CONCENTRATE AND BRINE MANAGEMENT THROUGH DEEP WELL INJECTION

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Abstract

The Reverse Osmosis (RO) process and other membrane filtration processes are now widely used for wastewater treatment, water reclamation, and desalinization facilities. These water purification processes generate high solids concentration brine. Managing such concentrated wastes is critically important for expanded and sustainable wastewater treatment and water reclamation worldwide.

Properly designed and operated, deep well injection provides a highly cost-effective means for wastewater brine management, with significant environmental advantages over alternative brine management options. These environmental advantages include:

1. Eliminating impact on surface water and shallow groundwater;
2. Reducing or eliminating long-distance pipelines and ocean outfalls;
3. Reducing surface imprint and land use impairment; and,
4. Providing a sustainable and local management option for urban areas and industrial facilities.

Long-term containment in the target formation is assured through three critical and important factors: appropriate geologic formation selection; appropriate well design, and appropriate operating and monitoring practices. This paper describes best practices for brine and other high solids concentrate injection into the deep subsurface (typically deeper than about 3000ft). We present technical design factors and optimum operating practices, with several field examples.
One such example includes digested sludge and RO brine injection for the City of Los Angeles at the Terminal Island Treatment Plant, where GeoEnvironment Technologies has successfully injected more than 120 million gallons of waste fluids during the past three years, reducing treatment plant brine disposal via pipeline and ocean outfall.

Introduction

With increasing urban development and industrial development comes ever increasing requirements for water and wastewater treatment. A variety of filtration processes, including membrane filtration and the Reverse Osmosis (RO) process, are now widely used for wastewater treatment, water reclamation, and desalinization facilities. These water purification processes generate high solids concentration brine. Managing such concentrated wastes is critically important for expanded and sustainable water reclamation worldwide.

In the past, concentrated brine and other solids laden wastewater were primarily discharged to surface waters, including rivers, channels, and to the ocean. Such practices present significant environmental concerns, and are becoming increasingly restricted. A practical and cost-effective alternative to surface water discharge and to long-distance pipeline and ocean outfalls is to manage such concentrated brines through deep well injection into an appropriately selected geologic horizon.

Deep well injection of liquid wastes into underground formations (porous, permeable, geologic strata) initiated in the 1930s by the US petroleum industry, which had an increasing need to dispose of saline water co-produced with oil and gas. In the 1970s and 1980s the practice was expanded to manage industrial and some municipal wastes (Testa, 1994). Regulations were implemented in 1980 by the US Environmental Protection Agency (EPA) to manage injection practices, with the primary goal to protect current and future sources of drinking water (pursuant to the mandate established by the Safe Drinking Water Act). Today there are more than 400,000 injection wells in the United States. The vast majority are used to re-inject produced water (brine) into oil and gas fields. About 4000 are used to manage municipal and industrial wastes.

Although deep well injection of brine has been practiced for many years, several recent advances in well design, operations, monitoring, and analysis, now allow the technology to be practically and safely applied to manage large volumes of high concentrations of brine for the wastewater treatment industry. This confluence of improving technology and increasing need suggests that deep well injection technology will play an increasingly critical and important role in wastewater treatment brine management to facilitate sustainable urban and industrial development worldwide.

Technology Summary

The primary objective for deep well injection projects is to place and permanently contain the injected fluid in the target subsurface formation. Long-term containment in the target formation is assured through three critical and important factors: appropriate geologic formation selection; appropriate well design, and appropriate operating and monitoring practices.

Geologic Formation Selection

Geologic strata most suitable for waste injection are relatively thick (greater than 50ft) sedimentary layers of relatively high porosity (greater than 15%) and relatively high permeability (greater than 100md). The injection target strata should be overlain by a relatively thick (greater than 50ft) and relatively impermeable (less than 10md) geologic layer to contain the injected fluids. To restrict vertical migration, the ideal geologic setting will include several alternating layers of such permeable sediments (flow sinks) and impermeable sediments (flow barriers).

The process to identify and verify such geology conditions usually involves several formation evaluation steps of increasing complexity and certainty. First, a regional geologic review is conducted to indicate if the general area is within the historical boundaries of a sedimentary basin. Such a regional review often includes topographic studies and rock outcrop studies.

The next step is to examine the well records of historical exploration and production wells in the area. These well records include electrical logs which provide an indication of lithology versus depth, and mud log data (observations and characterization of the rock chip material brought up during the drilling process. Such information may be used to develop an approximate geologic model of the stratigraphic column in the area.

The final step is to actually drill and test a characterization well in the area penetrating to the zone of interest. This well may eventually be converted into an injection or a monitoring well. During the drilling process, additional electrical logs are taken and analyzed. Core samples may also be taken and analyzed to quantify geology formation properties such as porosity and permeability. Finally, injection tests are conducted in the well to determine injectivity properties (pressure required to inject at a given flow rate) and in-situ stress properties (minimum stress and fracture pressure). Ideally, such tests are conducted in both target injection formation and in overlying containment strata (the caprock).

Well Design and Completion Process

Once a target injection interval has been identified, the next step is to install a properly designed injection well. An ideal configuration is shown in Figure 1 below. The well is drilled and completed in stages, from shallow to deep, and from larger diameter casing to smaller diameter. A large diameter borehole (typically about 12in to 16in diameter) is first drilled, ideally to a depth penetrating the base of the fresh water zone (defined as less than 10,000 ppm total dissolved solids). A surface casing is run into this hole and cemented to surface. The cement is placed in the annular space between the steel casing and the rock formation along the entire length of the casing.

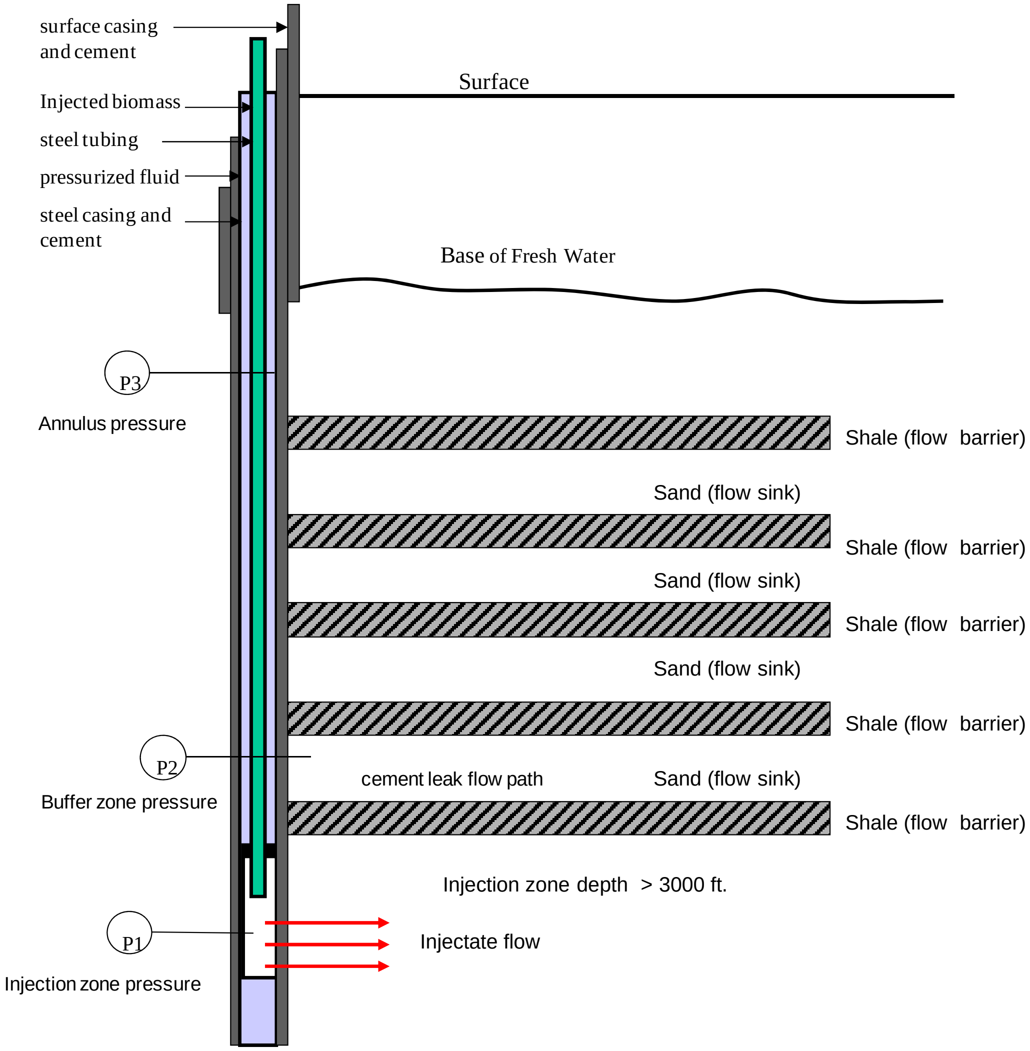


Figure 1. Wellbore design, geologic setting, and monitoring program combine to prevent fluid migration to fresh water

A smaller diameter hole is then drilled through the center of this larger casing, typically penetrating all the way to the final depth of the target injection interval. A smaller diameter casing (typically about 7in to 9in) is run into this hole, and cemented into place. This string of casing is also cemented in place, all the way to the surface. For very deep holes, greater than about 7500ft, an intermediate string of casing may be required. A perforating gun is lowered into the casing to the depth of the target injection interval, and used to shoot holes into the steel casing. Typical perforations sizes are about 0.5in diameter, spaced about 8 to 12 shots per foot.

Finally, steel tubing is run in the hole to a depth just above the perforations, and set in place with a packer to isolate the lower injection interval (see Figure 1). The typical diameter of this tubing is about 2.5in to 4.5in. The annular space between this tubing and the injection casing is filled with pressurized fluid and monitored. Waste fluids may then be injected down the center of the tubing. Above the packer, the waste stream is isolated from the geologic strata by a minimum of two layers of steel, the pressurized and monitored annular fluid, and the cement sheath outside the casing. In the near surface intervals with potential drinking water sources, there is one additional layer of steel casing and an additional sheath of cement, providing a total of 6 levels of protection (the steel tubing, the pressurized annular fluid, the inner casing steel and its cement sheath, and the outer casing steel and its cement sheath).

The injection well is typically drilled vertically, and penetrates the target formation perpendicular to bedding. For very large volume and high rate injection projects, however, highly deviated and horizontal wells can be considered. This has the practical effect of extending the length of the well within the target injection strata. A much longer length of perforations can be applied, with the result that there is significantly less pressure increase for any given flow (i.e. the effective length and resulting injectivity in a horizontal well is much higher than a vertical well). Horizontal well technology has developed significantly and rapidly in the last decade, providing an efficient and cost effective option for high rate injection projects.

Monitoring and Analysis

After an appropriate geologic strata is selected for injection, and after a properly designed well is installed and completed, it then critically important to properly monitor, analyze, and manage the ongoing injection operations. The key to operations management for large volume and high rate injection is to monitor and analyze injection operations on a continuous basis, and adjust operations as necessary. Monitoring and analysis for high volume injection projects ideally should include the following (Bruno et al, 2000):

1. Continuous recording of injectate properties (constituents, concentration, density, etc..);
2. Continuous recording of bottom-hole pressure during injection and during periodic shut-in periods;
3. Analysis of injection and fall-off pressure behavior to assess changing formation properties (injectivity, near wellbore skin effects, and far-field pressure buildup);
4. Continuous (ideally) or frequent temperature logging along the length of the casing to track fluid placement and containment in the target formation;
5. Continuous or periodic pressure and temperature monitoring at offset monitoring wells; and,
6. Periodic step-rate injection tests to determine formation fracture gradient, and any changes.

A typical schematic monitoring and analysis system is illustrated in Figure 2. Detailed monitoring and analysis is necessary to verify containment, to satisfy regulatory requirement, and to optimize injection operations. This is particularly true for very large volume brine injection projects (where injection rates can exceed several hundred thousand gallons per day per well).

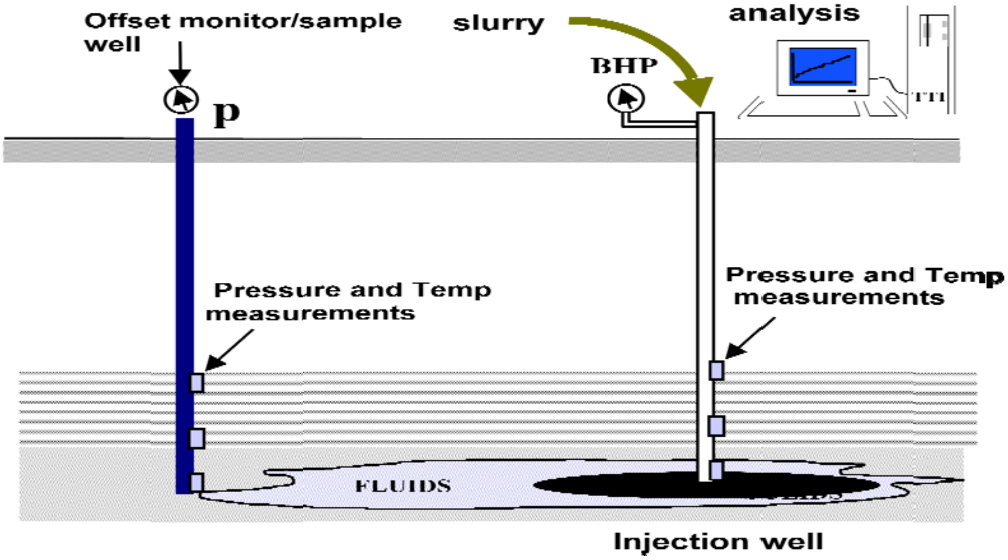


Figure 2. Typical monitoring and analysis system for large scale injection projects.

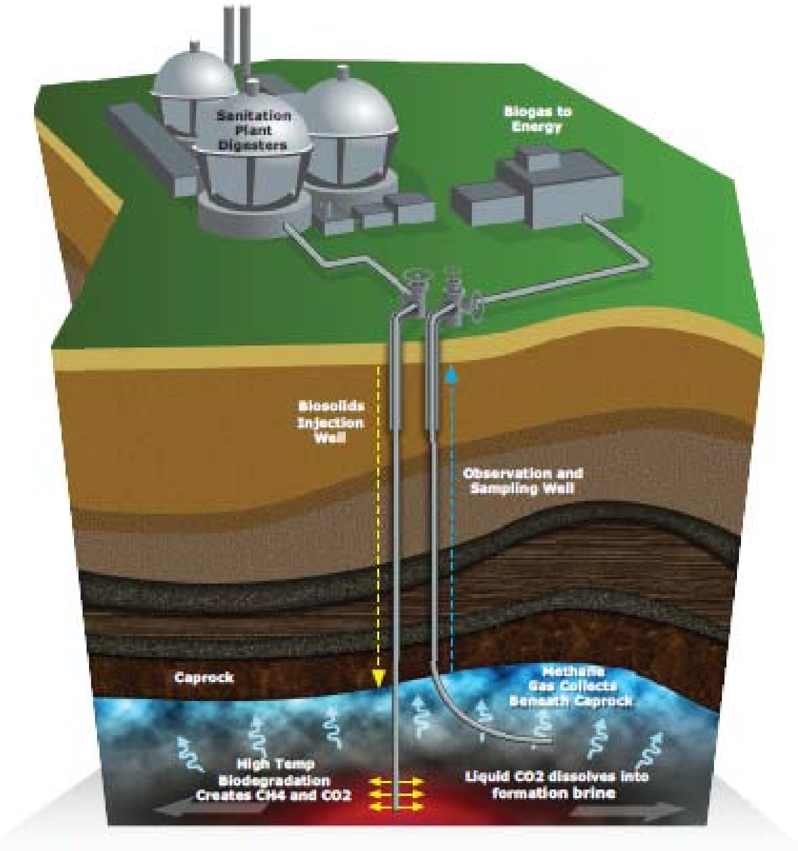
Field Example: Terminal Island Renewable Energy Project

The City of Los Angeles and it partners, GeoEnvironment Technologies, and the U. S. Environmental Protection Agency (US-EPA), are demonstrating an innovative technology to manage wastewater residuals (biosolids and brine). Slurry mixtures comprised of varying ratios of digested residuals, biosolids wetcake, and concentrated brine from advanced water treatment, are injected into sand formation in the deep subsurface (see Figure 3). Such deep well injection technology has been applied to manage petroleum waste slurry and solids in the oil and gas industry for many years (see for example Bruno, 2010; Bruno et al, 2000). But there are unique biodegradation and sequestration aspects during subsurface injection of organic mass.

In the deep subsurface (typically 3000 to 7000 feet) the earth's natural heat and pressure converts the organic mass into methane and carbon dioxide. Laboratory experiments at simulated deep subsurface temperatures (about 50C) and pressure (about 3000psi) indicate it takes about 90 days (Bruno et al, 2005) to biodegrade about 90% of the organic mass. Due to the high pressure in the deep subsurface, the CO2 generated exists as a liquid and dissolves into the native formation brine. The CH4 generated remains as a gas, and collects in relatively pure form beneath the caprock for storage or eventual recovery and use.

Geothermal Treatment Technology Summary

1. Inject biosolids into deep (hot) geologic formation
2. Allow material to undergo natural process of high-temperature anaerobic biodegradation, instantly (within 24 hrs) pasteurizing the material and over time (30-60 days) starting conversion to methane and carbon dioxide
3. Design process to capture and sequester generated $C0_2$ in formation water
4. Store or recover high purity methane for beneficial use



*US, Asian, and European Patents held by GeoEnvironment Technologies: www.geoenvironment-technologies.com

Figure 3. Technology summary for geothermal treatment of wastewater residuals

The Terminal Island Renewable Energy Project was approved by the US EPA as a Class V Demonstration Injection Project, and initiated operations in July, 2008. Three wells were drilled for the project, including one vertical injection well and two deviated monitoring wells with subsurface lateral spacing of about 600 feet. The injection interval is about 5200 feet deep. During the early stages of the project only wastewater effluent and concentrated brine from reverse osmosis filtration facilities were injected. After a few months digested sludge was introduced, followed a few months later by wetcake transported from the Hyperion Treatment Plant, about 15 miles away.

The project is now managing the entire wastewater residuals stream (digested sludge) output by the Terminal Island Plant, plus about 150 tons per day of trucked wetcake from the Hyperion Treatment Plant. We present in Figures 4 and 5 summary plot of the daily total slurry and equivalent wetcake injected at the project during the first 30 months of operations. More than 120 million gallons of total slurry have been successfully injected to date.

Injection operations at the City of Los Angeles slurry injection project are extensively and continuously monitored and analyzed with a variety of engineering and geophysical sensors. A fiber optic temperature sensor is placed outside the casing on the injection and monitoring well. Because injected slurry is a different temperature than native formation fluids (contained in the rock pore space), it is easy to track fluid migration by looking at the temperature signal from these three wells. Pressure sensors are also installed on all three wells.

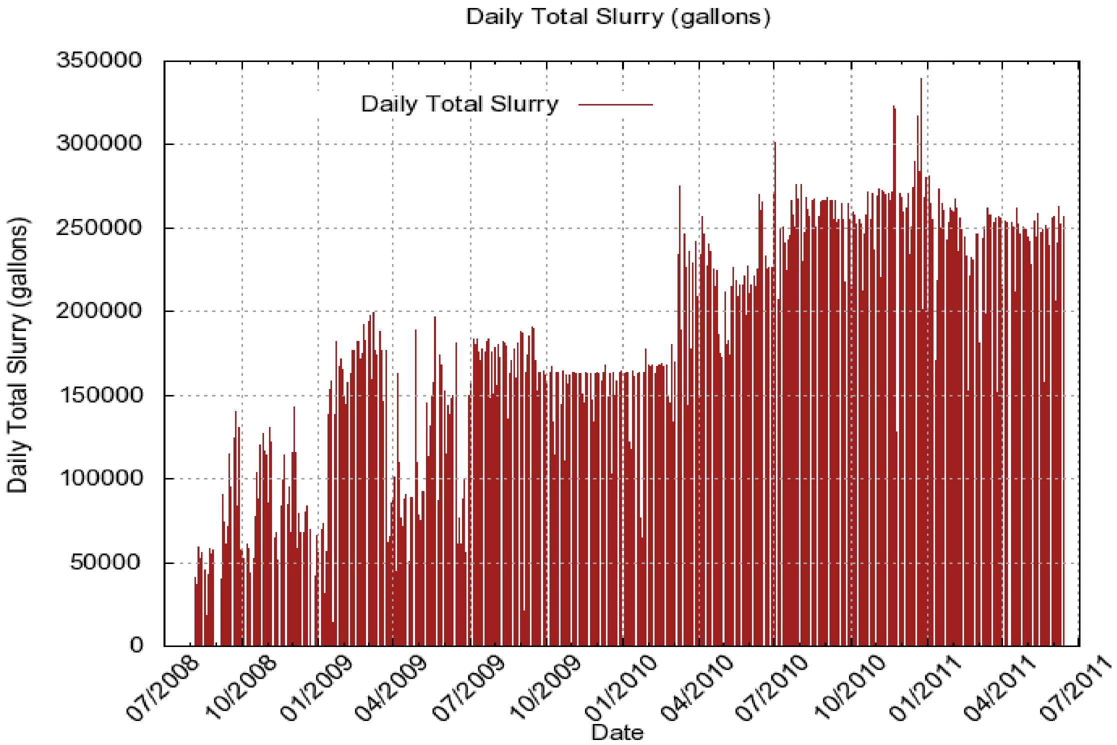


Figure 4. Daily total slurry injection from July, 2008, through July, 2011

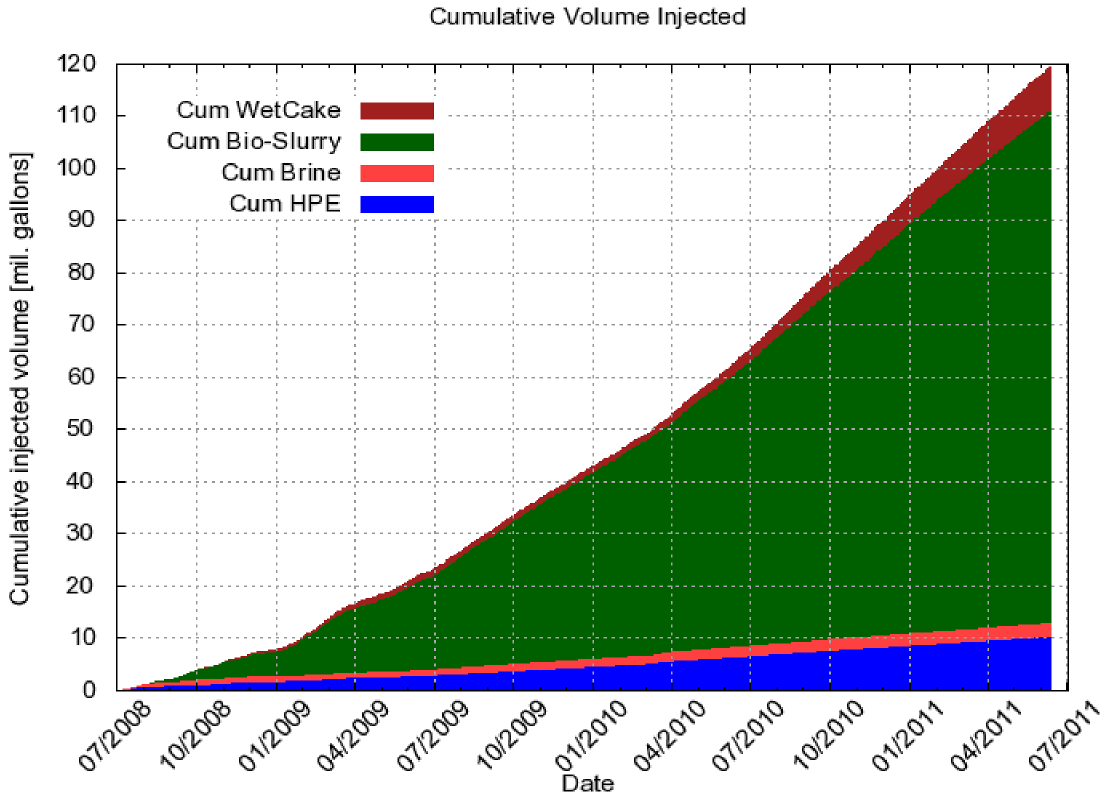


Figure 5. Cumulative slurry injection from July, 2008, through March, 2011

Analysis of the daily injection pressures and fall-off pressures during shut-in, and analysis of periodic step rate tests, provide information on fluid migration and on changing formation properties (see for example Chapter 10 and 11 of reference Bruno, 2010). The results of the monitoring and analysis are reported continuously on a public website, and in written reports submitted weekly and quarterly by GeoEnvironment Technologies to the City of Los Angeles and to the US EPA.

Environmental and Economic Benefits of Deep Well Injection for Brine Management

Properly designed and operated, deep well injection provides a highly cost-effective means for wastewater brine management, with significant environmental advantages over alternative management options. These environmental advantages include:

1. Eliminating impact on surface water and shallow groundwater;
2. Reducing or eliminating long-distance pipelines and ocean outfalls;
3. Reducing surface imprint and land use impairment; and,
4. Providing a sustainable and local management option for urban areas and industrial facilities.

Depending on location and local needs, deep well injection technology can provide a very cost-effective alternative for wastewater and brine management. A typical two or three well injection facility to manage up to a million gallons per day of concentrated brine can be constructed at a capital expense of less than 10 million dollars. In comparison, the capital costs to construct a long-distance pipeline and ocean outfall can easily ten times that amount.

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