Impact Case Study Year II: Aquitard Hydraulics and Aquifer Transport in the White Lodge Wellfield of the Dedham-Westwood Water District

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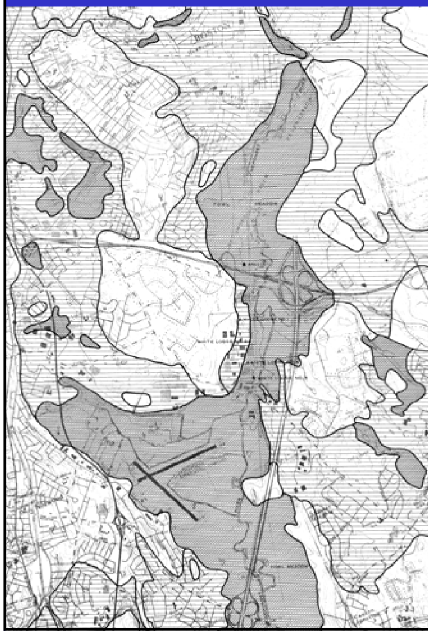
Overview

- Stratified drift deposits and WL #5 supply well
- Neponset River aquitard hydraulics-cascade calibration
- Fowl Meadow Aquifer transport
- Conclusions

Glaciated Bedrock Valley-Neponset River

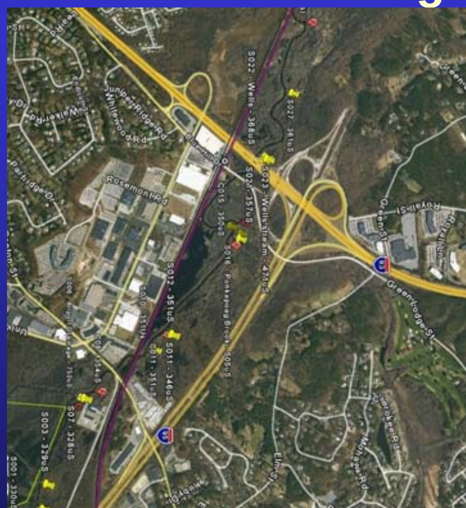


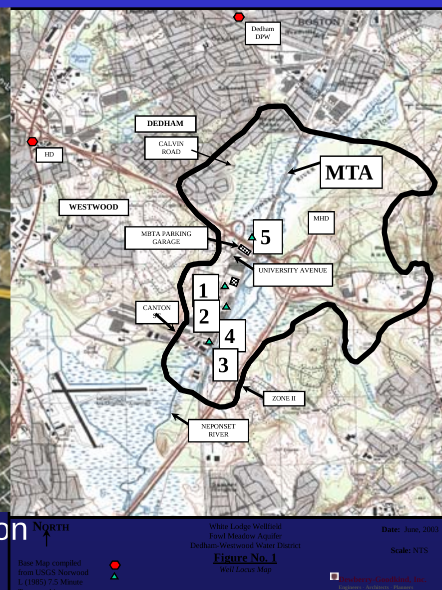
- Ice contact, stratified drift deposits in glaciated bedrock valleys of New England (Flint 1971)
- Deposits of dramatically different permeability beneath river basin
- Some deposits are aquifers, some are aquitards
- Potential for local water supply if aquifer underlies protective aquitard—artesian recharge
- Fowl Meadow Aquifer, Neponset River, Eastern Massachusetts
- USGS (Klinger 1996), DWWD (Dewberry Goodkind 2003)

Dedham-Westwood Water District

- Drinking water to 38,000 users in two towns
- 1.5 billion gallons per year, groundwater (MWRA emergency backup)
- 15 production wells, 205 miles water main, 2 water treatment plants, and 4 water storage tanks
- White Lodge Wellfield provides over 70% of supply (Ostendorf and Kilbridge 2009)

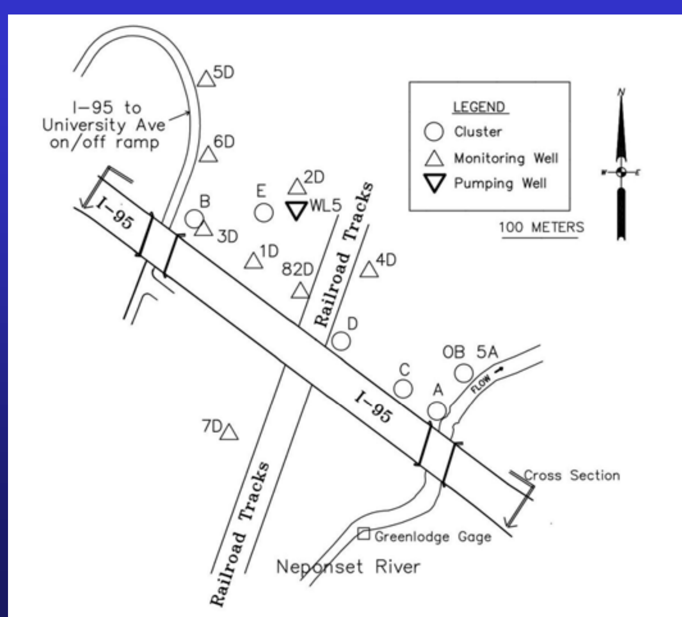
White Lodge Wells #1-5



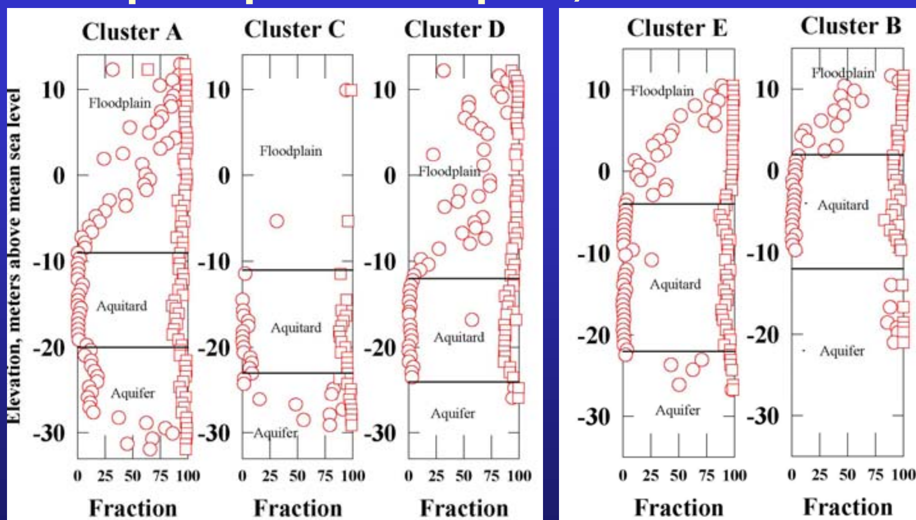


I93/I95, Dedham/Westwood/Canton streets, MBTA, airport, Neponset River, Fowl Meadow Aquifer

Mass Balance Sampling Network

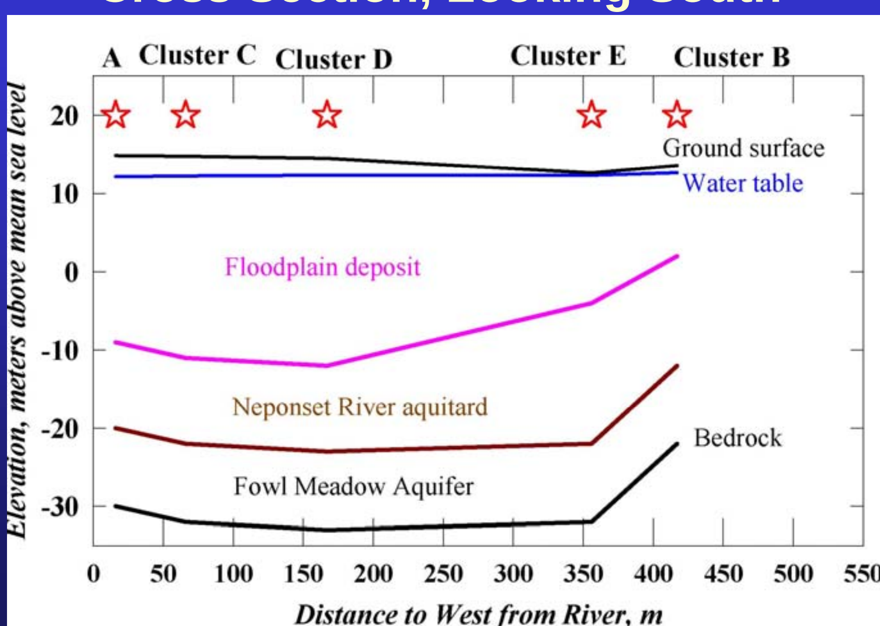


Split Spoon Samples, Grain Size

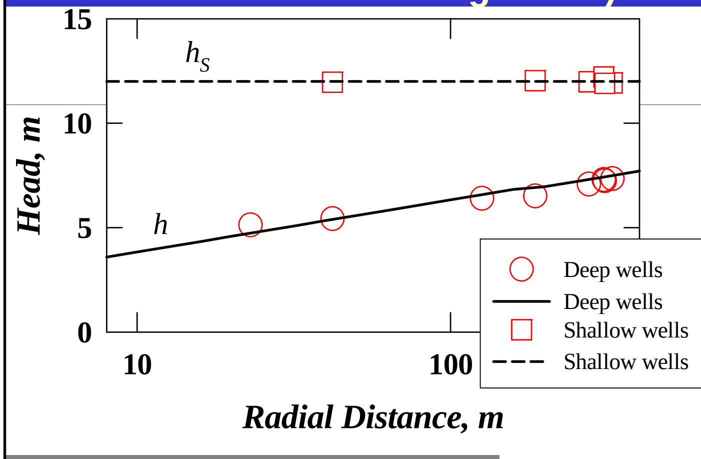


- Circles are sand, squares are silt plus sand
- **Fowl Meadow Aquifer**, about 10 m thick (-30 to -20 mmsl)
- **Neponset River aquitard**, about 10 m thick (-20 to -10 mmsl)

Cross Section, Looking South



Aquitard Permeability-Site Average Linear Leakage Steady Pumping (Ostendorf and Kilbridge 2009)

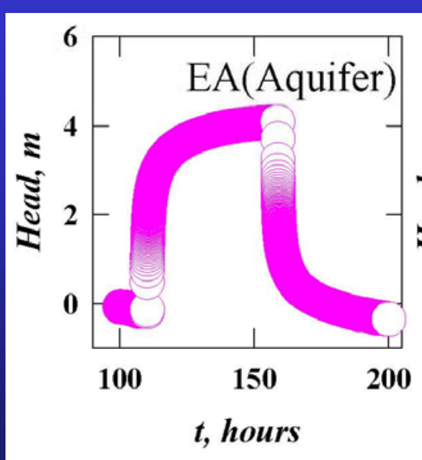


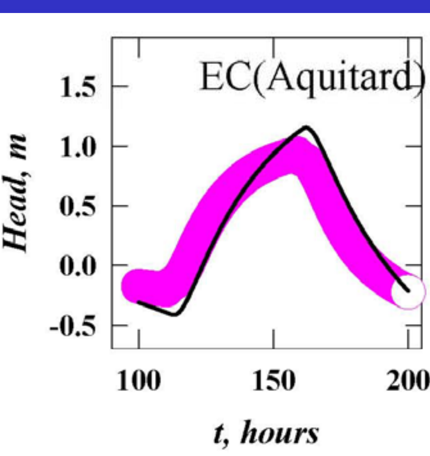
$1 \cdot kilometer$

$K' = 4.9x10^{-5}$ ft/day

$$h = h_S - \frac{Q}{2\pi T} K_O\left(r\sqrt{\frac{gk'}{\nu T b'}}\right) \quad k' = 2.3x10^{-17}\, m^2$$

Aquitard Consolidation Coefficient-Attenuation of Cyclic Pumping (Ostendorf et al. 2010)



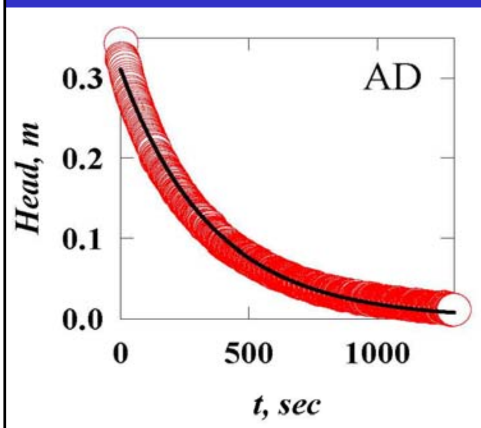


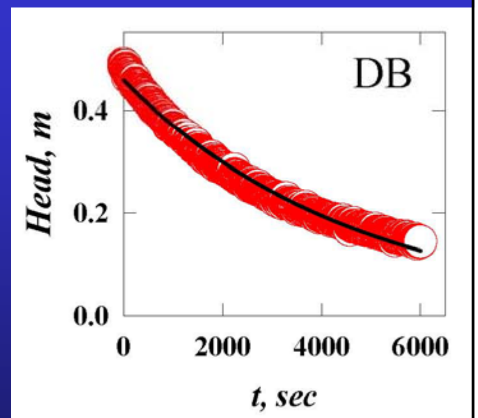
$$h = \int_0^t \frac{dh_O}{d\tau} erfc\left[\frac{z}{2\sqrt{c_V(t-\tau)}}\right] d\tau$$

$3 \cdot m(vertical)$

$$7.8x10^{-6} < c_V < 1.4x10^{-3}\, m^2/s$$

Aquitard Permeability-Wellscreen
Overdamped Slug Test (Bouwer and Rice 1976)





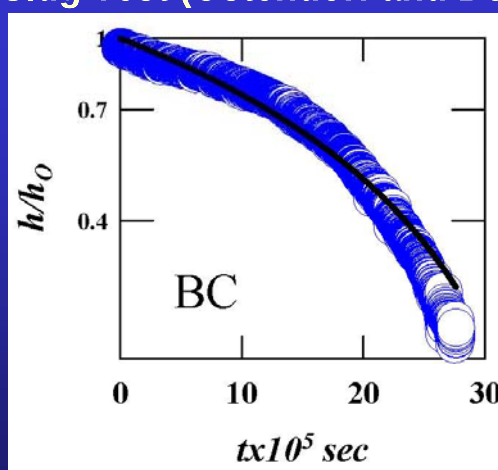
$1 \cdot m(\,horizontal\,)$

0.028<K'<0.30 ft/day

$$h = h_O\, exp(-\lambda t\,)$$

$$1.3x10^{-14} < k'(\,\lambda\,) < 1.4x10^{-13}\, m^2$$

Aquitard Permeability-Wellscreen
Extended Slug Test (Ostendorf and DeGroot 2010)



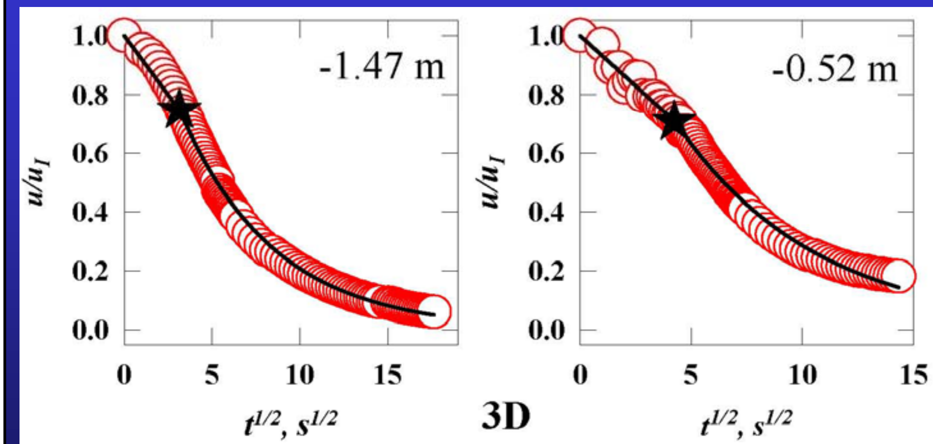
$$h = h_O\, exp(-\lambda t\,) + \frac{\kappa}{\lambda}[\,\lambda t + exp(-\lambda t\,) - 1]$$

$1 \cdot m(\,horizontal\,)$

3.6x10^{-5}<K'<9.2x10^{-5} ft/day

$$1.7x10^{-17} < k'(\,\lambda\,) < 4.3x10^{-17}\, m^2$$

Aquitard Consolidation Coefficient-Partial Piezocone Pore Pressure Dissipation Tests



$30 \cdot cm(vertical)$

$$h = h_M \exp[-\frac{4\sqrt{c_H t_M}}{r_S}(\sqrt{\frac{t}{t_M}} - 1)]$$

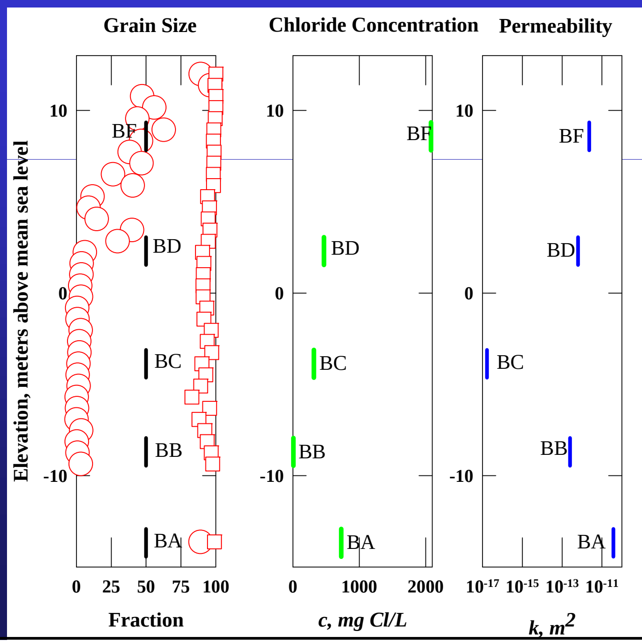
$$8.0x10^{-6} < c_H < 6.7x10^{-5} m^2 / s$$

Cascade Calibration of Neponset River Aquitard Hydraulics

- Steady WL#5 pumping boring logs-site averaged (1 km horizontal, decadal) k'_H, b'
- Cyclic attenuation-cluster wells (3 m vertical, diurnal) $c_V = k'_V/(\mu\alpha)$
- Slug tests-cluster wells (1 m horizontal, hourly-seasonal) k'_H
- Piezocone dissipation test (30 cm vertical, hourly) $c_H = k'_H/(\mu\alpha)$
- Laboratory permeameters-intact core samples (3 cm vertical, minutes) k'_V, α

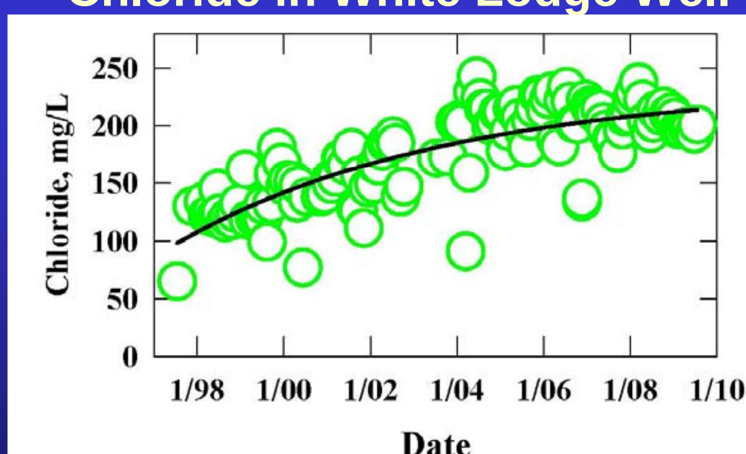
All confirm protective nature of the Neponset River Aquitard, decouples WL#5 from local runoff, floodplain deposit, and River

Cluster Well B Profiles



Aquitard decouples Aquifer from floodplain and river

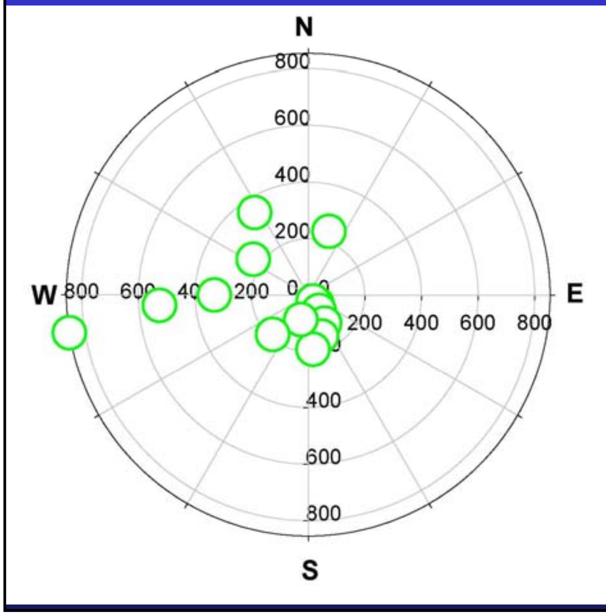
Chloride in White Lodge Well #5



- Average WL5 pumping $Q=0.0368\ m^3/s$
- Ambient $c_O=98\ mg/L$
- Input $c_{INPUT}=234\ mg/L$
- Aquifer volume $V_{AQUIFER}=2.11x10^7\ m^3$
- Aquifer porosity (0.35), thickness (10 m) imply $r_A=820\ m$

$$c = c_O + (c_{INPUT} - c_O)exp(-\frac{Qt}{nV_{AQUIFER}})$$

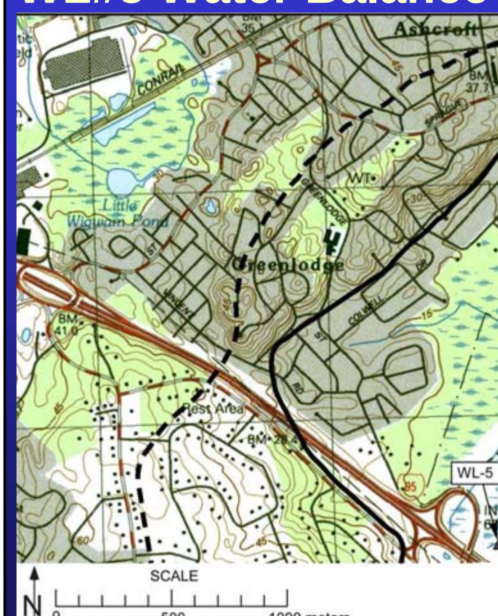
Flux of Chloride Input to WL#5



$$Qc_{INPUT} = Q\sum(\kappa\theta c)_{DEEP}$$

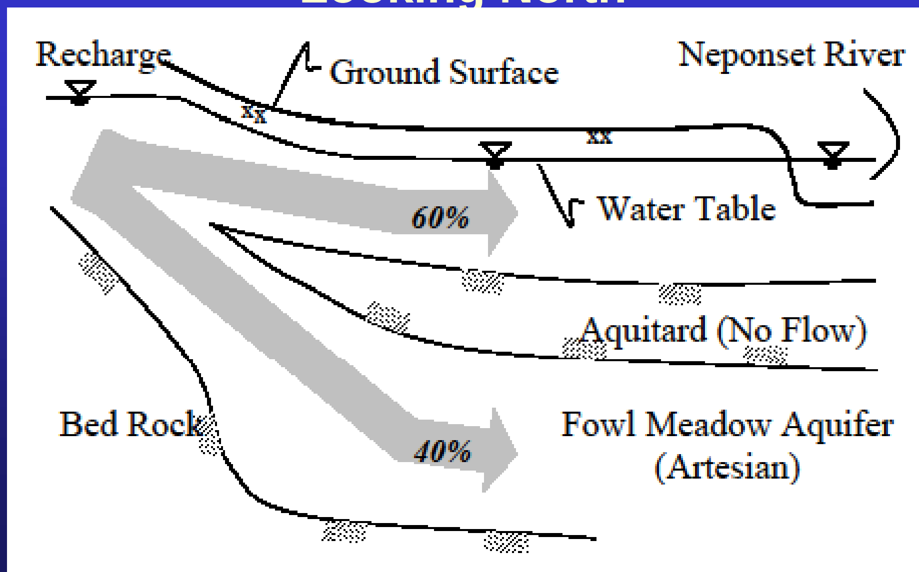
- *c_{INPUT}(WL#5 data), c_{DEEP}(14 deep wells, shown in mg Cl/L)*
- Observed c_{DEEP} implies *κ=0.72* deep wells characterize WL#5 source
- *Qc_{INPUT}=2.7x10^5 kg Cl/yr, towards WL#5*
- **Most (75%) chloride comes from northwest quadrant**

WL#5 Water Balance-Northwest Quadrant

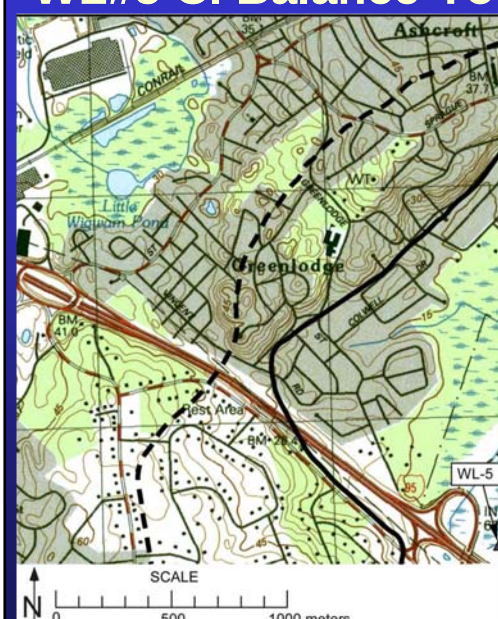


- 0.25Q=0.0092m^3/s leaves through WL#5
- Ppt*(1-evap)*A_{RECH}*(Aquifer/Floodplain) enters the Aquifer
- Evap=0.55 (25"/yr, Linsley et a 1982)
- A_{RECH}=1.4x10^6 m^2 dotted line is topographic divide
- **Aquifer/Floodplain=0.40**

WL#5 Water Balance-Cross Section, Looking North

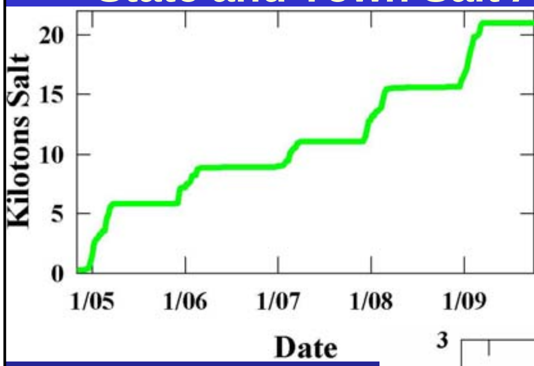


WL#5 Cl Balance-Town/State Attribution



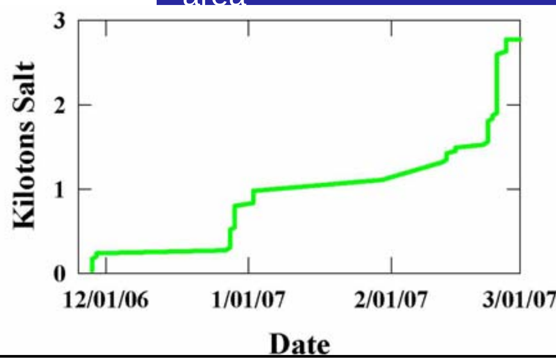
- *$2.0x10^5$ kg Cl/yr* towards WL#5 (NW, 75% of total)
- 11 miles of Town roads distributed over (NW) A_{RECH}
- Town=0.40*11 lane miles*town application rate (rest to floodplain/river)
- State=0.67*7.3 lane miles*state application rate (rest to floodplain/river)

State and Town Salt Application Rates



State Rate

- Canton Facility-84 lane miles
- 5 seasons
- 2.73×10^4 kg Cl/lane mile year
- Applied to I95 in study area



Town Rate

- Dedham Facility-110 lane miles
- 1 season
- 1.37×10^4 kg Cl/lane mile year
- Applied to Town roads in study area

WL#5 Cl Balance-Town/State Attribution

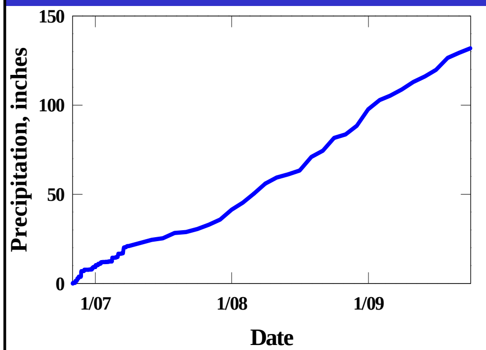
- *Town contributes 6.0×10^4 kg Cl/yr* towards WL#5, as areal source ("country drainage") distributed over NW quadrant, diluted, low strength flux

- *State contributes 1.32×10^5 kg Cl/yr* in NW through linear source (closed I95 drainage system) in NW quadrant, concentrated flux (not much water)

- Remaining quadrants 25% conservatively (from Town's point of view) assigned to the State

22% Town/78% State contribution
of salt towards WL#5

Pavement vs Weir Concentrations

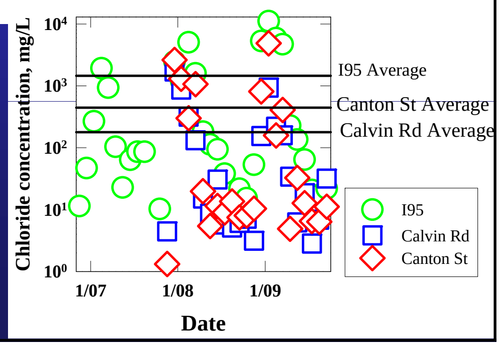


Pavement

- Applied mass/annual volume
- Volume=ppt*lane miles
- ppt=45.3 "/yr
- $c_{PAVEMENT}$=*3,700 mg Cl/L* (State)
- $c_{PAVEMENT}$=*1,800 mg Cl/L* (Town)

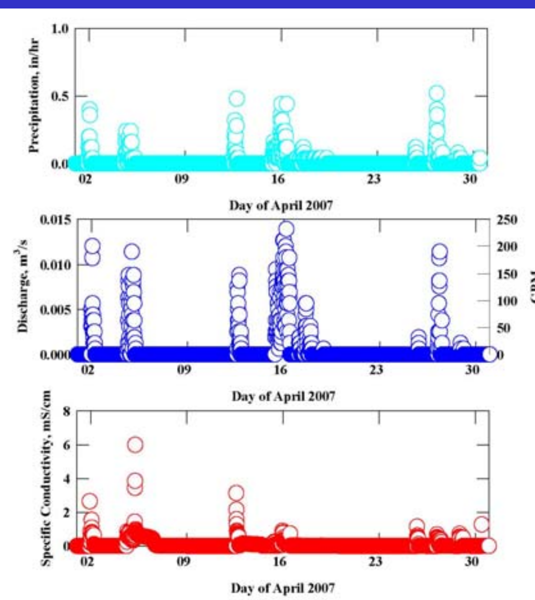
Weirs

- c_{I95}=*1,400 mg/L* (freeway) dilution factor of 2.6, focused, closed drainage source
- c_{Canton}=*426 mg/L* (commercial) dilution factor of 4.2, intermediate behavior
- c_{Calvin}=*171 mg/L* (residential) dilution factor of 10.5, distributed in the recharge



And The Weir Concentrations Are Measured

- Fifteen minute sampling interval-onsite ppt gage
- Telemetry via dedicated cell phone lines (can you hear me now? $$)
- Significant events without mobilization
- Specific conductivity a useful surrogate for deicing agents (major ions)
- Monthly average concentrations (advective chloride flux/water flux)



Measured vs NW Mass Balance Concentration

Town Contribution

6.03×10^{4} kg Cl/0.25Q=208 mg Cl/L (Mass balance)

$c_{Calvin}(171)<208<c_{Canton}(426\ mg\ Cl/L)$

Town contributes high Q, low c runoff to WL#5 (open drainage)

State Contribution

$c_{I95}=1{,}400\ mg/L$ *(weir) vs maximum* $c_{DEEP}=854\ mg/L$ *(MW3D)*

Closed drainage system into upgradient (westerly) recharge area

Lateral input to Aquifer, little gw dilution, not local leakage through aquitard

Year II Conclusions-Aquitard Hydraulics and Aquifer Transport

- Neponset River aquitard protects WL#5
- 10 m thick, cascade calibration
- 10^{-17}(large scale) $<k'<10^{-13}m^{2}$ (smaller scale)
- $c_{INPUT}=234\ mg\ Cl/L$ approaching WL#5
- NW sources, laterally upgradient, not leakage
- 78% State salting and closed drainage system, high concentration, low discharge
- 22% Town salting and open drainage, low concentration, high discharge

References

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Acknowledgements and Thanks for Listening……………

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Questions??