Review of Restoration and Stability Phases of *In-Situ* Uranium Mining in Texas 2009 – 2015, with Case Histories

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FRED DUFFY, P.G.

TEXAS COMMISSION ON ENVIRONMENTAL QUALITY

RADIOACTIVE MATERIALS DIVISION

Background Information

Texas Agency Responsible for Exploration Drilling for Uranium

Railroad Commission of Texas (RRC)

- Exploration drilling permit.

Texas Administrative Code (TAC)

Title 16	Economic Regulation
Part 1	Railroad Commission of Texas
Chapter 11	Surface Mining and Reclamation Division
Subchapter C	Uranium Exploration and Surface Mining

Texas Agency Responsible for *In-Situ* Uranium Mining

Texas Commission on Environmental Quality (TCEQ)

- UIC Class III permit for solution mining of minerals.
- UIC Class I deep disposal well.
- Aquifer Exemption Order (final approval by US EPA).

- License to receive, possess, use, dispose and transfer radioactive material and to use such radioactive material for the purpose of uranium recovery.

Texas Agency Responsible for *In-Situ* Uranium Mining

Texas Commission on Environmental Quality (TCEQ)

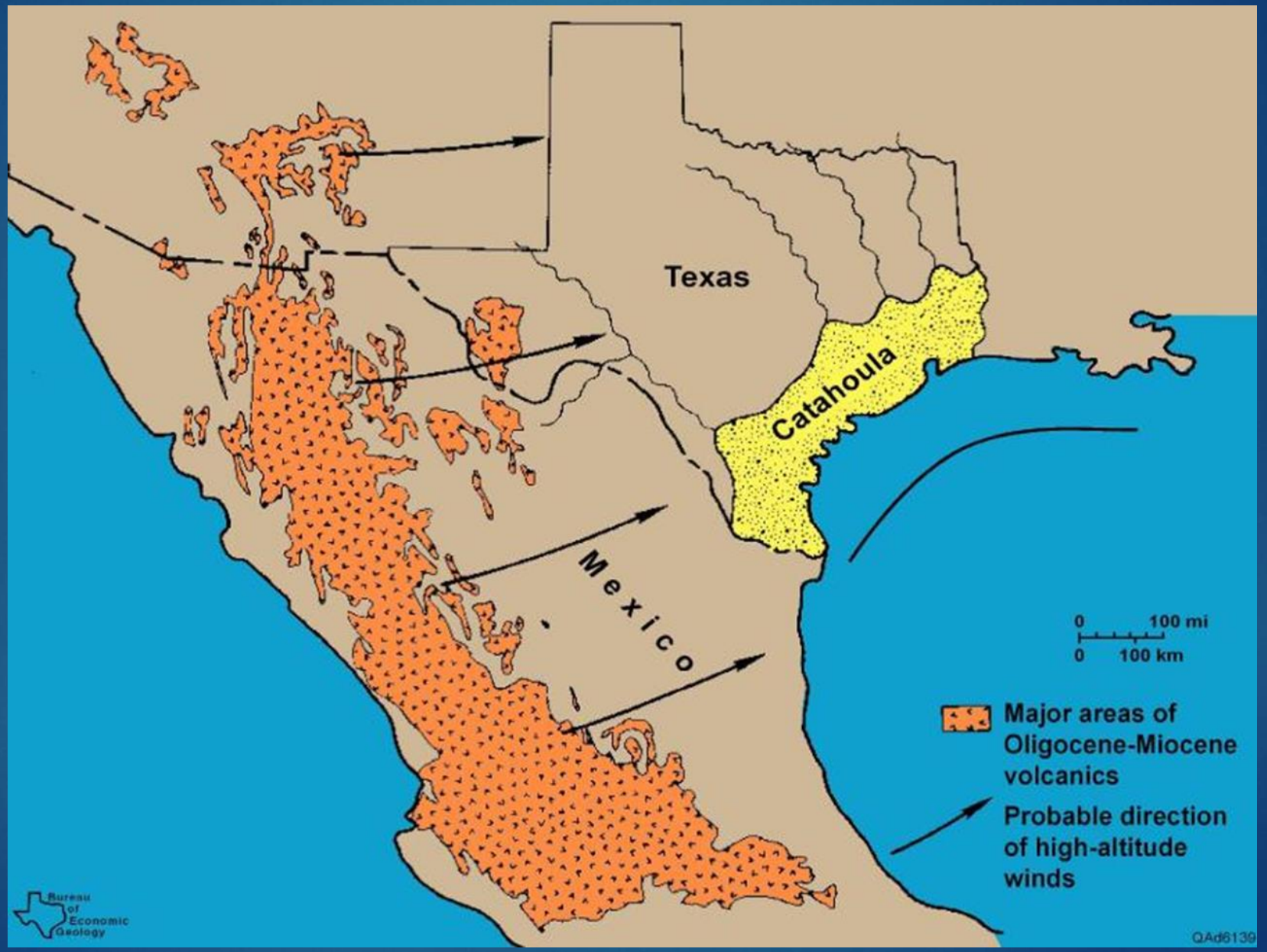
Texas Administrative Code (TAC)

Title 30	Environmental Quality
Part 1	Texas Commission on Environmental Quality
Chapter 331	Underground Injection Control
Chapter 336	Radioactive Substances Rules

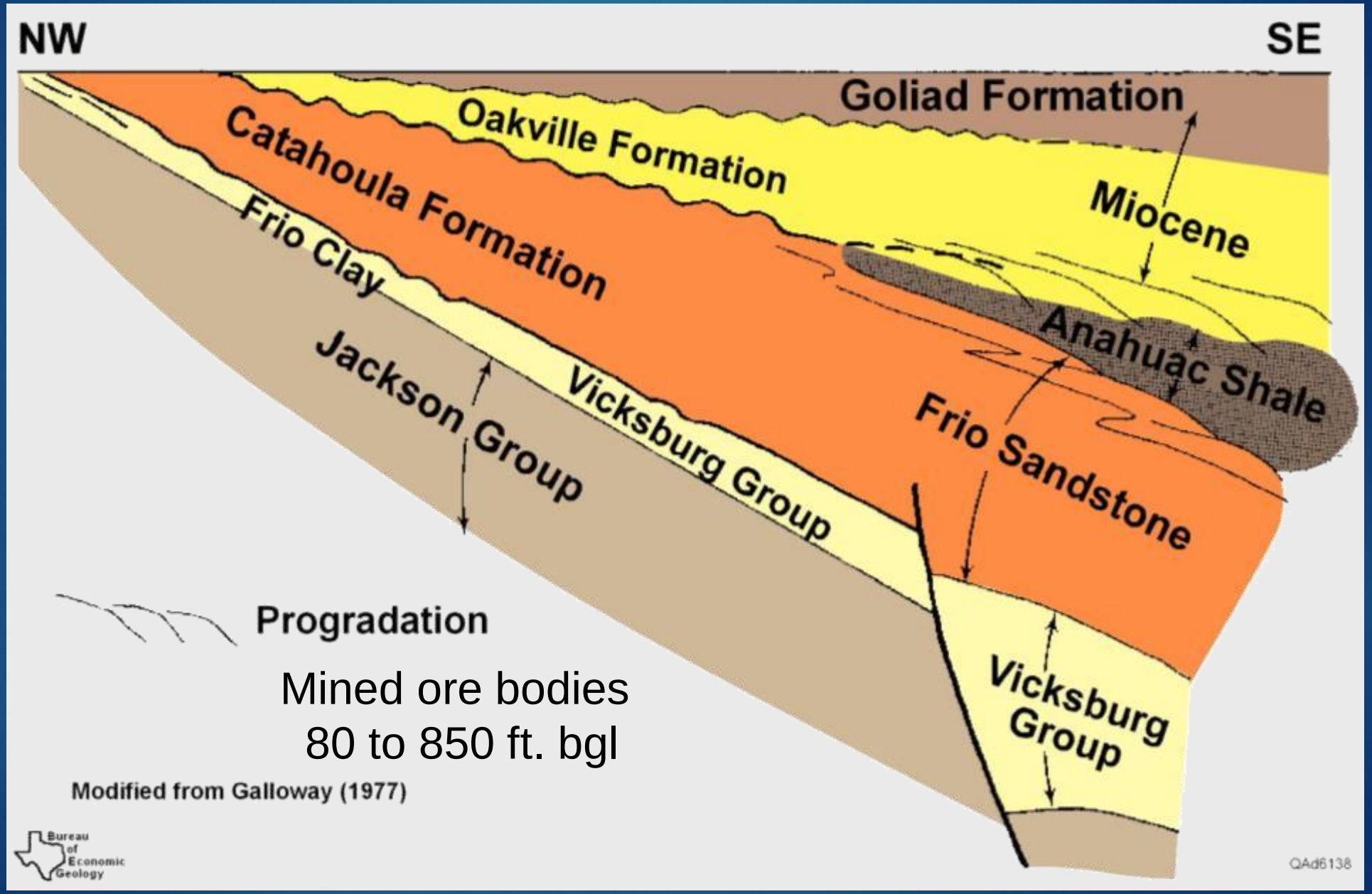
U.S. Nuclear Regulatory Commission (NRC)

Standard Review Plan for In Situ Leach Uranium Extraction License Applications – Final Report 2003 (NUREG-1569)

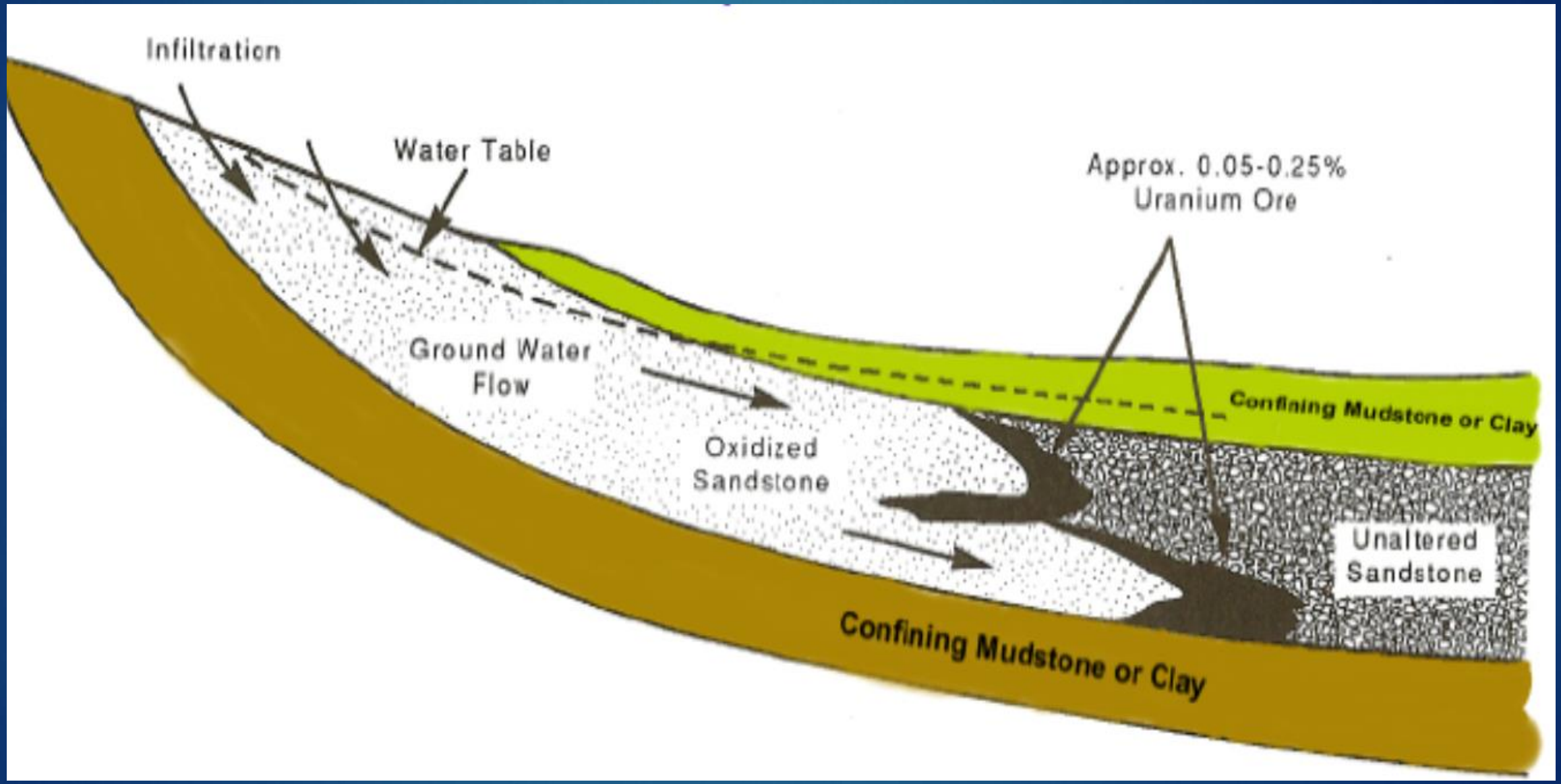
Source of Uranium



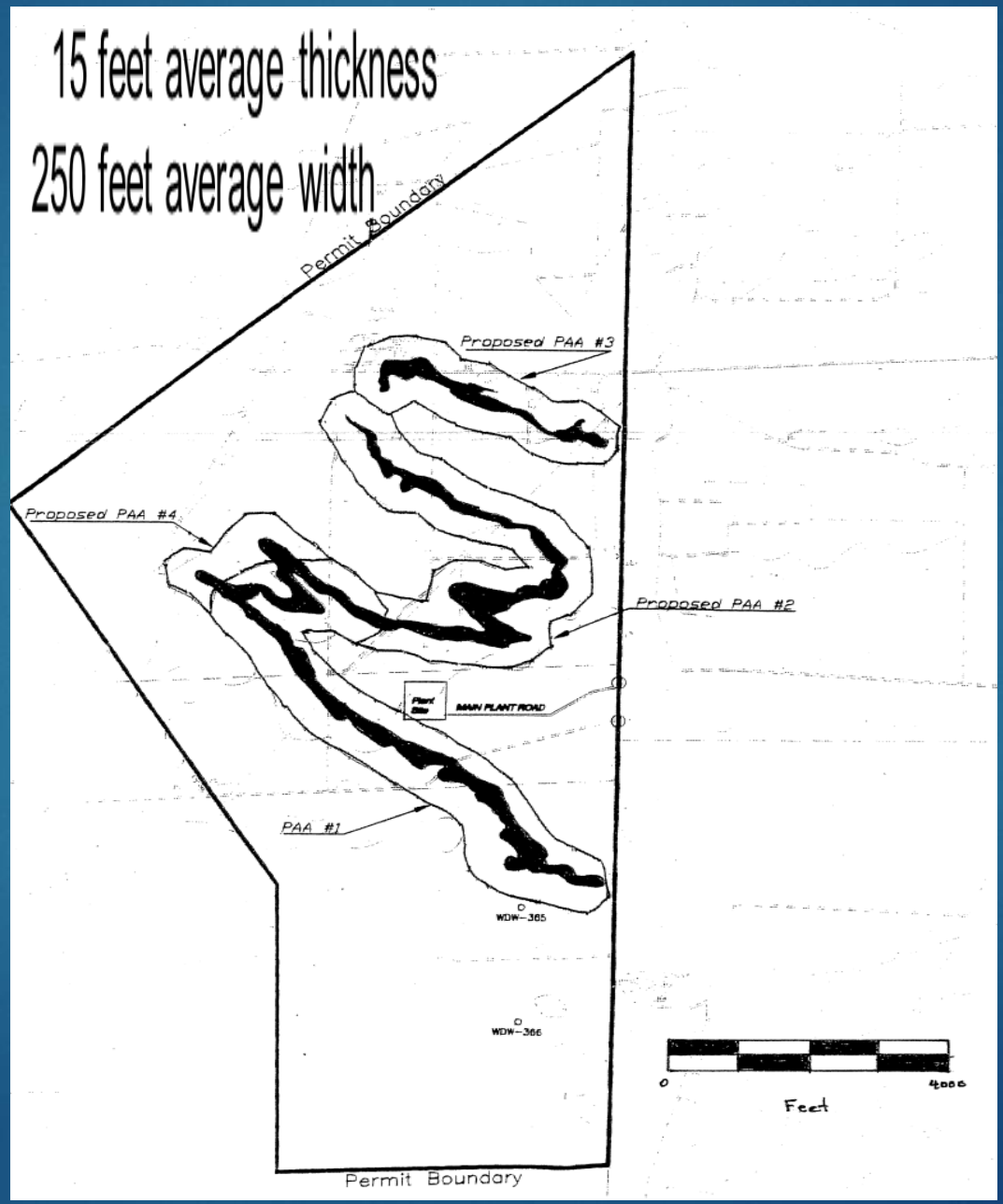
Gulf of Mexico Tertiary Uranium-Bearing Units



Profile of Uranium Roll-Front Deposit

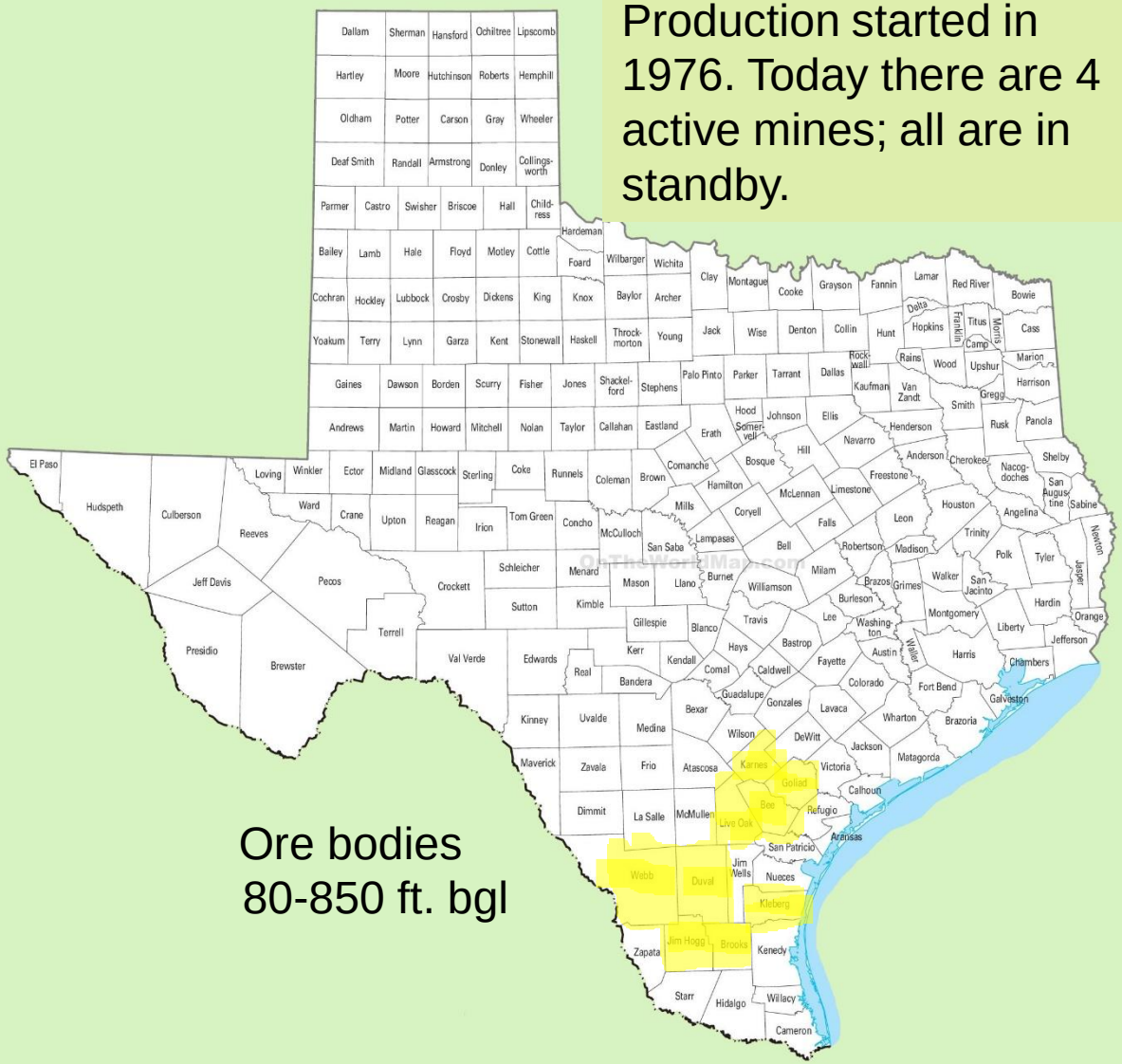


Aerial View of Uranium Roll-Front South Texas



Class III Uranium Mining Sites

Production started in 1976. Today there are 4 active mines; all are in standby.



Ore bodies
80-850 ft. bgl

Phases of an *In-Situ* Uranium Project

Exploration – exploratory drilling, permitted with the RRC.

Pre-production - acquire UIC permits, license, and aquifer exemption; establish water quality of the production and non-production zones (baseline).

Production – injection of mining solutions (lixiviant) to recover uranium.

Standby – conditional, production is temporarily halted due to low uranium prices.

Restoration –water quality of the production zone, within a production area, has by natural and artificial processes (groundwater sweep, reverse osmosis, etc.) returned to the restoration table values established in accordance with the requirements of 30 TAC §331.107. Restoration.

Stability – confirm restoration has been achieved; the average value from all baseline wells for all restoration parameters are equal to or below each respective restoration table value.

Closure – plug and abandon wells.

Types of Wells

- Exploration well - permitted with the RRC. After a well is drilled, within 3 business days, the well is either plugged or completed with casing and cement. The completed wells are transferred to the TCEQ as supporting data for an *in-situ* uranium permit application.

All of the wells below are permitted with the TCEQ as Class I or Class III wells.

- Disposal well - Class I well used to dispose of onsite nonhazardous mining solutions into deeper formations below the uranium production zone. The average depth of a disposal well is 5,000 feet. Usually one, sometimes two wells are located at a mine site.

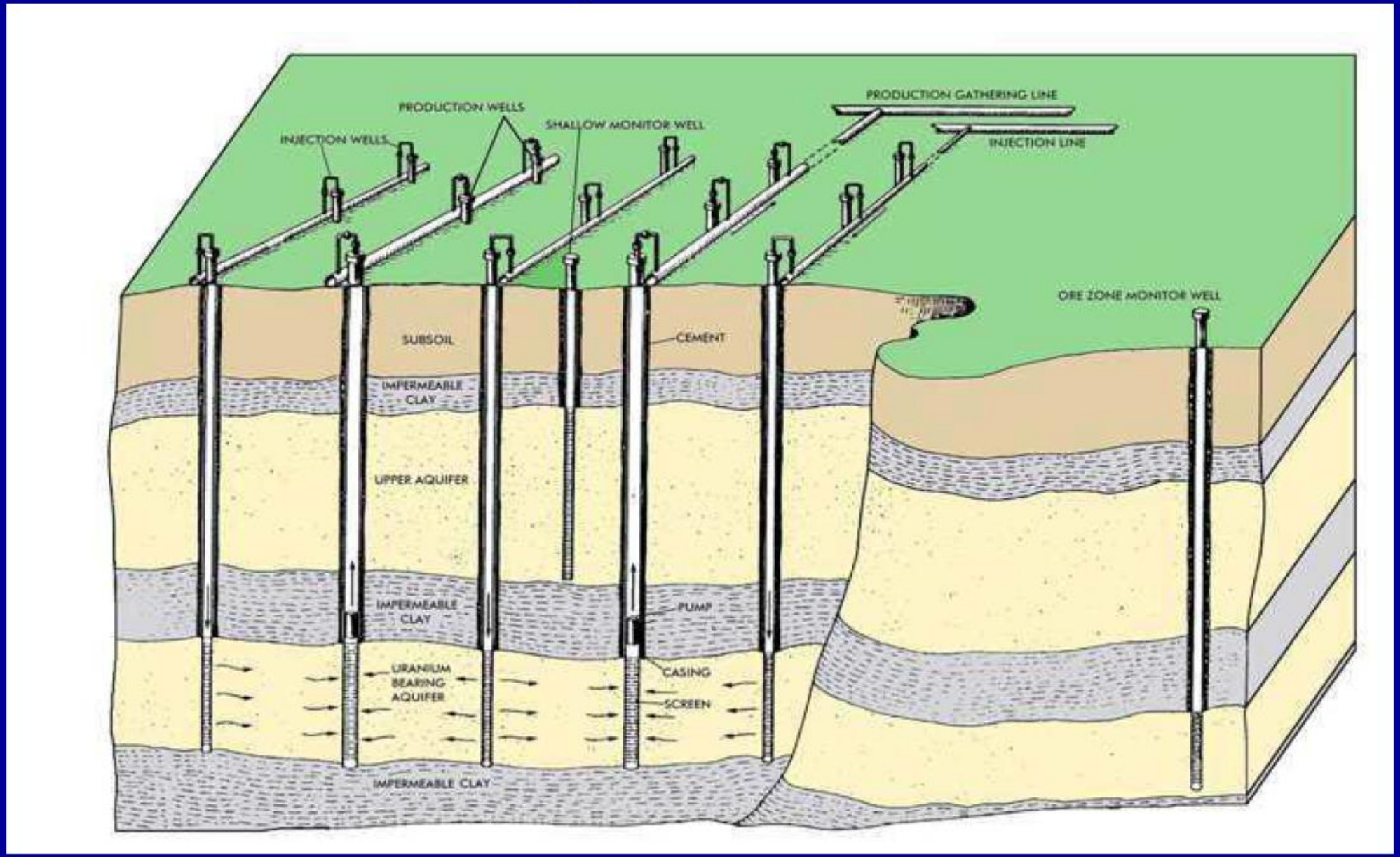
Types of Wells

- **Baseline well** - completed in the ore body (production area). An initial water sample is taken from every baseline well before production is started. All 26 parameters are analyzed to establish baseline. During restoration, select parameters are used to monitor and report the progress of restoration. Later, all 26 parameters (stability samples) are required to confirm restoration has been achieved.
- Production well - injection and production wells completed in the ore body and recover soluble uranium to the surface. The depth of mined ore bodies are 80 to 850 feet below ground level in South Texas. There are hundreds to thousands of these wells at a mine site.

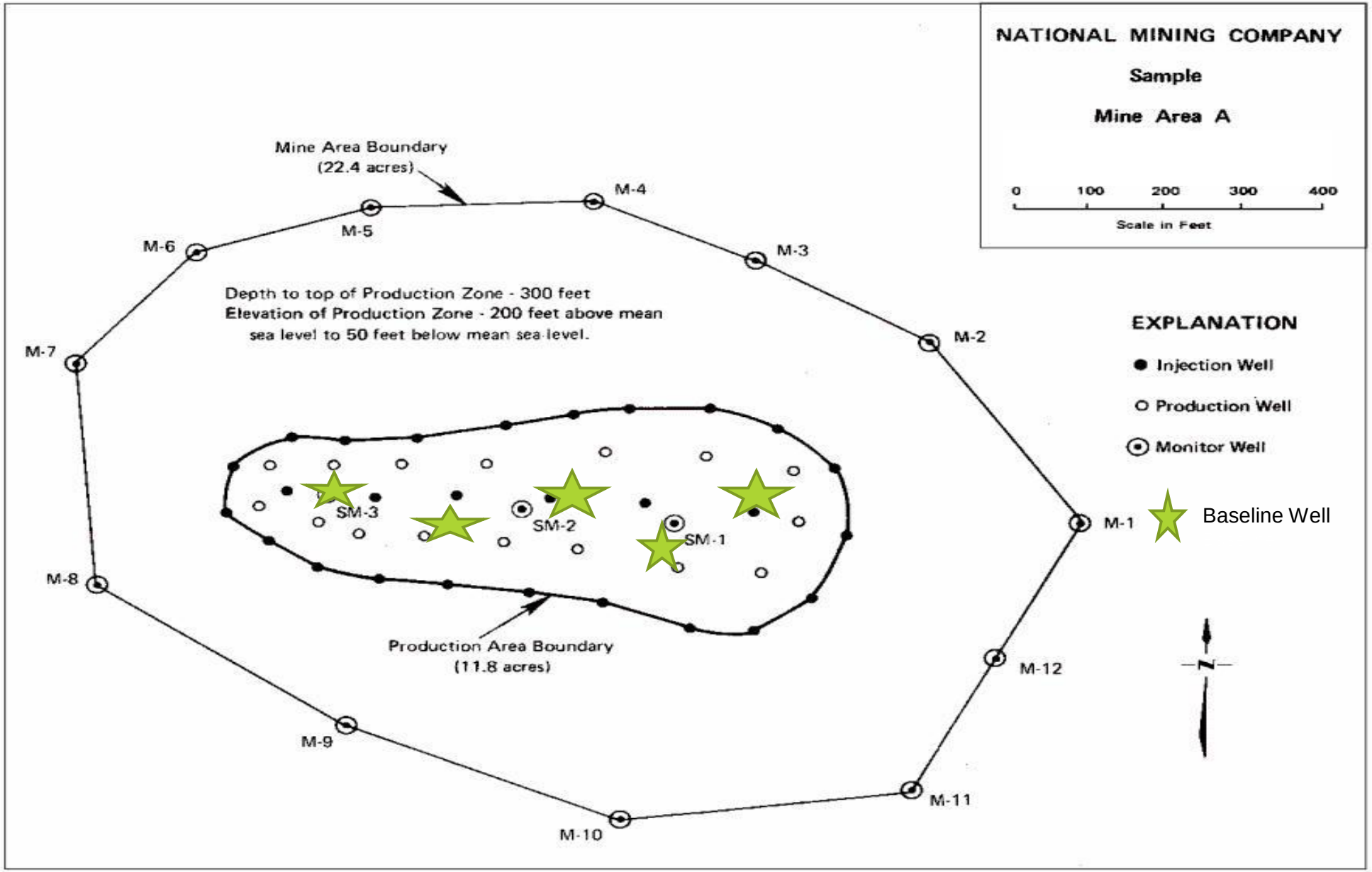
Types of Wells

- Monitor well - wells completed in the production zone, and aquifers immediately above and below the production zone to detect movements (excursions) of mining solutions. The ring of monitor wells, completed in the production zone, are used to collect water samples taken to establish the baseline of the mine area. There are less than 100 wells for a production area authorization (PAA).

Block Diagram of *In Situ* Uranium Mining Operation



Aerial View of a PAA



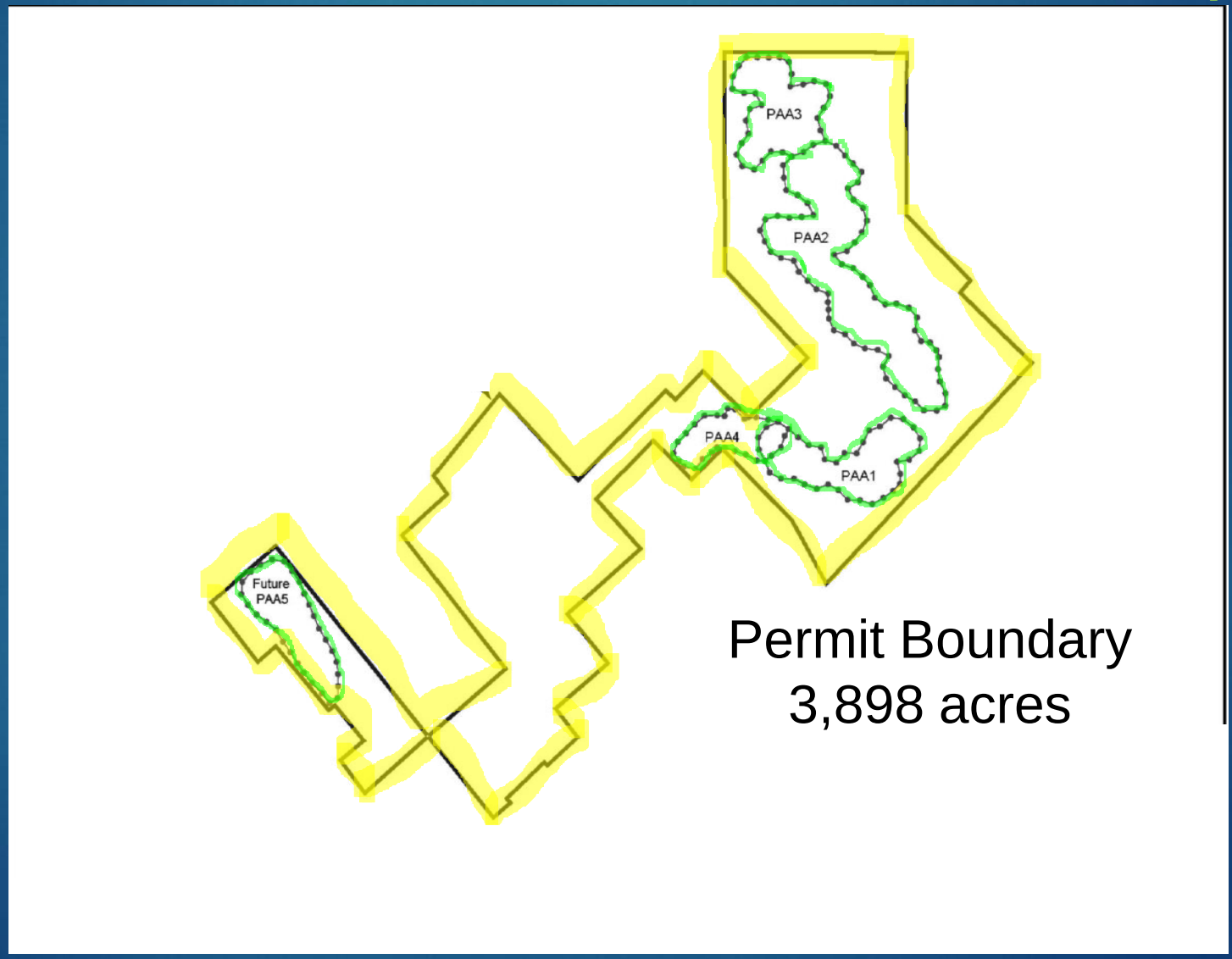
Restoration and Stability

Water Quality (Baseline) Parameters (26)

Calcium	Alkalinity	Fluoride
Magnesium	pH	Silica
Sodium	Arsenic	TDS
Potassium	Cadmium	E. Conductivity
Carbonate	Iron	Selenium
Bicarbonate	Lead	Ammonia
Sulfate	Manganese	*Uranium
Chloride	Mercury	*Radium-226
Nitrate	Molybdenum	

* Cannot be removed from list

Mine Area Map Showing Class III Area Permit Boundary (1) and Production Area Authorizations (PAA) (5)

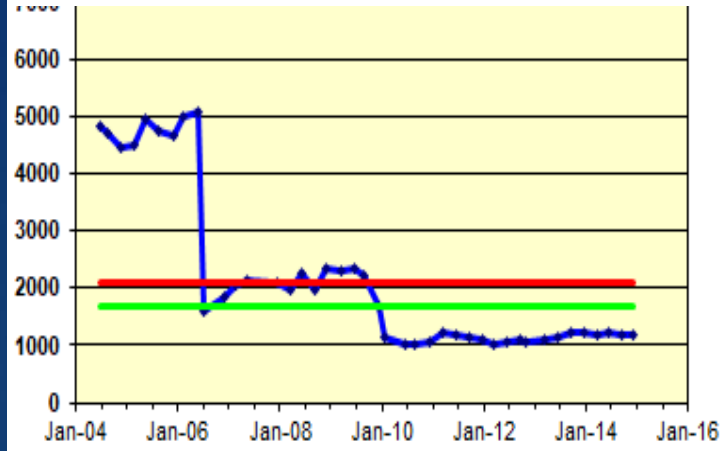


Select Parameters for In-Progress Restoration

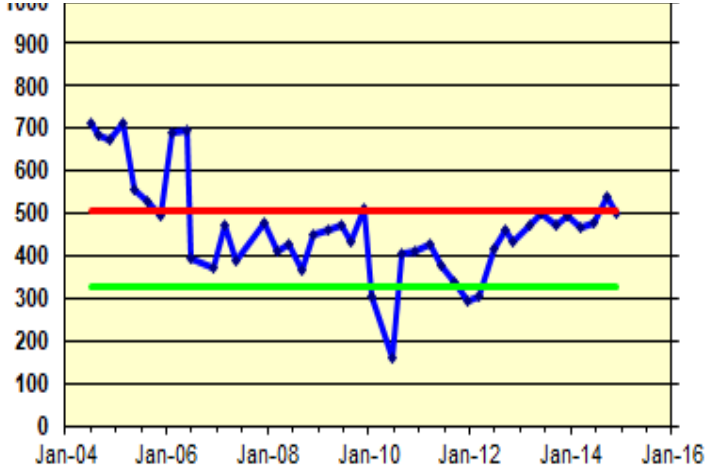
Company A	Company B
8 parameters	6 parameters
pH	pH
conductivity	conductivity
uranium	uranium
chloride	chloride
calcium	--
bicarbonate	--
sulfate	sulfate
molybdenum	molybdenum

Example of In-Progress Restoration Report

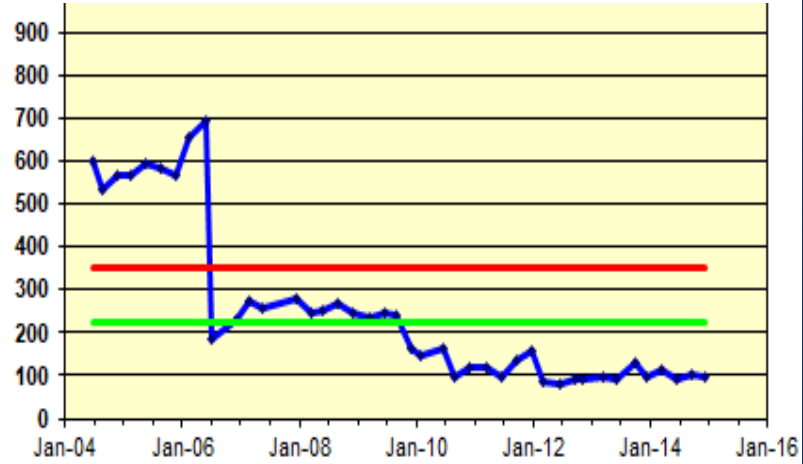
Conductivity



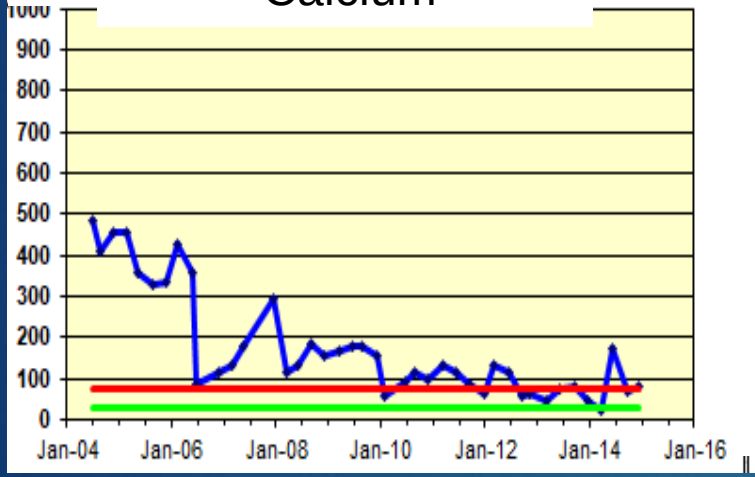
HCO3



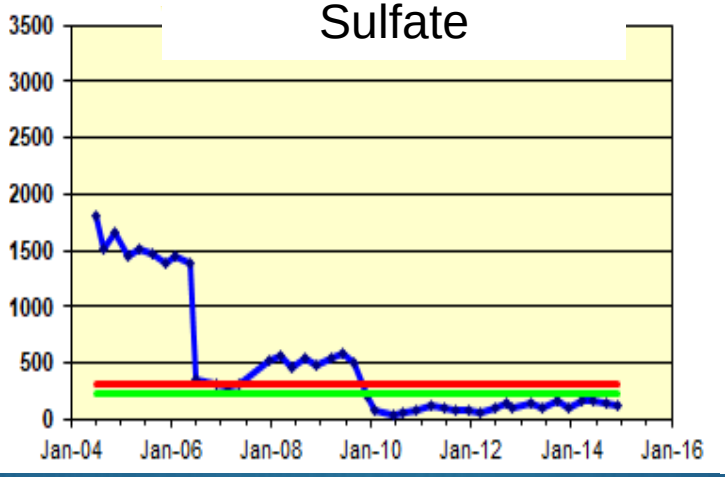
Chloride



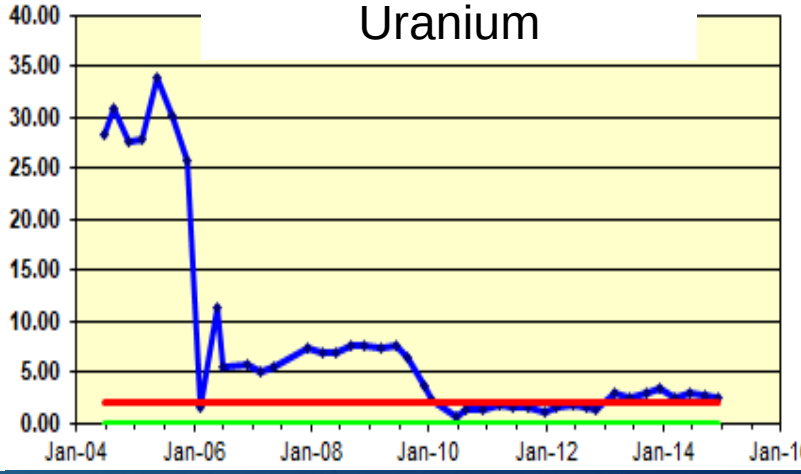
Calcium



Sulfate



Uranium



Red Line (Permit Range Table)

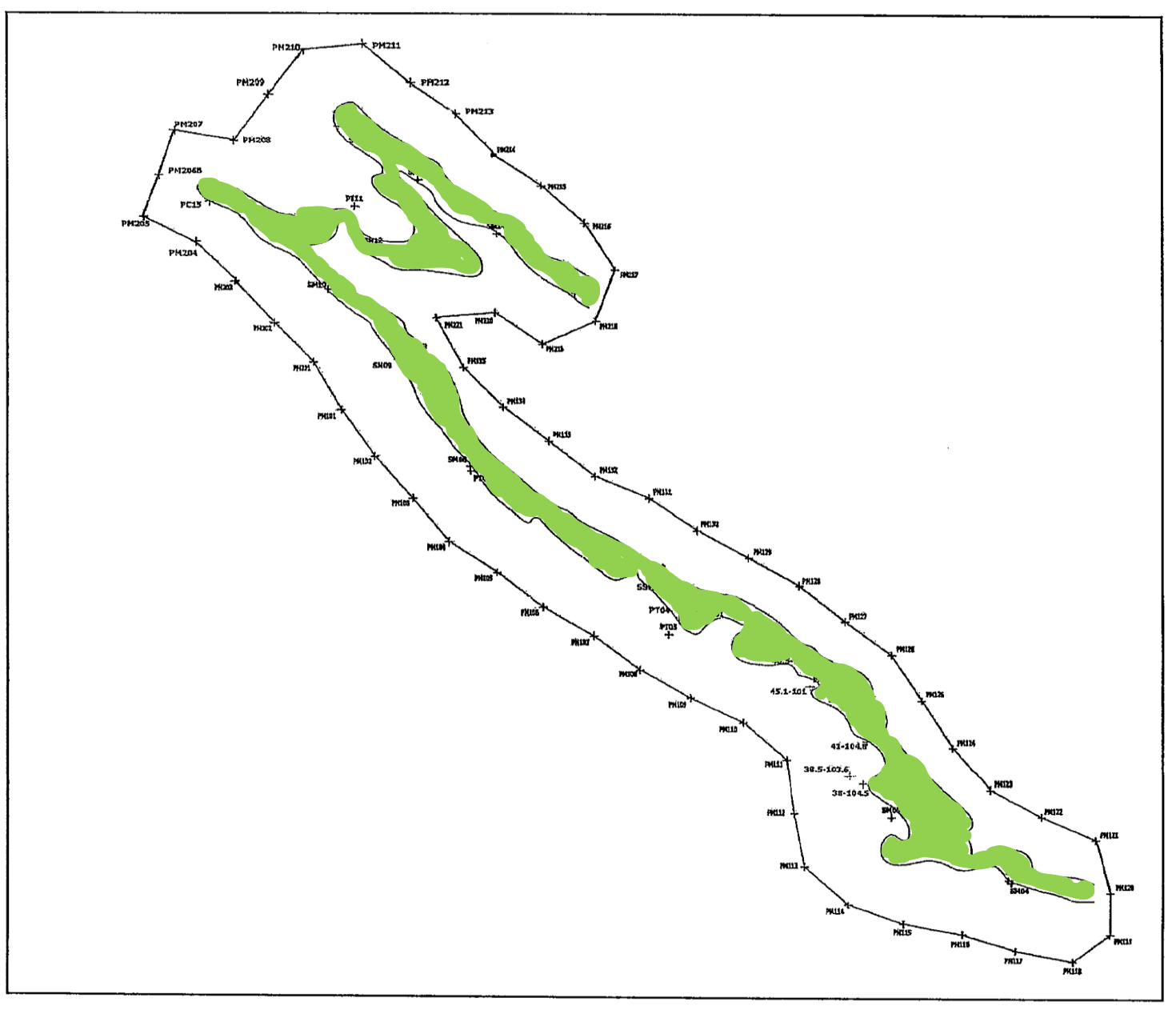
Green Line (Restoration Table)

U.S. Nuclear Regulatory Commission

- Standard Review Plan for In-Situ Leach Uranium Extraction License Applications (NUREG-1569)

  6.1.3(4)(a) Primary Restoration Standards – The primary goal of the restoration program is to return the water quality within the exploited production zone and any affected aquifers to pre-operational (baseline) water quality conditions. Recognizing that *in situ* leach operations fundamentally alter ground-water geochemistry, restoration activities are not likely to return ground-water quality to exact water quality that existed at every location prior to *in situ* operations.

Mine #1, PAA1



- 22 baseline wells
- 56 ring monitor wells
- 542 total wells

- 244 acres mine area
- 55 acres production area

- Ore body
  - 15 feet average thickness
  - 250 feet average width
  - Approx. 10,000 feet long

Mine #1, PAA1
Baseline Wells: 22

Amended Parameters: **9**
Pore volumes: 13

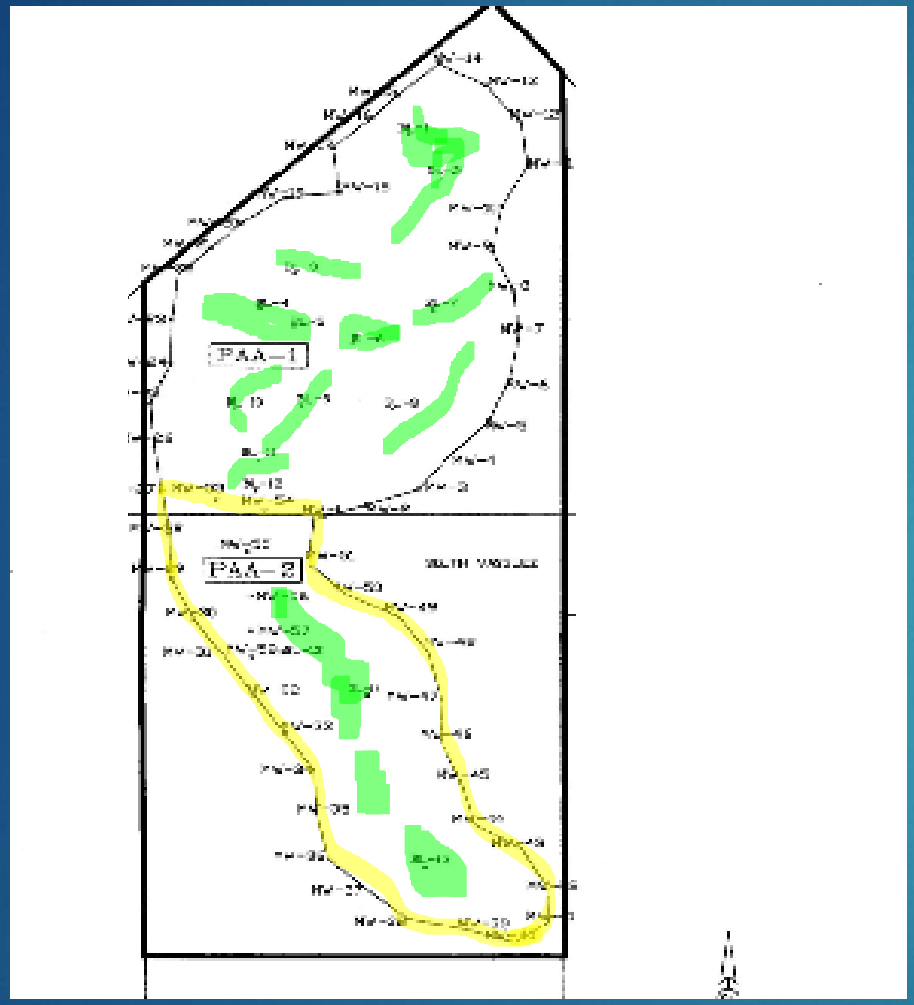
Parameter		Production Area Authorization (PAA) Restoration Table Average Values				Area Permit Range Table	EPA Public Water Systems Standards	
		Initial 2000	Stability 2012 - 15	Amended 2016	Stability 2017	Sand "C" 2014	Primary	Secondary
1 Calcium	mg/l	15	**47**	**150**	**51**	2 -221	-	-
2 Magnesium	mg/l	8.3	**15.4**	**40**	**17.1**	0.05 – 57	-	-
3 Sodium	mg/l	295	192			243 – 498	-	-
4 Potassium	mg/l	10.4	7.6			3 – 42	-	-
5 Carbonate	mg/l	4	1.2			<2 – 155	-	-
6 Bicarbonate	mg/l	335	258			27 – 658	-	-
7 Sulfate	mg/l	30	**98**	**250**	**110**	2 – 1,030	-	250
8 Chloride	mg/l	286	202			220 – 514	-	250
9 Fluoride	mg/l	.97	.50			0.01 – 74		2.0
10 Nitrate	mg/l	.08	< .2			<0.02 – 4	10	-
11 Silica	mg/l	21	15.2			8 – 46	-	-
12 pH		6.5-8.5	8.1			6.99 – 10.7	-	6.5-8.5
13 TDS	mg/l	812	725			714 – 2,160	-	500

Mine #1, PAA1
Baseline Wells: 22

Amended Parameters: **9**
Pore volumes: 13

Parameter			Production Area Authorization (PAA) Restoration Table Average Values				Area Permit Range Table	EPA Public Water Systems Standards	
			Initial 2000	Stability 2012 - 15	Amended 2016	Stability 2017	Sand "C" 2014	Primary	Second.
14	Conductivity	µmhos	1,482	1,241			1,060 – 3,070	-	-
15	Alkalinity	mg/l	280	261			51 – 658	-	-
16	Ammonia	mg/l	.1	.1			<0.1 – 1.5	-	-
17	Arsenic	mg/l	.051	.04			<0.001 – 0.75	.01	-
18	**Cadmium**	mg/l	.0001	**.0003**	**.0050**	**.0002**	<.0010 – .010	.005	-
19	**Iron**	mg/l	.02	**.10**	**1.00**	**0.20**	<0.02 – 3.73	-	.30
20	Lead	mg/l	.001	< .0001			<0.001 – 0.0598	.015	-
21	**Manganese**	mg/l	.03	**.05**	**.20**	**0.05**	<0.01 – 1.60	-	.05
22	Mercury	mg/l	.0002	< .0002			<0.001 – 0.001	.002	-
23	**Molybdenum**	mg/l	.1	**3.0**	**3.6**	**2.8**	<0.1 – 3.6	-	-
24	**Selenium**	mg/l	.002	**.004**	**.050**	**0.0003**	<0.001 – 1.97	.05	-
25	**Uranium**	mg/l	.201	**.468**	**1.000**	**0.438**	<0.001 – 2.72	.03	-
26	Radium 226	pCi/l	166	141			0.1 – 3,790	5	-

Mine #2, PAA2



- 5 baseline wells
- 24 ring monitor wells
- 256 total wells

- 102 acres mine area
- 34 acres production area

Mine #2, PAA2
Baseline Wells: 5

Amended Parameters: **4**
Pore volumes: 10.8

Parameter		Production Area Authorization (PAA) Restoration Table Average Values				Area Permit Range Table	EPA Public Water Systems Standards	
		Initial 2005	Stability 2014 - 2015	Amended 2017	Stability 2014-15, 2017	PAA1 and PAA2 2014 **2016 amended**	Primary	Secondary
1 Calcium	**mg/l**	**57**	**96**	**192**	**114**	20 – 235	-	-
2 Magnesium	mg/l	34	32			20 – 113	-	-
3 Sodium	mg/l	413	290			300 – 825	-	-
4 Potassium	mg/l	24	16			18 – 46	-	-
5 Carbonate	mg/l	2	0			0 – 12	-	-
6 Bicarbonate	mg/l	363	245			181 - 456	-	-
7 Sulfate	**mg/l**	**107**	**196**	**400**	**261**	21 – 997	-	250
8 Chloride	mg/l	557	436			424 – 1580	-	250
9 Fluoride	mg/l	.94	.81			.43 – 1.40		2.0
10 Nitrate	mg/l	.06	.06			<.01 - .11	10	-
11 Silica	mg/l	48	30			4 – 73	-	-
12 pH		6-9	8.05			7.25 – 8.55	-	6.5-8.5
13 TDS	mg/l	1,438	1,249			1150 – 3160	-	500

Mine #2, PAA2
Baseline Wells: 5

Amended Parameters: **4**
Pore volumes: 10.8

Parameter			Production Area Authorization (PAA) Restoration Table Average Values				Area Permit Range Table	EPA Public Water Systems Standards	
			Initial 2005, 2009	Stability 2014 - 2015	Amended 2017	Stability 2014-15, 2017	PAA1 and PAA2 2014 **2016 amended**	Primary	Secondary
14	Conductivity	µmhos	2,488	2,144			2070 - 5490	-	-
15	Alkalinity	mg/l	301	245			148 – 374	-	-
16	Ammonia	mg/l	.41	.03			<.01 – 1.30	-	-
17	Arsenic	mg/l	.041	.012			<.001 - .485	.01	-
18	Cadmium	mg/l	.0002	.0001			<.0001 - .0002	.005	-
19	Iron	mg/l	.05	.02			<.01 – .07 **.11**	-	.3
20	Lead	mg/l	<.001	.000			<.001 - .005	.015	-
21	**Manganese**	**mg/l**	**.02**	**.25**	**2.00**	**0.28**	<.01 – .10 **2.00**	-	.05
22	Mercury	mg/l	<.0002	.0000			<.0002 - <.0002	.002	-
23	Molybdenum	mg/l	.14	.04			<.01 – 2.80	-	-
24	Selenium	mg/l	.005	.001			<.001 - .010	.05	-
25	**Uranium**	**mg/l**	**.033**	**.724**	**2.000**	**0.73**	<.001 – 5.77	.03	-
26	Radium 226	pCi/l	50.54	45.83			.1 - 836	5	-

Amended Restoration Tables

Mine #1 PAA1	(9 parameters) - Ca, Mg, SO4, Cd, Fe, Mn, Mo, Se, and U	13.0 Pore Volumes
Mine #2 PAA1	(8) - Ca, SO4, NO3, pH, Fe, Mn, Mo, and U	9.0
Mine #2 PAA2	(4) - Ca, SO4, Mn, and U	10.8
Mine #3 PAA1	(7) - SO4, Cd, Pb, Mn, Mo, Se, and U	6.9
Mine #3 PAA2	(11) - Ca, HCO3, Alk, NH3, Cd, Fe, Pb, Mn, Mo, Se, and U	6.9

Calcium	4 / 5	none (No EPA Standard)	Alkalinity	1 / 5	none
Magnesium	1 / 5	none	Arsenic	0 / 5	primary
Sodium	0 / 5	none	Cadmium	3 / 5	primary
Potassium	0 / 5	none	Iron	3 / 5	secondary
Bicarbonate	1 / 5	none	Lead	2 / 5	none
Sulfate	4 / 5	secondary	Manganese	5 / 5	secondary
Chloride	0 / 5	secondary	Mercury	0 / 5	primary
Fluoride	0 / 5	secondary	Selenium	3 / 5	primary
Nitrate	1 / 5	primary	Ammonia	1 / 5	none
Silica	0 / 5	none	Molybdenum	4 / 5	none
pH	0 / 5	secondary	Radium	0 / 5	primary
TDS	0 / 5	secondary	Uranium	5 / 5	primary
Conductivity	0 / 5	none			

Conclusions

- The geochemistry of the production zone has been altered from an anaerobic to aerobic environment due to drilling of hundreds to thousands of wells, and injecting oxygenated fluids.
- In all cases, after active restoration not all 26 parameters returned to initial baseline.
- The restoration tables were revised with permit amendments allowing for higher parameter values.
- Between 4 to 11 parameters were amended for each restoration table.
- The second round of stability samples confirmed values were below amended restoration table values. Restoration is now complete / finished.

Questions ?

Fred Duffy, P.G.
Texas Commission on Environmental Quality
Office of Waste
Radioactive Materials Division
Radioactive Materials Section
(512) 239-6891
fred.duffy@tceq.texas.gov