BESST INC. GLOBAL SUBSURFACE TECHNOLOGIES

INTERA GEOSCIENCE & ENGINEERING SOLUTIONS

TRACKING THE SOURCES OF GROUNDWATER THROUGH WELL PROFILING

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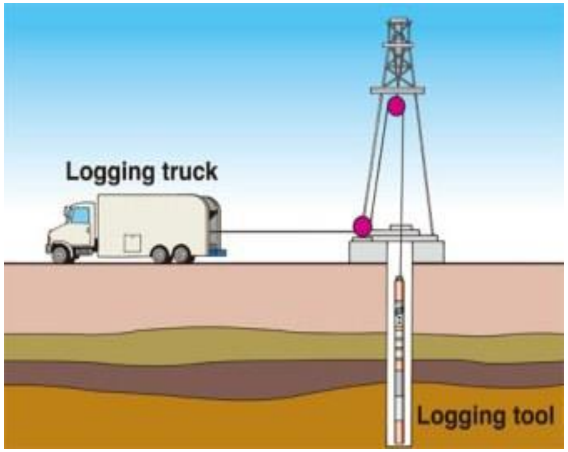
Well Profiling

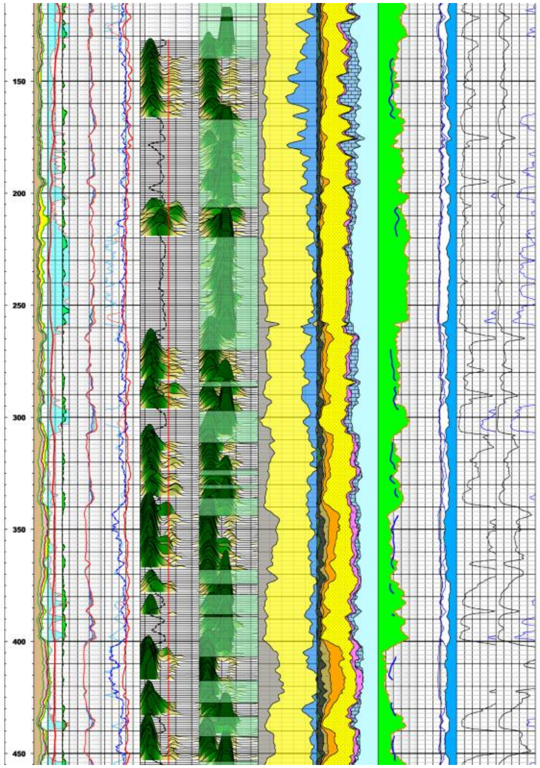
- Introduction
- Potential Benefits
- How to
- Results

Borehole Profiling Using Geophysical Logs

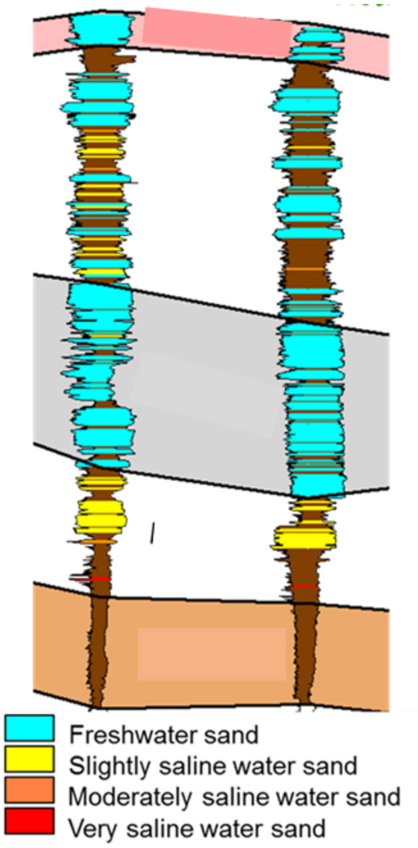
Borehole logging



Geophysical logs
(resistivity, gamma, neutron, spontaneous, magnetic)

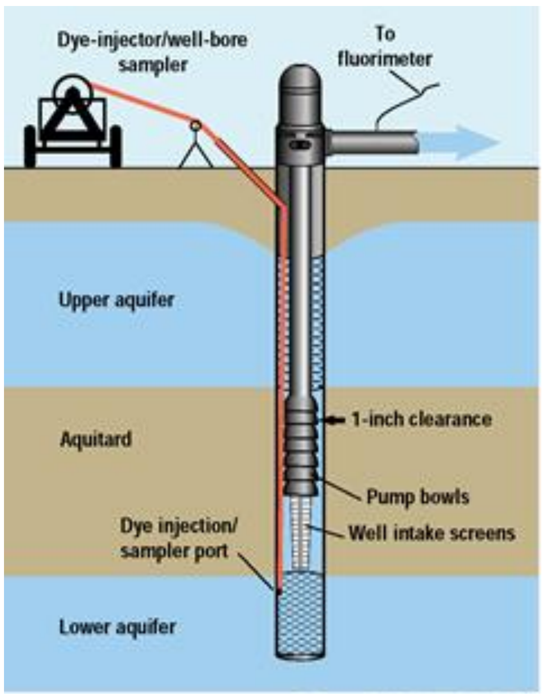


Analysis
(sands, clays, water quality)



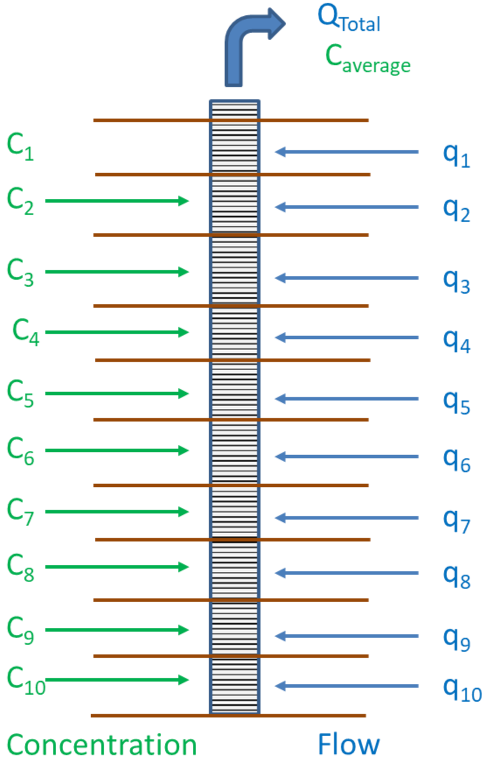
Well Profiling Using Tracer Pulse and Microsampling Technology

Well logging

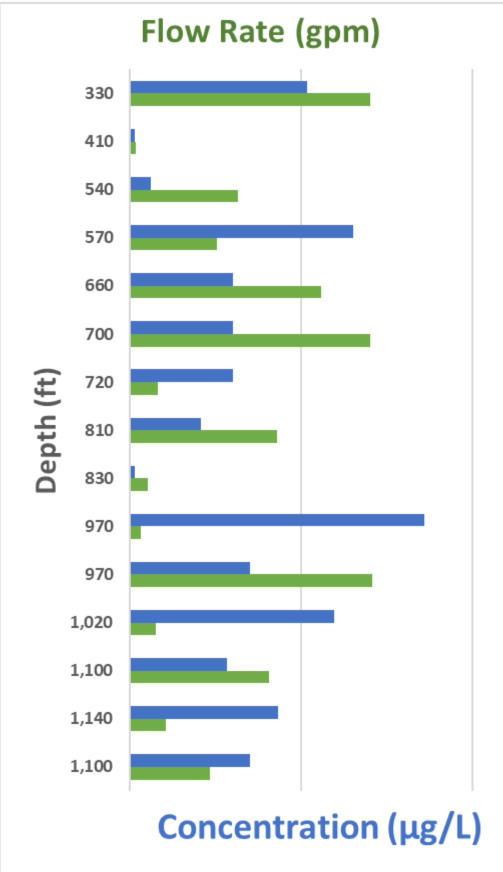


From USGS, FS 196-99

Cumulative Flow Rates and Composite Water Samples



Analysis (Flow rates and water quality by zones)

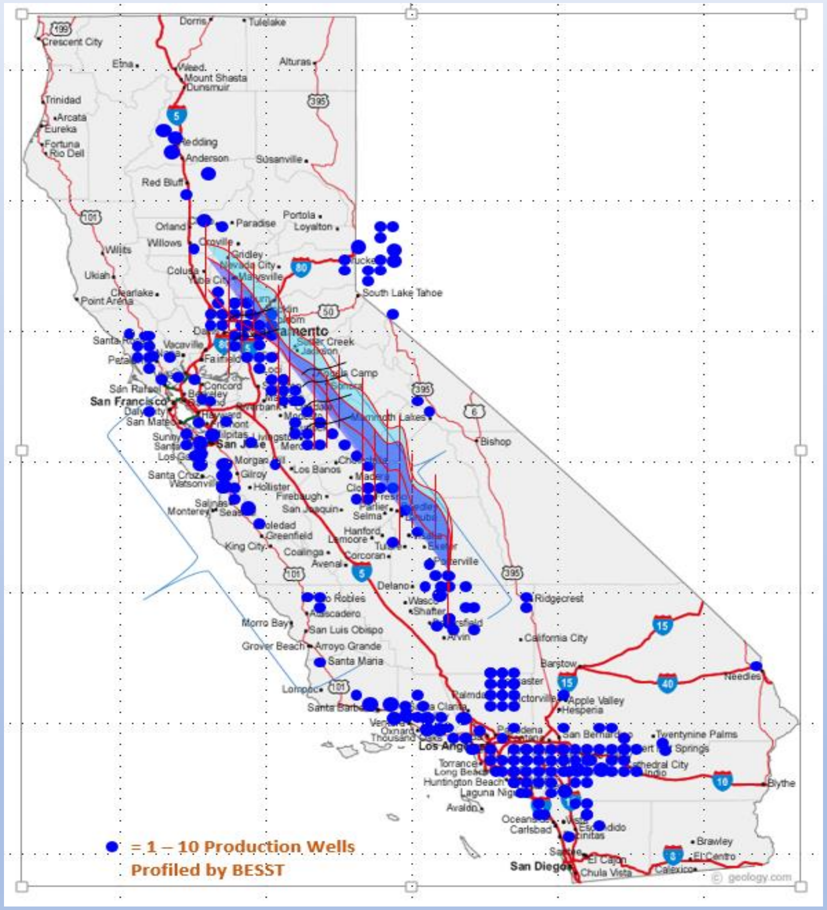


INTERA GEOSCIENCE & ENGINEERING SOLUTIONS

Reasons for Well Profiling

- Treatment Avoidance at Existing Wells
  - identify zones where “bad” water exists
  - modify well to block or reduce entry of “bad” water

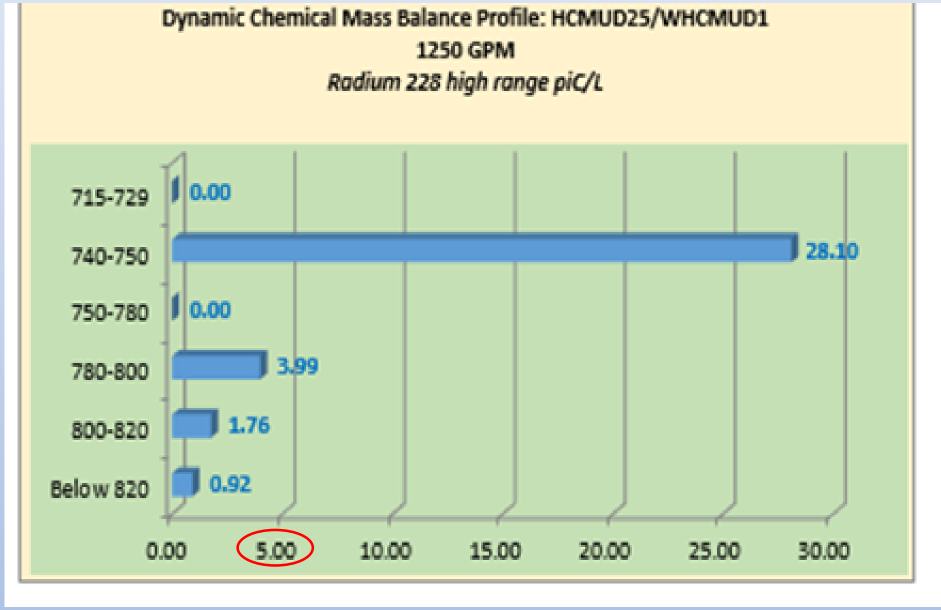
- Optimal Design for Future Wells
  - well construction specifications to avoid pumping “bad” water
  - depth to base of fresh water



Approximately 800 Wells have been Profiled by BESST in California

Reasons for Well Profiling

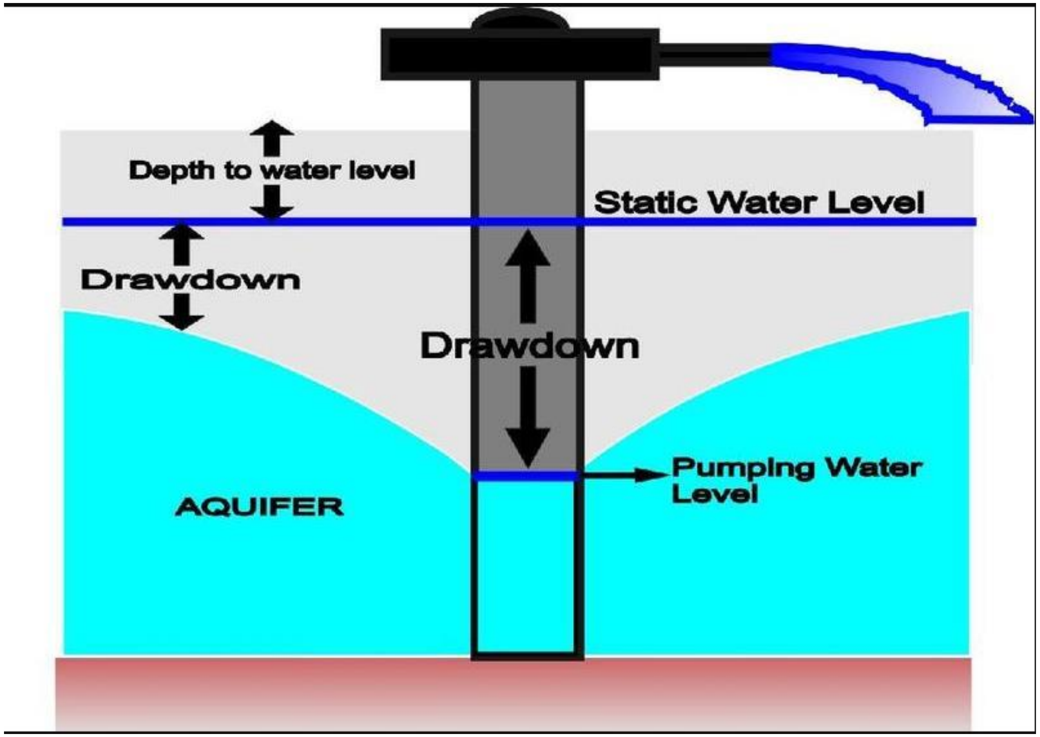
- Determine Potential for Comingling of different water qualities
  - Vertical flows in unpumped wells between zones in long well screens
  - Range in TDS concentrations
  - Locations highs for rads, arsenic, iron
- Understand Aquifer Flow System
  - Groundwater availability
  - Well field design

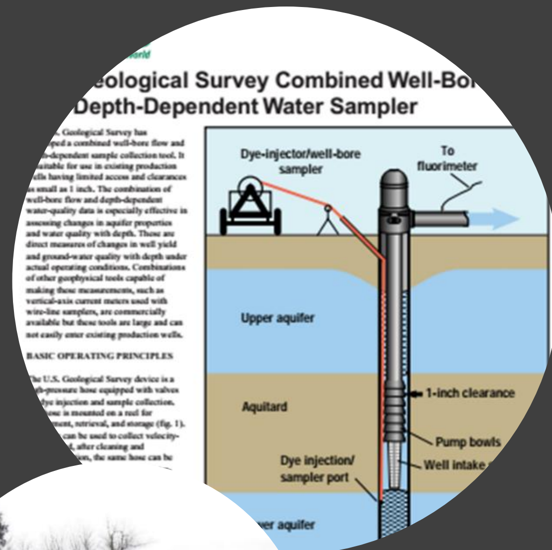


Flow Profile for Houston Well
Radium Standard (5 piC/L)

Method & Equipment

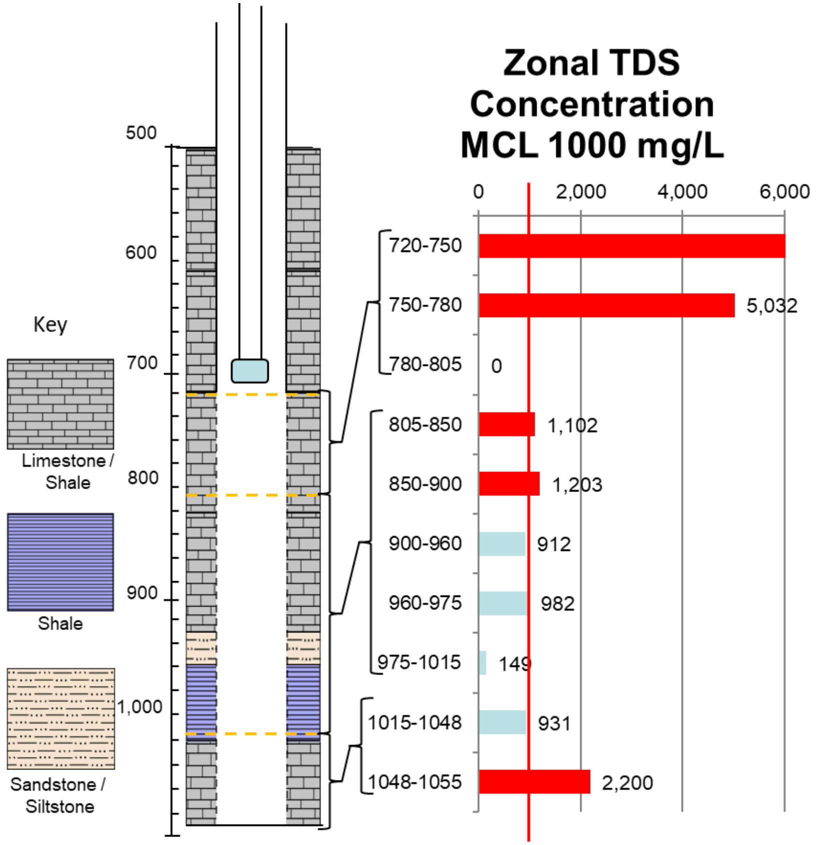
Tracking Groundwater Flow Under Dynamic Steady State Pumping Conditions





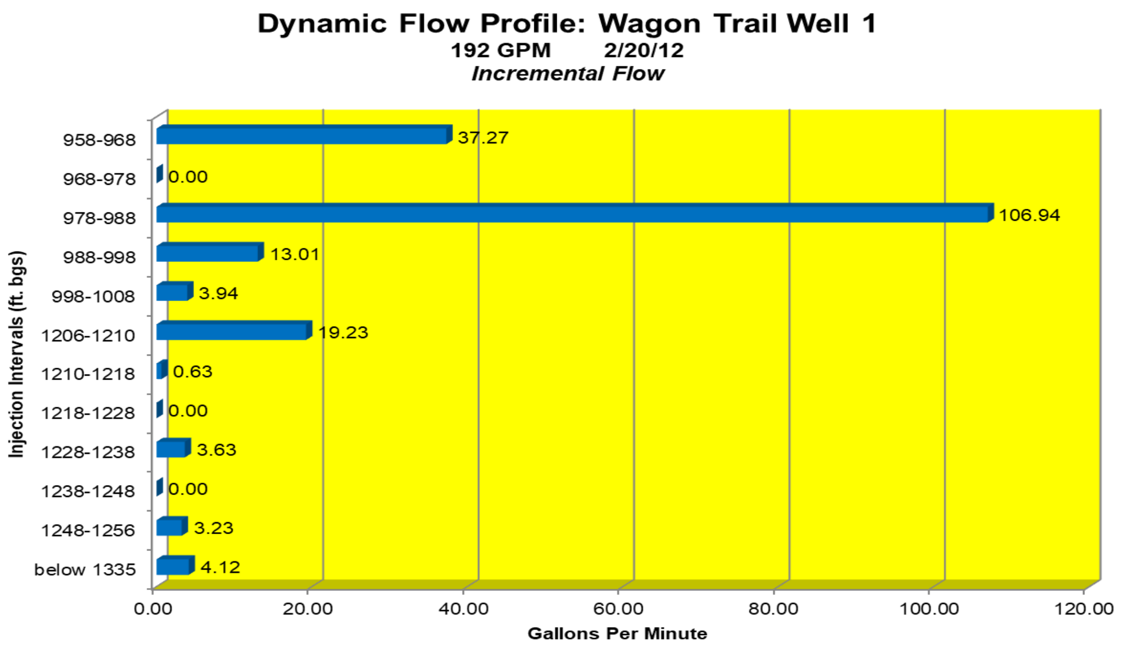
- **Tracer Pulse Flowmeter Test**
- **1. Highly detailed, accurate flow and chemistry profile.**
- **2. Very sensitive to detecting small zonal flow.**
- **3. Low overall cost.**
- **4. Groundwater supply well as a "monitoring well".**

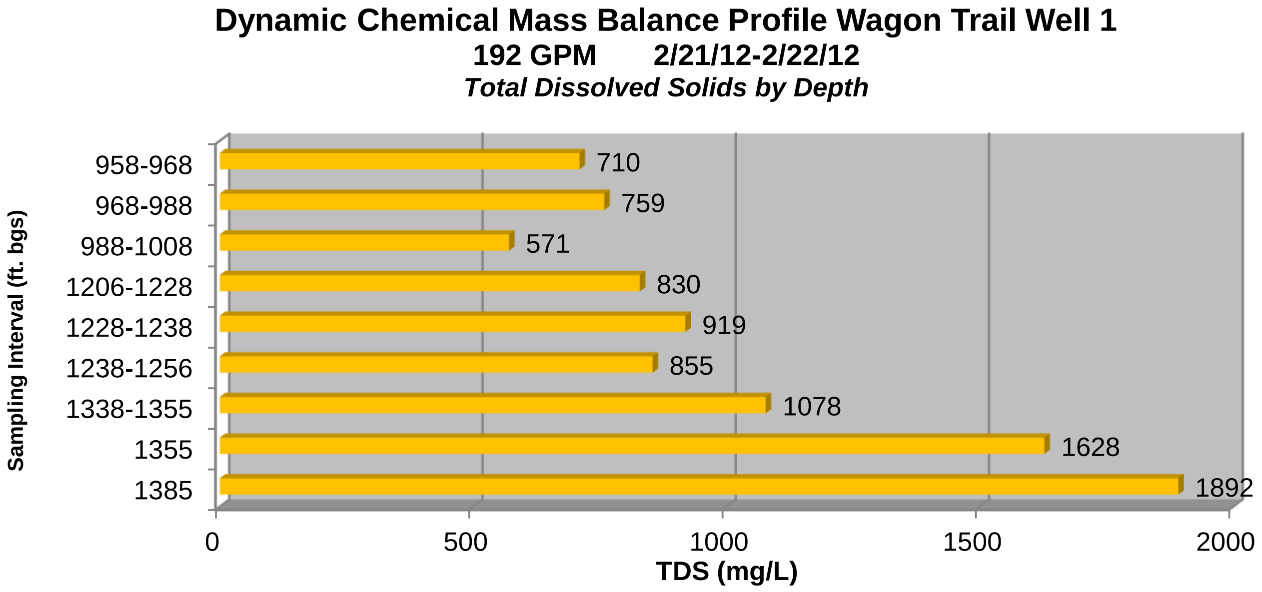
Trinity Aquifer



Sample Depth	Interval	Incremental Flow (Q1-Q2)
Sample	Ft BGS	GPM
715	720-750	0.5
750	750-780	0.1
785	780-805	0.1
805	805-850	4.0
850	850-900	2.6
900	900-960	36.2
960	960-975	32.3
975	975-1015	15.0
1015	1015-1048	11.7
1048	1048-1055	0.2

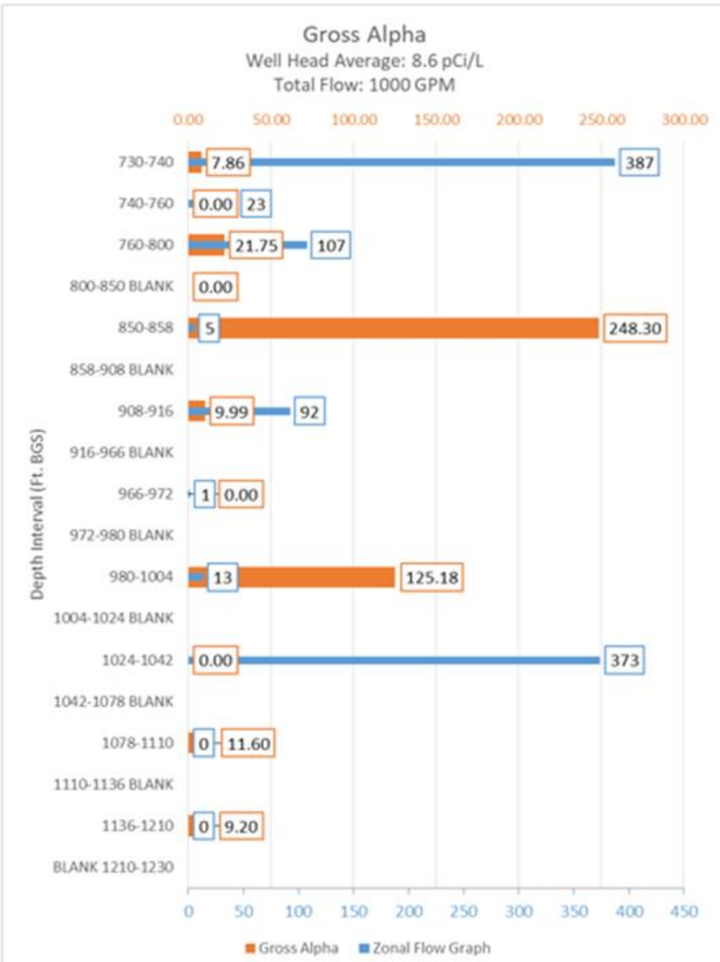
Trinity Aquifer



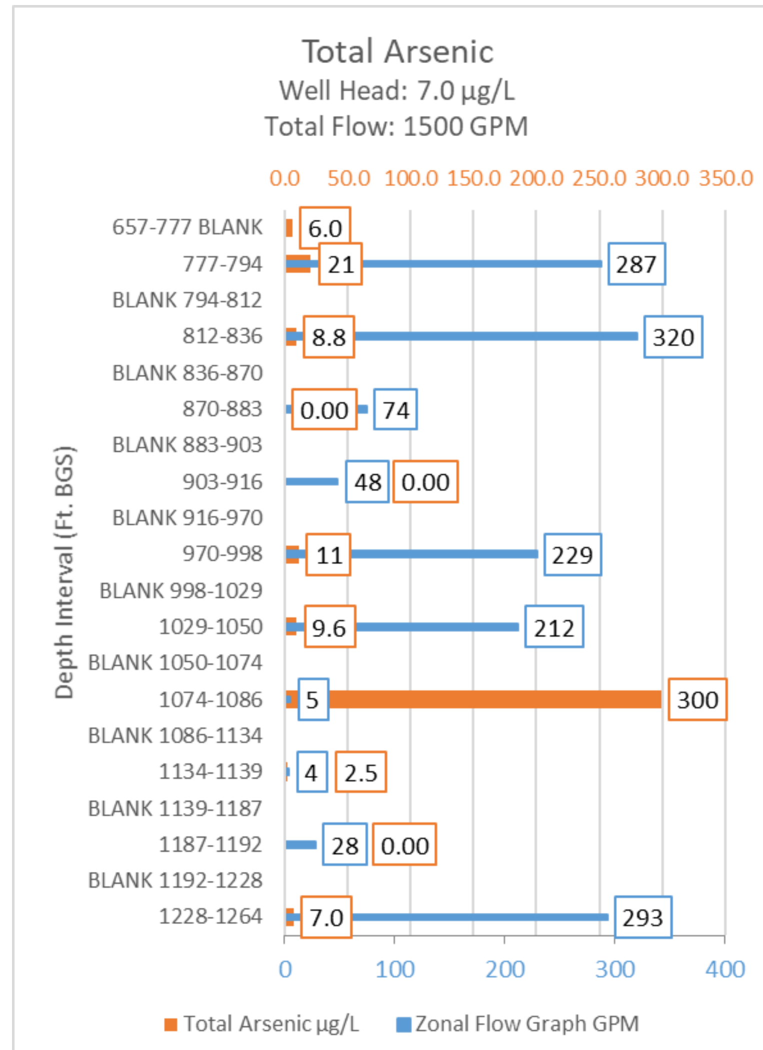


Gulf Coast Aquifer

Houston Well Morton Road MUD
Gross Alpha

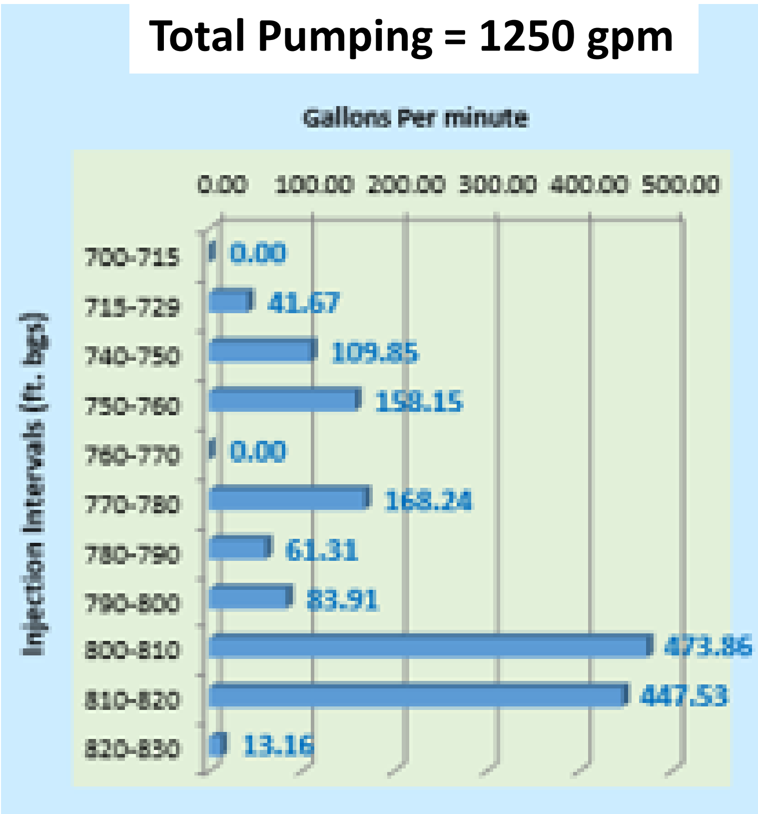


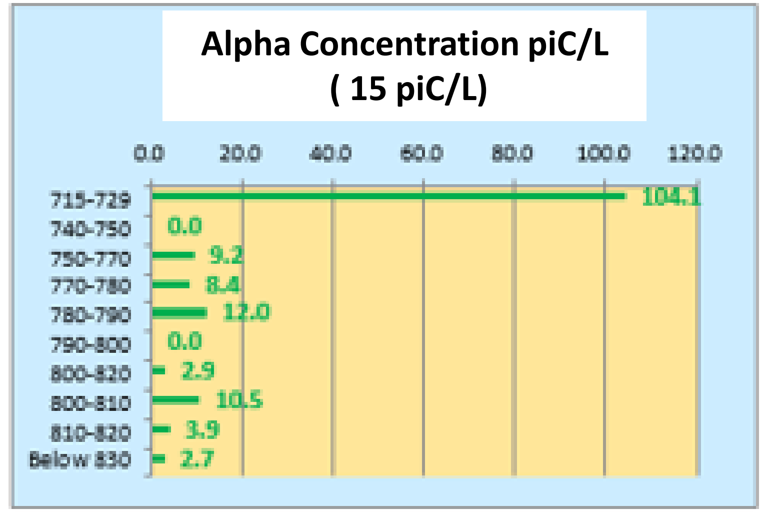
MUD # 81, Well #4
Arsenic

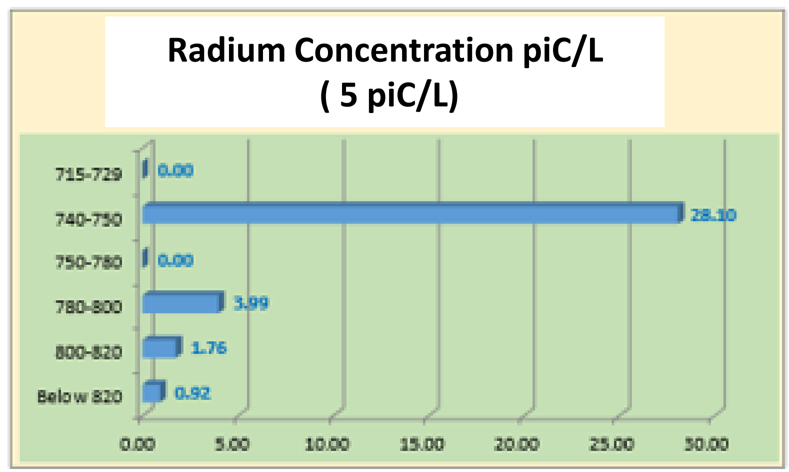


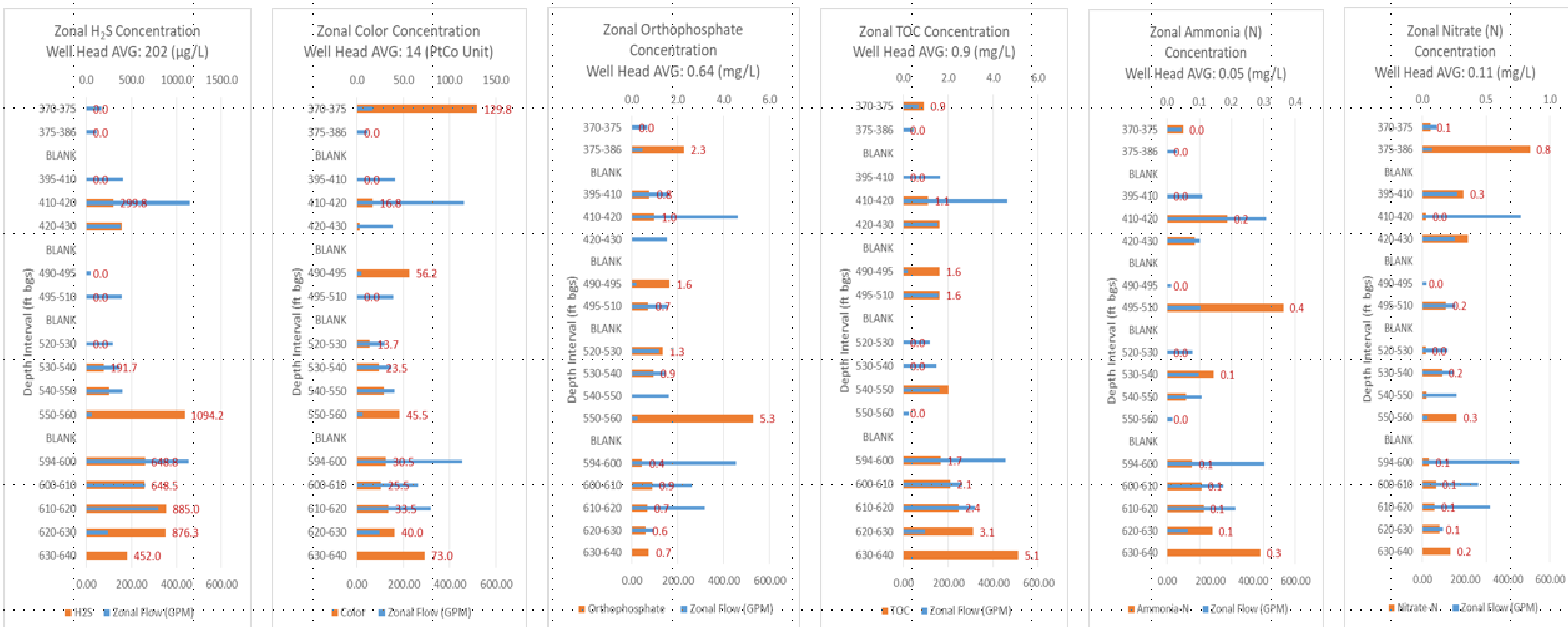
Gulf Coast Aquifer

Houston Well MUD 9



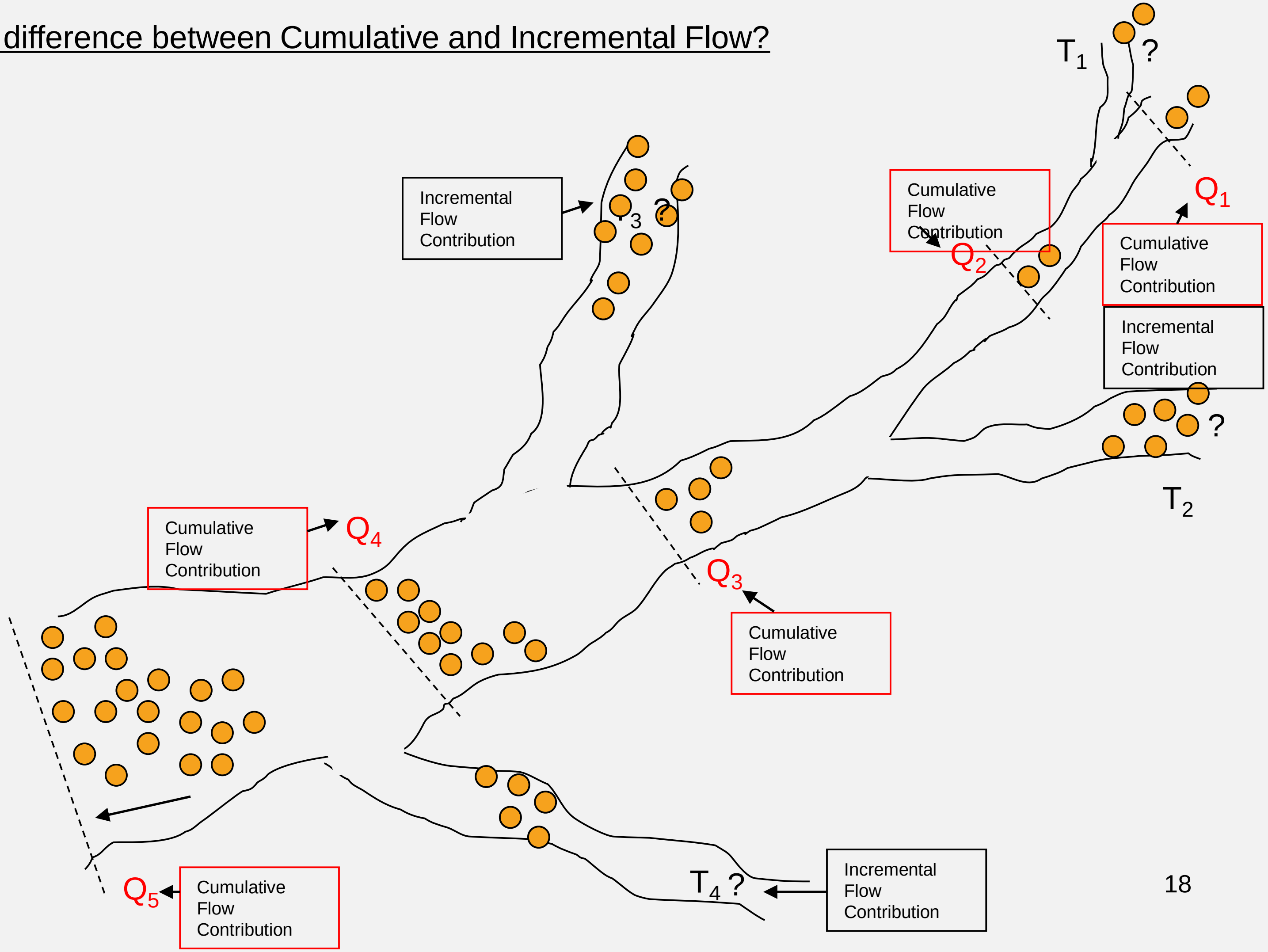






ZONAL SOURCES OF GROUNDWATER MEASURED UNDER PUMPING CONDITIONS

What is the difference between Cumulative and Incremental Flow?



HOW IT WORKS

Basic Idea

Velocity Measurement

Cumulative Flow

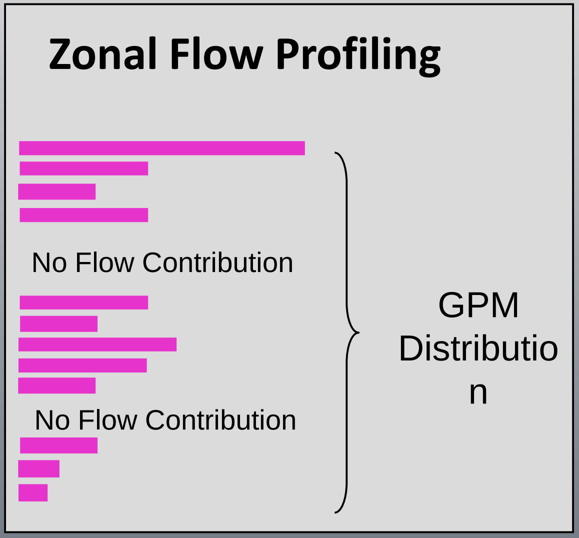
$Q_1 = V_1 \times A_1$

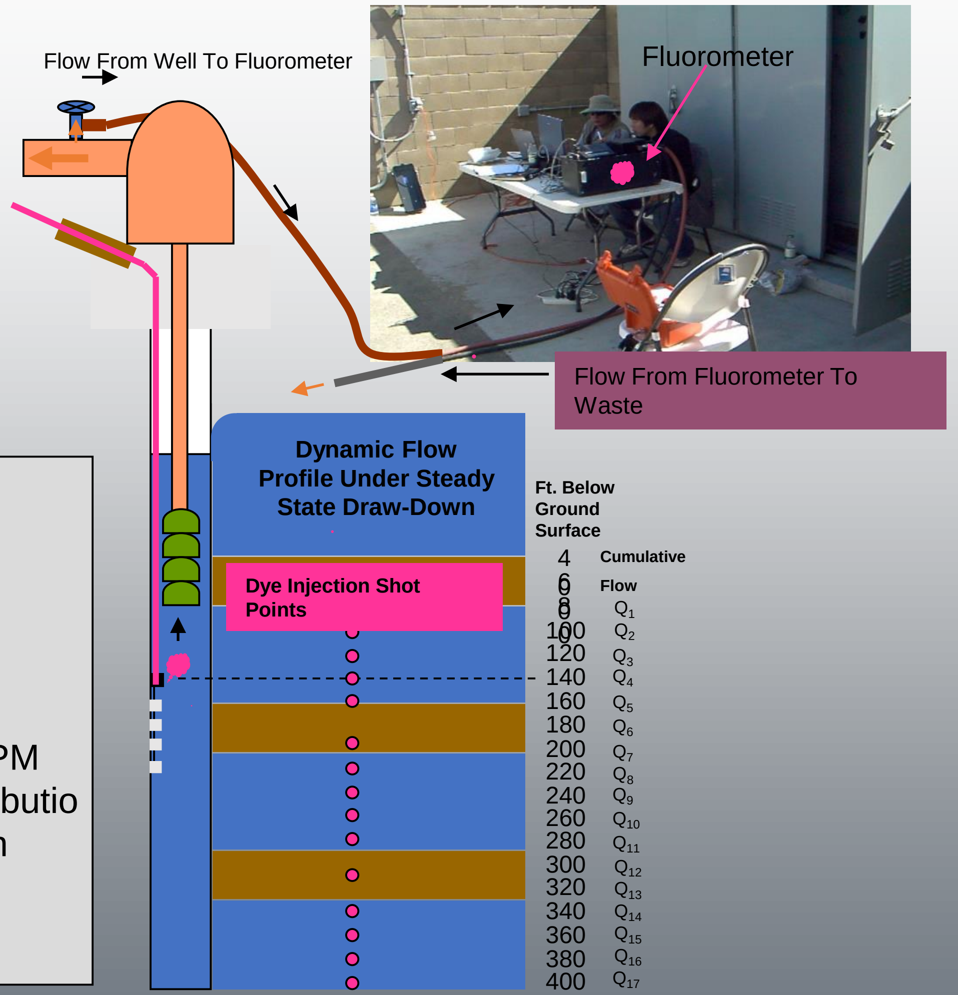
$V_1 = (d_1-d_2)/(t_1-t_2)$

$A1 = \pi r^2$

Zonal Flow

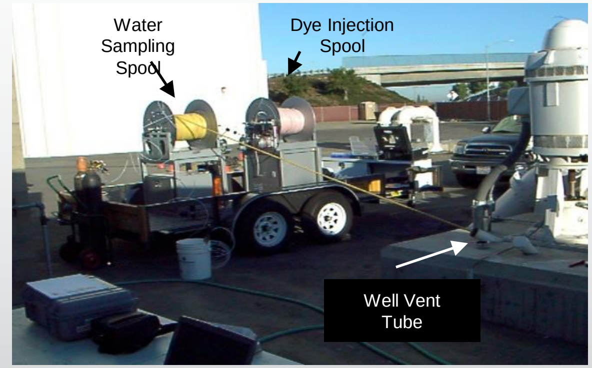
$Q_1 - Q_2$





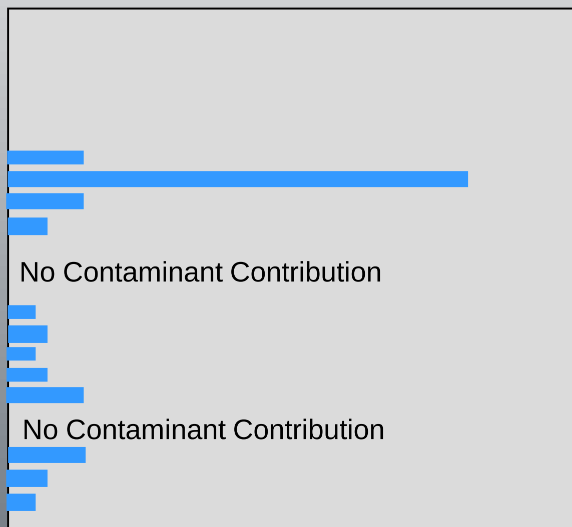
Zonal Water Chemistry Calculation

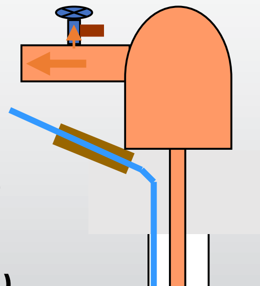
Basic Idea

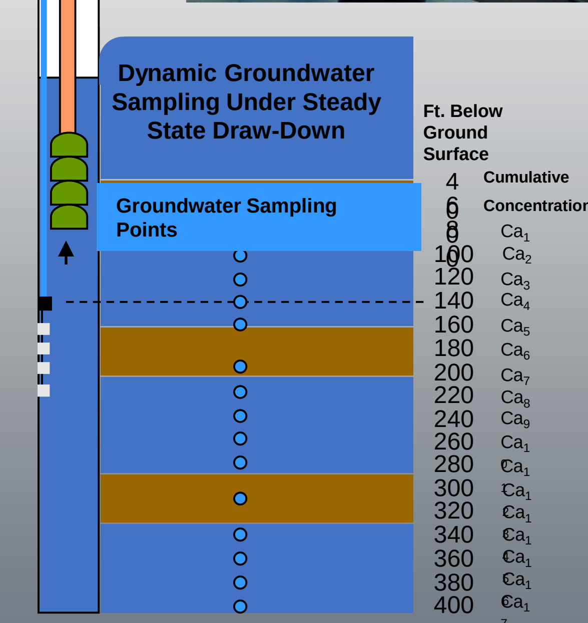


Zonal Mass Balance

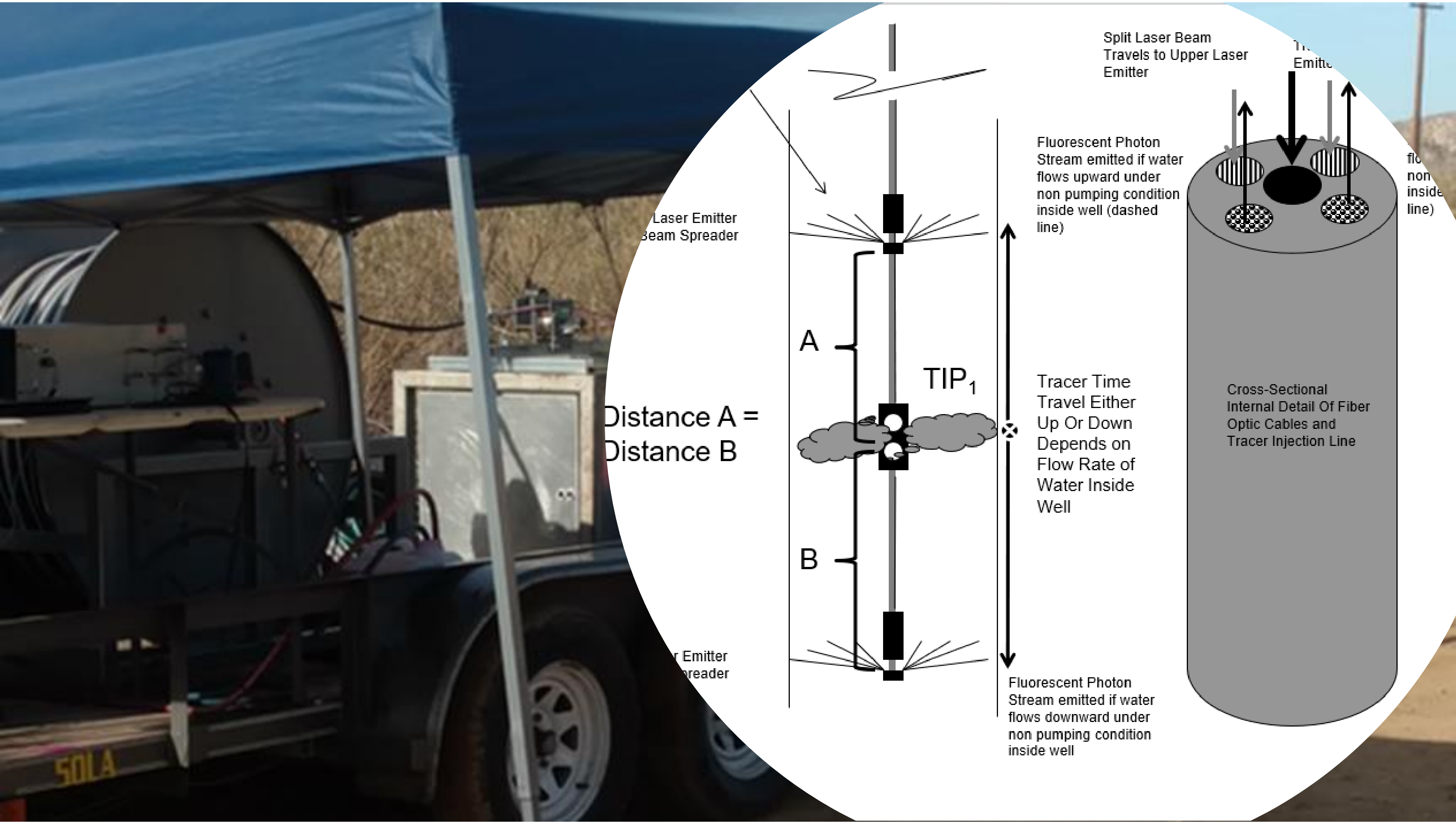
$$Ca_1 = (Q_1C_1 - Q_2C_2)/(Q_1-Q_2)$$



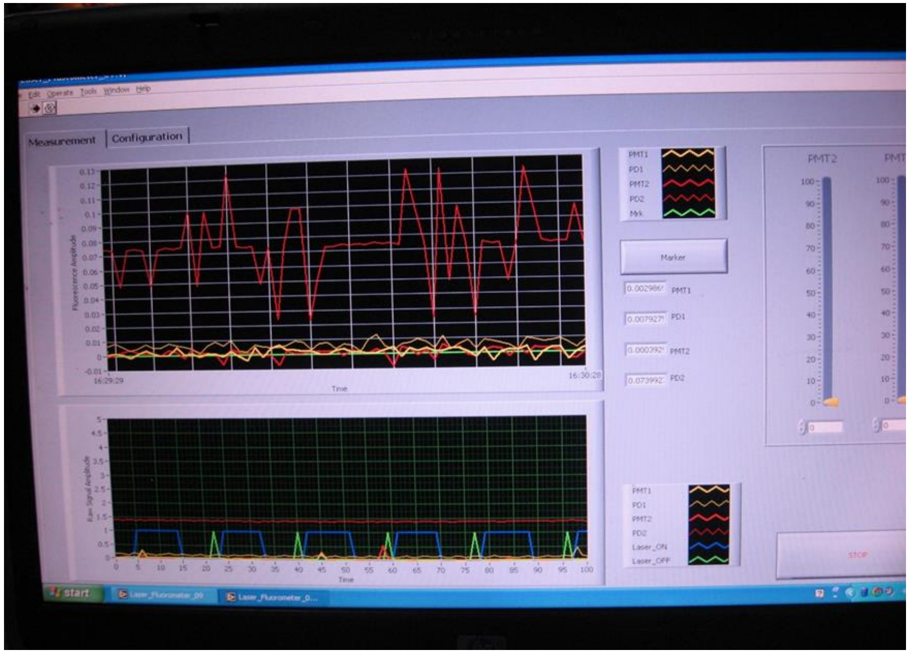




Tracking Groundwater Flow Under Ambient Steady State Pumping Conditions



SOLA
Split Laser Beam
Travels to Upper Laser
Emitter
Fluorescent Photon
Stream emitted if water
flows upward under
non pumping condition
inside well (dashed
line)
Laser Emitter
A
TIP$_1$
Tracer Time
Travel Either
Up Or Down
Depends on
Flow Rate of
Water Inside
Well
B
Emitter
Fluorescent Photon
Stream emitted if water
flows downward under
non pumping condition
inside well
Cross-Sectional
Internal Detail Of Fiber
Optic Cables and
Tracer Injection Line


Measurement
Configuration
PMT1
PD1
PMT2
PD2
Marker
PMT2
Time
start

Typical Profile Signatures for Iron and Uranium?

Highly Localized / Stratified Assymetrically

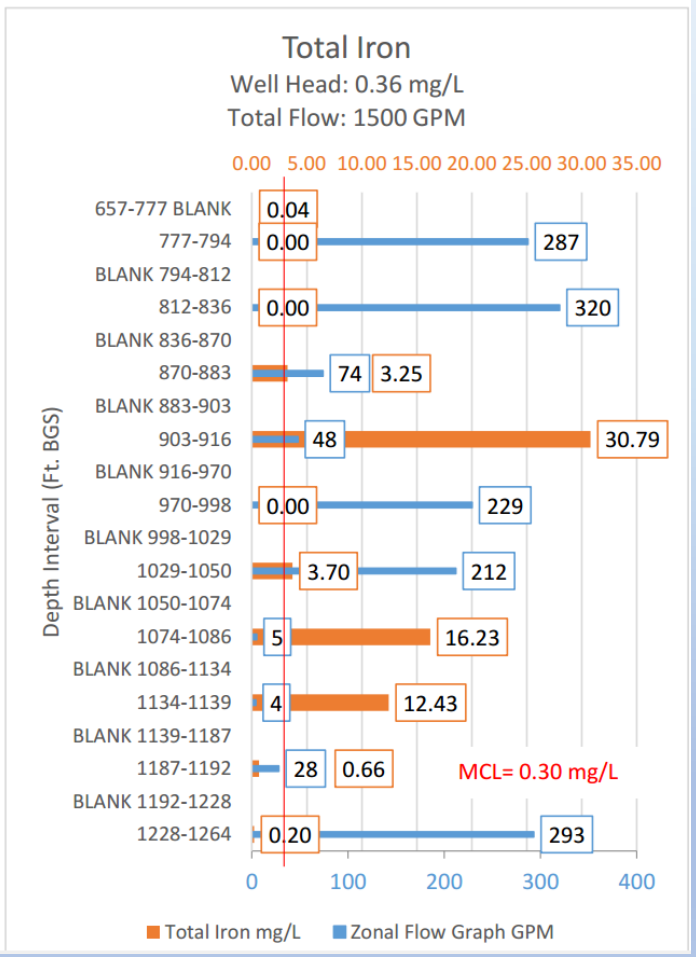
Iron Located at Permeability Barriers

Uranium Associated With Clays

Gulf Coast Aquifer

IRON

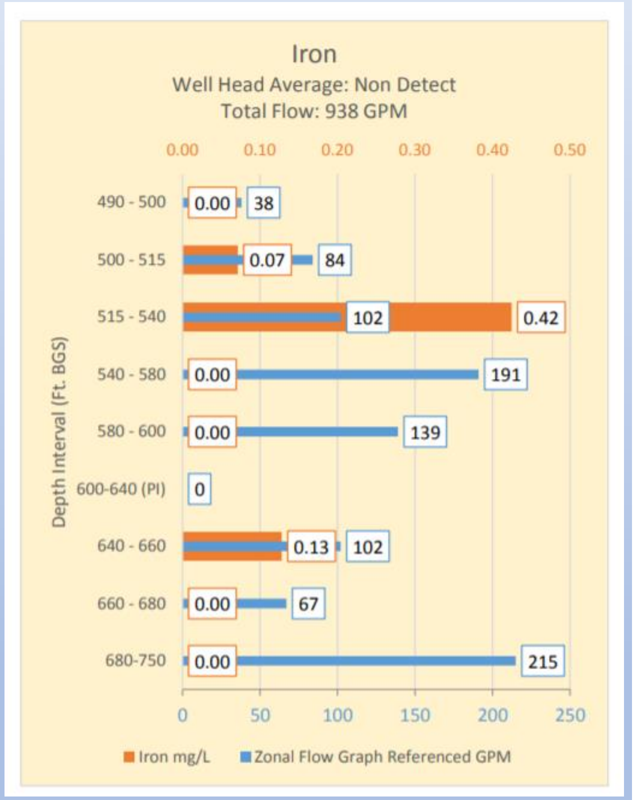
HOUSTON TX



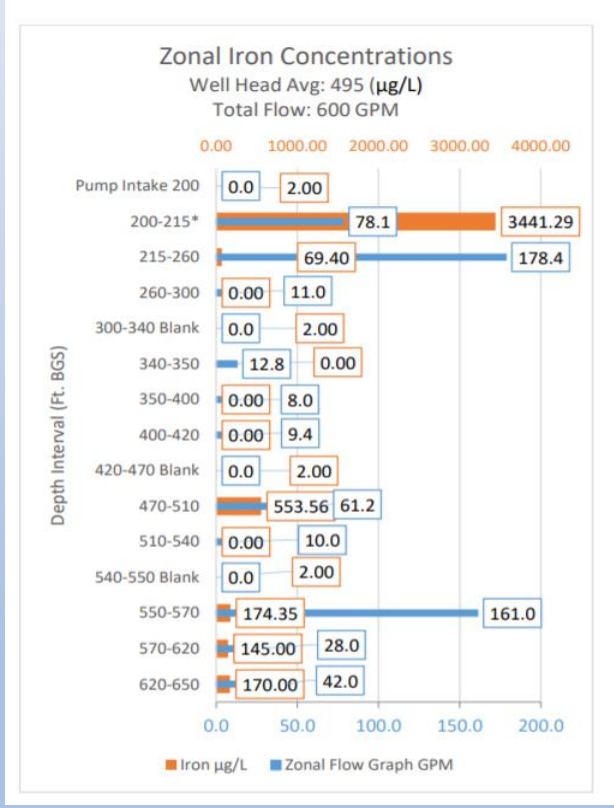
California

IRON

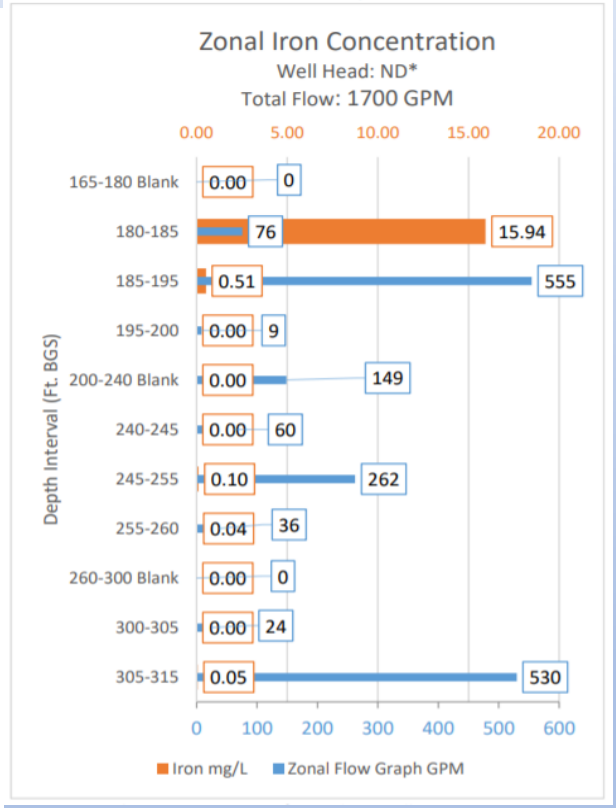
DELANO CA



SANTA CRUZ, CA



MODESTO, CA



Gulf Coast Aquifer

RADIONUCLIDE EXAMPLES: HOUSTON TX

BESST INC. GLOBAL SUBSURFACE TECHNOLOGIES

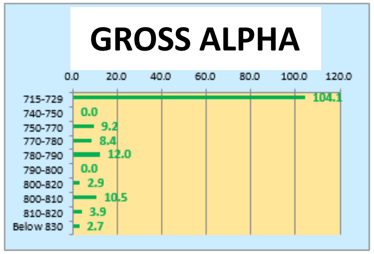
Prepared by Noah Heller, MS PG (CA 5792) / BESST, Inc.

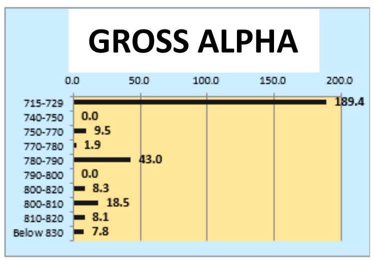
BESST Case Histories of Well Profiling for Radionuclides

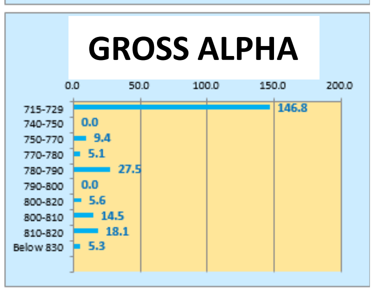
Over the past 12 years, BESST has profiled approximately 750 municipal supply wells in California and at various locations in Texas. This experience includes a variety of wells tested for Radionuclides. Our experience to date shows that radionuclide contaminants are typically very stratified – showing highly asymmetrical formation distribution. Since radionuclides it is worthwhile to consider well profiling to delineate formation stratification. If concentrations are stratified, then this increases the probability that impacted wells can be hydraulically manipulated to produce compliant groundwater without treatment; or by using a combination of hydraulic well modification with reduced treatment. The examples that follow show zonal chemistry and flow distributions for various well profiling projects where wells have been impacted by radionuclides. The first two examples are for wells in Texas and the two examples thereafter are for wells in California.

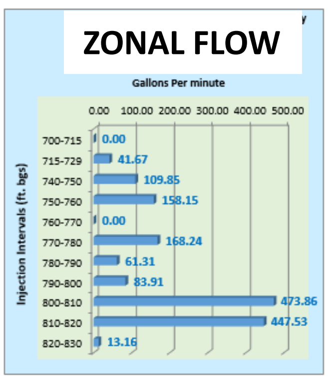
Case History 1: Harris County MUD 25 Well 1

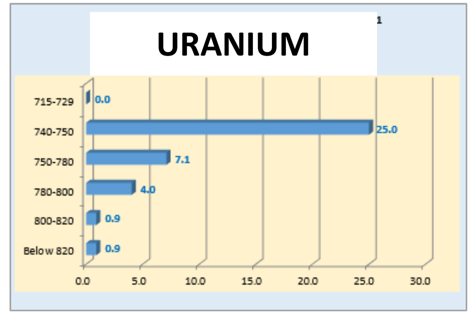
Located in the Houston TX metro area, Harris County MUD 25, Well 1 was zonally profiles for 3 constituents; including a) gross alpha, b) uranium 235, c) radium 228 and d) radium 226. The profiles for each constituent are presented below and all infer a highly stratified distribution within the surrounding formation. Moreover, the highest concentrations of radionuclides are associated with minimal flow contribution.

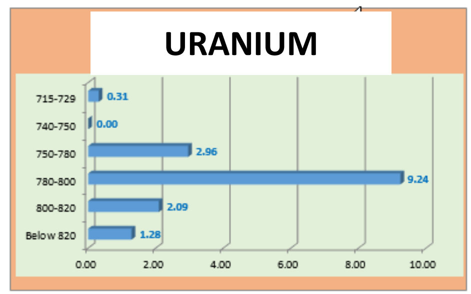


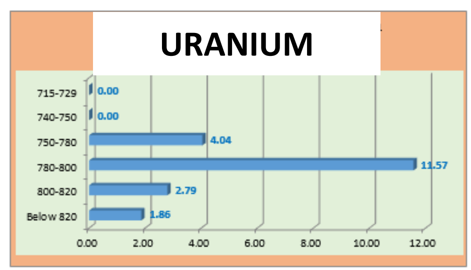


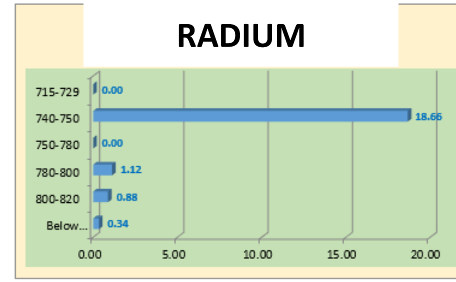


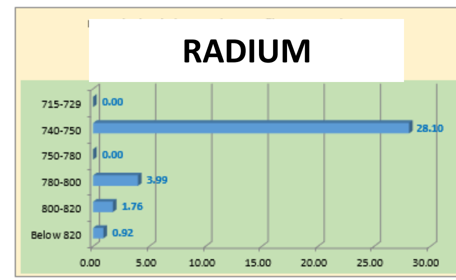






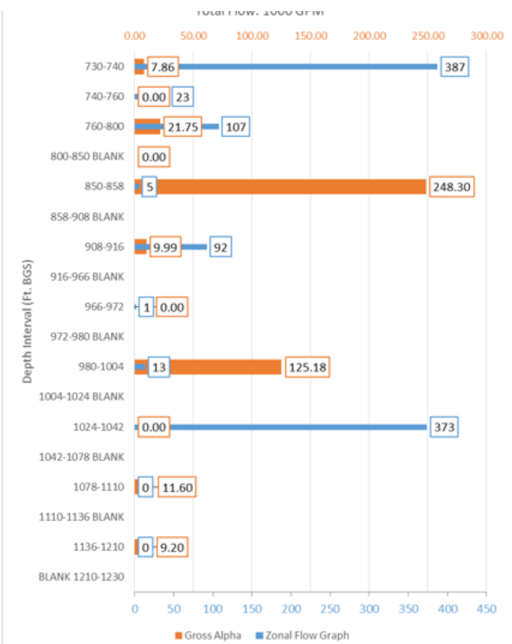




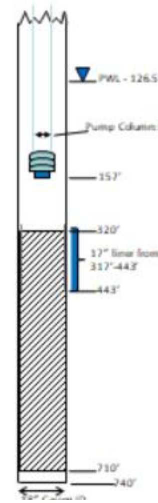


RADIONUCLIDES

GROSS ALPHA: HOUSTON TX



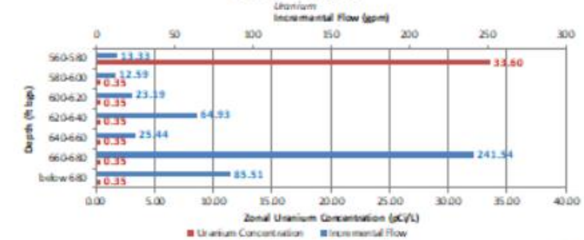
URANIUM: MODESTO, CA



Depth	Interval	Cumulative Flow	Measured Concentration	Incremental Flow	Zonal Concentration
560	560-580	466.53	1.5	13.33	33.60
580	580-600	453.20	<0.7	12.59	0.35
600	600-620	440.61	<0.7	23.19	0.35
620	620-640	417.42	<0.7	64.93	0.35
640	640-660	352.49	<0.7	25.44	0.35
660	660-680	327.05	<0.7	241.54	0.35
680	Below 680	85.51	<0.7	85.51	0.35
Tap 1	Cumulative	466.53	1.5		
Tap 2	Cumulative	466.53	1.5		

Dynamic Flow and Contaminant Contribution - Pico 9A

~467 GPM 1/25/2012



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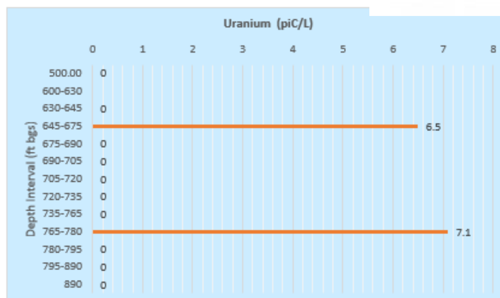
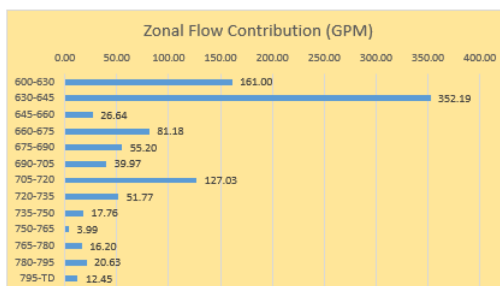
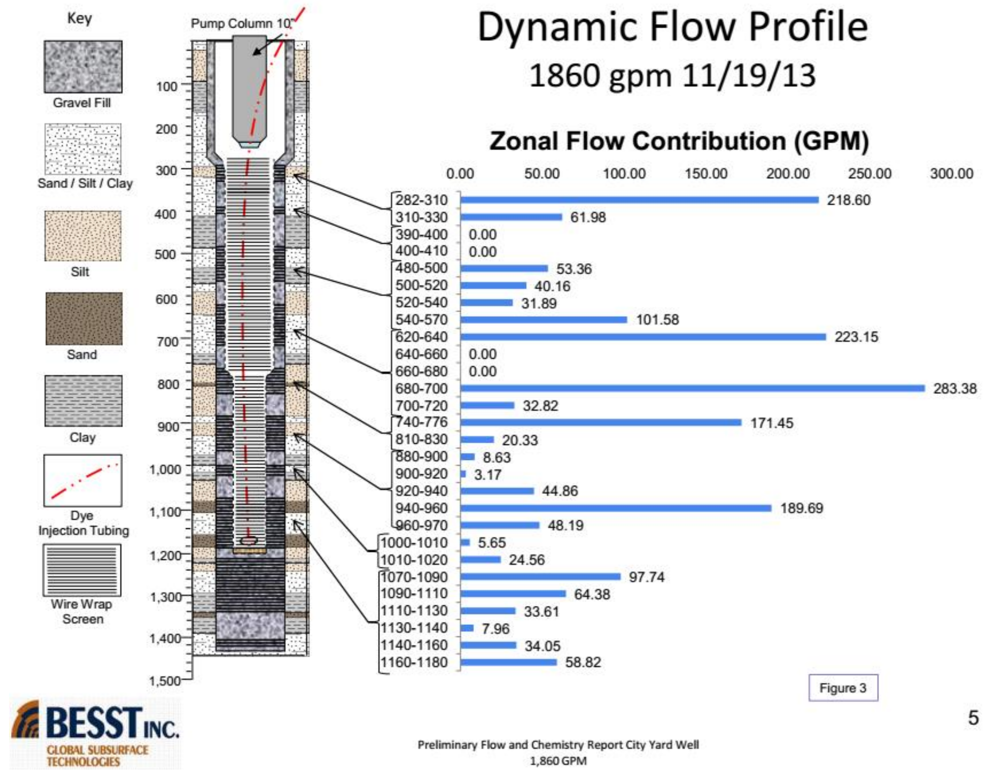
URANIUM; SANTA YNEZ, CA



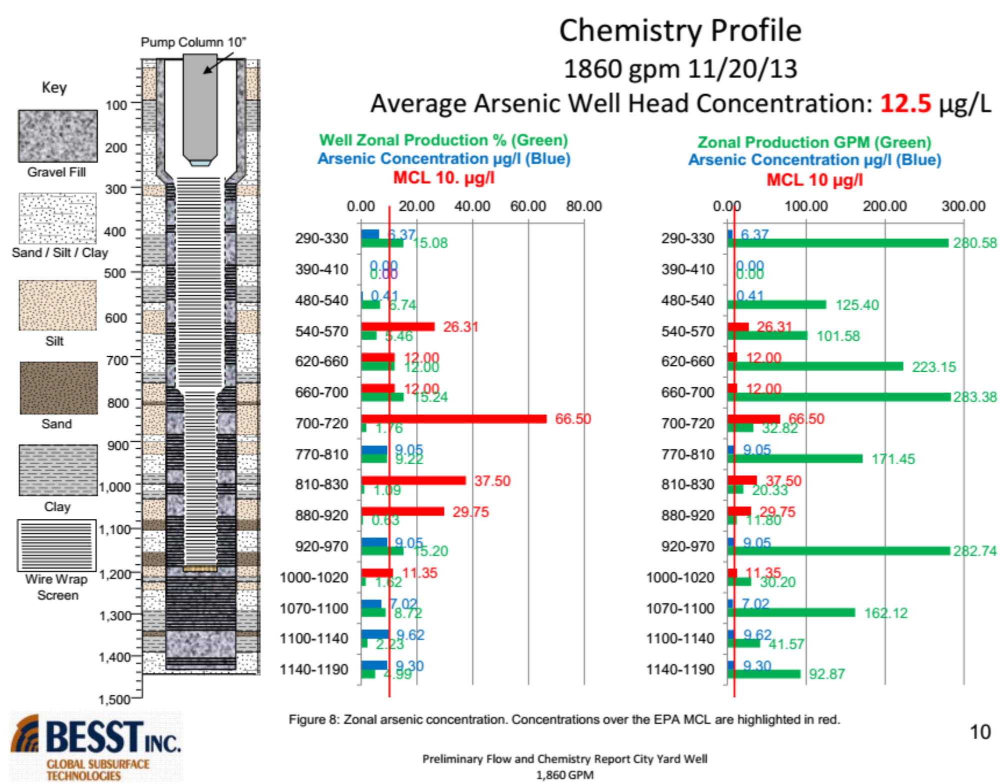


ARSENIC, MANGANESE AND IRON

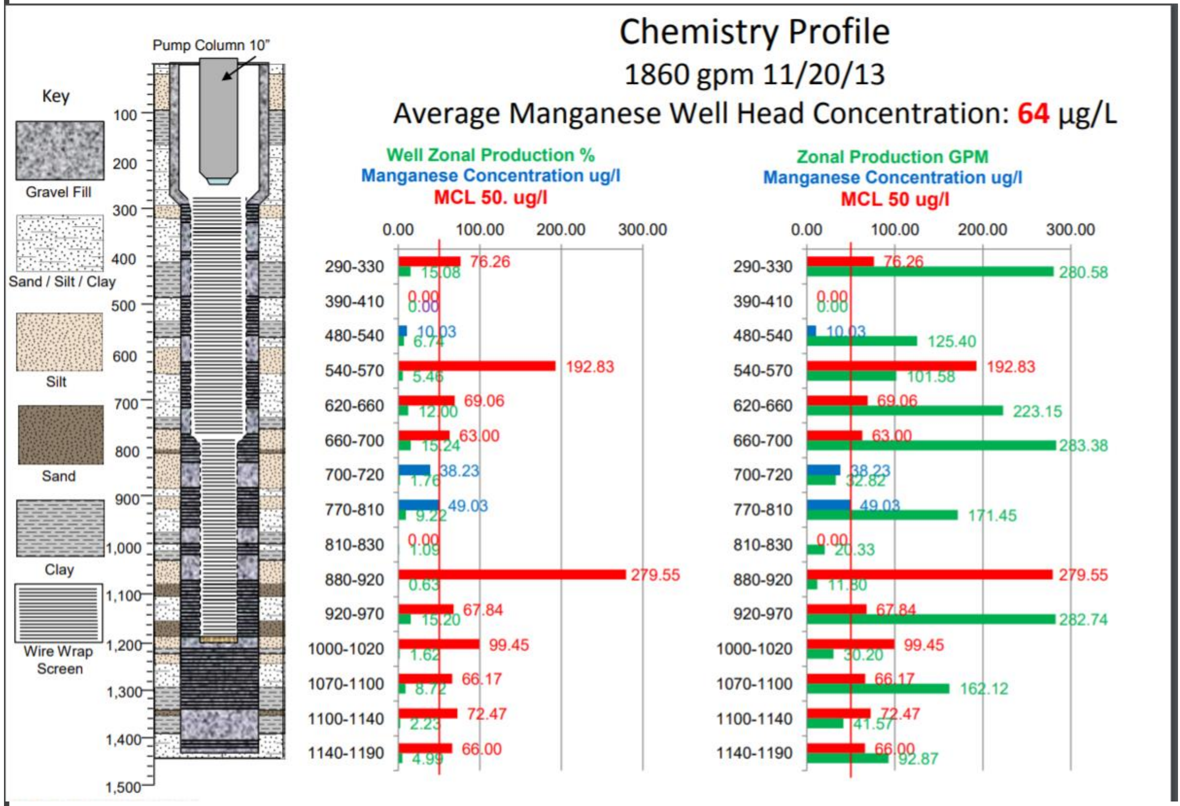
City of La Palma, CA: Arsenic, Manganese and Iron



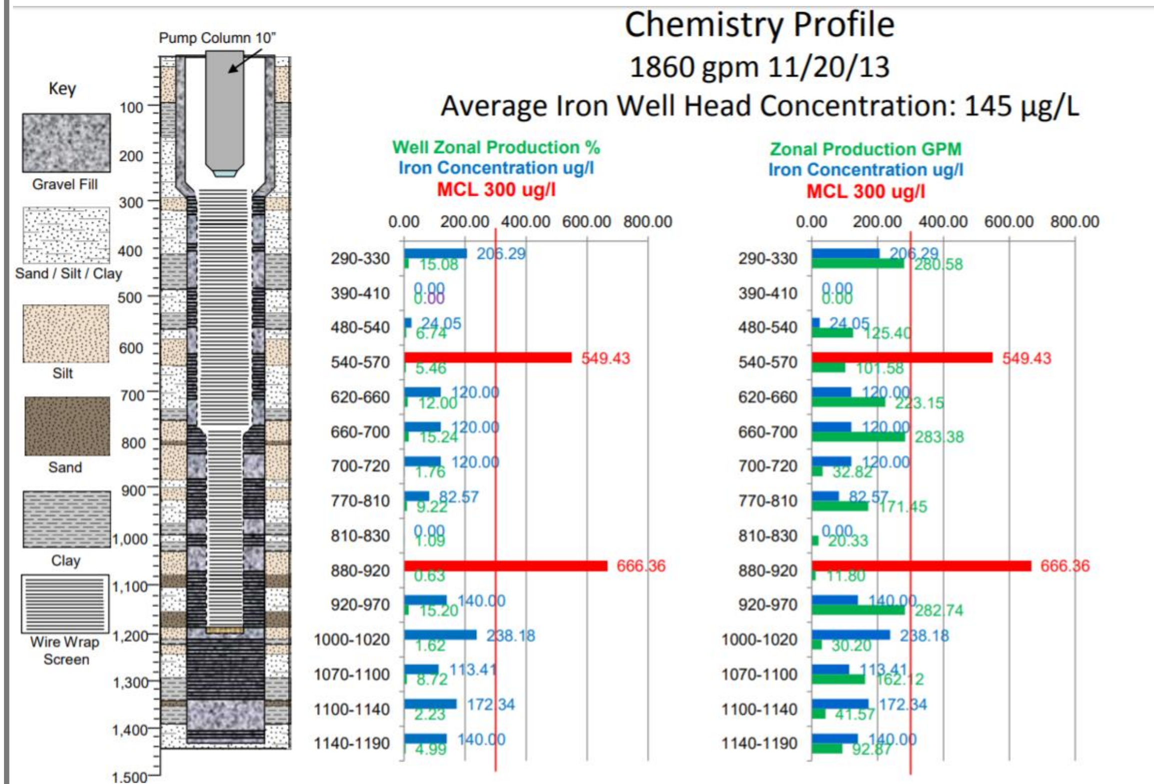
ZONAL ARSENIC DATA



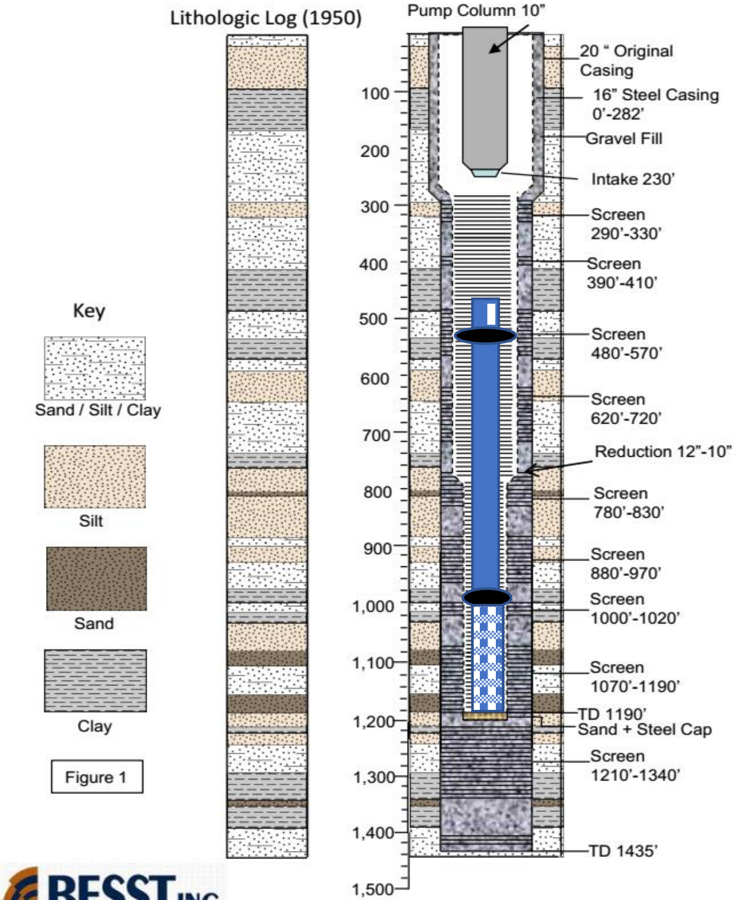
ZONAL MANGANESE DATA



ZONAL IRON DATA



Well Modification Design



City Yard Well Information and Lithology Log

Well Information

- Old (outside) well casing diameter: 20" -> 14"
- Outside screened Intervals (ft. bgs): (290-330), (390-410), (480-570), (620-720), (780-830), (880-970), (1000-1020), (1070-1190)
- New well casing diameter: 16" -> 12" -> 10"
  - New well casing is constructed with all stainless steel wire wrap.
- New pump column diameter (in): 10" (16" casing)
- Cross sectional area of new well casing:
  - From 0'-282': 1.40 ft^2
  - From 282'-786': 0.79 ft^2
  - From 786'-1206' : 0.55 ft^2
- Reported new well bottom: 1190 ft. bgs
- Pump Intake Depth: 230 ft bgs
- Pumping water level: 143 ft bgs
- Flow rate: 1860 USG min^{-1}

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NSF 61 Approved Rubber for Mechanical Packer