Ion Exchange Treatment Background

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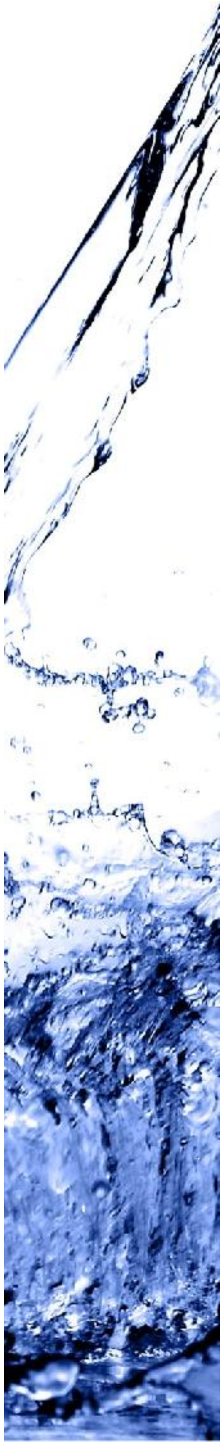
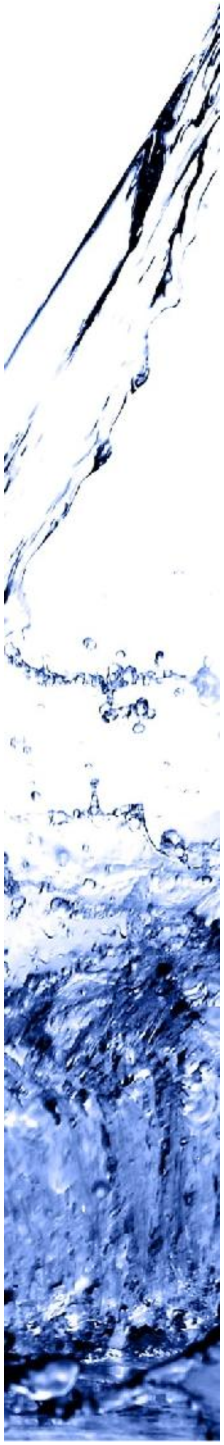


Webinar Overview

- Introductions
- Acknowledgements
- Background
- Nitrate Management Options
- Treatment Options and Selection
- California
  Violations, Occurrence, Treatment Installations, Costs
- Case Studies
- Conclusions



Acknowledgements

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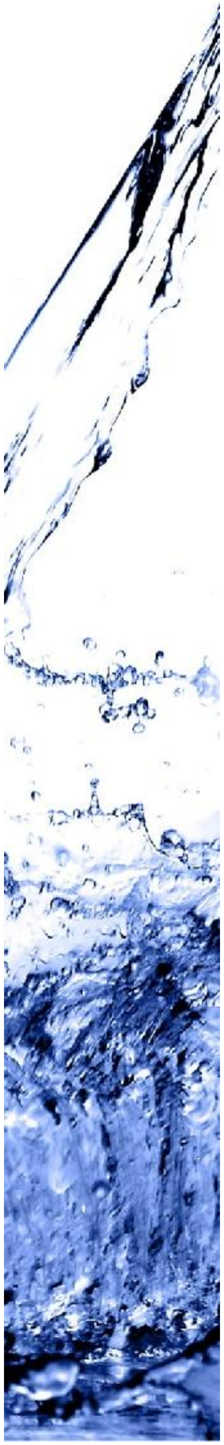
- Cal. State Water Resources Control Board, Contract No. 09-122-250



Associated Research

- *An Assessment of the State of Nitrate Treatment Alternatives* for AWWA (2011)

  http://www.awwa.org/Portals/0/files/resources/resource%20dev%20groups/tech%20and%20educ%20program/documents/TECNitrateReportFinalJan2012.pdf

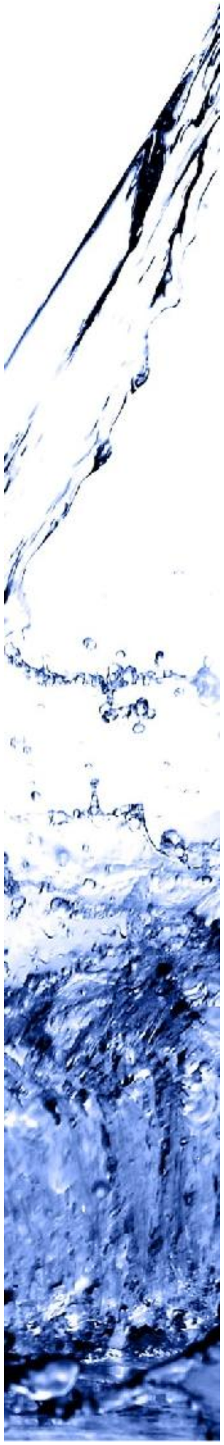
- California Nitrate Project, Implementation of Senate Bill X2 1 prepared for the California State Water Resources Control Board (Technical Report 6, 2012)

  http://groundwaternitrate.ucdavis.edu/

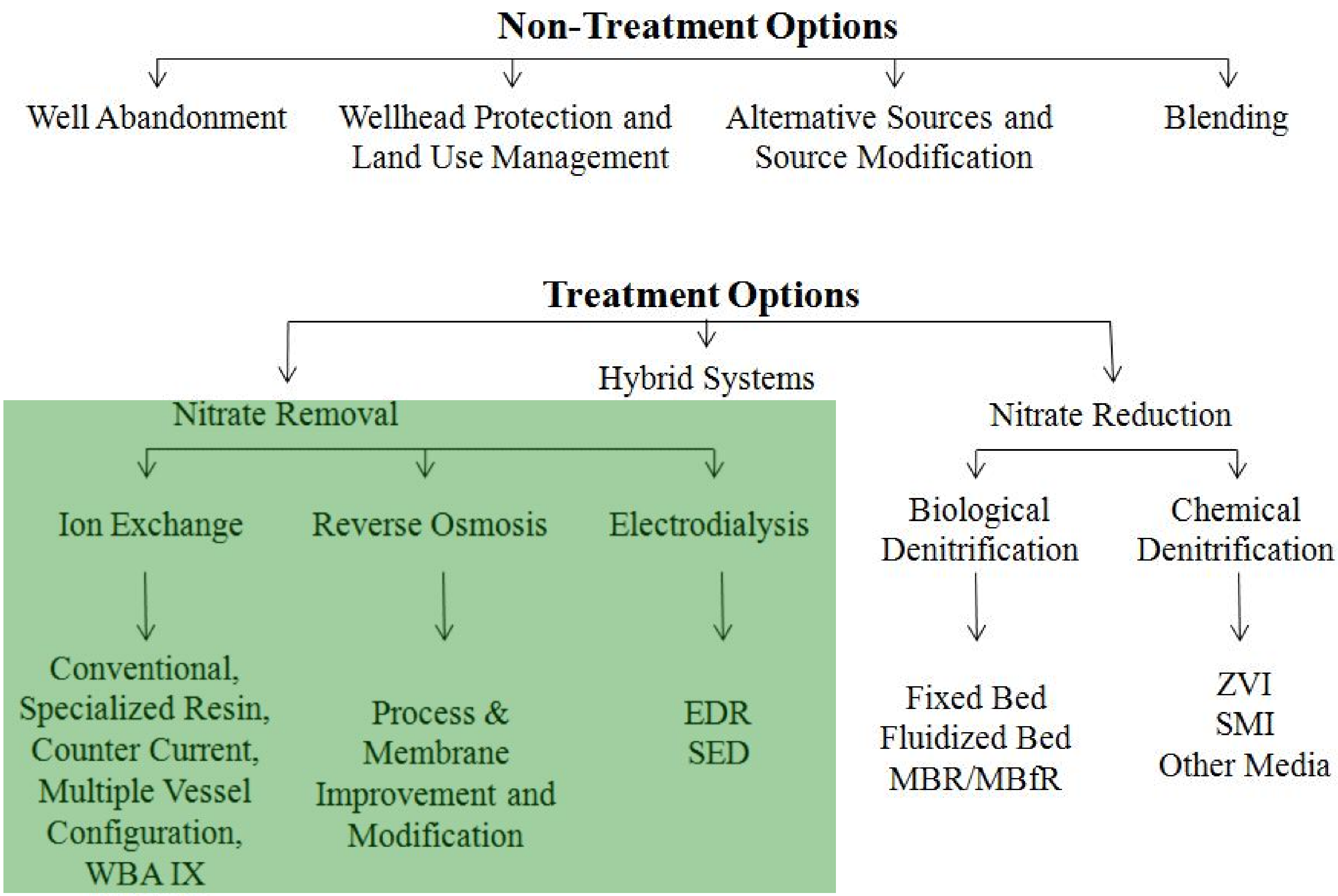
- The Center for Affordable Technology for Small Water Systems (Director: Dr. Jeannie Darby)

  http://smallwatersystems.ucdavis.edu/

- Jensen et. al., *Drinking Water Treatment for Nitrate*, Critical Reviews in Environmental Science and Technology, Accepted 2013

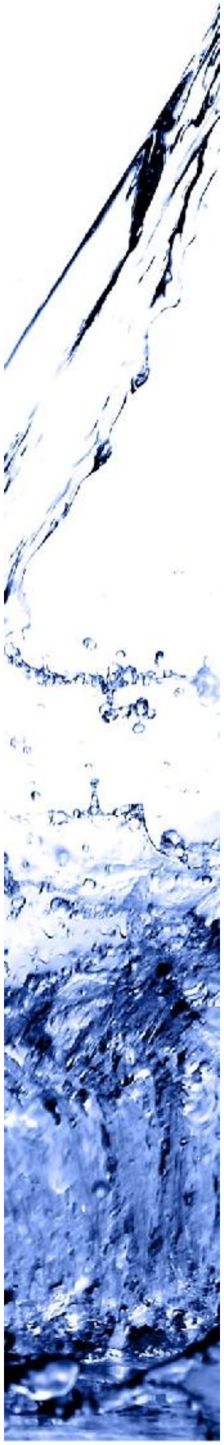


Treatment Options: Nitrate Removal



Ion Exchange Options

- Resin Types
  - Strong-base anion exchange (SBA, pH 6-9.5)
  - Weak-base anion exchange (WBA, pH 3-5)
- Equipment Configurations
  - Fixed bed columns
    - Downflow exhaustion-regeneration (“conventional”)
    - Counterflow exhaustion-regeneration (more efficient)
  - Multiple fixed-bed columns in parallel
  - Continuously mixed flow reactor
- Brine Management
  - Lower NaCl concentration, partial regeneration, brine reuse, brine denitrification

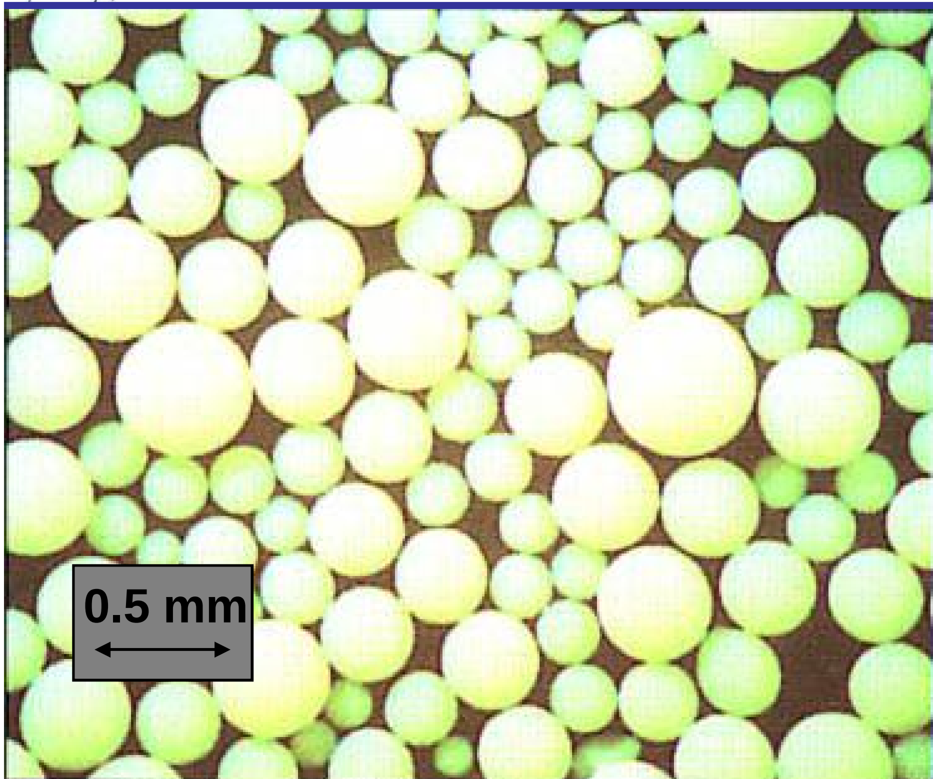


Strong-Base Ion Exchange

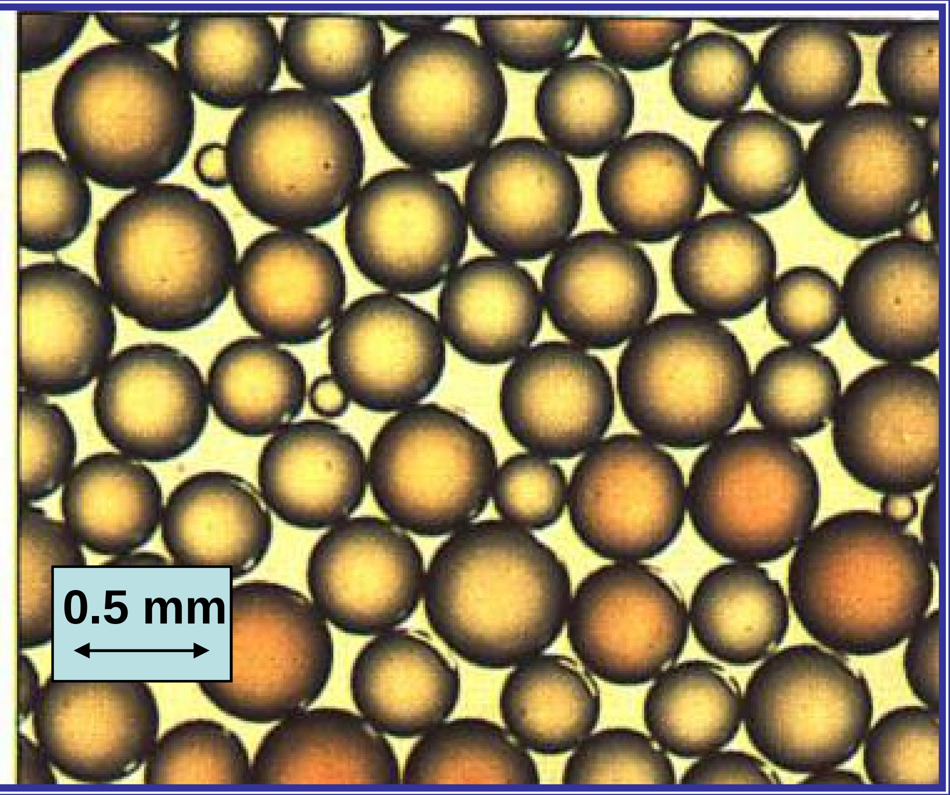
- Ion exchange with Cl-form SB anion resin
  - A “water softener for anions”
    - Exhaustion: $NO_3^- + RCl = RNO_3 + Cl^-$
    - Regen: $RNO_3 + 4NaCl = RCl + 3NaCl + NaNO_3$
- Advantages: Simplicity, on-demand operation, relatively low cost
- Disadvantages: Nitrate peaking (dumping) may occur; regeneration is inefficient, high NaCl consumption, produces large volume of nitrate-contaminated salt brine for disposal

Strong-Base Ion Exchange Resin

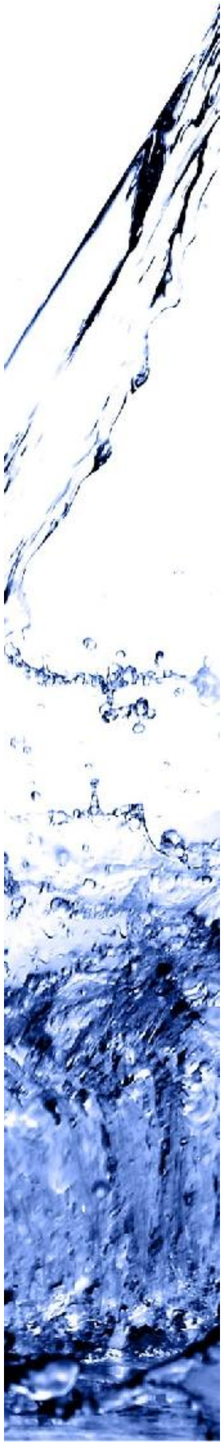
Polystyrene-DVB polymers, quaternary amine groups.
Typical particle size range 0.3-1.2 mm (16x50mesh)



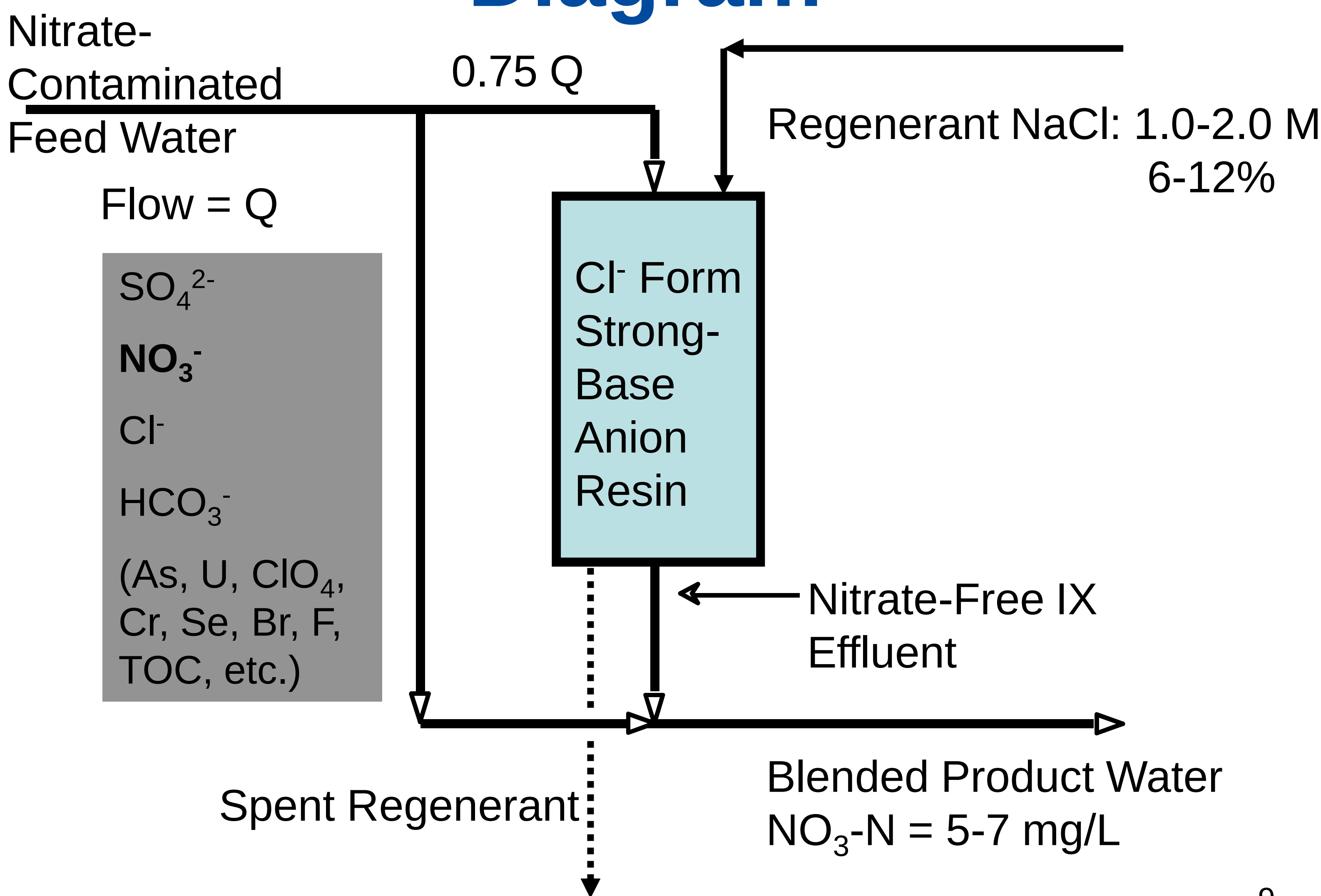
Macroporous
(Opaque)

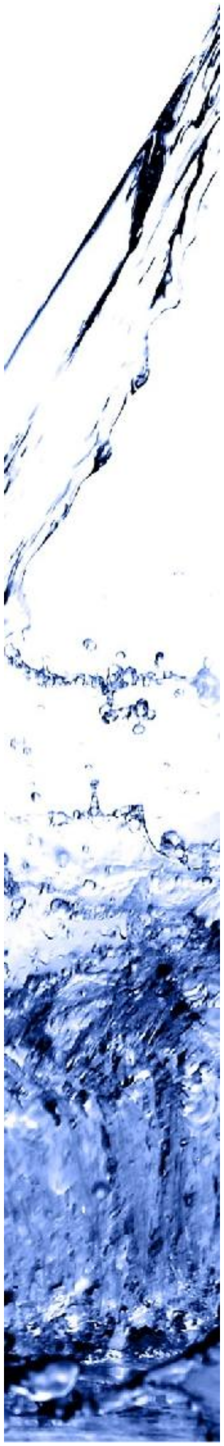


Microporous or Gel
(Translucent)



Simplified Process Flow Diagram

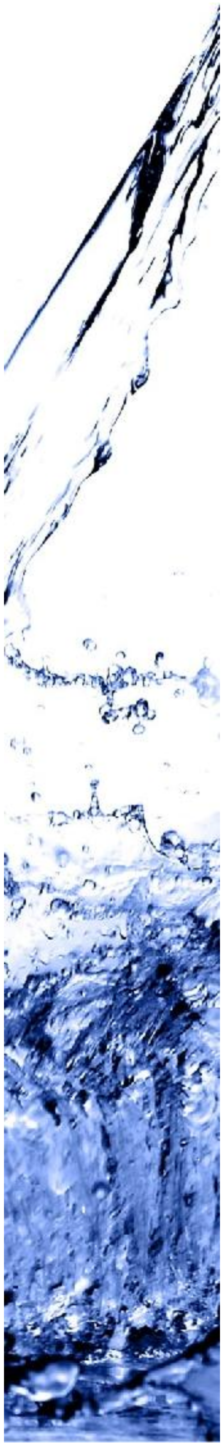




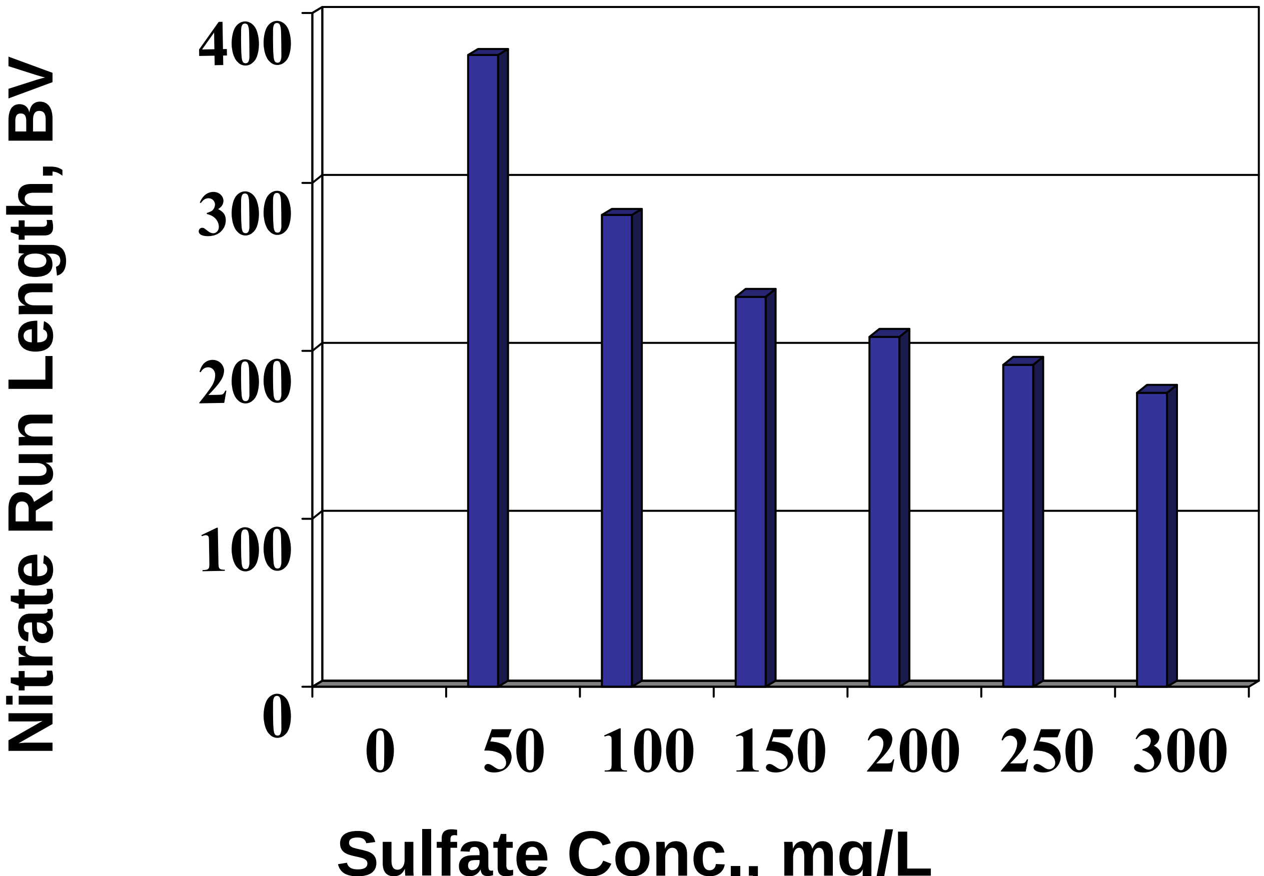
Typical Nitrate-Contaminated Water Example
Glendale, Arizona

Species	*mg/L*	*meq/L*
NO_3-N	21	1.5
SO_4^{2-}	48	1.0
Cl^-	106	3.0
HCO_3^-	122	2.0
TDS	**530**	**7.5**

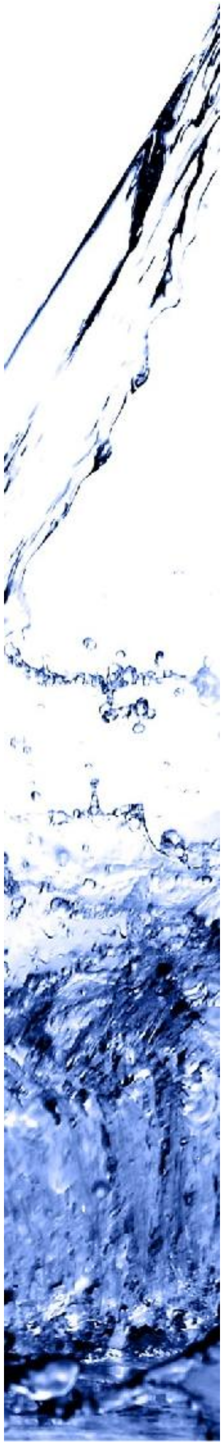
All background ions, especially sulfate, compete with nitrate for sites on the anion-exchange resin; higher TDS and SO_4 = fewer bed volumes (BV) (shorter run length).



Effect of Sulfate on Ion Exchange Run Length



Based on Glendale, AZ GW

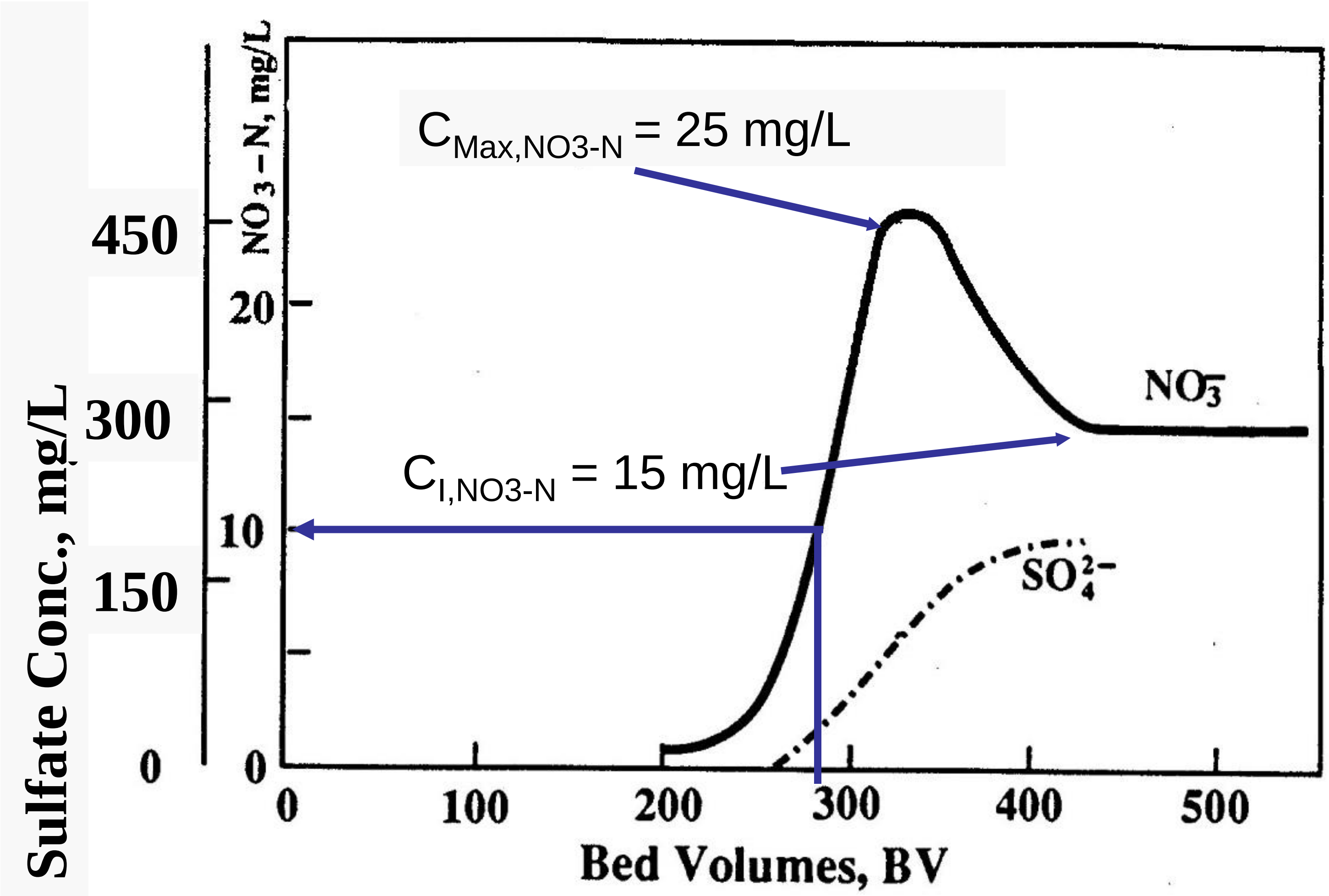


Anion Selectivity Sequence for Typical Strong-Base Anion Resins

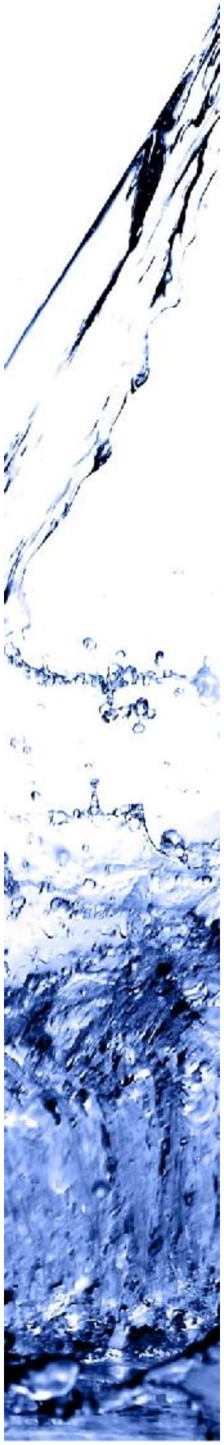
$$SO_4^{2-} > NO_3^- > Cl^- > HCO_3^-$$

- Problem: Less preferred ions will “peak”. Nitrate is less preferred than sulfate and therefore effluent nitrate concentration will be higher than influent nitrate concentration if the column is run beyond nitrate breakthrough.

Nitrate Peaking with Typical (Type 1 or Type 2) Sulfate-Selective SBA Resin

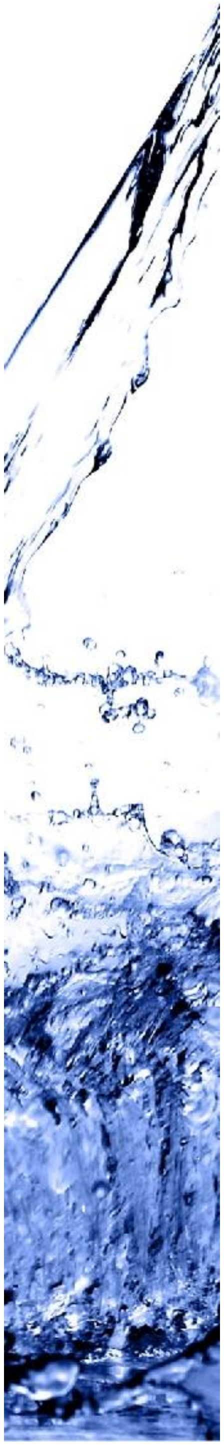


Based on Cox et. al. 1987



Three Ways to Eliminate Nitrate Peaking

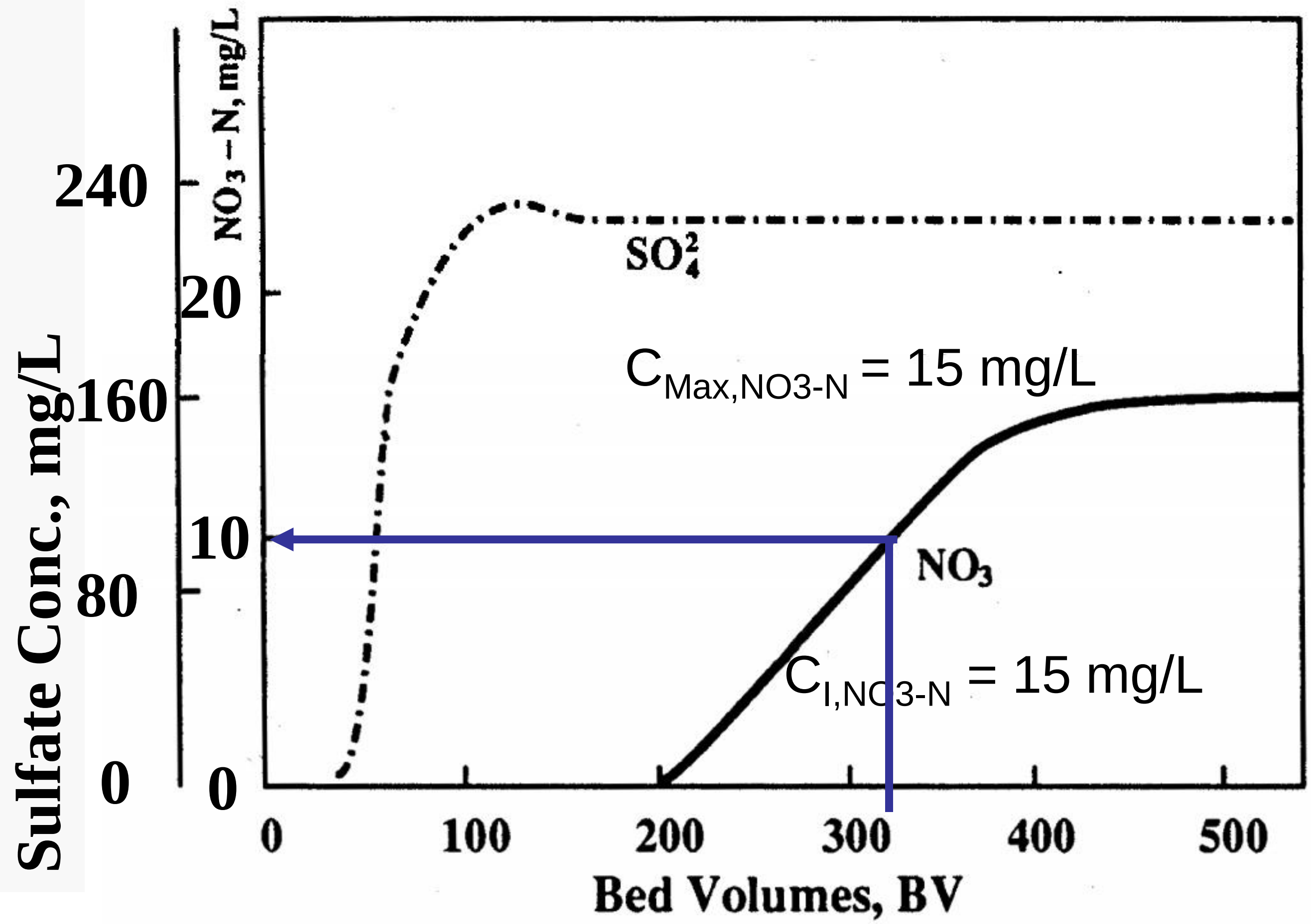
- Use a nitrate-selective (NS) resin
- Operate multiple columns in parallel at different stages of exhaustion
- Use a completely mixed flow reactor



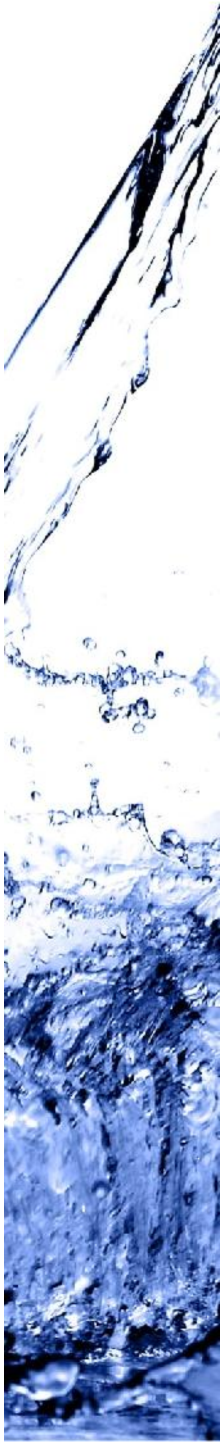
Nitrate Selective (NS) Resins

- In NS resins, sulfate affinity is decreased by increasing the charge-separation distance between exchange sites
- Nitrate affinity is increased by making the resins more hydrophobic in nature

Nitrate Peaking Eliminated with Nitrate-Selective Resin



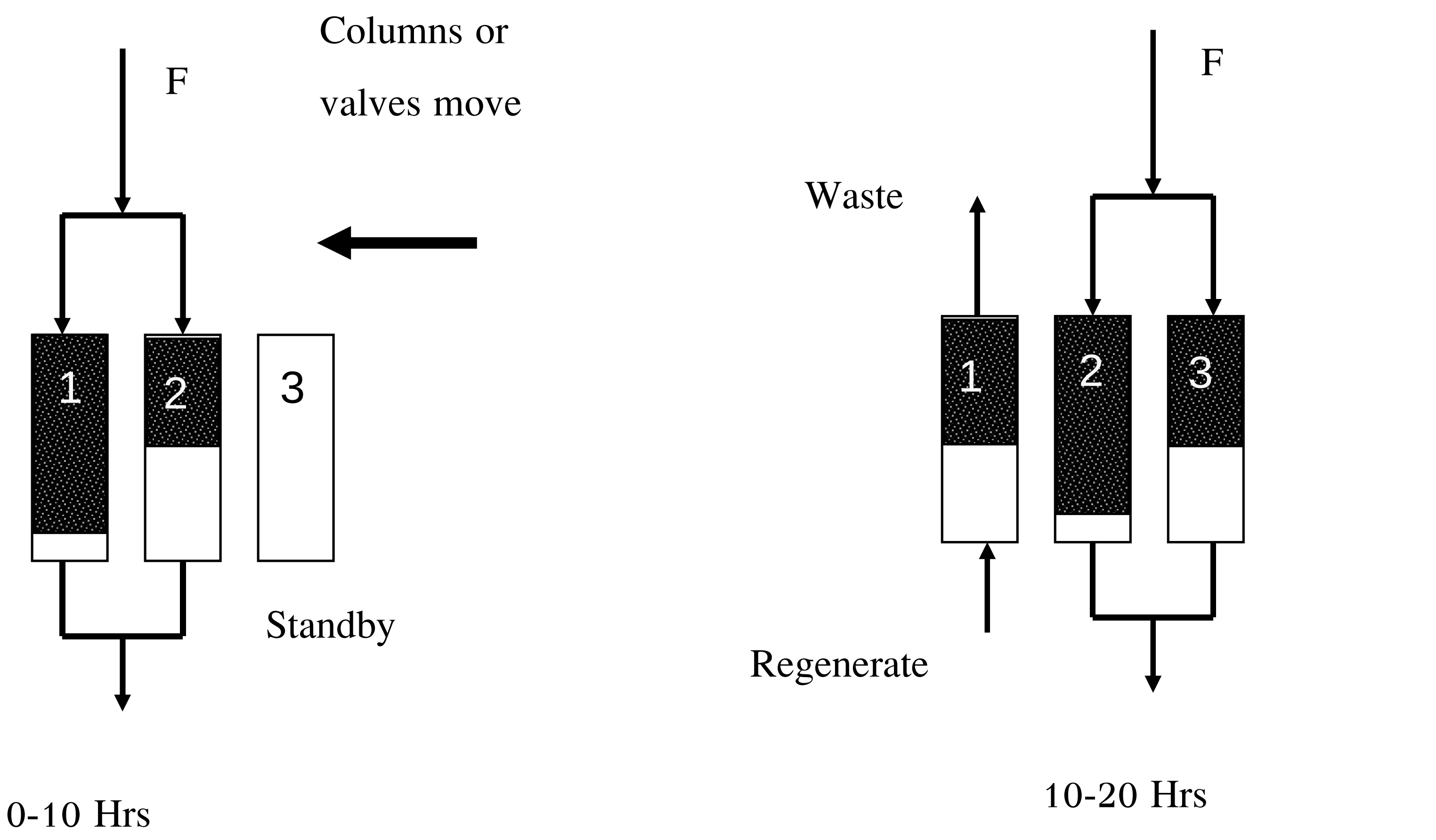
Based on Cox et. al. 1987



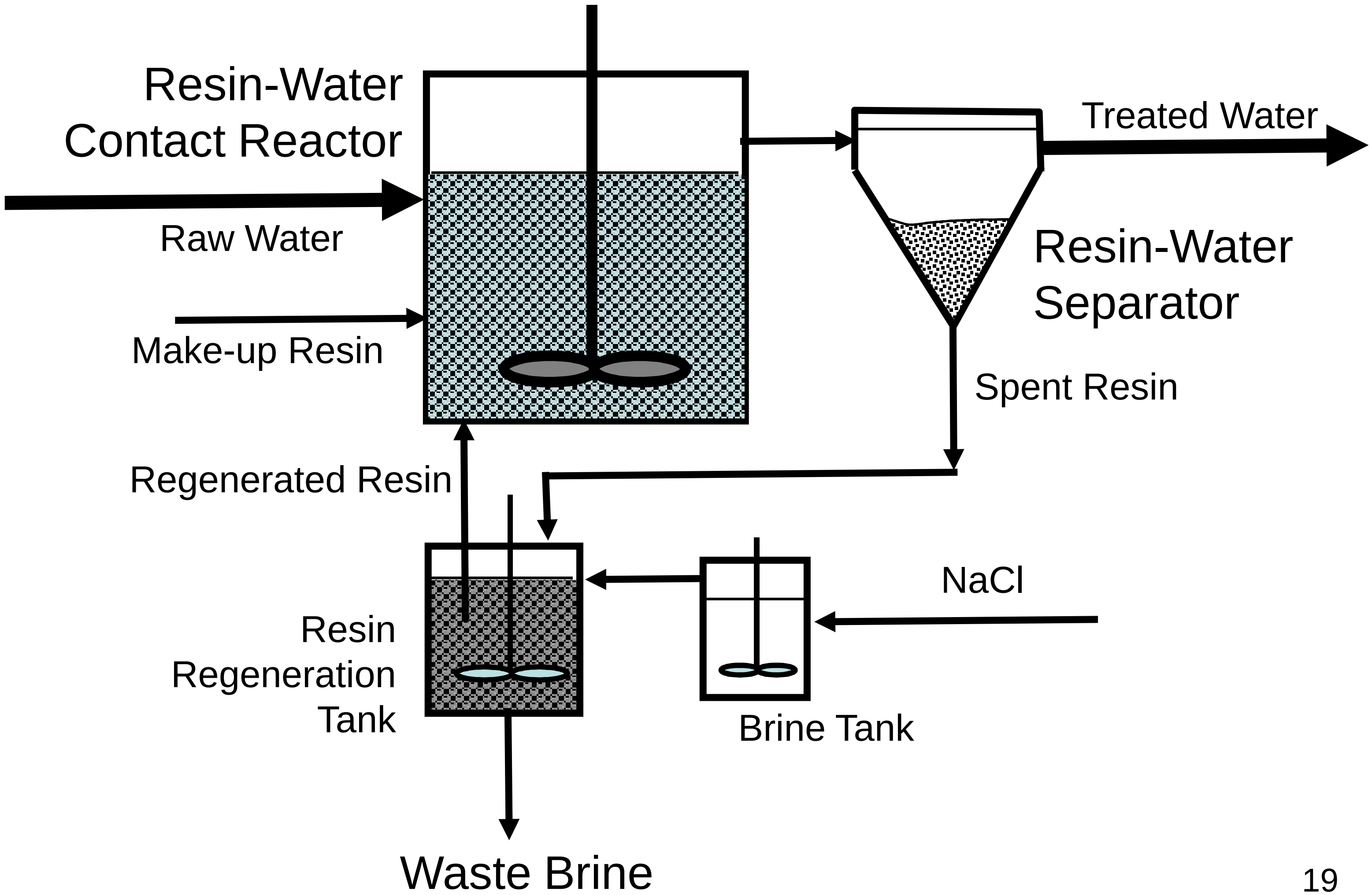
Multiple Parallel Columns Eliminate Peaking

- Operation of several (2-20) columns in parallel at different stages of exhaustion
  - A carousel or multiple stationary columns may be employed for multiple parallel columns
  - “Smoothes out” the effluent history
  - Minimizes or eliminates peaking
  - Upflow regeneration and partial brine/rinse reuse can conserve salt and reduce brine disposal volume

Operate Columns (2-20) in Parallel

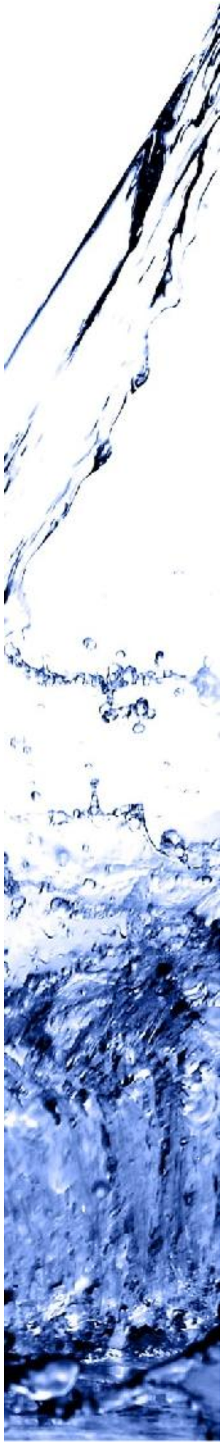


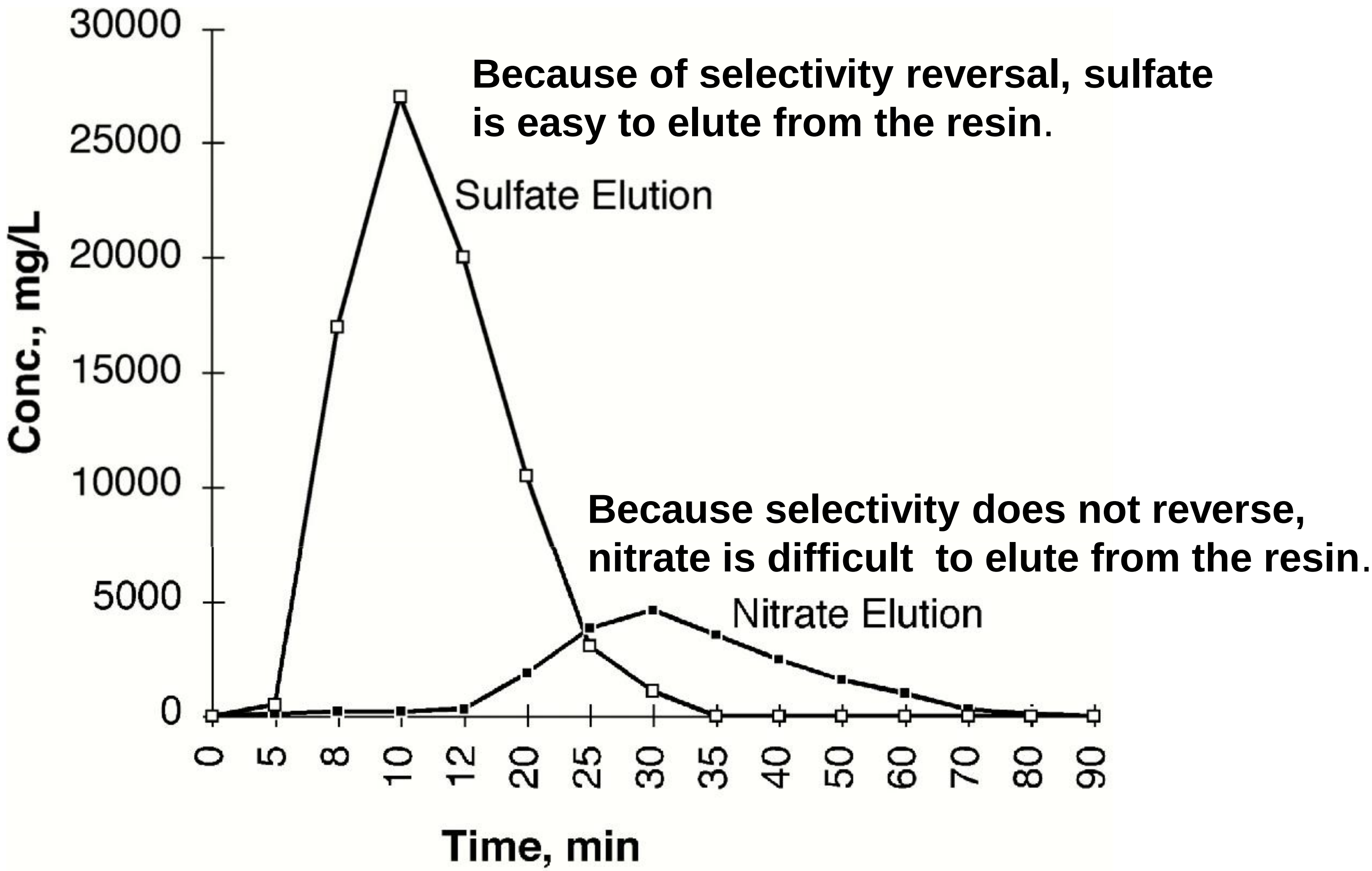
Completely Mixed IX Flow Reactor



Regeneration of Spent Resin

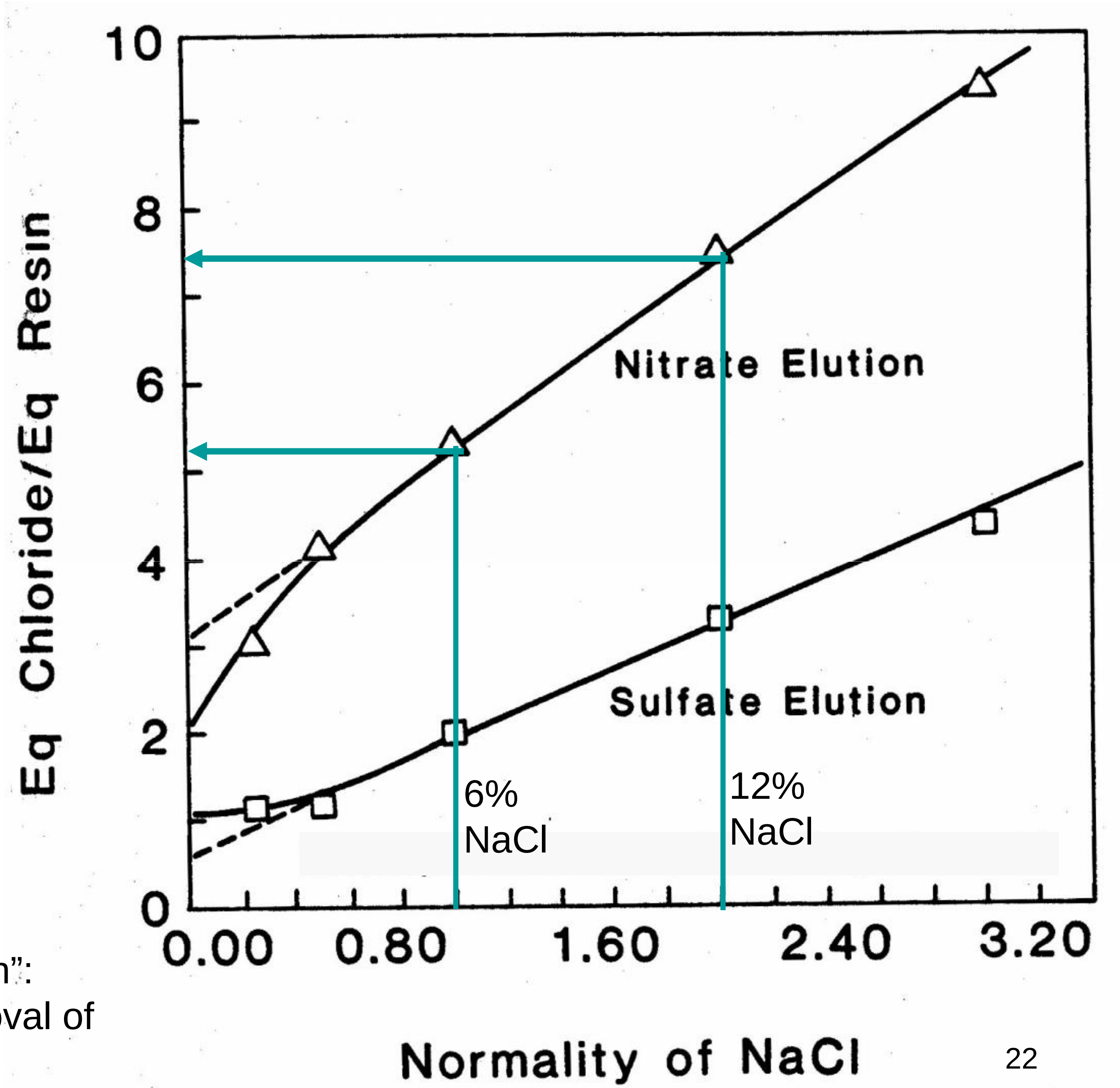
- Divalent SO_4^{2-} is easy to regenerate because of the "selectivity reversal" for SO_4^{2-}/Cl^- exchange.
- Monovalent nitrate ion does not undergo selectivity reversal during (NO_3^-/Cl) exchange;
  therefore, regeneration is more difficult
- The higher the NO_3^-/Cl selectivity, the harder the resin is to regenerate



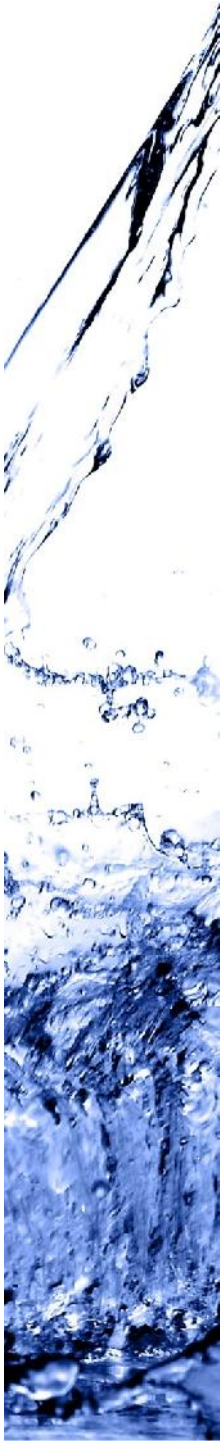


Typical sulfate and nitrate elution curves during regeneration of a standard SBA resin with 6% NaCl.

Higher Conc. NaCl Wastes Salt

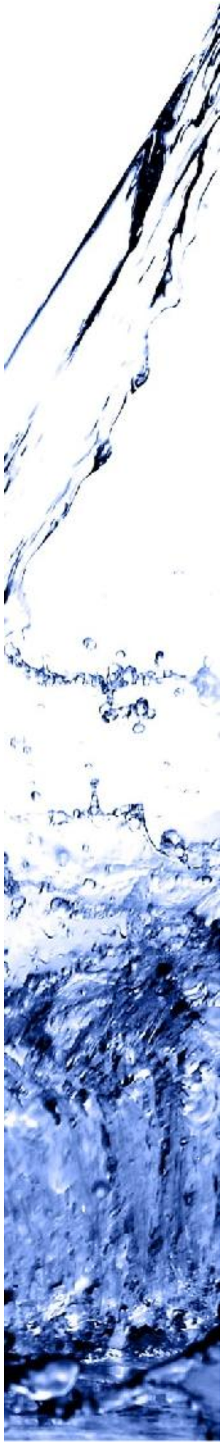


"Complete regeneration": > 95% removal of nitrate.



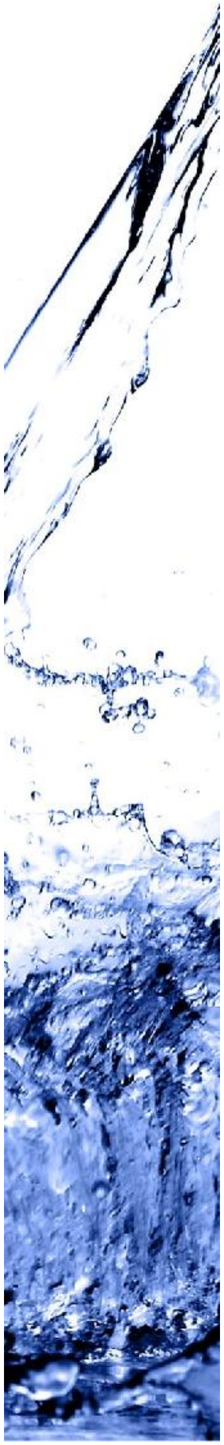
Possible Solutions to the Regeneration Problem

- Partial regeneration: 50-60% NO_3^- removal
  - Saves salt and reduces waste brine volume
  - High nitrate leakage on next run, may preclude blending
- Upflow regeneration, multiple parallel columns, mixed countercurrent ion exchange
- Denitrification (biological or chemical) and reuse
  - Brine reused more than thirty times
  - >90% reduction in brine waste
  - ~50% savings in NaCl consumption



Complete vs Partial Regeneration Glendale, AZ Well Water

Description	Complete	Partial
NaCl Concentration, N (%)	0.25 (1.5%)	1.0 (6.0%)
eq Cl/eq resin, (lbs NaCl/ft^3 resin)	3.0 (15.3)	1.2 (6.1)
Wastewater volume as % of blended product water	3.0	1.1
NaCl consumed for 1 Mgd blended product water, lb/day	3250	2360



Ion Exchange Summary

- SBA with Cl-form IX resin is effective for NO_3 (and U, As, Cr, TOC, ClO_4) removal
- Nitrate-selective resins, parallel columns, and continuous flow mixed reactor ion exchange smooth out peaks, improve run length, and conserve salt
- Brine disposal is primary challenge
- Partial regeneration (e.g. $\leq$6% NaCl) and denitrification and reuse can minimize brine disposal and salt consumption