Overview of Groundwater

Occurrence

Sustainability
Occurrence

- Saltwater: 97.3%
- Ice (Polar Ice Caps): 2.09%
- Surface Water: 0.15%
- Groundwater: 0.46%

About 2/3 of Groundwater not available

About 50% of population, or 80% of utilities use groundwater
The Water Cycle

- Evapotranspiration (ET)
- Precipitation
- Surface Water and Runoff
- Groundwater
Groundwater Concepts

• Quality and Quantity
  – Depends on factors such as depth, rainfall, geology

• Infiltration and Recharge
  – *Initial Infiltration* replaces moisture in the root or plant zones
  – Recharge Areas are surface areas having porous surface soils allowing water to percolate downward
Groundwater Concepts

• Unsaturated and Saturated Zones
  – *Soil Zone*, usually 3 to 5 feet. Supports plant growth
  – *Intermediate Zone*, varies in thickness. Less porous than the soil zone
  – *Capillary Fringe*, area where groundwater seeps up from the groundwater table by capillary action to fill pores
Groundwater Concepts

- **Rivers and Lakes**
- **Unsaturated Zone**
  - **Capillary Fringe**
  - **Intermediate Zone**
- **Saturated Zone**
  - **Groundwater**
- **Soil Zone**
- **Water Level**
- **Well**
Aquifers and Confining Beds

- Artesian Pressure
- Water Table
- Unconfined Aquifer
- Semi-Confined Aquifer
- Confined Aquifer
- Clay Layer
Hydraulic Conductivity

Hydraulic Conductivity (K) – the ability of water to flow through a porous material

\[ K = C(D_{10})^2 \]

C = Hazen’s empirical coefficient
D = The diameter of a 10 percentile grain size of material (mm)
K = Hydraulic Conductivity (cm/sec)
# Saturated Hydraulic Conductivity (K) Values

<table>
<thead>
<tr>
<th>K (cm/s)</th>
<th>100</th>
<th>10</th>
<th>1</th>
<th>$10^{-1}$</th>
<th>$10^{-2}$</th>
<th>$10^{-3}$</th>
<th>$10^{-4}$</th>
<th>$10^{-5}$</th>
<th>$10^{-6}$</th>
<th>$10^{-7}$</th>
<th>$10^{-8}$</th>
<th>$10^{-9}$</th>
<th>$10^{-10}$</th>
</tr>
</thead>
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<tr>
<td>K (ft/day)</td>
<td>100,000</td>
<td>10,000</td>
<td>1,000</td>
<td>100</td>
<td>10</td>
<td>1</td>
<td>0.1</td>
<td>0.01</td>
<td>0.001</td>
<td>0.0001</td>
<td>$10^{-5}$</td>
<td>$10^{-6}$</td>
<td>$10^{-7}$</td>
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<tr>
<td>Relative Permeability</td>
<td>Pervious</td>
<td>Semi-Pervious</td>
<td>Impervious</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
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<tr>
<td>Aquifer</td>
<td>Good</td>
<td>Poor</td>
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<td></td>
<td></td>
<td></td>
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</tr>
<tr>
<td>Unconsolidated Sand &amp; Gravel</td>
<td>Well Sorted Gravel</td>
<td>Well Sorted Sand or Sand &amp; Gravel</td>
<td>Very Fine Sand, Silt, Loess, Loam</td>
<td></td>
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</tr>
<tr>
<td>Unconsolidated Clay &amp; Organic</td>
<td>Peat</td>
<td>Layered Clay</td>
<td>Fat / Unweathered Clay</td>
<td></td>
<td></td>
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<td></td>
<td></td>
<td></td>
<td></td>
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</tr>
<tr>
<td>Consolidated Rocks</td>
<td>Highly Fractured Rocks</td>
<td>Oil Reservoir Rocks</td>
<td>Fresh Sandstone</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Fresh Limestone, Dolomite</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Fresh Granite</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
Overview of Groundwater

Occurrence

Sustainability
Sustainability

• Withdrawals = Consumption + Returns

• Sustainable Yield
  – Volume of water that can be drawn from an aquifer w/o exceeding the recharge potential

• Competition for Water Resources
  – Agriculture
  – Urban
  – Industrial
  – Ecosystems
Climate Impacts

- Warming may increase ET, reduce recharge
- Snow cover is projected to contract
- Rises in sea level, saltwater intrusion
- Weather extremes to continue
- Increase in precipitation at elevations, but as rainfall.
U.S. Drought Monitor
California

August 26, 2014
(Released Thursday, Aug. 28, 2014)
Valid 8 a.m. EDT

Drought Conditions (% of Area)

<table>
<thead>
<tr>
<th></th>
<th>None</th>
<th>D0-D4</th>
<th>D1-D4</th>
<th>D2-D4</th>
<th>D3-D4</th>
<th>D4</th>
</tr>
</thead>
<tbody>
<tr>
<td>Current</td>
<td>0.00</td>
<td>100.00</td>
<td>100.00</td>
<td>95.42</td>
<td>81.92</td>
<td>58.41</td>
</tr>
<tr>
<td>Last Week</td>
<td>0.00</td>
<td>100.00</td>
<td>100.00</td>
<td>97.59</td>
<td>81.92</td>
<td>58.41</td>
</tr>
<tr>
<td>3 Months Ago</td>
<td>0.00</td>
<td>100.00</td>
<td>100.00</td>
<td>100.00</td>
<td>76.68</td>
<td>24.77</td>
</tr>
<tr>
<td>Start of Year</td>
<td>2.61</td>
<td>97.39</td>
<td>94.25</td>
<td>87.53</td>
<td>27.59</td>
<td>0.00</td>
</tr>
<tr>
<td>Start of Year</td>
<td>2.63</td>
<td>97.37</td>
<td>95.95</td>
<td>84.12</td>
<td>11.36</td>
<td>0.00</td>
</tr>
<tr>
<td>One Year Ago</td>
<td>0.00</td>
<td>100.00</td>
<td>98.23</td>
<td>93.86</td>
<td>11.36</td>
<td>0.00</td>
</tr>
</tbody>
</table>

Intensity:
- **D0 Abnormally Dry**
- **D1 Moderate Drought**
- **D2 Severe Drought**
- **D3 Extreme Drought**
- **D4 Exceptional Drought**

The Drought Monitor focuses on broad-scale conditions. Local conditions may vary. See accompanying text summary for forecast statements.

Author:
David Simmeral
Western Regional Climate Center

http://droughtmonitor.unl.edu/
Impacts on Aquifers

Land Surface Subsidence

- Groundwater overdraft
- Re-orientation of aquifer grains
- Recharge will not restore land surface
- Estimating can be very difficult
Aquifer Evaluation

- Suitability
- Monitoring
- Quantitative Parameters
Evaluation of Aquifer

You should take into account:

• Quantity and quality required
• Availability of water resources
• Cost to Develop
• Existing and future pollution sources
• Current groundwater development
• Long term uses affecting recharge
• Conveyance costs
Water Quality Considerations

• Naturally occurring minerals
  – Dissolved inorganic salts

• Salt water intrusion (coastal wells)
  – Saline water can be drawn in after production

• Synthetic and other organic compounds

• Pollution control
  – Types of wastes generated locally
  – Hydrogeology of intervening materials
Land Use Consideration

• Agricultural land use
  – Pesticides, herbicides, fertilizers
  – Dairies, nutrient management

• Residential land use
  – Septic tanks

• Industrial land use
  – Industrial solvents
  – Oil industry, hydraulic fracturing
Locating Productive Aquifers

• Sustainable high quality water can typically be found in areas with large deposits of:
  – Unconsolidated sands and gravel
  – Sandstones and conglomerates
  – Limestone and dolomites
  – Porous of fractured crystalline or basalt rocks
Methods Without Drilling

• Electrical resistivity
  – Economical
  – Coarse sediments will have higher resistivity
  – Can be used to monitor chemical migration of a pollution source
  – Useful in simple geological environments
  – Best results with shallow groundwater
  – Useful to 1,500 ft.
Electrical Resistivity Method
Methods Without Drilling

• Seismic refraction and reflection
  – Relatively high cost
  – Very effective
  – Waves generated, geophones detect waves
  – Reflection vs Refraction
  – Reflection useful to 10,000 feet (petroleum)
  – Refraction useful to a few thousand feet
Seismic Refraction

SEISMIC REFRACTION
Borehole Logging

• Caliper - borehole diameter
• Electrical resistivity - qualitative information
• Spontaneous potential - geological correlation
• Gamma - geological correlation
• Fluid – flow velocity within the well
• Log suites – multiple logging techniques
Geophysical Log Suite
Aquifer Evaluation

• Suitability

• Monitoring

• Quantitative Parameters
California Well Standards

• Monitoring Well Standards (DWR)
  – Developed to address potential pathway for movement of poor quality water

• Bulletin 74-90
  – Part I: General Standards
  – Part II: Monitoring Well Construction
  – Part III: Destruction of Monitoring Wells
Monitoring Wells

• Provides initial groundwater assessment
• Monitor groundwater levels
• Detects changes in water quality
• Number and location determined from likely contamination and hydrology
• Multiple water bearing strata sampled
Monitoring Wells

Figure 2. MONITORING WELL TYPES
(Note: Schematic, not to scale)

A. INDIVIDUAL
- Casing Cap
- Concrete Pad
- Borehole
- Annular Seal
- Casing
- Filter Pack
- Screen

B. NESTED
- Borehole
- Annular Seal
- Filter Pack

C. CLUSTERED
(Separated but close to one another)

DWR – Southern District – Well Standards
Aquifer Evaluation

- Suitability
- Monitoring
- Quantitative Parameters
Quantitative Parameters

• Porosity is the ratio of voids to the total volume of a soil

\[ \eta = \frac{V_v}{V_t} \]

• Porosity determines the maximum amount of water a soil can hold when saturated
Quantitative Parameters

- *Specific Yield* – portion that will drain under the influence of gravity

- *Specific Retention* – portion that is retained as a film on surfaces and very small openings
## Examples of Selected Values

<table>
<thead>
<tr>
<th></th>
<th>Soil</th>
<th>Clay</th>
<th>Sand</th>
</tr>
</thead>
<tbody>
<tr>
<td>Porosity</td>
<td>55</td>
<td>50</td>
<td>25</td>
</tr>
<tr>
<td>Specific Yield</td>
<td>40</td>
<td>2</td>
<td>22</td>
</tr>
<tr>
<td>Specific Retention</td>
<td>15</td>
<td>48</td>
<td>3</td>
</tr>
</tbody>
</table>
Hydraulic Head and Gradient

• *Total Head* in a static well is the standing water elevation in a non-flowing well
  – Can be calculated by subtracting depth to water from the well head

• *Hydraulic Gradient* is the change in head per distance in a given direction
  – Using two or more well, this can be used to determine direction of groundwater movement
Groundwater Management

- Source Water Protection
- Regional Management
Source Water Protection

- 1986 amendments to the Safe Drinking Water Act
  - Wellhead Protection Program

- 1996 amendments to the Safe Drinking Water Act
  - Source Water Assessment Programs (SWAPs)
Source Water Protection

• Perception is that groundwater is less susceptible to contamination than surface water. This is not necessarily true
• Susceptible to both chemical and biological contamination
• Concerns related to wells taking water from multiple strata (Aquifer degradation)
• Significant portion of waterborne illnesses attributed to groundwater (up to 50%)
Source Water Protection

• Source Water Assessment (SWA)
  – An evaluation, using a specified set of procedures, to determine the human activities that are possible sources of contamination to which a drinking water source is most vulnerable
  – Non-regulatory measures (BMPs) are used to reduce threat from potential contamination activities
Elements of a SWA

- Step 1: Delineate the SWA area
Elements of a SWA

• Step 2: Conduct an inventory of potential sources of contamination
Elements of a SWA

- Step 3: Determine the susceptibility of the water supply to contamination
Figure 3. EFFECT OF REVERSAL OF GROUND WATER GRADIENT

- Pollutant
- Well
- Static Water
- Level
- Cone of Depression resulting from withdrawal of water when pumping.
- Direction of flow when pump is operating.
Contaminated GW Supplies

• What are the strategies to address a contaminated groundwater supply?
  – Blending
  – Pump and Treat
  – Non-potable Use
  – Relocate the Well
  – Abandon
Groundwater Management

- Source Water Protection
- Regional Management
Regional Management

• Interested entities are commonly brought together for the management of groundwater supplies
• Current law allows local agencies to come together to adopt and implement a groundwater management plan
• Basin management encouraged via funds administered by DWR
Regional Management

• Artificial Recharge – supplements natural recharge by use of surface aquifers, imported water and recycled water
Regional Management

- Conjunctive Use Projects – improves long term reliability by integrating SW and GW
  - Direct recharges aquifer with imported water
  - In-lieu recharge is when imported water is used instead of pumping groundwater
  - Water Wheeling is using one suppliers pipeline or canal to deliver another’s water supply
  - Water marketing and transfers is a sale of water or water rights.
Sustainable Groundwater Management Act (SGMA)

- AB 1739, SB 1168, SB1319
- Enacted in 2014
- Comprehensive Groundwater Management Legislation
What is Sustainable Groundwater Management?

• Management and use of groundwater in a manner that can be maintained during the planning and implementation horizon without causing an undesirable result.

WC § 10721 (Definitions)
What are Undesirable Results?

• Chronic lowering of groundwater levels

• Significant and unreasonable
  – Reduction in GW storage
  – Seawater intrusion
  – Degraded water quality
  – Land subsidence

• Surface water depletions that have significant and unreasonable adverse impacts on beneficial uses

WC § 10721 (Definitions)
Overall Intent

• Provide **local** authority to manage groundwater
• Establish minimum standards
• Assert State authority as required
• Respect overlying and proprietary rights to groundwater
• Recognize and preserve city and county authority
Events That Must Occur Under the SGMA

• DWR to prioritize all groundwater basins
  – ID basins in critical overdraft condition

• For medium or high-priority basins
  – Formation of local Groundwater Sustainability Agency (GSA)
  – GSAs develop a basin wide plan (GSP)
  – GSAs implement plan for sustainability within 20 years

• If local agencies do not perform
  – SWRCB will intervene
## California Statewide Groundwater Elevation Monitoring

<table>
<thead>
<tr>
<th>Hydrologic Region (HR)</th>
<th>CASGEM Groundwater Basin Ranking</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>High Ranking Range</td>
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<tr>
<td></td>
<td>&gt;21.08</td>
</tr>
<tr>
<td>North Coast</td>
<td>0</td>
</tr>
<tr>
<td>San Francisco Bay</td>
<td>0</td>
</tr>
<tr>
<td>Central Coast</td>
<td>9</td>
</tr>
<tr>
<td>South Coast</td>
<td>13</td>
</tr>
<tr>
<td>Sacramento River</td>
<td>5</td>
</tr>
<tr>
<td>San Joaquin River</td>
<td>7</td>
</tr>
<tr>
<td>Tulare Lake</td>
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</tr>
<tr>
<td>North Lahontan</td>
<td>0</td>
</tr>
<tr>
<td>South Lahontan</td>
<td>2</td>
</tr>
<tr>
<td>Colorado River</td>
<td>0</td>
</tr>
<tr>
<td>Statewide:</td>
<td>43</td>
</tr>
</tbody>
</table>

http://www.water.ca.gov/groundwater/casgem/basin_prioritization.cfm
Establishing GSAs

- Local agency or group of agencies may elect to become a GSA for the basin
- Must consider the interests of all beneficial uses and users of groundwater
- Upon establishment of GSAs, Notify DWR

WC § 10723
Options

- Single GSA/GSP for entire basin
- Multiple GSAs with a single GSP
- Multiple GSAs and GSPs
- If multiple plans in a basin
  - Multiple GSPs in one basin must coordinate and use common data and methods
  - DWR will review multiple GSPs together
- May use existing plan
Minimum Contents GSP

- Physical setting and boundary
- Stakeholders and GSA governance
- Background data
- Groundwater balance/budget
- Measurable Objectives (20 yr. sustainability)
- 50 year planning & implementation
- Monitoring protocols
- Consider county and city general plans

wc § 10727.2
Included Where Appropriate

• Control of saline water intrusion
• Wellhead protection and recharge areas
• Migration of contaminated groundwater
• Well abandonment & destruction program
• Replenishment of groundwater extractions
• Conjunctive use or underground storage

WC § 10727.4
Included Where Appropriate

- Well construction policies
- Groundwater contamination cleanup, recharge diversion to storage, conservation, water recycling, conveyance and extraction
- Efficient water management practices
- Processes to review and coordinate land use plans
- Impacts on groundwater dependent ecosystems

WC § 10727.4
Important Dates

• June 30, 2017 – Formation of GSA
• January 31, 2020 – Completion of GSPs for critically over drafted basin
• January 31, 2022 – Completion of GSPs for all other basins
• 20 year implementation period – Implementation under local management
Resources

• SGMA Statutes
  – [http://www.opr.ca.gov/docs/](http://www.opr.ca.gov/docs/)

• DWR Groundwater Information Center
Pumps and Motors

- Some Basic Terminology
- Classification
- Pump Selection
- Installation
Terminology

• Capacity - Rate of flow delivered by the pump
• Dynamic head - Resistance to flow produced by the system (static head, velocity head and friction head)
• Static head - Sum of static discharge head and suction head
Terminology

Static Discharge

Head

Centerline of Pump Total Static Head

Static Suction Head

Static Discharge Head
Pumps and Motors

- Some Basic Terminology
- Classification
- Pump Selection
- Installation
Centrifugal Pump

• Velocity and head developed through centrifugal force
• Volute-type - the impeller discharges fluid into a gradually expanding case.
• Diffuser-type – the impeller is surrounded by stationary guide vanes
• Shallow wells, less than 20 feet suction head
Centrifugal Pump with Volute

Centrifugal Pump with Vaned Diffuser Ring
Reciprocating Pump

- A positive plunger type pump
- High delivery pressure, low volume
Deep Well Turbine

• Deep well turbine pumps are a combination of centrifugal impellers connected in series to a common shaft
• High capacity, 25,000 gpm or more, and up to 1,000 feet of head
• The number of stages of impellers depends on the dynamic head
Deep Well Turbine

• Elements of a deep well turbine pump
  – Prime mover (pump motor)
  – Column pipe to transport water to the surface
  – Pump shaft and bearings connecting the prime mover to the impellers
  – Tubing that acts as a housing for the shaft
Deep Well Turbine
Submersible Pump

- Turbine pump
- The motor is close-coupled below the bowls of the pump
- Flows up to 4,500 gpm, 2,000 feet
- Advantages
  - Useful in crooked well casings
  - Wells can be completely sealed
  - Little surface equipment
Submersible Pump
Submersible Pump
Submersible Pump
Pumps and Motors

• Some Basic Terminology
• Classification
• **Pump Selection**
• Installation
Pump Selection

• Factors to consider
  – Capacity
  – Depth of well and pumping level
  – Inside diameter of well
  – Condition of borehole
  – Water quality
  – Total head
  – Costs
Pump Performance

• Water Horsepower: The work required to lift water.

• 1 hp = 33,000 ft-lb/min

\[
whp = \frac{(\text{flow Rate in gallons per minute})(\text{total head in feet})}{3,960}
\]

• Calculate whp if 2,000 gpm is lifted 300 ft.
  – \(whp = \frac{(2,000 \text{ gpm})(300\text{ft})}{3960}\)
  – \(whp = 152\)
Pump Performance

• Efficiency
  – Brake Horsepower: horsepower necessary at the shaft
    \[ bhp = \frac{whp}{\text{Efficiency of pump}} \]
  – Motor Horsepower: total power required to operate the system
    \[ mhp = \frac{whp}{(\text{Eff. of pump}) X (\text{Eff. of motor})} \]
    (Wire to Water Efficiency)
Pump Performance

• Overall Efficiency: $E = E_P \times E_M \times E_D$

• Power required = \( \frac{\text{theoretical power required}}{E} \)
Pumping Cost Equations

- 1 horsepower = 0.746 kilowatts power
- kW-h demand = \( \frac{Q \times HT \times 0.746}{3,960 \times E} \)
- kW-h = \( \frac{Q \times HT \times 0.746 \times \text{hours}}{3,960 \times E} \)
- power cost = \( \frac{Q \times HT \times 0.746 \times \text{hours} \times \text{cost}}{3,960 \times E} \)
Suction Head Requirements

• The Net Positive Suction Head (NPSH) is designated by the pump manufacturer
• NPSH is the minimum water level above the pump intake
• It is the head value required to prevent cavitation
Typical Pump Curve

- Capacity in U.S. Gallons per minute
- Total Dynamic Head per Stage (ft)
- NPSH
- BHP

- Impeller Dia.
  - 71
  - 72
  - 73
  - 73.5
  - 72
  - 71
Pumps and Motors

• Some Basic Terminology
• Classification
• Pump Selection
• Installation
Pump Installation

• Proper installation:
  – Increases pump efficiency
  – Minimizes maintenance
  – Prolongs the life of the piping
Pump Installation

• Aboveground, pumps should have a good foundation, concrete with foundation bolts
  – easily accessible for inspection
  – provide access for crane, hoist or rig to install and remove pump equipment
  – proper alignment
  – gate valve and check valve installed in the discharge pipe close to the pump (check valve between pump and gate valve)
Pump Installation

• Deep-well installation, pump must be set to ensure NPSH is always met
  – Excessive drawdown
  – Lowered pumping levels at intake
Pump Installation

• Check Valve installed close to pump to prevent water flowing back into the well when the pump is shut off
  – backwashing can disturb stabilized particles
  – backflow which can cause “backspin”
  – refilling delivery pipe at each start
  – vacuum and water hammer
    • air and vacuum release valve
    • surge control
Pump Installation

• Manufacturers documentation include:
  – column pipe assembly
  – bearings and shaft
  – lubrication
  – alignment
  – mounting and alignment of drive
  – setting of the impellor position
  – use of proper controls
Well Design and Construction

- Types of Wells
- Construction
- Well Development
Types of Wells

- Dug Well
  - 8 to 30 feet wide, 20 to 40 feet deep

- Bored Well
  - Shallow depths, 25 to 100 feet. 36 in diameter

- Driven Wells
  - Up to 4 inches diameter, 40 feet deep

- Drilled Wells

- Radial Wells
Well Design and Construction

• Types of Wells

• Construction

• Well Development
Well Location

• Separation – Wells should be located an adequate horizontal distance from known or potential sources of pollution and contamination. DWR Bulletin 74-90
  – sanitary, industrial, and storm sewers;
  – septic tanks and leach fields;
  – sewage and industrial waste ponds;
  – barnyard and stable areas;
  – feedlots;
  – solid waste disposal sites;
  – above and below ground tanks and pipelines for storage and conveyance of petroleum products or other chemicals; and,
  – storage and preparation areas for pesticides, fertilizers, and other chemicals.
# Required Separation

<table>
<thead>
<tr>
<th>Potential Pollution or Contamination Source</th>
<th>Minimum Horizontal Separation Distance Between Well and Known or Potential Source</th>
</tr>
</thead>
<tbody>
<tr>
<td>Any sewer (sanitary, industrial, or storm; main or lateral)</td>
<td>50 feet</td>
</tr>
<tr>
<td>Watertight septic tank or subsurface sewage leaching field</td>
<td>100 feet</td>
</tr>
<tr>
<td>Cesspool or seepage pit</td>
<td>150 feet</td>
</tr>
<tr>
<td>Animal or fowl enclosure</td>
<td>100 feet</td>
</tr>
</tbody>
</table>
Drilling Methods

• Cable Tool Method
  – Smaller diameter sizes
  – Uses lifts of several feet
  – An accurate sample of formations obtained
  – Drilling mud not used
Cable Tool Method
Drilling Methods

• Rotary Method
  – Cuttings removed by circulating fluid
  – Drill Pipe is hallow to allow fluid to be pumped to the bit
  – Engineered mud (bentonite) used for best results
Rotary Method
Drilling Methods

• Reverse-Circulation Rotary Method
  – Drilling Fluid flows down the borehole and rise through the drill pipe
  – Drilling fluid kept at a high velocity, 500 gpm or more
  – Cuttings settle in pit, decant recirculates
  – Typically, no engineered mud is used
Reverse-Circulation Rotary
Drilling Methods

• Drillers must keep log of cuttings
• Additional data on subsurface geology is desirable (electrical conductivity)
• All well log information submitted to owner
• The Department of Water Resources keeps a copy of all well logs
Casing Installation Rotary Methods

• For rotary methods, casing is installed after drilling is complete
• Casing is smaller diameter than the drilled hole
• Casing wall thickness must be strong enough to withstand formation and hydrostatic pressures
• AWWA Standard A100
Casing Installation Rotary Methods

• Casing equipped with centering guides to ensure radial thickness of the annular seal and gravel pack
• Screened casing in desirable aquifers
• Blank casing in aquifers with poor quality water
Types of Screens

Louver Screen

Wire Wrapped
Gravel Pack Installation

• Gravel must be carefully designed
• Clean, washed and well rounded
• Engineered for natural formation
• After outer casing is installed, permanent casing and screens are lowered
• Gravel placed in 2 to 4 foot layers, outer casing is slowly raised
• Calcium hypochlorite added with gravel
Gravel Pack Installation

Figure 6-13. Double-casing, gravel-pack placement
Sealing off Poor Quality Strata

- Neat cement, cement grout or bentonite clay
- Install Annular seal, a minimum of 50 feet for community water supplies
Measuring Drill Alignment

• Use a gyroscope, laser or plummet

• The following provided by the driller
  – Test sheet with alignment data
  – Well diagram indicating proposed and actual
  – Plumbness graph with calculated drift
  – Alignment graph indicating proposed and actual
  – Diagram indicating effective well diameter and determination of largest pump that can be installed without bending
Surface Construction Features
Disinfection

- Sufficient chlorine added to make 50 mg/L
- “Surge” well by alternating starting and stopping
- Contact time a minimum of 24 hours
- Calcium hypochlorite added to gravel during installation (1 lb. per cubic yard)
Well Design and Construction

• Types of Wells
• Construction
• Well Development
Well Development

• Preliminary Techniques
  – Bailing, surging, flushing, pumping, jetting and air lifting

• Final Development and Testing
  – Use a pump with capacity in excess of final production capacity
  – Set pump to a depth in excess of anticipated pumping level
Well Development

• During well development, record the following information:
  – Amount of gravel added during development
  – Quantity and description of materials
  – Static pumping water levels
  – Methods of measurement
  – Duration of each operation
  – Observation of results
  – Pump discharge rates and specific capacity
  – Sand content as a function of pump discharge
Operational Issues

- Evaluating Performance
- Operational Problems
Evaluating Performance

• Wells typically provide many years of trouble free service
• Regular maintenance can extend the life of wells
• Early detection of well performance problems is key to maintaining a consistent, maintenance free supply
Evaluating Performance

- Mechanical failures
- Poor operating and maintenance procedures
- Poor well design
- Hydrologic constraints
- High silt and sand content
- Plugging and fouling from hydrologic, geologic, geochemical, engineering and construction factors
Evaluating Performance

• Specific Capacity as a tool to evaluate well performance

\[
\text{Specific Capacity} = \frac{Q \text{ (gallons/minute)}}{\text{Drawdown (ft)}}
\]

• Plugging increases drawdown, which increases specific capacity even though total yield is not significantly decreased
Evaluating Performance

• With Plugging of a portion of the well screen, velocity of water passing the unplugged portion increases
• Sand, silt and colloidal matter can be pulled in through increased velocity
• Wire wound screens designed for velocities less than 0.1 ft/s
Evaluating Performance

• Low velocities assuming laminar flow designed to minimize:
  – turbulence around the well screen
  – precipitation of Fe, Mn and Ca
  – particulates on the screen

• In some cases, higher entrance velocities account for less fouling problems
  – long shutter type screen common
Evaluating Performance

• Performance problems observed from fouling or sand and silt
  – Water level decline in the well
  – Lower specific capacity
  – Lower yield
  – Sand/silt pumping
  – Silt/clay infiltration
Evaluating Performance

• Common causes of performance problems
  – Poor selection of materials
    • Significant corrosion/collapse
  – Incorrect pump specifications
  – Poor construction
    • Casing cracks, missing grout, misplaced screen poor alignment
  – Lack of well development
    • Poor well yield, sand pumping, biofouling, incrustation, excessive drawdown
Operational Issues

- Evaluating Performance
- Operational Problems
Operational Problems

• Breaking Suction (exceeding NSPH)
  – Cavitation, pump damage
  – Surge when pump breaks suction
  – Damage to well
  – Sand production
  – Air entrained in water
  – Encrusted materials
  – Pump lubricant
Operational Problems

• Causes of a lowered pumping level
  – Lowered water table
    • Temporary or long term overdraft
    • Lower pump bowls to maintain NSPH
  – Clogged intake
    • Perforations clogged with incrusted materials
    • Chemical of physical removal of incrustations
• Static and pumping water levels should be routinely monitored
Operational Problems

• Physical Deterioration
  – Particulate Plugging
    • Sand, silt and colloidal matter
    • Collapse of formation
  – Iron and Manganese
    • Fe$^{+2}$ and Mn$^{+3}$ converted to Fe$^{+3}$ and Mn$^{+4}$ solids
  – Calcium carbonate to calcium bicarbonate
  – Corrosion
Operational Problems

• Sand production operational problems
  – Excessive wear on pumps and valves
  – Plugging of control orifices, meters and sprinkler heads

• Possible solutions
  – Reduce pumping rate by increasing discharge head
  – Discharge directly into a large reservoir
Operational Problems

• Centrifugal Sand Separators
  – Lakos: water enters body of separator at an angle below a baffle
  – High velocity, small radius throws sand to sides of separator and collected in bottom of separator tube
  – Sand free water flows through hole in center of baffle
  – Monitor sand collected
Operational Problems

• Microbiological Fouling
  – Symptoms include
    • decrease in water quality
    • increase drawdown
    • reduced specific capacity
    • change in iron and manganese
    • observance of slimes or staining from well water
Operational Problems

• Microbiological Fouling
  – Biofilms form, clogging screens
  – Absorbs Fe, Mn, As, N and O$_2$, forming tubercles and films that reduce capacity
  – Ideal environment

• Common Forms
  – Iron-oxidizing bacteria
  – Manganese and sulfur-depositing bacteria
  – Sulfur-reducing bacteria
Operational Problems

• Detecting biofouling problem
  – Down hole camera (thoroughly clean equip.)
  – Biological Activity Reaction Test (BART)
  – If BART indicates bacteria, a microbiological lab can be consulted
  – Coliform testing using the membrane filter method can help reveal other bacteriological strains (pink dots)
Membrane Filtration

- Petri dish with sterile absorbent nutrient pad
- Add 2 mL of m-endo broth (selective media)
- Place membrane filter in the petri dish on top of the nutrient pad
Membrane Filtration: Incubation and Results

- Incubate for 24 hours at 35°C
- Coliform bacteria grow into colonies with a green metallic sheen
- Non-coliform bacteria may grow into red colonies
- Coliform concentration is __________________ ____________
  
  8 coliform/100 mL
Operational Problems

• Treatment methods for fouling problems:
  – Acidification (HCl): can improve performance, but does little against biofouling. Risk to older wells
  – Physical agitation and surging
  – Jetting
  – CO$_2$ injection
Groundwater Quality

• Chemicals in Groundwater

• Contamination
Chemicals in Groundwater

• Almost any chemical can be found in groundwater.
• Chemical, physical, biological and radiological quality varies widely, depending upon the physical and geochemical environment.
• Generally, groundwater exhibits some common characteristics.
Chemicals in Groundwater

• pH: 6.0 to 8.5
• Temperature: constant, just above annual mean air temperature. Temperature increases one degree Fahrenheit every 64 feet in depth
• Hardness: Ca and Mg cations. Can combine with anions to form scale. Less than 100 mg/L as CaCO$_3$ considered not objectionable
• Gases: CO$_2$, O$_2$, H$_2$S, CH$_4$
Chemicals in Groundwater

• Natural Chemical Constituents

<table>
<thead>
<tr>
<th>Chemical</th>
<th>Constituent</th>
</tr>
</thead>
<tbody>
<tr>
<td>Silica</td>
<td>Carbonate</td>
</tr>
<tr>
<td>Iron</td>
<td>Bicarbonate</td>
</tr>
<tr>
<td>Manganese</td>
<td>Sulfate</td>
</tr>
<tr>
<td>Calcium</td>
<td>Chloride</td>
</tr>
<tr>
<td>Magnesium</td>
<td>Fluoride</td>
</tr>
<tr>
<td>Sodium</td>
<td>Nitrate</td>
</tr>
<tr>
<td>Potassium</td>
<td>Dissolved Solids</td>
</tr>
</tbody>
</table>
Groundwater Quality

• Chemicals in Groundwater

• Contamination
Groundwater Contamination

• The three groups of biological contaminants associated with waterborne diseases are
  – Protozoans
  – Bacteria
  – Viruses
Biological Contaminants

• Amoeba:
  – Because of their size, amoeba typically not found in groundwater
  – Contamination through cross connection
  – Brain eating amoeba. Infection usually through nasal passage.
  – Resistant to disinfection
Biological Contaminants

• Protozoans
• *Giardia lamblia* and *Cryptosporidium* can be present in unfiltered surface water or GUI
• Not a common groundwater contaminant, too large to move in groundwater systems
Biological Contaminants

• Bacteria
• Inhabit almost every subsurface environment
• Produce methane gas and consume organic rich soil
• Smaller than protozoans, can move in subsurface
Biological Contaminants

• Viruses
• Require a host cell to multiply
• Very small in size, 20 nm to 300 nm
• Can replicate in bacteria (bacteriophages)
• In natural water, associated with fecal material
• Rotavirus can survive wastewater treatment and disinfection – injection program concerns
Chemical Contaminants

• Primary Standards
• Inorganic and Organic
Inorganic Compound

• Nitrogen
• Major sources include:
  – irrigated agriculture
  – dairy and livestock
  – sanitary wastes (septic tanks)
  – landfill leachate
  – manufacturing wastes
Inorganic Compound

- Total Dissolved Solids
- Recommended, Upper and Short secondary MCL (500 mg/L, 1,000 mg/L, 1,500 mg/L)
- High TSD impair aesthetics
Inorganic Compound

• Minerals
  – Arsenic, barium, cadmium, chromium, copper, lead, fluoride, mercury, sulfates, chlorides perchlorate
Inorganic Compound

• Radionuclides
  – Radium 226
  – Radium 228
  – Uranium
Organic Groups

• Volatile organic chemicals
• Synthetic organic chemicals
• Trihalomethanes and Haloacetic acids
• Nitrosomines
• Pharmaceuticals
Sources of Chemical Contamination

- Landfills
- Superfund sites
- Leaking underground storage tanks
- Wastewater plants
- Oil production and refining facilities
- Industrial and manufacturing facilities
- Septic tanks
- Spills and accidents
- Agriculture
- Dairies and feedlots
- Seawater intrusion
- Urban run-off
- Oil, sewer pipeline networks
- Oilfield brine injection
- Seawater intrusion
- Acid-mine drainage
Groundwater Treatment

- Aeration
- Oxidation
- Ion Exchange
- Filtration
- Adsorption
- Corrosion Control
- Disinfection
- Fluoridation
- Blending
Aeration

• Removes dissolved gases (H$_2$S, CO$_2$)

• Remove VOCs

• Oxidize reduced constituents (Fe, Mn)
Methods of Aeration

• Natural Draft
• Forced or induced draft
• Packed tower
• Diffused
Chemical Oxidation

• The process whereby a substance loses or donates electrons (oxidize)

• Oxidation examples:
  – Fe\(^{+2}\) (dissolved) to Fe\(^{+3}\) (precipitate)
  – Mn\(^{+2}\) (dissolved) to Mn\(^{+4}\) (precipitate)
Methods of Oxidation

• Chlorine and Chlorine Compounds (Cl₂)
• Potassium Permanganate (KMnO₄)
• Ozone (O₃)
• Advanced oxidation (OH⁻)
  – Hydrogen peroxide (H₂O₂) and ozone
  – UV light and ozone
  – UV light and hydrogen peroxide
Ion Exchange

• Cationic Exchange
  – Softening (greensand)
  – Also iron and manganese removal

• Anionic Exchange
  – nitrate
Filtration

- Granular Filtration
- Cake Filtration
- ATEC Iron and Manganese Filtration
ATEC Fe and Mn Removal

- Proprietary filter media
- Based on MnO$_2$ mineral (Pyrolusite)
- Chlorine injected immediately upstream of filters.
- Fe$^{+2}$ is oxidized to Fe$^{+3}$ ppt, Mn is adsorbed to media
Adsorption

- Activated Carbon
  - Granular Activated Carbon
  - Powdered Activated Carbon
1,2,3 – Trichloropropane \( \text{C}_3\text{H}_5\text{Cl}_3 \)

- Commonly used as an industrial solvent
- Paint or varnish remover, cleaning and degreasing agent
- A byproduct of processes used to produce dichloropropene
- Does not adhere to soil particles, moves quickly into aquifer
- Heavier than water
Regulatory Outlook

• Notification Level: 5 ppt = 5 $\mu$g/L = 0.000005 mg/L

• Public Health Goal (PHG) 0.7 ppt set August 2009

• CDPH developing MCL, expected draft available 2014 for public review?
## Sources (Active and Standby) Reporting 1,2,3-TCP Detections and Their Peak Concentrations

<table>
<thead>
<tr>
<th>County</th>
<th>TOTAL Sources</th>
<th>&lt;0.0051 µg/L</th>
<th>0.0051 - 0.05 µg/L</th>
<th>0.051 - 0.5 µg/L</th>
<th>0.51 - 5.0 µg/L</th>
<th>5.1 - 50 µg/L</th>
<th>&gt;50 µg/L</th>
<th>No. of Systems</th>
</tr>
</thead>
<tbody>
<tr>
<td>Kern</td>
<td>108</td>
<td>.</td>
<td>46</td>
<td>56</td>
<td>.</td>
<td>5</td>
<td>.</td>
<td>16</td>
</tr>
<tr>
<td>Fresno</td>
<td>45</td>
<td>.</td>
<td>34</td>
<td>10</td>
<td>1</td>
<td>.</td>
<td>.</td>
<td>7</td>
</tr>
<tr>
<td>Tulare</td>
<td>32</td>
<td>.</td>
<td>24</td>
<td>8</td>
<td>.</td>
<td>.</td>
<td>.</td>
<td>7</td>
</tr>
<tr>
<td>Merced</td>
<td>25</td>
<td>.</td>
<td>7</td>
<td>11</td>
<td>7</td>
<td>.</td>
<td>.</td>
<td>11</td>
</tr>
<tr>
<td>San Joaquin</td>
<td>11</td>
<td>.</td>
<td>5</td>
<td>6</td>
<td>.</td>
<td>.</td>
<td>.</td>
<td>3</td>
</tr>
<tr>
<td>Kings</td>
<td>1</td>
<td>.</td>
<td>1</td>
<td>.</td>
<td>.</td>
<td>.</td>
<td>.</td>
<td>1</td>
</tr>
<tr>
<td>TOTAL</td>
<td>222</td>
<td>0</td>
<td>117</td>
<td>91</td>
<td>8</td>
<td>5</td>
<td>0</td>
<td>45</td>
</tr>
</tbody>
</table>
Propane $\text{C}_3\text{H}_8$
1,2,3 – Trichloropropane $\text{C}_3\text{H}_5\text{Cl}_3$
Treatment Options

• Granular Activated Carbon

• In situ Oxidation

• UV and chemical oxidation
Source Water
State Project Water
Kern River
Friant-Kern Canal
Groundwater
Blends of above

PAC (5 to 20 mg/L* seasonally for TOC or T&O)

Flash Mixer
Sulfuric Acid
Alum
Cationic Polymer

Filter Influent
Cl₂

Orthophosphate (1.4 mg/L for corrosion control)

~10 min
~30 min
~2 hour

Sampling Locations
Powdered Activated Carbon

- Taste and Odor Control
- Total Organic Carbon Reduction
- Can be used seasonally
- Existing facilities in place
PAC Slurry Tank
## Jar Test TCP Removal Results

<table>
<thead>
<tr>
<th>Test 1 – PAC Screening</th>
<th>TCP (ng/L)</th>
<th>% Removal</th>
</tr>
</thead>
<tbody>
<tr>
<td>20 mg/L MP23</td>
<td>&lt;5</td>
<td>95</td>
</tr>
<tr>
<td>20 mg/L WPH</td>
<td>18</td>
<td>82</td>
</tr>
<tr>
<td>20 mg/L AQ CP1</td>
<td>7.2</td>
<td>93</td>
</tr>
<tr>
<td>20 mg/L HDB (NCSU)</td>
<td>9.6</td>
<td>90</td>
</tr>
<tr>
<td>20 mg/L HDB (KCWA)</td>
<td>7.9</td>
<td>92</td>
</tr>
</tbody>
</table>
Implications

• PAC could be used effectively to reduce 123-TCP concentrations.

• Assuming a maximum PAC dosage of 20 mg/L, a GW source value of 30 ng/L and a GW/SW blend of 40 ng/L could be reduced to below the notification level.

• To date, all samples taken from the water banks have been determined to be non detect for 1,2,3-TCP
Corrosion Control

• Water is considered corrosive if:
  – Low pH, alkalinity, hardness
  – High dissolved oxygen, chlorine, TDS, $H_2S$, $CO_2$
• Langelier Index (LSI)
• $LSI = pH(\text{actual}) - pH(\text{saturated CaCO}_3 \ \text{ppt})$
Chemical Factors Influencing Corrosion

• Alkalinity
• pH
• Dissolved Oxygen
• Dissolved Solids
• Hardness
• Chloride and Sulfate
• Phosphate and Silicate
• Trace Metals
Biological Factors Influencing Corrosion

• Iron Bacteria
  – Slimy, reddish or brown-colored masses
  – Filamentous
  – *Crenothrix, Sphaerotilus, and Gallionella*
  – Convert Fe$^{+2}$ to Fe(OH)$_3$

• Sulfate-Reducing Bacteria
  – Rotten egg odor of H$_2$S
Methods of Controlling Internal Corrosion

• Calcium Carbonate Saturation
  – Quick lime, hydrated lime and caustic soda

• Zinc, Silica and Polyphosphates
  – Form effective cathodic films

• Cathodic Protection
  – Introduction of external D.C. sufficient to offset or cancel corrosion producing action.
Disinfection

- Chlorine
- Chloramines
- Chlorine Dioxide
- Ozone
## Microbial Standards

<table>
<thead>
<tr>
<th>Contaminant</th>
<th>Maximum Contaminant Level</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Total Coliform</strong></td>
<td>&lt;40 samples/month, no more than 1 positive.</td>
</tr>
<tr>
<td></td>
<td>≥40 samples/month, no more than 5% positive</td>
</tr>
<tr>
<td><strong>Giardia Lamblia</strong></td>
<td>3-Log(99.9%) Removal/Inact.</td>
</tr>
<tr>
<td><strong>Viruses</strong></td>
<td>4-Log(99.99%) Removal/Inact.</td>
</tr>
</tbody>
</table>
Factors Influencing Cl₂ Disinfection

- pH
- Temperature
- Turbidity
- Organic Matter
- Inorganic Matter
- Reducing Agents
- Microorganisms
Reaction With Water

- Chlorine + Water $\leftrightarrow$ Hypochlorous + Hydrochloric Acid
- $\text{Cl}_2 + \text{H}_2\text{O} \leftrightarrow \text{HOCl} + \text{HCl}$

Depending of pH, dissociation occurs

- Hypochlorous $\leftrightarrow$ Hydrogen + Hypochlorite Acid Ion Ion
- $\text{HOCl} \leftrightarrow \text{H}^+ + \text{OCl}^-$
Disinfection Effectiveness

- At pH 6, nearly 100% HOCl
- At pH 9.5, nearly 100% OCl⁻
- At pH 7.5, 50% HOCl and 50% OCl⁻
- HOCl % increases with temperature

<table>
<thead>
<tr>
<th>Type</th>
<th>Chemical Abbreviation</th>
<th>Estimated Effectiveness</th>
</tr>
</thead>
<tbody>
<tr>
<td>Hypochlorous Acid</td>
<td>HOCl</td>
<td>1</td>
</tr>
<tr>
<td>Hypochlorite ion</td>
<td>OCl⁻</td>
<td>1/100</td>
</tr>
<tr>
<td>Monochloramine</td>
<td>NH₂Cl</td>
<td>1/150</td>
</tr>
</tbody>
</table>
## Reducing Agents Effect

<table>
<thead>
<tr>
<th>Inorganic Reactant</th>
<th>Part of Cl₂ required per part of Inorganic</th>
</tr>
</thead>
<tbody>
<tr>
<td>Iron</td>
<td>0.6</td>
</tr>
<tr>
<td>Manganese</td>
<td>1.3</td>
</tr>
<tr>
<td>Nitrite</td>
<td>1.5</td>
</tr>
<tr>
<td>Sulfide to sulfur</td>
<td>2.1</td>
</tr>
<tr>
<td>Sulfur to sulfate</td>
<td>6.2</td>
</tr>
</tbody>
</table>
Formation of Chloramines

• Mono-chloramine \((\text{NH}_2\text{Cl})\) pH 6.5 to 7.5

• Di-chloramine \((\text{NHCl}_2)\) pH 4.0 to 7.5

• Tri-chloramine \((\text{NCl}_3)\) pH below 4.0

• \(\text{Cl}_2: \text{NH}_3\text{-N}\) ratio of 7.6:1 = Breakpoint
Use of Chloramines

- Reduction in formation of TTHMs
- Maintains a detectable residual
- Reduce potential for coliform growth
- Killing Heterotrophic plate count bacteria
- Reduction in taste and odor problems
Special Considerations

- Must be removed from water used in dialysis treatments.
- Deadly to fish
- Blending with chlorinated water
- Nitrification
Chlorine Dioxide

- \[ 2 \text{ClO}_2 + \text{H}_2\text{O} \rightarrow \text{ClO}_3^- + \text{ClO}_2^- + 2 \text{H}^+ \]

- Does not form carcinogenic compounds

- Effective oxidizing agent for Fe and Mn

- Does not react with organics
Ozone

• Triatomic form of oxygen (normal oxygen gas is diatomic)
• Very unstable, and must be made on-site
• Oxygen-containing gas is contacted with electricity
• So reactive that residual is gone in minutes
• Additional benefits in treatment
• Produces DBP “Bromate” with bromide
Fluoridation

- Hydrofluorosilicic acid ($\text{H}_2\text{SiF}_6$)
- Sodium fluoride (NaF)
- Sodium Fluorosilicate ($\text{Na}_2\text{SiF}_6$)
Hydrofluorosilicic Acid  – $\text{H}_2\text{SiF}_6$

Comes dissolved in water
Extremely corrosive, low pH liquid
Percent Fluoride: 79.2 %
Percent Purity: 20 – 30 %
(Major “impurity” is water)
Sodium Fluoride – NaF

Solid chemical, similar to table salt
Percent Fluoride: 45.25 %
Percent Purity: 97 – 98 %
Will dissolve readily to form a constant 4% solution (0.15 lb F/gallon)
Sodium Fluorosilicate – \( \text{Na}_2\text{SiF}_6 \)

Solid chemical
Generally, the least expensive
Percent Fluoride: 60.7 %
Percent Purity: 98 – 99 %
Saturation level varies with temperature
Blending

• Lowest cost treatment
• Blending facilities
• Verification of proper blending