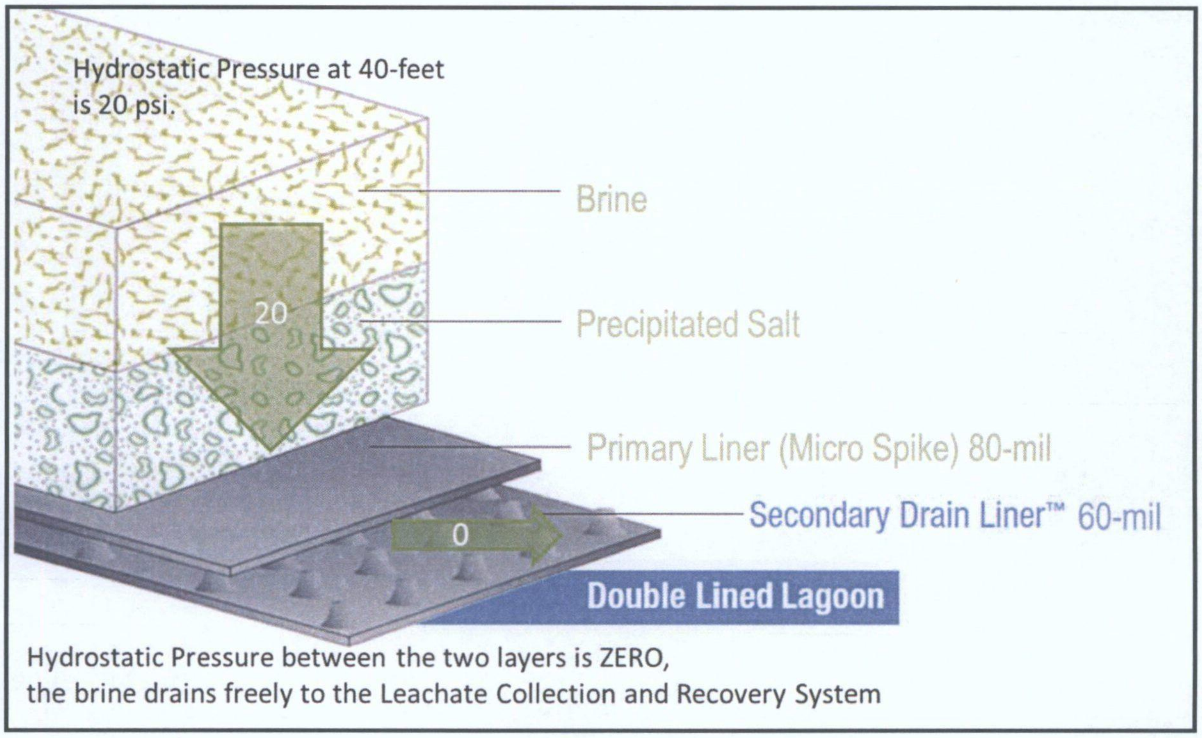


Figure A-13 Brine Evaporation Pond Double Liner System

Attachment B

Groundwater Testing Plan

Groundwater Testing Plan

As part of the Groundwater Monitoring, Mitigation, and Protection Plan (GWMMP) for the Magnum Gas Storage Project (Project), the following Aquifer Testing Plan (Plan) has been developed. The purpose of the Plan is to provide clear protocols for the monitoring of water levels within the Sevier Basin Aquifer relative to the Project's raw water production. The Project has three types of monitoring wells dedicated to monitoring water levels within the aquifer: MH Raw Water Production Wells (5); Observation Wells (2); and Off-Site Monitoring Wells (3). The locations of all monitoring wells associated with the Project are depicted in Figure 1 of the GWMMP.

Water Production Well Testing

Testing Procedures and Duration

New wells will be tested per the Technical Specification requirements contained within this section which were generally used in the current well drilling contract. Note that the "Performance Testing" section discusses a minimum pump test of 24 hours. The 24-hour pump test is required by the Utah State Division of Drinking Water and is the typical standard for definition of aquifer characteristics. A minimum 7 day pump extended period pump test will be conducted on each new well drilled to evaluate the local impact of the new well on adjacent wells and the aquifer in general. Any anomaly in test data at the pumped well or at adjacent monitored wells showing unexpected pumping impact, including water level data inflection points, may prompt extended testing.

In the event of extended testing, water level and flow records will continue to be evaluated to determine the causes and implications of the data anomalies. Testing procedures for this extended period test will however follow the same general specifications as the 24-hour pump test, except that down time will be allotted for generator maintenance without the requirement to fully re-start the pump test. The 24-hour and/or extended period pump test(s) can be conducted by either/or the well driller, or an independent well maintenance/well pumping company with equipment sufficient to achieve the testing criteria as outlined herein.

Pump Testing Equipment

Test pumping equipment shall be furnished which consists of a deep well turbine type pump capable of pumping not less than 2,500 gpm, or the capacity indicated in the bid schedule. A satisfactory throttling device shall be provided so that the discharge may be reduced to as little as 250 gallons per minute. The pumping equipment, complete with ample power source for development of the well, shall be delivered to the site prior to the completion of well development with the drilling rig. A centrifugal sand separating meter shall be used to measure the rate of sand production during well development with the test pump equipment. Test pumping equipment shall include a suitable metering device providing an accuracy of two percent.

Production for Test Pumping

After installation of test pump equipment, the contractor shall commence well development by pumping and surging to clear the well of all additional accumulation of mud, sand, and sediment. The quantity of water being pumped at the commencement of the development shall be limited, and shall be gradually increased as development continues. The quantity shall be measured by an approved orifice plate, manometer, or other approved method. From time to time, the well shall be surged by the following operation: the pump shall be stopped and the water in the pump column shall be allowed to flow back through the pump bowls and through the perforations into the aquifer. These surging operations, with increasing pumping rates shall be repeated as development of the well continues and shall be done in a manner satisfactory to the engineer.

The well shall be thoroughly developed so that it will produce a maximum capacity based on the consideration of depth and nature of the water bearing formations, and so that it will not produce an amount of fine sands in excess of the sand production limitations. Well development shall be continued until the well produces not more than 5 parts per million of sand by volume within 20 minutes after surging at the maximum pumping rate, or as directed by the engineer. In addition, the specific capacity will be stable at any selected pumping rate. During testing, the rate of sand production shall be measured by a centrifugal sand separating meter as described in the Journal of American Water Works Association, Volume 45, No. 2, February 1984. The centrifugal sand separating meter shall be furnished by the contractor. Development procedures, quantities, sand production, and times shall be recorded in the Driller's Log.

Upon completion of the development operations, the contractor shall demonstrate to the satisfaction of the engineer that the bottom of the well is clear of all sand, mud, and other foreign material.

Performance Testing

Testing Method

A step-drawdown test shall be conducted to determine pumped-well capacity and to obtain data from which to design the permanent production pump. The wells shall be pumped at progressively increasing fractions of the maximum discharge capacity in accordance with a test procedure to be furnished to the contractor by the design engineer upon completion of the well development. The length of each discharge step shall be long enough to plot a straight-line trend of drawdown versus logarithm of time since pumping began. All gauges, valves, discharge measuring, and other equipment required for the test shall be furnished and installed by the contractor prior to initiation of the testing. The discharge shall be controlled and maintained at approximately the desired discharge for each step with an accuracy of plus or minus 5 percent. Pump discharge shall be measured with a totalizing meter and stop watch, circular orifice meter, or Venturi meter as approved by the engineer. An electric sounder and/or appropriate sounding tube shall be provided by the contractor to obtain water level measurements during the drawdown test.

After water levels have returned to static conditions subsequent to the step draw down test, a constant rate test shall be conducted by pumping the well at the design rate determined by the engineer or at maximum yield for a period of not less than 2 hours and until the pumping level remains constant for at least 4 hours, or until the engineer terminates the test.

Discharge shall be checked and adjusted, if necessary, every 10 minutes during the first hour of pumping and at 30-minute intervals thereafter. The discharge and time of measurement shall be recorded each time it is checked and a note made of any adjustments. The static or non-pumping water level trend shall be established prior to the start of the test. Drawdown shall be measured according to the following schedule: 0 to 10 minutes-every minute; 10 to 45 minutes-every 5 minutes; 45 to 90 minutes-every 15 minutes; 90 to 180 minutes-each half hour; 180 minutes to the end of the test-each hour. Should the measurements not be made exactly at the times specified, the actual time of each measurement shall be recorded. On completion of pumping, recovery measurements shall be made according to the above drawdown schedule until sufficient data have been collected to extrapolate the full recovery of the well or until the engineer requires no further data.

Aborted Test

Whenever continuous pumping at a uniform rate has been specified, failure of pump operation for a period greater than one per cent of the elapsed pumping time shall require suspension of the test until the water level in the pumped well has recovered to its original level. For the purposes of this Section, recovery shall be considered "complete" after the well has been allowed to rest for a period at least equal to the elapsed pumping time of the aborted test except that if any three successive water level measurements spaced at least 20 minutes apart show no further rise in the water level in the pumped well, the test may be resumed immediately. The engineer shall be the sole judge as to whether this latter condition exists.

Aquifer Monitoring

Monitoring Frequency and Testing

Flow monitoring will be recorded through the use of pressure transducers and data loggers. The type and brand may vary, but will be similar in nature to the Level Troll series as manufactured by *in-situ*. A separate unit will be dedicated to each monitoring zone identified Figure 1 of the GWMMP. Unless field conditions are found to indicate otherwise, a 0-100 psi rated pressure transducer, with a full scale range accuracy of ±0.2% will be used for the well being pump tested. Flow data will be provided by the contractor and recorded manually or electronically via a totalizing meter and stop watch, circular orifice meter, or Venturi meter as approved by the engineer. New well monitoring frequency is discussed under "Performance Testing" above. Water level monitoring in adjacent wells will be conducted on minimum 60 minute intervals during the length of the pump test and for a period of at least half the pump test duration following the termination of pumping.

Analysis and Reporting

Data retrieved from each new well tested will be analyzed using AQTESOLV, or similar data matching software capable of evaluating, at a minimum, confined and confined-leaky aquifer conditions with a choice of solution methodology. Said software shall also have the capability of determining storage coefficients using extraneous observation well level data and of projecting water level declines over extended time periods. Due to the extensive nature of confining beds as noted to date, the aquifer will be evaluated utilizing The Confined Aquifer solution. If the solution shows a poor data match, other solutions will be evaluated in an attempt to find a better data match.

Hydrologic boundary conditions will be identified through the identification of data inflection points, or changes in water level response in plotted data.