Groundwater Restoration at In Situ Uranium Recovery Operations (ISR) in Texas: A Regulatory Perspective on its Success

Reverse Osmosis Water Processing Equipment

Restored and Reclaimed Uranium *In-Situ* Wellfield

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April, 2014

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Summary

Concerns have recently been raised about the record of in situ uranium recovery (ISR) projects when it comes to restoring groundwater to baseline uses. A 2009 United States Geological Survey (USGS) report, *Groundwater Restoration at Uranium In-Situ Recovery Mines, South Texas Coastal Plain,* is often cited as evidence. Unfortunately, the USGS report did not distinguish between baseline and water quality use class and did not assess the public health impacts of any deviations from the baseline levels. Also, the USGS report did not provide enough detail on the regulatory considerations of restoration. Using data from the USGS report and additional data from the historical restoration documents at the Texas Commission on Environmental Quality (TCEQ), this paper presents a very different story on restoration – a story of success.

Overview

Several years ago when in situ uranium recovery (ISR) was undergoing resurgence, the USGS decided to conduct a review of restoration efforts to determine if water was properly restored to baseline levels. Achieving baseline consistent with each of the 26 ions in a restoration table developed by the regulatory agency, has always been industry's goal. Regrettably, some have translated "consistent with baseline" into rigid black and white terms that were applied to each ion. In an effort to evaluate restoration, the USGS decided to review and compare the historical pre-mining (baseline) and post-mining restoration groundwater records maintained by the Texas Commission on Environmental Quality (TCEQ) and its predecessors (Texas Department of Water Resources, Texas Water Commission and Texas Natural Resources Conservation Commission).

In its conception, the plan must have appeared to be fairly straight forward – compare and contrast baseline water quality with post-restoration water quality for most or all of the mines. As it turned out, however, a scarcity of data does not support a definitive answer on the effectiveness of restoration for all of the 77 sites. A quote from the Conclusions section of the USGS paper highlights this point: "Has any ISR mine in the United States returned post-mining groundwater to baseline? Answer: Not based upon analysis of the Texas database because "final value" records were found for only 22 of the 77 PAAs …." [*Emphasis added*]. In other words, there was not an adequate database to answer the question globally (for all sites).

Another complicating factor when assessing past restoration is whether the original sampling routines followed today's high standards of compliance and consistency. Several decades ago inconsistencies in groundwater sampling techniques (pumping vs. jetting) were common.

Pumping a well for sample collection is the preferred method because it is physically less disruptive to the formation and it allows for a more accurate measure of the volume of water removed. To obtain a representative sample, all of the water standing in a well casing must be removed to allow water from the aquifer formation to be collected and analyzed, and this is why an accurate measure of the volume of water is important. Air jetting does not allow for accurate measurement of water volume.

In addition, standardized methods for locating baseline wells within a production area and for estimating sample adequacy (the number of samples needed for developing a representative baseline) did not exist in the infancy or mining for a given area (acreage). Without standardized methods, uniform and accurate baselines could not be established.

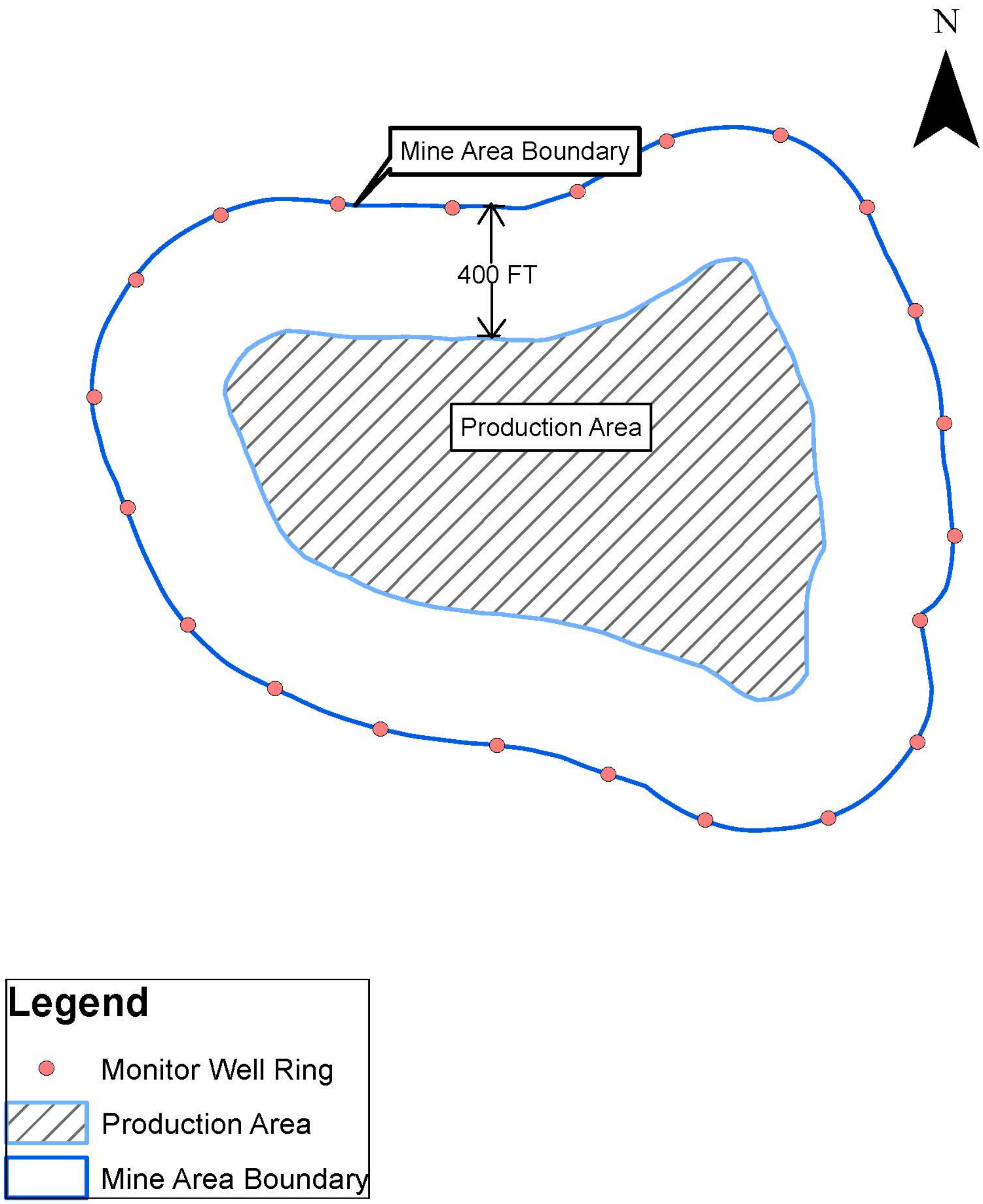
The complexity of evaluating historical baseline values, especially for elements such as radium and uranium, which were reported at extremely low levels of detection expressed in parts per million (ppm) and parts per billion (ppb) had significant variations from laboratory to laboratory. Because environmental laboratories at the time did not have rigorous quality assurance/quality control (QA/QC) requirements as they do today, the variation in the level of accuracy and in error is not surprising.

Recognition of this issue peaked in the 1990s while efforts were being made to develop a national accreditation program. It wasn't until approximately 2005 that data from environmental laboratories used for state and federal purposes were required to be accredited through the National Environmental Laboratory Accreditation Program (NELAP). And, it wasn't until 2008 that TCEQ announced that starting July 1, 2008 laboratory analytical data used for permitting and remediation will not be accepted unless the lab is accredited under NELAC-NELAP. One final point that must be made with respect to laboratories is that advances in technology since the 1980s has resulted in modern laboratory equipment that produces significantly higher resolution and accuracy in the analytical results.

As with laboratories, older technology used by uranium operators to delineate production areas in the past was more limited than today's tools, and this led to the inclusion of areas with very weak ore and hence improved water quality (i.e., lower uranium and radium values), into production areas.

Although early restoration tables were developed by choosing the highest average from either the production area, the area that was targeted for mining, or the mine area perimeter monitoring well rings which were 400 feet away from the actual production area (Figure 1), this provided no guarantee that the groundwater quality within the area to be mined was accurately characterized, let alone artificially elevated as stated in the USGS report. The report states, "Although baseline is artificially elevated in this database because the operator is selecting the highest average values within the production or mine area …"

Figure 1. Typical Mine Area and Production Area Configuration



The high-end ranges for uranium, measured in parts per billion (ppb) and radium measured in parts per trillion (ppt) collected from individual baseline wells strongly indicate that higher density sampling would likely produce a higher baseline for uranium and radium, and the higher results could well be higher than the baseline generated from the limited sampling where the highest average was used from either the mine area or the production area.

Examples of the extreme ranges that are commonly found at ISR sites are summarized below in Table 1 from the USGS report. As correctly noted in the USGS report, Table 1 is a typical datasheet summarizing baseline water quality. The large gap between low and high baseline values was commonly reported for the vast majority of the sites.

Table 1: Baseline Water Quality for Zamzow PAA-1
USGS Report

	Mine Area		Production Area	
Uranium (mg/l)	Low	High	Low	High
	<0.001	1.7	<0.001	0.432
Radium (pCi/l)	1.5	959	6.5	744

Because the sites contained commercial levels of uranium mineralization, the enormous ranges exhibited by uranium and radium are not surprising, they are expected.

For uranium in the Mine Area, the highest baseline concentration is 1,700 times greater than the lowest value, and the high in the Production Area is 432 times greater than the low value. The gap between low and high values for radium is also quite large. In the Mine Area, the high value is 639 times greater than the low, and in the Production Area the high is 114 times greater than the low value.

It is of value to note from Table 1 that the highest uranium and radium values are not always in the Production Area. Finding higher values in the Mine Area is not a mystery when one considers the fact that the uranium ore zone is not neatly confined in a given area. Pockets of mineralization, areas too small for economic recovery, are often found during exploration and during the installation of monitoring wells. Expectedly, additional areas of mineralization occurred within the production area and between the production area and the monitoring well ring but, because of the low density of production area baseline wells, the presence of uranium and radium was likely understated in the baseline water quality.

Given the presence of such high baseline values, there is little doubt that if higher density sampling had occurred, especially in the production areas where the main ore body was located, uranium and radium baseline levels would have been higher and better reflective of the water quality. In fact, this was actually tested in 2006 and 2007 when new ISR sites were being permitted. The following example corroborates this point.

The first production area authorization (PAA-1) at Mestena Uranium's operation in Texas was permitted, but not mined, in the 1980s and early 1990s. The monitoring well ring and a number of baseline production area wells were completed and sampled as part of the early PAA application. Because of lessons learned, a decision was made to amend the PAA prior to mining.

The purpose of the amendment was to more thoroughly characterize the production area water quality by adding 10 additional baseline wells more widely distributed over the ore zone whose shape was delineated using more modern logging technology. The 10 additional wells not only bolstered information on water quality, they also provided more data points for improving the footprint of the ore. Baseline water quality characterization in Table 2 below shows that uranium and radium levels were found to be significantly higher than previously established. Baseline levels for manganese and molybdenum were also found to be more elevated while arsenic was approximately 17% lower, but still in excess of the EPA Primary Drinking Water Standard. The table also shows what has been commonly established in the past: namely, natural water quality in uranium ore zones invariably exceeds Primary Drinking Water Standards for uranium and radium. Other elements such as arsenic and selenium can also be found at elevated levels.

Table 2: Baseline Restoration Table Comparisons

	1990s Baseline Values	**2006 Baseline Values**	**Change**	**EPA Primary Drinking Water Standards**
Uranium	0.034 mg/l	0.201 mg/l	+590%	0.03
Radium	83 pCi/l	166 pCi/l	+200%	5 pCi/l
Arsenic	0.06 mg/l	0.051 mg/l	-17% lower	0.01 mg/l
Manganese	0.011 mg/l	0.03 mg/l	+273%	None
Molybdenum	0.05 mg/l	0.1 mg/l	+200%	None

Source: TCEQ Production Area Authorization URO3055-011 (pre-2006).
TCEQ Production Area Authorization URO3060-011 (September 18, 2006).

Obviously, attempting to restore to the pre-2006 values, which did not fully characterize the baseline, would be difficult indeed, especially for uranium and radium. The reason why it is so important to accurately develop a baseline is that the water quality elements reflect the average levels associated with the naturally occurring minerals and metals in the sand, silt, shale and clay, and this is a huge amount of mass.

Restoration Background

Before providing an interpretation and summary of the data from the USGS report, an important point that should not be overlooked is the fact that amended restoration table values were administratively accepted by the regulatory agency only after groundwater quality was restored to levels that would allow pre-mining use. The regulatory rule that has been in existence from the early days of mining and continues to be law summarizes this point: 30 Texas Administrative Code (TAC) Rule § 331.107 (g) (2) "The commission may amend the restoration table if it finds that: (C) the formation water present in the exempted aquifer would be suitable for any use to which it was reasonably suited prior to mining; …" [emphasis added] In other words, restoration always achieved a return to levels consistent with baseline.

When some claim that groundwater has never been returned to baseline on an ion for ion basis one must consider what is meant by baseline. Until the passage of HB-1079 in 2013, baseline was a set of arithmetical averages for 26 different water quality ions that were listed in a restoration table. If the groundwater was not restored to a level at or below the absolute average – a nearly impossible feat since water quality has a natural range above and below an average – then it was said that the industry has never returned groundwater to baseline.

With the passage of HB-1079, came the recognition of the fact that groundwater has a natural range for each of the constituents that it contains. In contrast to the past, current-day regulations require that a Restoration Range Table (RRT) be developed showing the low and high values. The new RRT is somewhat akin to the consistent with baseline term in the sense that if water is restored to values within its pre-mining natural range its use class will not have changed and its quality will therefore be consistent with baseline.

The USGS report addressed amended values. Final amended values in the USGS report are not actually the final achieved restoration values at each of the projects, rather they are values rounded up and administratively authorized after the completion of reasonable restoration efforts and proof that the final achieved values have stabilized. As correctly stated in the USGS report the restoration table amended values do not necessarily reflect the actual level of achieved restoration. The report states: "The final restoration table for Zamzow PAA-1 shows an amended limit of 3.00 milligrams per liter for uranium.

This amended value is believed to be a relatively arbitrary value set by the regulators, as illustrated by the number of PAAs that set amended values at rounded whole numbers that were unrelated to any restoration level actually achieved in the PAAs." To compare restoration effectiveness, the table columns herein titled Final Restoration Value or Restored Value are the important numbers that indicate the level of achieved restoration.

In large part, it was demonstrated that several key parameters had become asymptotic approaching baseline and further restoration would only result in a waste of water. In other words, to preserve groundwater resources restoration tables were amended only after considerable effort was expended and proof was provided that groundwater quality was in fact returned to levels consistent with baseline. The proof consisted of semi-annual restoration progress reports on the volume of water pumped through the production area (groundwater sweep) and water quality analysis. Once it was demonstrated that water quality was returned to levels consistent with pre-mining use, a stability period was required to demonstrate that the water quality values were not showing any significant rebounding; that is, the constituents were remaining at the restored levels. In time the values will become even more closely equilibrated to the constituents of host materials (sand, clay, silt and shale) mentioned earlier.

Restoration Reviewed

This review focuses on four of the most important and most discussed water quality constituents which were the subject of ISR restoration: radium, uranium, arsenic and selenium. Each of these elements has an EPA Primary Drinking Water Standard.

From the beginning of the Safe Drinking Water Act (SDWA) in 1974 and through its amendments in 1986 and 1996, it has been recognized that portions of aquifers contain valuable hydrocarbon or mineral resources, and therefore an exemption process must be part of the statute and implemented in rules to allow the safe development of important economic resources while protecting underground sources of drinking water (USDW). An Aquifer Exemption (AE) is a legal and protective permit that must be obtained prior to developing a portion of an aquifer that is known to contain commercial quantities of mineral or hydrocarbon resources.

The requirements that must be met before an AE can be granted are provided in Part 40 of the Code of Federal Regulations. The requirements are as follows.

§ 146.4(a): It does not currently serve as a source of drinking water; and

§ 146.4(b) (1): It cannot now and will not in the future serve as a source of drinking water because: It is mineral, hydrocarbon or geothermal energy producing or it can be demonstrated … to contain minerals or hydrocarbon … that are expected to be commercially producible.

By law, exempted aquifers cannot serve as a drinking water source. Since they are not sources of drinking water, the drinking water standards do not apply to their quality. They are exempt from the SDWA and EPA's drinking water standards. However, although restoration of exempt aquifers is not measured against drinking water standards, there are important regulatory requirements that must be met. When assessing restoration, the most important factors are whether:

1. a reasonable effort has been made to restore the groundwater (30 TAC 331.107 (G) (2) (A);

2. the restoration effort has resulted in stabilizing the water (30 TAC 331.107 (2) (B); and

3. the water can be used for pre-mining uses § 331.107 (g) (C) .

Using the data from the USGS report, these factors will now be reviewed.

The first factor considered by TCEQ and its predecessors is whether reasonable efforts have been undertaken to restore groundwater. During restoration, semi-annual restoration progress reports have to be filed showing how much water was used and how key water quality constituents are returning to levels consistent with pre-mining levels. Acknowledgment of this effort also appears in the USGS report. At each of the sites, multiple acre-feet (one acre-foot = 325,850 gallons) of groundwater were swept through the production areas, and in a number of cases reverse osmosis (RO) and ion exchange were used to enhance the effectiveness of restoration. The positive effect of combining RO with groundwater sweep is recognized in the USGS report (see Table 9 in the USGS report).

The second major factor considered by the regulatory agency is whether the restored levels are stable. This requirement takes approximately 9 months to a year to complete and it includes three separate sample sets. If the sample sets do not show re-bounding effects (increases in concentrations from restored levels), the regulatory agency is satisfied on the stability requirement.

Finally, restoration progress reports/amendment requests address the fact that the water can be used for pre-mining use. Satisfying this requirement is of paramount importance, and the TCEQ has a rule that specifically addresses this point. The rule at 30 TAC § 107 Restoration (g) (2) states: "The commission may amend the restoration table if it finds that: (C) the formation water present in the exempted portion of the aquifer would be suitable for any use to which it was reasonably suited prior to mining …" [emphasis added] This requirement and industry goal sums up the most important goal of restoration. Only after satisfying all three points just noted, restoration tables were amended in the interest of preserving groundwater resources while not causing any harm to human health or the environment.

With this descriptive background now complete, a review of the actual numbers from the USGS report will provide additional important insight into the effectiveness of past restoration efforts.

Radium Restoration

Radium is a decay product of uranium, and it is considerably more radioactive than its parent – more than 2.5 million times more radioactive. Because of its radioactivity, EPA has set a very low protective drinking water standard of 5 pCi/l – parts per trillion (ppt). As shown on Table 3 Radium Restoration, natural baseline levels significantly exceeded EPA's protective drinking water standard. Because of these naturally high levels, water from these sites was clearly not suitable for human drinking water.

Table 3 Radium Restoration clearly shows that with respect to this significant health-related element, ISR operators in fact have an excellent record of restoring to baseline. As the tabulation illustrates, 19 of the 20 sites presented in the USGS report have been restored to baseline, or better. In spite of successfully restoring to baseline or better, the water quality still does not meet drinking water standards, but it does meet pre-mining uses.

The single value not reaching baseline was just at 18.7pCi/l, compared to the baseline value of 9.36 pCi/l, which was above the 5 pCi/l drinking water standard. The exceedingly slight difference between 9.36 pCi/l and 18.7 pCi/l does not cross any threshold regarding measurable impacts on human health or the environment.

Table 3 Radium Restoration

ISR Site	Baseline (pCi/l)	Compared to Drinking Water Standard (5 pCi/l)*	Final Restoration Value (pCi/l)	Restored to Baseline
Pawnee-1	274	54.8 Times Above	149	Yes
Travino-1	274	54.8 Times Above	149	Yes
Bruni 5-2	90.5	18.1Times Above	88	Yes
Benavides-4	83	16.6 Times Above	61.3	Yes
Bruni 5-1	90.5	18.1 Times Above	59.6	Yes
Longoria-1	97	19.4 Times Above	47.93	Yes
Hobson-1	45.1	9.0 Times Above	41.87	Yes
Benavides-3	173.1	34.6 Times Above	40.5	Yes
McBride	365	73 Times Above	27.8	Yes
Longoria-2	36.72	7.3 Times Above	27.01	Yes
Holiday-3	429.8	86 Times Above	23.6	Yes
Nell-1	57.2	11.4 Times Above	23	Yes
Brelum-2	9.36	1.9 Times Above	18.7	No
Benavides-1	83	16.6 Times Above	17.35	Yes
El Mesquite-3	116.68	23.3 Times Above	17.1	Yes
O'Hern-2	48.2	9.6 Times Above	16.2	Yes
Travino-2b	19	3.8 Times Above	13.6	Yes
Travino-2a	60	12.0 Times Above	13.2	Yes
El Mesquite-1	9.98	1.9 Times Above	8.6	Yes
Brelum-1	9.36	1.9 Times Above	5.8	Yes
Benavides-2	45.17	9.0 Times Above	5.2	Yes
O'Hern-4	29.49	5.98 Times Above	No Data	----

*The EPA drinking water standard is also known as the enforceable maximum contaminant level (MCL).
Source for Final Restoration Values: Groundwater Restoration at Uranium In-Situ Recovery Mines, South Texas Coastal Plain Open-File Report 2009-114. U. S. Geological Survey.

Uranium Restoration

It should be remembered that unlike radium, arsenic and selenium, EPA did not have a drinking water standard on uranium until the year December 2000. By that time, all of the legacy sites had been mined and nearly all had been restored. Applying a post-restoration history drinking water standard for uranium to a restoration expectation level is not appropriate. Also, as noted earlier, drinking water standards do not apply to exempt aquifers. EPA and other regulatory agencies never intended exempted aquifers (aquifers which exceeded drinking water standards prior to mining) to be "restored" to levels better than their natural condition. Again, although there was no standard at the time when most of the ISR projects were permitted, a review of their baselines for uranium shows that the water in these areas was not suitable for human consumption.

Table 4 Uranium Restoration shows that with respect to EPA's protective drinking water standard of 0.03 mg/l baseline values range from a low at one site of 0.025 mg/l (near the standard) to 2 mg/l at three sites (66.7 times above the drinking water standard).

On average (Table 4) baseline uranium at the 22 sites was 0.521 mg/l or 17 times greater than the drinking water standard. Another important point worth noting from the table is that the final restoration average value for all 22 sites was 0.857 mg/l, or just 1.6 times baseline. Even though the final restoration values for eight of the sites are <u>below</u> baseline, these values do not meet the drinking water standard. Yet again, restoring to baseline or better does not make a non-drinking water aquifer into a drinking water aquifer. Restoration values should be used as a determining factor in whether the water use category has been changed.

The point to be remembered is that even when baseline is achieved, it does not mean the water is suitable for human consumption. Like radium, meeting baseline for uranium does not make the water suitable for human consumption.

Table 4 Uranium Restoration

ISR Site	Baseline (ppm)*	Compared to Drinking Water Standard** (0.03 ppm)	Final Restoration Value (ppm)	Baseline versus Restored Values (ppm)
Bruni 5-2	0.461	15.4 Times Above	3.02	2.569
El Mesquite-3	0.840	28 Times Above	2.53	1.690
Longoria-2	0.037	1.23 Times Above	1.81	1.773
Benavides-3	0.120	4 .00 Times Above	1.5	1.380
Longoria-1	0.047	1.57 Times Above	1.21	1.163
McBride	0.831	27.7 Times Above	1.2	0.369
Bruni 5-1	0.461	15.4 Times Above	1.185	0.724
Benavides-1	0.083	2.77 Times Above	1.04	0.957
O'Hern-4	0.307	10.2 Times Above	0.96	0.653
Benavides-4	2	66.7 Times Above	0.95	-1.050
Trevino 2b	0.036	1.20 Times Above	0.7	0.664
Pawnee-1	2	66.7 Times Above	0.672	-1.328
Trevino-1	2	66.7 Times Above	0.672	-1.328
El Mesquite-1	0.029	~ The Same	0.308	0.279
Trevino-2a	0.036	1.2 Times Above	0.293	0.257
Benavides-2	0.078	2.6 Times Above	0.279	0.201
Hobson-1	0.025	Less than the standard	0.206	0.181
Holiday-3	1.60	53.3 Times Above	0.134	-1.466
O'Hern-2	0.371	12.4 Times Above	0.124	-0.247
Brelum-1	0.037	1.23 Times Above	0.025	-0.012
Brelum-2	0.030	At the Standard	0.013	-0.017
Nell-1	0.041	1.37 Times Above	0.013	-0.028
Average	**0.521**	**17.4 Times Above**	**0.857 (1.6 Times higher than baseline)**	

*ppm: parts per million.
**The EPA drinking water standard is also known as the enforceable maximum contaminant level (MCL).

Source for Final Restoration Values: Groundwater Restoration at Uranium In-Situ Recovery Mines, South Texas Coastal Plain Open-File Report 2009-114. U. S. Geological Survey.

Arsenic Restoration

A review of the USGS final restoration values for arsenic shows a similar success story. Table 5 shows that 18 of the 22 sites (82%) reached baseline. More importantly, with the exception of a single site, all of the final restoration values met the EPA Primary Drinking Water Standard of 0.05 ppm at that time. It is also important to note that the single site (Hobson-1) that did not meet the EPA standard had a naturally high baseline value of 0.15 ppm that was three times greater than the standard.

The USGS report made comparisons to an arsenic standard that did not exist when the sites were being permitted, operated and restored. EPA replaced the 0.05 ppm standard with a 0.01 ppm standard. The new standard became effective on February 22, 2002. When viewed against the new standard, only 6 of the sites in Table 5 had baseline values at or below 0.01 ppm. Restoration at all of these sites returned water quality to a level that meets today's new standard of 0.01 ppm or less.

In summary, the data in Table 5 shows that restoration of arsenic was highly successful. The restoration values provide verification that the water could be used for pre-mining uses.

Table 5 Arsenic Restoration

Site	Baseline mg/l	Restored Value mg/l	EPA Drinking Water Standard* mg/l	Restored Value Compared to EPA Standard
Benavides-1	0.004	0.002	0.05	25 Times Lower
Benavides-3	0.037	0.002	0.05	25.0 Times Lower
Brelum-2	0.013	0.003	0.05	16.7 Times Lower
Bruni 5-2	0.009	0.003	0.05	16.7 Times Lower
Benavides-2	0.008	0.004	0.05	12.5 Times Lower
El Mesquite-1	0.007	0.004	0.05	12.5 Times Lower
Bruni 5-1	0.009	0.005	0.05	10.0 Times Lower
McBride	0.041	0.007	0.05	7.1 Times Lower
Holiday-3	0.08	0.010	0.05	5.0 Times Lower
Nell-1	0.028	0.012	0.05	4.2 Times Lower
Pawnee-1	0.05	0.016	0.05	3.1 Times Lower
Trivino-1	0.05	0.016	0.05	3.1Times Lower
Brelum-1	0.074	0.017	0.05	2.9 Times Lower
Longoria-2**	0.023	0.021	0.05	2.4 Times Lower
O'Hern-4	0.042	0.039	0.05	1.3 Times Lower
Longoria-1	0.023	0.025	0.05	2.0 Times Lower
El Mesquite-3	0.08	0.027	0.05	1.9 Times Lower
Trevino-2b	0.032	0.026	0.05	1.9 Times Lower
Trevino-2a	0.032	0.036	0.05	1.4 Times Lower
O'Hern-2	<0.2	0.047	0.05	~Equal
Benavides-4	0.004	0.010	0.05	5.0 Times Lower
Hobson-1***	0.15	0.323	0.05	6.5 Times Higher

*The EPA Drinking Water Standard during the life of the mines was 0.05 mg/l. The standard was changed to 0.01 ppm on February 22, 2002. These standards are also known as enforceable maximum contaminant levels (MCLs).
Source for Final Restoration Values: Groundwater Restoration at Uranium In-Situ Recovery Mines, South Texas Coastal Plain Open-File Report 2009-114 U.S. Geological Survey.
**The USGS report showed what may by a typo for this site. The report shows values of 0.23 and 0.21 mg/l. Two different TCEQ reports (Texas Water Commission Restoration Table Amendment History and UIC Restoration – Site Specific Information) show the values to be as listed above.
***The Hobson-1 site had elevated baseline arsenic at 0.15 mg/l or 3 times greater than the drinking water standard at the time. By today's standard, the Hobson baseline would be 15 times greater.

Selenium Restoration

Table 6 Selenium Restoration requires little explanation in terms of summarizing the industry's restoration success. With the exception of a single site, selenium was restored to levels that meet the EPA Primary Drinking Standard of 0.05 mg/l.

Table 6 Selenium Restoration

ISR Site	Final Restoration Value mg/l	EPA Drinking Drinking Water Standard* mg/l	Restored Value Compared to EPA Standard
Brelum-2	0.001	0.05	50.0 Times Lower
Nell-1	0.001	0.05	50.0 Times Lower
Pawnee-1	0.001	0.05	50.0 Times Lower
Trivino-1	0.001	0.05	50.0 Times Lower
Brelum-1	0.002	0.05	25.0 Times Lower
O'Hern-2	0.002	0.05	25.0 Times Lower
Trevino-2a	0.002	0.05	25.0 Times Lower
Longoria-1	0.003	0.05	16.7 Times Lower
Benavides-3	0.04	0.05	1.25 Times Lower
Hobson-1	0.004	0.05	12.5 Times Lower
McBride	0.004	0.05	12.5 Times Lower
Trevino-2b	0.004	0.05	12.5 Times Lower
Benavides-1	0.005	0.05	10.0 Times Lower
Holiday-3	0.006	0.05	8.3 Times Lower
Longoria-2	0.008	0.05	6.3 Times Lower
El Mesquite-1	0.008	0.05	6.3 Times Lower
Benavides-4	0.010	0.05	5.0 Times Lower
Bruni 5-1	0.012	0.05	4.2 Times Lower
Bruni 5-2	0.015	0.05	3.3 Times Lower
Benavides-2	0.033	0.05	1.5 Times Lower
O'Hern-4	0.039	0.05	1.3 Times Lower
El Mesquite-3	0.102	0.05	2.0 Times Higher

*The EPA drinking water standard is also known as the enforceable maximum contaminant level (MCL).
Source for Final Restoration Values: Groundwater Restoration at Uranium In-Situ Recovery Mines, South Texas Coastal Plain Open-File Report 2009-114. U. S. Geological Survey.

Other Restoration Table Elements Non-Health Related

Up to this point, the major water quality elements of concern have been addressed along with their respective Primary Drinking Water Standards – also known as Maximum Contaminant Levels (MCLs). Restoration tables also contained 22 other constituents (Table 7 below). As shown in the table, 11 elements do not have an EPA standard; 6 have a Secondary Standard; and 9 have a Primary Standard. Because many of the elements are not considered to be a risk to human health (see definitions in Table 7), they either do not have a standard or they have a secondary standard. When some claim that groundwater has never been restored to baseline, they are usually including these 17 non-health related elements.

Although the scope of this paper is mainly concerned with examining data presented in the USGS paper on the restoration effectiveness of uranium, radium, arsenic and selenium, a brief review on several of the non-health related elements will show that groundwater was effectively restored to pre-mining use.

Before reviewing the restoration of these elements, a brief background discussion is in order for five of the nine elements in the table (cadmium, mercury, nitrate, lead and fluoride) that have a primary standard. Over the past 30 years voluminous baseline data has shown extremely low or non-detectible levels of cadmium and mercury at ISR sites. The reason for the extremely low concentration is attributed to the fact that these elements are not naturally occurring in the parts of Texas where ISR mining has been or is being carried out. Additionally, because these elements are not part of the mining or processing of uranium, they cannot be introduced to the environment. Although nitrate and fluoride are found in groundwater, the baseline values of these elements are not affected by uranium mining. Because they are unrelated and unaffected by mining, it is not surprising that these elements were never an issue of restoration. The same can be said for lead. Because lead does not occur in the formations were uranium was or is being mined and because it is not part of mining or processing of uranium, it was not and is not a parameter of concern. Recognizing that these elements and others may not be part of the mining process or do not occur naturally in groundwater where mining is being proposed, a new rule was adopted by TCEQ in 2009. The rule at 30 Texas Administrative Code § 331.104 (b) allows for elements as just described to be excluded from a restoration table.

Table 7 Restoration Table Elements and EPA Standards

	EPA Primary Standard	EPA Secondary Standard
Calcium	None	None
Magnesium	None	None
Potassium	None	None
Carbonate	None	None
Bicarbonate	None	None
Ammonia-N*	None	None
Molybdenum	None	None
Silica	None	None
Conductivity	None	None
Alkalinity	None	None
Sodium	None	None
pH	None	6.5 to 8.5 standard units
Iron	None	0.3 ppm
Manganese	None	0.05 ppm
Sulfate	None	250 ppm
Chloride	None	250 ppm
TDS	None	500 ppm
Fluoride	4 ppm	2 ppm
Nitrate-N	10 ppm	None
Arsenic	0.01 ppm	None
Cadmium*	0.005 ppm	None
Lead*	0.015 ppm	None
Mercury*	0.002 ppm	None
Selenium	0.05 ppm	None
Uranium	0.03 ppm	None
Radium-226	5 pCi/l	None

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*These elements do not occur naturally in the South Texas aquifers where uranium is mined and they are not part of the recovery process.

Primary Standard: Primary Drinking Water Standards have established Maximum Contaminant Levels (MCLs). An MCL is the highest level of a contaminant that is allowed in drinking water.

Secondary Standards: Secondary standards are non-mandatory standards established as guidance for public water systems. These elements are not considered to present a risk to human health. The elements are defined by EPA as cosmetic and aesthetic considerations in terms of taste, color, odor or staining.

No Standard: EPA conducts studies based on health effects and occurrence of numerous constituents in groundwater and surface water and their potential occurrence in public drinking water systems. Elements are prioritized in terms of their health effects and occurrence. Based on these criteria, the 11 items above have not received either a primary or secondary standard.

Treatment Technique: Treatment used to reduce a contaminant level in drinking water.

Source: U.S. EPA Primary and Secondary Drinking Water Regulations.

The USGS paper did not examine the non-health related elements such as calcium, magnesium, carbonate, potassium, pH, and others as it did for uranium, radium, arsenic and selenium. Instead, the USGS paper discussed the non-health related elements in broader terms of baseline and post-restoration ranges and percentages. Because these constituents are of less importance in terms of risk to human health, the broader treatment in the USGS report is understandable. The following discussion provides examples of site-specific restoration for some of the non-health related constituents that appear in restoration tables. Four elements were chosen. Two of the elements, Total Dissolved Solids (TDS) and chloride have EPA Secondary Standards and the other two (silica and potassium) have no EPA standard (Table 7).

Total Dissolved Solids (TDS)

Starting with TDS, it can be seen from Table 8 that restoration was highly successful. With just a few exceptions all of the sites were restored to levels very near or better than baseline. The success of restoration at the listed sites can be further appreciated by noting the 500 ppm (200%) difference between EPA and Texas standards. The EPA Secondary Standard is 500 ppm and the Texas Secondary Standard is 1000 ppm. Because TDS has such a large natural range and because groundwater in Texas is known to have generally higher concentrations of TDS than other parts of the country, the gap between the two standards is understandable. Another example of the high natural baseline range of TDS is noted Table 7 of the USGS paper. The table shows that TDS at the 22 sites had a baseline range of 785.7 ppm to 6349 ppm, or 800%. When viewed from this perspective and from the 200% range in the EPA/Texas standards, the few departures above baseline ranging from 5% to 24% (a single site) in Table 8 are insignificant for TDS. Another reason why these slight elevations are insignificant is that the difference between baseline and the final restoration value does not approach any threshold that would change the water use class.

Table 8 Total Dissolved Solids (TDS)
Non-Health Related* EPA Secondary Standard: 500 ppm
Texas Standard: 1000 ppm

Mine	Baseline (ppm)	Restored Value (ppm)	Amended Value (ppm)	Change between Baseline and Restored Value
Bruni-5-2	2282	1366	2282	-40%
Bruni-5-1	2282	1395	2282	-39%
Pawnee	903	710	900	-21%
Benavides-4	1211	1088	1211	-10%
O'Hern-2	979	890	**	-9%
Longoria-1	1928	1860	1928	-4%
Brelum-2	6349	6155	6349	-3%
Holiday-3	1442	1414	1442	-2%
Benavides-1	1211	1351	1211	0%
Brelum-1	5970	6065	5971	0%
Bruni-6	1333	***	1333	0%
El Mesquite-1	1071	1075	1071	0%
Nell-1	5383	5372	5383	0%
Trevino-2A	1635	1628	1884	0%
Trevino-2B	1635	1627	1635	0%
Trevino-1	1577	1661	1700	+5%
McBryde-1	1580	1727	1738	+9%
Longoria-2	2013	2208	2200	+10%
Benavides-2	1663	1875	2100	+13%
Benavides-3	1356	1560	1358	+15%
El Mesquite-3	786	900	910	+15%
Hobson-1	1111	1379	1492	+24%

*As a constituent with a Secondary Standard, TDS is not considered to present a risk to human health. EPA Secondary Standards are set for cosmetic and aesthetic considerations in terms of taste, color, odor or staining.
**The O'Hern Restoration Table was not amended.
***When the baseline and amended values are reported to be the same it is assumed that the final restoration values were at or very close to the baseline value and therefore the value in the amended column remained unchanged.
Values in the table are from TCEQ records.

Chloride

Restoration for chloride was certainly successful as shown in Table 9. Eighteen of the 22 sites (82%) were restored to levels at or below baseline. Two of the 4 sites that exceeded baseline did so by only 3% (Brelum-1) and 6% (Longoria-2). Although two of the sites exceeded baseline by 11 and 12%, this is a very small departure when viewed against the 20% range between the EPA (250 ppm) and Texas (300 ppm) standards. Chloride, like TDS, has a naturally wide range of concentration in groundwater. To illustrate, the USGS Report (Table 7) shows baseline values from the 22 sites ranged from 196.9 ppm to 3505 ppm, or 1780%.

It is worth noting that even though restoration achieved or improved baseline water quality at most of the sites, the restored values remained above the EPA and Texas Secondary Standards. Since 100% of the baseline values were at or well above the standards, this is not surprising. Again, the point to take away here is that an aquifer cannot be "restored" to conditions that exceed its natural baseline. All of the baseline values in Table 9 were at or in excess of the EPA Secondary Standard and the restored values are comparable to baseline. In summary, restoration of chloride was quite successful.

Table 9 Chloride
Non-Health Related* EPA Secondary Standard: 250ppm
Texas Secondary Standard: 300 ppm

Mine	Baseline (ppm)	Restored Value (ppm)	Amended Value (ppm)	Change between Baseline and Restored Value
OHern-4	278	156	279	-44%
Bruni-5-2	1010	634	1010	-37%
Bruni-5-1	1010	684	1100	-32%
Trevino-1	641	499	639	-22%
Trevino-2A	572	447	650	-22%
El Mesquite-1	423	347	423	-18%
Longoria-1	854	712	854	-17%
McBryde-1	692	576	692	-17%
Benavides-1	517	432	517	-16%
O'Hern-2	254	220	**	-13%
Holiday-3	630	566	630	-10%
Trevino-2B	572	531	572	-7%
Brelum-2	3505	3326	3505	-5%
Benavides-3	653	629	653	-4%
Nell-1	2956	2849	2956	-4%
Bruni-6	607	***	607	0%
Benavides-4	517	497	517	~0%
Pawnee	250	242	250	~0%
Brelum-1	3130	3226	3130	+3%
Longoria-2	856	905	856	+6%
Benavides-2	814	903	814	+11%
Hobson-1	377	421	425	+12%

*As a constituent with a Secondary Standard, chloride is not considered to present a risk to human health. EPA Secondary Standards are set for cosmetic and aesthetic considerations in terms of taste, color, odor or staining.
**The O'Hern Restoration Table was not amended.
***When the baseline and amended values are reported to be the same it is assumed that the final restoration values were at or very close to the baseline value and therefore the value in the amended column remained unchanged.
Values in the table are from TCEQ records.

Silica

With respect to silica, which has no EPA water quality standard and no health related issues, restoration was very successful by meeting or improving baseline values at 19 of the 22 the sites (Table 10). The single site with the highest departure from baseline, Bruni-5-2, had a restored value of 39 ppm, which is lower than the baseline values at 11 of the sites. When compared with the natural baseline range for 22 sites reported in the USGS Report (Table 7), the 39 ppm value at Bruni-5-2 falls well within the expected range.

Because there are no standards and because all of the restored values, including the Hobson-1 and Bruni-5-2, are similar to other baseline values, restoration for this benign constituent was highly successful.

Table 10 Silica
No EPA Standard

Mine	Baseline (ppm)	Restored Value (ppm)	Amended Value (ppm)	Change between Baseline and Restored Value
Bruni-5-1	16	1.5	10	-94%
O'Hern-4	55	28	55	-49%
Benavides-1	26	14	26	-46%
El Mesquite-3	23	13	23	-43%
Benavides-4	26	16	26	-38%
Brelum-1	50	31	50	-38%
Longoria-2	42	30	42	-29%
El Mesquite-1	19	14	19	-26%
Brelum-2	44	33	44	-25%
McBryde-1	76	57	76	-25%
Holiday-3	20	16	20	-20%
O'Hern-2	44	35	*	-20%
Trevino-2A	54	44	60	-19%
Longoria-1	36	30	36	-17%
Trevino-1	51	43	52	-16%
Nell-1	55	47	55	-15%
Benavides-3	21	18	21	-14%
Trevino-2B	54	50	54	-8%
Bruni-6	33	**	33	0%
Benavides-2	20	23	23	+15%
Hobson-1	50	78	75	+56%
Bruni-5-2	16	39	40	+244%

*The O'Hern Restoration Table was not amended.
**When the baseline and amended values are reported to be the same it is assumed that the final restoration values were at or very close to the baseline value and therefore the value in the amended column remained unchanged.
Values in the table are from TCEQ records.

Potassium

Yet again, the claim by some that restoration was not successful is simply not supported by the historical record. Instead, the record shows that restoration was in fact successful. As the values in Table 11 show, restoration to levels at or better than baseline were achieved for all sites. For those couple of sites that had just a one ppm difference between baseline and restored value, the difference was assumed to be approximately zero. A one ppm difference has no significant threshold value and it is well within the error range of laboratory analysis at the time. In brief, restoration for potassium at these sites was 100% successful.

Table 11 Potassium
No EPA Standard

Mine	Baseline (ppm)	Restored Value (ppm)	Amended Value (ppm)	Change between Baseline and Restored Value
McBryde-1	43	15	43	-65%
Benavides-4	14	7	14	-50%
Nell-1	93	52	93	-44%
Trevino-2A	26	16	26	-38%
Longoria-1	20	13	20	-35%
Trevino-2B	26	17	26	-35%
El Mesquite-1	9	6	9	-33%
Brelum-2	101	70	101	-31%
O'Hern-2	10	7	**	-30%
Longoria-2	23	17	23	-26%
Trevino-1	23	17	25	-26%
Holiday-3	16	12	16	-25%
Ohern-4	9	7	9	-22%
Benavides-2	20	16	20	-20%
Benavides-3	14	13	14	-7%
Brelum-1	52	49	52	-6%
Benavides-1	26	*	26	0%
Bruni-5-1	18	17	35	0%
Bruni-6	33	*	33	0%
Hobson-1	29	30	36	~0%
Bruni-5-2	18	19	35	~0%
El Mesquite-3	6	7	6	~0%

*When the baseline and amended values are reported to be the same it is assumed that the final restoration values were at or very close to the baseline value and therefore the value in the amended column remained unchanged.
**The O'Hern Restoration Table was not amended.
Values in the table are from TCEQ records.

Conclusion

Now that the final restoration values of the key elements of concern (uranium, radium, arsenic, selenium, cadmium, mercury, nitrate, fluoride and lead) have been examined as well as some of the non-health related water quality constituents, it is unfortunate that the USGS report has been so misunderstood by a number of readers. Hopefully, this paper will help remove the confusion over the important difference between Amended Values and the Final Restoration Values. As the data in this paper shows, Final Restoration Values are invariably lower than Amended Values and they reflect the level of restoration actually achieved. There are just a few instances where the final restoration value is slightly higher than the amended value, and this could be due to entry error because final restoration values and stability values are supposed to be at or below amended values.

A second misconception is that restoring to baseline somehow turns the groundwater into a quality that is fit for human consumption. One of the key points made in this paper is that all of the sites considered in the USGS report significantly exceeded the primary drinking water standard for radium and nearly every site exceeded today's primary drinking water standard for uranium. Therefore, returning water quality to baseline does not make the water fit for human consumption.

In closing, the key question is whether water is effectively restored to baseline use and whether there are any negative public health impacts. Contrary to the claims of some, the data clearly support the industry's long and successful legacy of restoration.

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