Recycled Water for Groundwater Recharge:

Innovative Recharge Projects and Source Water Implications

Central & West Coast Basins, Los Angeles County, California

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WRD

Executive Summary

- Overdrafted Southern California groundwater basins require artificial replenishment to remain usable.
- Reclaimed (recycled) municipal wastewater has been successfully used for recharge for nearly 50 years.
- State is increasing goals for recycled water reuse to make up for losses in traditional supplies.
- Innovative projects to enhance recharge while protecting source waters.
- Case Study: Central and West Coast Basins

Central & West Coast Basins in Coastal Los Angeles County

Overdraft History:

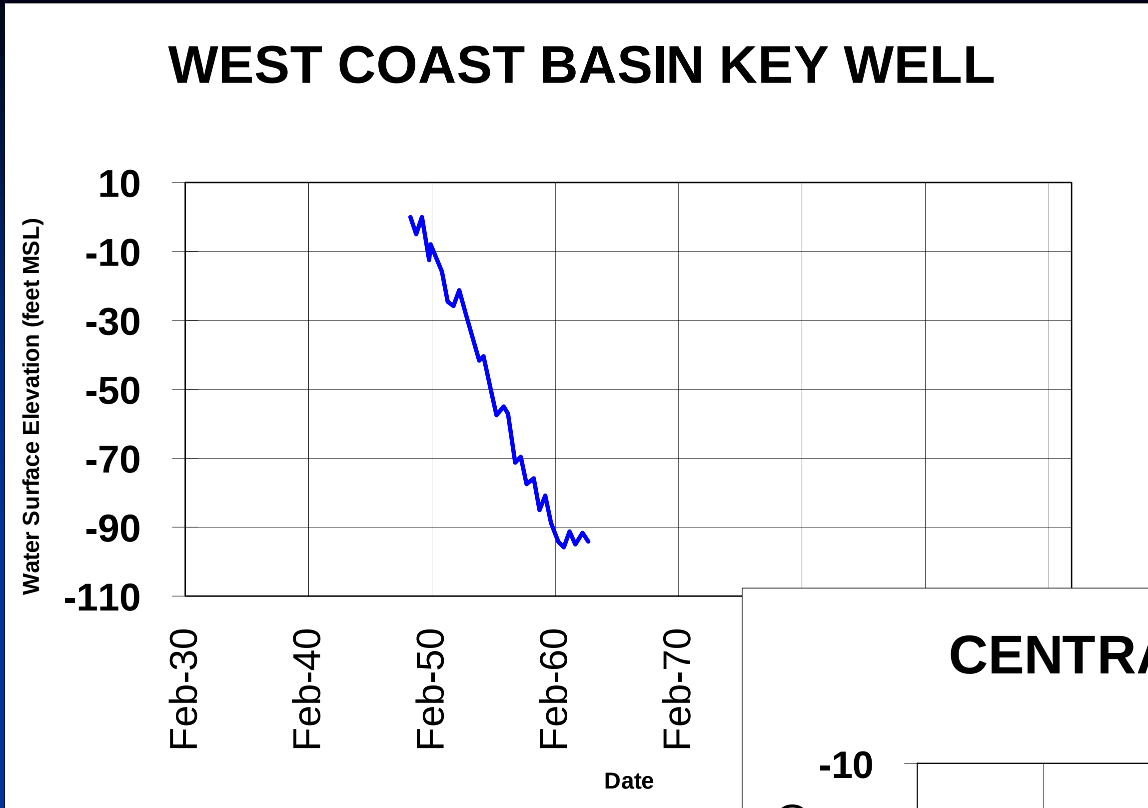
- Rapid Population Growth in 1900s leads to high water demand.

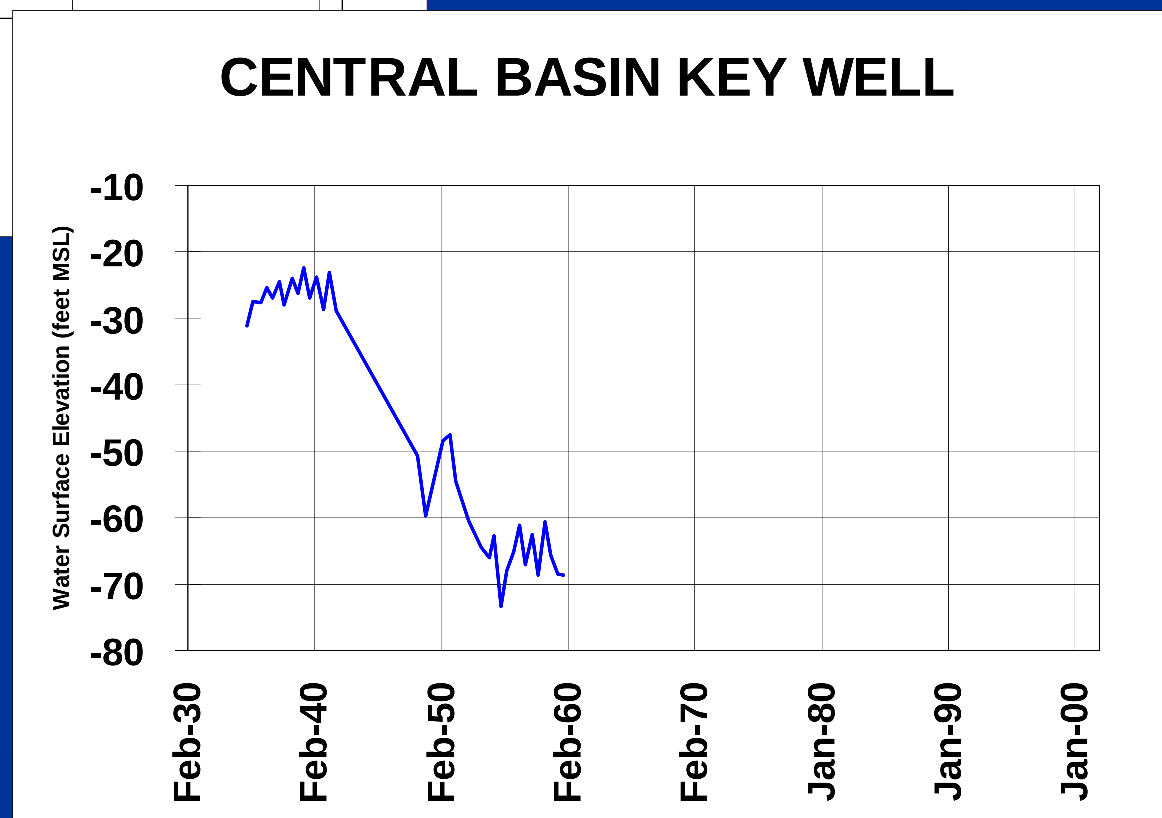
- Groundwater Pumping Double Natural Recharge. OVERDRAFT

- Water levels declined up to 10 ft / yr. Wells went dry.

- Seawater intrusion contaminated wells with salt. Wells Abandoned.

BASIN OVERDRAFT





Solutions

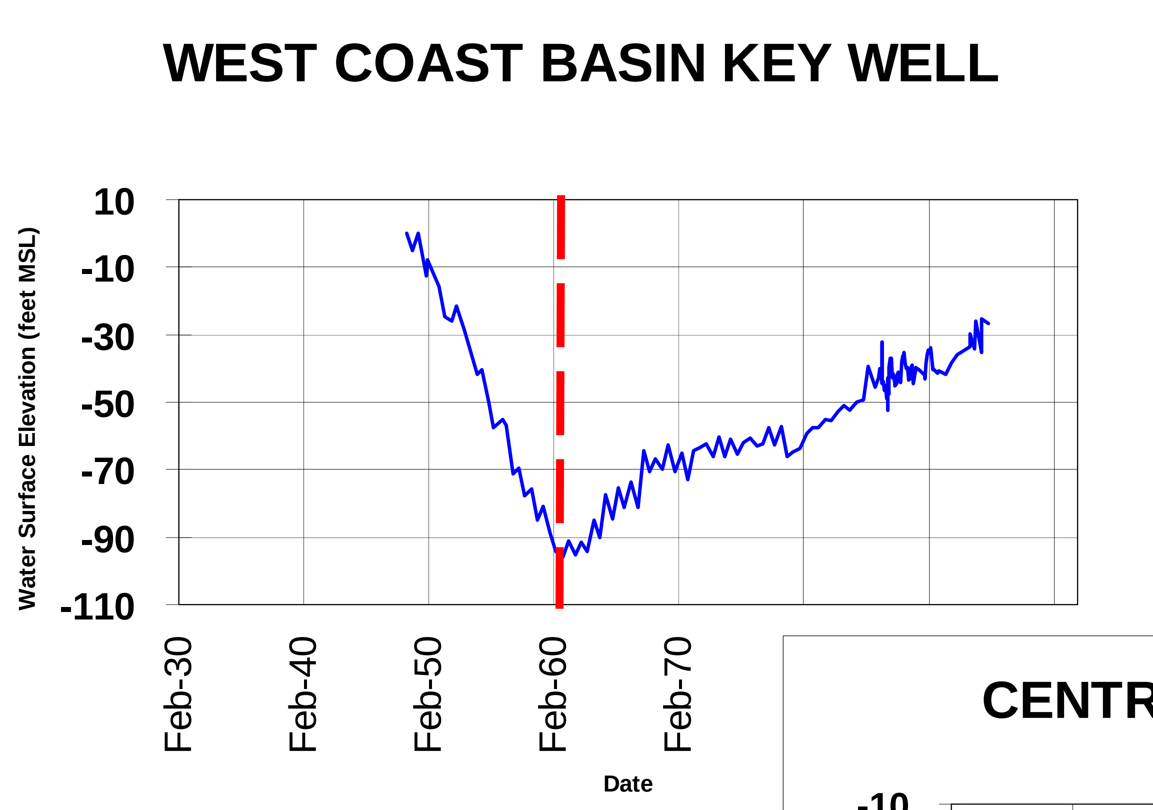
1) LA County Flood Control captured storm water in riverbeds and off-stream spreading grounds since late 1930s.

2) LA County installed a 16-mile barrier of injection wells to halt seawater intrusion. First wells in early 1950s.

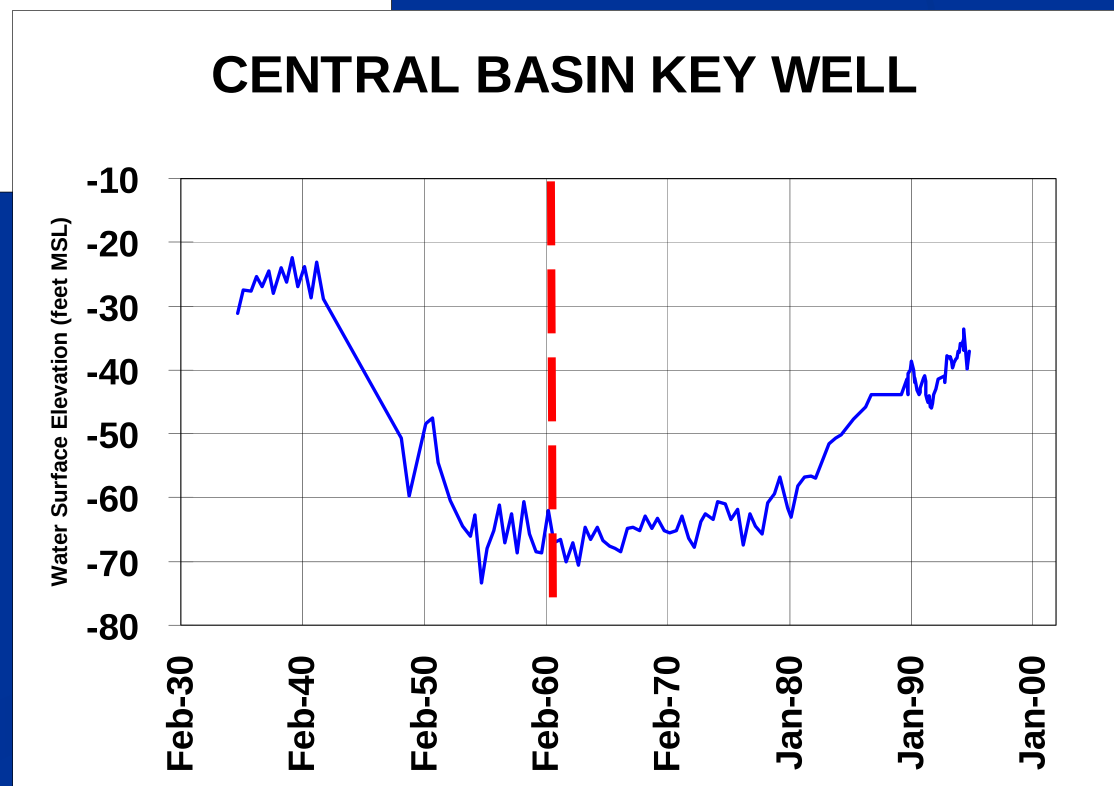
3) WRD formed in 1959 to provide artificial replenishment water (imported & recycled).

4) Court-ordered adjudications of pumping in 1960s sets a maximum cap on extractions.

RESULTS



WEST COAST BASIN KEY WELL
Water Surface Elevation (feet MSL)
10
-10
-30
-50
-70
-90
-110
Feb-30
Feb-40
Feb-50
Feb-60
Feb-70
Date

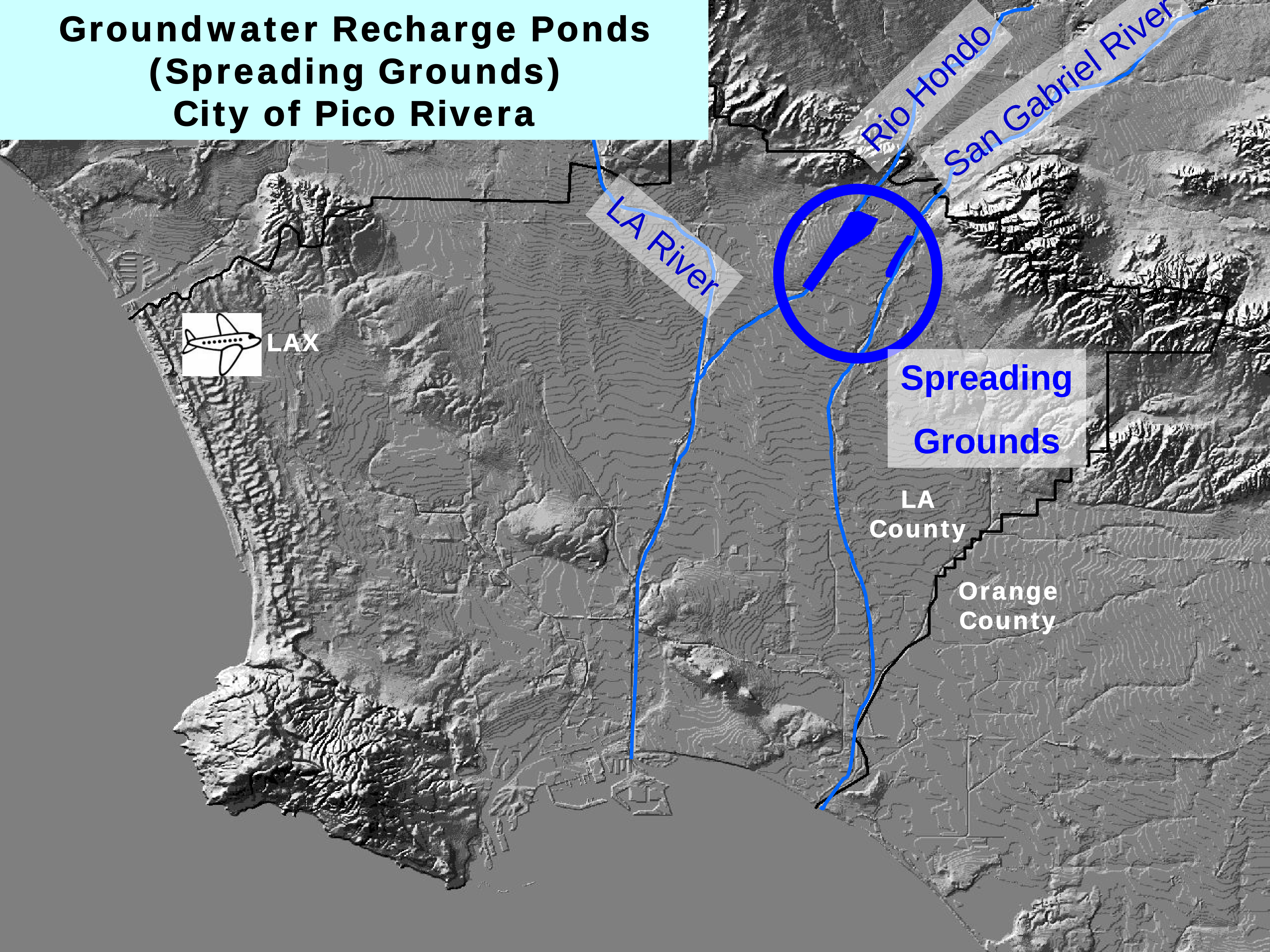


CENTRAL BASIN KEY WELL
Water Surface Elevation (feet MSL)
-10
-20
-30
-40
-50
-60
-70
-80
Feb-30
Feb-40
Feb-50
Feb-60
Feb-70
Jan-80
Jan-90
Jan-00

Recycled Water for Recharge

- Desirable Resource:
  - Imported and storm waters are getting harder to obtain.
  - Reliable. High Quality. Lower Cost than Imported.
- Spreading Grounds:
  - Disinfected tertiary from local wastewater treatment plants.
  - 35% of total recharge.
  - Over 1.4 MAF spread since 1962.
- Seawater Barrier Injection Wells:
  - Disinfected tertiary + MF/RO/AOP since 1995.
  - Currently 17,500 afy (64% of total barrier demand).
  - 100,000 af recycled injected to date.
  - Eventually get to 100% recycled at barriers.

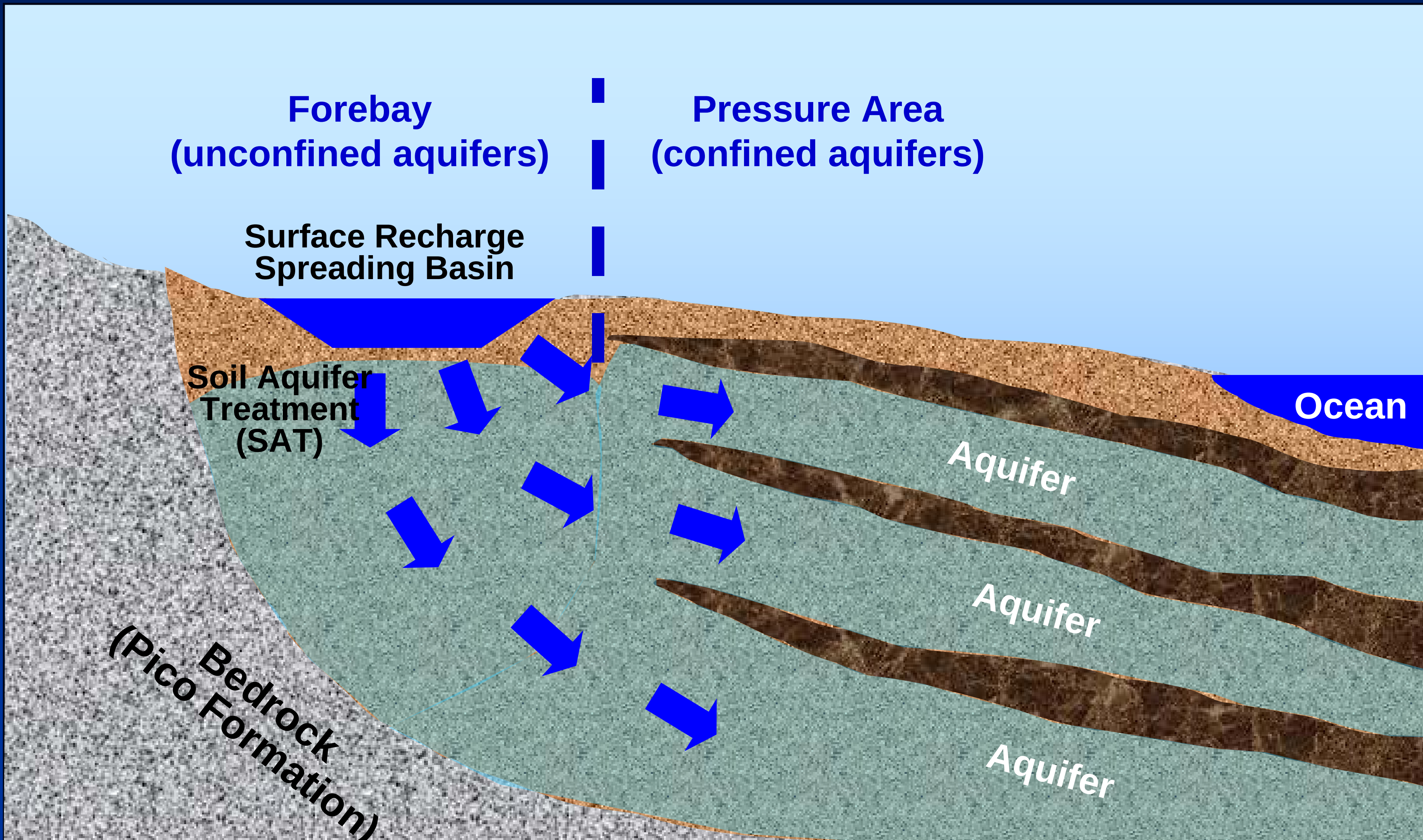
Groundwater Recharge Ponds (Spreading Grounds) City of Pico Rivera



Rio Hondo Spreading Grounds

San Gabriel Spreading Grounds

Spreading Grounds



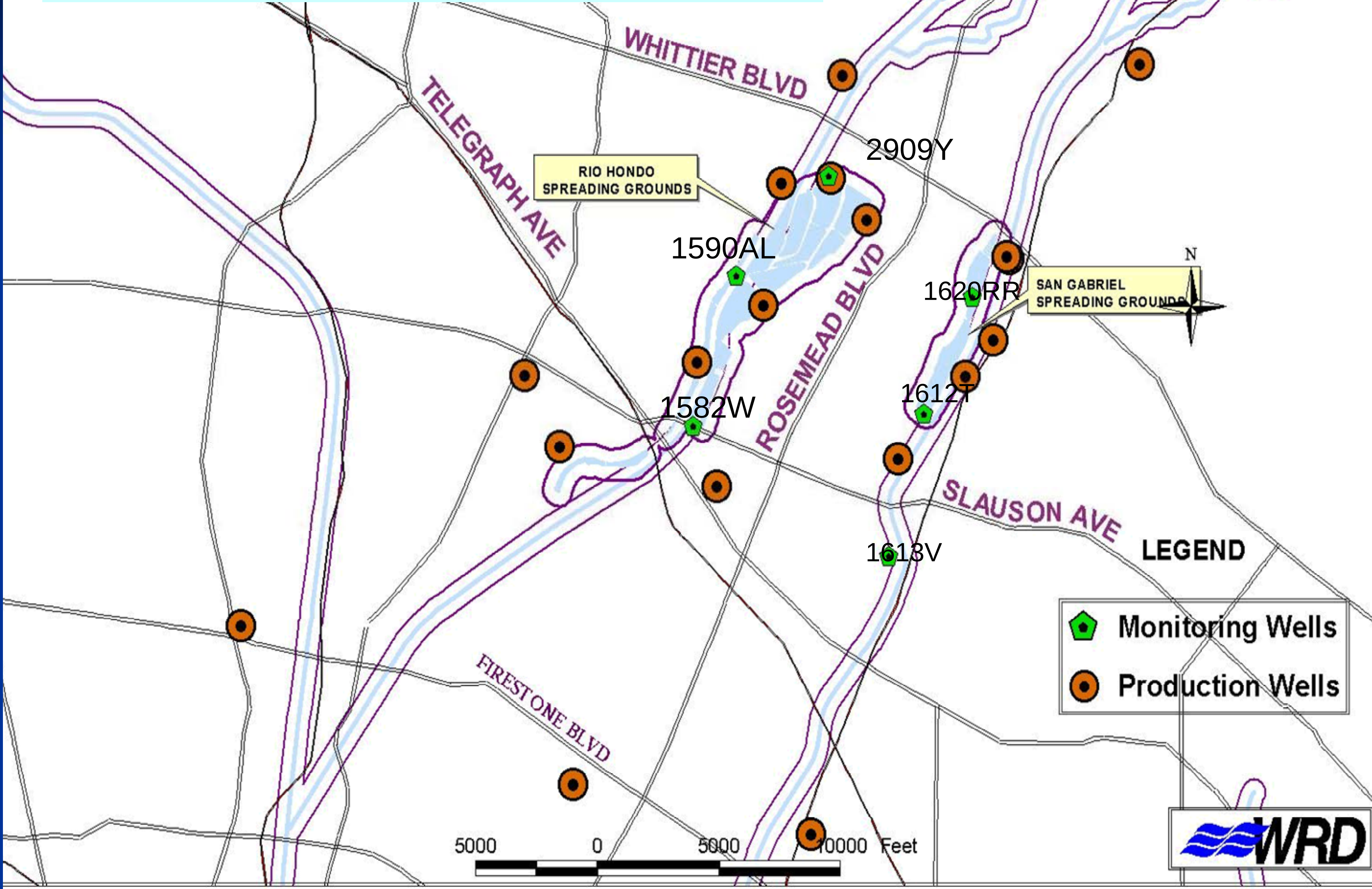
Spreading Water Sources

- Local Storm Water Runoff
  avg ~ 50,000 afy. Cost = free

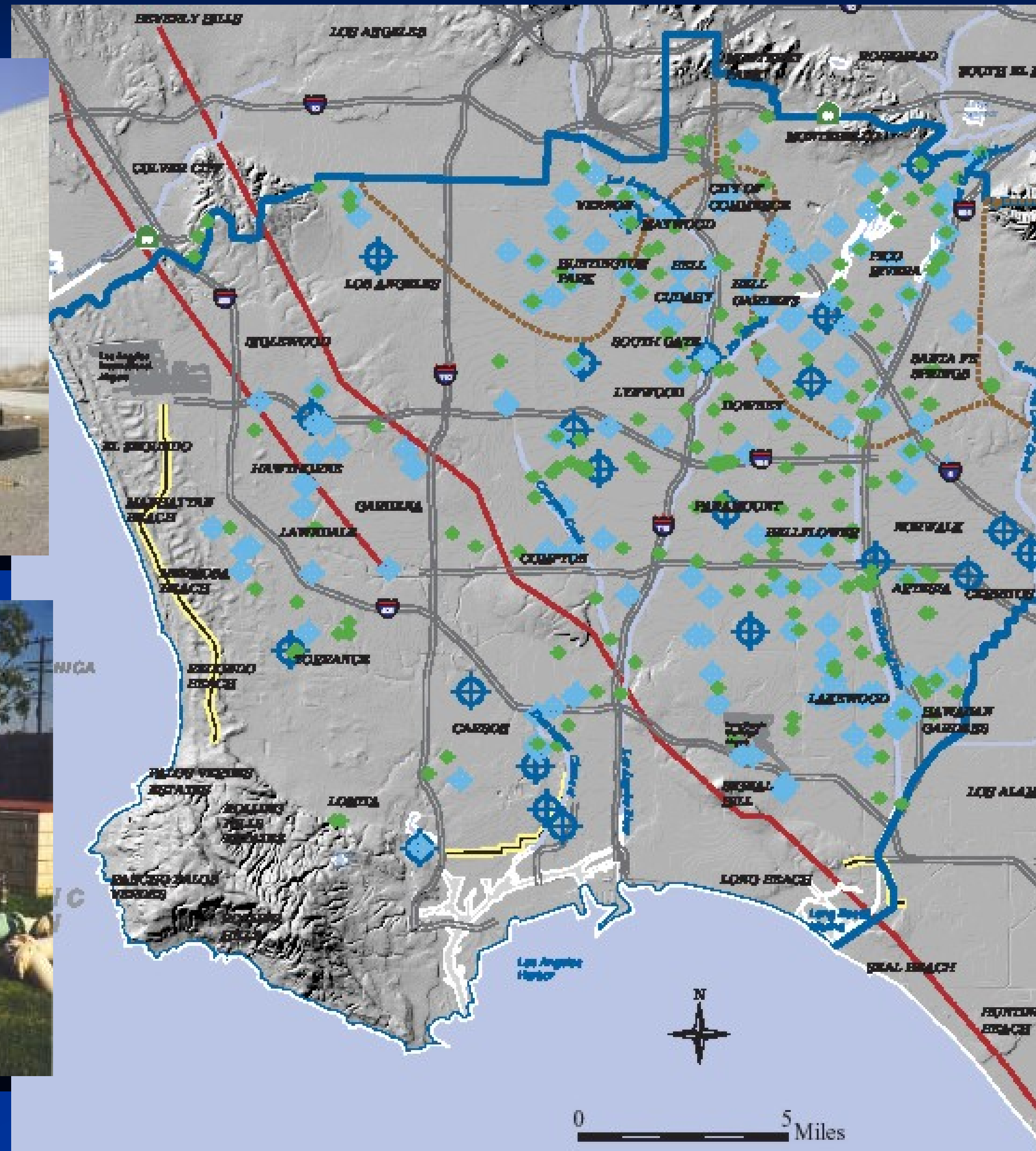
- Imported River Water (raw)
  avg ~ 20,000 afy. $327/af

- Recycled Water
  (disinfected tertiary)
  avg ~ 50,000 afy
  $21/af

23 Drinking Water Wells within 500 feet of Recharge Ponds

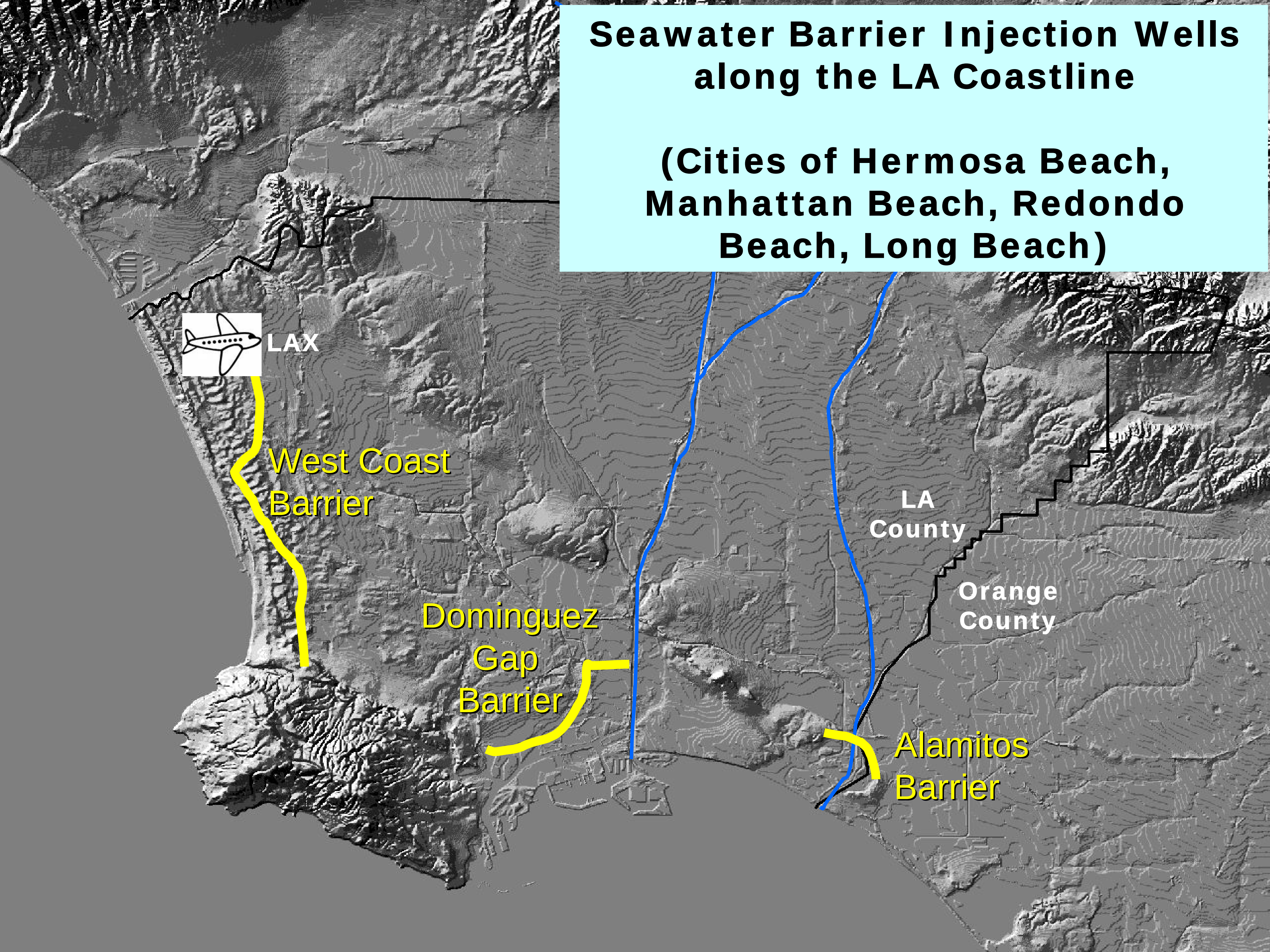


Over 500 Wells in Basins

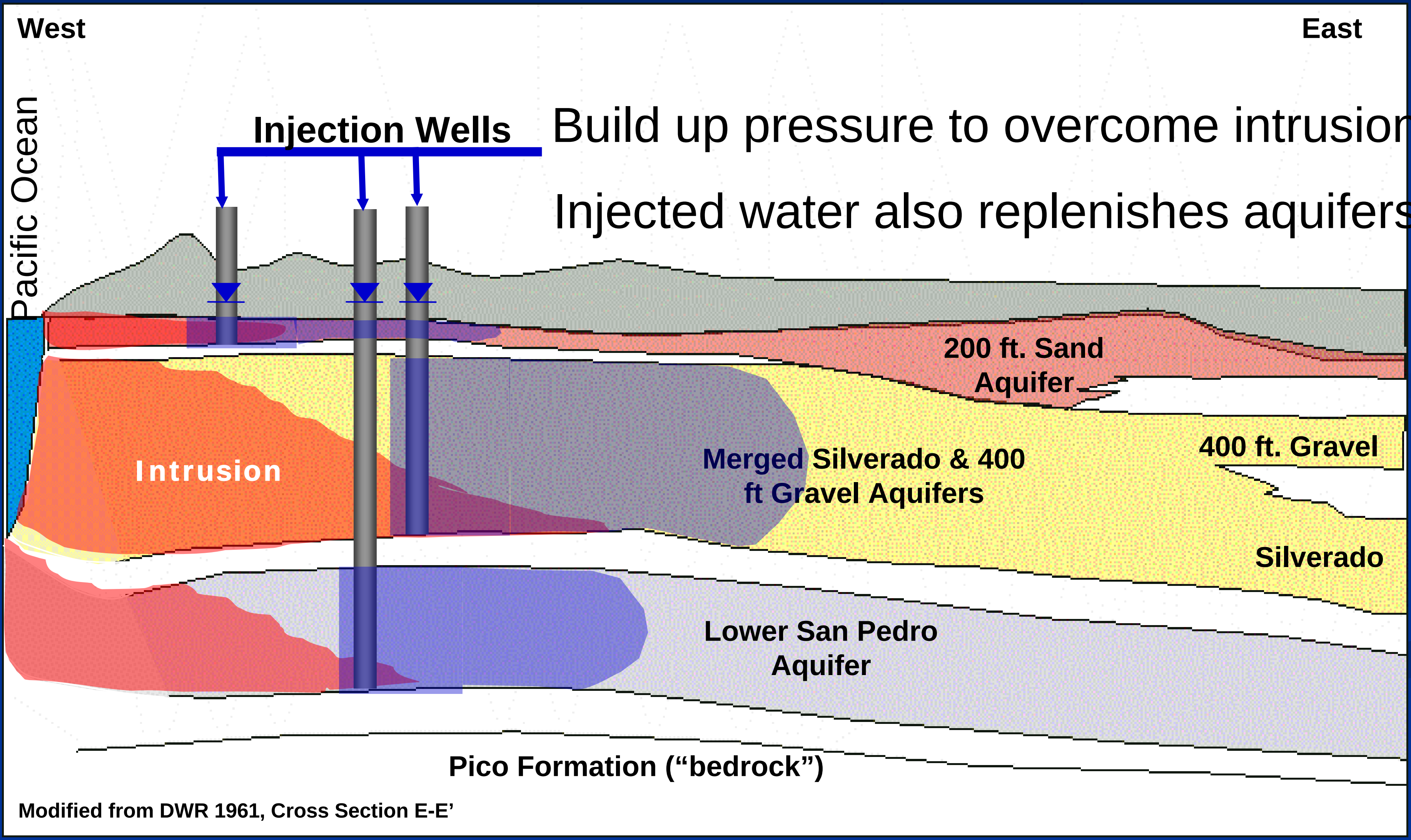


Seawater Barrier Injection Wells along the LA Coastline

(Cities of Hermosa Beach, Manhattan Beach, Redondo Beach, Long Beach)



Seawater Barrier Injection Wells



Seawater Barrier Water & Costs

- Imported Water (potable)

  $706/af - $845/af

- Recycled Water

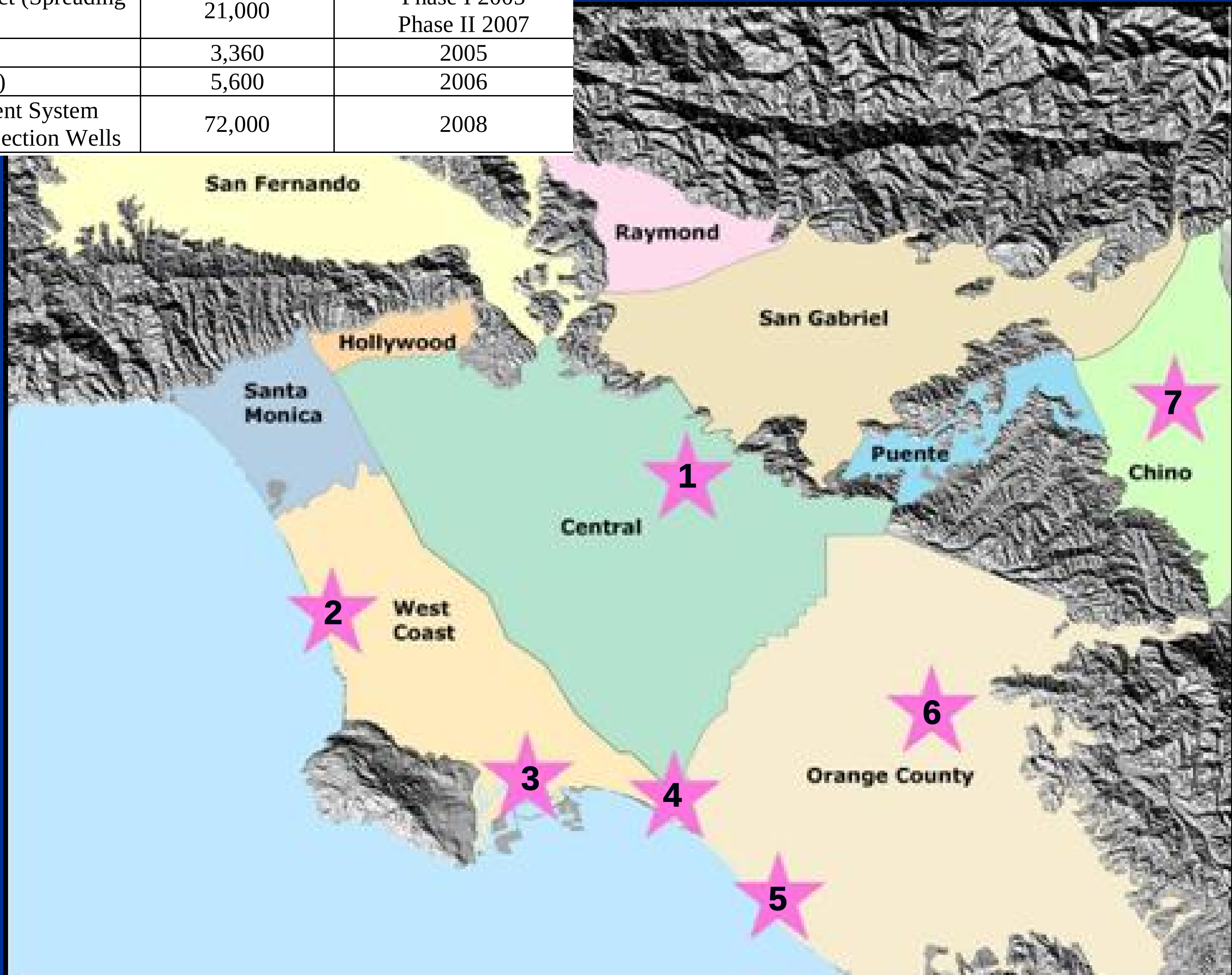
  (MF+RO+AOP)

  $287/af - $504/af

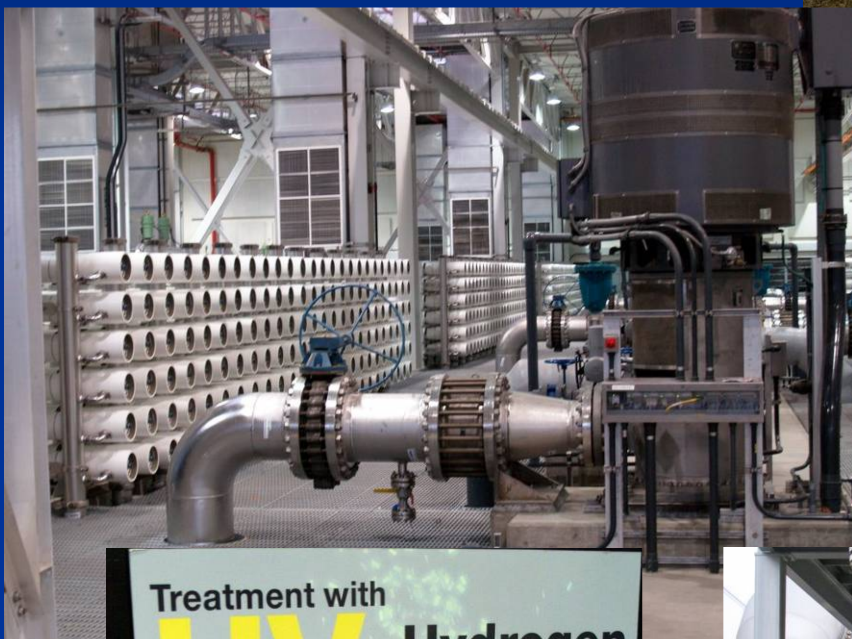
  Cost includes local, state, and federal subsidies

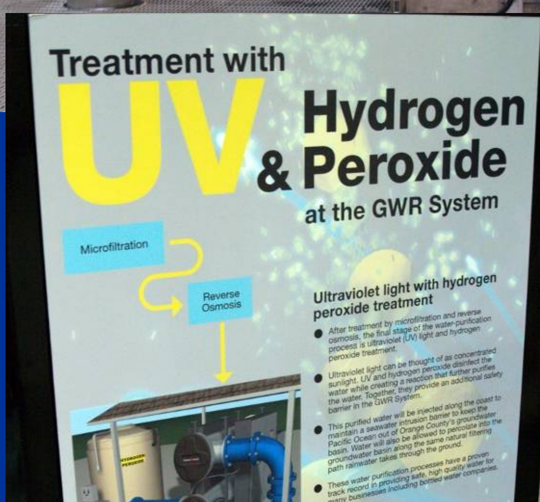
Major Recycled Water Recharge Projects in So. Cal.

	Project	Amount of Recycled Water Acre feet/Year	Project Start Date
1	Montebello Forebay Groundwater Recharge Project (Spreading Basins)	50,000	1962
2	West Coast Basin Barrier Project (Injection)	14,000	1994
7	Chino Basin Groundwater Recharge Project (Spreading Basins)	21,000	Phase I 2005 Phase II 2007
4	Alamitos Barrier Project (Injection)	3,360	2005
3	Dominguez Gap Barrier Project (Injection)	5,600	2006
5,6	Orange County Groundwater Replenishment System Spreading Basins and Seawater Barrier Injection Wells	72,000	2008

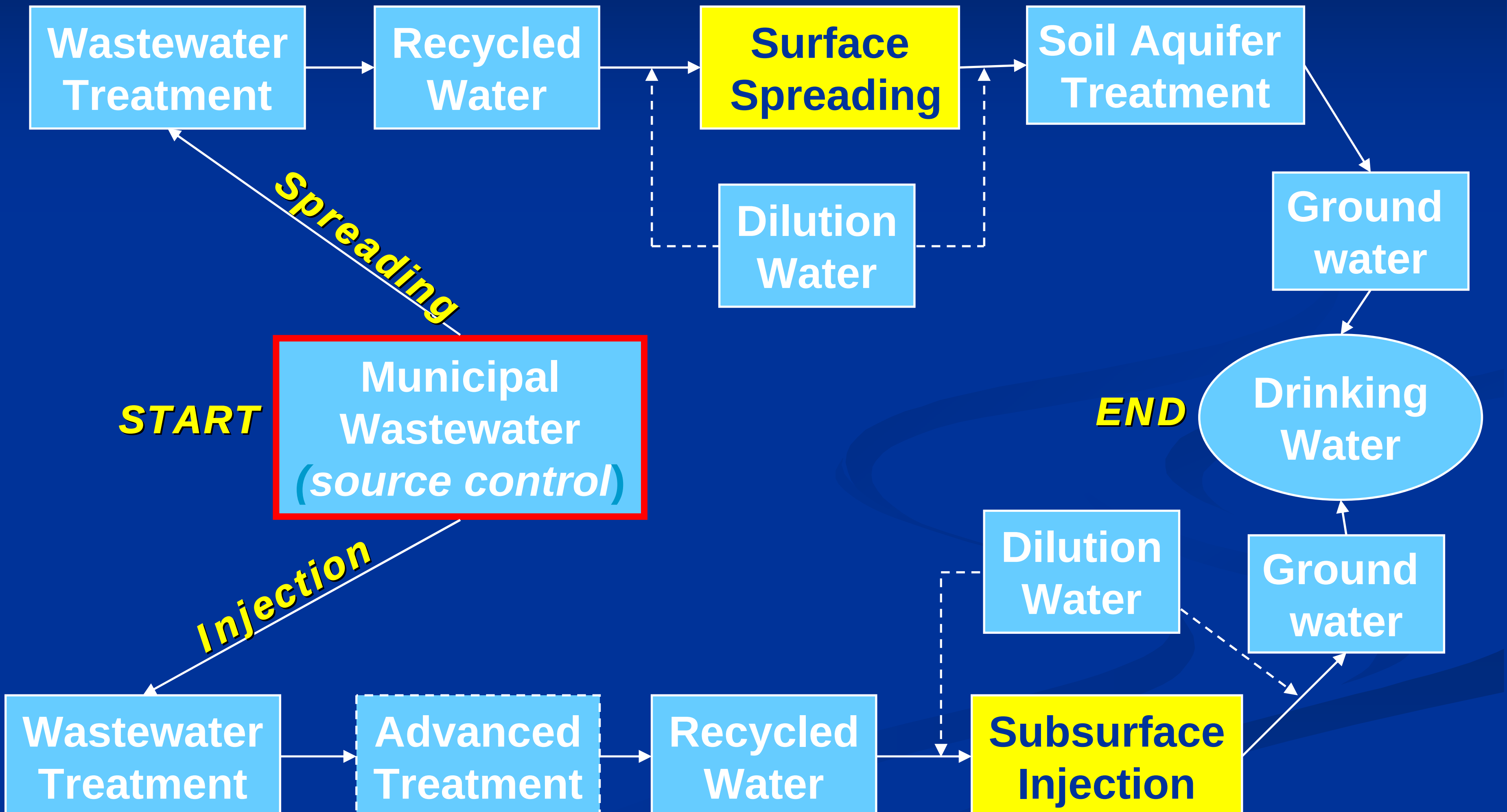


Orange County Water District



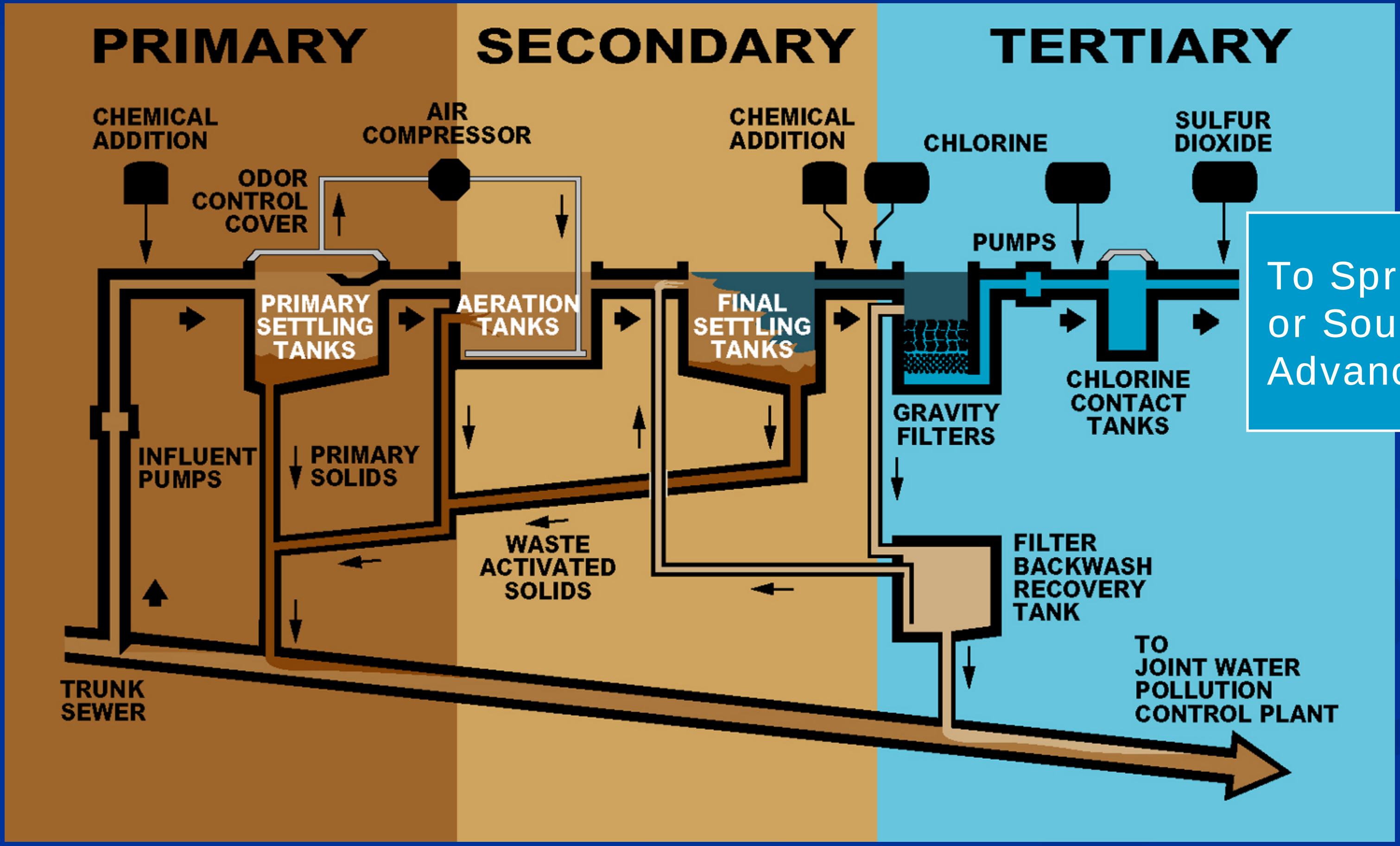


Wastewater to Drinking Water through Groundwater Recharge Via Two Paths



Modified from: CDPH Brian Bernado

Recycled Water Produced at Water Reclamation Plants



To Spreading Grounds or Source Water for Advanced Treatment

LA County Sanitation Districts

Advanced Treatment

WRP Efflulent

Microfiltration

Reverse Osmosis

Ultra Violet Light

Hydrogen Peroxide

To Barriers

State is Supporting Increasing Recycled Water Reuse

- New State Water Board Recycling Policy (2009).
- Recognizes water shortage problems in the state.
- Purpose of the Policy is to focus on increasing the use of recycled water from municipal wastewater sources in a manner consistent with state and federal water quality laws.
- Increase the use of recycled water over 2002 levels by at least one million afy by 2020 and by at least two million afy by 2030.
- Substitute as much recycled water for potable water as possible by 2030.

Permit Process for CA Recycled Recharge Projects

CDPH Draft Regulations (August 2008)

- General Requirements (water liability, source control)
- Non Regulated Chemicals (pharms, PCPs)
- Total Organic Carbon (TOC) requirements
- Pathogenic Microorganisms
- Nitrogen Compounds
- Regulated Chemicals
- Aquifer Travel Time Requirements
- Monitoring Wells
- Engineering Report
- Annual and Five Year Reports

Title 22, CALIFORNIA CODE OF REGULATIONS

DIVISION 4. ENVIRONMENTAL HEALTH

CHAPTER 3. RECYCLING CRITERIA

August 5, 2008

ARTICLE 1. DEFINITIONS

Section 60301.080. 24-hour Composite Sample.

"24-hour composite sample" means an aggregate sample derived from no fewer than eight discrete samples collected at equal time intervals or collected proportional to the flow rate over the compositing period. The aggregate sample shall reflect the average source water quality covering the composite of sample period.

NOTE: Authority cited: Section 100275, Health and Safety Code and Section 13521, Water Code. Reference: Section 13520, Water Code.

Section 60301.190. Diluent Water.

"Diluent water" means water used to dilute recycled municipal wastewater in a groundwater recharge reuse project.

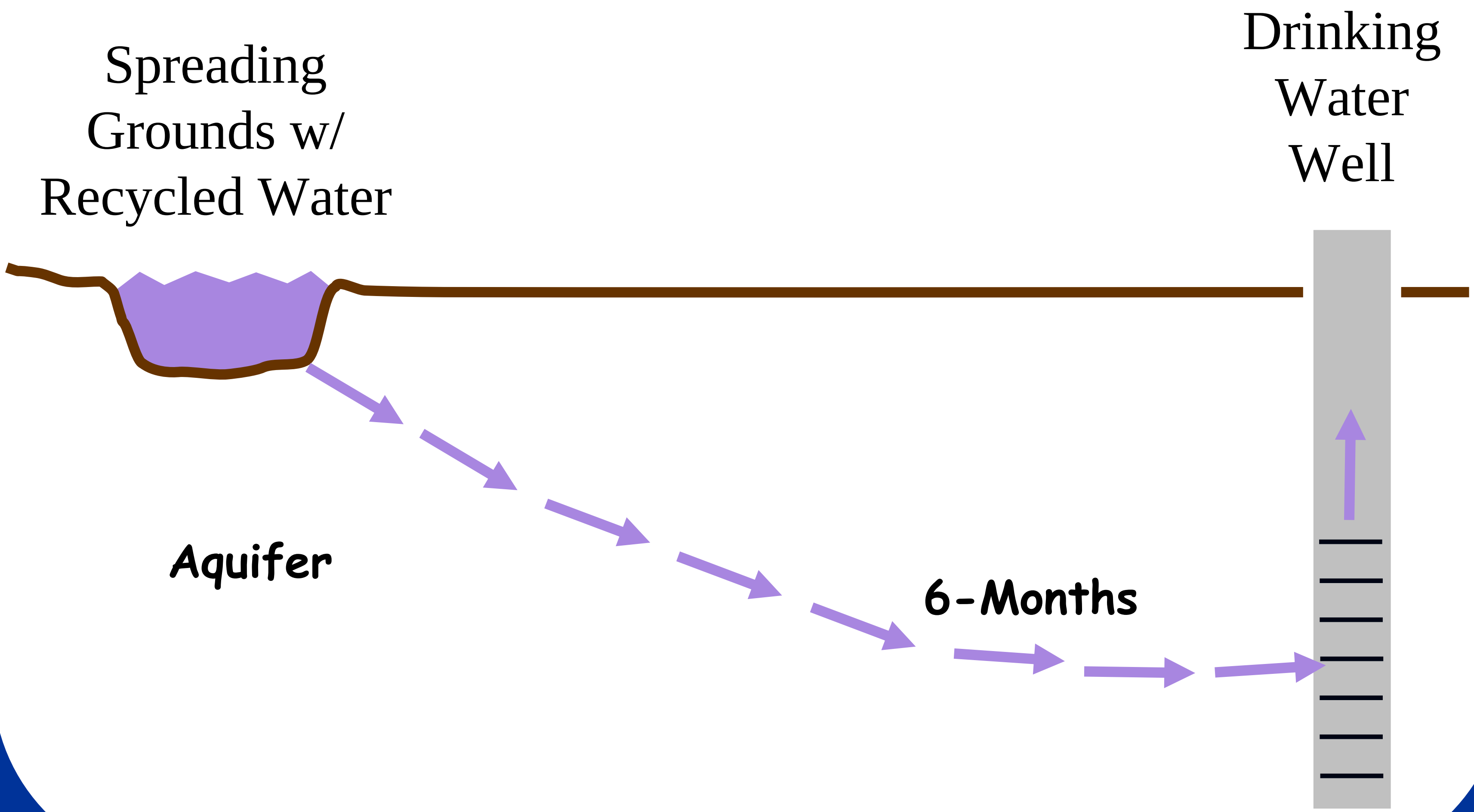
NOTE: Authority cited: Section 100275, Health and Safety Code and Section 13521, Water Code. Reference: Section 13520, Water Code.

http://ww2.cdph.ca.gov/HealthInfo/environhealth/water/Pages/Waterrecycling.aspx

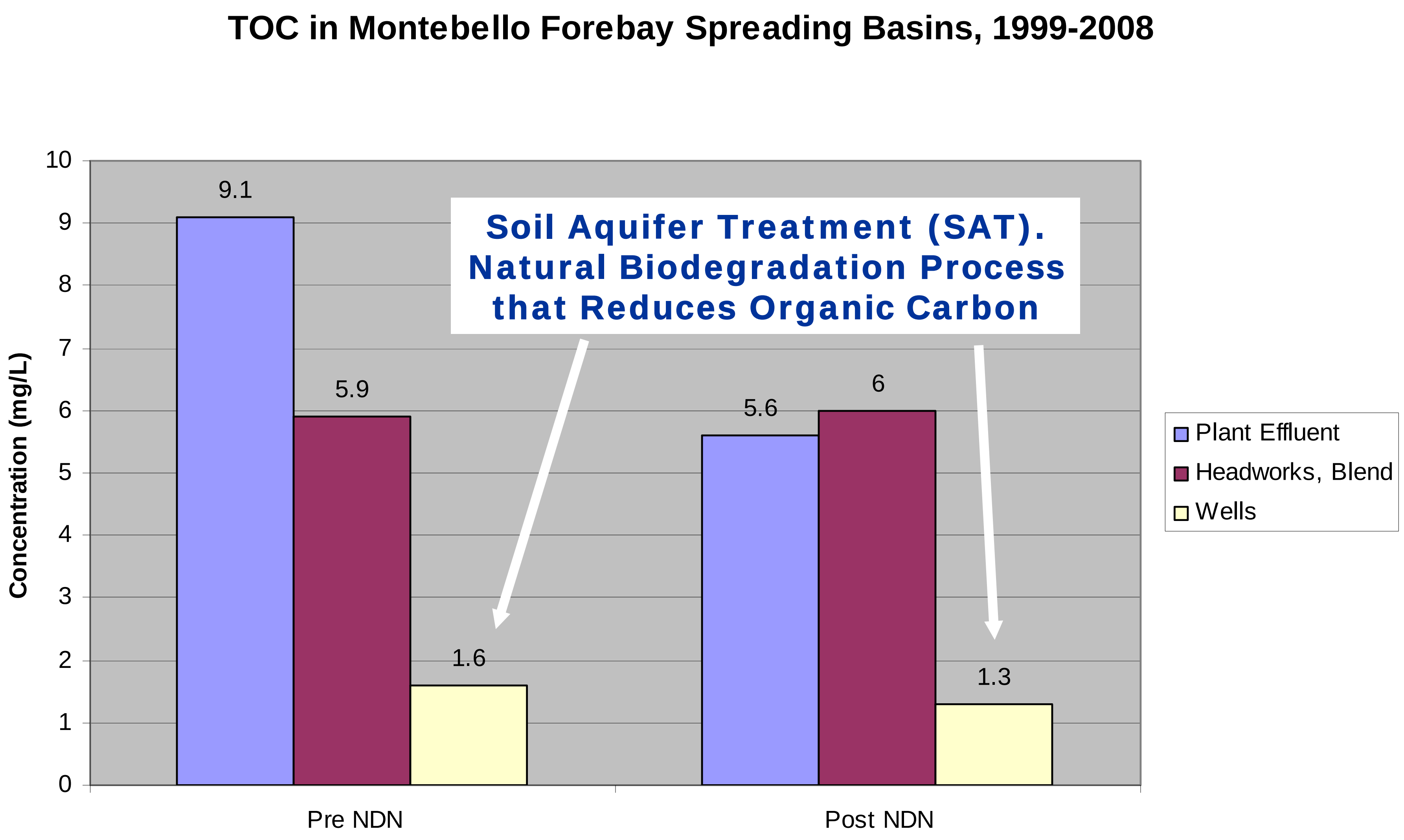
Control of Pathogenic Microorganisms

- Disinfected tertiary filtered recycled water
- Retained underground for a minimum of 6 months prior to extraction for use as a drinking water supply
- GRRP must demonstrate that the minimum retention time has been met
- A tracer study utilizing an added tracer (e.g. sulfur hexafluoride – but recently banned GHG)
    - prior to the end of the third month of operation (including prior to initial operation),
    - under hydraulic conditions representative of normal operations.

Groundwater Travel Time



Changes in Total Organic Carbon (TOC) 1999 – 2008 Full Scale Operations



What about PPCP's???

Headlines from Recent AP articles

AP: Drugs found in drinking water

By Jeff Donn, Martha Mendoza and Justin Pritchard, Associated Press

A vast array of pharmaceuticals — including antibiotics, anti-convulsants, mood stabilizers and sex hormones — have been found in the drinki

Cities rarely release water test results

The Associated Press

When water providers find pharmaceuticals in drinking water, they rarely tell the public. When researchers make the same discoveries, they usually don't identify the cities involved.

Fish, wildlife affected by contaminated water

By Jeff Doon, Martha Mendoza and ustin Pritchard, Associated Press writers

Little done to test, limit contaminated water

By Jeff Donn, Martha Mendoza And Justin Pritchard, Associated Press Writers

No standards in place for bottled water

By Justin Pritchard, Associated Press Writer

The federal standards for acceptable levels of pharmaceutical residue in bottled water are the same as those for tap water — there aren't any.

PPCP = Pharmaceuticals and Personal Care Products

Occurrence

- U.S. Geological Survey (USGS), 2001 – National survey of streams.
- USGS, 2002 – National survey of groundwater
- USGS, Groundwater Ambient Monitoring Assessment (GAMA) Study, 2007 – statewide study to investigate presence of PPCP's in local basins.

USGS, 2001

FIGURE 1. Location of 139 stream sampling sites.

- 95 of 139 streams sampled had PPCPs (68%).
- 5 new analytical methods
- 7 of 15 groups found in over 60 percent of samples.
- 3 of 15 groups made up 80% of concentration (detergents, plasticizers

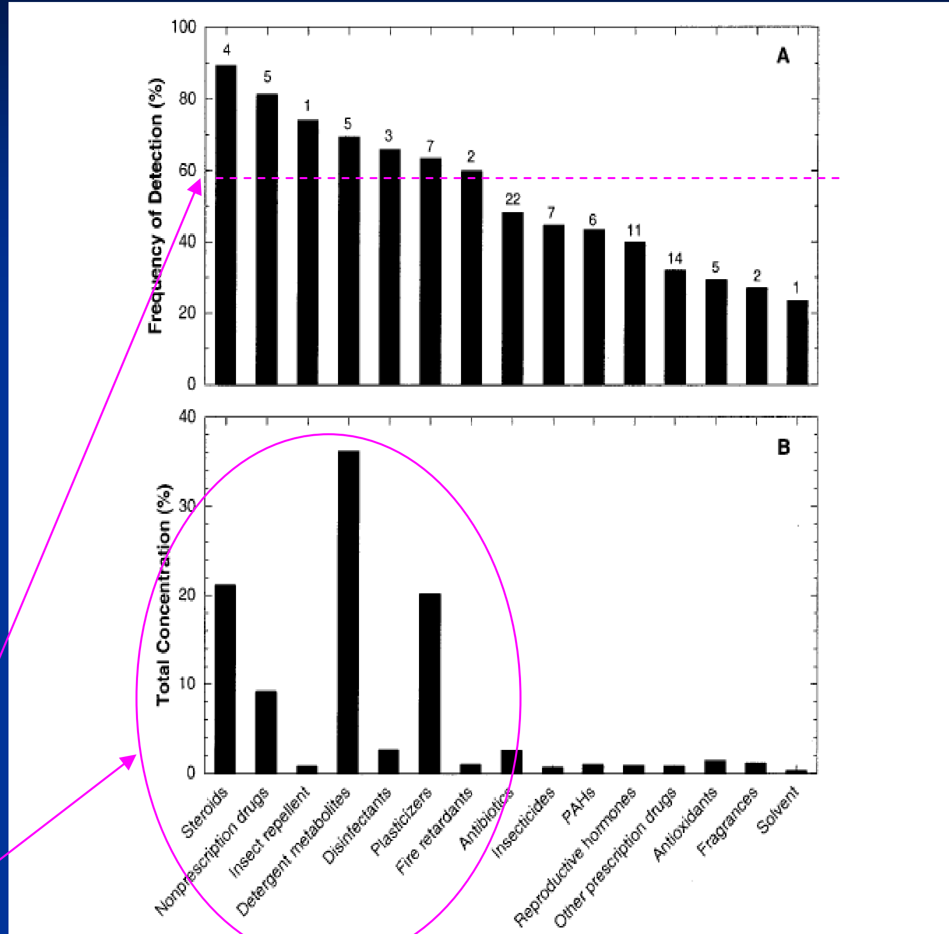


FIGURE 4. Frequency of detection of organic wastewater contaminants by general use category (4A), and percent of total measured concentration of organic wastewater contaminants by general use category (4B). Number of compounds in each category shown above bar.

Locations of Municipal Discharges in Colorado River and State Water Project Watersheds

City of San Diego estimated that 9 – 17% of base flows of imported water are of wastewater origin.

Table 13.4
Removal trends summary for various treatment processes under typical conditions

Target Compound	Coagulation: Alum	Coagulation: Ferric Chloride	Softening	PAC	Cl_2: pH 5.5	Cl_2: Ambient pH	NH_2Cl	O_3	O_3/H_2O_2	UV	UV/H_2O_2	Membrane: UF	Membrane: NF	MIEX
Acetaminophen	low	low	low	high	high	high	high	high	high	low	high	low-med	low	low
Androstenedione	low	low	low	med-high	med	low-med	low	high	high	low	med	low	med	low
Atrazine	low	low	low	med-high	low	low	low	med	med-high	low	med	low	med	low
Benzo(a)pyrene	med-high	med-high	med-high	high	high	high	med-high	high	high	low	med-high	high	high	low
Caffeine	low	low	low	med	med	low	low	high	high	low	low	low	low-med	low
Carbamazepine	low	low	low	med-high	high	low	low	high	high	low	low	low	med	low
DDT	low-med	low-med	low-med	med-high	low	low	low	med	med	low	high	high	high	low
DEET	low	low	low	med	low	low	low	high	high	low	low	low	med	low
Diazepam	low	low	low	med	high	low	low	high	high	low	low	low	med	low
Diclofenac	low	low	low	med	high	high	medium	high	high	med	high	low-med	med	high
Dilantin	low	low	low	med	med	low	low	high	high	low	med	low	low	low-med
Erythromycin	low	low-med	low	med	high	high	low	high	high	low	low	med	med-high	
Estradiol	low	low	low	med	high	high	high	high	high	low	high	low	low	low
Estriol	low	low	low	med	high	high	high	high	high	low	high	low	med	low
Estrone	low	low	low	med-high	high	high	high	high	high	low	hgih	low	med	low
Ethynyl Estradiol	low	low	low	med-high	high	high	high	high	high	low	high	low	med-high	low-med
Fluorene	low	low	low	high	low	low	low	high	high	low	low-med	high	high	med
Fluoxetine	low	low	low-med	high	low-med	low	low	high	high	low	high	high	high	low
Galaxolide	low	low	low	med	med	low-med	low	high	high	low	low-med	med-high	med-high	med
Gemfibrozil	low	low	low	low	high	med-high	low	high	high	low	low	low	med	low-med
Hydrocodone	low	low	low	med-high	high	high	med	high	high	low	med	low	med	low
Ibuprofen	low	low	low	low	med	med	low	high	high	low	med	low	med	low-med
Iopromide	low	low	low	low	low	low	low	med	med-high	low	med-high	low	med	low
Lindane	low	low	low	med-high	low	low	low	low	low	low	low	low	med	low
Meprobamate	low	low	low	low	low	low	low	med-high	med-high	low	low	low	low	low
Metolachlor	low	low	low	med	med	low	low	high	high	low	med-high	low-med	med	low
Musk Ketone	low	low	low	med	med	high	low	low-med	low-med	low	low-med	med	med	low-med
Naproxen	low	low	low	med	high	high	low	high	high	low	high	low	low	med
Oxybenzone	low	low	low	high	high	high	high	high	high	low	low	med	high	med
Pentoxifylline	low	low	low	med-high	high	low	low	high	high	low	low	low	low-med	low
Progesterone	low	low	low	high	med	low-med	low	high	high	low	med	med	med	low
Sulfamethoxazole	low	low	low	med	high	high	low	high	high	med	high	low	med	low
TCEP	low	low	low	med	low	low	low	low	low	low	low	low	med	low
Testosterone	low	low	low	med-high	med	med	low	high	high	low	med	low	med	low
Triclosan	low	low	low	high	high	high	high	high	high	med	high	high	high	high
Trimethoprim	low	low	low	med-high	high	high	low	high	high	low	low-med	low-med	med	low

Advanced Oxidation and Membranes most effective treatment

Table 9.14
Summary of percent removal by membranes

	Percent Removal				
Membrane Size	MF	UF	UF/MBR	NF	RO
# of Systems Tested	n=3	n=5	n=4	n=3	n=9
Acetaminophen (Tylenol)	<20	<20	>80	20-50	>80
Androstenedione	<20	20-50	>80	50-80	>80
Atrazine	*	<20	*	50-80	*
Benzo(a)pyrene	*	>80	*	>80	*
Caffeine	<20	<20	>80	50-80	>80
Carbamazepine	<20	<20	20-50	50-80	>80
DDT	*	>80	50-80	>80	*
DEET	<20	<20	50-80	50-80	>80
Diazepam (Valium)	*	20-50	<20	50-80	>80
Diclofenac	<20	<20	<20	50-80	>80
Dilantin	<20	<20	<20	50-80	>80
Erythromycin	<20	20-50	20-50	>80	>80
Estradiol	<20	20-50	50-80	50-80	>80
Estriol	*	<20	>80	50-80	>80
Estrone	<20	20-50	>80	50-80	>80
Ethinyl Estradiol	*	20-50	>80	50-80	>80
Fluorene	*	>80	*	>80	*
Fluoxetine (Prozac)	20-50	>80	20-50	>80	>80
Galaxolide	<20	20-50	*	50-80	>80
Gemfibrozil	<20	<20	20-50	50-80	>80
Hydrocodone	<20	<20	20-50	50-80	>80
Ibuprofen (Advil)	<20	<20	50-80	50-80	>80
Iopromide	<20	<20	<20	>80	>80
Lindane (γ-BHC)	*	20-50	*	50-80	*
Meprobamate	<20	<20	<20	50-80	>80
Metolachlor	*	20-50	*	50-80	*
Musk Ketone	<20	20-50	*	>80	>80
Naproxen	<20	<20	>80	20-50	>80
Oxybenzone	<20	50-80	>80	>80	>80
Pentoxifylline	<20	<20	>80	50-80	>80
Progesterone	*	50-80	>80	50-80	>80
Sulfamethoxazole	<20	20-50	20-50	50-80	>80
TCEP	<20	<20	<20	50-80	>80
Testosterone	*	20-50	>80	50-80	*
Triclosan	20-50	>80	50-80	>80	>80
Trimethoprim	<20	<20	20-50	50-80	>80

* Not detected

Table 2

Treatment Removal Bins for Indicators of SAT Systems (Conditions: Travel Time in Subsurface >4 Weeks; Predominant Redox Conditions: Oxic Followed by Anoxic; Dilution: 0%)

Good Removal		Intermediate Removal		Poor Removal
> 90%		90-50%	50-25%	< 25%
Acetaminophen	Ketoprofen	Meprobamate	Chloroform	Carbamazepine
Acetyl cedrene[1]	Mecoprop			Primidone
Atenolol[2]	Methyl dihydrojasmonate[2]			TCEP
Atorvastatin[1]	Methyl ionine[3]			TCPP
Atorvastatin (o-hydroxy) [1]	Methyl salicylate[2]			TDCPP
Atorvastatin (p-hydroxy) [1]	Metoprolol			Dilantin
Benzyl acetate[2]	Musk ketone[1]			
Benzyl salicylate[3]	Musk xylene[1]			
Bisphenol A	Naproxen			
Bucinal[3]	NDMA			
Butylated hydroxyanisole[3]	Nonylphenol			
Caffeine	OTNE[1]			
DEET	Phenylphenol[2]			
Dichlorprop	Propranolol			
Diclofenac	Propylparaben[2]			
EDTA	Salicyclic acid			
Erythromycin-H_2O	Simvastatin hydroxy acid[3]			
Estriol	Sulfamethoxazole			
Estrone	Terpineol[1]			
Fluoxetine	Tonalide[1]			
Galaxolide[1]	Triclocarban[1]			
Gemfibrozil	Triclosan			
Hexyl salicylate[3]	Trimethoprim			
Hexylcinnamaldehyde[1]				
Hydrocodone				
Ibuprofen				
Indolebutyric acid[2]				
Iopromide				
Isobornyl acetate[1]				
Isobutylparaben[3]				

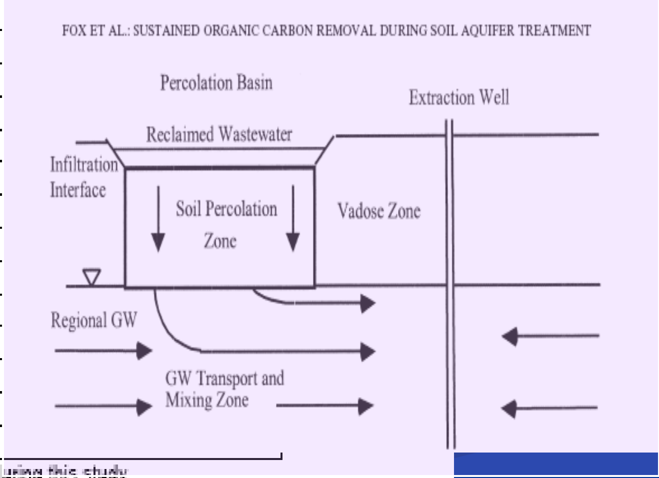
Note: Removal of compounds with no footnote was verified through peer-reviewed literature data or experimental data generated during this study.

1 Removal estimated based upon logD>3.0 (pH 7)

2 Removal estimated as fast biodegradation based upon BioWin prediction

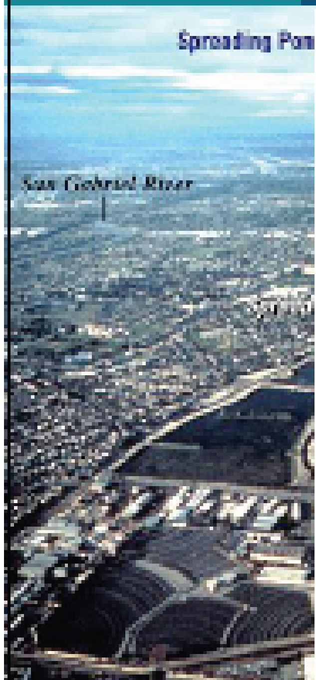
3 Removal estimated based upon logD>3.0 (pH 7) AND fast biodegradation based upon BioWin prediction

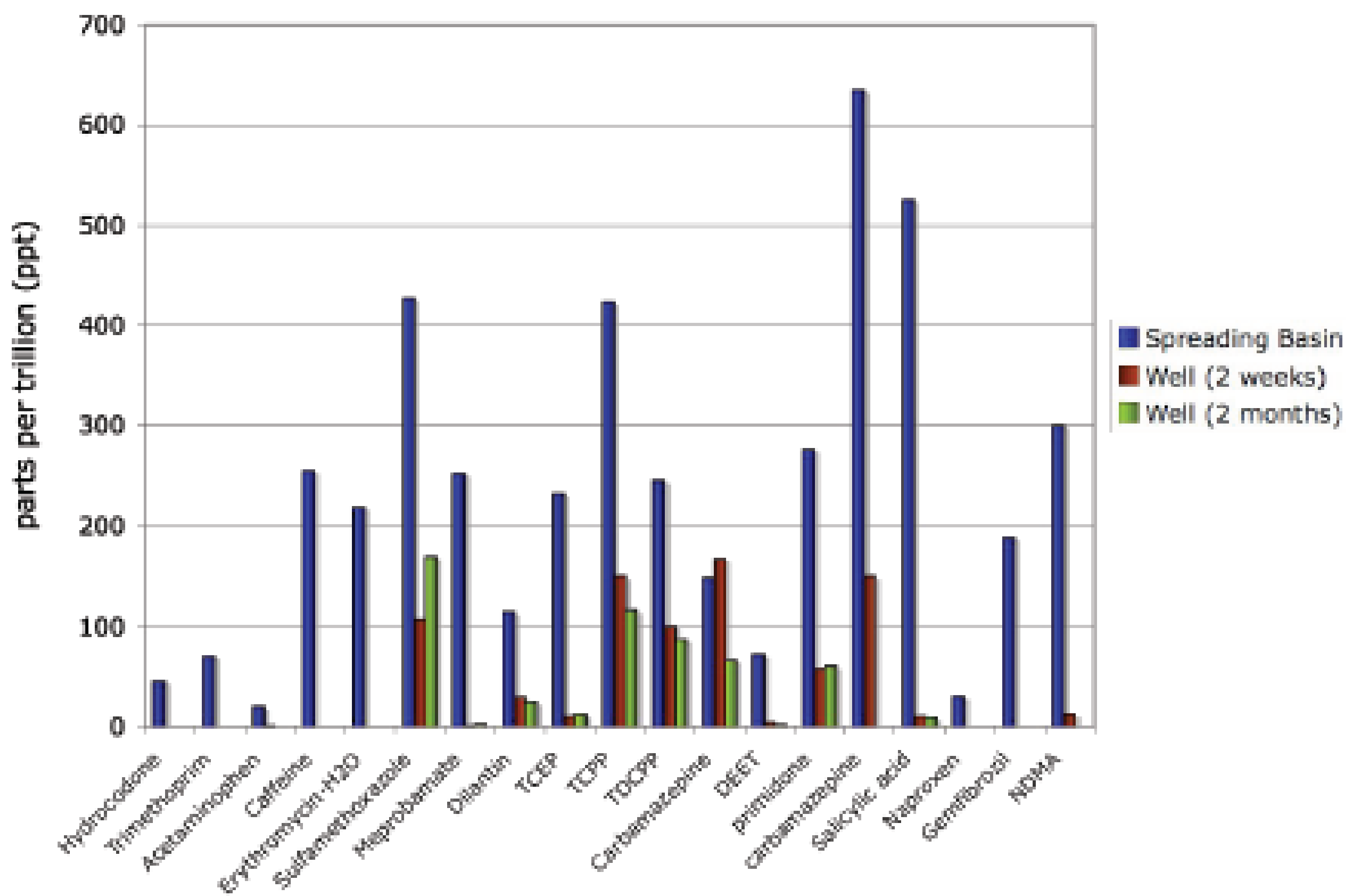
Soil Aquifer Treatment (SAT) is effectively removing most PPCP's



Drewes, Ref. 2

Fate of Trace Organics during SAT - Rio Hondo, CSDLAC





Only Some of the Research…

1. Snyder, etal, “Removal of EDCs and Pharmaceuticals in Drinking and Reuse Treatment Processes”, 2007, AWWARF Report No. 91188.
2. Drewes, et al, “Development of Indicators and Surrogates for chemical Contaminant Removal during Wastewater Treatment and Reclamation”, 2007, WateReuse Foundation Draft Final Project Report 03-014.
3. Coss, Ron, etal, “Reservoir Augmentation in the Arid Southwest – Is it a viable option?”, WateReuse Association California Section 2007 Conference Proceeding, May 2007.
4. Kolpin, Dana W., etal, “Pharmaceuticals, Hormones, and Other Organic Wastewater Contaminants in U.S. Streams, 1999-2000: A National Reconnaissance, Environmental Science and Technology, 2002, 36, 1202-1211.
5. Barnes, K.K., Kolpin, D.W., Furlong, E.T., Zaugg, S.D., Meyer, M.T., Barber, L.B., and Focazio, M.J., 2005, “Studies examine contaminants--Pharmaceuticals, hormones and other organic wastewater contaminants in ground water resources,”: National Driller Magazine, v. 26, no. 3, p. 38-39.
6. http://epa.gov/ppcp/faq.html - EPA website, Frequent Questions, PPCP’s

Results of PPCP Studies

- PPCP's are present in extremely low levels at ng/L range in waterways receiving wastewater effluent and non-point surface runoff.
- Reverse Osmosis and Advanced Oxidation combined are the most effective treatment methods, however they are expensive, create waste (brine), and produce a sterile water that does not promote SAT.
- Soil Aquifer Treatment (SAT) is very effective at removing many PPCPs, is sustainable and natural, but needs organic carbon to be effective.
- Human health effects at these levels not identified.

Summary

- Recycled water has proven to be a safe and effective resource for indirect potable reuse via groundwater recharge for decades.
- State of California is promoting increased recycled reuse to makeup for water losses from traditional sources.
- Extensive control and monitoring measures in place to ensure protection of source waters, environment, and human health.
- Emerging issues come up that require thorough research and scientific analysis to separate fact from fiction.

Questions? Contact Ted Johnson: tjohnson@wrd.org