PREEMPTIVE RELEASE OF BRINE FROM A PRESSURIZED BRINE RESERVOIR UNDERLYING WIPP

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ABSTRACT

Human intrusion events are potentially troublesome in demonstrating environmental compliance at the WIPP. One scenario is an exploratory borehole at some time in the future that penetrates both the repository and an underlying pressurized brine reservoir, followed by artesian flow and transport of radionuclides to the surface. If this event proves to be a barrier in complying with environmental standards, recourse to preemptive release of brine through drilling and pumping is proposed as a remedial action to obtain compliance. It is recommended that this remedial action procedure be evaluated now so that it is available when and if needed. A computerized reservoir model has been prepared and preliminary calculations completed to illustrate the preemptive release concept.

INTRODUCTION

Performance Assessment (PA) of the Waste Isolation Pilot Plant (WIPP) is proceeding at the Sandia National Laboratories to provide the basis for demonstrating compliance with EPA environmental standards (1). The PA includes a wide range of scenarios to examine the aggregate risk of release of more than allowable quantities of radionuclides and other hazardous materials over specified time periods. The most troublesome potential category of scenarios involves human intrusion by exploratory boreholes at some future time. EPA guidelines (1) state that up to 30 boreholes per square kilometer of repository area for 10,000 years should be assumed for repositories in proximity to sedimentary rock formations. This leads to an expected value of about four boreholes into or through the WIPP over a 10,000 year period. A transient electromagnetic (TEM) survey at the WIPP site in 1987 (2) indicates that brine appears to be present in the Castile Formation, below portions of the waste panel horizon in the Salado Formation. Brine reservoirs appear to be isolated from each other and from horizons in the Salado Formation. There is a possibility that one or more of the four boreholes projected to penetrate the WIPP may be continued downward and intercept a pressurized brine reservoir underlying the WIPP. The ensuing artesian flow can transport radionuclides to the surface.

It is outside the scope of this paper to examine the consequences of a borehole penetrating both the WIPP and an underlying brine reservoir. Consequences, examined in the course of the PA, depend upon many factors that vary with time and upon a number of mitigating processes. However, if this human intrusion event proves to be a barrier in complying with environmental standards at WIPP, it would place the entire project in jeopardy. It is proposed here that recourse to preemptive release of brine offers a remedial action to obtain compliance. During drilling of exploratory borehole WIPP-12 near the WIPP site in 1981, a large pressurized brine reservoir was encountered (3). Extensive flow tests at this borehole provide the basis for development of a reservoir model and a preliminary application of the model to calculations for a concept of preemptive release of brine by drilling and pumping near the WIPP site.

PRESSURIZED BRINE RESERVOIR AT WIPP-12

The brine reservoir encountered at a depth of approximately 920 m during the drilling of the WIPP-12 exploratory borehole displays a double-porosity behavior. A high permeability portion referred to as the local large-fracture group serves as a brine collective system and yields relatively high initial flow rates when provided a conduit (such as a penetrating borehole). A large volume portion, the microfracture group, has relatively low permeability and serves as a slow recharge source for the large-fracture portion. Table I summarizes the WIPP-12 reservoir characteristics estimated and discussed in detail in a DOE report on brine reservoirs (3). The large-fracture group contains less than 7 percent of the total reservoir brine volume. The fractures encountered at WIPP-12 are in a near vertical orientation. Gases in WIPP-12 brine are predominantly methane and hydrogen sulfide. Table C.2 in the DOE report (3) indicates an average H_2S content of 0.99 kg per cubic meter of brine. This represents 0.65 m^3 gas at STP or 0.010 m^3 if condensed to a liquid in off-gas treatment.

PREEMPTIVE DRILLING AND PUMPING CONCEPT

Completion of the WIPP Performance Assessment will lead to a determination of whether WIPP meets the EPA standards (1) or whether meeting the standards is dependent upon meeting certain conditions. If it develops that the consequences of inadvertent drilling that intercepts waste and a pressurized brine reservoir would result in a failure to meet the EPA standards, remedial action is proposed. Preemptive drilling from the surface into the brine reservoir, followed by pumping, can relieve reservoir pressure and alleviate the potential for future releases by human intrusion scenarios.

A sequence for the proposed preemptive drilling and pumping is now described. Drill a borehole near the edge of the repository in an area expected to intercept brine but not waste. Case the hole down through most of the Salado Formation before drilling into the Castile Formation. Salt creep will quickly seal around the outside of the casing and avoid compromising the site. Continue drilling to encounter brine. Conduct a flow test with shut-in recovery to obtain data for the brine reservoir model. This data will indicate the apparent storage volume of the reservoir and its initial pressure, and provide for quantifying parameters in the model. Using the

TABLE I

Characteristics of Pressurized Brine Reservoir at WIPP-12 Borehole

	Large-Fracture Group	Microfracture Group	Total
Volume, m^3	1.74E+5	2.54E+6	2.71E+6
(gal)	(4.6E+7)	(6.7E+8)	(7.2E+8)
Initial pressure, MPa	12.6	12.6	
(psi)	(1831)	(1831)	
Compressibility, Pa^{-1}	1.45E-8	1.45E-8	
(psi-1)	(100E-6)	(100E-6)	

computer model, establish the brine pumping program. It should be noted that without pumping, the flow rate would rapidly drop to the natural recharge flow rate; artesian flow to the surface would continue at a low rate for several years. This is shown in Fig. 1 and Table II, calculated for the WIPP site using the model described in following sections. Install a submersible pump in the borehole and maintain pumping until the planned equilibrium depth after shut-in will be obtained. Shut in and confirm the depth achieved. Plug the well. One plugging option is to plug at a depth below the repository horizon and pump out any brine remaining above the plug.

This procedure can be repeated at other locations around the repository, if deemed necessary. If significant brine is not encountered, this fact by itself reduces the probability of encountering brine during a future intrusion, and therefore reduces the consequences of the intrusion scenarios. If brine is encountered, it occurs over a relatively large area in fine fractures, minimizing potential subsidence from brine removal. However, safety considerations may preclude the pre-emptive pumping until after repository operations are completed, in case some subsidence is expected. This does not preclude earlier drilling into the Castile Formation to confirm existence of brine, determine pressure, and to conduct a flow test to define size and other characteristics for modeling and designing the pumping program. One question that can not be answered at this time is whether creep would recompress the reservoir over a period of time. It is suggested that WIPP-12 be revisited to determine whether any measurable increase in surface pressure (after release of accumulated gas cap) has occurred in the past several years.

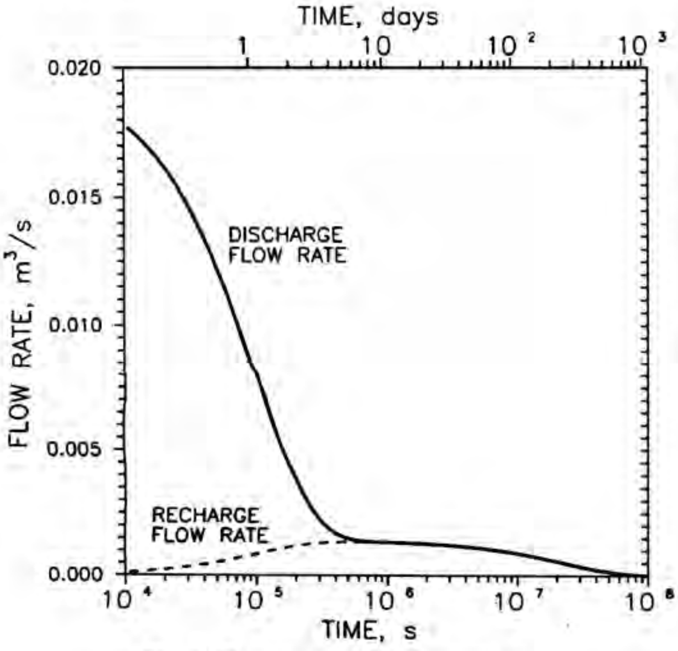

Fig. 1. Flow rates with no pumping.

Surface facilities require provisions for handling the hydrogen sulfide released from solution as brine is brought to the surface. Releases to the atmosphere may exceed air quality limits. The boiling point for H_2S is 211 K which readily permits separation and collection from the off-gas by cryogenic means.

MODELING OF PRESSURIZED BRINE RESERVOIR

A brine reservoir such as the one encountered at WIPP-12 (3,4) is used as the basis for modeling. Such a reservoir appears to have the large-fracture group interspersed within the microfracture group. The former serves as a relatively high conductivity collection manifold for slow recharge from the much larger microfracture group. The total reservoir is ideally modeled as two porous chambers with a distributed porous interconnection. Each of the chambers represents one of the fracture groups. Because of the slow nature of recharge flow, use of only the average pressure in the microfracture group is adequate for the model. In the large-fracture group, the "downhole pressure" in the vicinity of a penetrating borehole is depressed below the average pressure in this fracture system during discharge flow. Modeling to account for this lower pressure at the point of withdrawal is provided.

Model Development

Development of the generalized model is first described. In the next section, the model is implemented with WIPP-12 characteristics. Major nomenclature for the governing equations is:

V = total brine volume in reservoir, m^3
V_M = volume of microfracture group, m^3
V_L = volume of large-fracture group, m^3
p = equilibrium pressure in total reservoir, Pa
p_M = pressure in microfracture group, Pa
p_L = pressure in the large-fracture group, Pa

TABLE II

Reservoir Pressure and Artesian Flow with No Pumping

	Time, s				
	0	8.64E+5 (10 d)	3.15E+7 (1 y)	6.31E+7 (2 y)	9.47E+7 (3 y)
Reservoir pressure, MPa	12.6	12.6	12.0	11.8	11.8
(psi)	(1831)	(1827)	(1740)	(1716)	(1711)
Flowrate, m^3/s	1.96E-2	1.34E-3	3.4E-4	8.47E-5	2.02E-5
(gpm)	(311)	(21)	(5.4)	(1.3)	(0.3)
Accumulated flow, m^3	0	3.02E+3	2.54E+4	8.13E+4	3.27E+4
(gal)	0	(7.97E+5)	(6.71E+6)	(8.27E+6)	(8.64E+6)

c = compressibility, Pa^{-1}
W = recharge coefficient, s^{-1}

Incremental changes with time are denoted by delta (Δ), and rates by a prime mark (′).

The total brine volume in the reservoir, as determined by the measured change in equilibrium pressure from a discharge volume ΔV, is

$$V = \Delta V / \Delta p c \qquad \text{(Eq. 1)}$$

The compressibility, c, is the sum of fluid compressibility (combination of brine and gas compressibility) and the pore compressibility, and is dominated by the latter. Subsequent incremental equilibrium pressure decline for the total system accompanying an incremental discharge of brine is

$$\Delta p = \Delta V / V c \qquad \text{(Eq. 2)}$$

Similarly, pressure declines in the large-fracture and microfracture groups, before allowing for recharge flow, are

$$\Delta p_L = \Delta V_L / V_L c \qquad \text{(Eq. 3)}$$

and

$$\Delta p_M = \Delta V_M / V_M c \qquad \text{(Eq. 4)}$$

The rate of pressure recovery in the large-fracture group by recharge flow from the microfracture group is

$$\Delta p_L' = W(p_M - p_L) \qquad \text{(Eq. 5)}$$

where the recharge coefficient, W, is defined as the rate of pressure recovery per unit pressure difference. The value is chosen to obtain a match with intermediate experimentally observed pressures during flow tests and after shut-in. The corresponding recharge flow rate becomes

$$\Delta V' = V_L c \Delta p_L' = V_L c W(p_M - p_L) \qquad \text{(Eq. 6)}$$

The series of pressure drops during artesian flow from the reservoir to discharge at the surface may be expressed as

$$p_L - \Delta p_r - \Delta p_b - \Delta p_h - \Delta p_s = 0 \qquad \text{(Eq. 7)}$$

where

Δp_r = reservoir pressure drop from p_L to borehole p_D, Pa
Δp_b = pressure drop in borehole, Pa
Δp_h = elevation pressure head difference, Pa
Δp_s = pressure drop in surface facilities, Pa

For borehole diameters and flow rates involved, the pressure drop in the borehole can be neglected. The elevation pressure head difference for height difference ΔH, brine density ρ, and acceleration of gravity $a = 9.807 \text{ m/s}^2$, is simply

$$\Delta p_h = a \rho \Delta H \qquad \text{(Eq. 8)}$$

The average brine density in the WIPP-12 well bore was measured to be 1,241 kg/m^3. In porous flow, the flow rate is proportional to pressure drop. Then, the reservoir pressure drop from the average large-fracture pressure, p_L, to the "downhole pressure," p_D, during flow q, is

$$\Delta p_r = p_L - p_D = q/k_1 \qquad \text{(Eq. 9)}$$

The pressure coefficient k_1, $m^3/(s \cdot Pa)$, is estimated on the basis of initial measured flow rate and initial immediate pressure recovery upon shut-in. It is adjusted as necessary, to obtain a match between calculated and flow test results.

The surface facilities are a complex system of valves, flowmeters, bypasses, and other piping. In addition, partial to full blockage by salt deposits occurred at WIPP-12. For simplicity, it is assumed that the flow rate (m^3/s), is

$$q = k_2 \Delta p_s \qquad \text{(Eq. 10)}$$

where k_2, $m^3/(s \cdot Pa)$ is a pressure coefficient for the surface facilities. Its value may be determined by use of data pairs of q and p_s from flow test measurements. Then,

$$\Delta p_s = p_s = q/k_2 \qquad \text{(Eq. 11)}$$

Substituting in Eq. (7) and simplifying, the discharge flow rate is

$$q = (p_L - a\rho\Delta H)k_t \qquad \text{(Eq. 12)}$$

where

$$k_t = 1/(1/k_1 + 1/k_2) \qquad \text{(Eq. 13)}$$

The above equations are incorporated in a computer program that calculates discharge and recharge flow rates, accumulated discharge and recharge volumes, and the pressures p_L, p_M, p_D, and p_s. Provision is added to the model for pumping with a submersible pump in the borehole, in which case the head difference, ΔH, varies, and depths to the brine surface are calculated.

Model Applied with WIPP-12 Reservoir Characteristics

The model was applied to the pressurized brine reservoir encountered at WIPP-12. Using reservoir characteristics in

Table I, and flow test data, the recharge coefficient W and the pressure coefficients k_1 and k_2 were adjusted to obtain agreement with the discharge flow rate and downhole pressure variations with time during flow, and downhole pressure variations with time during the recovery after shut-in. The values obtained for these three coefficients were 6.944E-7 s^{-1}, and 3.128E-8 and 8.968E-8 $m^3/(s \cdot Pa)$, respectively. The model was then applied to a brine reservoir beneath WIPP, assumed to have characteristics similar to the one at WIPP-12 except slightly deeper at 968 m. Without pumping, the discharge and recharge flow rates are as shown in Fig. 1. Flow and pressure calculated at various times up to three years are given in Table II. Zero time refers to the time artesian flow is allowed to commence after the borehole penetrates the brine horizon.

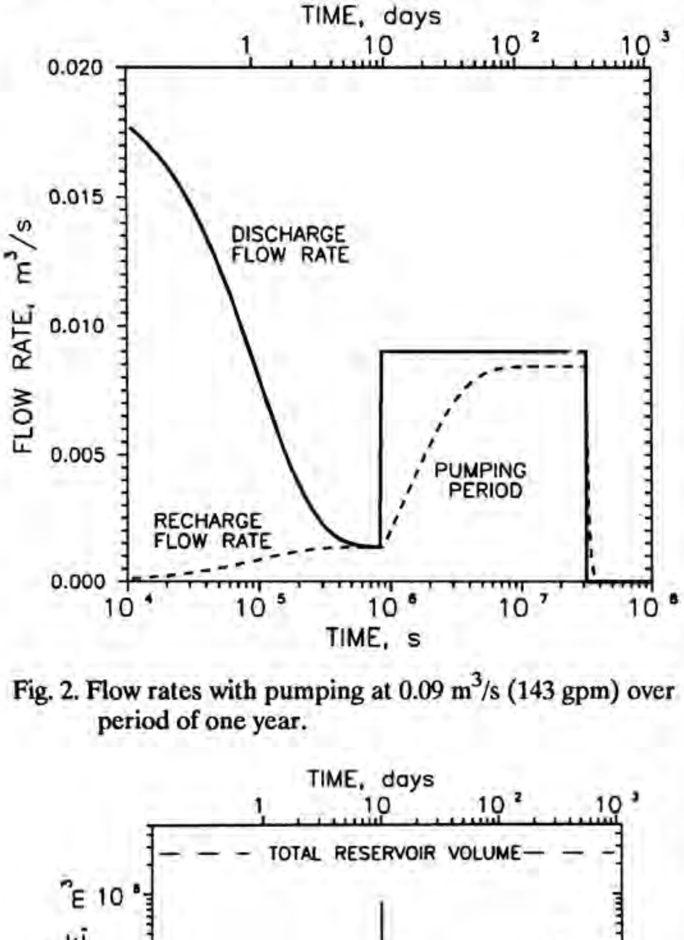

Fig. 2. Flow rates with pumping at 0.09 m^3/s (143 gpm) over period of one year.

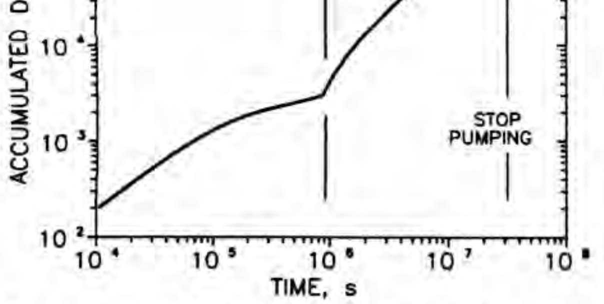

Fig. 3. Accumulated brine discharge with pumping at 0.09 m^3/s over period of one year.

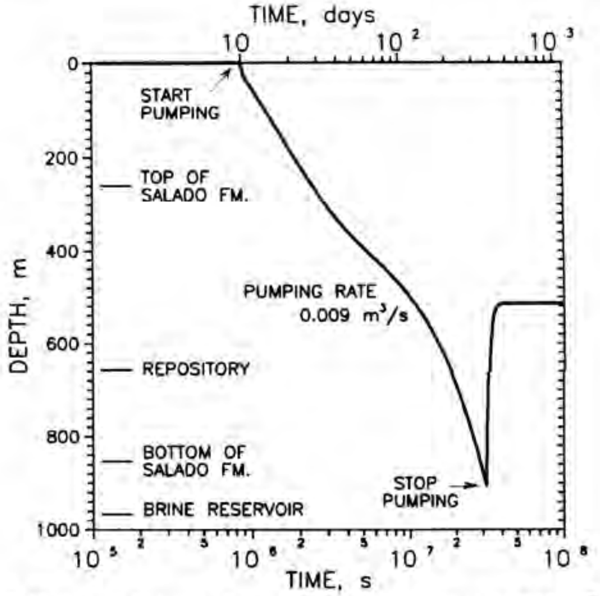

Fig. 4. Depth to brine in borehole with pumping at 0.09 m^3/s over period of one year.

RESULTS OF CALCULATIONS

The model described earlier was applied with pumping at several constant rates from 0.0015 to 0.009 m^3/s (24 to 143 gpm), to illustrate the preemptive pumping concept. Pumping is assumed to start after the initial surge of artesian flow rate drops to near the recharge flow rate, reached after ten days. Pumping was assumed to be stopped one year after the start of flow. Figures 2 through 5 show calculated results for the highest pumping rate. Flow rates are shown in Fig. 2. As pumping progresses and the downhole pressure (P_D) and large-fracture pressure (P_L) drop, recharge flow rate increases and draws down the microfracture pressure (P_M). The corresponding accumulated discharge is shown in Fig. 3. A holding pond 400 m square and 1 m deep would contain the total quantity of discharged brine, without allowance for expected evaporation which itself can amount to over 1 m per year. The total volume discharged with this pumping program represents 10.3% of the initial reservoir volume. The depth to brine in the borehole is shown in Fig.4, illustrating that the pumping depth would approach the depth of the reservoir after one year for this pumping rate, and would recover nearly 400 m following the stop of pumping. Pressure distributions are shown in Fig. 5. The equilibrium pressure after pumping is stopped shows that 56% of the initial pressure is depleted.

The depths during and after pumping, as previously shown in Fig. 4, plus three lower rates are shown in Fig. 6; the corresponding major parameters are listed in Table III. The capacity of submersible *multistage turbine* pumps varies with the pumping head. Instead of constant pumping rates as shown, an actual installation would begin with a relatively high pumping rate. This rate would then steadily decrease as the pumping head increases with lowering of the level in the borehole. A longer duration pumping program than used here would permit correspondingly lower pumping rates. If desired, a pumping program can be defined that would obtain an equilibrium brine level lower than the repository horizon.

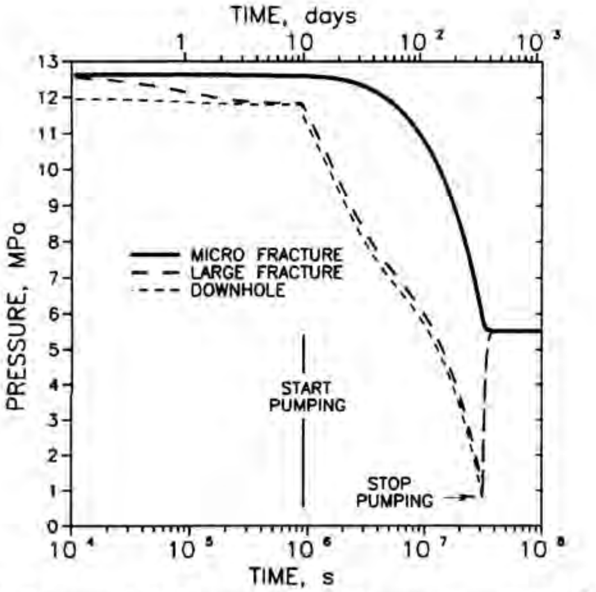

Fig. 5. Pressure in brine reservoir with pumping at 0.09 m^3/s over period of one year.

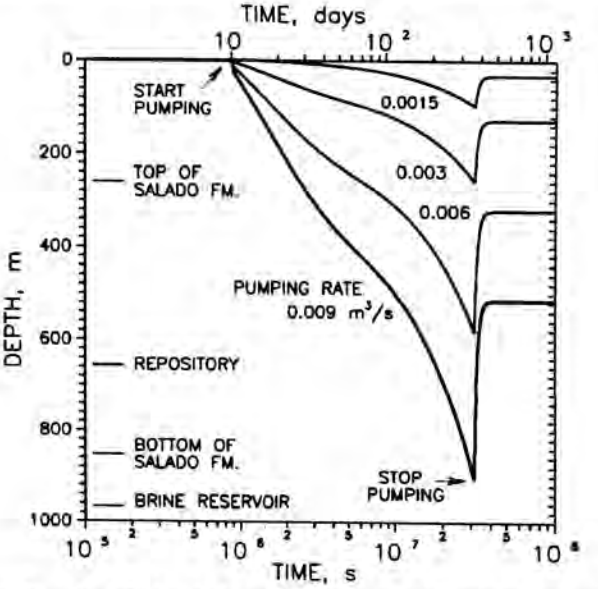

Fig. 6. Depth to brine in borehole for several pumping rates over period of one year.

TABLE III

Calculated Results for Pumping at Various Rates Over Period of One Year

	Pumping Rate, $m^3/s \times 10^3$			
	1.5	3.0	6.0	9.0
Maximum pumping depth, m	98	260	583	905
Final equilibrium depth, m	33	129	322	514
Total brine discharge, m^3	4.9E+4	9.5E+4	1.9E+5	2.8E+5
Final reservoir pressure, MPa (initial pressure 12.6 MPa)	11.4	10.2	7.86	5.52

CONCLUSIONS AND RECOMMENDATIONS

If human intrusion events involving penetration of a brine reservoir prove to be a barrier in complying with environmental standards at WIPP, placing the repository in jeopardy, recourse to preemptive release of brine offers a remedial action to obtain compliance. It is recommended that this remedial action concept be evaluated now so that it is available when and if needed.

Preemptive release of brine requires pumping to obtain adequately reduced reservoir pressure. Without pumping, artesian flow can continue at a low rate for several years.

A pumping rate of 0.006 m^3/s (95 gpm) or greater can obtain a significant lowering of pressure within a one year period of time in a brine reservoir similar to the one at WIPP-12. With longer pumping periods, lower pumping rates are feasible.

It is proposed that boreholes for preemptive release of brine be cased for most of their length to avoid compromising repository integrity. There are a number of options for cementing or plugging, and even arguments for leaving them open for monitoring and future re-pumping.

This preliminary study, using a range of constant pumping rates, should be extended to refine the model for use of available submersible pumps, reflecting pumping rates that vary with the instantaneous pumping head. An additional study should also consider a parametric range of reservoir volumes and other characteristics.

There is a potential for repressurization due to creep over an extended period of time. One means to explore this is to revisit WIPP-12 to determine whether any measurable increase in surface pressure (after release of accumulated gas cap) has occurred in the past several years. Even if repressurization is expected to occur, a benefit by preemptive release of brine can be obtained. Depending upon the rate of repressurization and the level of initial pressure depletion obtained by preemptive release, the resulting time delay may adequately reduce risk from intrusion scenarios to obtain environmental compliance. In the extreme, a pumping program can be continued long enough to virtually exhaust the brine inventory.

REFERENCES

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