SB X2 1
Nitrate in Groundwater
Report to the Legislature

DRINKING WATER TREATMENT

December 1, 2011

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Conceptual Overview

Literature Review

- Design and cost considerations
- Case studies - Full scale systems
- Pilot studies - Emerging technologies

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Water Quality Data

- Assess nitrate occurrence
- Locate potable water systems
- Characterize water quality
- WQM and PICME databases

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Survey

- Survey of water systems
- Applied treatment in project area
- Cost information

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Nitrate treatment recommendations with consideration of water quality, system size, feasibility and cost

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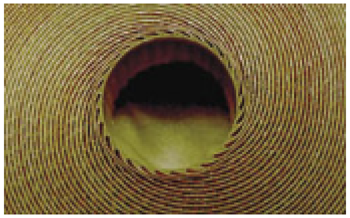
Removal Technologies


Source: Siemens

- Ion Exchange
  - Nitrate displaces chloride on anion exchange resin
  - Resin recharge with brine solution
  - Limitations: sulfate, resin fouling, disposal

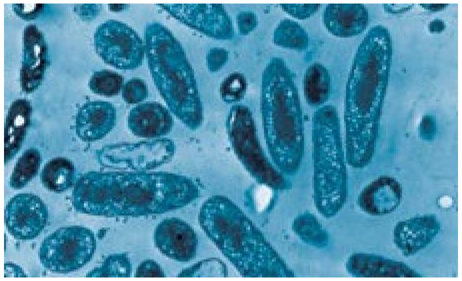

Source: Dow Chemical

- Reverse Osmosis
  - Water molecules pushed through membrane
  - Contaminants left behind
  - Limitations: membrane fouling, pretreatment, disposal


Source: PC Cell

- Electrodialysis
  - Electric current governs ion movement
  - Anion and cation exchange membranes
  - Limitations: operationally complex, disposal

Reduction Technologies



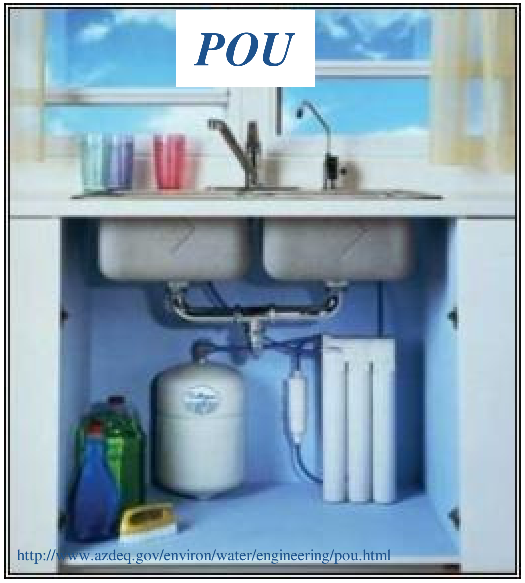
Source: AnoxKaldnes

- Biological Denitrification
  - Bacteria transform nitrate to nitrogen gas
  - Anoxic conditions
  - Requires electron donor (substrate)
  - Limitations: lack of U.S. full scale systems, substrate requirement, post-treatment (filtration, disinfection)

Source: Hepure Technologies

- Chemical Denitrification
  - Metals reduce nitrate to ammonia (typically)
  - Zero-valent iron (ZVI)
  - Catalytic denitrification
  - Limitations: pilot studies only, reduction to ammonia, dependence on temperature and pH

POU/POE



From CDPH Emergency Regulations, as of December 21, 2010,

"…a public water system may be permitted to use point-of-use treatment devices (POUs) in lieu of centralized treatment for compliance with one or more maximum contaminant levels… if;

(1) the water system serves fewer than 200 service connections,

(2) the water system meets the requirements of this Article,

(3) the water system has demonstrated to the Department that centralized treatment, for the contaminants of concern, is not economically feasible within three years of the water system's submittal of its application for a permit amendment to use POUs,

… no longer than three years or until funding for the total cost of constructing a project for centralized treatment or access to an alternative source of water is available, whichever occurs first…"

Treatment Options

Table i Comparison of Major Treatment Types[1]

Concerns	IX	RO	EDR	BD	CD
High Nitrate Removal					
High TDS Removal					
Arsenic Removal					
Radium and Uranium Removal					
Chromium Removal					
Perchlorate Removal					

Priorities	IX	RO	EDR	BD	CD
High Hardness Not a Major Concern					
Reliability					
Training/ Ease of operation					
Minimize Capital Cost					
Minimize Ongoing O&M Cost					
Minimize Footprint					
Industry Experience					
Ease of Waste Management					

Good	→	Poor	Unknown (blank)

1 Ion Exchange (IX), Reverse Osmosis (RO), Electrodialysis Reversal (EDR), Biological Denitrification (BD), Chemical Denitrification (CD). This table offers a generalized comparison and is not intended to be definitive; there are notable exceptions to the above classifications.

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Treatment Selection

Option	Practical Nitrate Range	Considerations
Blend	10-30% above MCL	Dependent on capacity and nitrate level of blending sources.
Ion Exchange	Up to 2X MCL	Dependent on regeneration efficiency, costs of disposal and salt usage. Brine treatment, reuse, and recycle can improve feasibility at even higher nitrate levels.
Reverse Osmosis	Up to many X MCL	Dependent on energy use for pumping and number of stages. May be more cost-effective than IX for addressing very high nitrate levels.
Biological Denitrification	Up to many X MCL	Dependent on the supply of electron donor and optimal conditions for denitrifiers. May be more cost-effective than IX for addressing high nitrate levels.

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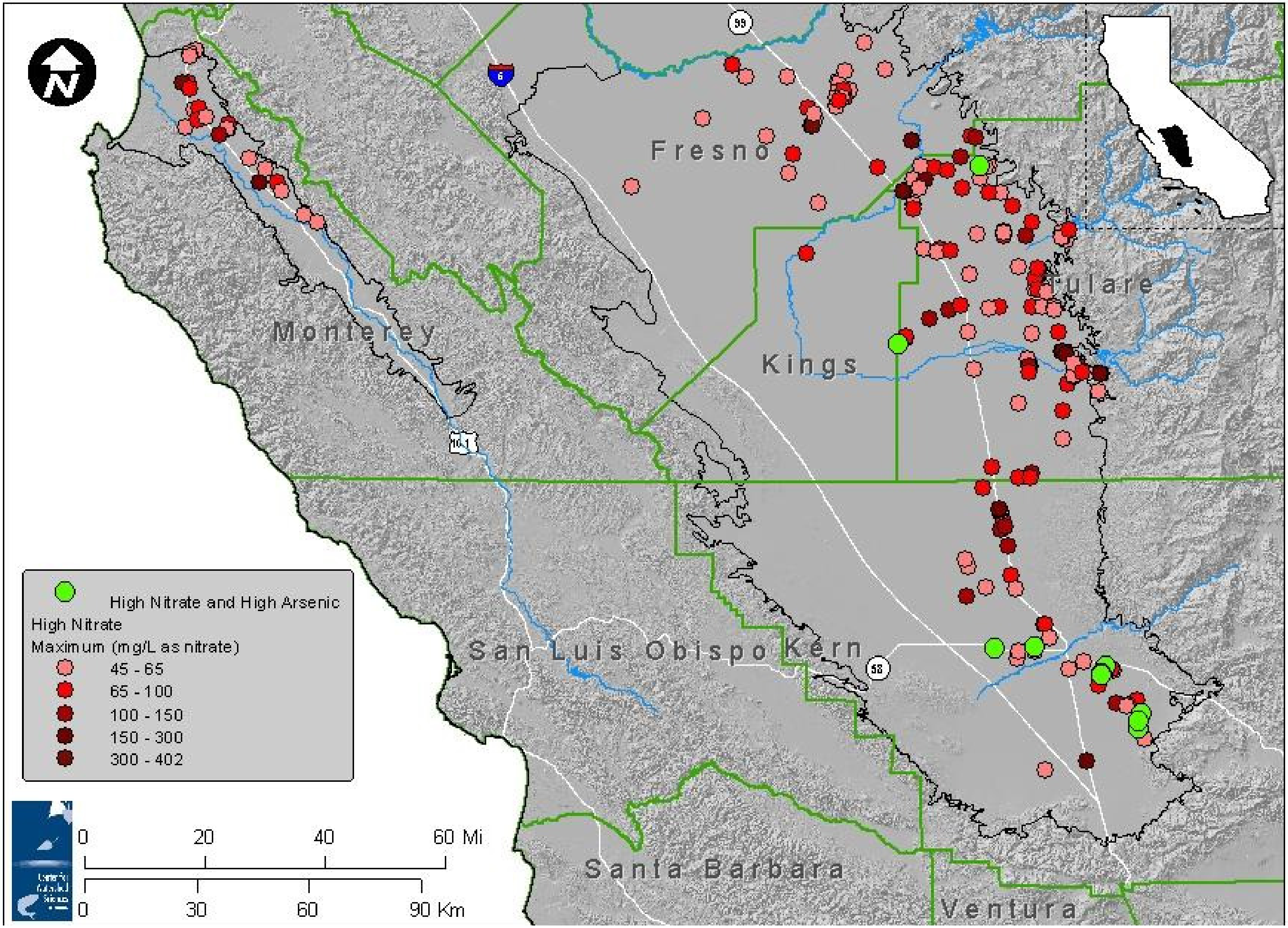
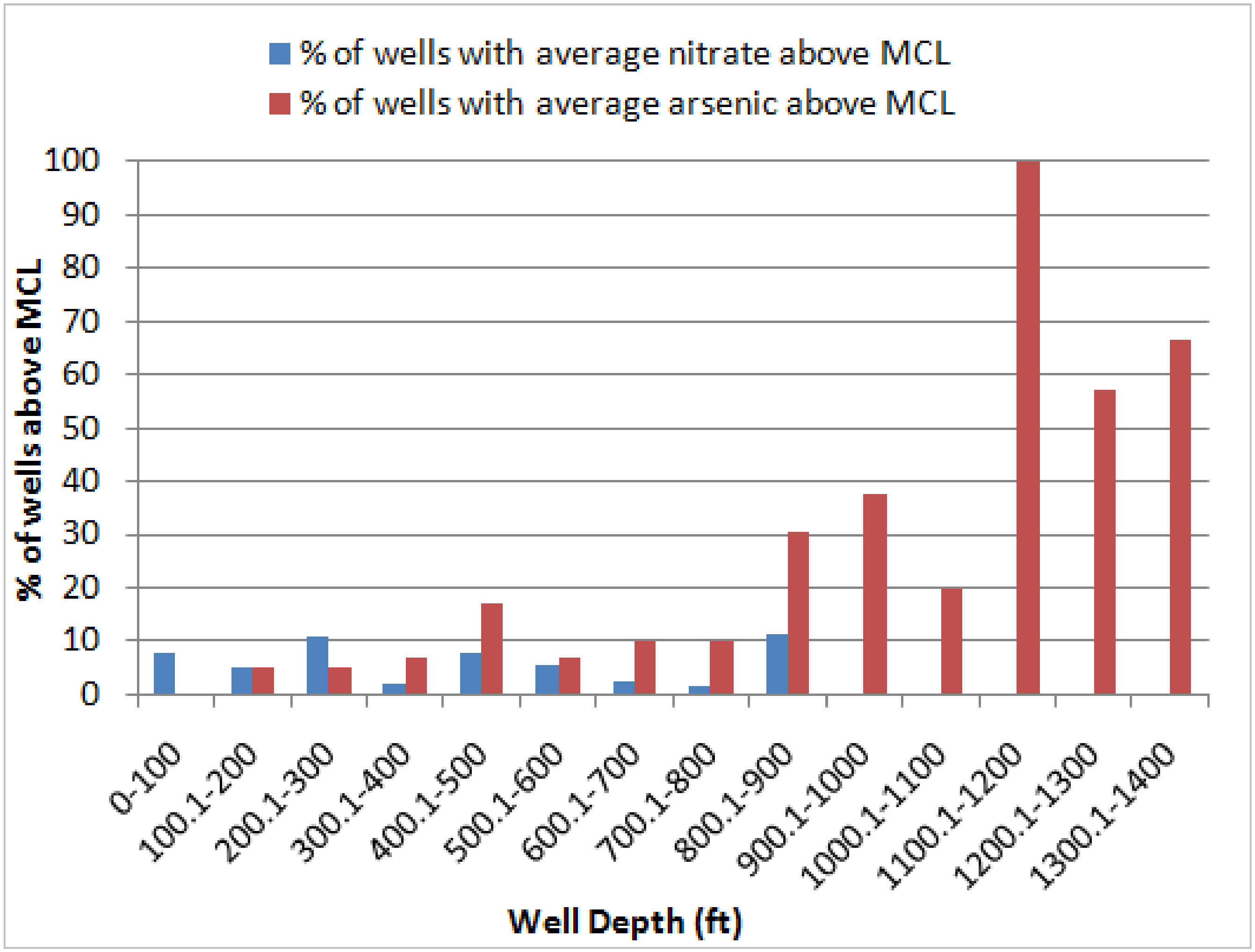
Raw Water Nitrate Levels Exceeding the MCL (45 mg/L as nitrate) and Consideration of Co-contaminants



Arsenic, Nitrate and Depth



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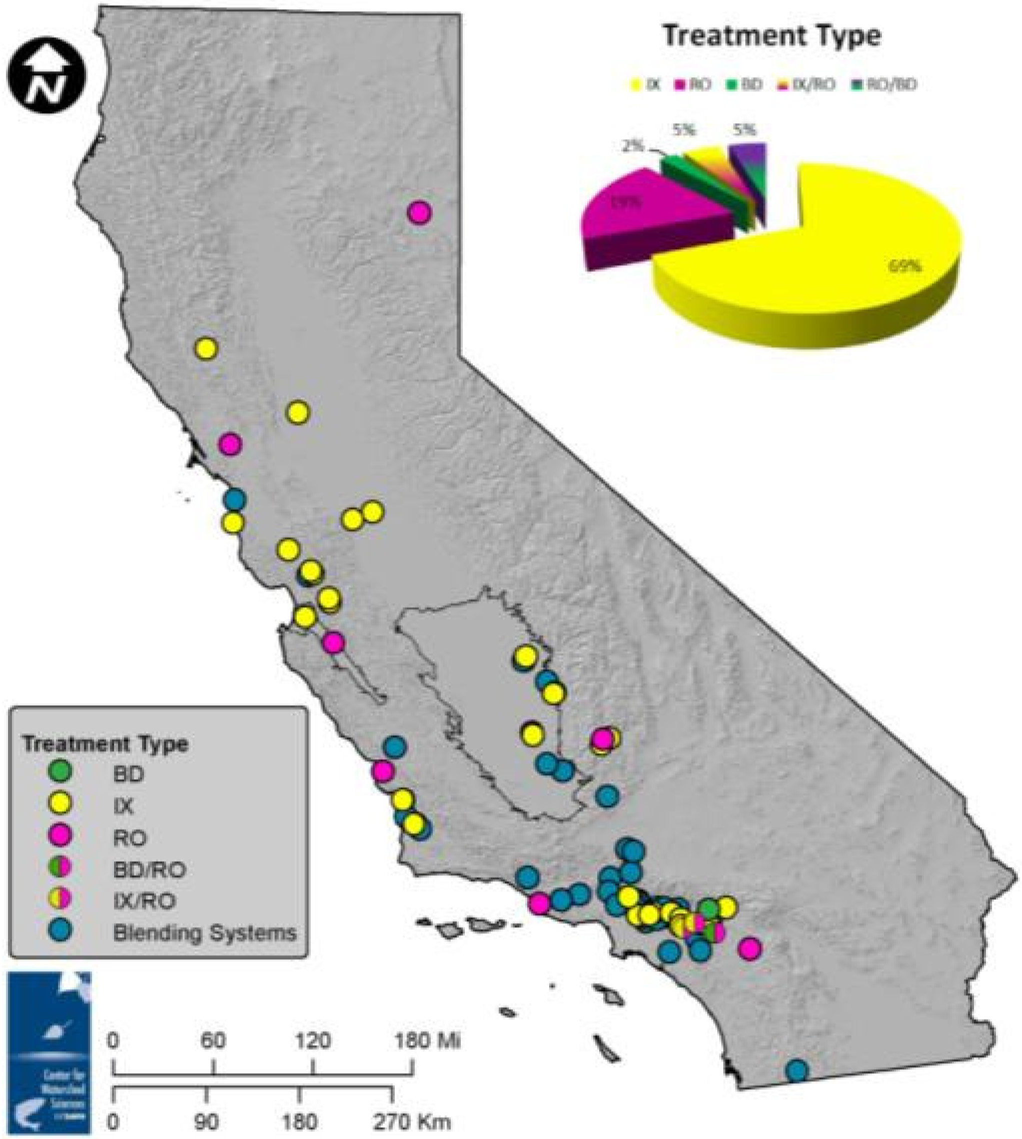
Treating and Blending



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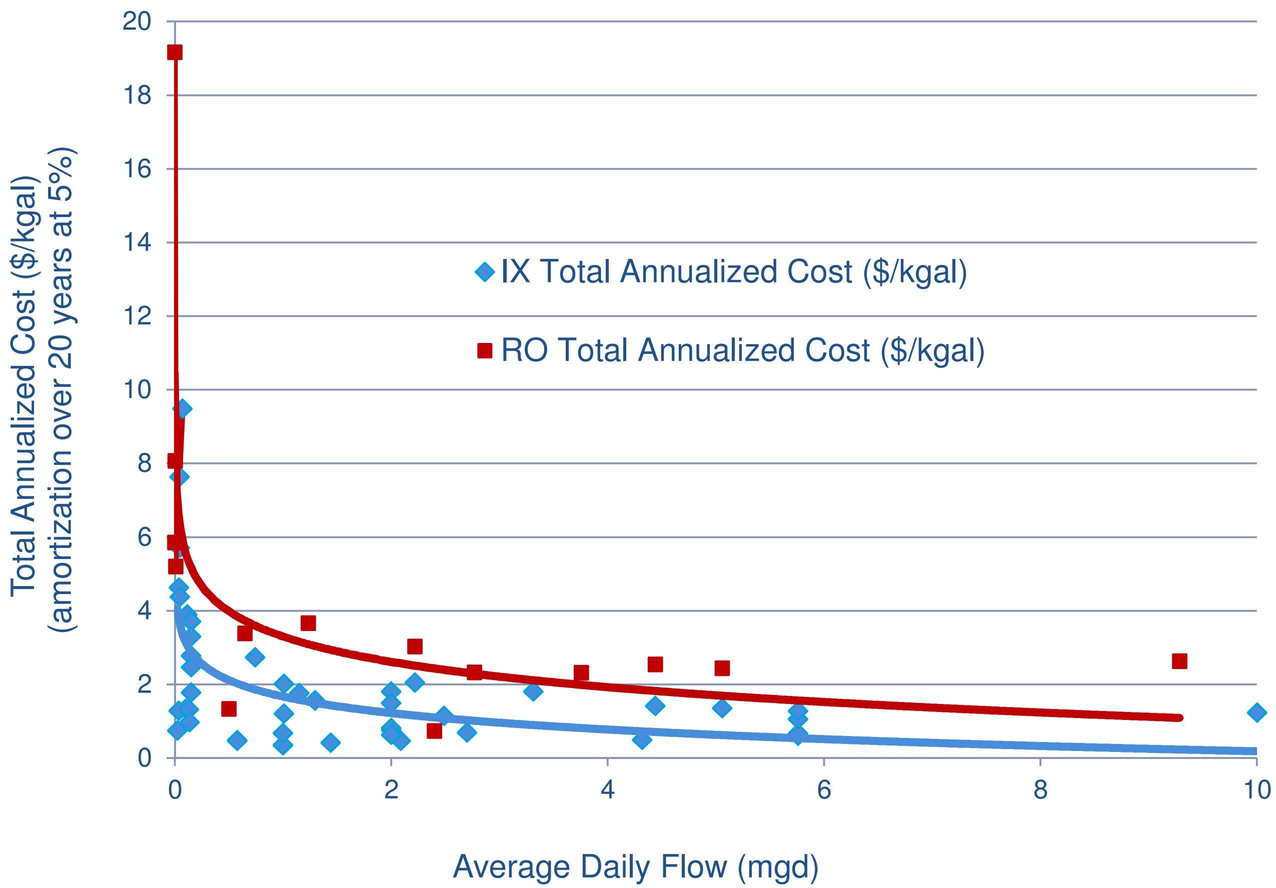
Treatment Costs

System Size (people)	Design Flow Range (typical average flow range)	Treatment Type	Annualized Costs in $/1000 gallons		
			Capital Cost Range (Avg.)	O&M Cost Range (Avg.)	Total Combined Cost Range (Avg.)
	MGD		$/1000 gallons	$/1000 gallons	$/1000 gallons
Very Small (25 – 500)	0.009 – 0.17 (0.002 – 0.052)	Ion Exchange	0.05 – 1.53 (0.75)	0.28 – 3.81 (1.22)	0.62 – 4.60 (1.97)
		Reverse Osmosis	0.47 – 4.40 (2.43)	0.22 – 16.16 (4.22)	0.69 – 19.16 (6.64)
Small (501 – 3,300)	0.17 – 1.09 (0.052 – 0.39)	Ion Exchange	0.08 – 0.25 (0.15)	0.15 – 2.63 (0.87)	0.34 – 2.73 (1.05)
		Reverse Osmosis [1]	0.19 – 1.13 (0.47)	0.23 – 1.15 (0.57)	0.58 – 1.34 (0.93)
Medium (3,301 – 10,000)	1.09 – 3.21 (0.39 – 1.3)	Ion Exchange	0.06 – 0.52 (0.19)	0.12 – 1.69 (0.84)	0.36 – 2.04 (1.06)
		Reverse Osmosis [1]	0.44 – 0.63 (0.53)	0.91 – 2.76 (1.89)	1.35 – 3.39 (2.59)
Large (10,001 – 100,000)	3.21 – 30.45 (1.3 – 15.51)	Ion Exchange	0.09 – 0.41 (0.26)	0.13 – 1.39 (0.66)	0.22 – 1.81 (0.97)
		Reverse Osmosis	0.33 – 1.46 (0.97)	0.40 – 2.21 (1.48)	0.73 – 3.67 (2.38)

[1] Limited data set for the indicated system size and treatment type.

Costs by System Size

Centralized Treatment



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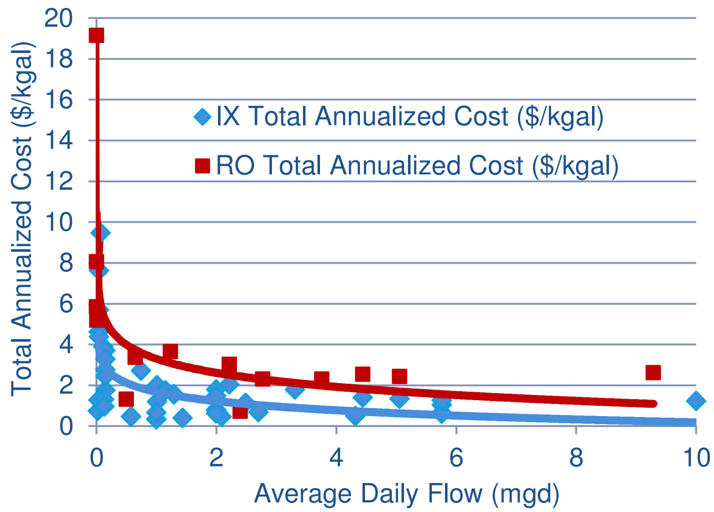

Point-of-Use

	Upfront Investment	Annual Costs	Comments
Ion Exchange	$660-$2425	Salt costs ($3.30-$4.40/bag)	Requires disposal of brine waste, high sodium levels
Reverse Osmosis	$330-$1430	$110-$330/yr + electricity	Requires filter replacement, high maintenance, lower water recovery

From (Mahler et al., 2007)

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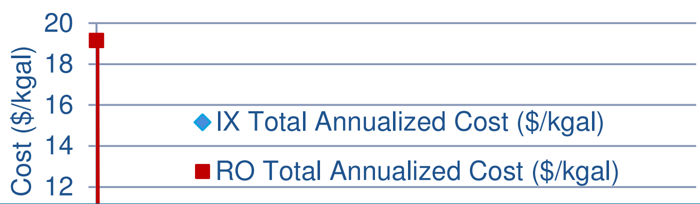

Treatment costs are unique to individual systems based on:

*system size	*treatment type	*nitrate level
*co-contaminants	*blending options	*seasonal variation
*location	*disposal options	*others…

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Sustainability Considerations

Brine Management - Disposal costs

	Annualized Capital Cost	O&M Cost	Total Annualized Cost	Total Range
Average Cost by Waste Volume ($/1000 gallons)				
Evaporation Ponds	10.23	5.62	15.85	7 to 27
Solar Ponds	20.48	18.80	39.27	8 to 88
Well Injection	12.00	18.52	30.52	13 to 111
Sewer	2.40	5.51	7.91	6 to 11
Average Cost by Treated Volume ($/1000 gallons)				
Evaporation Ponds	0.046	0.015	0.061	0.03 to 0.14
Solar Ponds	0.063	0.047	0.110	0.07 to 0.20
Well Injection	0.051	0.077	0.128	0.03 to 0.33
Sewer	0.007	0.034	0.041	0.02 to 0.12

– Reuse/Recycle the brine waste stream from IX
– Emerging brine treatment technologies

Biological Denitrification

– Promising for multiple contaminants and potentially less expensive
– 2 systems being implemented in CA: Rialto and Riverside
– Proposed pilot :Glendale, CA

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- Account for unique needs of each individual water system.
- Consider future water quality changes in treatment selection.
- Consider future water system changes in treatment selection.
- Where centralized treatment or consolidation are not feasible, implement a system of centralized management.
- Fund for the best long-term solution.

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Conclusions

- In the selection of treatment options, the unique needs of each individual water system must be considered.
- A single treatment solution will not fit every community; however, the provision of safe drinking water for all communities can be achieved using currently existing technology.
- Centralized treatment may not be feasible for widespread rural communities, but centralized management (e.g., design, purchasing, and maintenance) could minimize costs.
- Technologies capable of multiple contaminant removal will likely become the dominant choice in the future.

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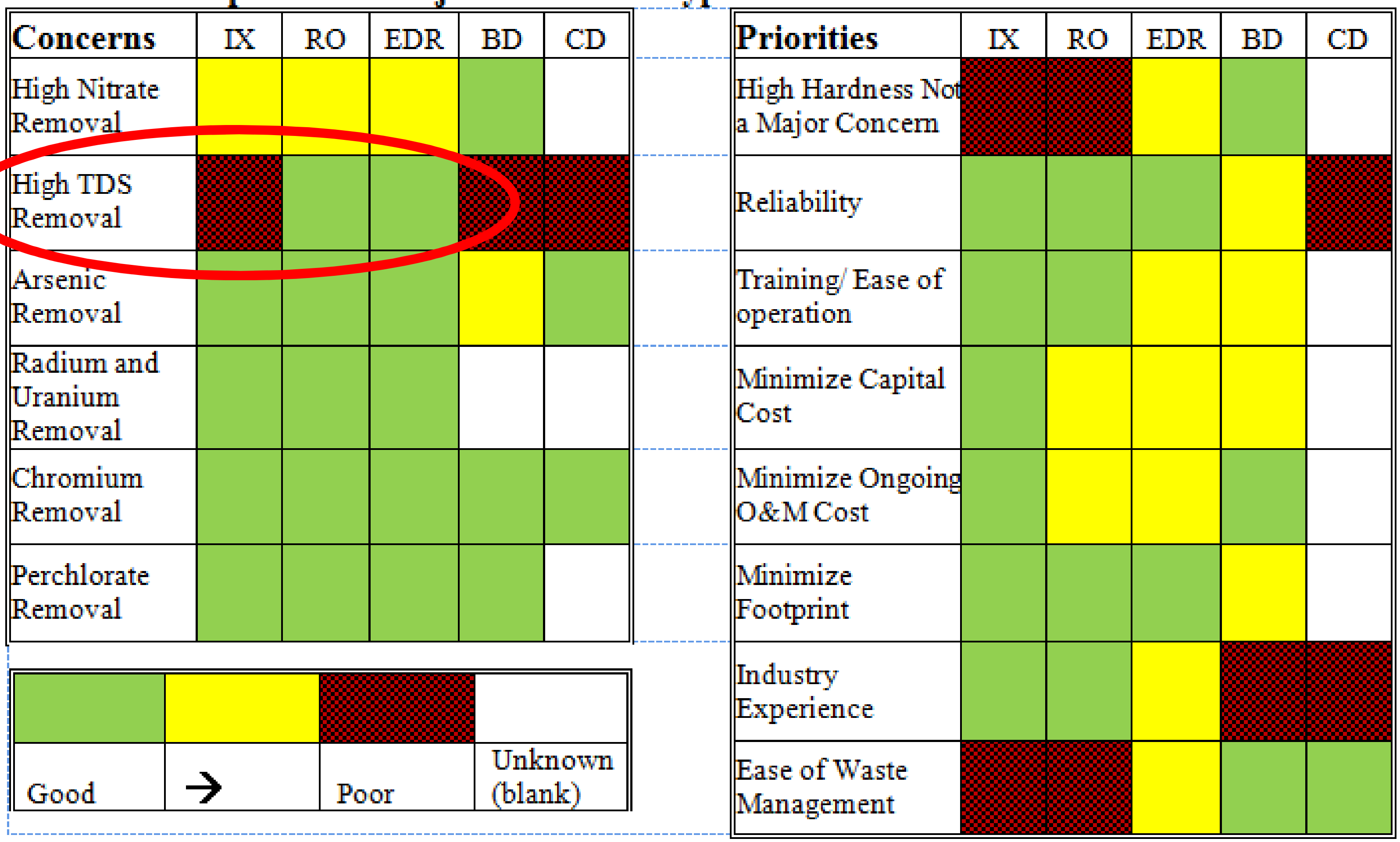

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Table A.6 Advantages and Disadvantages of the Five Major Treatment Options for Nitrate Removal.		
	Advantages	**Disadvantages**
Ion Exchange	• Years of industry experience, • Multiple contaminant removal, • Selective nitrate removal, • Financial feasibility, • Use in small and large systems, and • The ability to automate.	• The disposal of waste brine, • The potential for nitrate dumping specifically for non-selective resin use for high sulfate waters, • The need to address resin susceptibility to hardness, iron, manganese, suspended solids, organic matter, and chlorine, and • The possible role of resin residuals in DBP formation.
Reverse Osmosis	• High quality product water, • Multiple contaminant removal, • Desalination (TDS removal), • Feasible automation, • Small footprint, and • Application for small and POU applications.	• The disposal of waste concentrate, • Typically high capital and O&M costs, • The need to address membrane susceptibility to hardness, iron, manganese, suspended solids, silica, organic matter, and chlorine, • High energy demands, and • The lack of control over target constituents (complete demineralization).
Electrodialysis/ Electrodialysis Reversal	• Limited to no chemical usage, • Long lasting membranes, • Selective removal of target species, • Flexibility in removal rate through voltage control, • Better water recovery (lower waster volume), • Feasible automation, and • Multiple contaminant removal	• The disposal of waste concentrate, • The need to address membrane susceptibility to hardness, iron, manganese, and suspended solids, • High maintenance demands, • Costs (comparable to RO systems, but may not be cost effective for large systems), • The need to vent gaseous by-products, • The potential for precipitation with high recovery, • High system complexity, and • Dependence on conductivity.
Biological Denitrification	• High water recovery, • No brine or concentrate waste stream (nitrate reduction rather than removal to waste stream), • Low sludge waste, • Less expensive operation,	• The need for substrate and nutrient addition, • High monitoring needs, • Significant post-treatment requirements, • High capital costs, • Sensitivity to environmental conditions (sometimes), • Large system footprint (sometimes),

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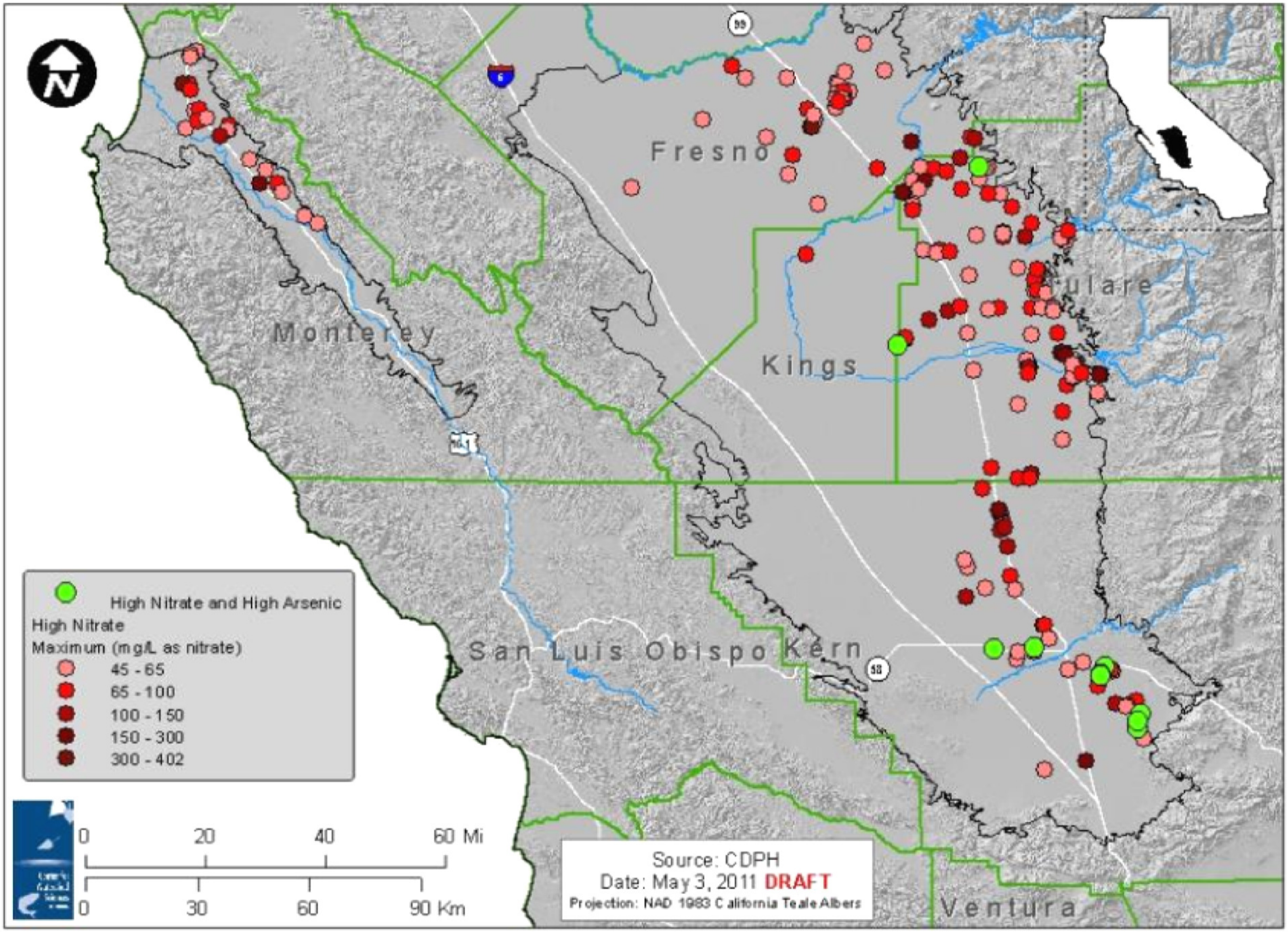

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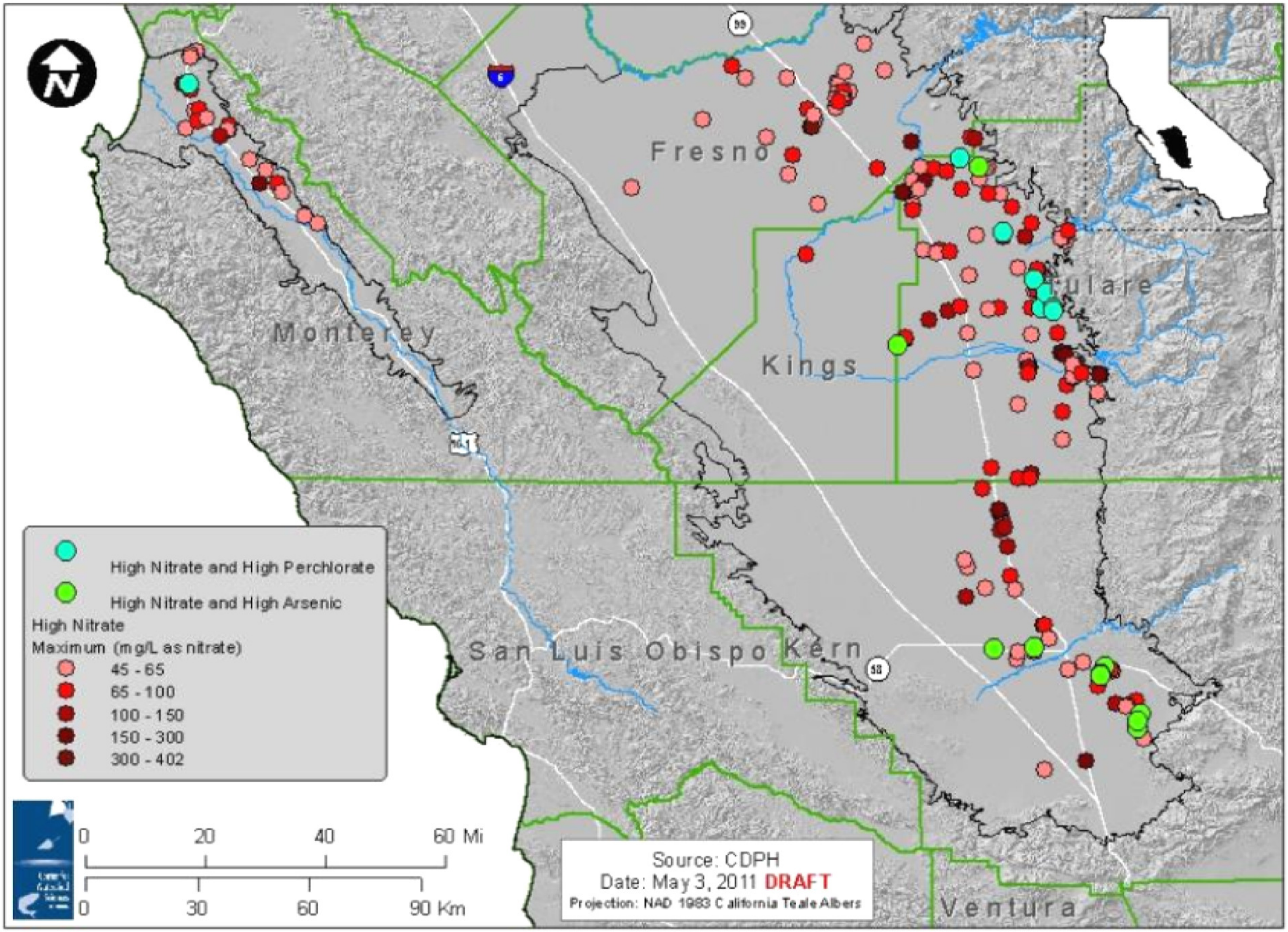

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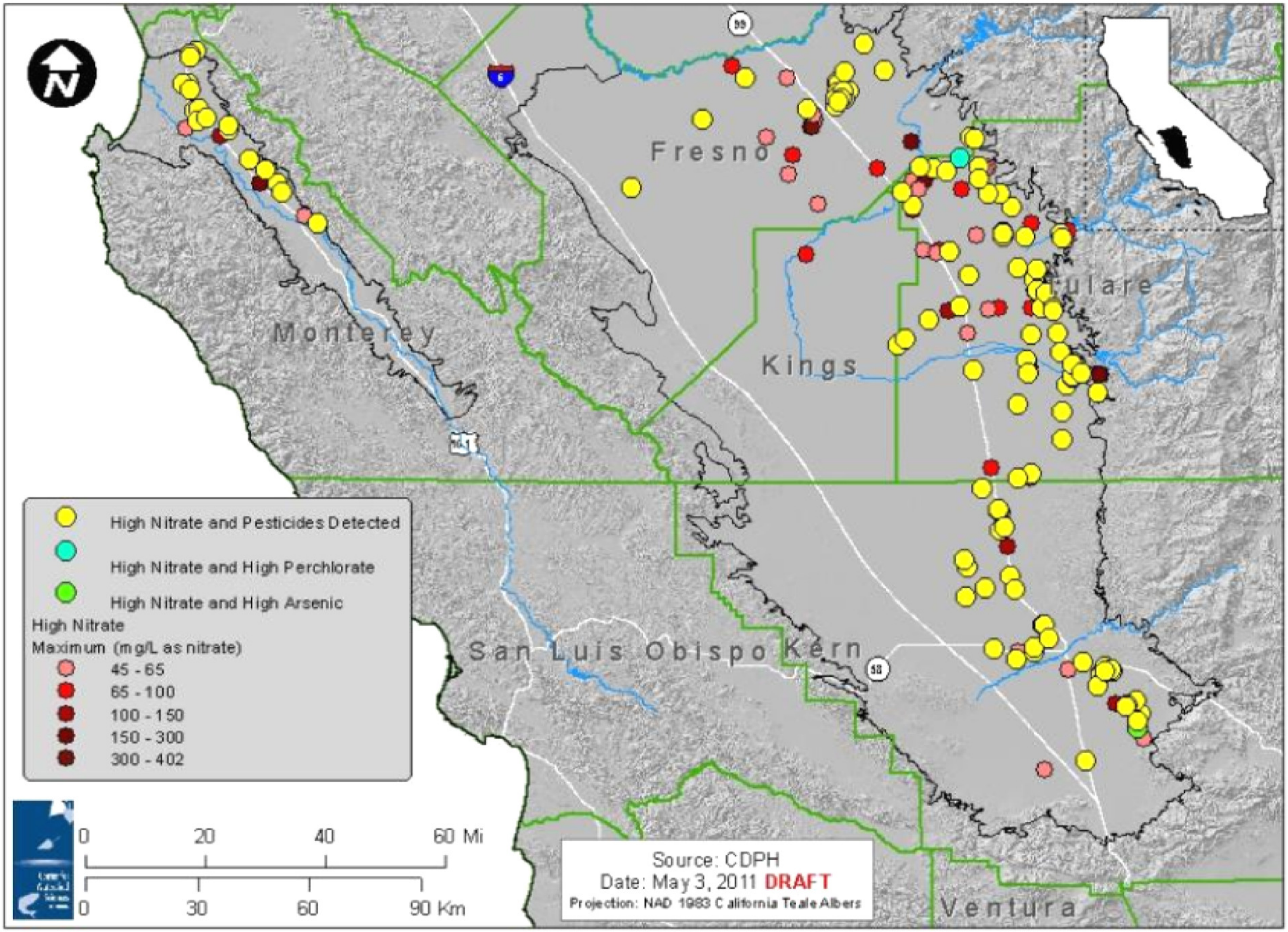

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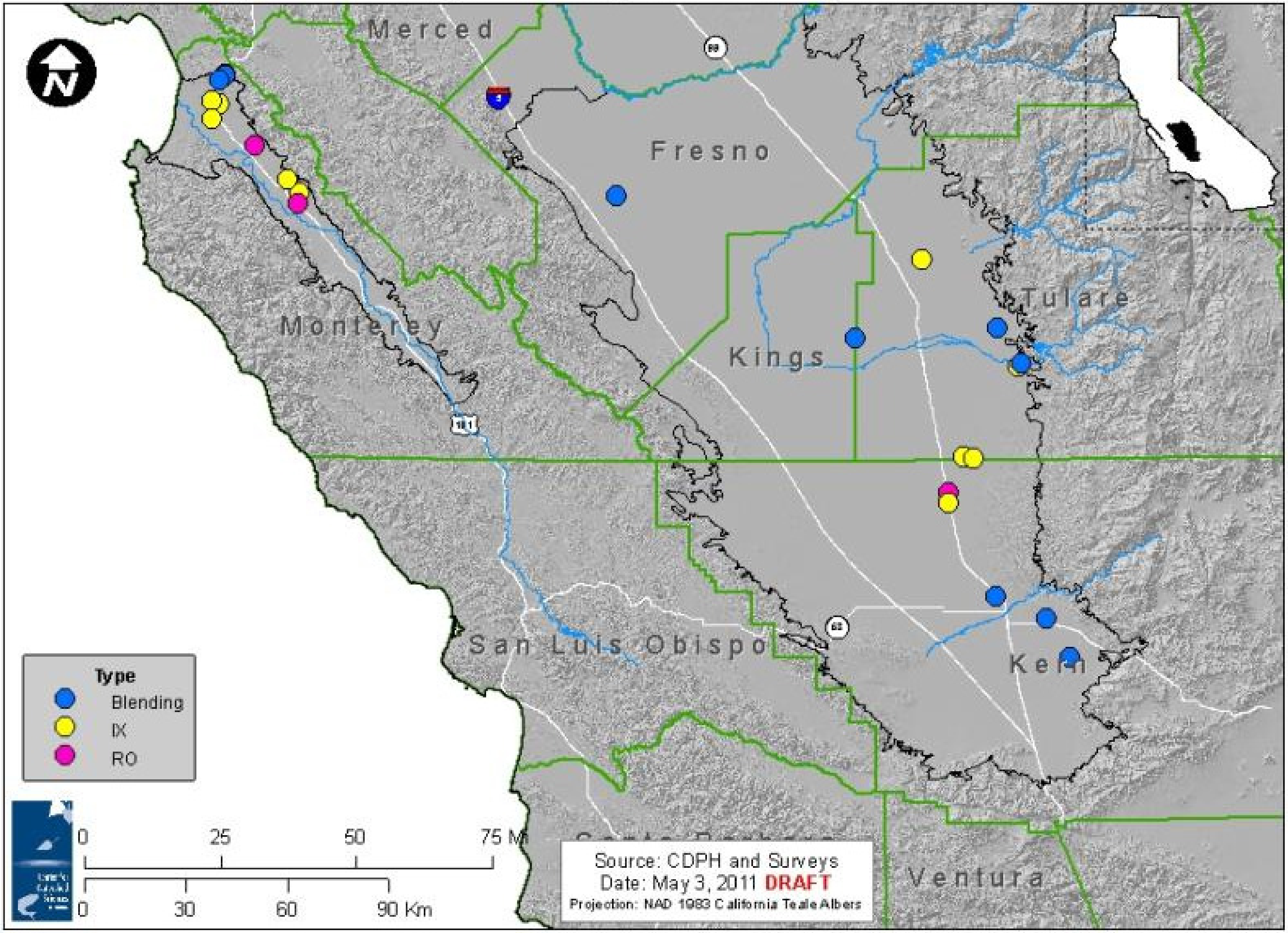

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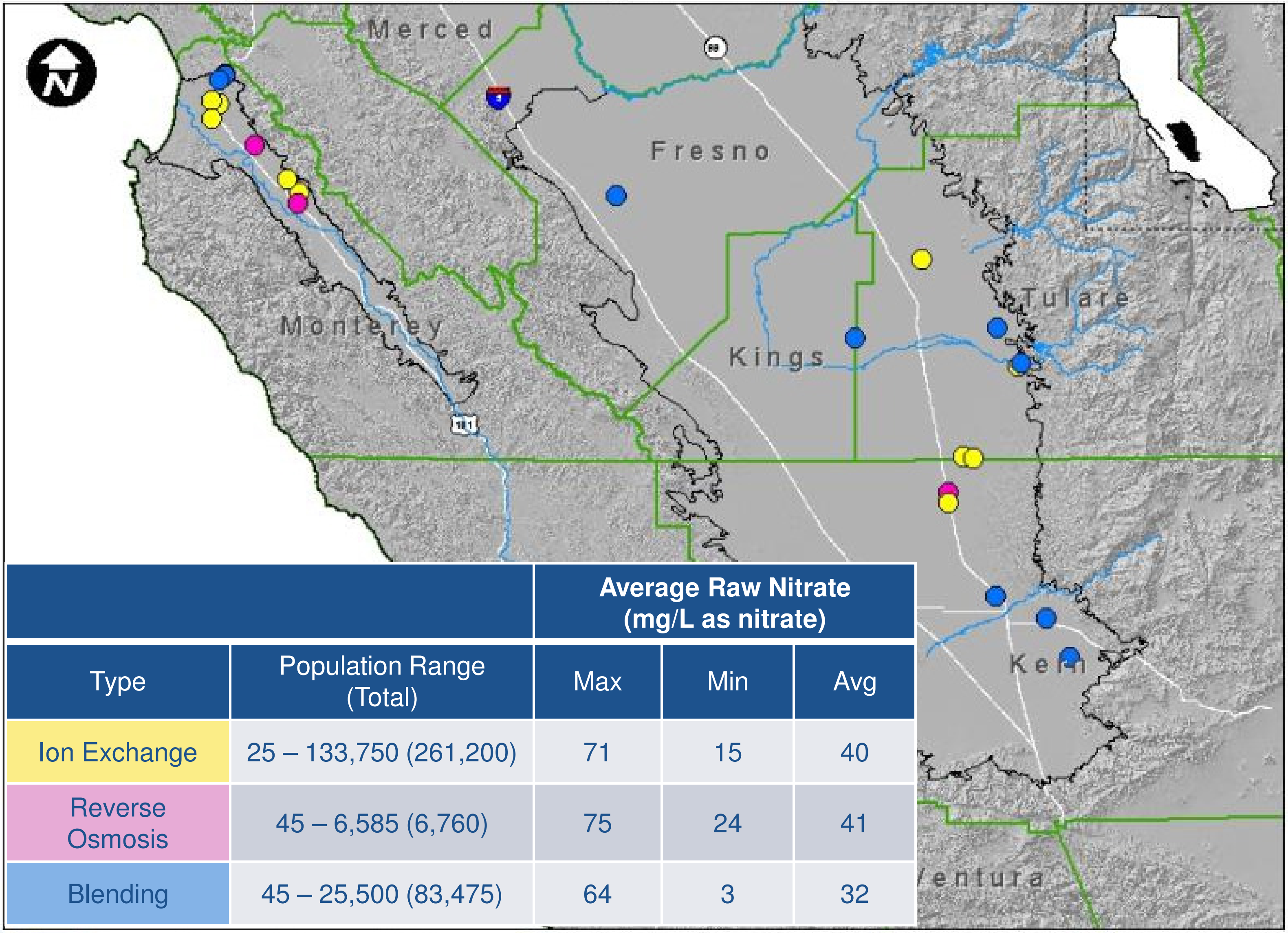
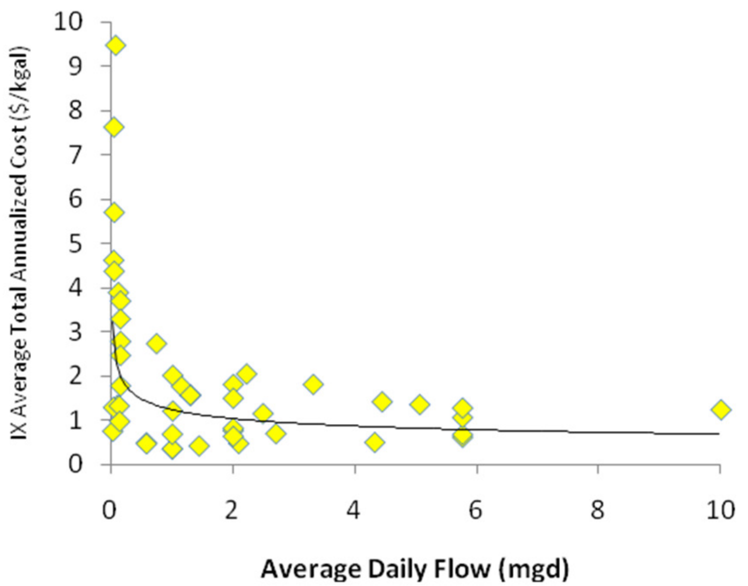
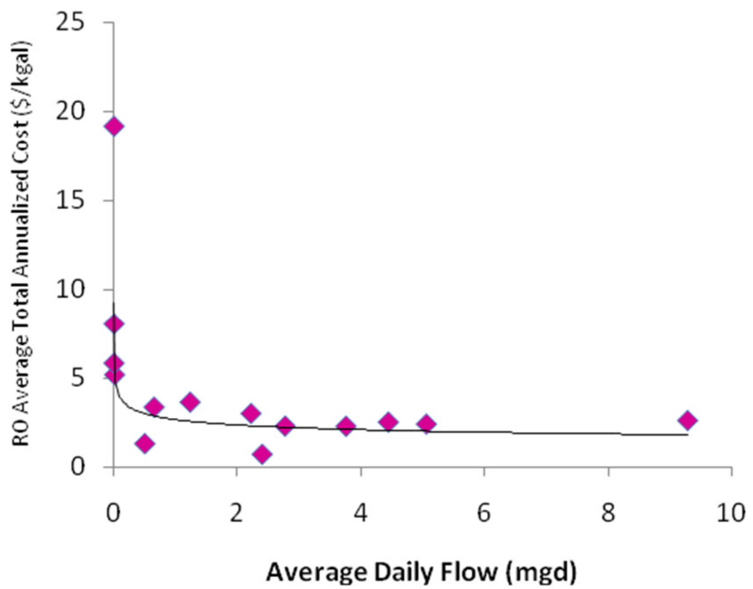


		Average Raw Nitrate (mg/L as nitrate)		
Type	Population Range (Total)	Max	Min	Avg
Ion Exchange	25 – 133,750 (261,200)	71	15	40
Reverse Osmosis	45 – 6,585 (6,760)	75	24	41
Blending	45 – 25,500 (83,475)	64	3	32

Treatment Costs

Centralized Treatment





Point-of-Use

	Upfront Investment	Annual Costs	Comments
Ion Exchange	$660-$2425	Salt costs ($3.30-$4.40/bag)	Requires disposal of brine waste, high sodium levels
Reverse Osmosis	$330-$1430	$110-$330/yr + electricity	Requires filter replacement, high maintenance, lower water recovery

Costs by Technology

Ion Exchange (IX)

Pro: Generally the least expensive

Con: Brine disposal

Reverse Osmosis (RO)

Pro: Wide treatment capabilities

Con: More expensive

Biological Denitrification (BD)

Pro: Long term sustainability

Con: Limited application

Type	Annualized Capital Cost ($/kgal)	Annual O & M Cost ($/kgal)	Total Annualized Cost ($/kgal)
IX – Literature	0.08 – 0.80	0.15 – 1.25	0.34 – 2.04
IX – Survey	0.06 – 0.94	0.12 – 2.63	0.41 – 2.73
RO – Literature	0.81 – 4.40	1.22 – 2.00	2.32 – 5.86
RO – Survey	0.19 – 3.16	1.15 – 16.16	1.35 – 19.16
BD	0.47 – 0.83	0.30 – 0.94	0.92 – 1.56

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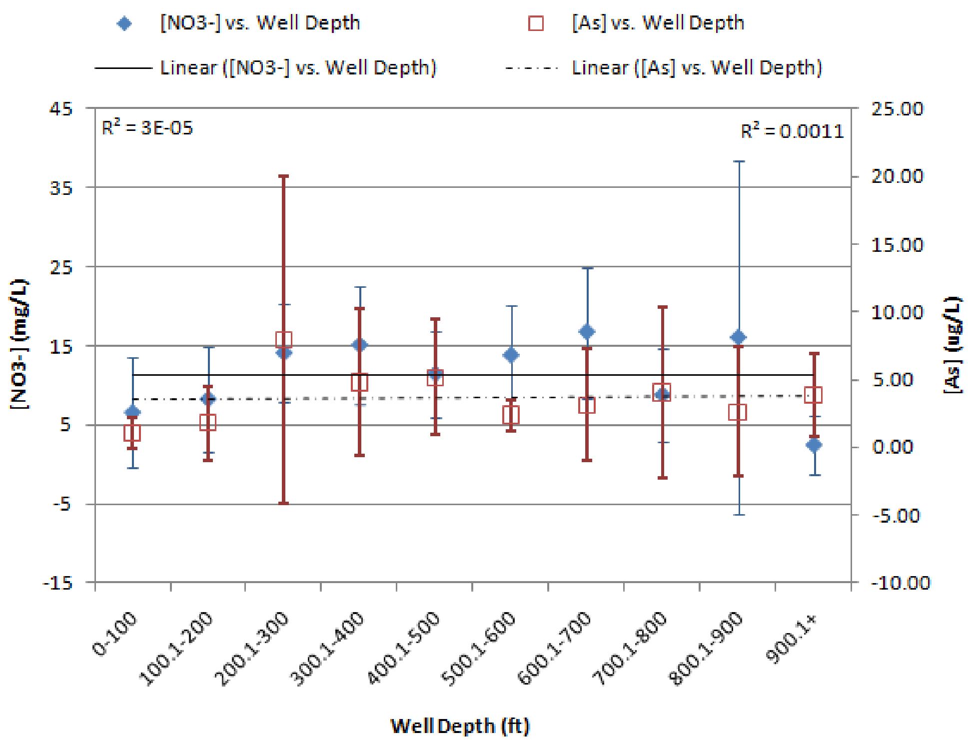
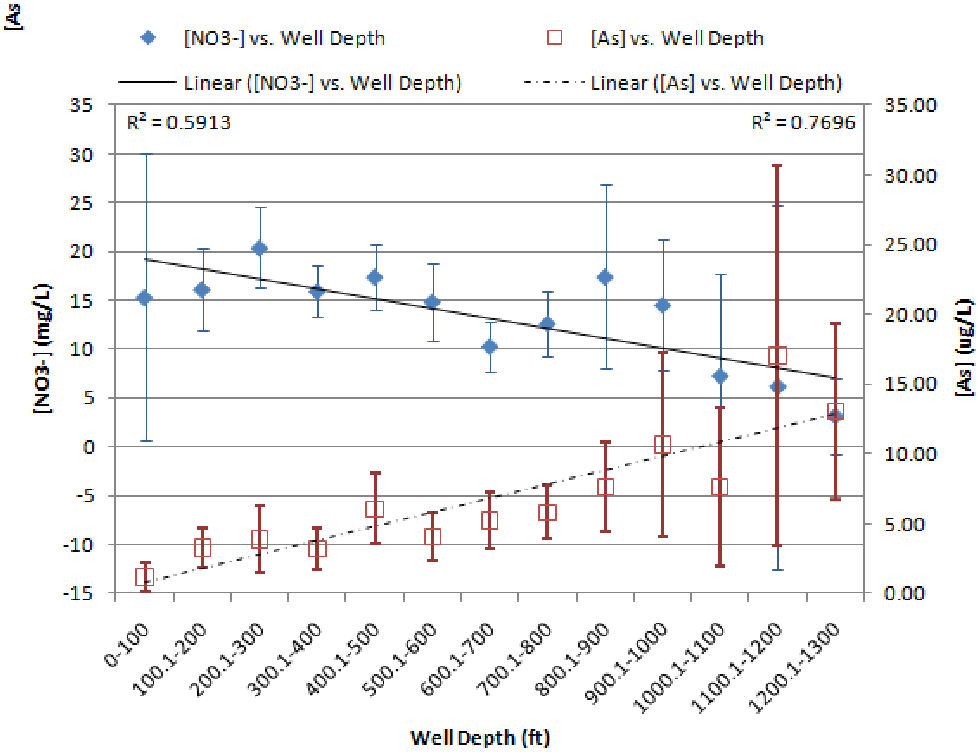
Treatment costs are unique to individual systems based on:

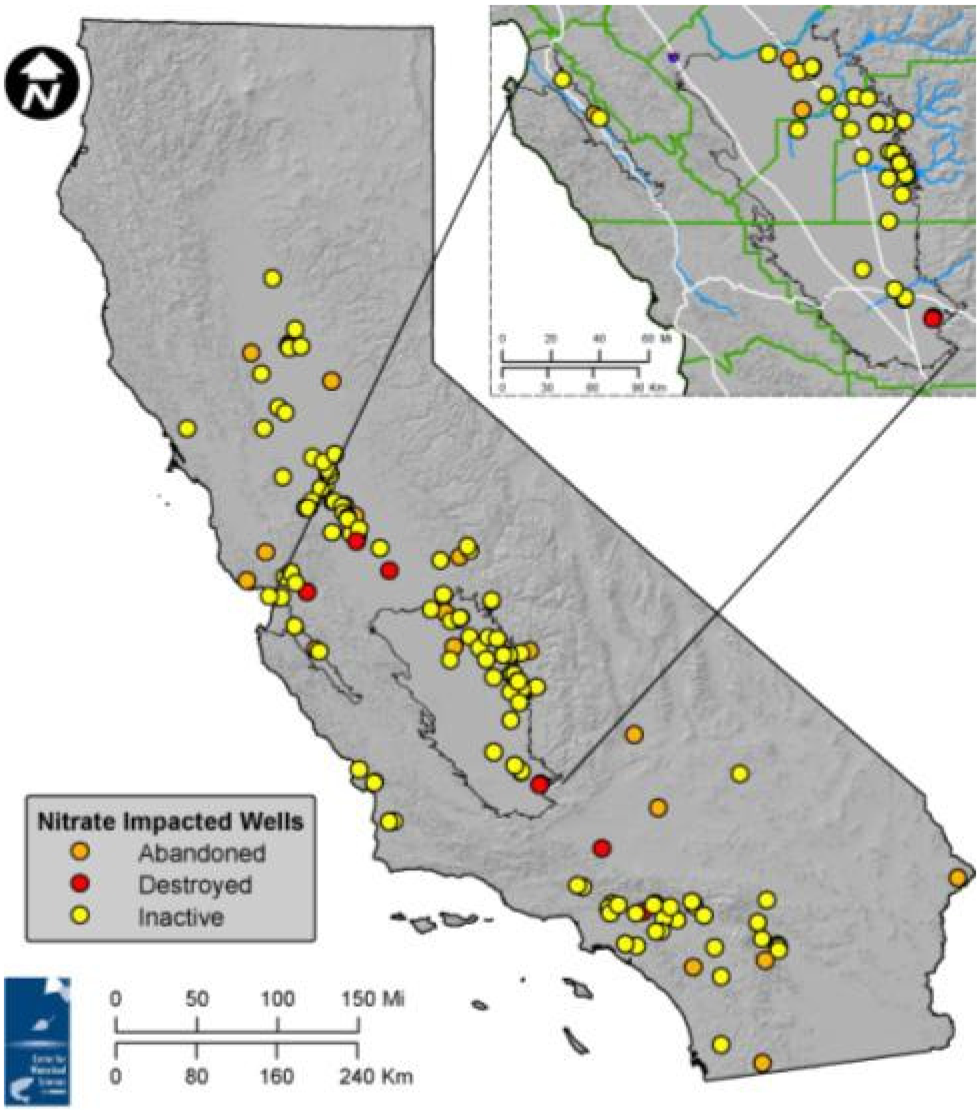
*system size
*treatment type
*nitrate level
*co-contaminants
*blending options
*seasonal variation
*location
*disposal options
*others…

Arsenic, Nitrate and Depth





	TLB	SV	Study Area Total	CA
Destroyed	1	0	1	9
Abandoned	2	1	3	28
Inactive	33	2	35	138
Total	***36***	***3***	***39***	***175***



Nitrate and Well Abandonment, Destruction and Inactivation

- Source: CDPH PICME and WQM databases.
- This analysis utilizes exceedance of the nitrate MCL as an indicator of the reason for well status change; however, a portion of these wells may have been abandoned, destroyed or inactivated for reasons other than nitrate contamination.