Case Study of Integrated Approach to the Cleanup of Ogallala Groundwater Impacted by Oilfield Brine, Haskell County, Kansas*

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Search and Discovery Article #80041 (2008) Posted December 15, 2008

*Adapted from oral presentation at AAPG Annual Convention, San Antonio, TX, April 20-23, 2008

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Abstract

In 1983 it was discovered that an injection well had released chloride-rich oilfield brine into the groundwater of the Ogallala aquifer near Satanta, Haskell County, Kansas. Monitor wells installed between 1984 and 1989 indicated that the brine was confined to a paleochannel incised into the Cretaceous Blanco Formation at the base of the Ogallala aquifer and was moving down the topographic gradient in the channel. The channel axis lies at about 419 feet below ground surface (ft bgs) in the southeast part of the site, where the depth to groundwater was about 320 ft bgs. In 1992-1993 four recovery wells were installed to extract the brine, which was disposed of in a replacement injection well. Brine-recovery rates were restricted by the limited capacity of the injection well.

Pioneer Natural Resources USA, Inc. used an integrated approach to reassess remediation and disposal alternatives. All available wells were sampled for chloride, a 72-hour aquifer test was performed to evaluate aquifer parameters, groundwater modeling was performed to optimize locations of new recovery wells, and a magneto-telluric survey was conducted to delineate the chloride plume and subsurface stratigraphic features. Based on these analyses, additional recovery wells were installed at the site. Recovered brine is currently directed to a nearby subsurface water-flood project, thus removing the limit on extraction rates and expediting the cleanup of the oilfield brine.

Case Study of Integrated Approach to the

Cleanup of Ogallala Groundwater Impacted by Oilfield Brine, Haskell County, Kansas

In association with:

Presented by K. Hopson:

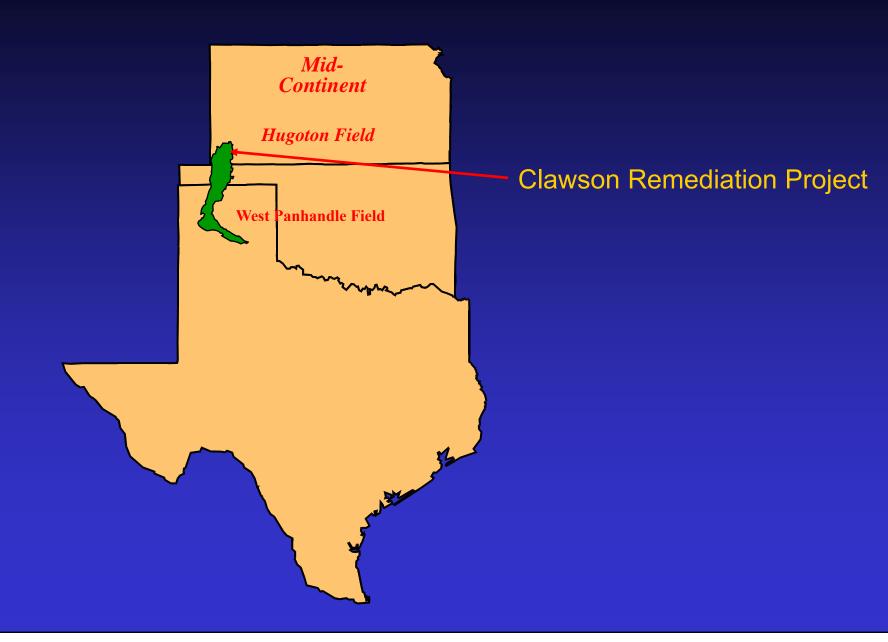




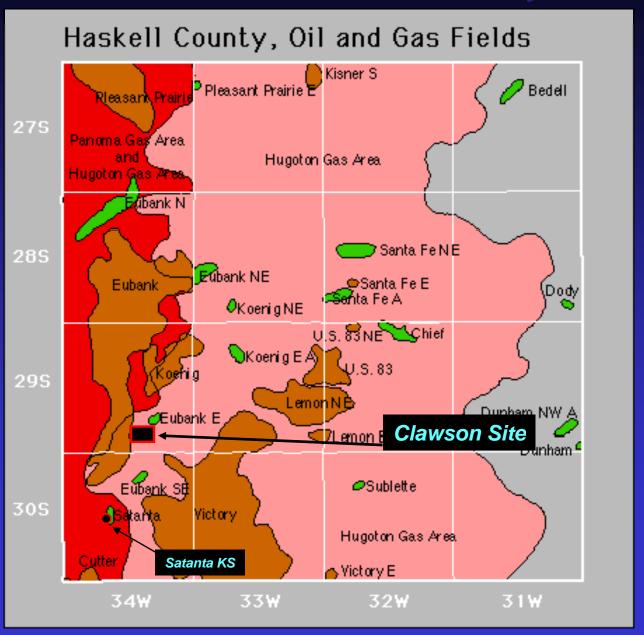
Location



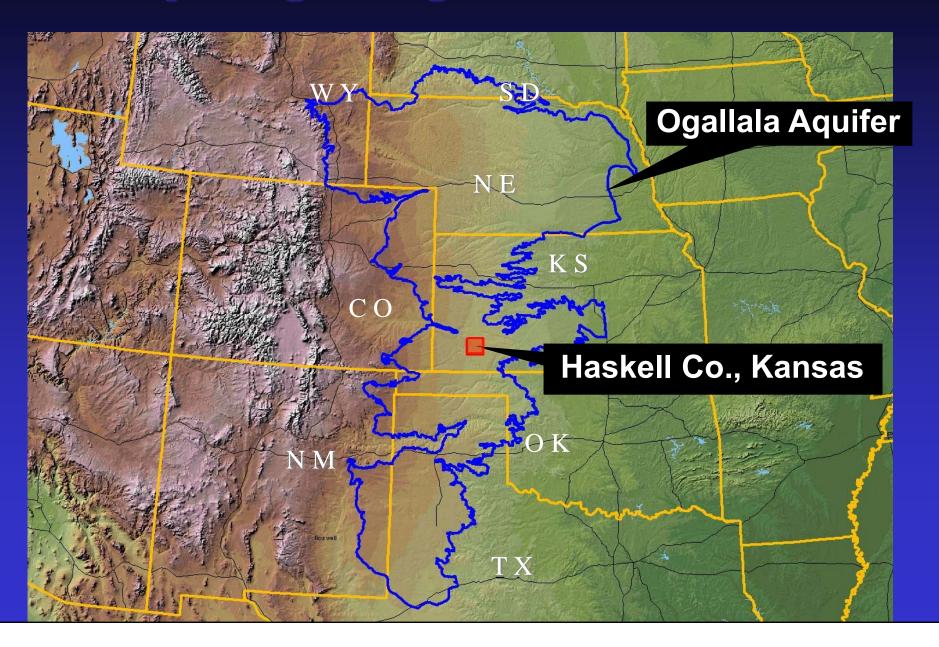
Regional Setting of Clawson Site in Relation to Pioneers' Oil & Gas Production



Oil and Gas Fields- Haskell County, Kansas



Hydrogeological Location



Importance of Ogallala Aquifer to SW Kansas

"Whiskey is for drinking and water is for fighting" – Mark Twain

- > 30% of all U.S. livestock is processed by plants in SW Kansas
- ➤ The abundance of good cattle feeds (corn, alfalfa, sorghums) made possible by irrigation technology is a source of relatively cheap inputs for feedlots in the area
- Farming, ranching, and feedlots ("Farm") in SW Kansas produce earnings in excess of \$300 million on an annual basis.

Haskell Co. Crops	Corn	Wheat	Milo	Soybeans	Alfalfa	Total
Number of Sections % of Sections	202	109	8	6	4	329
	%61.4	%33.1	%2.4	%1.8	%1.2	%100

Data taken from "The Value of Ogallala Aquifer Water in Southwest Kansas" - Southwest Kansas Groundwater Management District

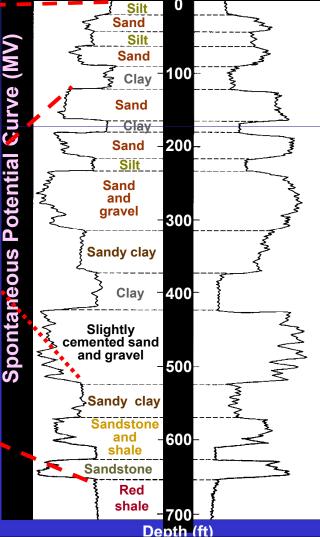
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Generalized Section of Geologic Units and Water-Yielding Characteristics

System	Series	Strati- graphic unit	Thk. (ft)	Physical character	Well supply	
	Holocene and Pleistocene	Alluvium 0-60 Holocene age over sand, gravel, and		Clay, silt, and sand of Holocene age overlying sand, gravel, and cobbles of late Pleistocene age	A potential aquifer	
Quaternary		Dune sand	0-75	Fine to medium quartzose sand with lesser amounts of clay, silt, and coarse sand	Lies above the water table, and does not yield	
- Vale	Pleistocene	Loess	0-30	Wind-blown silt	water to wells	
Ō.		Meade – 250 Rexroad 550 Formation		Medium to very coarse sand and gravel interbedded with clay, silt, and fine sand	Sand and gravel beds are principal water-yielding	
Tertiary	Pliocene	Ogallala Formation	0-300	Poorly sorted clay, silt, sand and gravel	deposits in the country	
	Upper Cretaceous	Blanco Shale	0-30	Dark-gray calcareous shale interbedded with black noncalcareous shale	Not known to yield water to wells	
Cretaceous	Lower Cretaceous	Dakota SS	0-260	Yellow, brown, and gray fine- to medium-grained sandstone	Sandstones within the unit commonly yield 30 to 300 gpm to wells	
Permian	Upper Permian	Undiffer- entiated rocks	200- 400	Red shale, sandstone, sandy shale, and anhydrite	Yields no potable water to wells	

Source: E. D. Gutentag and L.E. Stullken, Hydrologic Investigations Atlas HA-515, sheet 1 of 2, 1974

Generalized Electric Log of Typical Drill Hole



Upper Ogallala Aquifer-Meade/Rexroad Fm. (Pleistocene) Cimarron River Channel (5.3 mi. SW)





Site Contaminant History Adams #2 SWD

- ➤ Drilled in 1960 as an oil well by United Producing Company (Ashland Oil Company), converted to saltwater disposal well (SWD) in 1961 and operated as a SWD from 1961 to 1982
- ➤ MESA Petroleum acquired operations in 1979

Avg. Brine Injection Rate:

- ■17,950 bbls/mo = 427.38 bbls/day = 1.10 L/sec
- Average chloride concentration: 83,636 mg/L
- ➤ In 1983 the KCC passed State water injection rules requiring Mechanical Integrity Tests (MIT). The Adams #2 SWD was plugged and abandoned in April 1983, after failing a Mechanical Integrity Test (MIT) indicating a potential casing leak.
- ➤In August 1983 water analyses performed on the Clawson irrigation well indicated abnormally high chloride content (700 mg/L) indicating aquifer contamination from the Adams #2 SWD
- ➤ 1984 1989 MESA drilled a total of forty-nine (49) test and/or monitor wells to characterize the brine plume. MESA initiated brine recovery in 1988 with the drilling and completion of Water Recovery Well No. 88-21

Site Contaminant History Adams #2 SWD

- In 1993 MESA and the Kansas Department of Health and Environment (KDHE) signed a Consent Order directing MESA to drill four (4) additional brine water recovery wells and two (2) additional monitor wells. Cleanup standards set at 500 mg/L chlorides.
- Water Recovery Well Nos. 92-46, 92-50, 92-54 and 92-57 were completed in June 1993.
- Pioneer acquired MESA in 1997. Current Study was initiated in September 2001.
- As of December 31, 2007 808,026,117 gals (2,479 acre/ft) of brine contaminated water have been recovered and disposed of into the Clawson SWD Well No. 1 and the nearby water flood project.

Adams #2 & Clawson SWD Injection Zone

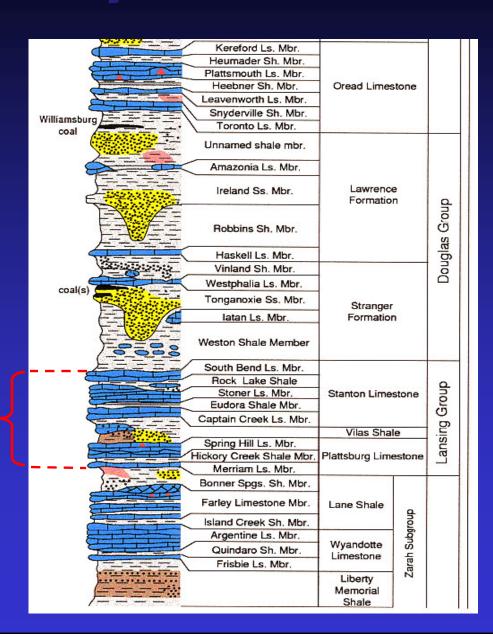
<u>Upper Pennsylvanian Lansing Group</u>

≈ 290 ft thick - consists of porous and permeable zones @ ≈ 3950 ft to 4250 ft BGS

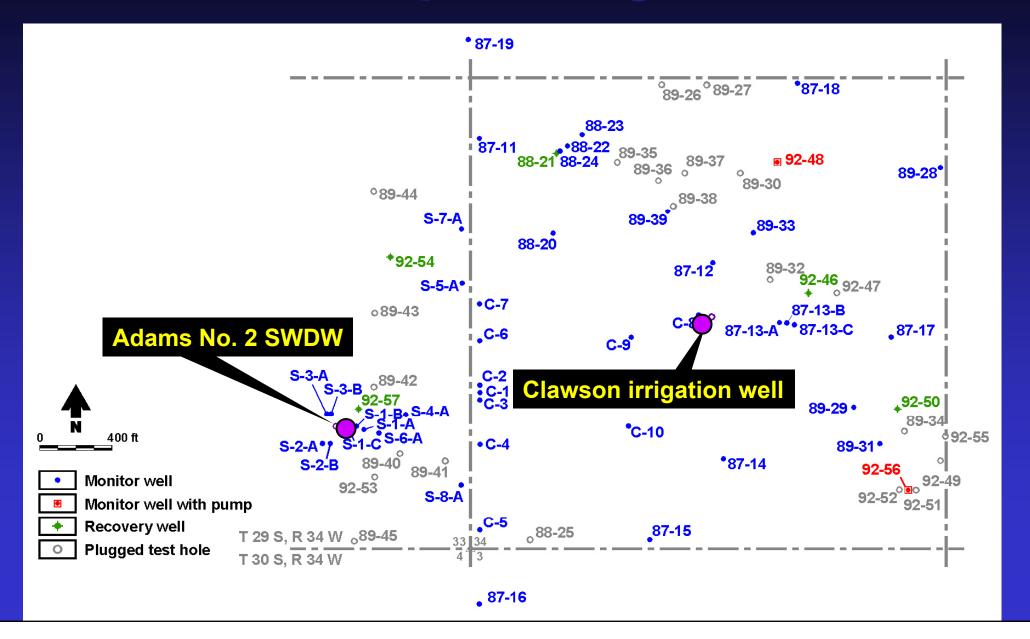
Adams #2 SWD (≈ 1,260 psi)

8

Clawson SWD (900-1,100 psi)

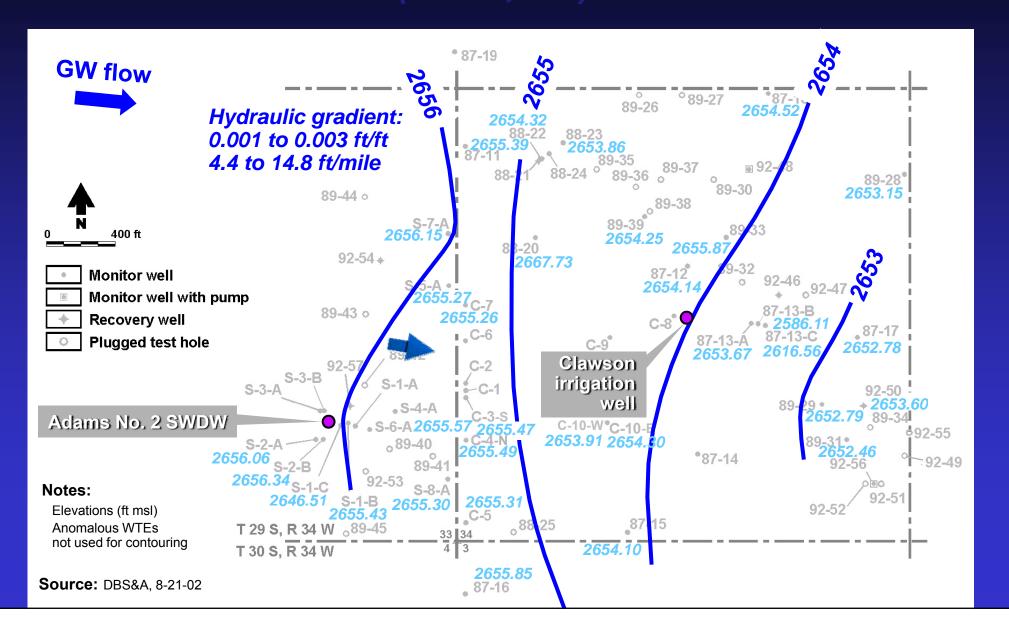


Site Map - May 2002

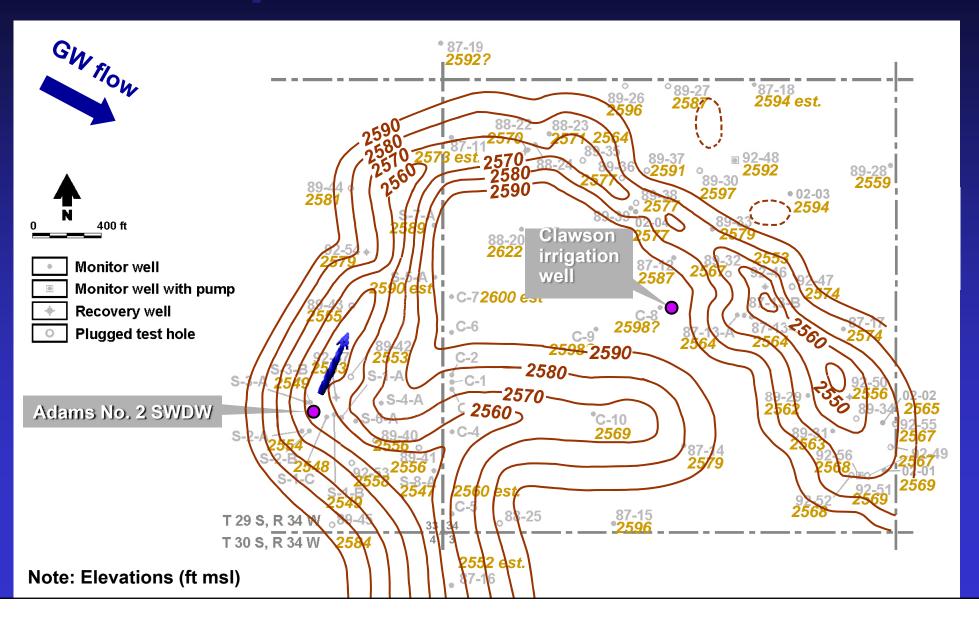


Water Table Elevations

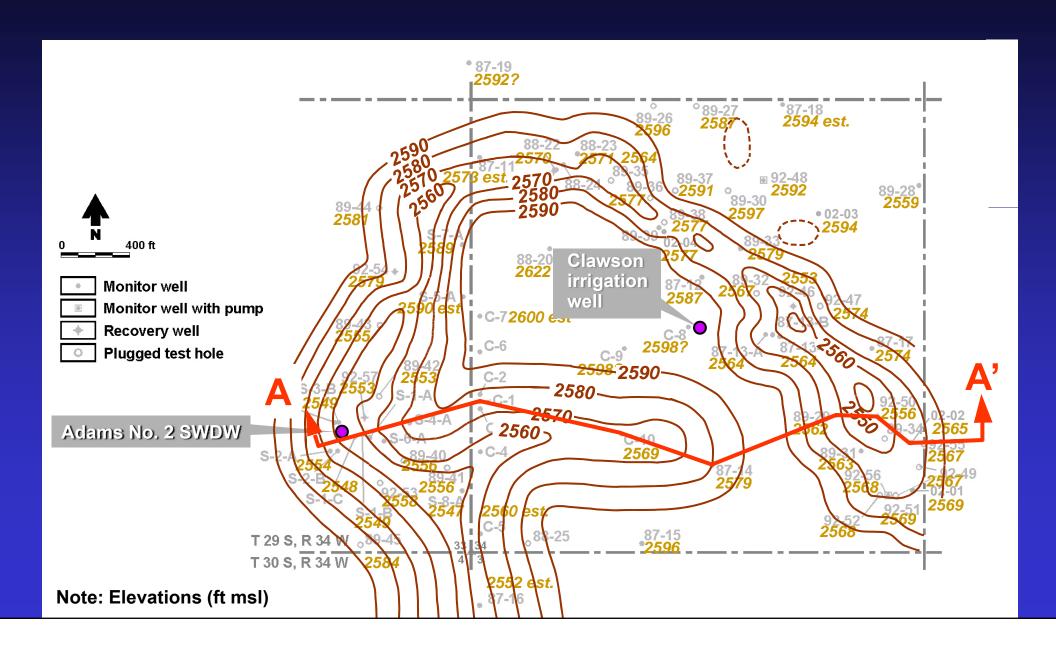
(June 24, 2002)



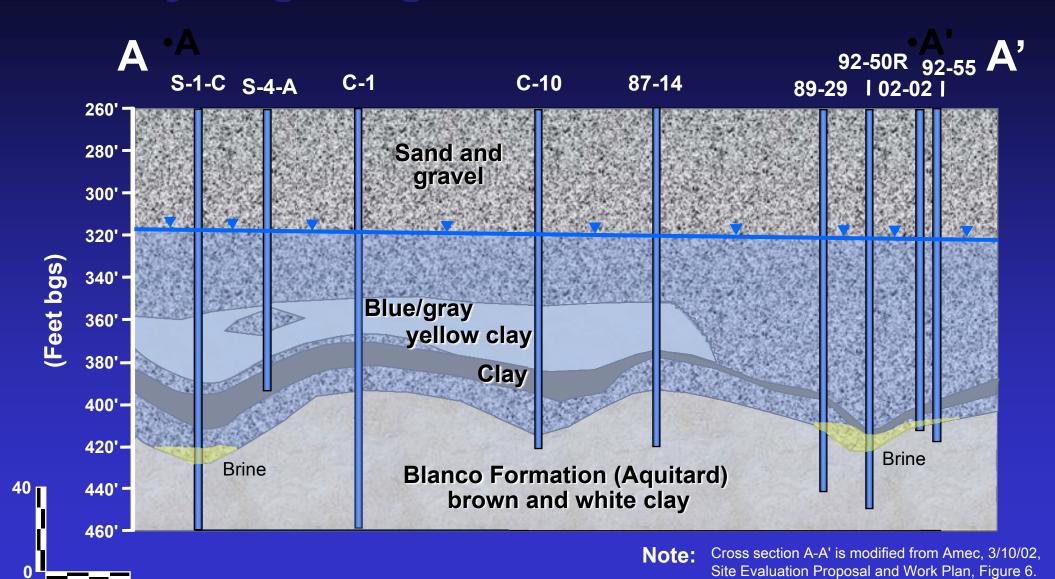
Structure Contour Map of Top of Blanco Formation



Geologic Cross-Section A-A'

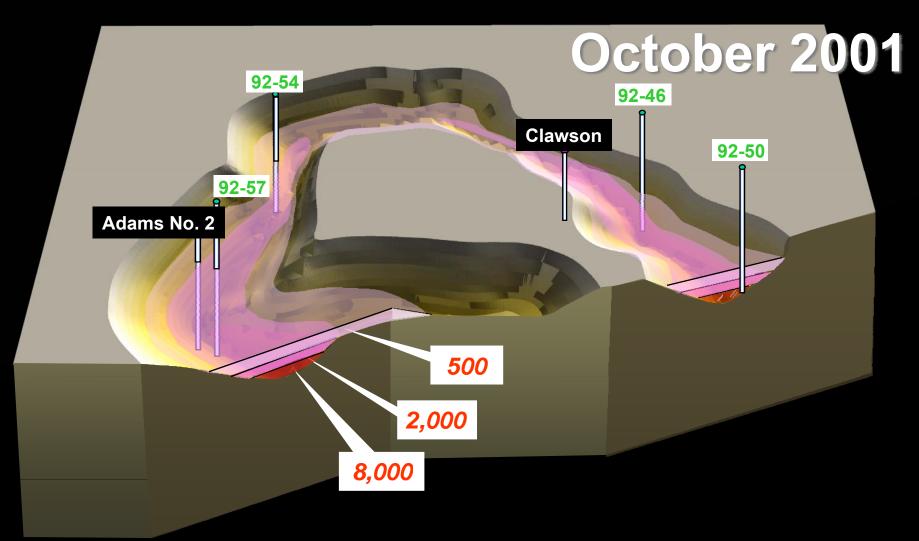


Hydrogeologic Cross Section A-A'



400 ft

3D View of Top of Blanco Formation with Chloride Concentrations



Note: Chloride concentrations (mg/L) based on Conductivity to Chloride conversion

Brine Plume Characteristics

- > Brine Plume Dimensions
 - **■** ≈ 5,000 feet long
 - ≈ 400' wide (average)
 - ≈ 40' Thick
- ➤ Density of Brine Fluids = 1.1 g/cm³ (9.2 lbs/gal)

(Density of fresh water = 1.00 g/cm³ = 8.34 lbs/gal)

➤ One Pore Volume of Plume is ≈ 179.5 MM gallons

(Volume recovered to 12/31/07 = 808 MM/gals ≈ 4.5 Pore Volumes)

Clawson Pump & Treat System



Halliburton Digital Flow-meters

Digital Conductivity Meters



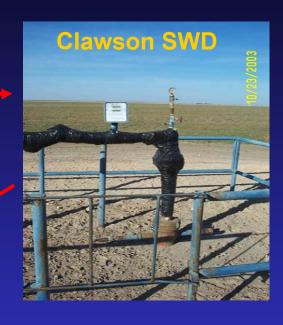
Clawson Brine Station



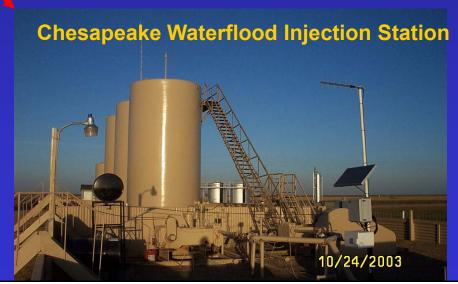


Clawson Pump & Treat System





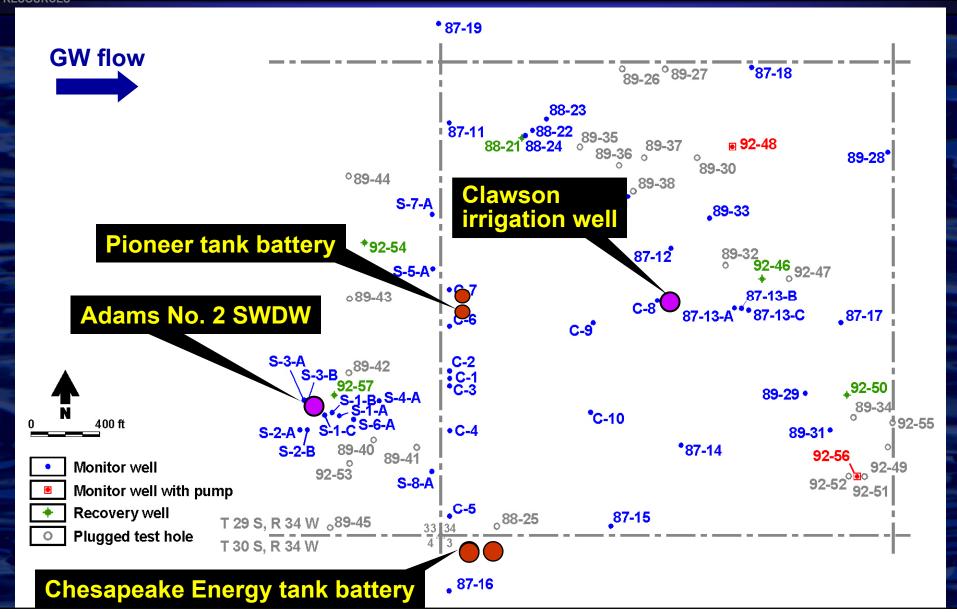






Site Map





Annual Operating Expense

► Brine Recovery Wells ■Electrical Costs – 6 Recovery Wells	\$25,116
■Pump Repair and Maintenance	\$ 7,300
► <u>Injection Pumps</u> ■Electrical Costs	\$21,444
Pump Repair and Maintenance	\$24,100
►Consulting Costs (Bi-annual Sampling)	\$18,500
► <u>Laboratory Analytical Costs</u>	\$ 2,400
≻ <u>Pioneer Costs (Foreman</u>)	\$ 6,500
► <u>Estimated Annual Expense</u>	

Preliminary Evaluation of Pump and Treat Remediation System

1. <u>Limited capability to dispose of recovered brine due to injection capacity</u> <u>of Clawson SWD Well</u>

Limits number of recovery wells - Clawson SWD operating at maximum disposal capacity @ 1,260 psi

2. Limited pumping rates of recovery wells due to layered - dense brine

Recovery wells limited to 35 gpm pump rate due to dilution of brine from inflow of fresh water at increased pumping rates – limits capture zone radius

3. <u>Limited recovery well spacing due to confinement of brine layer in a paleochannel</u>

Recovery wells limited to in-line placement in narrow paleochannel

4. Uncertain delineation and containment of brine due to old collapsed/plugged monitoring wells and existing recovery well placement

KCC concerns regarding off-site plume migration due to adjacent irrigation wells

KCC concerns regarding length of time of clean-up

Integrated Approach Scope of Work

Scope of Work & Tasks - D.B. Stephens (w/ Pioneer Support)

- 1. Locate, Assess and Survey Monitor and Recovery Wells
- 2. Conduct Time-Domain Electromagnetic Survey
- 3. Conduct Groundwater Sampling
- 4. Conduct Pump Test for Aquifer Characterization
- 5. Groundwater Modeling and Contaminant Capture Zone Analysis
- 6. Plug all Damaged and Non-essential Monitor Wells
- 7. Develop Plan for Optimization Groundwater Recovery System
- 8. Drill and Complete New Recovery and Monitor Wells

Pioneer Engineering and Operations Department Tasks

- 1. Drill additional Salt Water Disposal Well and Construction of Associated Equipment (AFE cost estimate = \$501K)
- 2. Upgrade Continuous Monitoring Equipment (Digital Conductivity Meters)

Integrated Approach Scope of Work - Task 1

Scope of Work & Tasks - D.B. Stephens

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- 7. Drill and Complete New Recovery and Monitor Wells Optimize Groundwater Recovery System

Physical Assessment of Site Wells

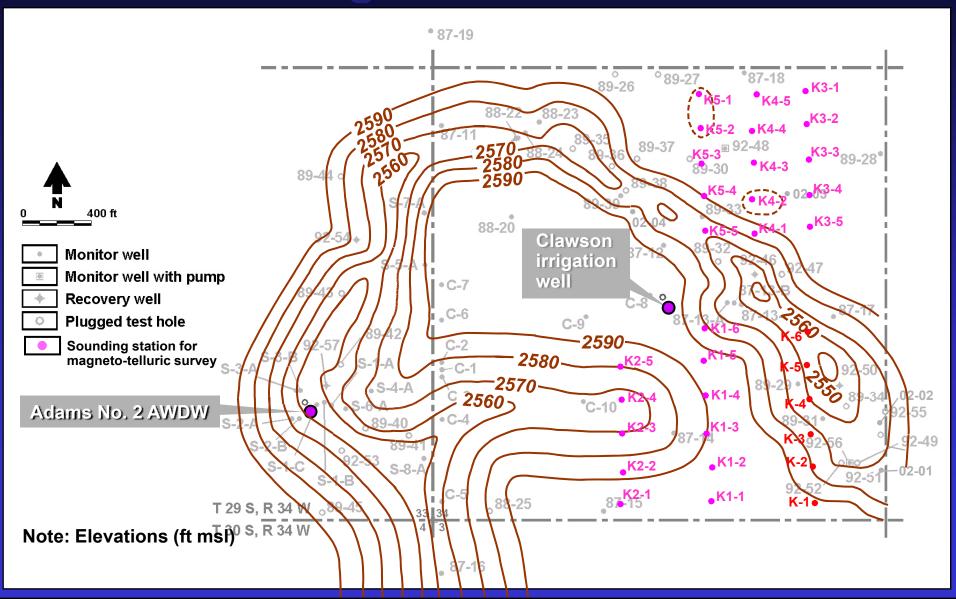
- >52 Wells were identified in the field
 - 4 Extraction wells
 - 48 Monitor wells
 - 23 Monitor wells plugged and abandoned:
 - Small diameter (not functional)
 - Obstruction (not functional)

Integrated Approach Scope of Work - Task 2

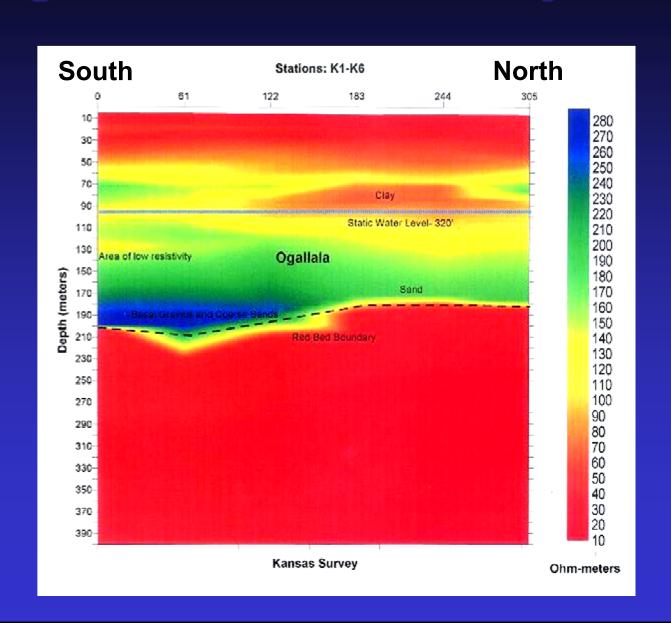
Scope of Work & Tasks - D.B. Stephens

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- 7. Drill and Complete New Recovery and Monitor Wells Optimize Groundwater Recovery System

Top of Blanco Formation with Sounding Station Locations



Magneto-Telluric Survey Line



Integrated Approach Scope of Work - Task 3

Scope of Work & Tasks - D.B. Stephens

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Aqueous Geochemistry of Aquifer Waters and Brine

Well Name	pН	Ca	Mg	Cl	SO ⁴	Na	TDS	Specific Cond.	HCO ³	SAR	Density g/cm ³
Murphy Irrigation Well NW,NW,SE, Sec 34, T29S, R34W	8.2	76	25	37	132	46	609	714	292	1.17	1.00
S. Murphy Irrigation											
Well NE, SE, NE, Sec 3, T30S, R34W	7.9	69	23	20	145	52	577	684	267	1.38	1.00
Test Hole C-1											
Dakota SS NW, SW, SW, Sec 34, T29S, R34W	7.7	49	18	27	169	77	492	506	152	2.30	1.00
Test Hole C-2 - Ogallala NW, SW,SW, Sec 34, T29S, R34W	5.2	2,040	111	26,400	154	12,500	46,756	51,050	186	73	1.033
Produced Water (avg.)	7.2	4,457	1,564	84,636	1,874	47,856	140,675	127,508	287	157	1.103
Recovery Well #02-04	7.3	172	11.9	1,170	193	525	2,306	4,250	220	10.4	1.002
Recovery Well #92-50	7.5	360	128	1,710	182	568	3,147	5,910	182	6.55	1.002

analyses in mg/L

Water Quality – Sodicity Classifications for Irrigation Water

SAR (sodium absorption ratio)	Sodicity class
Less than 4 (Background Wells 1.17-2.30)	No sodium problem
4 to 6	1. Low sodium, few problems except with sodium sensitive crops.
6 to 8 (RW Effluent 6.55-11.86)	2. Medium sodium, increasing problems.
8 to 14	3. High sodium - not generally recommended.
Greater than 14 (Produced Water 157)	4. Very high sodium - unsuitable.

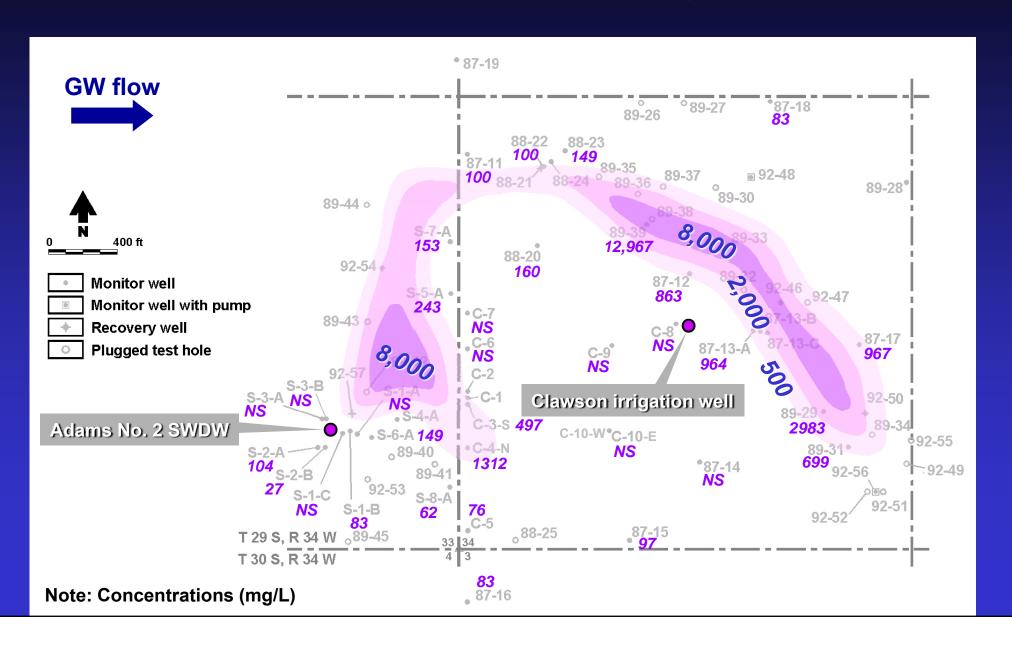
Water Quality – Chloride Classes for Irrigation Water

Chloride ion concentration	Suitability for irrigation
Less than 350 mg/L (Background Wells 20-37 mg/L)	1. Suitable all crops.
350 - 700 mg/L	2. Suitable for high, medium and low salt tolerant crops.
700 - 900 mg/L	3. Suitable for high and medium salt tolerance crops.
900 - 1300 mg/L (RW Effluent 1,170-1,710 mg/L)	4. Suitable for high salt tolerant crops only.
Greater than 1300 mg/L (Produced Water – 84,636 mg/L)	5. Too saline for irrigation of any crops.

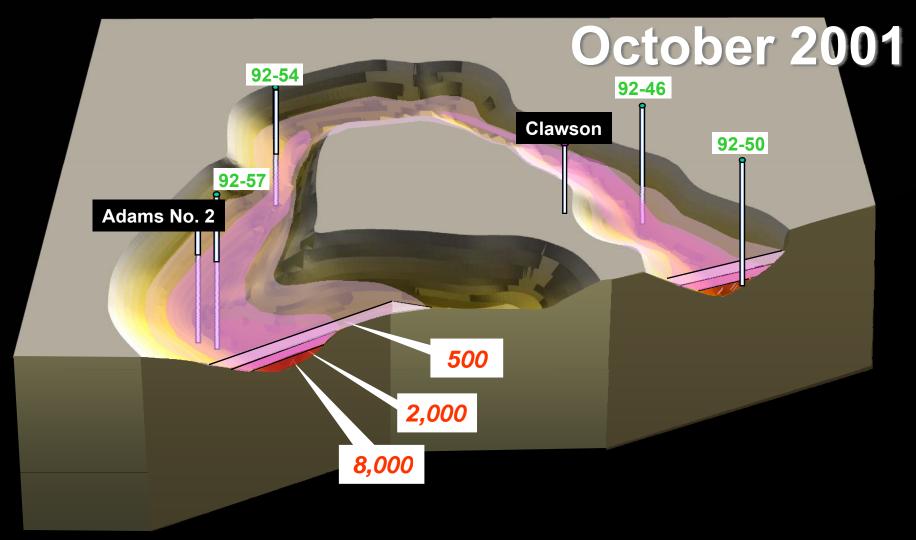
Water Quality-Salinity Classification for Irrigation Water

Conductivity	Salinity class
< 650 (Background Wells 506-714 μMhos)	1 - Low salinity water, suitable for use on all crops except tobacco, with all methods of water application, with little probability of a salinity problem developing.
650 – 1300	2 - Medium salinity, suitable for use on all but very low salt tolerance crops. Water can be used if a moderate amount of leaching occurs. Plants with medium salt tolerance can be grown, usually without special practices for salinity control. Sprinkler irrigation with the more saline waters in this group may cause leaf burn on salt-sensitive crops
1300 - 3000	3 - High salinity - suitable for use on medium and high salt tolerant crops only. Water should not be used on soils with restricted drainage. Even with adequate drainage, special management for salinity control may be required.
3000 – 5000 (RW Effluent 4250-5910 μMhos)	4 - Very high salinity - suitable for use only on high salt tolerant crops. For use soils must be permeable, free draining, and water must be applied in excess to provide considerable leaching.
5000 - 8000	5 - Extremely high salinity generally unsuitable for irrigation unless soils are permeable, well drained and crops are of very high salt tolerance.
> 8000 (PW 127,508 µMhos)	6 - Too saline for irrigation

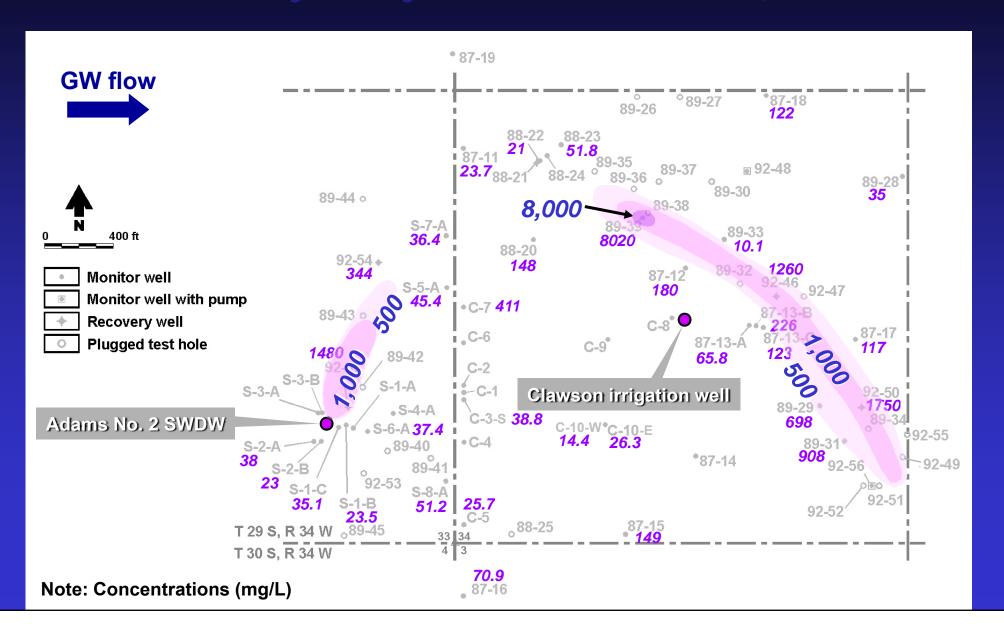
Chloride Concentrations based on Conductivity to Chloride Conversion – October, 2001



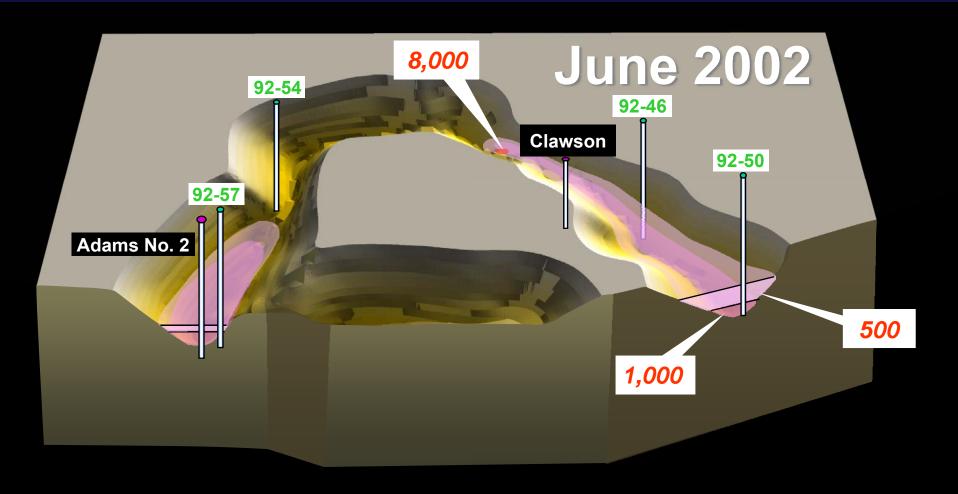
3D View of Top of Blanco Formation with Chloride Concentrations



Chloride Concentrations based on Laboratory Analytical Data - June 11, 2002



3D View of Top of Blanco Formation with Chloride Concentrations



Note: Laboratory Chloride concentrations (mg/L)

Integrated Approach Scope of Work - Task 4

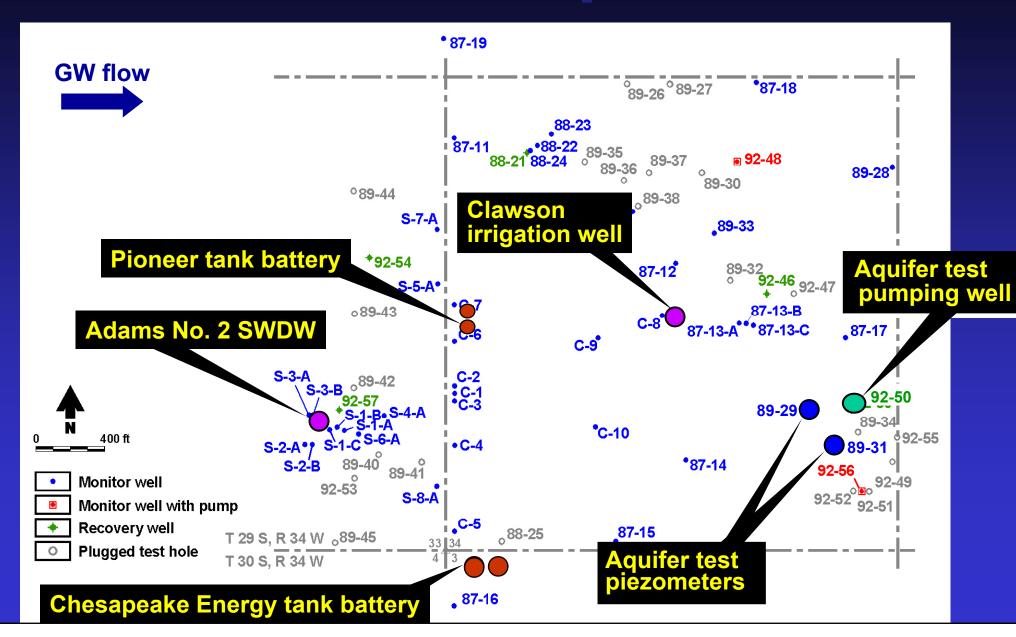
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- 7. Drill and Complete New Recovery and Monitor Wells Optimize Groundwater Recovery System

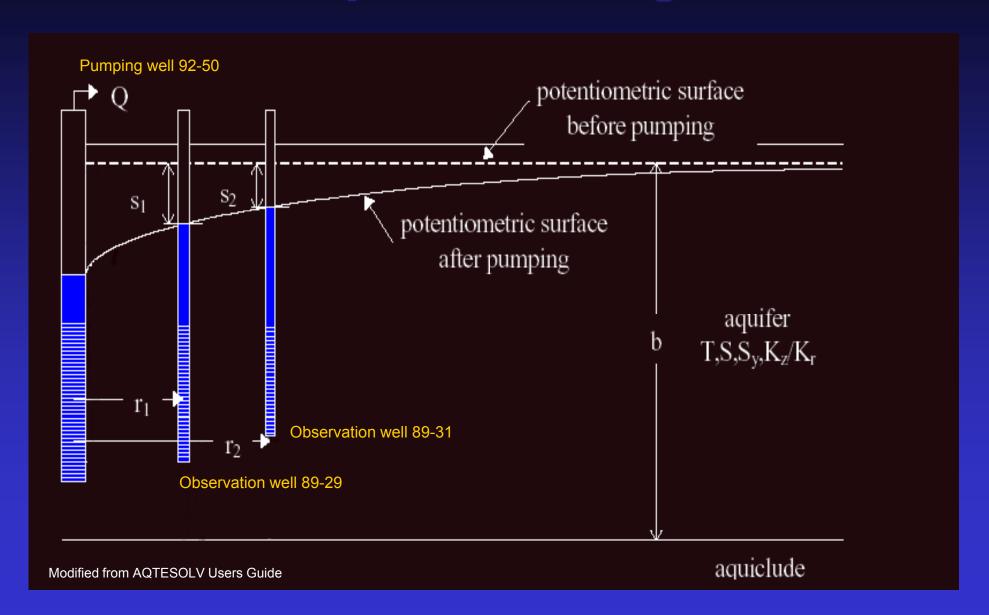
Hydrogeologic and Hydraulic Parameters Important for Aquifer Characterization, Modeling, & Cleanup

<u>Parameter</u>	Importance To Groundwater Cleanup
Hydraulic Conductivity K	Ease with which water can move through a formation and influences the rate at which groundwater can be pumped for treatment. Influences the total flow rate of the system.
Hydraulic gradient <i>∪</i>	Influences the direction of contaminant movement based upon the elevation and pressure differences.
Transmissivity T	Influences the rate at which groundwater can be pumped and, thus, influences the total flow rate of the system.
Groundwater velocity V _i	Influences the direction and velocity of dissolved contaminant movement - important when designing a containment system.
Porosity θ	Pores store water and contaminants. Influences the hydraulic conductivity and impacts the fate of the contaminants due to various physical, chemical, and biological processes that take place in the saturated zone.
Effective porosity $ heta_{ m e}$	Has an impact on the groundwater velocity.
Storage coefficient s	Influences the quantity of groundwater that can be obtained by pumping.
Specific yield s,	Fraction of total pore volume released as water by gravity drainage during pumping of an unconfined aquifer and influences the quantity of groundwater that can be obtained by pumping.

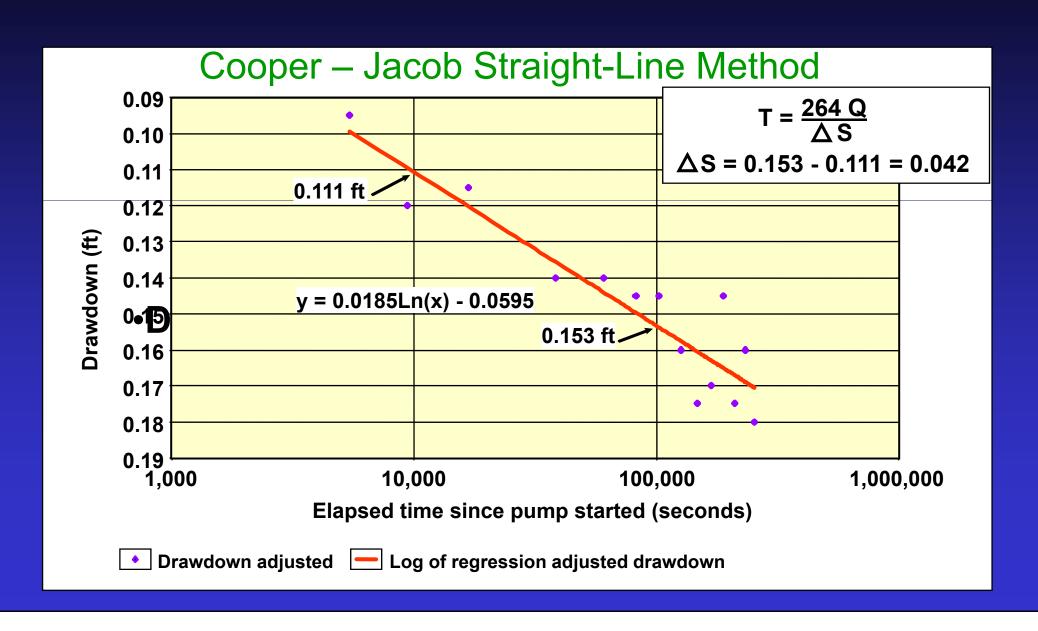
Site Map



Aquifer Testing



Drawdown vs. Time Since Pump Started and Trend Line for Monitor Well 89-31



Clawson - Aquifer Test Data

Recovery test data analysis

$$T = 264 Q$$
 Δs Δs $T - Determined from Pump Test$

T = Transmissivity (gallons/day/feet or gal/day/ft)

Q = Well discharge (gallons/minute or gpm) =31.806gpm (120.39 L/sec)

 Δs = Delta residual drawdown per time log cycle (feet or ft)

 $\Delta s' = 0.040ft$; 92-50 Pumping well (Note: s' is residual drawdown once pumping stopped)

 $\Delta s = 0.043ft; 89-29 Observation well$

 $\Delta s = 0.042ft$; 89-31 Observation well

b = Saturated thickness = 97.1 feet

Ogallala Aquifer Parameters Derived From Clawson Site Pump Test

- ➤ K Hydraulic Conductivity = 278 ft/day
- ➤ T Transmissivity = 26,726 ft² /day
- b Saturated Thickness = 97.1 ft
- Groundwater Velocity = 2.5 ft/day

Integrated Approach Scope of Work - Task 5

Scope of Work & Tasks - D.B. Stephens

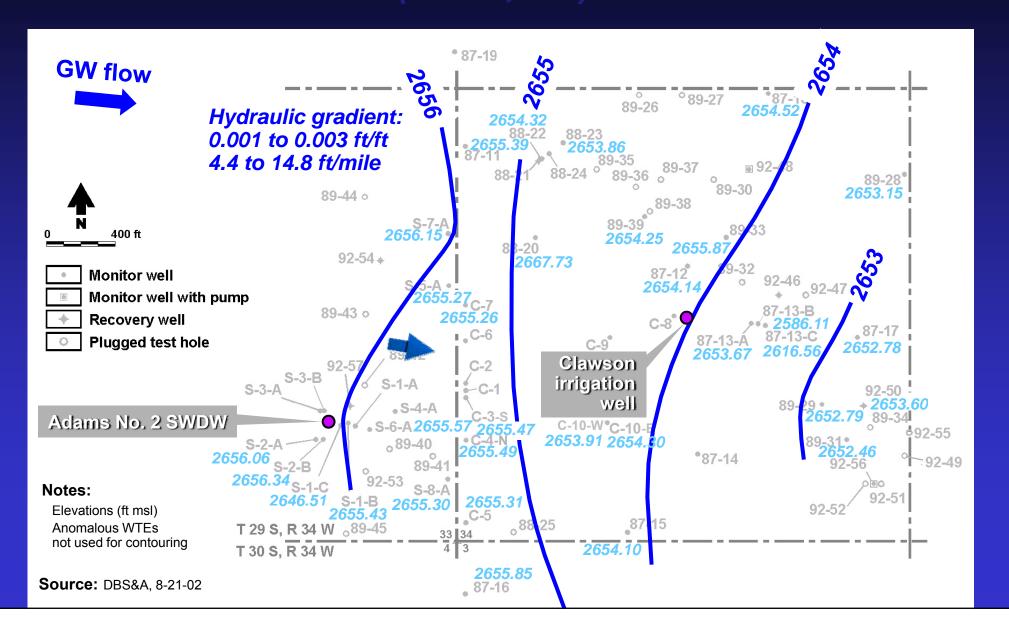
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USEPA – Wellhead Protection Area (WHPA) Model (Blandford & others)

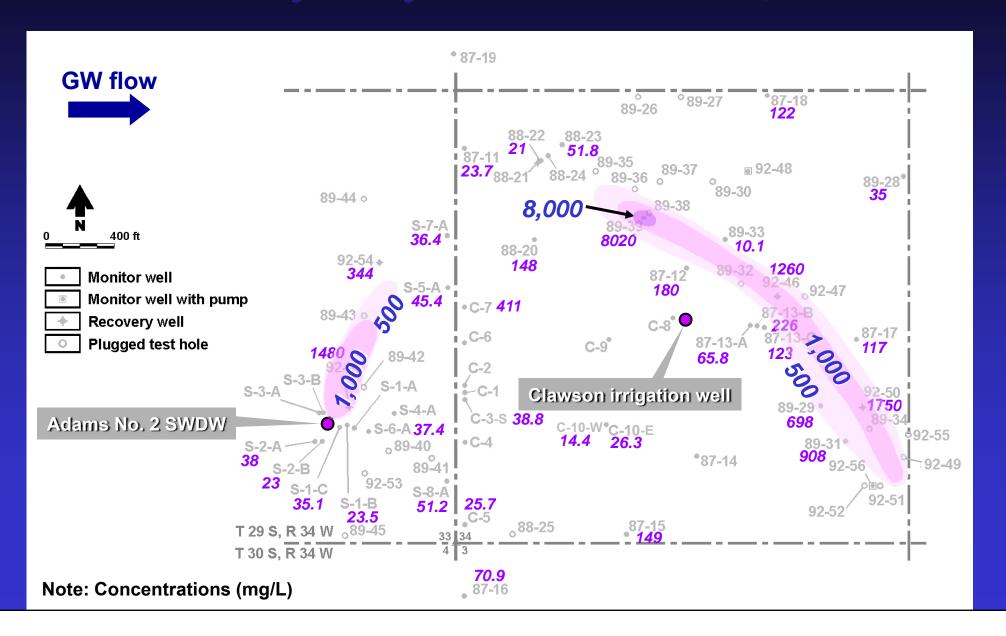
- **≻**RESSQC
- **MWCAP**
- > GPTRAC
 - Semi-analytical Option: Delineates time-related capture zones for pumping wells in homogeneous aquifers with steady and uniform ambient ground-water flow
- **MONTEC**

Water Table Elevations

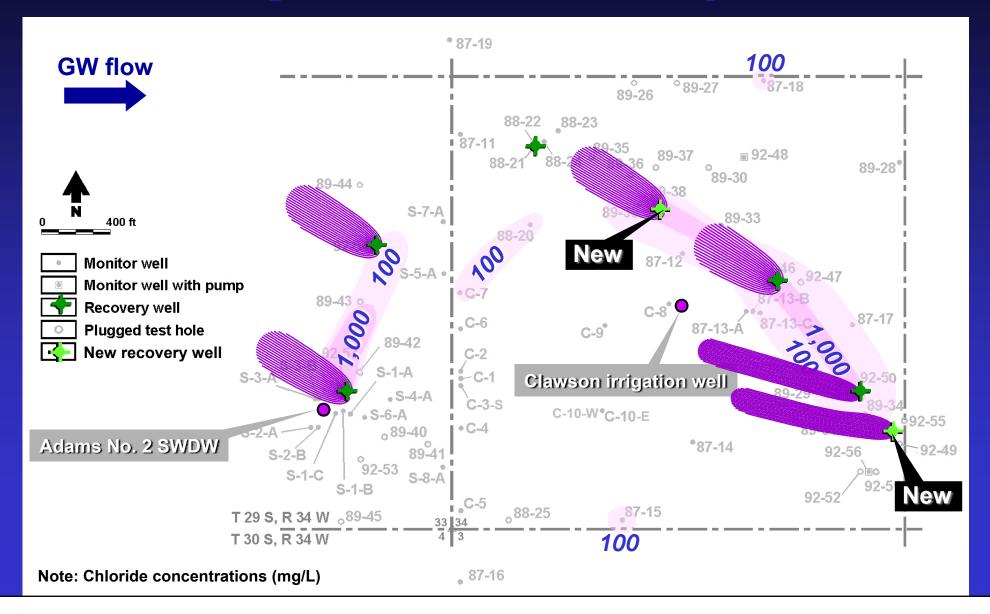
(June 24, 2002)



Chloride Concentrations based on Laboratory Analytical Data - June 11, 2002



Simulated Capture Zones for Existing and New Recovery Wells





Monitor Well #89-39

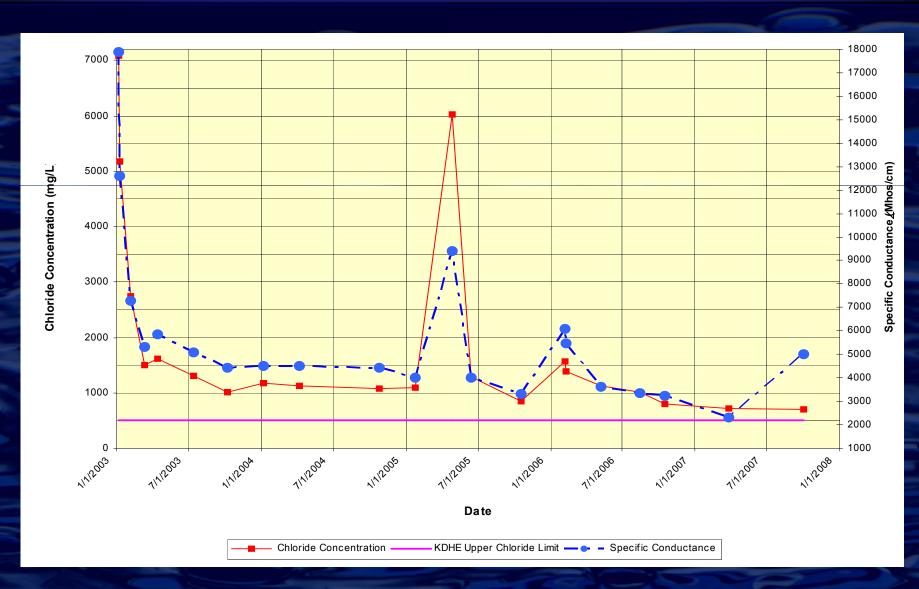




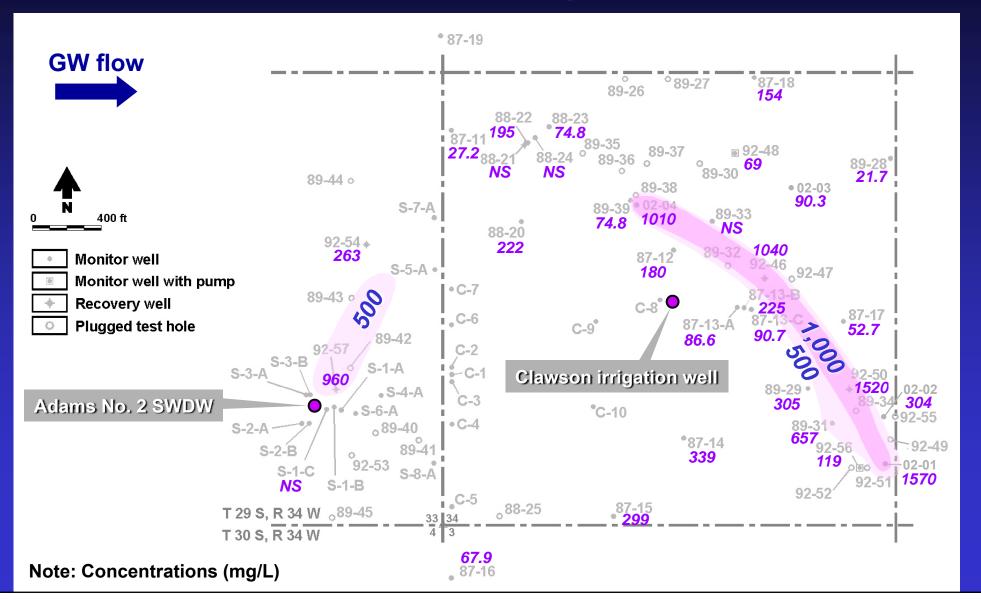


Recovery Well #02-04

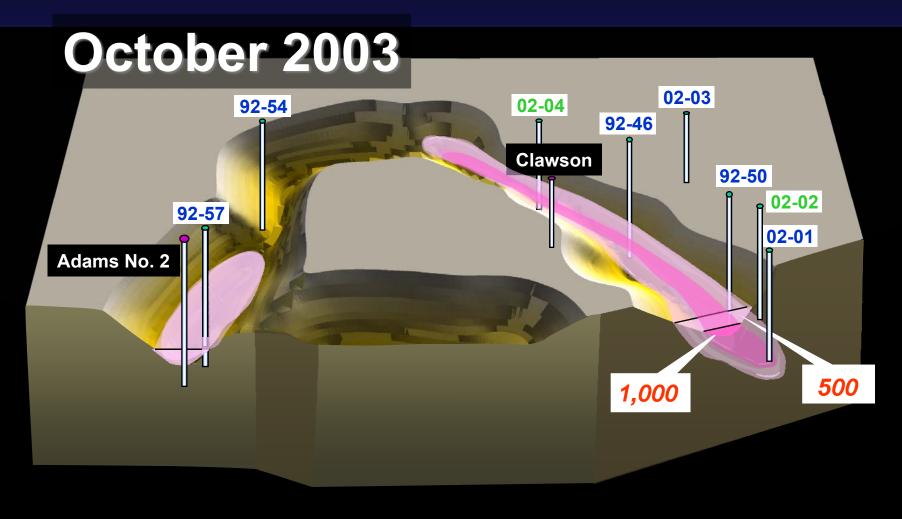




Chloride Concentrations October 8-24, 2003



3D View of Top of Blanco Formation with Chloride Concentrations

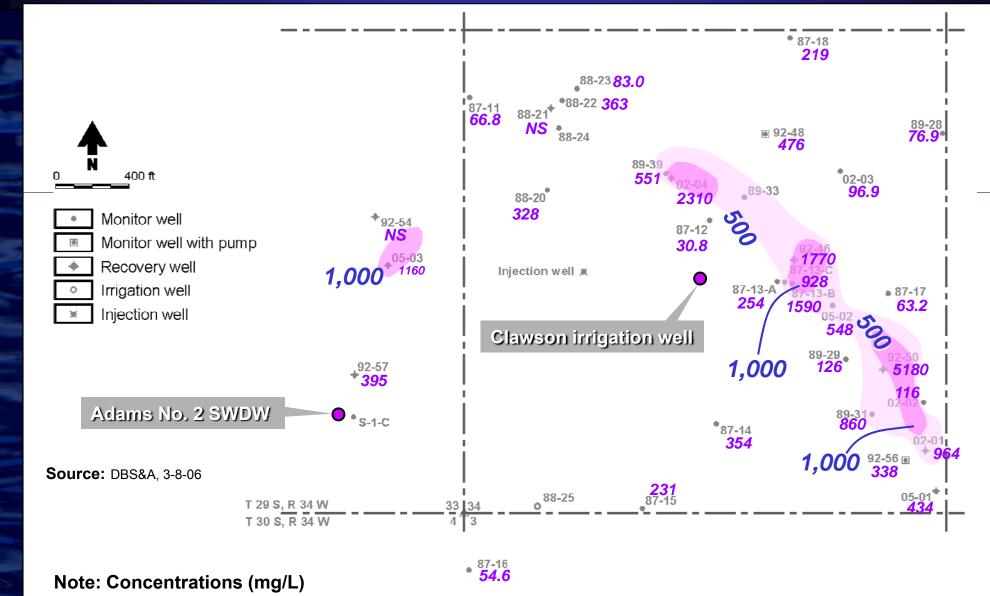


Note: Chloride concentrations (mg/L)



Chloride Concentrations based on Laboratory Analytical Data – March 27-28, 2007

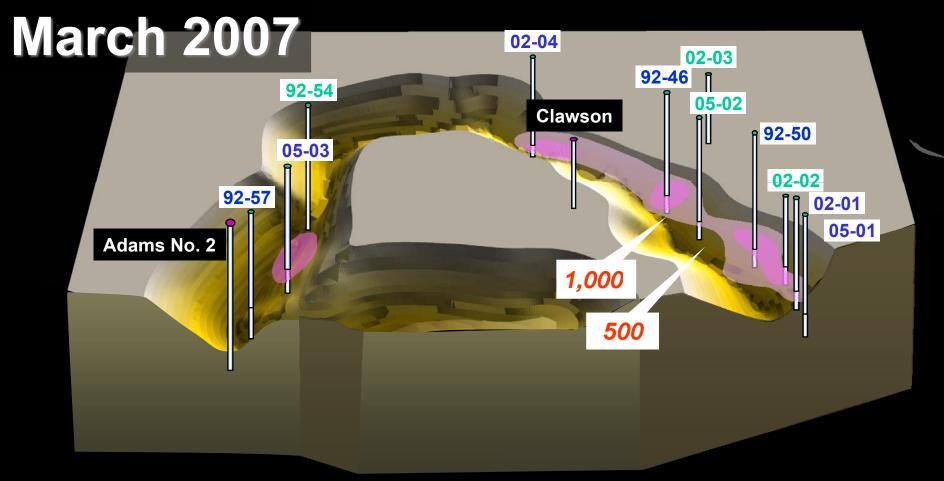






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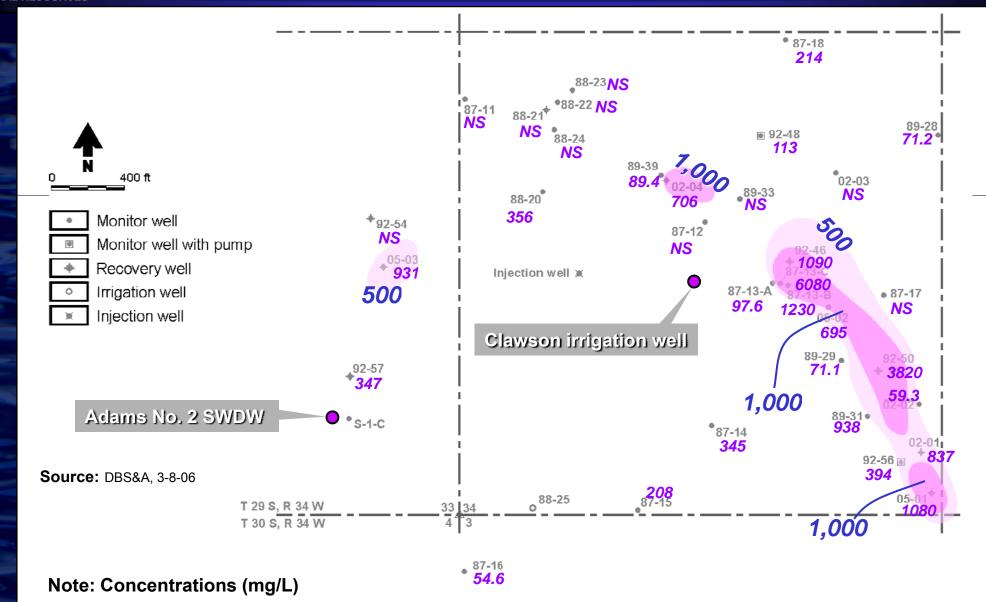


Note: Chloride concentrations (mg/L)



Chloride Concentrations based on Laboratory Analytical Data – October 3-4 & 10, 2007

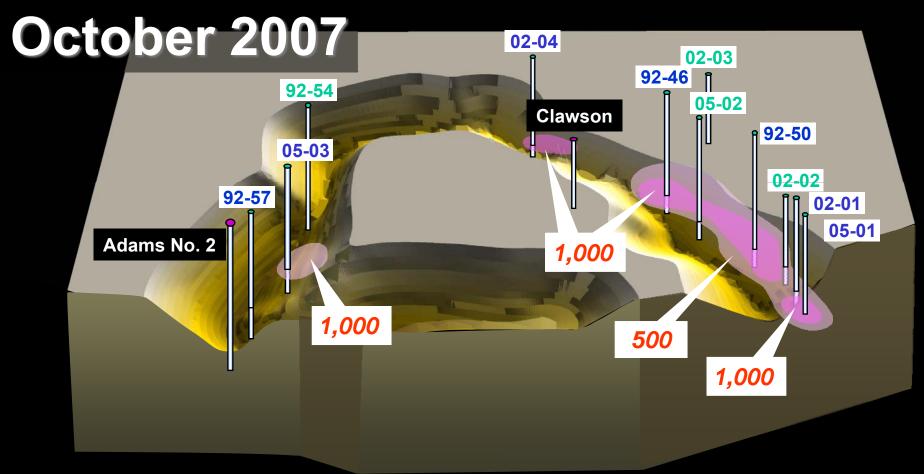






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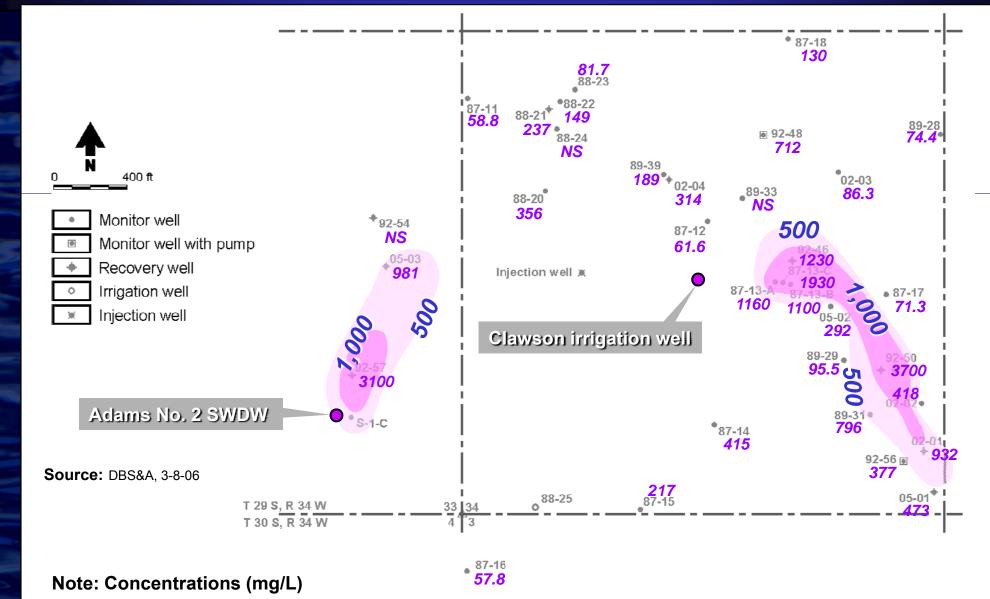


Note: Chloride concentrations (mg/L)



Chloride Concentrations based on Laboratory Analytical Data – March 5-6 & 20, 2008





Results & Conclusions

- Optimization of Remediation Design Resulting In
 - ► More Efficient Plume Capture
 - ► Increased Flexibility in Remediation System
 - ► More Efficient Monitoring Program
 - Quicker Cleanup Time Time to Closure
 - = \$ Saving to Pioneer

References

AMEC (A Managerial and Engineering Company), Site evaluation proposal and work plan: Web (http://www.amec.com).

AQTESOLV (Aquifer Test Analysis Software), Users Guide: Web (http://www.aqtesolv.com).

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