Fundamentals of Water Well Design, Construction and Testing

Dan Matlock, Principal Hydrogeologist
Pacific Groundwater Group ~ Seattle, WA

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Discussion Overview

- Planning for a New Supply Well
- Well Design Considerations
- Well Drilling Methods
- Well Screen Design and Development
- Well Testing

Planning for a New Supply Well

- Determine location for supply opportunities (USGS & consultant reports, well logs, geologic maps, cross sections)
- Assess aquifer properties (depth, thickness, SWL, available drawdown, transmissivity, well yield & specific capacity)
- Review available water quality (Fe, Mn, organic content, Na, Cl, TDS, NO_3, other contaminants)

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Assess Design and Drilling Approaches

- Develop generalize design (depth, potential well yield, diameter, seal locations, sand pack or natural design)
- Select drilling method based on soil conditions, well depth, design, and costs
- Prepare cost estimates and replan as necessary

WSD Example (Vancouver)

- Lack of planning compromised the yield of a GWHP well system
- Wells installed with wrong drilling method
- Wells completed in wrong aquifer
- Well design did not allow corrective actions for sand pumping problems
- Solution to problem was to install replacement wells
- Cost to State was approximately $500K

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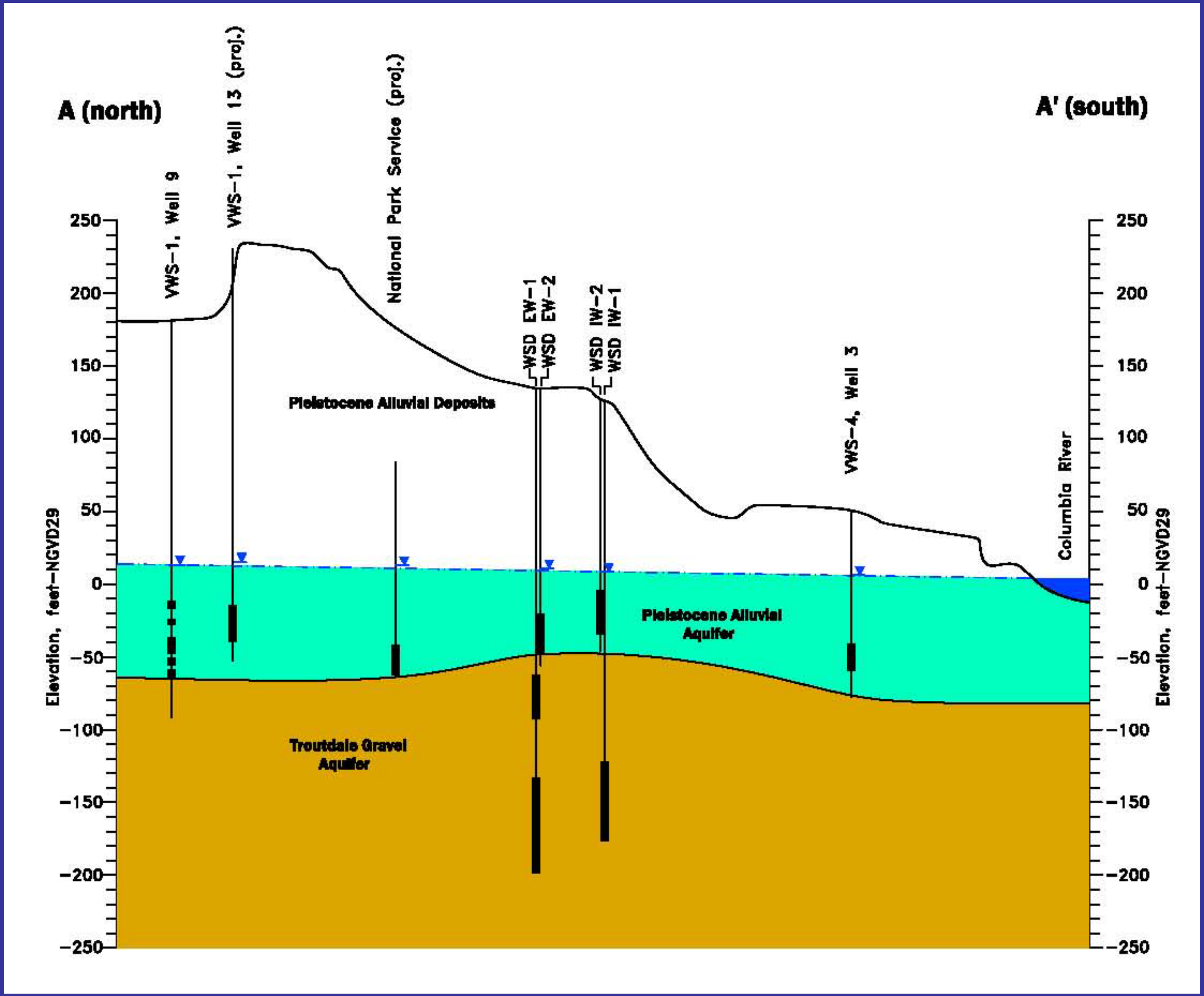
Aquifer Conditions beneath Vancouver



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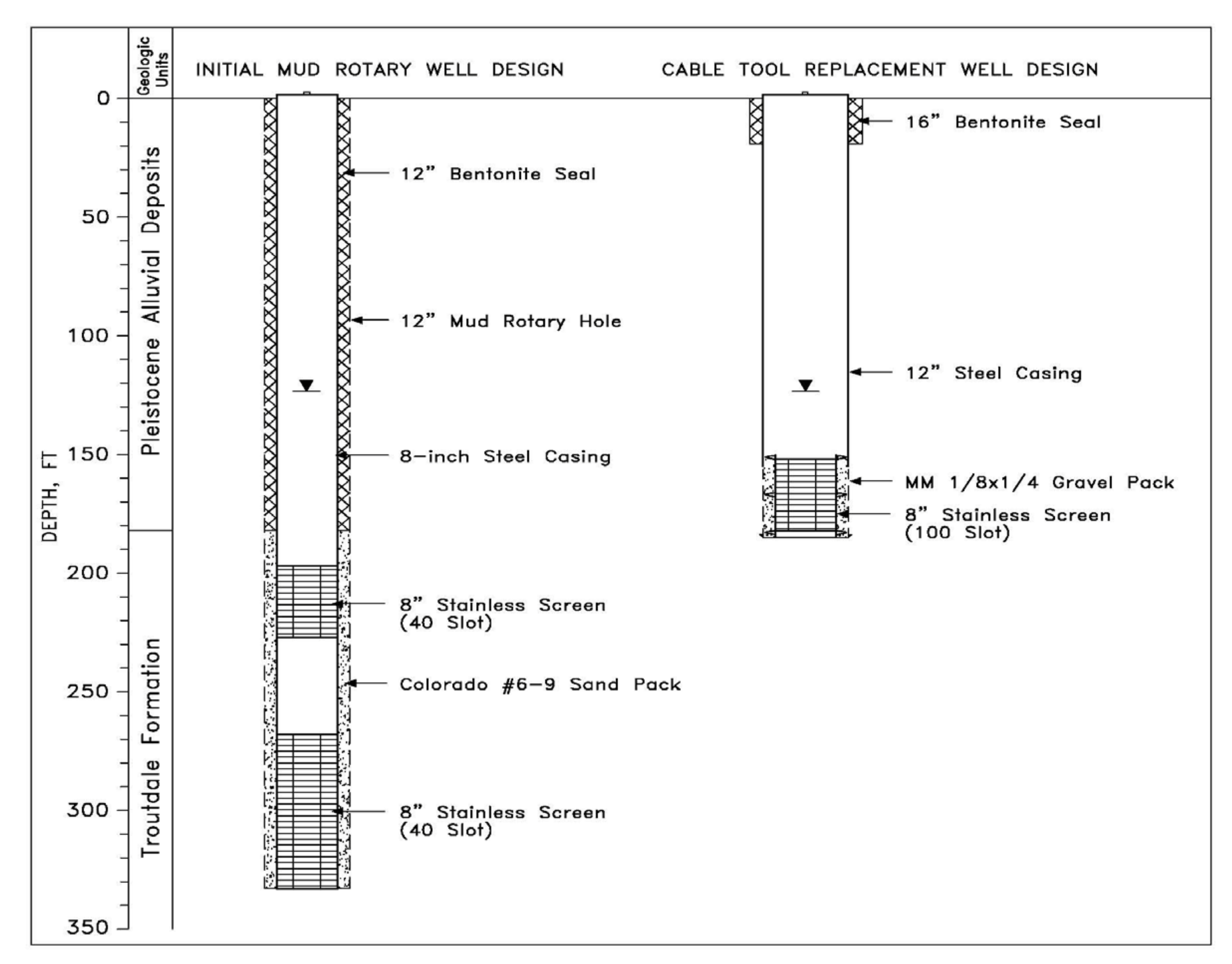
Comparison of Well Designs



Well Components

- Well seals
- Casing/liner
- Drive shoe
- Well screen assembly
- Optional sand/gravel pack

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Well Sealing

- Minimum 18-foot sanitary seal seated into fine-grained unit
- Install deeper seals as necessary to avoid interaquifer connections
- May need deep seal or several casing reductions to avoid interaquifer connection
- Complete well in a single aquifer

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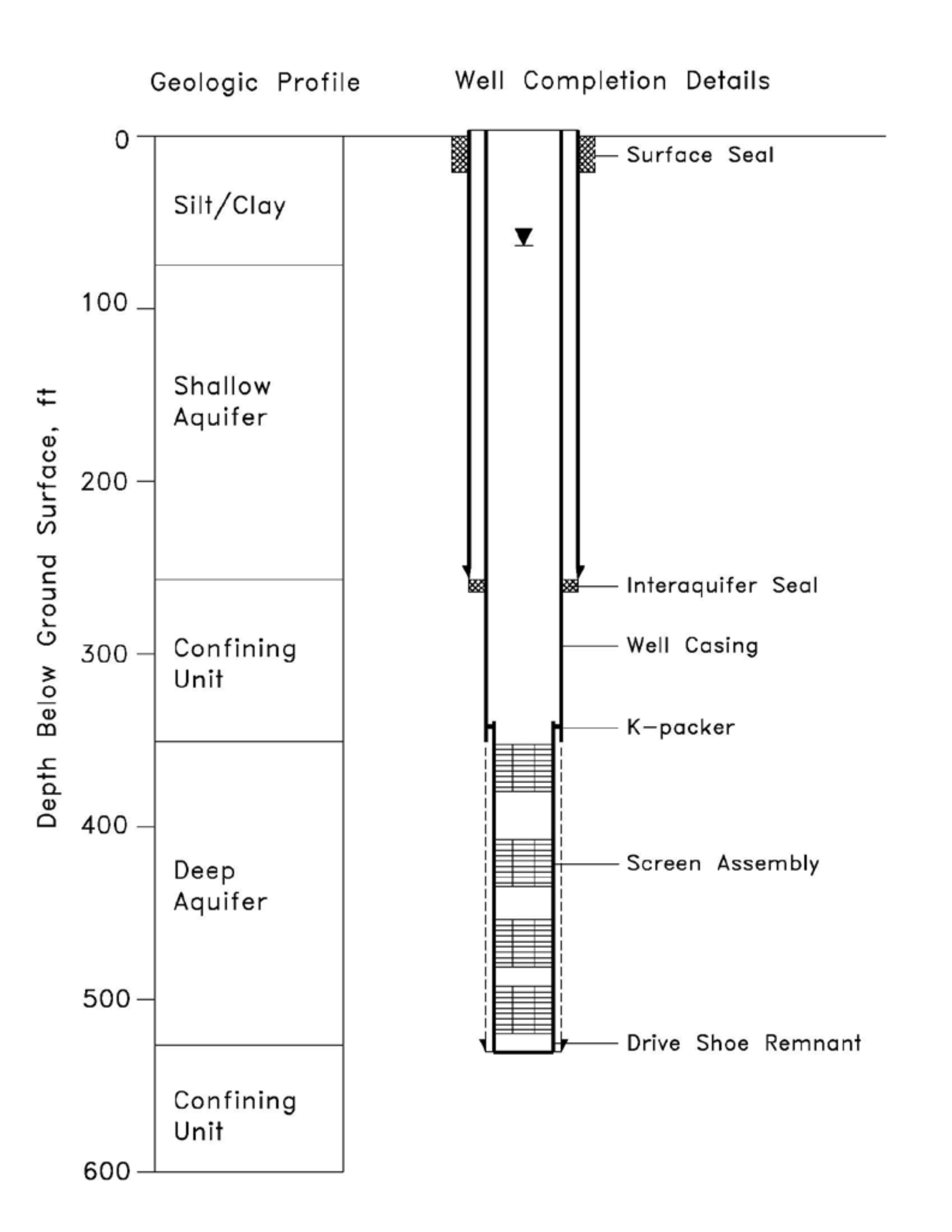

Well Completion Details for Unconsolidated Formation

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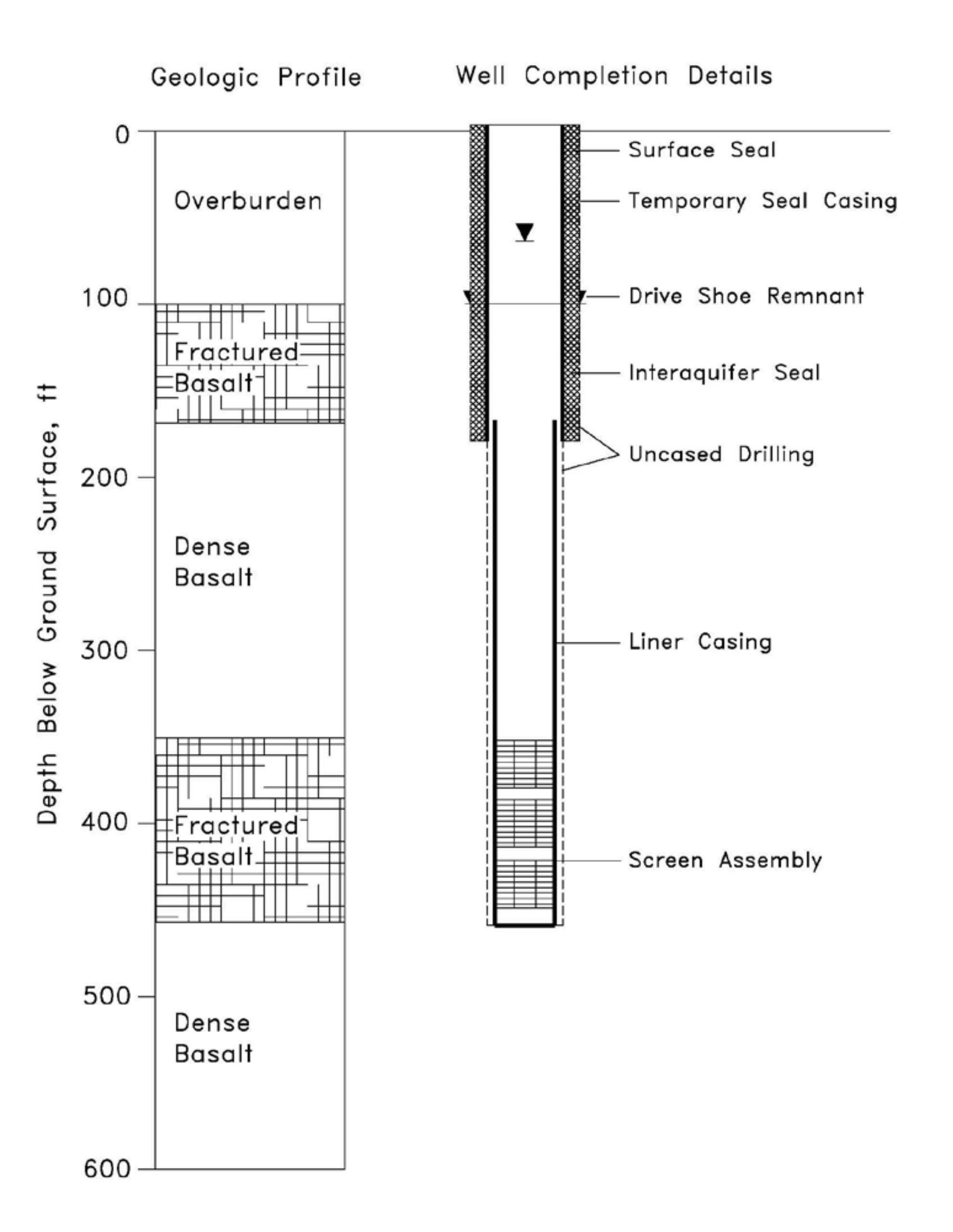

Well Completion Details for Consolidated Formation

Water Well Drilling Methods

- Cable tool
- Air rotary
- Mud rotary
- Flooded reverse circulation dual rotary

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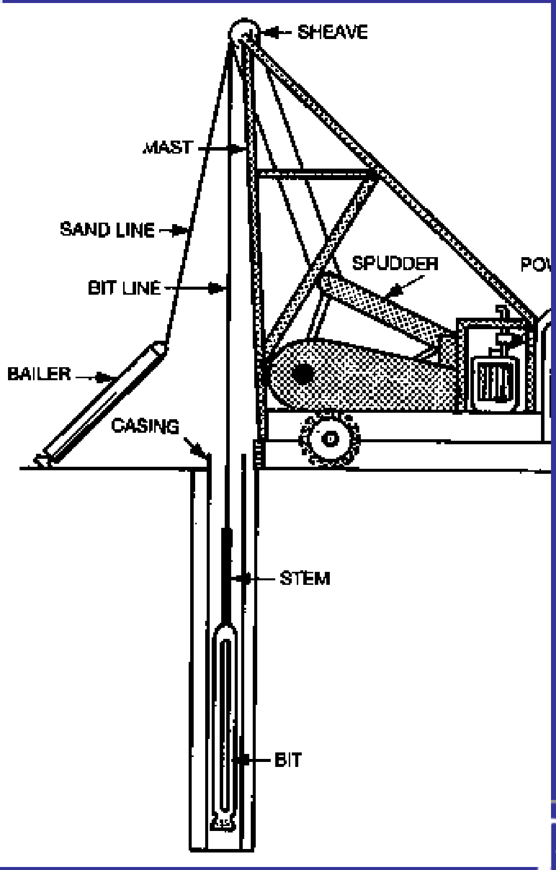
Cable Tool Drilling



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Cable Tool

- Inexpensive and good for all well designs
- Good soil samples & WL information
- Small drilling footprint
- Good for well completion/development
- Alignment needs to be constantly assessed
- Not effective for consolidated formations
- Slow advance rate

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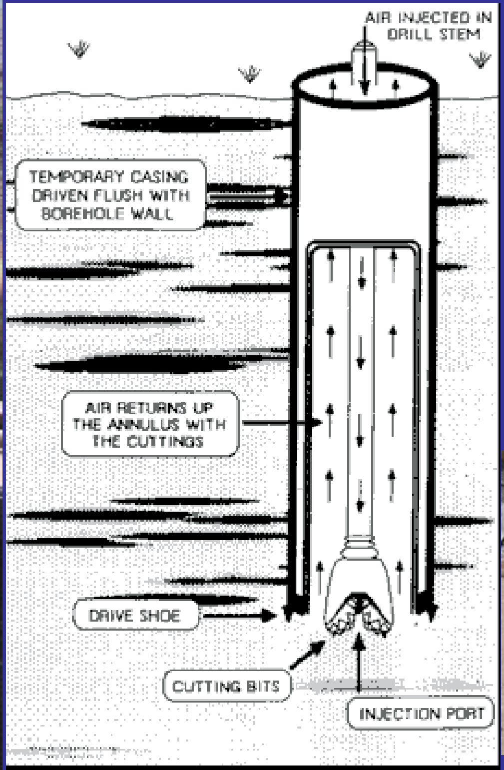
Air Rotary Drilling



Air Rotary

- Cost effective for domestic wells
- Good WL entry information
- Good for consolidated formations
- Not effective for large diameter wells (> 12/16")
- Poor sample recovery
- Fast advance rate

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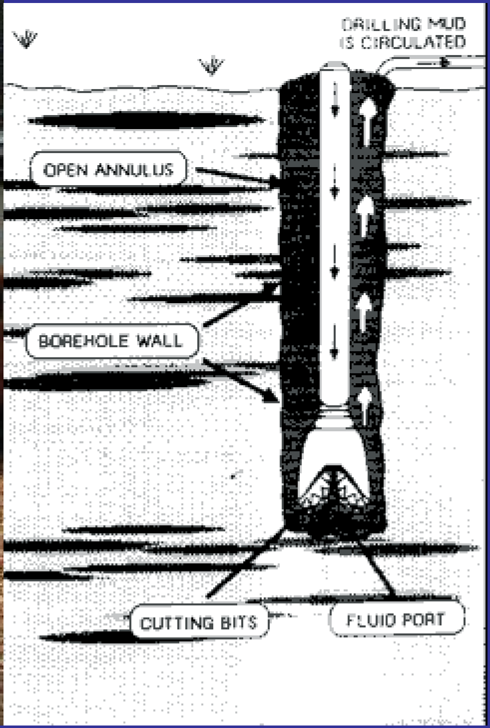
Mud Rotary Drilling



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Mud Rotary

- Very cost effective for deep exploration (no casing)
- Poor sample recovery
- Need to run complementary borehole geophysics
- Limited information on water entry (fluid losses)
- Maintains good well alignment
- Larger drilling footprint required
- Well construction/development is more complicate
- Very fast advance rate

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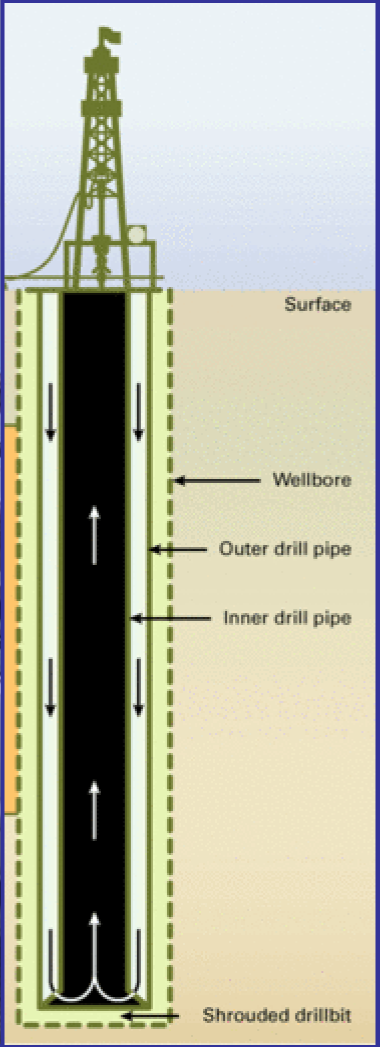

Flooded Reverse Circulation Dual Rotary Drilling

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Flooded RC Dual Rotary Drilling

- More expensive
- Good for large well designs
- Good for unconsolidated and consolidated formations (versatile)
- Maintains good well alignment
- Inconsistent soil recovery
- Large drilling footprint required
- Fast advance rate

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Well Screen Design

- Sieve analysis of sand fraction to assess screen slot openings
- Avoid screening too close to fine sand zones
- Use natural pack design to optimize well efficiency
- Use sand/gravel pack design if fine sand is problematic

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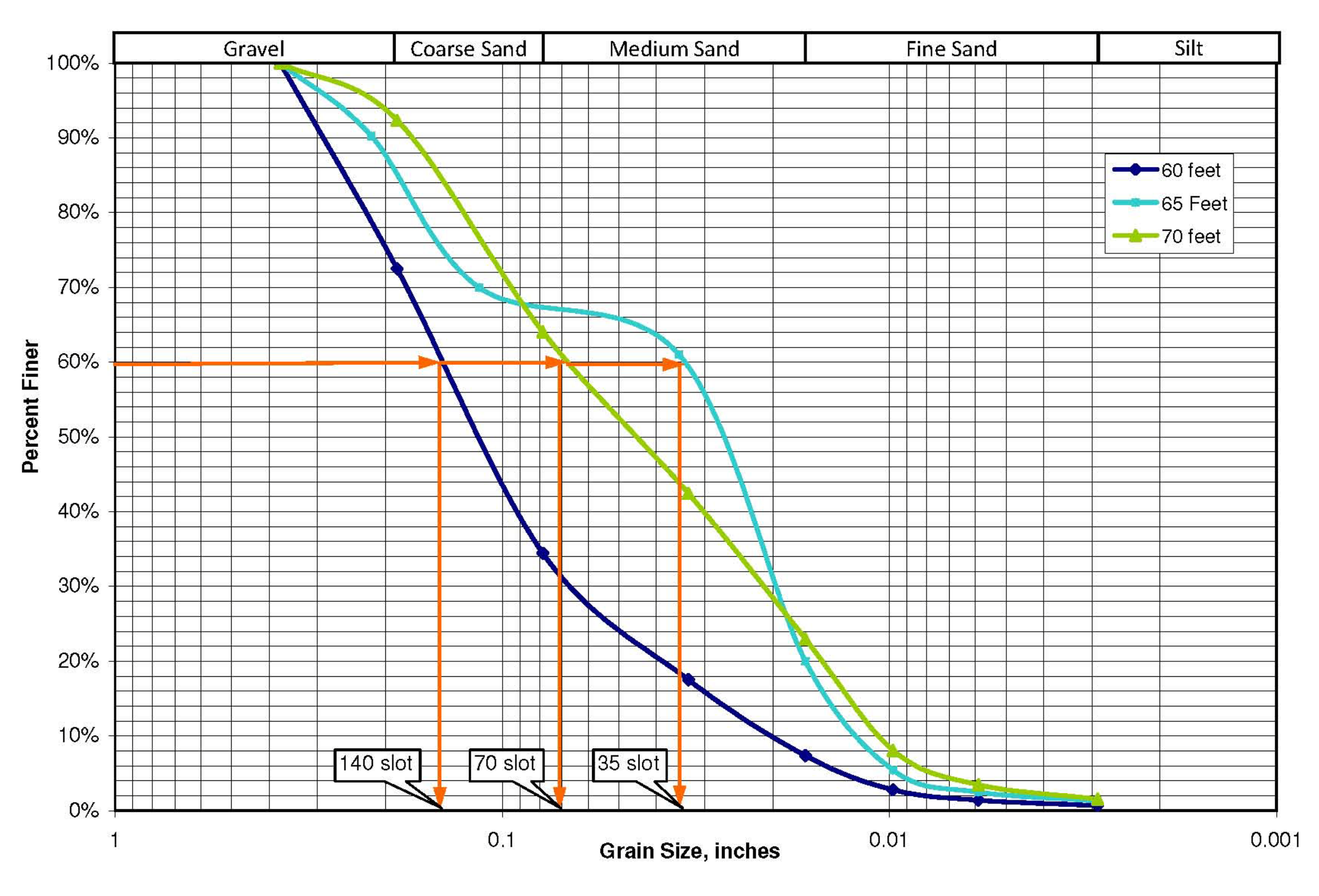
Grain Size Evaluation for Design



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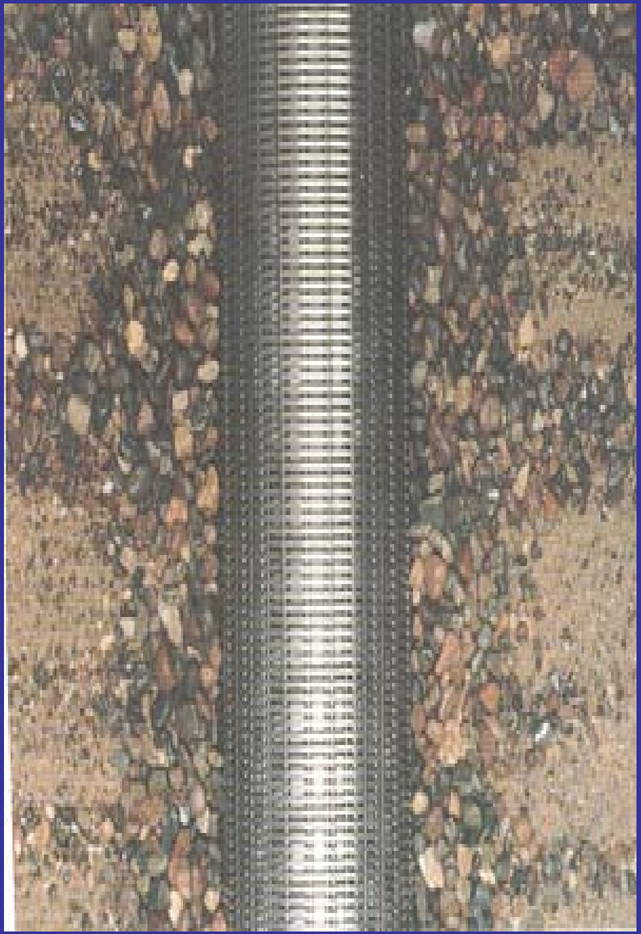
Well Development

- Purpose of development
  - Remove fines to enhance well efficiency
  - Stabilize formation & limit sand production
- Development methods
  - Surging with swabbing tool
  - Air lift surging
  - Water jetting
  - Chemical additives for breakdown of clay/silt (AquaClear PFD)



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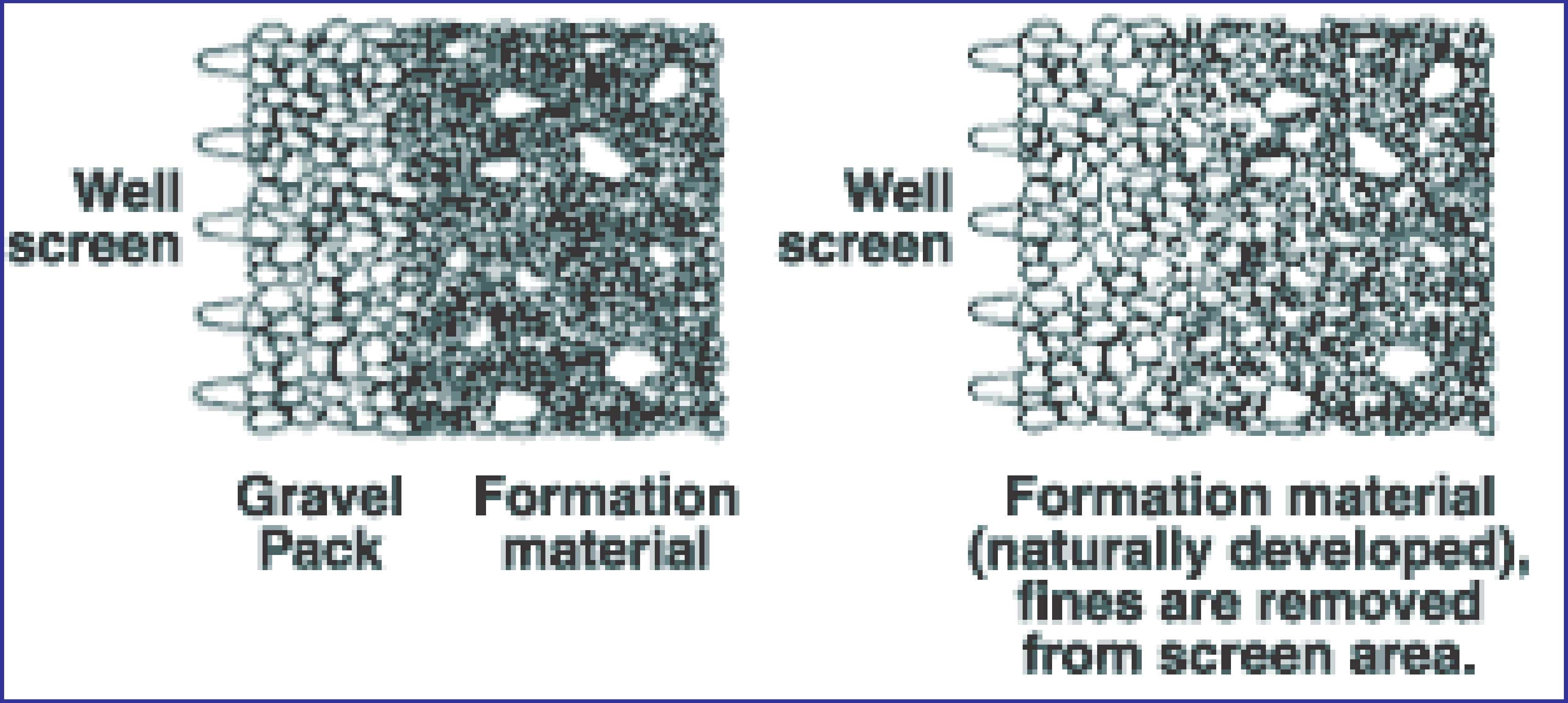
Natural vs Gravel Pack Completion



Well Testing

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Well Testing

- Assess aquifer productivity (drawdown controlled by aquifer properties and boundary influences)
- Assess well efficiency (drawdown controlled by well design)
- Assess aquifer properties (T,K,S)
- Evaluate boundary influences (recharge/discharge boundaries)

Types of Pumping Tests

- Air lift tests (most common/mostly worthless except for domestic wells)
- Step-rate drawdown tests (well efficiency)
- Constant-rate tests (aquifer properties/boundary influences)

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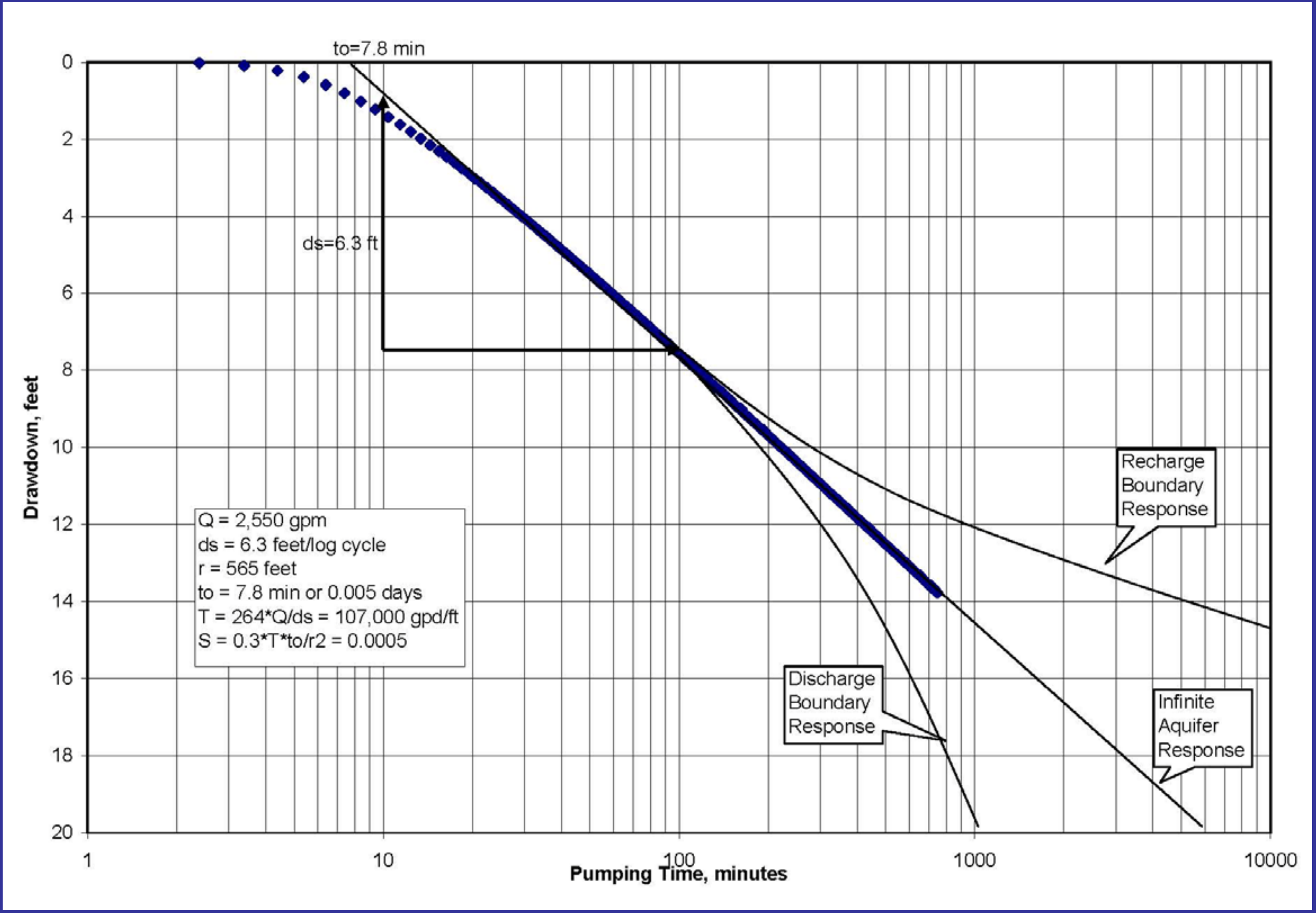
Testing Considerations

- Where to discharge water
- Accurate metering of pumping rate and drawdown
- Desirable to have one or more obs. wells
- Pretest monitoring for baseline trends
- Other issues (noise, regulating valves, WQ sampling, barometric corrections)

Assessing Drawdown Response



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Thank You-Questions?

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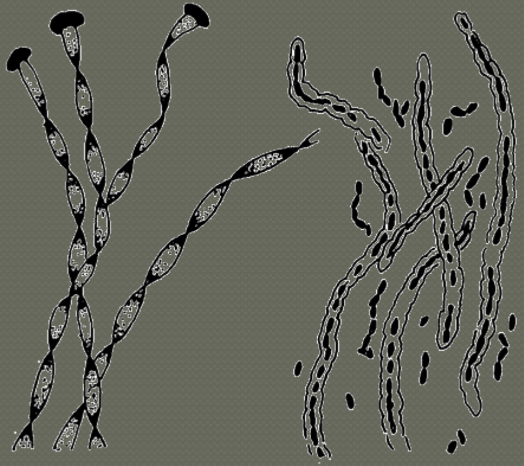


Water Well Rehabilitation

Tips, Tricks and Technologies for Tackling a Well Rehabilitation Program

Chris Augustine

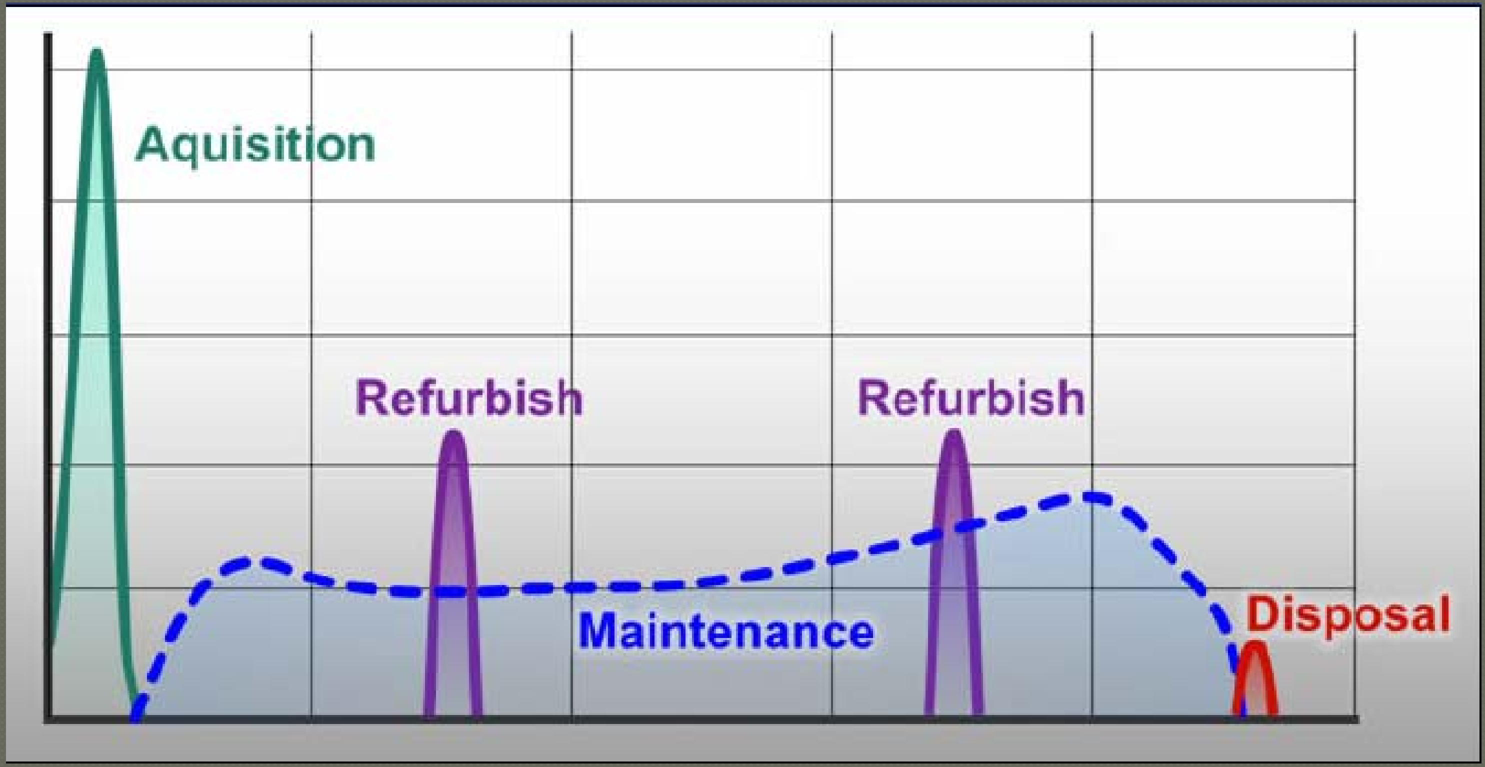
PNWAWWA Annual Conference May 2-4 2012
Yakima, Washington

GSI Water Solutions, Inc.

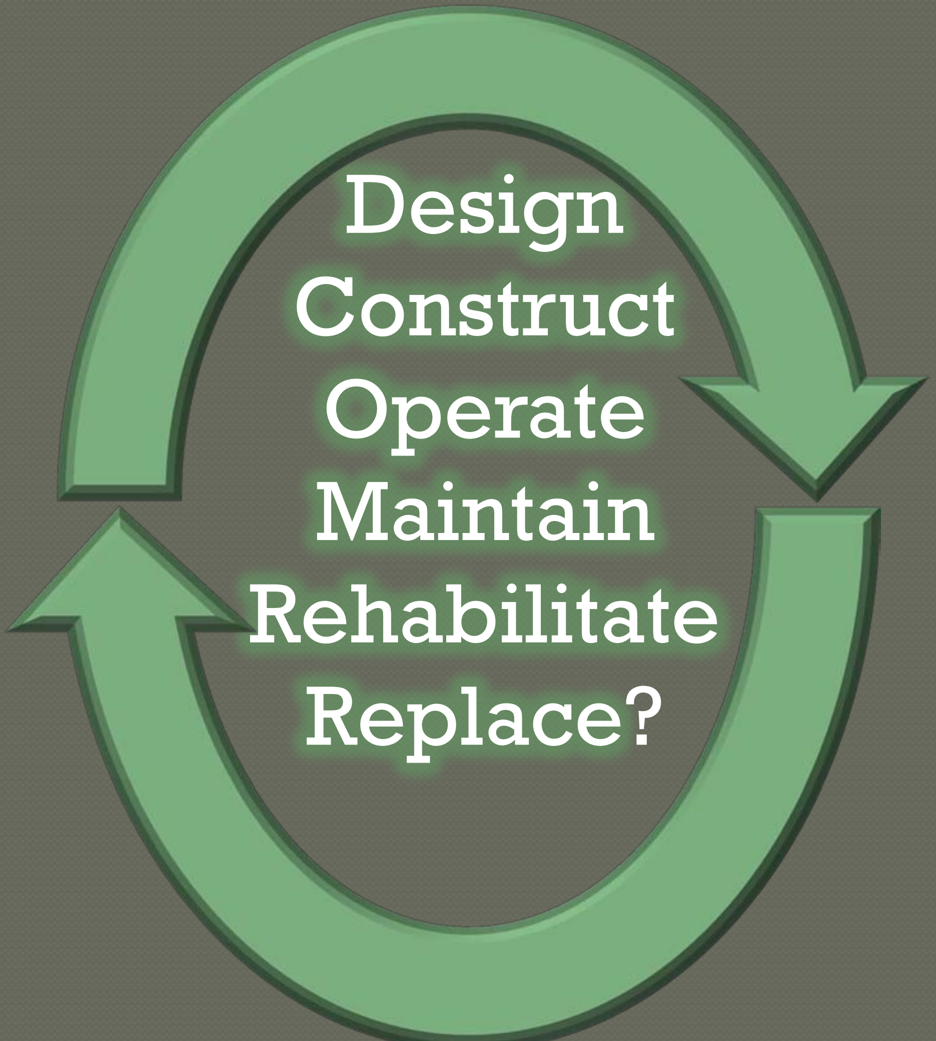
Well Rehabilitation - Defined

"restoring a well to its **most efficient condition** by various treatments or reconstruction methods"

Life Cycle for a Typical Asset



The Circle of Life for a Well



Tip No. 1 – Plan Ahead

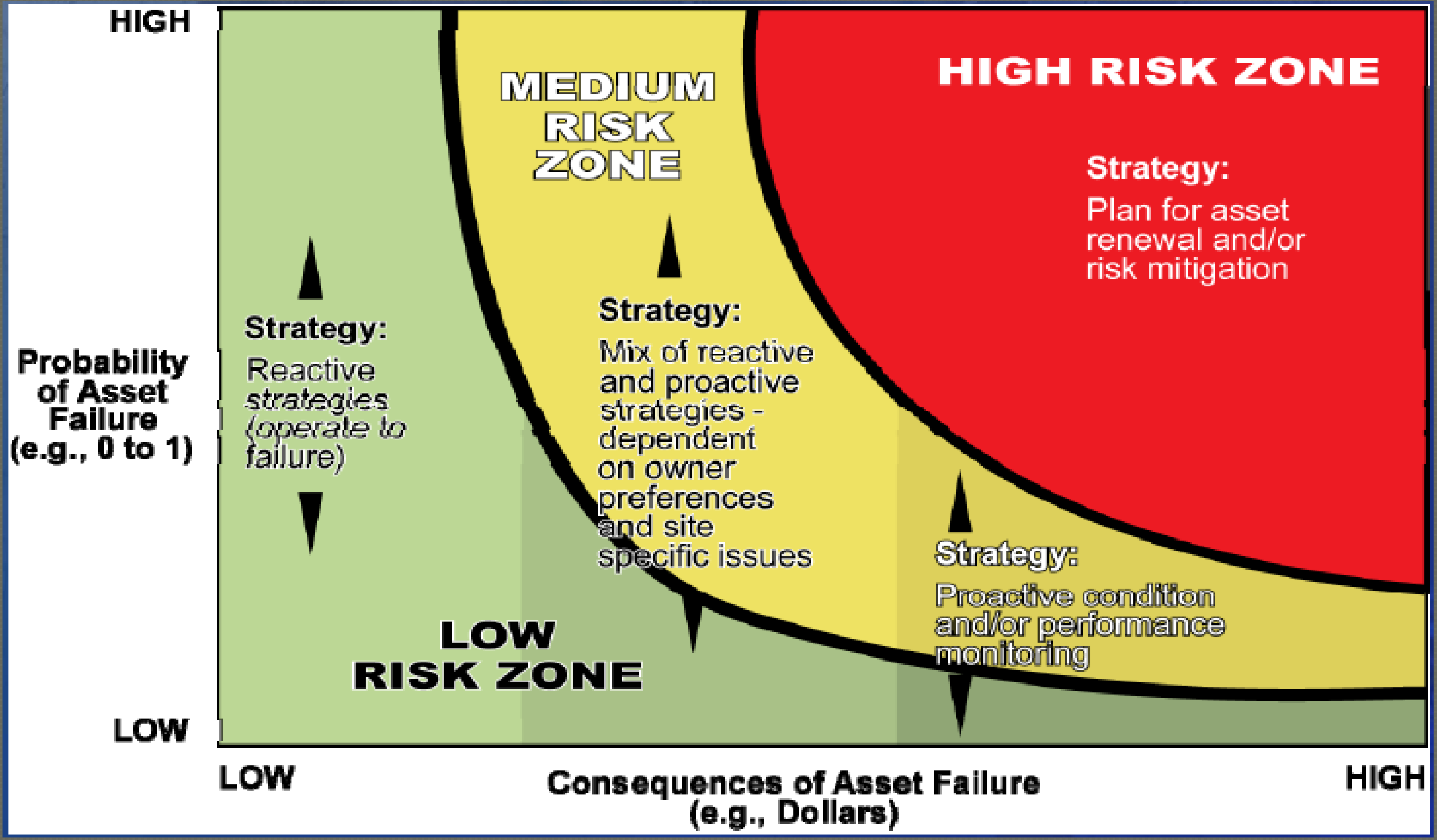
Dennis Waitley

"Expect the best, plan for the worst, and prepare to be surprised "

What is Your Approach?

- Proactive Approach
  - Evaluate well on a periodic basis
  - Evaluate pump on a periodic basis
  - Water chemistry monitoring
  - Bacterial assessments
  - Perform systematic maintenance
- Reactive Approach
  - Respond only when well approaching failure
  - Lack of identification of a problem
  - Cost benefit or budgetary to delaying response

What is Your Risk?



Rehab or Not? Decision Points

- Is the well replaceable?
- What's the cost of being reactive?
  - Cost per gallon of water
  - Costs of pumping – wire-to-water efficiency
  - Replacement costs of equipment – microbially mediated corrosion
- Rehabilitation vs. new construction
  - Can be 10% to 100% of a new construction
  - Typically less for large diameter deep wells ~10 to 50%
  - How far gone is the well? If > 50% loss of yield and specific capacity may not want to attempt to rehabilitate

Tip No. 2 – Evaluate Performance as Part of Operation and Maintenance

Steve Jobs

"You Can't Connect the Dots Looking Forward"

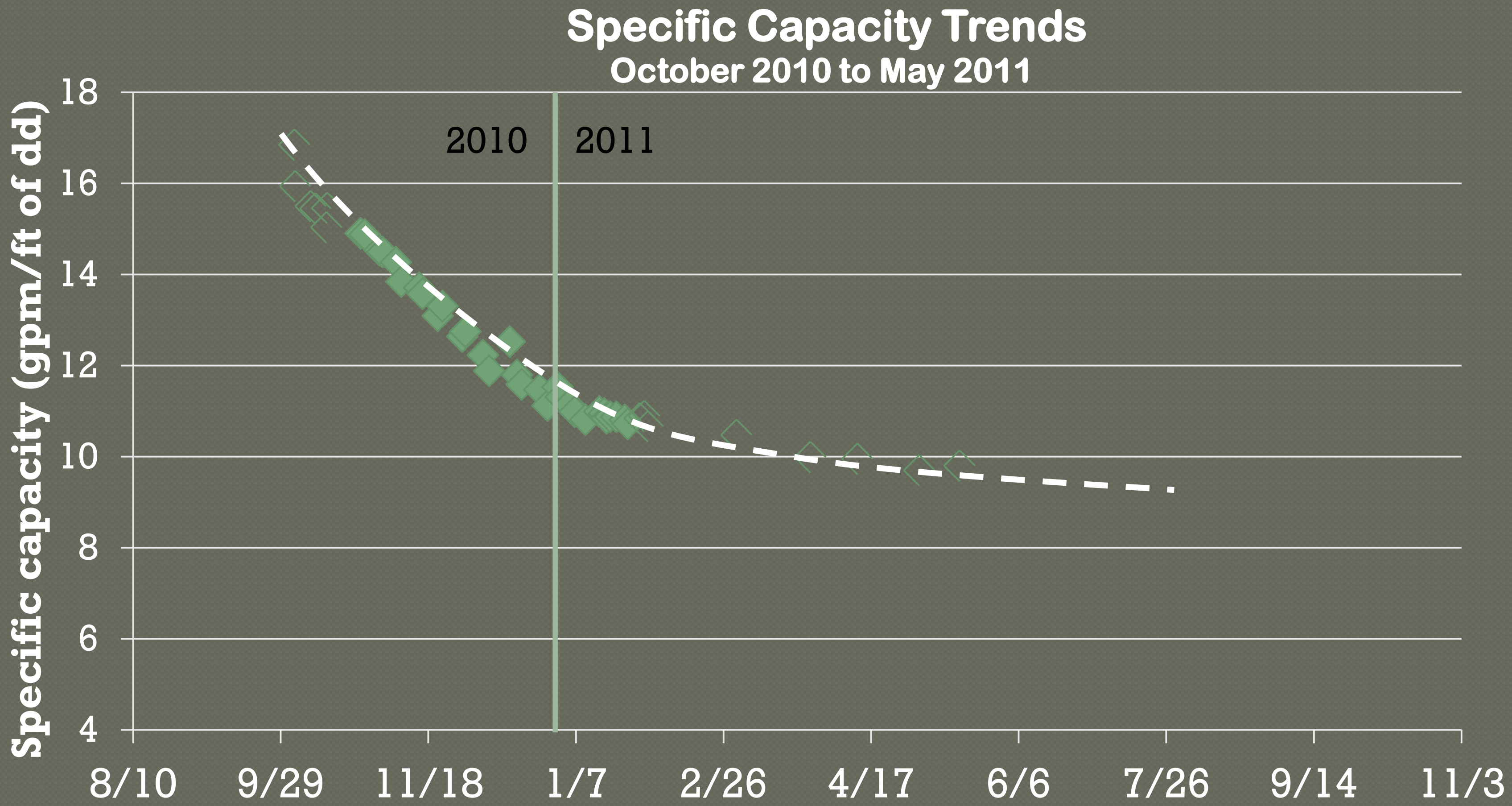
Monitor as Part of Regular Operation and Maintenance

- Collect Well Performance Information (PLC or SCADA)
  - Pumping rate
  - Drawdown
  - System pressures
- Collect Pump Performance Data
  - Voltage, Amperage, Power Factor, VFD Frequency
- Water Quality
  - Major Ion chemistry and nutrients – iron, manganese
  - Alkalinity, Hardness, pH and Redox conditions
- Bacterial Assessment
  - Heterotrophic Plate Counts (HPC) – 97% of all bacteria **are not** culturable using an agar media!

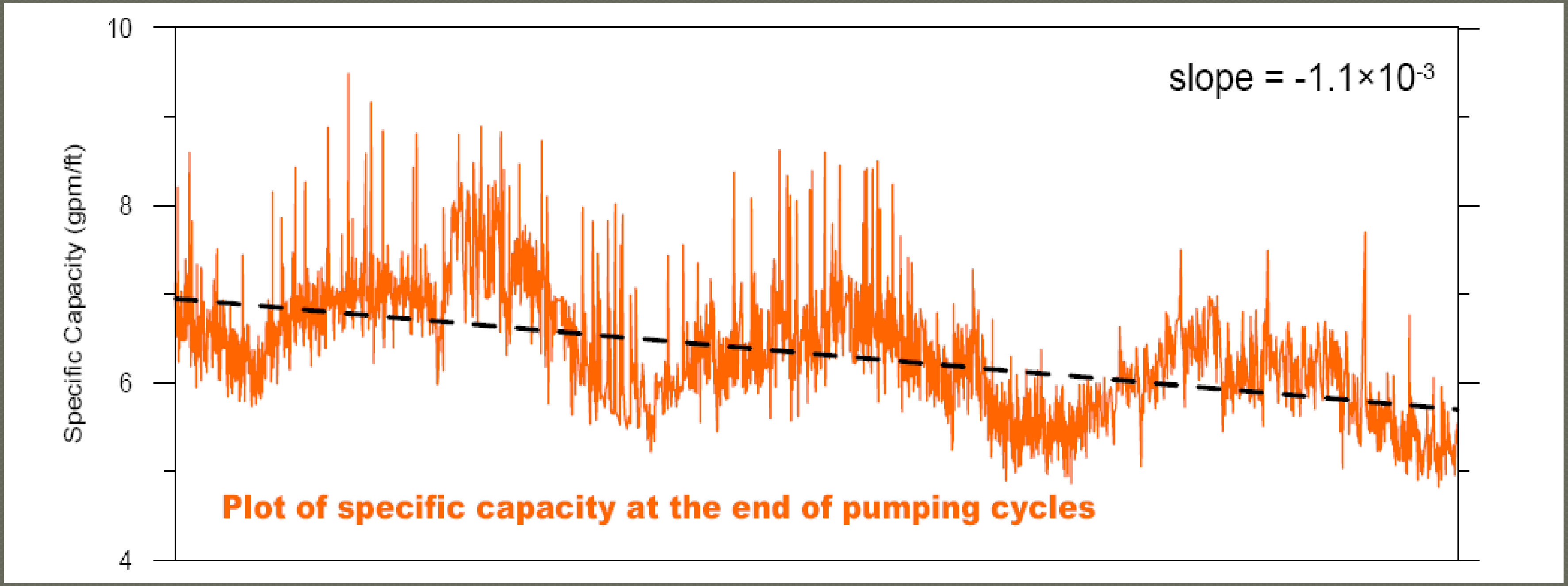
How Do I Identify a Problem?

- Visually
  - Surface clues – deposit/slimes
  - Downhole Camera
- Chemically
  - Water quality testing – iron, manganese, biological
- Mechanically
  - Evaluate Pump Performance and Energy Usage
  - Evaluate Changes in Flow or Pressure
- Hydraulically
  - Well Performance – Well Yield or Specific Capacity

How Fast Can a Problem Develop?



More Typical Plot of Well Loss

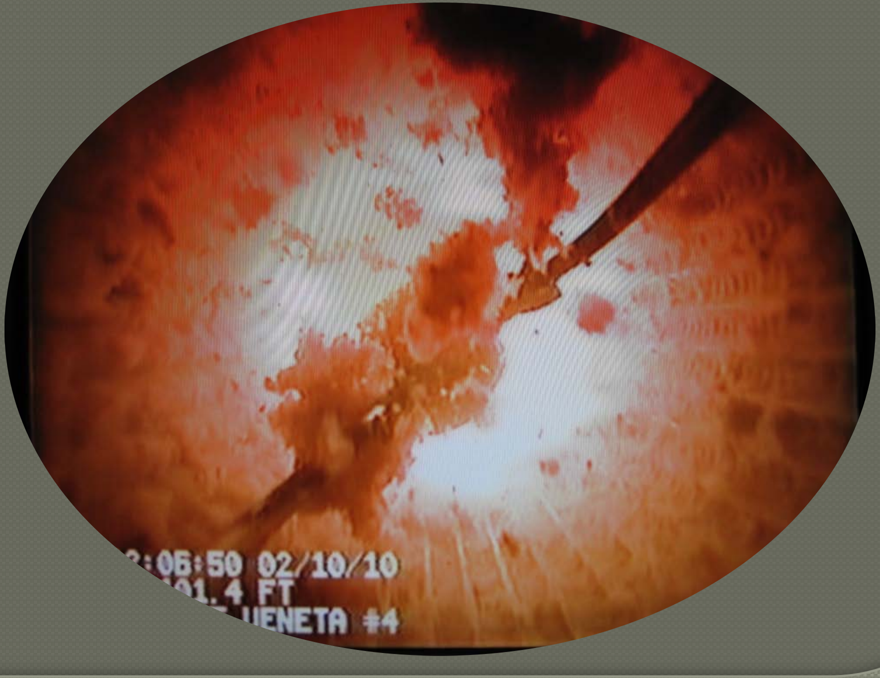


What Are Well Performance Loss Mechanisms?

- Physical, Chemical or Biological ?
- Well Design
  - Screen intake velocity
  - Screen placement/Filter pack
  - Lack of development
  - Sump

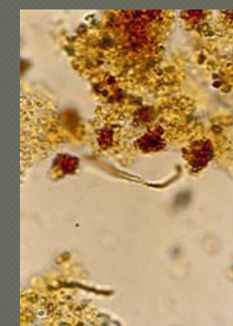
- Groundwater Chemistry
  - High Iron, Manganese, or Nutrients
  - Highly oxidizing conditions – aquifer conditions or due to pump operation
  - Improper disinfection results in precipitation – Calcium Hypochlorite
  - Positive Saturation Index, Hardness, Alkalinity, pH – Precipitation of $CaCO_3$ or $CaSO_4$

Bacterial Fouling or Biofouling



"It's the Water" ....and a whole lot more

- Iron Related Bacteria
  - Most Common Strains – Gallionella, Leptonoptrix, etc.
  - Microbes facilitate FeII, FeIII and Mn reactions at well aquifer interface
- Aerobic Bacteria
  - Slime forming bacteria
- Anaerobic Sulfate Reducing Bacteria
  - Symbiotic relationship with Aerobic
  - Hydrogen Sulfide smell/Black deposits
- Need Nutrients
  - Oxygen, Iron, Manganese, Nitrate, Sulfate, Phosphate and Organic Carbon



How Do I Diagnose Biofouling?

- Qualitative
  - BART testing – Bacteria specific tests
  - General Chemistry – Iron, Manganese, and Nutrients
  - Field testing of deposits on pump and piping
    - HCL testing

- Quantitative
  - Analytical Specialty Lab
    - Visual Identification of Bacteria
    - ATP Count
    - Nutrients – iron, manganese, nitrate, phosphate and sulfate
    - Organic Carbon

Technologies

Arthur C. Clarke

"Any sufficiently advanced technology is indistinguishable from magic"

Well Rehabilitation Technologies

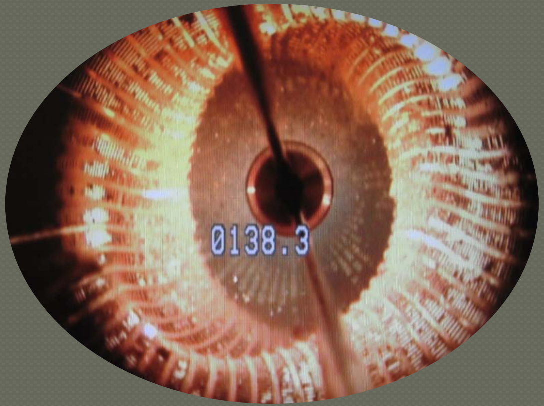
- What does it include?
  - Downhole Video Survey
  - Physical or Mechanical Development
  - Sonic or Fluid Impulse Generation Tools
  - Chemical Treatment
  - Thermal Treatments
  - Carbon Dioxide
  - Bacteriaphage Therapy
  - Whole Kitchen Sink? AKA – Blended Methods
  - Geophysics, Flowmeter or Flow profile

General Sequence of Work

1. Remove the Pump
2. Video Survey
3. Brush, Surge and Bail
4. Mechanical Development – Fluid Impulse
5. Re-Test Well Performance
6. Chemical Treatment
7. Re-Test Well Performance
8. Mechanical Development
9. Video Survey
10. Re-install Pump

Video Survey Methods

- Open Hole Video Survey
  - Removal of Pump
  - Camera Operator
  - Rental Equipment



- Pump in place video survey
  - 2-Inch Access Tube

Physical or Mechanical Methods

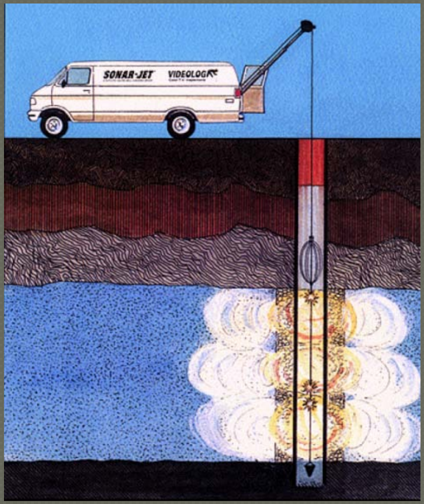
- Brushing
  - Cleans the inside of the well by removing plugging from well screen
  - Stiff Nylon or Steel Bristles
- Jetting
  - High pressure injection of water to clean screen and filter pack
  - Unidirectional – can result in compaction of filter pack

- Surging
  - Double flanged surge block
  - Multidirectional

- Air-lifting or Pumping
  - Simple, easy and practical
  - Zonal isolation tooling

Fluid Impulse Generation Methods

- Goes by Proprietary Names
  - AirShock™
  - AirBurst™
  - Hydropulse™
  - SonarJET™



- What's the Diff?
  - Some are repetitive impulse generation
  - Some are single "shots"

Chemical Treatment
The Pharmacopeia

- Acids – Inorganic and Organic
- Alphabet Brews
  - Penetrants, Polymers and Dispersing Agents
  - Corrosion Inhibitors
- Anti-Bacterial
  - Chlorine
  - Ozone
  - Hydrogen Peroxide

Should I Use Acids?

- High degree of plugging from mineral encrustation or biofilm = good candidate
- Good understanding of groundwater chemistry, hydrogeology and well hydraulics
- Limitations
  - Cost per increases for regained capacity
  - Condition of the Well
  - Nearby groundwater users
  - Nearby surface waters
  - Chemical incompatibilities
  - Neutralization of recovered chemicals
  - Disposal of recovered chemical
  - Safety

A Word on Disinfection

- Chlorination
  - AWWA suggest a 50 ppm chlorination solution for routine disinfection
- Shock or Super Chlorination
  - Used to be 500 to 1000 ppm – more is better right?
  - Now the rule of thumb is 200 to 300 ppm (maximum)

Tip No. 3 – Buyer Beware

Paul Parker

"People like to feel they are buying of their own good judgment as a result of the information the salesman has given them"

Get A Few Opinions

- No One Tool or Approach will be the Silver Bullet
- Identify an Experienced Hydrogeologist or Engineer
- Identify a Qualified Drilling or Well Rehabilitation Contractor
- Talk to Water Well and Well Rehabilitation Suppliers
  - Water Well Suppliers – Johnson Screen
  - Chemical Suppliers – Cotey Chemical, Baroid

Tricks

Will Rogers

"Good judgment comes from experience, and a lot of that comes from bad judgment"

Well Installation and Design

- Plan for Future Access to the Well

- Optimize Screen Length
  - Available Drawdown
  - Entrance Velocities
  - Percent Open Area
  - Filter Pack
- Allow for Declines in the Aquifer Water Levels
- Pump to Waste Capacity

Rehabilitation Specifications

- Have a Well Defined Scope of Work
- Outline the Sequence of Work
- Desired Pump and Tool Specifications
- Detailed Description of Methods
- Chemical Volumes, Concentrations and Disposal
- Pumping Rates and Recovery Rates Specified

Contracting

Lump Sum/Unit Cost

- Mob/Demob
- Pumping Tests
- Fluid Impulse
- Chemical Treatment (and Recovery/Neutralization)
- Superchlorination

Time and Materials

- Brushing/bailing
- Mechanical Development
- Stand-by and Delay Time
- Hourly work

Contractor Management

- Watch the Contractor Carefully During Execution
  - Specifications are just a suggestion to some
  - The field crew is likely disconnected from the decision making – no specs on site, no MSDSs
- Make sure contractor and any subcontractor(s) are on the same page
  - Time considerations
  - Sequencing of work
  - Equipment needed
- Verify they have delivered the scope of work
- Document what was done whether successful or not

Did it Work?

When it does – Great!   When it doesn't work - What went wrong?

<u>Be Prepared to Re-evaluate the Approach and Methods</u>

After the Rehabilitation

- Preventative Maintenance Program
  - Redevelopment or Treatments
- Periodic monitoring
  - Pump Performance
  - Well Performance
  - Chemistry
  - Bacterial monitoring

- Develop Threshold Criteria for Action
  - Loss of Specific Capacity
  - Bacterial Population

Address the Mechanisms

Changes in Operation

- Longer Run Cycles
- Lower Pumping Rates

Changes in Well Construction

- Eliminating "trouble zones" in well
- Physically Limiting Oxygen to the Well
- Flexible Pump Column
- Access to the Well

Thank You!

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Cornell Names PumpTech Its Top Industrial Distributor

Cornell Pump Company (Clackamas, Oregon) has named PumpTech its number one industrial pump distributor in the US. Cornell manufacturers a wide line of clear water, solids handling, hot oil and food processing pumps for numerous industrial applications.

Mike Shoemaker, PumpTech's Industrial Products Manager, accepted the award at the annual distributor's meeting in Chicago. Our industrial sales team covers Idaho, Oregon and Washington and focuses on the food processing, petrochemical, oil & gas, lumber, pulp & paper, power generation, and aluminum industries.

In addition to Cornell, PumpTech represents a number of other manufacturers of specialty industrial products. Congratulations to our industrial sales team !

PumpTech Named NW Master Distributor for Grundfos

Grundfos Pumps (Olathe, Kansas) has selected PumpTech as the Pacific Northwest master distributor for its Grundfos Dosing line of chemical metering pumps.

The product line includes a wide range of diaphragm metering pumps with flows to 1050 GPH and pressures up to 3000 PSI. Grundfos Dosing pumps offer a variety of metering technologies including digital dosing. Digital dosing pumps utilize stepper-motors that allow a 1000:1 turn down. In addition to dosing pumps, Grundfos offers a complete line of measurement & disinfection equipment including one of the best chlorine generators on the market.

Per this agreement PumpTech will stock $100,000 of Grundfos Dosing pumps to support sales in the Pacific Northwest. This inventory will be centrally located in our Canby, OR branch and will allow quick delivery to other distributors, end users, and OEM's. Additionally, this inventory will support our MeterMan division which manufactures chemical metering systems in our Canby facility and also functions as the Grundfos Key Systems provider for the entire western United States.

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Ammonia Skids
Oil Sands Skid
Maintenance
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PumpTech's Feature Rich Multi-Pump Controller

PumpTech's intelligent, multi-pump controller features an integrated PLC and Color Touch-Screen Human Machine Interface (HMI) that makes setup simple and extremely flexible. Up to four pumps can be set up for VFD control, across the line starting or a combination of the two.

The controller is preprogrammed for pump down, level control and booster applications. At start up all you have to do is select the application and follow the setup instructions on the screen.

The PLC provides for 22 digital inputs and 12 digital outputs. Also two 4-20mA or 0-10VDC transducer inputs are provided.

When motors are started across the line or via RVSS, "smart" motor

Continued on Page 4

QCEC Introduces New Refrigerated Sampler

Quality Control Equipment Company (QCEC) has introduced a new sampler with a modular refrigeration system. The refrigerator unit slides out for easy service or replacement. All units are made right here in the US and come with a 2 year warranty.

It features the same, time proven sampling technology that has set QCEC apart from its competition for over 40 years. All samplers use vacuum pumps rather than peristaltic pumps for higher reliability and accuracy. Vacuum pumps never need hose replacement and increase the sampling range by providing lifts to 28 feet and horizontal runs up to 150 feet. This provides lots of flexibility when locating the sampling unit.

The QLS model is the only sampler in the world that provides repeatable, self calibration and consistent sample size. It also provides flow - paced samples from a 4 - 20 input.

For more information on the features and benefits of QCEC samplers, contact your local PumpTech branch.

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Joe Evans, Ph.D

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Vertical Turbine Pumps

Approved for 0.3 CEU's

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OR – OESAC # 2228
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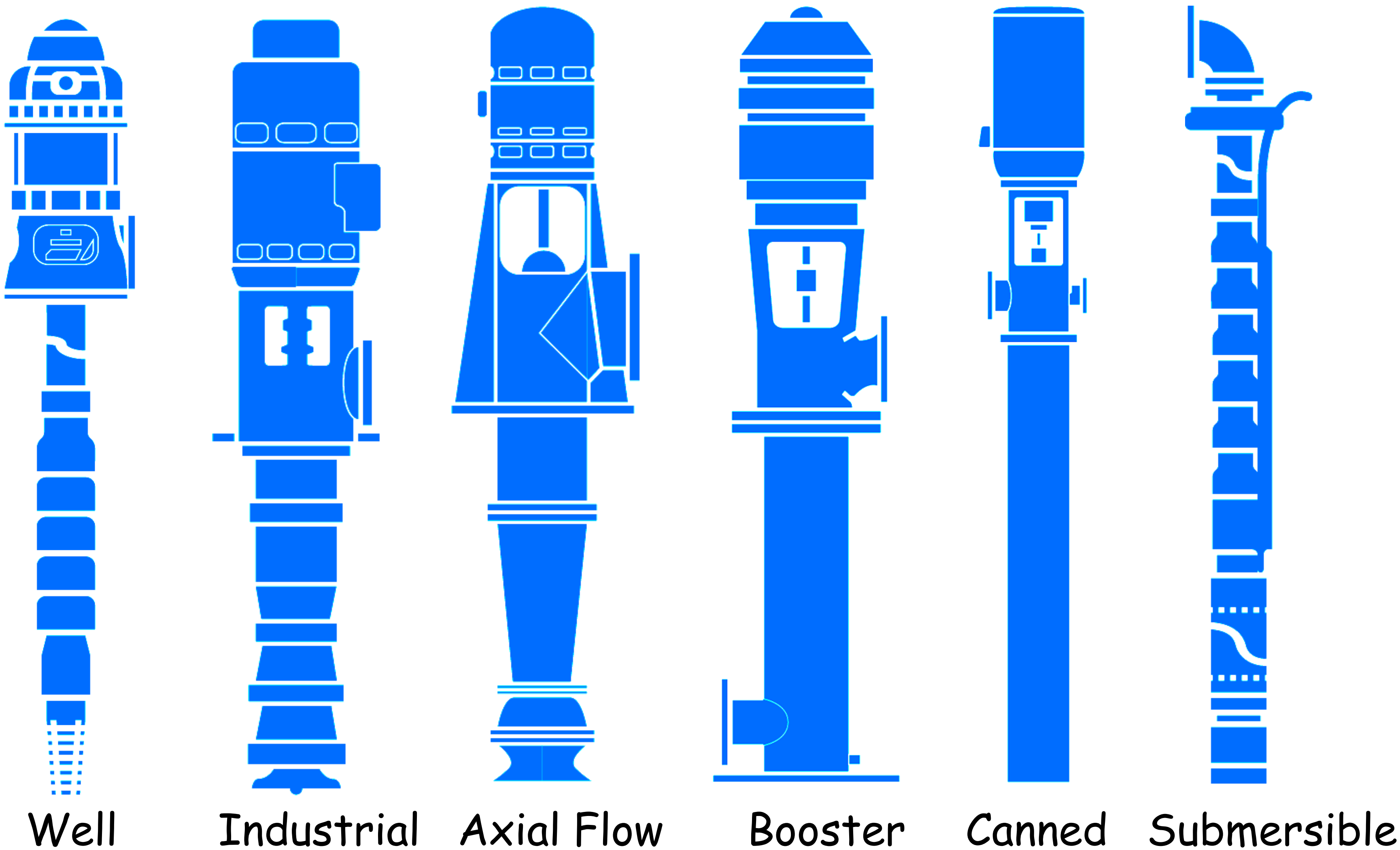
Vertical Turbine Types



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Lineshaft versus Submersible

1750 RPM
Versus
3450 RPM

Wear ≈ ΔS^2

Tension
Versus
Compression

Lineshaft versus Submersible

When & Why Should You Choose a Submersible ?

Lineshaft versus Submersible

When & Why Should You Choose a Submersible

Small Well Installations Under 40 HP

When First Cost is the Only Factor

Extremely Deep Settings

Crooked Wells

Some Ag Irrigation Applications

Flooding

Noise

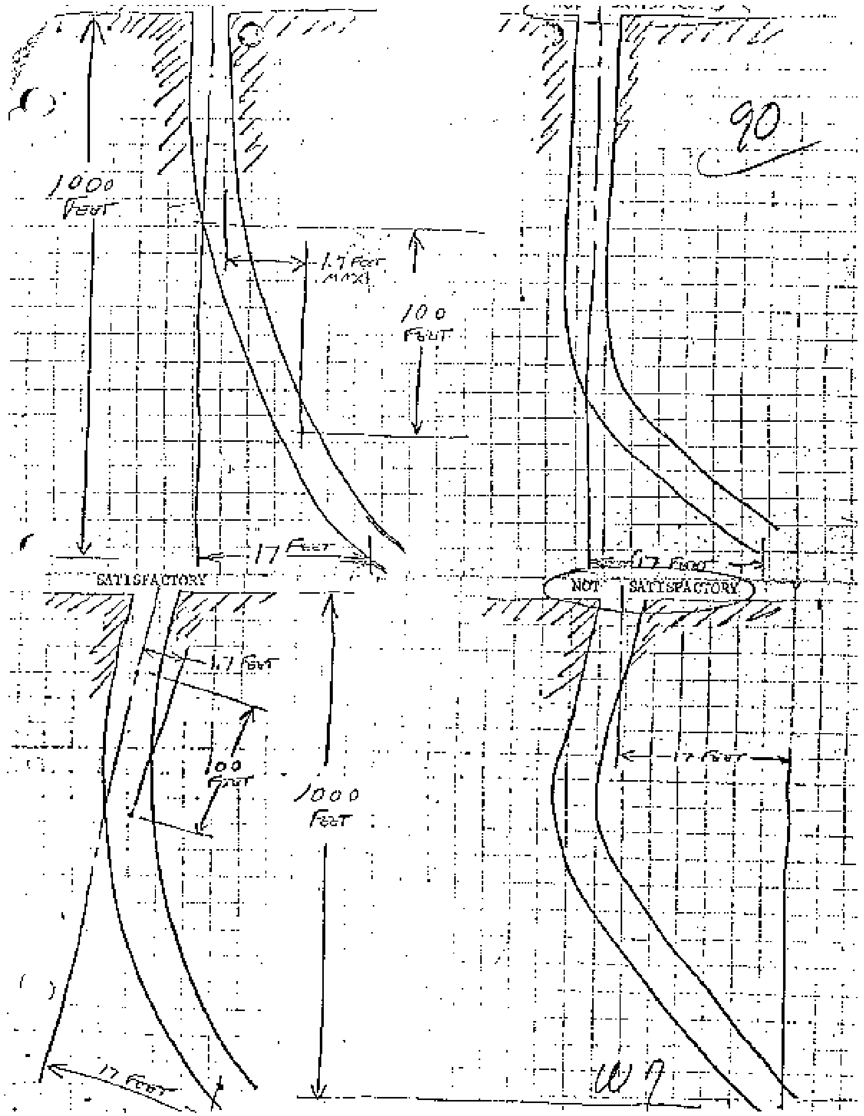
Well Angle & Straightness

No bore is ever perfectly straight but, there are limitations that cannot be exceeded.

Most lineshaft manufacturers recommend a non-straightness of no more than 20" (1.7') per 100' of column pipe.

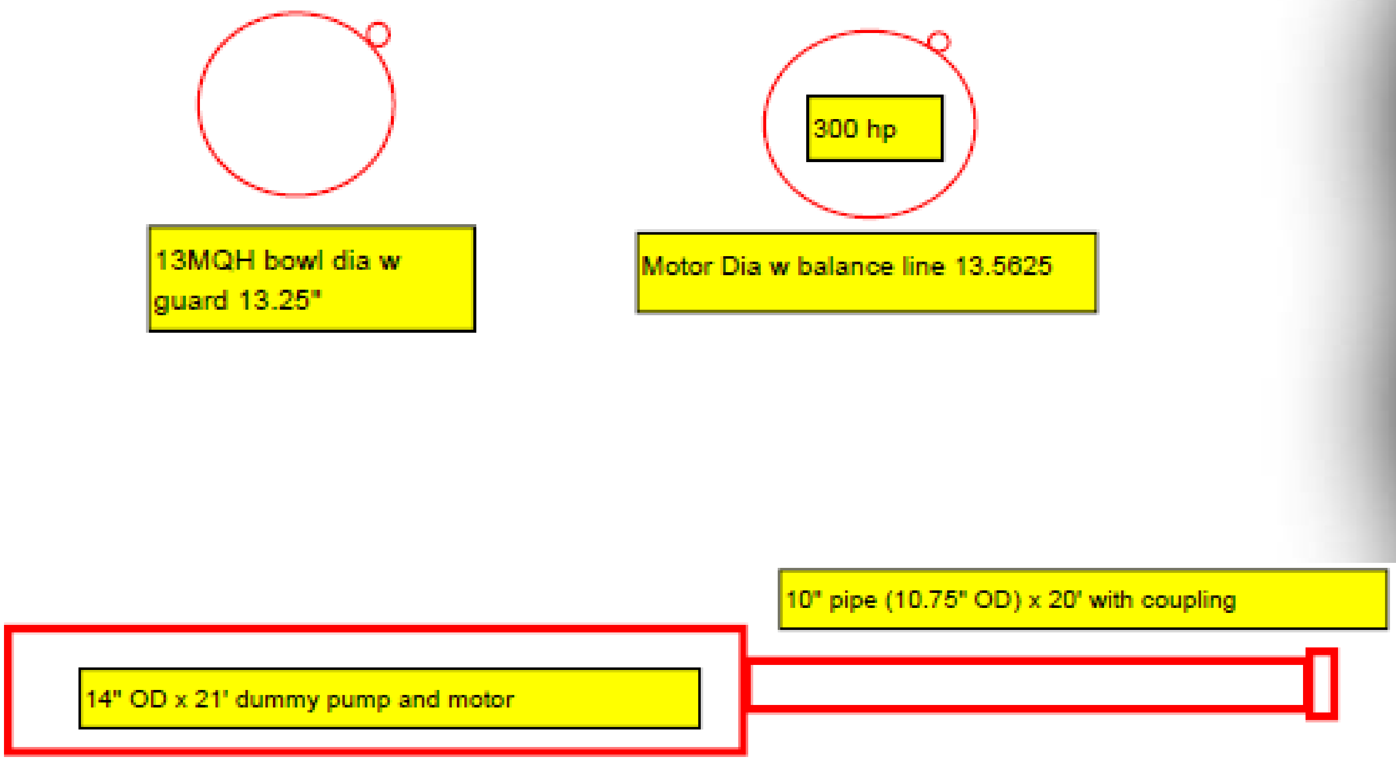
For example a 1000' deep well could have a total offset of 17' between the top and bottom but each 100' section cannot exceed 1.7'.

Well Angle & Straightness



Pump ED 101

Dummy Pump Test



Well Development

Well development can be more critical for submersible pump installations.

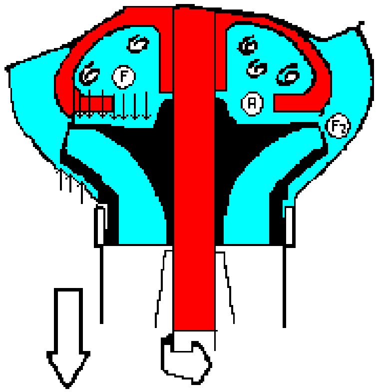
Sand Locking

The submersible pump lateral clearances must be adjusted prior to installation.

If excessive amounts of sand is present after installation the pump can sand lock when it stops.

Lineshaft versus Submersible

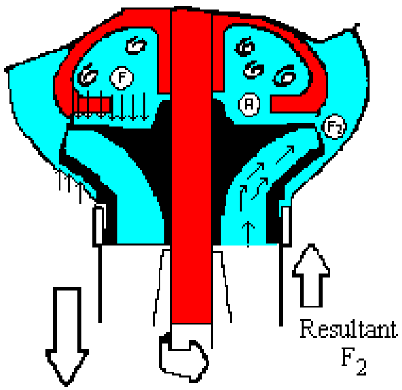
Downthrust



Highest at Shut Off

Kingsbury Thrust Bearing

Upthrust



Usually Occurs During Starting

Can be continuous at 125% of BEP flow

Also high static water level & slow drawdown

Bolt Thrust Bearing

Lineshaft versus Submersible Motors

Lineshaft Motors

Hollow or Solid Shaft

1750 RPM & Lower

Premium Efficiency

Lower Cost

Replaceable Thrust Bearings

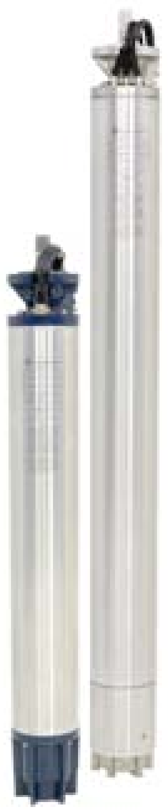
Adjustable Impeller Clearances

Lots of Options

Shaft Losses

Lineshaft versus Submersible Motors

Submersible Motors



Lower Efficiency

Lower PF

Higher Starting Current (25%)

Lower Tolerance to Overload & Voltage Drop

Usually 3450 RPM

Higher Cost

Cable Costs

Cable Losses

Carbon Thrust Bearing

No Upthrust Capability

PumpTech inc.

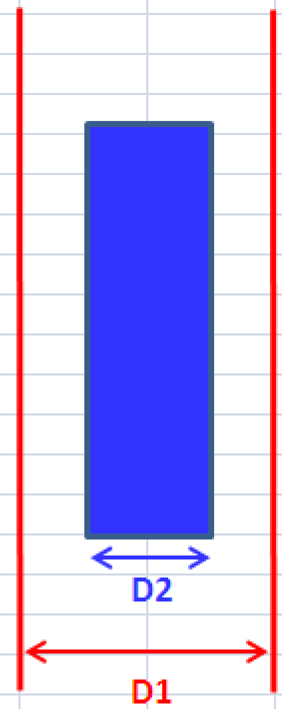
Lineshaft versus Submersible Motors

SUBMERSIBLE MOTOR FLOW VELOCITY CALCULATOR

INPUT DATA	
D1 Casing ID (inches)	10.0
D2 Motor OD (inches)	7.5
Flow (GPM)	1000.0
CALCULATED RESULTS	
Effective Flow Area (sqare inches)	34.4
Effective Flow ID (inches)	6.6
Flow Velocity (ft/sec)	9.3
Friction Loss (per foot of motor length)	0.04

Notes:

Friction loss is in feet of water & assumes smooth steel (HW=140)



*

Motor & Pump Efficiency

Motor Efficiency = Mechanical Power / Electrical Power

Pump Efficiency = Fluid Power / Mechanical Power

Total Efficiency = Pump Efficiency X Motor Efficiency

*

Motor & Pump Efficiency

Total Efficiency = Pump Efficiency X Motor Efficiency

10 Bags → **Motor** → 9 Bags → **Pump** → 7 Bags → **Total**

Motor	Pump	Total
90 %	78 %	70 %

0.90 X 0.78 = 0.70 = 70%

*

Motor & Pump Efficiency

Wire to Water Energy Calculator

REQUIRED DATA	PUMP 1	PUMP 2
Pump Operation - Hours / Day	8	8
Pump Operation - Days / Year	365	365
Pump Flow - GPM	500	500
Pump Head - Feet	300	300
Pump Efficiency - %	80%	75%
Motor Efficiency - %	94.1%	83.0%
Energy Cost in $/KWH	$0.10	$0.10
RESULTS		
BHP At Design Point	47.3	50.5
Wire to Water Efficiency - %	75%	62%
Annual Energy Cost	$10,960.70	$13,254.96
KW Per 1000 Gallons Pumped	1.251	1.513
Cost Per 1000 Gallons Pumped	$0.125	$0.151

PumpTech Inc.

12020 SE 32nd Street #2
Bellevue, WA 98005
888-644-6686

2425 SE Ochoco Street
Portland, OR 97222
503-659-6230

209 S Hamilton Road
Moses Lake, WA 98837
509-766-6330

$ 2294.00 / Year

Pump ED 101

Centrifugal Pump Training Series

Lineshafts Versus Submersibles

Joe Evans, Ph.D

http://www.PumpEd101.com

http://www.Pumptechnw.com

CH2MHILL

Groundwater Treatment Technologies

PNWS
IDAHO • OREGON • WASHINGTON

GO WITH THE FLOW
2012 PNWS • YAKIMA, WA

Meeting regulatory, customer, and supply challenges

Groundwater Treatment Challenges

Regulatory

Arsenic
Volatile Organics
Perchlorate
Hexavalent Chromium

Customer

Iron
Manganese
Hydrogen Sulfide

Supply

Brackish Water
Nitrate
Ammonia
Very High Iron
Aquifer Recovery
Advanced Water Treatment

Treatment Technology is Evolving to Make Treatment for Cost Effective

Regulatory Treatment Challenges

Arsenic –	**MCL in 2001, new Health effects info**
Volatile Organics –	**CVOCs regulated as a contaminant Class**
Perchlorate -	**Regulatory determination expected this fall**
Hexavalent Chromium -	**Long way off, but in the news**

Arsenic

Coagulation Filtration

- Ferric Chloride
- Optimized Treatment
  - Pre-oxidation
  - Optimized dose
  - pH adjustment
- Deeper Filter Beds,
- Higher Loading Rates

Adsorptive Media

- Iron, Titanium, AA, ZVI
- Media costs remain high
- Water quality dependent
- Can test duration using RSSCT
- Provide your own tanks, negotiate media supply/disposal contracts
- Do it yourself with GAC, ferric, citric acid

Arsenic Strategies for Future

Comparison of Contact Time Impact on Prechlorination for Arsenic Removal, CH2M HILL 2010

FIGURE 1: CHLORINE/ACID/FERRIC/CONTACT TANK

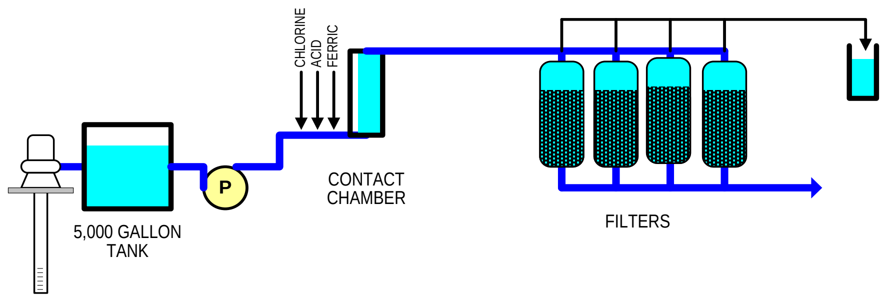
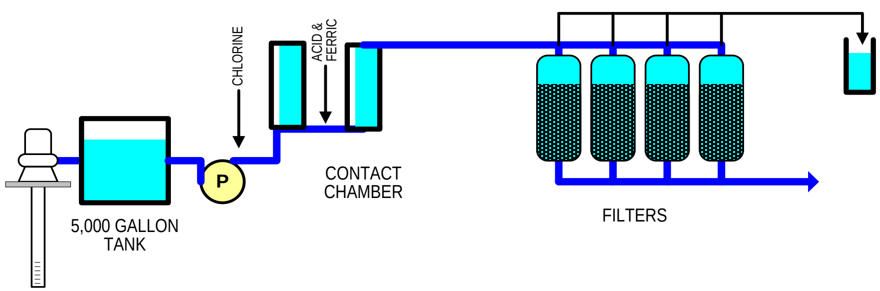


FIGURE 2: CHLORINE/CONTACT TANK/ACID/FERRIC/CONTACT TANK



TMWA I-Street Well

Sparks, NV

	Non Optimized	Optimized
Process	See Figure 1	See Figure 2
Raw Water Arsenic, ug/L	158	158
Finished Water Arsneic, ug/L	9.02	1.24
Percent Removal	94.3%	99.2%
Number of Samples	23	19
Raw Water pH	7.7	7.7
Ferric Chloride Dose, mg/L	26	21
Treated Water pH	6.7	6.72
Filter Loading Rate, gpm/sq ft	6.0	6.0
Media Type	Manganese Dioxide	Manganese Dioxide
Media Depth, In	42"	42"

CH2MHILL

Arsenic Strategies for Future

Media	Initial Arsenic, µg/L	Water Source	BV to 10 µg/L	mg As Absorbed per g Media	g Iron per g Media	Source
Iron–citric acid preloaded GAC	50–60	Rutland, Mass. pH 6	150,000	4.96	0.0054	AwwaRF, 2007
Ferrichite ($FeCl_3$ + chitosand)	3,580	Superfund Tacoma, Wash.	700	1.1	0.61	Chen et al., 2000
Chemical coating onto absorption media G2	200	Spiked distilled water	5,000	2	-	Winchester et al., 2000
Granular ferric hydroxide; Wasserchemie	16	Wildeck, Germany	85,000–7 µg/L	0.82	0.58	Driehaus, 2000
Granular ferric hydroxide	21	Stadtoldentrof, Germany	75,000–7 µg/L	1.08	0.58	Jekel and Seith, 2000
Granular ferric oxide media; US Filter/Siemens	18	Stockton, Calif.	25,000	0.2	0.58	McAuley, 2004
Granular ferric oxide media; Severn Trent	18	Stockton, Calif.	25,000	0.2	0.63	McAuley, 2004
Granular ferric oxide media; Wasserchemie	8	Barkersfield, Calif.	80,000–4 µg/L	0.26	0.58	McAuley, 2004
Granular ferric oxide media; Severn Trent	8	Barkersfield, Calif.	80,000–4 µg/L	0.26	0.63	McAuley, 2004
Granular ferric oxide media; Wasserchemie and US Filter/Siemens	15	Deionized water spiked with As	60,000–7 µg/L	0.58	0.58	Bradruzzaman et al., 2001
Zirconium-loaded activated carbon	500	Carbonate buffer spiked with As	5,900	2.8	0.028 g Zr/g	Daus et al., 2004
Absorptionsmittel 3	500	Carbonate buffer spiked with As	1,000	2	0.075	Daus et al., 2004
Iron hydroxide granules	500	Carbonate buffer spiked with As	13,100	2.3	0.323	Daus et al., 2004
Iron-impregnated polymer resin	50	Deionized water with anions, pH 7.5	4,000	0.32	0.09–0.12	DeMarco et al., 2003
Iron oxide–impregnated activated alumina	500	Deionized water with As, pH 12	500–50 µg/L	0.29	0.066	Kuriakose et al., 2004

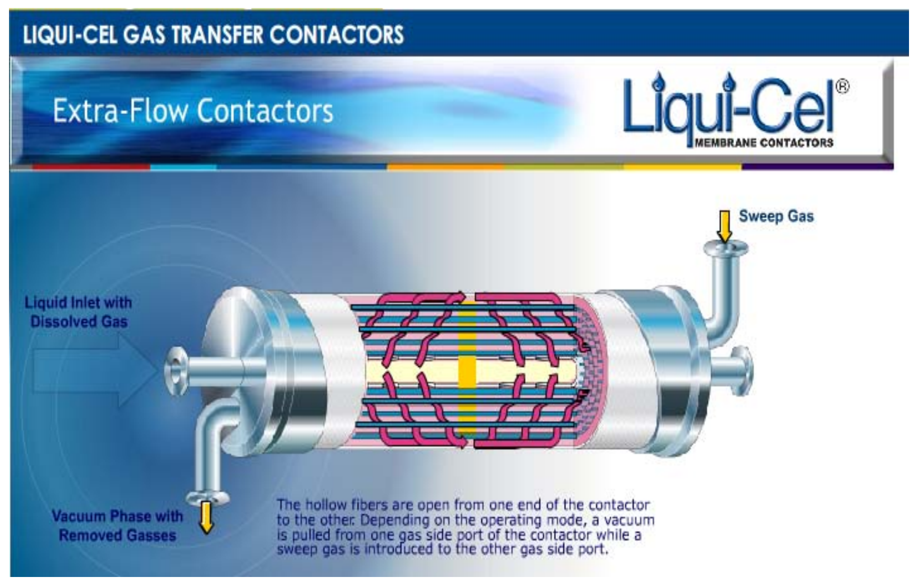
Owner-Purchased Tanks

Contract for Media Supply and Performance

Carcinogenic Volatile Organic Carbon - Class

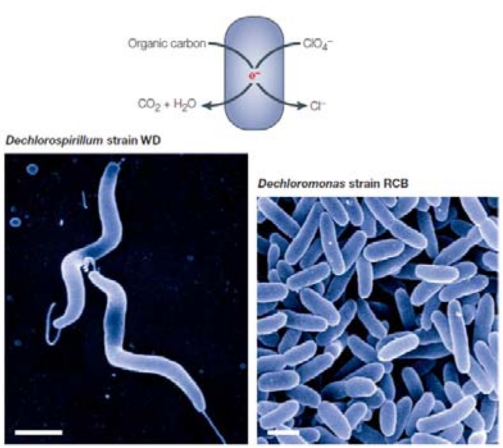
- What can you expect:
  - Treatment Technique
  - Best Available Technologies
  - Performance Standards

- Aeration
- GAC adsorption
- Degassing
- Advanced Oxidation
- Biological Degradation



Perchlorate

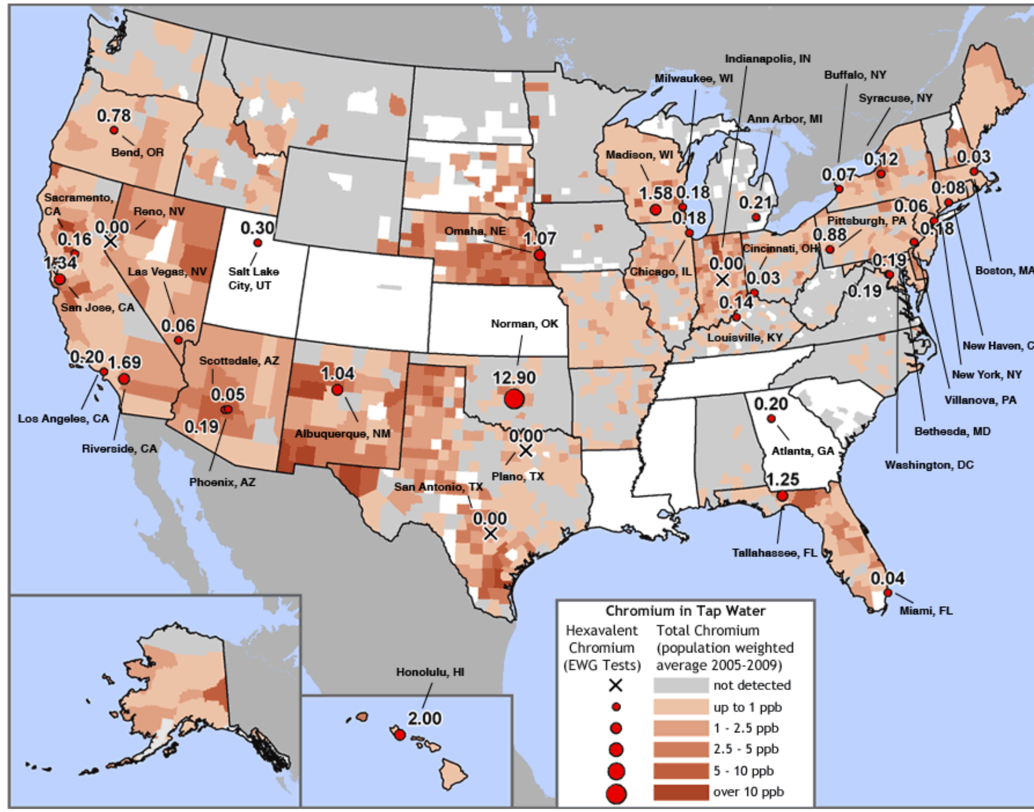
- Membrane Processes
  - Reverse Osmosis
  - Nanofiltration
- Ion Exchange
  - Perchlorate selective resins are available
- Biological Degradation
  - Anaerobic Reduction



- Costs, Energy, pretreatment, fouling
- Well understood
- Could adopt commercial de-nitrification processes

Hexavalent Chromium

- •Reduction/Coagulation/Filtration
- •Anion Exchange with WBA Resins
- •Anion Exchange with SBA resins
- •Granular Activated Carbon (low pH)
- •Reverse Osmosis
- •Reduction/Microfiltration
- •Nanofiltration
- •Electrodialysis
- •Zero-Valent Iron Adsorption
- •Biological Reduction/Filtration



Customer Treatment Challenges

Iron, Manganese –	**Keeping costs low is a design philosophy**
Hydrogen Sulfide –	**Off tastes and odors challenging**

Iron and Manganese Removal

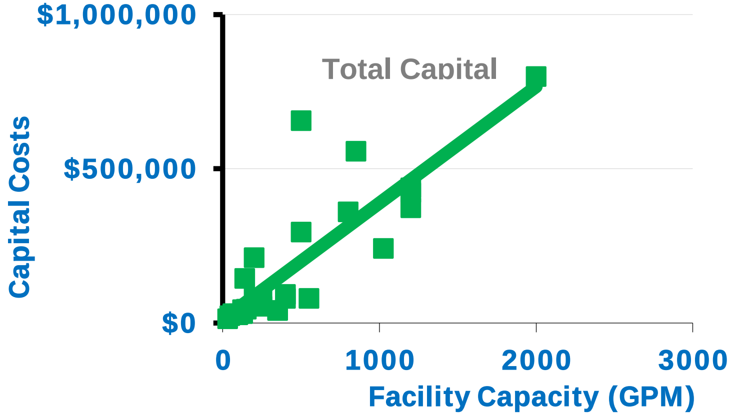
High Rate Removal

- Skid mounted systems
- Equipment supplier controls
- Eliminate Backwash Pumps
- Skid Mount Chemical Feed

Biological Removal

- High iron concentrations
- One or two stage systems
- Commercially available systems emerging

$0.3 to $0.8/ gallon of capacity



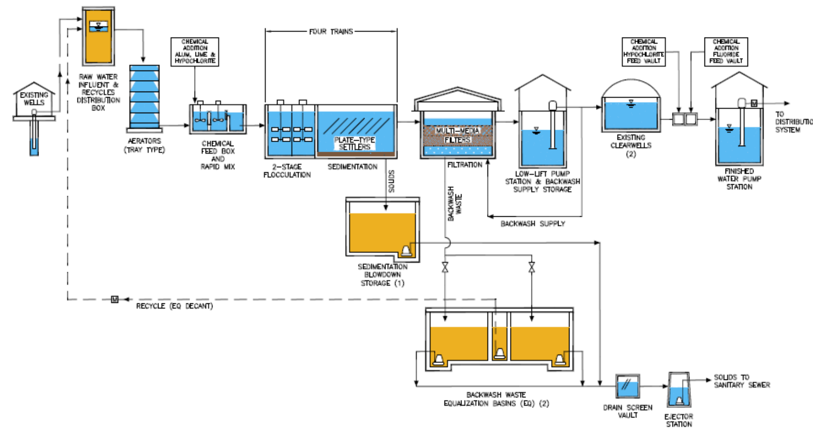
High Rate Removal

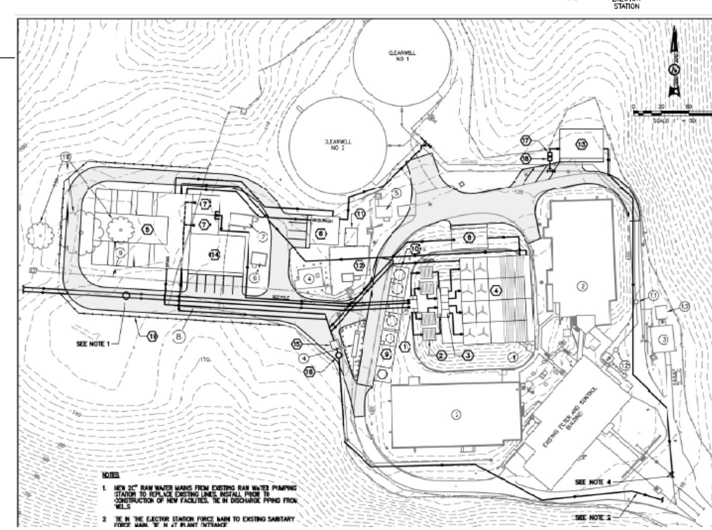
10 MGD SouthLake Plant, $4.5 million

Clark Public Utilities

Vancouver, WA

8 MGD Plant, Est $50 million





Biological Removal

Commercially Available Technology

Removal Capability

- Iron – 50 mg/L
- Manganese – 2 mg/L
- Ammonia – 1 mg/L
- Arsenic - 50 ug/L

Hydrogen Sulfide

Occurrence

- Biologically formed from SRB, can happen in distribution system, hot water tanks

Polysulfide Compounds

- Metallic Tastes,
- 24 hours to oxidize to sulfate
- Can revert back to H2S

Treatment Alternatives

Catalytic carbon–granular activated carbon
Greensand
Pyrolusite
Ion exchange
Chlorination
Ozonation
Advanced Oxidation
Aeration
Oxidation/reduction
Degassing
Biological Filtration

Water Supply Treatment Challenges

Brackish Water	**-**	**RO/NF**
Nitrate	**-**	**Biological Denitrification**
Ammonia	**-**	**Biological/adsorptive**
Very High Iron	**-**	**Biological**
Aquifer Recovery	**-**	**Arsenic/ Conditioning**
Advanced Water Treatment	**-**	**TDS, Disinfection, DBPs, EDCs, Nitrosamines**

Brackish Water

BWRO

Slime Formation in Strainers

Ammonia & Nitrogen

Ion Exchange

Biological Removal

Adsorption

Nitrate

Ammonia

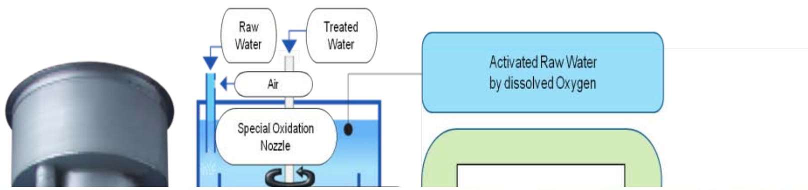
Glendale AZ Nitrate and Arsenic Removal Plant

Zone 4 Groundwater Treatment Plant
Glendale Arizona

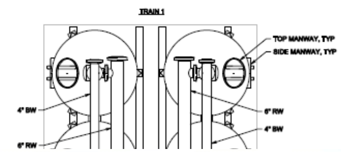
- 10 MGD Capacity
- Nitrate and Arsenic Removal
- Five, Twelve foot Diameter Vessels, 4.5 feet of Standard SBA Resin
- Two 75 Ton Brine Makers
- Recycles Waste Water
- Discharges 0.5% of Production
- S::CANs monitor Nitrate, pH, TOC and Turbidity

Very High Iron

Single Stage

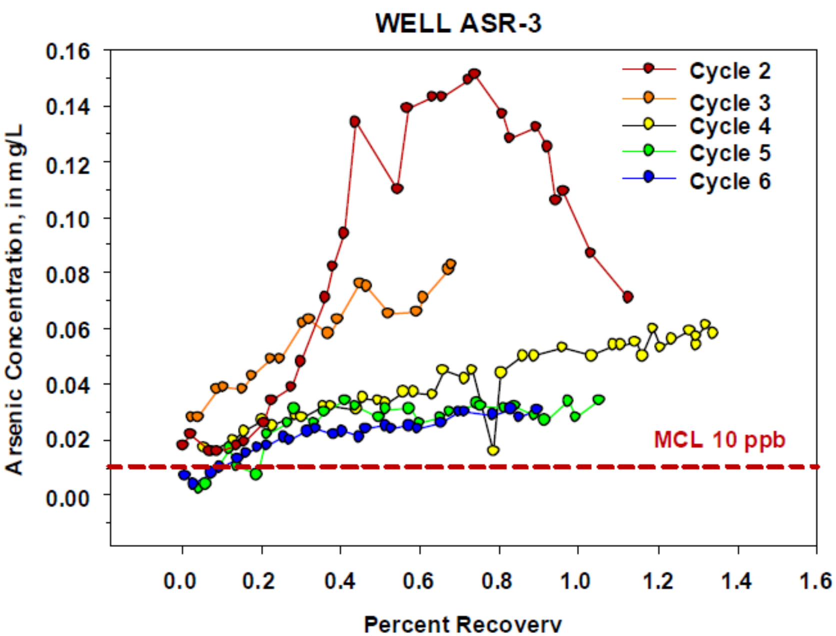


Dual Stage

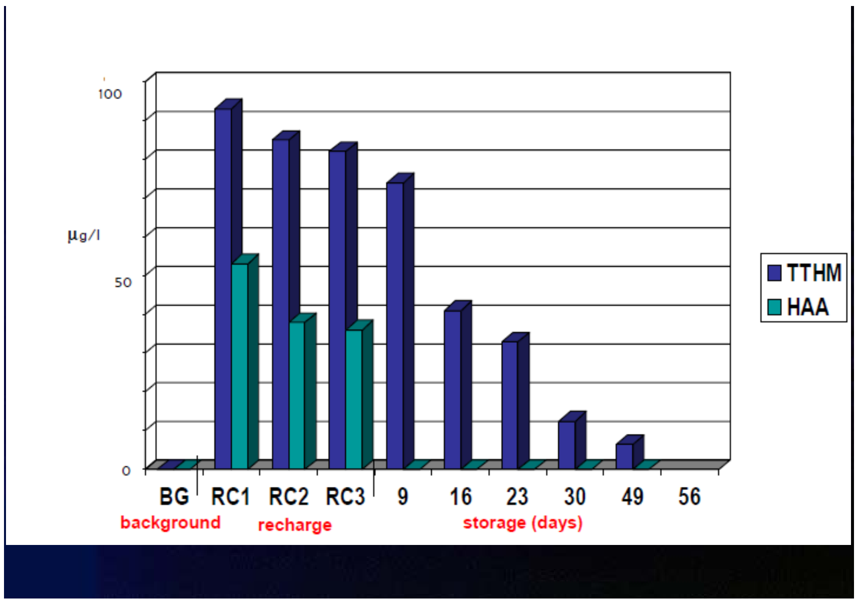


Aquifer Recovery

Arsenic



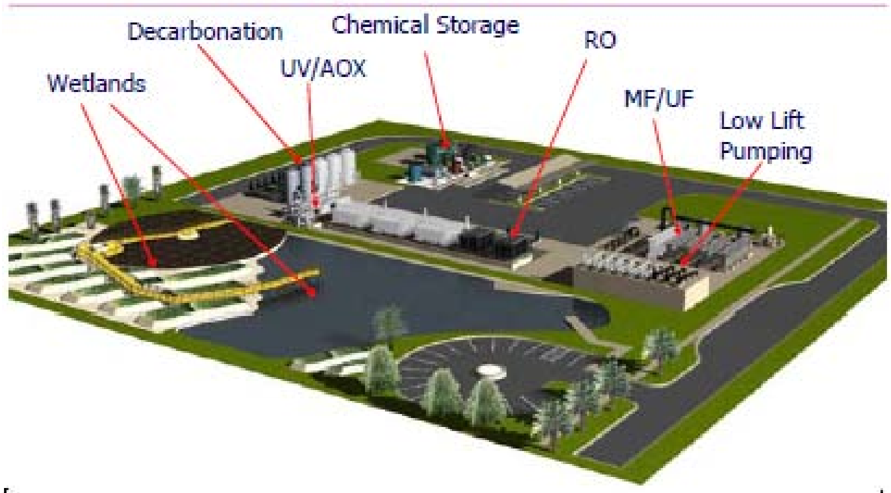
Aquifer Conditioning



Advanced Water Treatment

Groundwater Replenishment

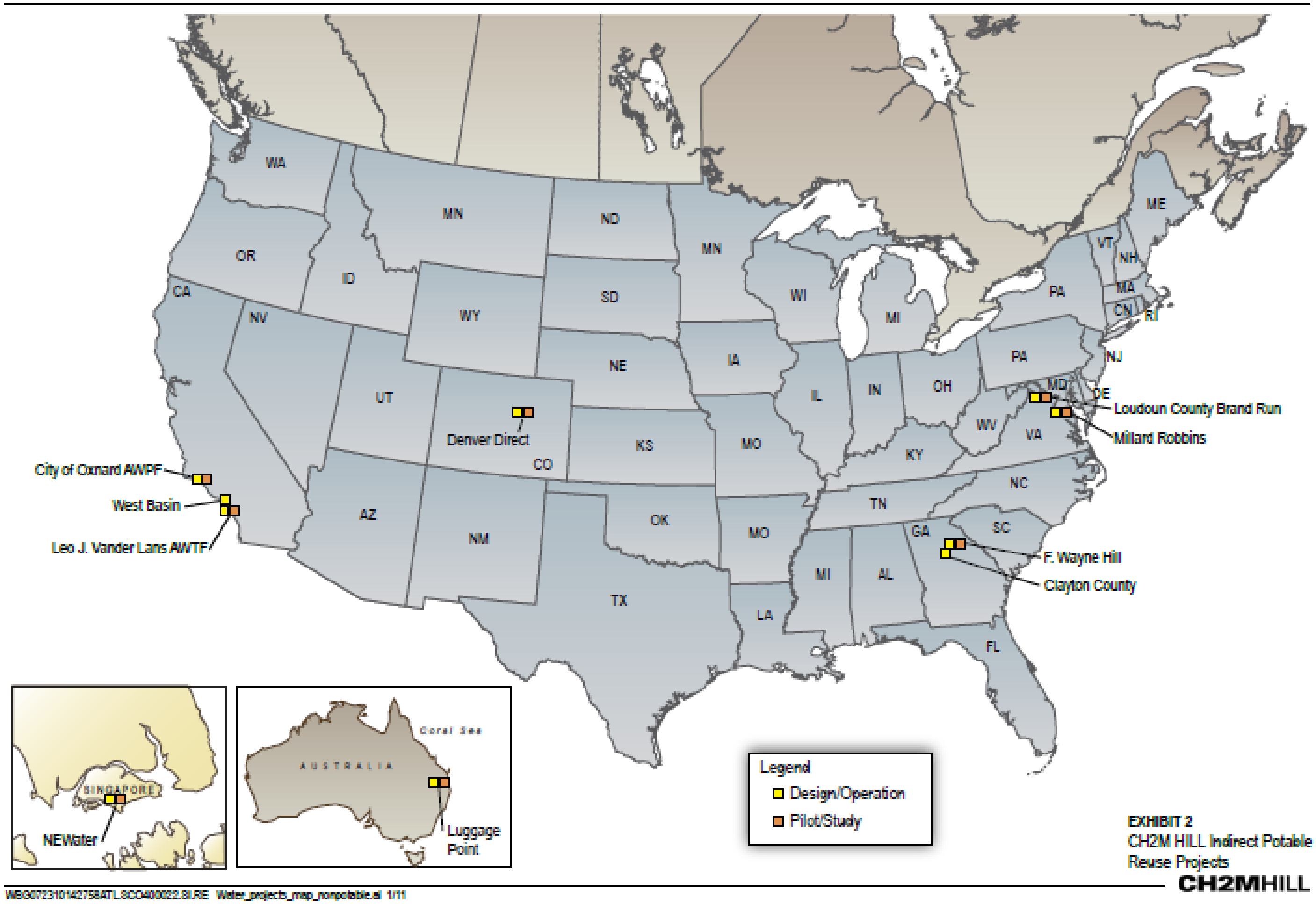
Oxnard groundwater recovery and enhancement Treatment (GREAT)



Advanced Water Purification

West Basin Recycling

Advanced Water Purification Projects



Questions?

Thank you!

Lee Odell, PE
Water Treatment Global Technology Lead
CH2M HILL

Groundwater Contaminants of Concern (or not)

Samuel A. L. Perry

Water Treatment Engineer

PUBLIC HEALTH
ALWAYS WORKING FOR A SAFER AND HEALTHIER WASHINGTON

Washington State Department of Health

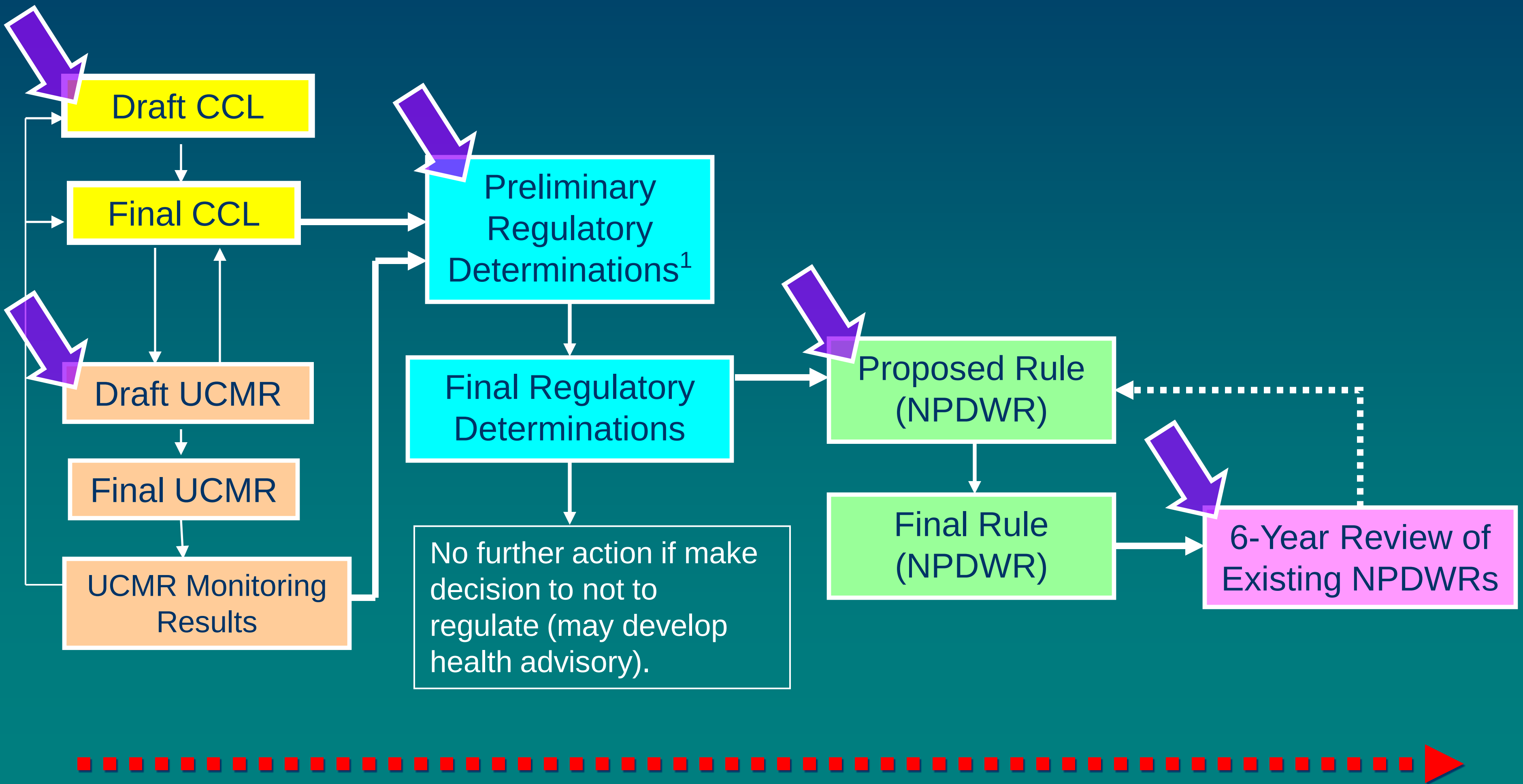
Mission

To protect the health of the people of Washington State by ensuring safe and reliable drinking water.

Overview

- General SDWA Regulatory Process
- Carcinogenic VOCs (Group)
  - 8 Regulated (Benzene, PCE, TCE, etc...)
  - 8 Unregulated (CCL3)
- Hexavalent Chromium
- Perchlorate

SDWA Regulatory Process



Three Criteria Used to Determine Whether or Not to Regulate

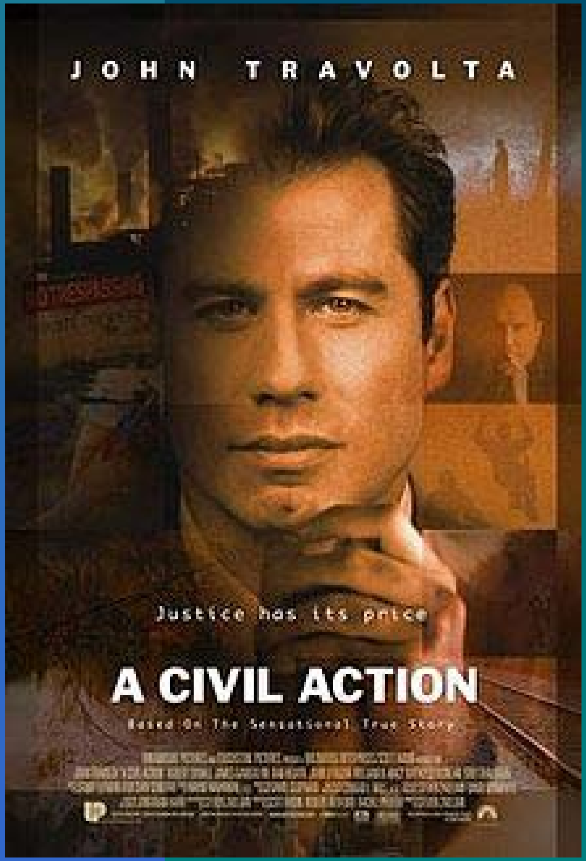
EPA is required to develop an MCLG and MCL for a contaminant if the Administrator determines that:

1. **The contaminant may have an adverse human health effect**
2. **The contaminant occurs or is likely to occur in drinking water at a level of public health concern**
3. **Regulation of the contaminant presents a meaningful opportunity for health risk reduction**

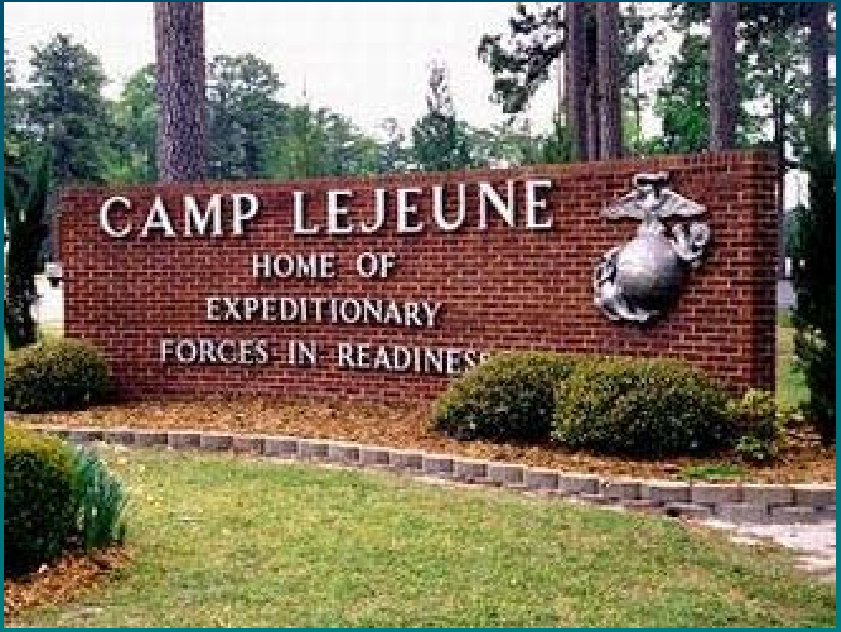
#1 - Carcinogenic VOCs (cVOCs)

High Profile Carcinogenic VOCs

Woburn, MA - 1970's



Camp LeJeune, NC - 2009



EPA's New Drinking Water Strategy

March 22, 2010 – EPA Administrator Lisa Jackson outlines new approach for protecting drinking water and public health at AMWA meeting:

1. ***Address contaminants as groups rather than one at a time***
2. **Foster development of new drinking water technologies**
3. **Use the authority of multiple statutes to help protect drinking water**
4. **Partner with States to share more complete data from monitoring at public water systems**

Groups for Potential Regulatory Development

Near Term

- Carcinogenic VOCs
- Nitrosamines
- DBPs from Chlorination

Future Consideration

- Perfluorinated compounds (7)
- Organophosphate pesticides (31)
- Carbamate pesticides (11)
- Triazine pesticides (6)
- Chloroacetanilides (9)
- Cyanotoxins (3)

Carcinogenic VOCs (cVOCs)

Currently Regulated (8)
- Benzene
- Carbon tetrachloride
- 1,2 dichloroethane
- 1,2 dichloropropane
- Dichloromethane
- Tertrachloroethylene
- Trichloroethylene
- Vinyl chloride

Unregulated – CCL3 (8)
- Aniline
- Benzyl chloride
- 1,3 butadiene*
- 1,1 dichloroethane*
- Nitrobenzene
- Oxirane methyl
- 1,2,3-trichloropropane*
- Urethane

*On proposed UCMR3

Carcinogenic VOCs (cVOCs)

Currently Regulated	MCL
Benzene	0.005 mg/L
Carbon tetrachloride	0.005 mg/L
1,2 dichloroethane	0.005 mg/L
1,2 dichloropropane	0.005 mg/L
Dichloromethane	0.005 mg/L
Tertrachloroethylene	0.005 mg/L
Trichloroethylene	0.005 mg/L
Vinyl chloride	0.002 mg/L

cVOCs – Update from EPA

- EPA has initiated the process to develop a group cVOC standard and will:
  - Develop a group NPDWR for regulated and unregulated carcinogenic VOCs (cVOCs) that improves or maintains public health protection
  - Assess potential cVOCs for the group based upon
    - Similar health effect endpoints [Carcinogenic]
    - Common analytical method(s) [EPA Method 524.3]
    - Common treatment or control processes [Air Stripping; GAC]
    - Occurrence/co-occurrence in drinking water [TCE/PCE/????]

cVOCs – Update from EPA (cont.)

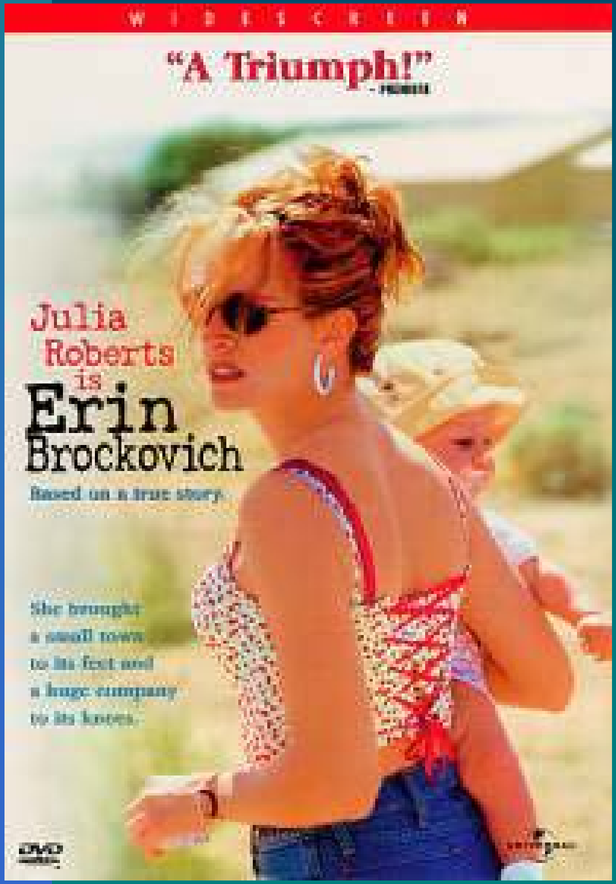
- EPA will also:
  - Evaluate options for setting cVOC MCL(s) and examine the feasibility of analytical methods and treatment technologies, and costs/benefits for the group
  - Hold consultations from June-December 2012:
    - Public stakeholder meeting
    - Science Advisory Board
    - National Drinking Water Advisory Council
    - Small Business Regulatory Enforcement Fairness Act
    - National Tribal Water Council
- EPA expects to propose a regulation in Fall 2013

Ref. U.S. EPA 3/2012

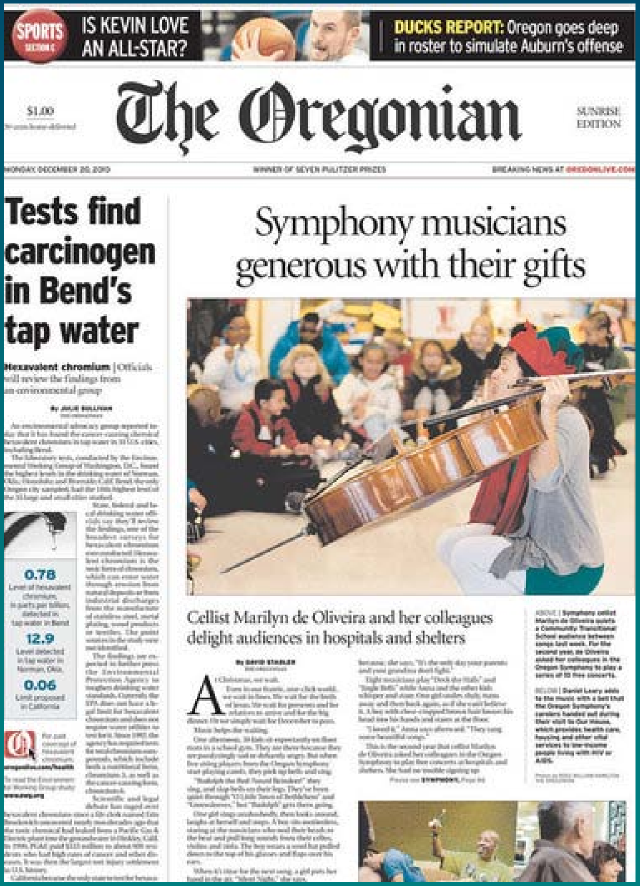
#2 – Hexavalent Chromium

Chromium – Then. . . And Now

March 2000



December 2010


SPORTS
IS KEVIN LOVE AN ALL-STAR?
DUCKS REPORT: Oregon goes deep in roster to simulate Auburn's offense

The Oregonian

SUNRISE EDITION

Tests find carcinogen in Bend's tap water

Hexavalent chromium | Officials will review the findings from an environmental group

0.78 Level of hexavalent chromium, in parts per billion, detected in tap water in Bend

12.9 Level detected in tap water in Norman, Okla.

0.06 Limit proposed in California

Symphony musicians generous with their gifts

Cellist Marilyn de Oliveira and her colleagues delight audiences in hospitals and shelters

Chromium – Ancient History

- 1946 – USPHS standard of 50 ppb (measured as total chromium)
- 1975 – U.S. EPA reaffirms 50 ppb standard
- 1991 – U.S. EPA increases MCL to 100 ppb

… Meanwhile – WHO standard stay at 50 ppb

- 1999 – CA Public Health Goal of 2.5 ppb

Chromium – Recent History

- **Aug. 2009 – CA Public Health Goal of 0.06 ppb**
- **Sept. 2010 – U.S. EPA releases draft tox review – Cr+6 in drinking water likely to be carcinogenic**
- ***Dec. 2010 – EWG releases report on Cr+6***
- **Jan. 2011 – U.S. EPA recommends utilities conduct "voluntary monitoring" for Cr+6.**
- **March 2011 – Proposed UCMR3 released**
- **May 2011 – AWWA supports Cr/Cr+6 monitoring in the final UCMR3**
- **July 2011 – CA Public Health Goal of 0.02 ppb**
- **Feb. 2012 – AWWA Webcast – MOA Research**

Chromium – Occurrence

Percent of Systems with Source Waters Exceeding Cr(VI) Thresholds

Concentration	All Sources	Groundwater	Surface Water
0.2 ppb	39.0%	46.5%	23.9%
1.0 ppb	17.5%	25.4%	1.8%
3.0 ppb	8.8%	12.7%	0.9%
5.0 ppb	5.6%	7.9%	0.9%
10.0 ppb	1.5%	2.2%	0.0%

Ref. Drinking Water Research (2011)

Chromium – Recent Toxicology

- **ToxStrategies Inc. Report (May 2011; Feb. 2012)**
  - **Tumor formation in small intestine - high doses cause chronic tissue wound and healing**
  - **At concentration of 100 ppb (current MCL), there is no direct toxicity to intestinal cells**
  - **Low doses of Cr+6 are reduced to Cr+3 in the stomach, but reduction can be saturated**
  - **Extrapolation from high dose to low dose using a linear model is <u>not</u> supported (there is a threshold)**

Chromium – EPA Update

- Toxicological Review
  - Sept. 2010, peer review draft IRIS Toxicological Review of Cr+6, proposed to classify Cr+6 as likely to be carcinogenic to humans when ingested
  - Based on the recommendations of the external peer review panel, EPA will consider the results of recent research on Cr+6 before finalizing the IRIS assessment
  - EPA anticipates that a revised draft assessment for Cr+6 will be released for public comment and external peer review in 2013, and that a final assessment will be completed by 2015

Ref. U.S. EPA 3/2012

#3 - Perchlorate

Perchlorate

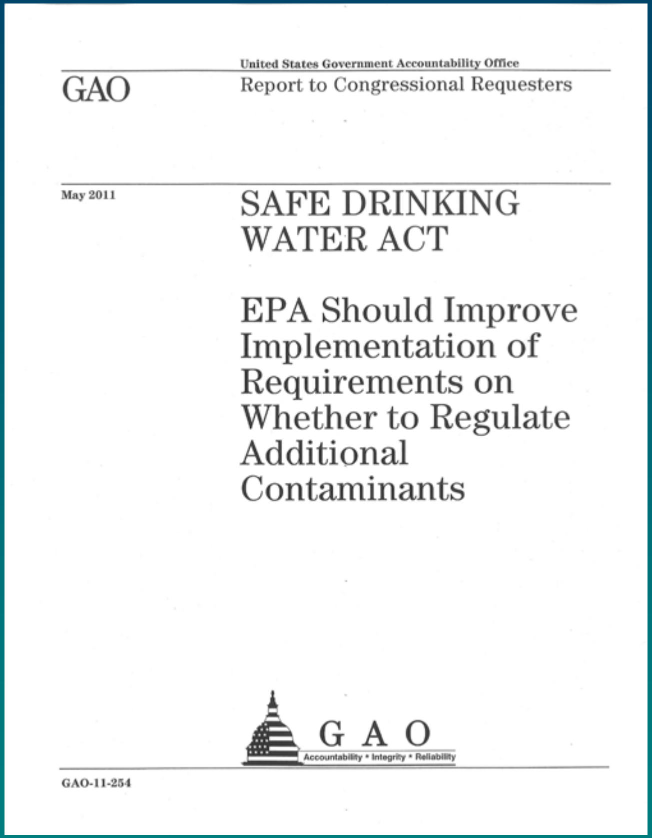
- Sources in the environment:
  - Solid rocket fuel (90% of use)
  - Flares, fireworks, ordinance
  - Chilean nitrate fertilizer
  - Lightning
  - Hypochlorite (high strength, storage)
- Very soluble in water
- Disrupts iodine uptake by thyroid
- Pregnant women and infants most vulnerable
- Regulated in some states
- Monitored under the UCMR 1, other sources of information

Perchlorate – Regulatory History

- Early 1990s – Perchlorate >1,000 ppb found in CA
- 1997 – EPA Method 314.0 - lower detection limit
- 1998 – Perchlorate added to CCL1
- 2001 – Perchlorate monitoring under UCMR1
- 2002 – Proposed Reference Dose = DWEL 1 ppb
- 2005 – National Academy of Sciences Risk Assessment; EPA sets DWEL 24.5 ppb
- Oct. 2008 – Preliminary Regulatory Determination
- Jan. 2009 – EPA Interim Health Advisory - 15 ppb
- Feb. 2011 – Final Regulatory Determination

Perchlorate – GAO Audit

- **GAO report released May 2011**
- **Broadly critical of political appointees involvement in the scientific process**
  - **In 2008 preliminary regulatory determination, "*EPA used a process that … lacked transparency and limited the agency independence in developing scientific findings*".**
  - **"*The Assistant Administrator directed staff to develop a determination not to regulate*"**
  - **"*The agency mischaracterized important scientific findings on the sensitivity of [infants] to perchlorate*"**


GAO

United States Government Accountability Office

Report to Congressional Requesters

May 2011

SAFE DRINKING WATER ACT

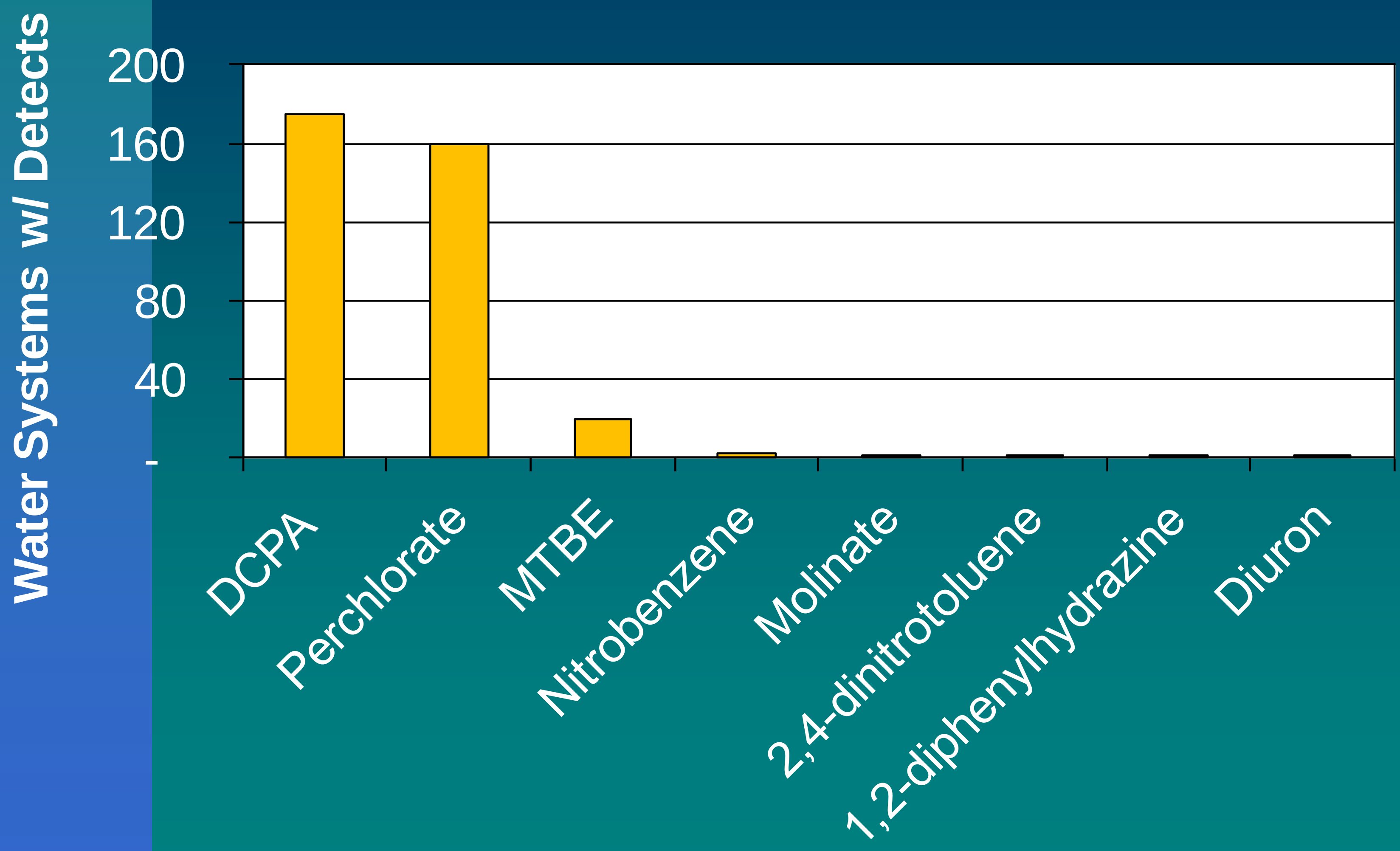
EPA Should Improve Implementation of Requirements on Whether to Regulate Additional Contaminants

GAO

Accountability * Integrity * Reliability

GAO-11-254

Perchlorate – UCMR Round 1



Perchlorate – Occurrence

Percent of Systems with Source Waters Exceeding Perchlorate Thresholds

Concentration	UCMR - 1	CA- DHS
2 ppb	4.1%	10.5%
4 ppb	2.6%	5.8%
6 ppb	1.6%	3.2%
10 ppb	0.9%	1.5%
20 ppb	0.2%	0.3%

Ref. Clark and Brandhuber (2005)

Perchlorate – EPA Update

- **EPA has initiated the process to develop a perchlorate standard and will:**
  - Continue to evaluate perchlorate health effects and occurrence
  - Evaluate the feasibility of treatment technologies to remove perchlorate and examine the costs and benefits of potential standards
  - Seek guidance from SAB regarding how to best use new information for the derivation of a perchlorate MCLG
  - Consult with the National Drinking Water Advisory Council prior to proposing the perchlorate rule
  - EPA briefed the National Tribal Water Council and held two consultations with Tribes-final consultation is scheduled for May 1
  - EPA intends to hold a public stakeholder meeting in summer 2012

Perchlorate – EPA Update (cont.)

- The SDWA deadline to publish the proposed regulation for comment is February 2013
- SDWA requires final regulation within 18 months of the proposal

Ref. U.S. EPA 3/2012

Conclusions

- SDWA Regulatory Determination Process – No new chemical MCLs since 1996
- cVOCs – Expect a proposed group MCL in late 2013
- Cr+6 – A revised MCL is questionable
- Perchlorate – Expect a proposed MCL by early 2013

Questions & Comments

PUBLIC HEALTH
ALWAYS WORKING FOR A SAFER AND
HEALTHIER WASHINGTON

Washington State Department of
Health

For More Information

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Water Right Permitting 101

TIPS FOR SUCCESSFUL WATER RIGHT PERMITTING

PGG

Let's Talk About

- Ways to get your application processed
- Understanding the actual work load
- Why use Water Conservancy Boards
- Understanding and making the most of Cost Reimbursement process

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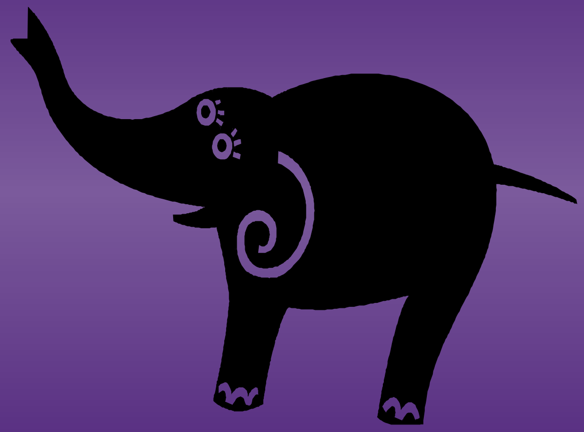
The Obvious

- New water rights are hard to get but still possible
- Changes and transfers still a good option
- Investment in process can be considerable
- CRA’s and WCB’s predictable and timely



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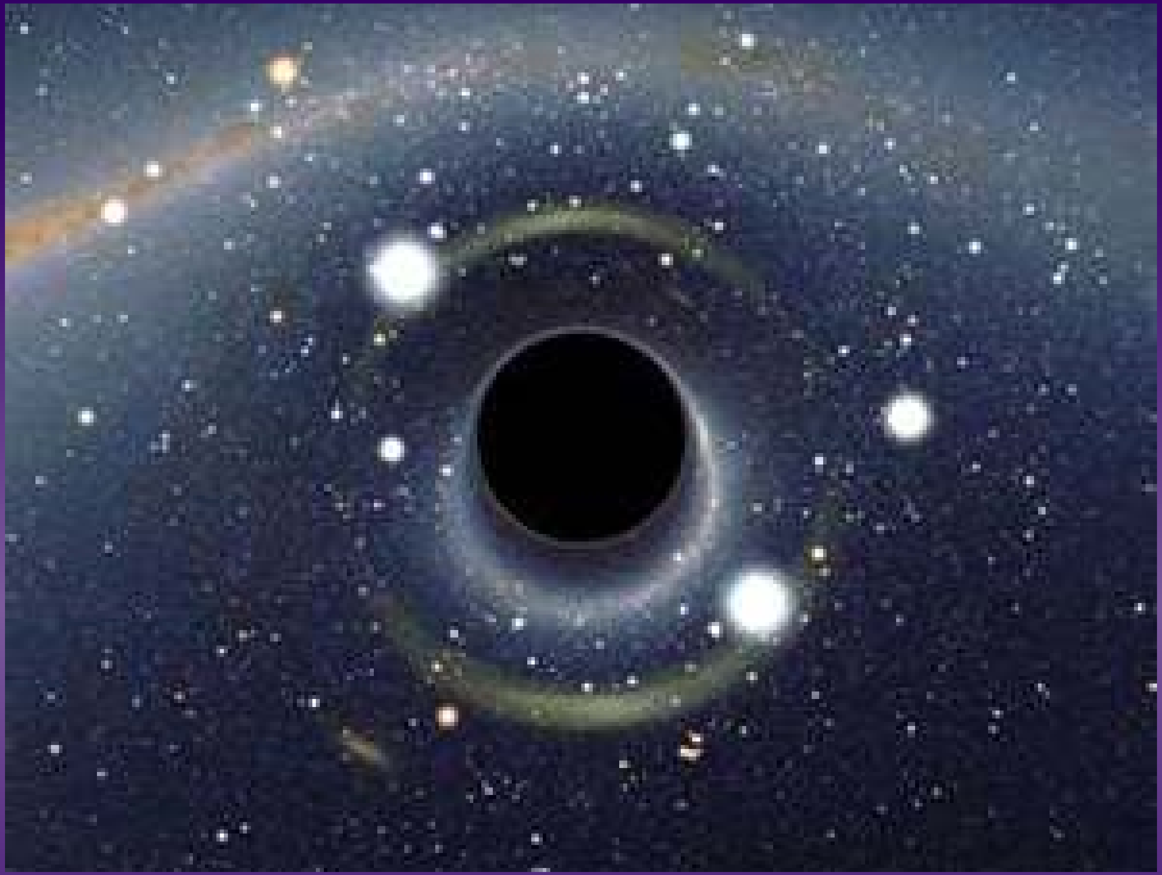
Basic Steps

- Filing Applications
- Publishing Notice
- **Conduct Investigation and Prepare ROE**
- Get Ecology's Approval
- Perfecting the right or completing the change



Investigating Your Water Right Application

Would it surprise you to learn that one of those steps is actually a black hole?

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Investigation of a Change Application

- Attributes of your water rights
- Legal standing - relinquishment
- Quantification – Tentative determination
- Role of other water rights
- Public Interest
- HG Considerations – same body/impairment
- Impairment – and Mitigation

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New Application

- 4-tests (Availability, Impairment, Beneficial Use and Public Interest)
- How are other rights affected?
- How are surface water bodies affected?
- Will mitigation address those effects?

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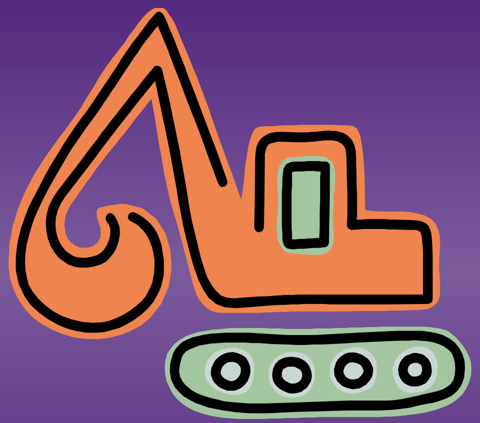
Ways to Get Processed

- Direct "In house" Processing by Ecology
- Water Conservancy Boards (Changes)
- Cost Reimbursement Program (All)



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Ecology "In house" Processing

- Two Lines
- "Hillis" Rule Priorities
  - Public Health and Safety
  - Substantial Environmental Benefits
  - Public Water supply for Regional Areas
  - Court ordered - Adjudications

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Conservancy Boards

- Work only on Change Applications
- Working in 21 Counties
- Independent fee based
- Recommendations made to Ecology
- Authority to review same as Ecology

PGG

Cost Reimbursement

- Classic Pay-to-Play
- Agreement between Ecology and Applicant to pay for processing
- Can be used for Change Applications or New Applications
- Can be the only game in town

PGG

Cost Reimbursement

- Work done by pre-approved consultant roster
- Consultants hired to conduct investigation
- Consultants draft ROE and make recommendations to Ecology

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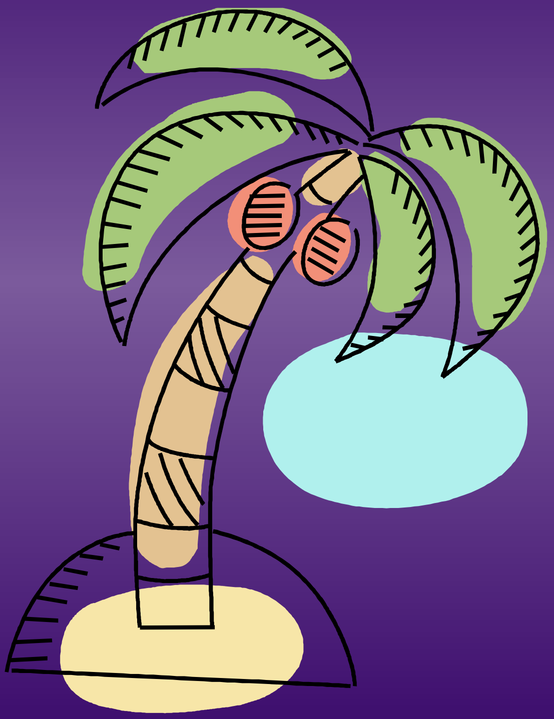
Who Benefits?

- Isolated Applications
- Applications with built-in mitigation
- Water Budget Neutral projects



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Basic Steps

- Starts with a formal request
- Phase 1 prepared that identifies other applicants
- Applicant picks a consultant team
- Consultant prepares a scope and budget
- Consultant proceeds to draft ROE for Ecology

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Standard CRA

- Usually a Single Applicant
- Contract between applicant and Ecology
- Contract between Ecology and Consultant

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CRA Costs $$$$

- You will be paying four times!
  - Your own consultant
  - Ecology's consultant
  - Ecology for Direct Costs
  - Ecology for Backfill

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Questions?

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