Technical Paper

Excursions of Mining Solution at the Kingsville Dome In-situ Leach Uranium Mine

by George Rice

Hydrologist, GRGwH

Abstract

In-situ leach (ISL) uranium mining differs from conventional mining in that it does not require excavation of ore. Instead, uranium is mobilized by injecting leaching fluids into a groundwater-saturated ore body. The uranium enriched groundwater (mining solution) is then brought to the surface through extraction wells. Approximately 1 to 3 percent more water is extracted from a uranium production well field than is injected. The purpose of this "bleed" is to prevent the escape of mining solution (excursions) by maintaining a hydraulic gradient toward the extraction wells.

The Kingsville Dome Mine is 13 km southeast of Kingsville, Texas. ISL mining began in 1988 and continued intermittently until 2009. The mine covers 864 ha and is divided into three production areas. This paper focuses on production area three (PA-3).

The bleed at PA-3 did not contain the increased pressures caused by injection of leaching fluids. A hydraulic gradient was rapidly established between the injection wells and the mine boundary, as shown by a rise in water levels in monitor wells surrounding PA-3. This gradient drove mining solution beyond the mine boundary. These excursions affected a well on the Garcia property, approximately 300 m down gradient of the mine. Since mining began, uranium concentrations in the Garcia well have increased from less than 200 µg/L, to more than 600 µg/L. This is the first time that contaminants in an off-site domestic well have been linked to ISL uranium mining in the United States of America.

In-situ leach uranium mining

In-situ leach (ISL) uranium mining differs from conventional mining in that it does not require excavation of ore. Instead, uranium is mobilized by injecting leaching fluids into a groundwater-saturated ore body (figure 1). The uranium-enriched groundwater (mining solution) is brought to the surface through extraction wells and routed to a processing plant where the uranium is removed. The uranium-depleted solution is then re-injected into the ore body. This cycle of injection and extraction continues as long as the ore body contains economically recoverable amounts of uranium.

Leaching fluids typically consist of water, oxidants (e.g., oxygen, hydrogen peroxide), and complexing agents (e.g., carbonates, sulfates) (NRC 2007). The oxidants convert uranium from the relatively insoluble U^{+4} state to the soluble U^{+6} state. The complexing agents combine with the oxidized uranium to form anionic or neutral complexes that remain in solution (e.g., $UO_2(CO_3)_3^{4-}$, $UO_2(SO_4)_3^{4-}$) (Charbeneau 1984). Uranium ore usually contains other toxic constituents such as radium, arsenic, molybdenum, and selenium (NRC 2007). These are also mobilized during ISL mining.
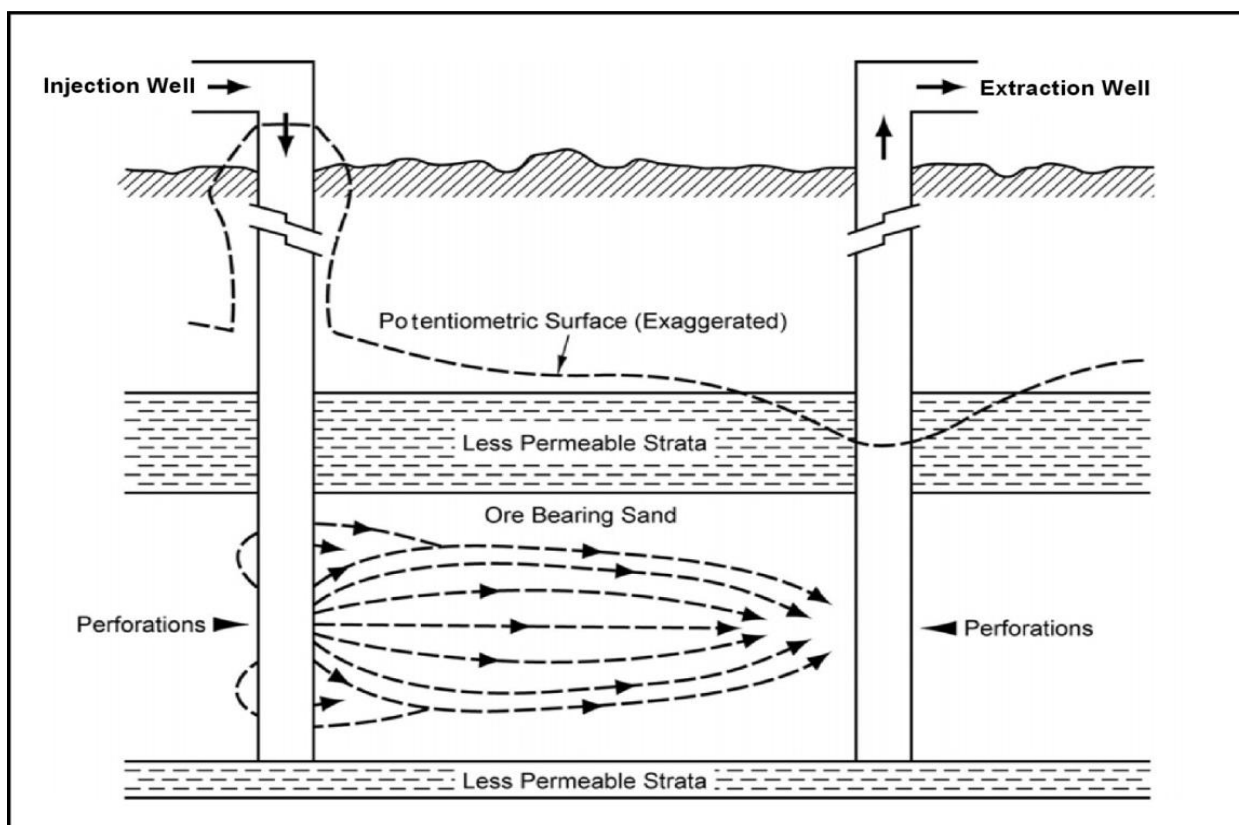
Figure 1.   Schematic Cross Section, Injection and Extraction Wells (adapted from NRC 2009)

Most ISL mining occurs in fluvial sandstone aquifers (Staub et al. 1986). These fluvial systems are heterogeneous and anisotropic, consisting of interbedded clays, silts, sands, and gravels. They contain paleochannels that act as preferential flow paths, and overbank deposits that impede flow.

Injection and extraction wells are organized in patterns. Figure 2 shows a 5-spot pattern. Other patterns, e.g., 7-spot, are also used. A uranium production well field will usually contain a series of patterns arranged to follow the form of the uranium ore body. Well fields are grouped in production areas, and production areas are surrounded by a ring of monitor wells (NRC 2009).

Approximately 1 to 3 percent more water is extracted from a production area well field than is injected. The purpose of this "bleed" is to prevent the escape (excursion) of mining solution by maintaining a hydraulic gradient toward the extraction wells. An excursion is the flow of mining solution beyond the monitor well ring.

Figure 2 is an idealized depiction of groundwater flow. In practice, excursions are initiated when mining solution flows beyond the capture zones of extraction wells. This may be caused by failure to balance injection and extraction rates, failure to maintain sufficient bleed rates, or when mining solution is diverted by paleochannels.

After mining at a production area is completed, groundwater is supposed to be restored to its pre-mining quality (Texas Administrative Code, Title 30, §331.107). However, groundwater restoration after ISL mining is difficult. The United States Geological Survey reviewed 22 uranium production areas in Texas (USGS 2009). Toxic constituents (e.g., uranium, arsenic, selenium) had been restored to their pre-mining levels at only two of them. In no case had all constituents, including non-toxic constituents such as calcium and sulfate, been restored to their pre-mining levels (USGS 2009). Nonetheless, the Texas Commission on Environmental Quality (TCEQ) considers groundwater restoration to be complete at all 22 production areas (USGS 2009).
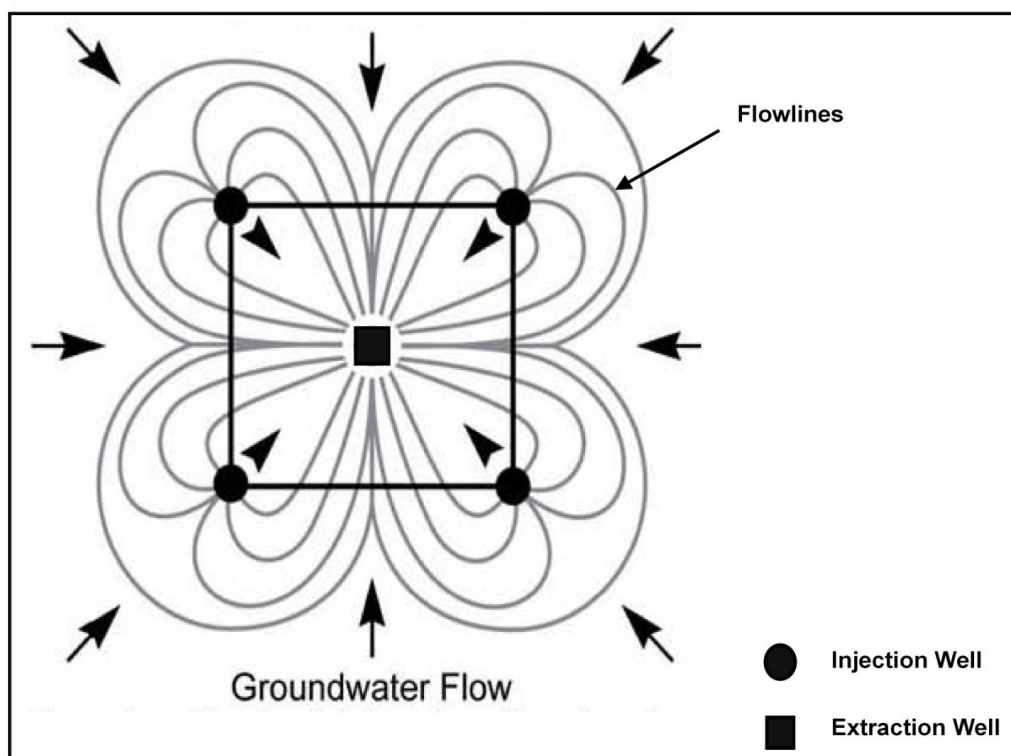
*Figure 2.   Schematic, 5-spot Injection-Extraction Well Pattern (Adapted from NRC 2009)*

ISL mining at Kingsville Dome

The Kingsville Dome (KVD) mine is owned and operated by Uranium Resources Inc. (URI). The mine is in Kleberg County, Texas, approximately 13 km southeast of Kingsville (figure 3). ISL mining began in 1988 and continued intermittently until 2009. The area licensed for mining covers 864 ha (TBRC 1985) and is divided into three production areas (PAs) (figure 4). This paper focuses on PA-3. Unless otherwise noted, all of the site-specific data regarding the KVD mine was obtained from documents submitted by URI to the TCEQ or its predecessor agencies.

There are domestic wells near the mine. All of them are monitored for uranium and other constituents associated with ISL mining. Two of them, the Garcia wells, are directly down gradient of PA-3 (figure 4).

The ore occurs in the Goliad Aquifer, a fluvial deposit consisting of interbedded clay, silt, and sand (Rice 2006). The ore is found between about 150 m and 225 m below land surface. The principal uranium minerals are believed to be uraninite (UO_2) and coffinite ($U(SiO_4)(OH)_4$) (McKnight 2006).

The groundwater is confined (Rice 2006) and generally flows toward the northwest (TBRC 1985). The current flow direction is not the natural direction. Under natural conditions, groundwater flowed southeast, toward the coast. However, pumpage in the vicinity of Kingsville reversed the hydraulic gradient and groundwater now flows toward Kingsville (Rettman 1983). Local groundwater flow directions vary. Calculated flow rates range from about 0.3 m/yr to 100 m/yr (Rice 2006). This range reflects the heterogeneity of the fluvial deposits. It should be noted that these flow rates are for non-mining conditions. During mining, local flow rates may be much higher due to the steep gradients caused by the operation of injection and extraction wells.
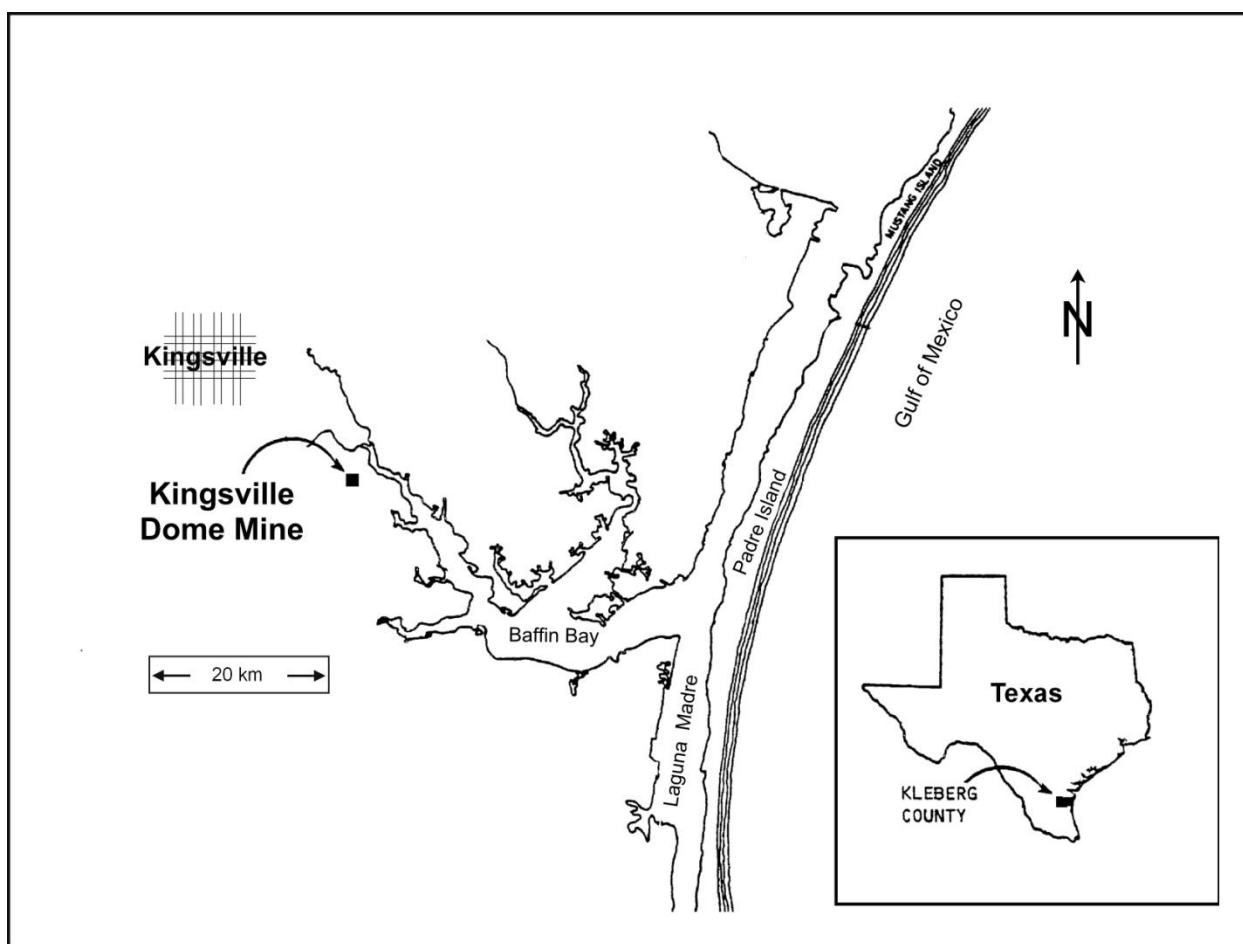

Figure 3. Mine Location Map

The leaching fluid used at the KVD mine is oxygenated water. Table 1 shows typical concentrations of constituents in the mining solution. URI uses a computerized model to adjust injection and extraction rates, but the model does not account for aquifer heterogeneities (Grant 2006). URI maintains a bleed of approximately one percent. The bleed is supposed to continue until groundwater restoration is completed, but URI has not always maintained the bleed as required (TCEQ 2003).

Table 1   Concentrations of Constituents in a Typical Mining Solution at the KVD Mine*

pH	Electrical cond.	Uranium	Chloride	Calcium	Bicarb-onate	Sulfate	Molyb-denum
(SU)	(μmhos/cm)	(μg/L)	(mg/L)	(mg/L)	(mg/L)	(mg/L)	(mg/L)
6.6	4000	80,000	600	400	800	1200	10

*URI analysis of mining solution from extraction wells. It may be a mixture of mining solutions from many extraction wells. Data from Mark Pelizza of URI, 2005.
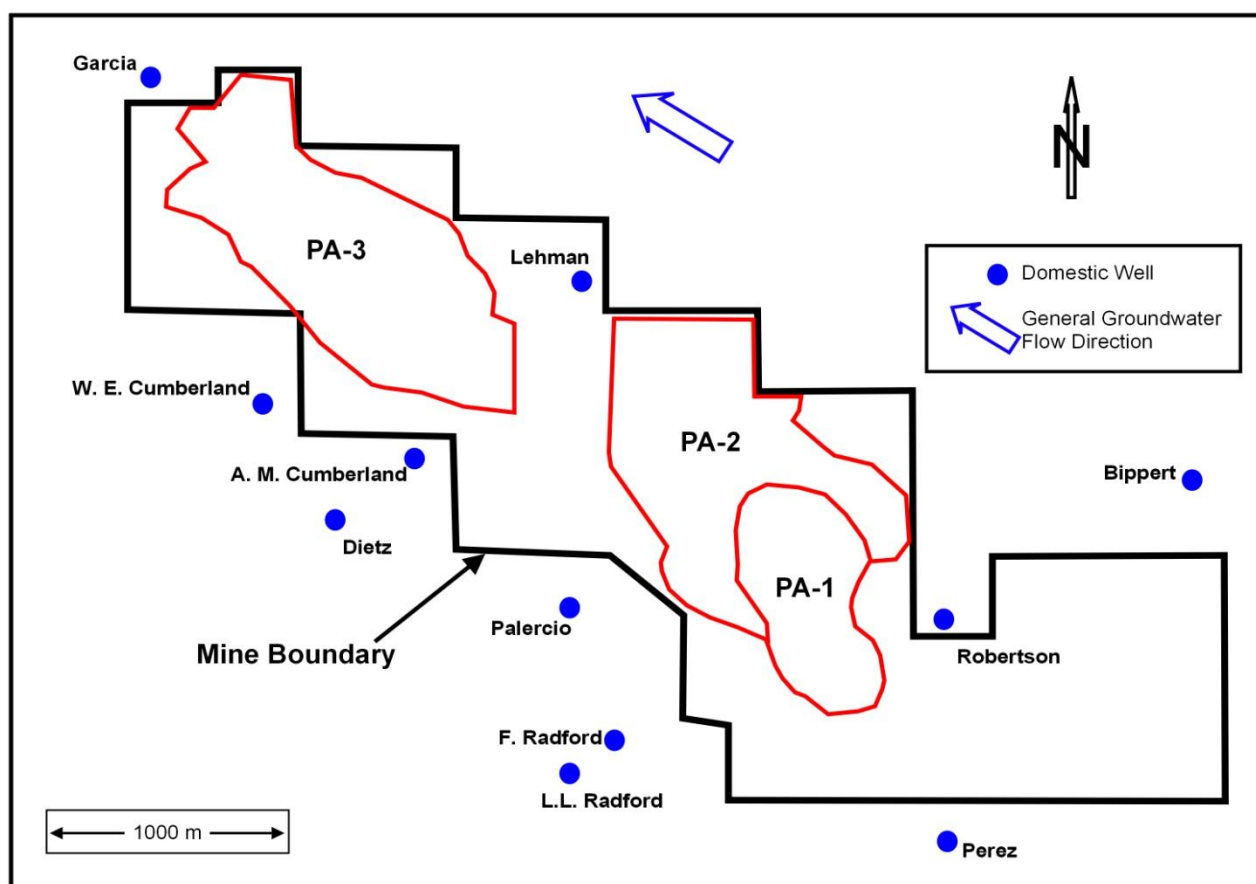
Figure 4. KVD Mine Map

The Effects of Mining on Hydraulic Gradients at PA-3

Excursions are driven by hydraulic gradients. During mining at PA-3, the hydraulic gradients driving excursions were the result of the injection of leaching fluids.

PA-3 covers 151 ha. Mining at PA-3 first began in June 1998 and was suspended in June 1999. During this first period, uranium was produced from well fields 9 and 10 (figure 5). Mining resumed in January 2007 and was

suspended again in June 2009. During this second period, uranium was produced from well fields 13, 14, 15a, 16a, 16b, 17a and 17b. Well field 15b was installed but was not used to produce uranium (Van Horn 2012). Well field injection rates ranged from about 1400 L/min to 5000 L/min (TCEQ 2008; URI 1999). Complete well field injection data are not available. A request to URI for additional data was refused (URI 2012b).

PA-3 is surrounded by a ring of 49 monitor wells. Water levels have been measured in all the monitor wells, but the lengthiest records are from seven wells monitored under an agreement between URI and Kleberg County. Beginning in 2005, water levels were measured in wells MW-78, MW-83, MW-85, MW-89, MW-97, MW-102, and MW-125. Water levels in these wells were measured quarterly when mining was not taking place, and twice a month during mining. Water levels from these seven wells are used in the discussion below.

The injection of leaching fluids had a rapid effect on water levels in the monitor wells. The effect can be seen by comparing water levels before, during, and after mining. Water levels rose an average of 1.7 m in the year after the resumption of mining (table 2), and fell an average of 2.3 m in the year after the suspension of mining (table 3). Figure 6 shows water levels in two monitor wells for the one year periods immediately before and after mining resumed.
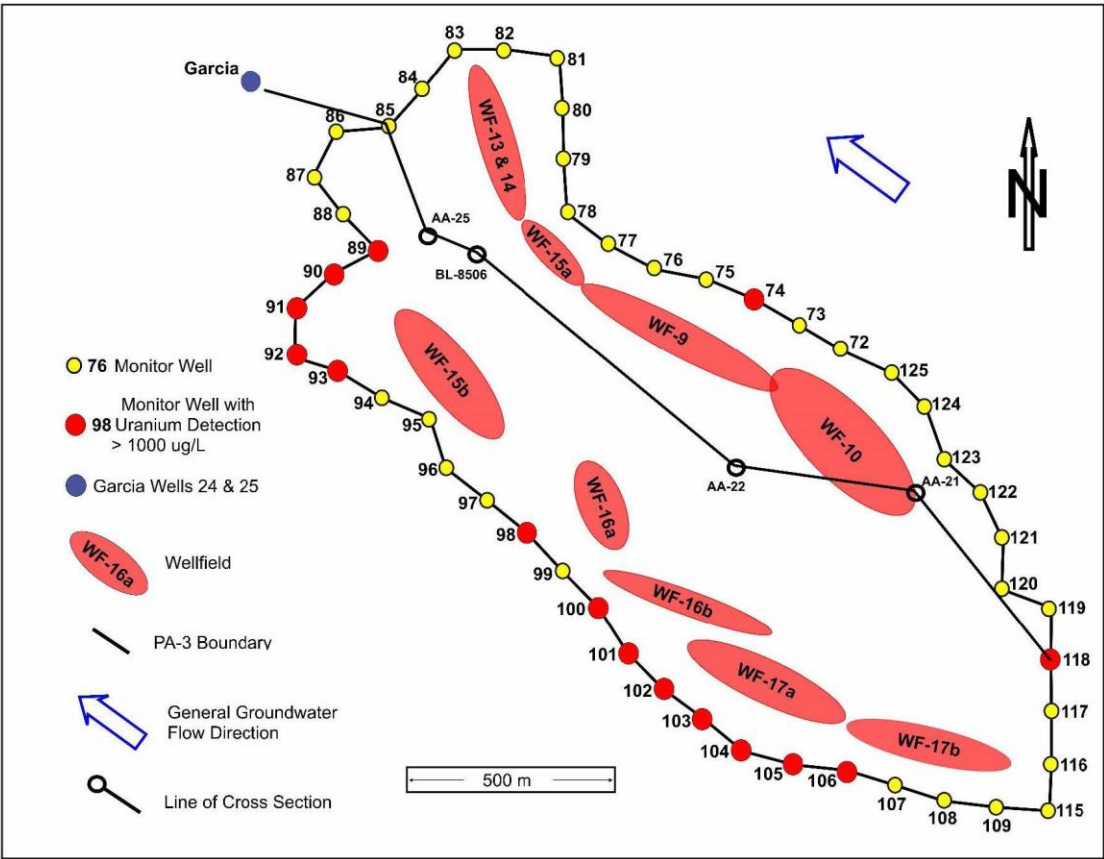

Figure 5.   PA-3, Well Fields and Monitor Wells

Table 2   Water Level Rises in Response to Resumption of Mining*

Well ID	Average depth to water in the year before mining resumed (Dec 2005 – Dec 2006, m btoc**)	Average depth to water in the year after mining resumed (Jan 2007 – Dec 2007, m btoc)	Average rise in water level in year after mining resumed (m)
MW-78	36.21	34.53	1.68
MW-83	39.40	37.29	2.11
MW-85	40.45	37.77***	2.68
MW-89	37.69	36.67	1.02
MW-97	36.80	35.61	1.19
MW-102	37.28	35.84	1.44
MW-125	34.06	32.37	1.69
		Average of all wells:	1.67

URI, 2012a. The average bleed rate during the year preceding mining was 62 L/min (URI 2007a, no pumping for restoration appears to have occurred during this period). The average bleed rate during the first three quarters of mining was 67.8 L/min (URI 2007b and 2008). There was no bleed during the remaining period of mining.

*** btoc: below top of casing.*

*** With outlier removed. The outlier (56.48 m Aug 13, 2007) was approximately 18 m lower than any other measurement (URI 2012a). The average depth without removing the outlier was 38.58 m.*

Table 3   **Water Level Declines in Response to Suspension of Mining***

Well ID	Average depth to water in the year before mining suspended (June 2008 – May 2009 m btoc)	Average depth to water in the year after mining suspended (June 2009 – May 2010 m btoc)	Average decline in water level in year after mining suspended (m)
MW-78	35.27	37.71	2.44
MW-83	37.47	40.27	2.80
MW-85	39.45	42.00	2.55
MW-89	37.08	39.46	2.38
MW-97	36.44	38.60	2.16
MW-102	36.90	38.79	1.89
MW-125	33.27	35.38	2.11
		Average of all wells:	2.33

URI 2012a. The average pumping rate (bleed plus restoration) during the year following mining was 428 L/min (URI 2010).

This rapid effect on water levels is to be expected. In a confined aquifer, changes in head are quickly propagated in response to the extraction or injection of water (Kruseman and De Ridder 1976). A similar response was seen during a pumped aquifer test at the KVD mine. In that test, water levels more than 1200 m from the pumped well began dropping less than ten hours after pumping began (TBRC 1985).

The rise in water levels shows that the bleed did not contain the increased pressures caused by injecting leaching fluids. The increased pressures were propagated beyond the monitor well ring, creating a gradient between the

injection wells and monitor wells. Mining solution flowed down this gradient, toward the monitor wells. This resulted in excursions.

Excursions at PA-3

Excursions are monitored by measuring the concentrations of uranium and chloride, and the value of electrical conductivity (EC) at the monitor well ring. Monitor wells are sampled quarterly when mining is not taking place, and twice a month during mining.

Excursions at PA-3 are most readily identified by increases in uranium concentrations. This is because the concentration of uranium in the mining solution is more than 1000 times greater than the groundwater background concentration, while the concentration of chloride and the value of EC are only about two times greater than background (table 4).
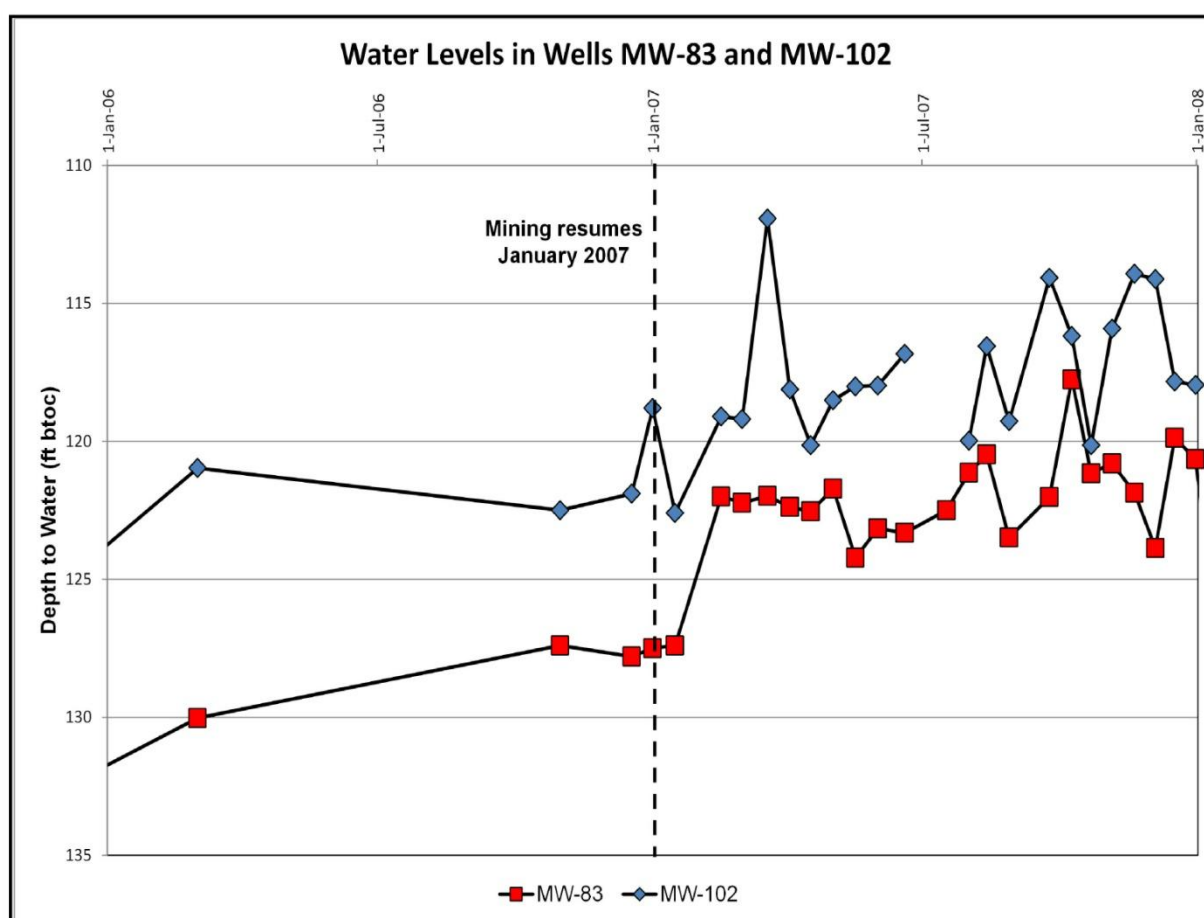
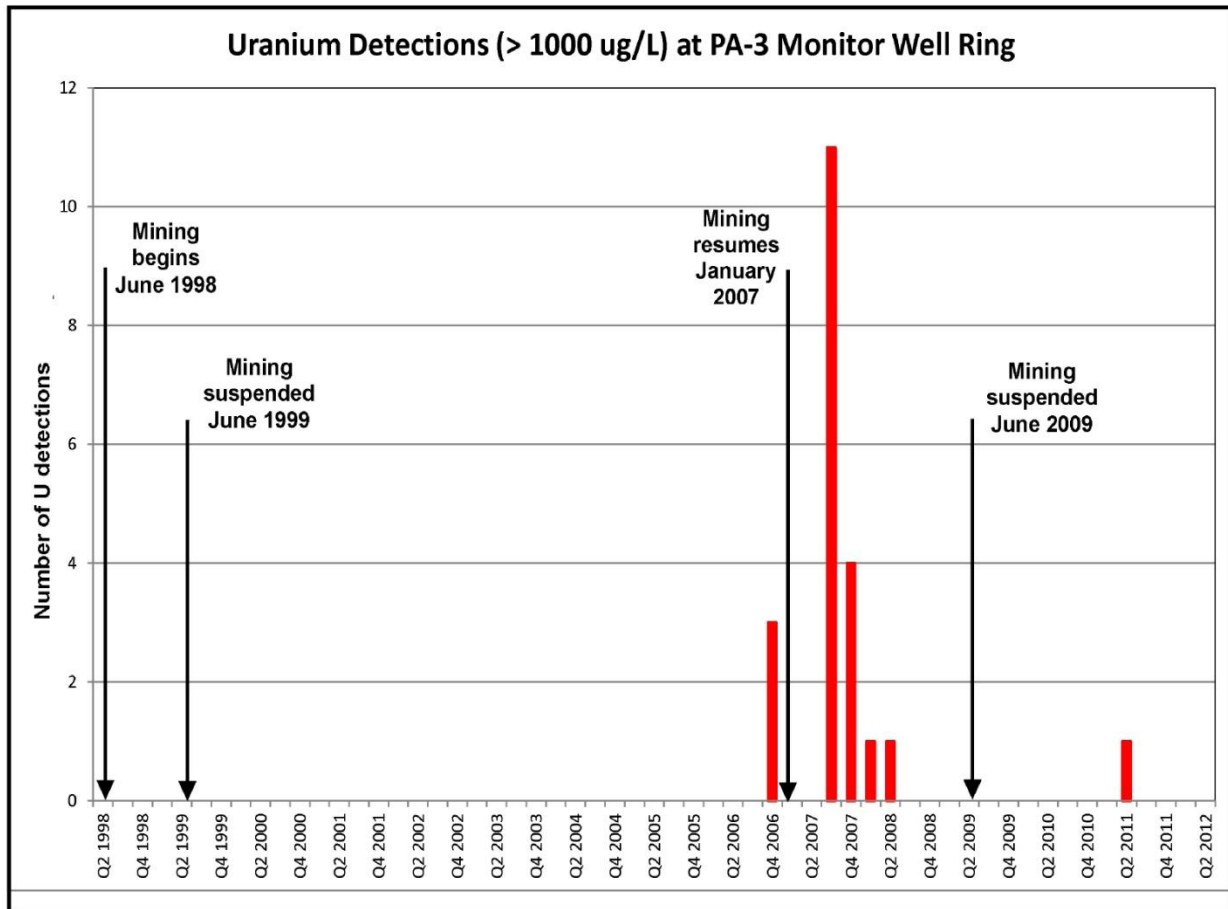*Figure 6.   Response of Water Levels to Injection of Leaching Fluids*

Figure 7. Timeline of Uranium Detections at PA-3

Table 4. Uranium, Chloride, and EC Values In Mining Solution and Background Groundwater at PA-3

Parameter	Typical mining solution value	Range of background values*	Average background values*	Ratio of mining solution value to average background value	EPA drinking water standard**
Uranium (µg/L)	80,000	< 0.001 - 187	41	1950	30 µg/L
Chloride (mg/L)	600	214 - 443	282	2.1	250 mg/L
EC (µmhos/cm)	4000	1600 - 2590	2017	2.0	NA

Pre-mining values in monitor well ring surrounding PA-3 (URI 1997).
*** The uranium standard is a primary maximum contaminant level (MCL). MCLs are health-based and legally enforceable. The chloride standard is a non-enforceable secondary standard based on aesthetic effects (e.g., taste, odor) (EPA, 2009). NA: not applicable.*

Given the values in table 4, a mixture of 2% mining solution and 98% background groundwater would have the following values of uranium, chloride, and EC.

Uranium: 0.02 (80,000 µg/L) + 0.98 (41 µg/L) = 1640 µg/L
Chloride: 0.02 (600 mg/L) + 0.98 (282 mg/L) = 288 mg/L
EC: 0.02 (4000 µmhos/cm) + 0.98 (2017 µmhos/cm) = 2057 µmhos/cm

Thus, a mixture of several percent mining solution with background groundwater could be readily identified by the increase in uranium concentrations, but the chloride and EC values would be difficult to distinguish from background values.

At least two factors act to reduce concentrations in the sampled mining solution. As the mining solution travels from the well field to the monitor well ring, hydrodynamic dispersion dilutes the concentrations of uranium and other constituents. There is also an apparent reduction in concentrations resulting from the design of the monitor wells. The well screens are 30 m long. Therefore, a plume of mining solution that is less than 30 m thick will be diluted by native groundwater when it is pumped from the well.

It should be noted that it is not necessary for uranium to travel from the well fields to the monitor well ring in order to increase uranium concentrations in the monitor wells. If uranium is present in the formation near the monitor wells, uranium concentrations can be increased by the arrival of oxidizing mining solution.

Apparent excursions of mining solution have been detected 21 times at PA-3 (table 5, and figures 5 and 7). More excursions have probably occurred, but URI does not report the values of uranium concentrations that are less than 1000 µg/L (see below).

Quality of analytical data and false positives

The uranium concentrations cited in this paper come from analyses performed by commercial laboratories and by URI's in-house laboratory. The background samples and samples from the Garcia wells were analyzed by commercial laboratories. All the monitor well samples, except the background samples, were analyzed by URI's laboratory.

There are two problems with the analyses produced by URI's laboratory. First, although TCEQ accepts the results, problems with their accuracy have been documented (Rice 2006). Second, when reporting uranium concentrations for monitor wells, URI reports only those values greater than 1000 µg/L. If a value does not meet this threshold, it is reported either as less than 1000 µg/L, or as zero. Zero is not an analytical result. It means that the concentration is below the detection limit. In this case, the detection limit appears to be about 20 µg/L (URI 2005). Thus, the uranium analyses reported by URI's laboratory fall into three groups: less than 20 µg/L, between 20 µg/L and 1000 µg/L, and greater than 1000 µg/L. The author has asked URI for the laboratory data showing uranium values below the 1000 µg/L threshold. URI refused (URI 2012b).

The problems with URI's uranium analyses raise the possibility that URI might have reported false negatives or false positives. In the absence of additional data, individual false negatives cannot be identified. But false positives may be identified by examining the circumstances associated with analytical results.

Table 5   Monitor Wells with Elevated Uranium Concentrations

Well ID	Background U concentration (µg/L)	U concentration during excursion (µg/L)	Date U detected
MW-74	21	3200	11/16/06
MW-89	22	1690	8/17/07
MW-90	24	1320	8/17/07
MW-90	24	1060	11/27/07
MW-91	31	2140	8/17/07
MW-91	31	1500	3/5/08
MW-92	36	1670	8/17/07
MW-92	36	1440	10/11/07
MW-92	36	1300	4/16/08
MW-93	37	2500	10/11/07
MW-98	59	1100	4/18/11
MW-100	30	3600	8/17/07
MW-101	53	2520	8/17/07
MW-102	20	1300	11/7/06
MW-102	20	5170	8/17/07
MW-103	16	2790	8/17/07
MW-104	36	2140	8/17/07
MW-105	31	2320	8/17/07
MW-106	32	3900	11/7/06
MW-106	32	1260	8/17/07
MW-118	101	1170	10/19/07

The uranium concentrations shown in table 5 would not be considered excursions by TCEQ. According to TCEQ, an excursion has not occurred unless uranium concentrations exceed 6540 µg/L (TCEQ 2006).

Figure 7 is a timeline showing the 21 uranium detections greater than 1000 µg/L. Four of the detections may be false positives because they are inconsistent with the history of mining at PA-3. Three of the four are from samples collected in November 2006, approximately two months before mining resumed. The fourth is from a sample collected in April 2011, almost two years after mining was suspended. There are other possible explanations for these four detections. The 2006 detections could be the result of pre-mining activities (e.g., testing of injection wells), or they could represent slow-moving, remnant solution from mining that occurred in 1998 and 1999. The 2011 detection could also be the result of slow-moving solution from earlier mining. At best, these four detections are suspect.

There are several reasons to believe that the other 17 uranium detections shown in figure 7 are not false positives. First, all of them occurred during mining. Second, all of them occurred after water levels in the monitor wells rose sharply in response to mining. This rise indicates that mining solution was being driven toward the monitor wells. Third, with one exception, the 17 detections are grouped in two clusters of wells: MW-89 – MW-93 and MW-100 – MW-106 (table 5 and figure 5). If the detections were false positives, one would expect them to be distributed

randomly around the monitor well ring. In four of the wells, values greater than 1000 µg/L were detected more than once (table 5).

A suspicious feature of the detections shown in figure 7 is that 11 of them are from samples that were collected on one day, August 17, 2007. These detections could have been the result of problems in URI's laboratory. However, there are reasons to believe that this is not the case. First, a total of 27 samples were collected on August 17, 2007. Sixteen of the analytical results from that day were below 1000 µg/L. Second, all 11 detections occurred in the two well clusters mentioned above. Third, the 11 detections are not temporally isolated. That is, they are not anomalies that were preceded and followed by non-detections. The 11 wells where the detections occurred were sampled in the two-month periods immediately before and immediately after August 17, 2007. Seventeen samples were collected in the two-month period before August 17th. All of the results were between 20 µg/L and 1000 µg/L. Thirty samples were collected in the two-month period after August 17th. Twenty eight of the results were between 20 µg/L and 1000 µg/L, one result was less than 20 µg/L, and one result was more than 1000 µg/L.

Although there are problems with the uranium analyses performed by URI's laboratory, careful consideration of the data leads to the conclusion that most of the uranium detections are not false positives.

Garcia wells

The Garcia family used to drink water from two wells on their property, W-24 and W-25 (figure 5). These wells are about 60 m apart, and less than 300 m northwest of PA-3. Both of them are completed in the Goliad Aquifer (figure 8). Their depths are approximately 180 m and 240 m (Saenz 2012a). Well W-24 is now used only to water cattle and goats, and W-25 is no longer used (Saenz 2012a).

Water from wells W-24 and W-25 has been sampled since 1996, if not earlier; the records are unclear (figure 9). Before mining began at PA-3, the average concentration of uranium was 180 µg/L. The uranium was probably due to the presence of uranium ore in the Goliad Aquifer where the Garcia wells are completed.
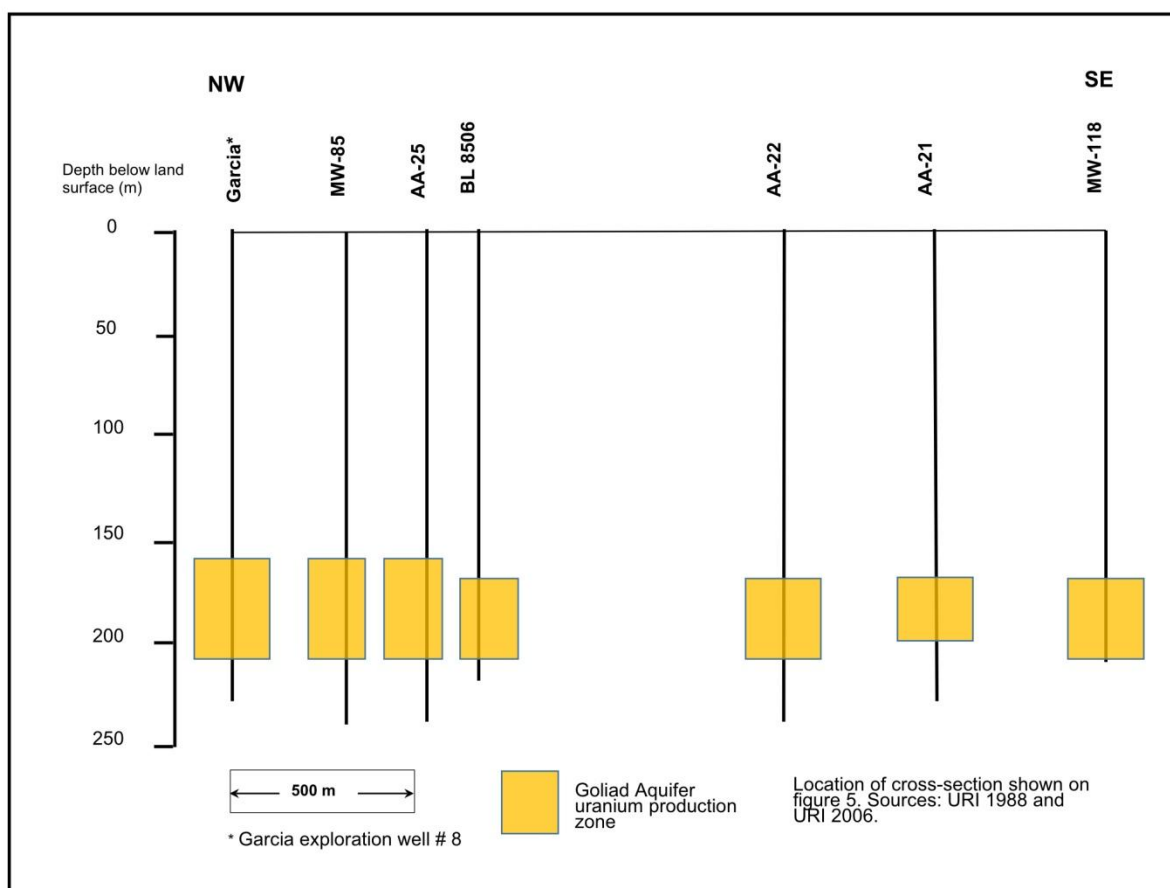
*Figure 8.   Cross section through PA-3 and Garcia property*

Until late 2005, water from both Garcia wells was pumped to a single tank, and analyses were performed on samples from the tank. The only exception to this was in June 1998, when separate samples were collected from wells W-24 and W-25. The uranium concentrations were 152 μg/L and 167 μg/L, respectively. Since late 2005, W-24 has been sampled nine times and W-25 one time. The samples from W-24 had an average concentration of 670 μg/L, and the sample from W-25 had a concentration of 10.4 μg/L.

The cause of the low concentration in W-25 is unknown. W-25 no longer contains a pump. At the time it was sampled, W-25 had been unused for about two years and the sample may have been affected by deterioration of the well casing (e.g., occlusion of uranium by precipitating iron). The sample was collected by the author after purging three bore volumes. At the beginning of the purge, the water appeared to be black. When the sample was collected, the water was lightly tinted.

There are two possible causes of the increased uranium concentrations in W-24. First, concentrations in W-24 may have always been high, but were diluted in the tank by low concentrations from W-25. Second, they represent excursions from PA-3.

There are two problems with the first possibility. First, when W-24 and W-25 were individually sampled in 1998, the uranium concentrations were about equal. Second, the volume of water pumped into the tank by each well appears to have been about the same. Three horse-power pumps were installed in both wells, and when the

storage tank was filled, both wells turned on and off at the same time. (Saenz 2012b). When the author sampled the wells in December, 2008, both wells produced water at a rate of about 35 L/min. An equal mixture of waters containing 10 µg/L and 670 µg/L uranium would contain 340 µg/L uranium. This is almost twice the average value measured in the tank between 1996 and 2005.
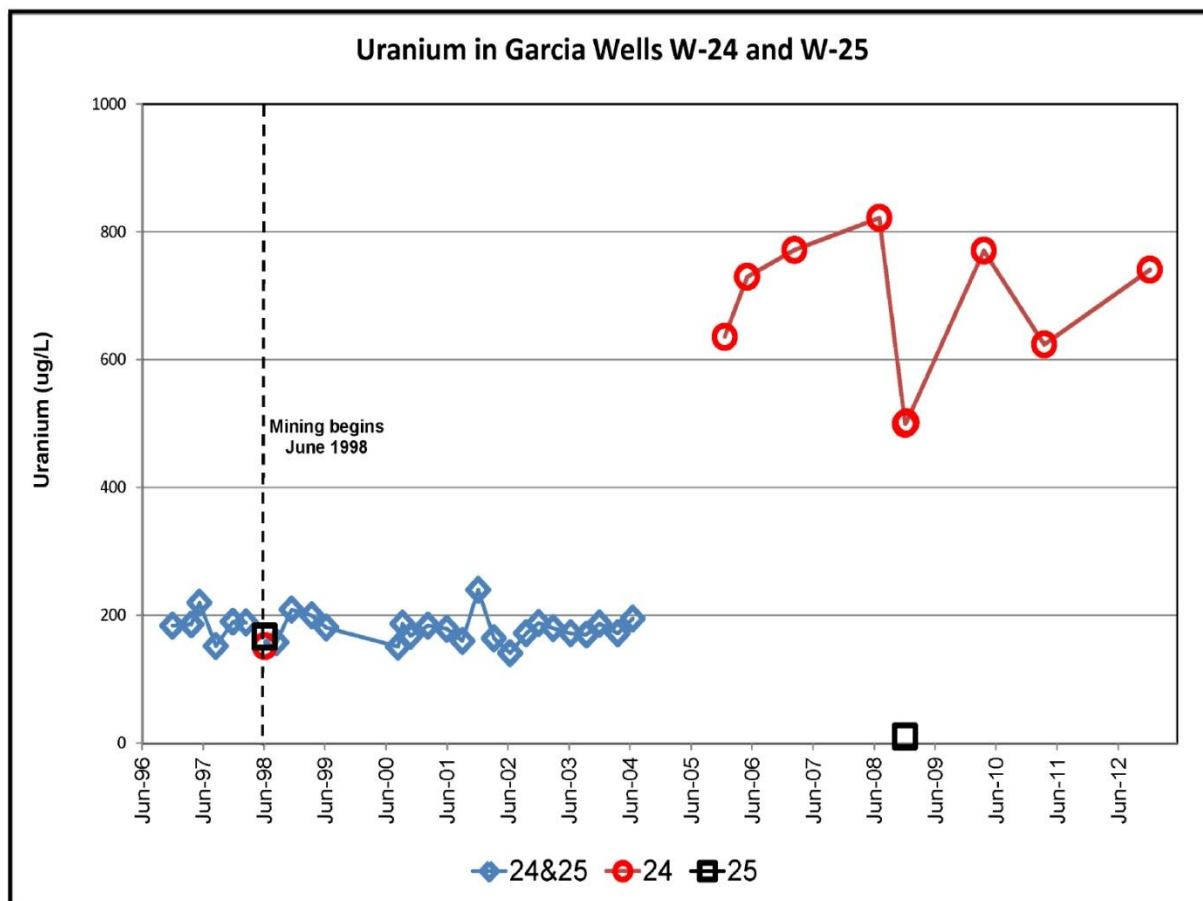
Figure 9.   Uranium Concentrations in Garcia Wells

There is also a problem with the second possibility. The increased uranium concentrations in W-24 were first detected in late 2005, but excursions at PA-3 were not reported until 2007. However, unreported excursions, that is excursions where the uranium concentration did not reach the 1000 µg/L threshold, probably did occur. This possibility is supported by the following. First, the increased concentrations occurred after mining began at PA-3. Second, the general direction of groundwater flow from PA-3 is toward the Garcia wells, and flow may have been accelerated by pumping of the Garcia wells. Third, excursions have been detected in monitor wells less than 600 m from the Garcia wells (figure 5).

The available data indicate that the likely source of the increased uranium concentrations in the Garcia well is PA-3. To the author's knowledge, this is the first time that contaminants in an off-site domestic well have been linked to ISL uranium mining in the United States of America.

Conclusions

Although there are uncertainties associated with some of the available information, a conservative assessment leads to the following conclusions.

1) The injection of leaching fluids at PA-3 created a hydraulic gradient that caused mining solution to flow from injection wells, toward the monitor well ring.
2) The mining solution contained concentrations of uranium that were significantly higher than background concentrations.
3) Excursions occurred. That is, mining solution flowed beyond the monitor well ring surrounding PA-3.
4) The excursions reached the Garcia property. They caused uranium concentrations in well W-24 to increase from an average of less than 200 µg/L, to more than 600 µg/L.

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Author

George Rice has a BS and MS in Hydrology from the University of Arizona. He is an independent consultant in San Antonio, Texas, doing business as George Rice, Groundwater Hydrologist (GRGwH) since 1993. His email address is jorje44@yahoo.com.

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