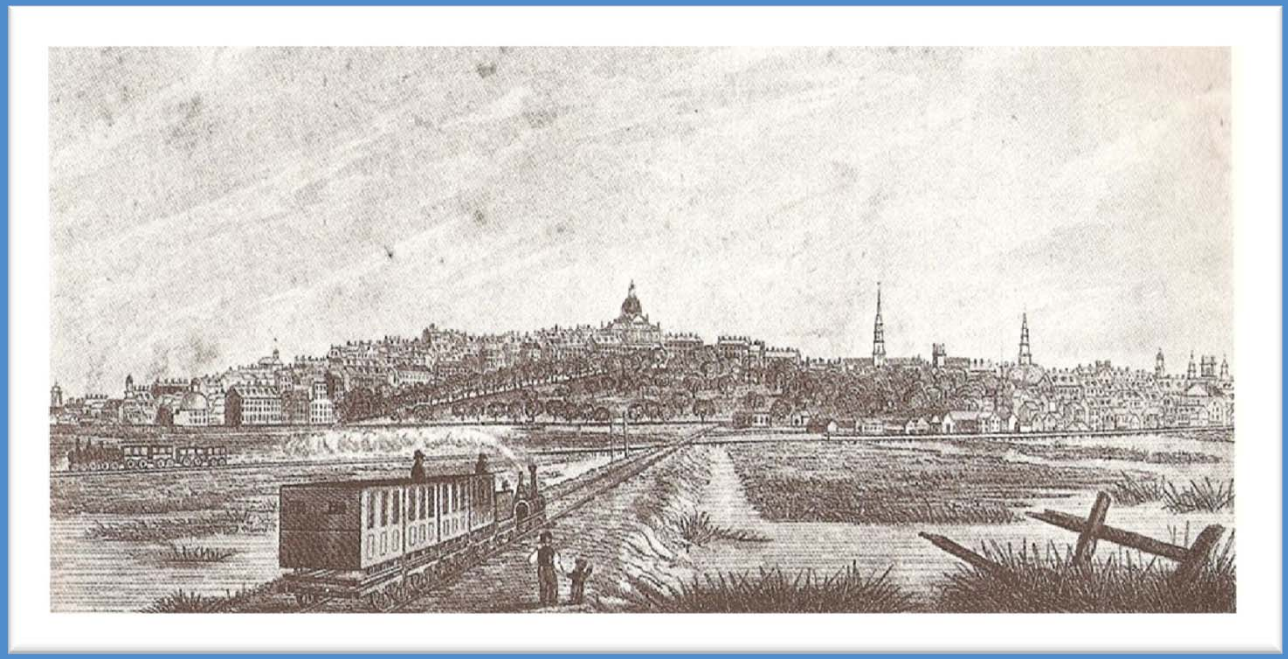
The Impact of Stormwater Recharge Practices on Boston Groundwater Levels

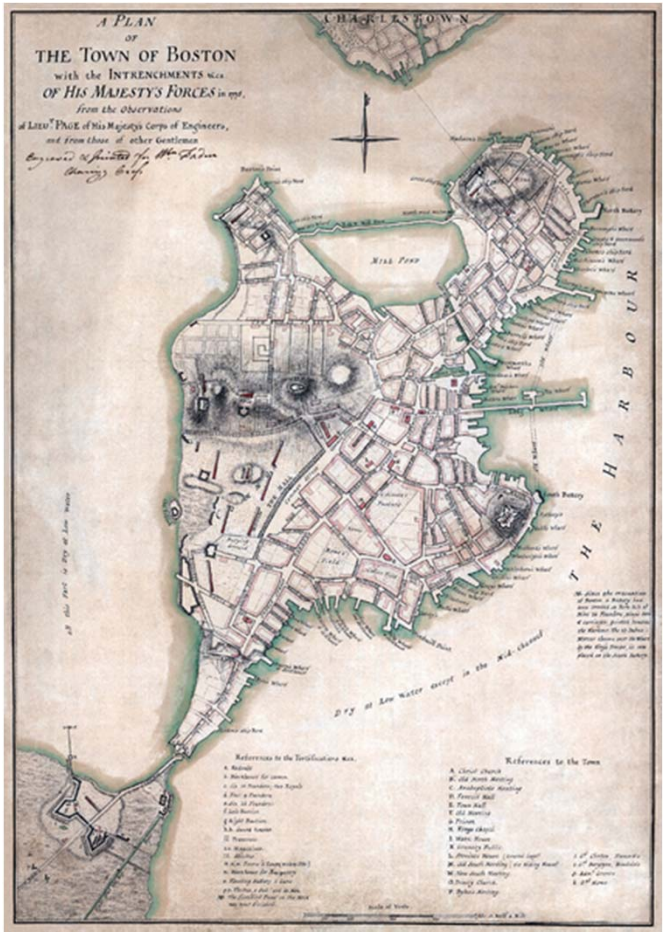


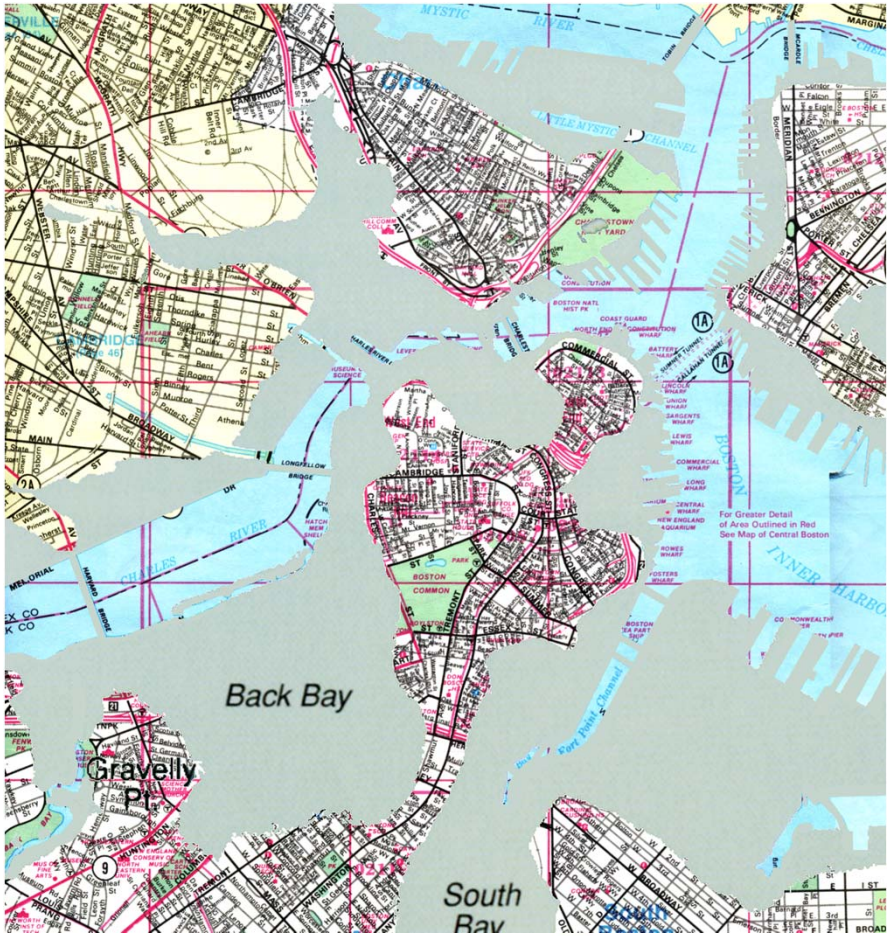
Richard M. Vogel and Brian F. Thomas

Tufts University

Lenox Hotel, January 27, 2011

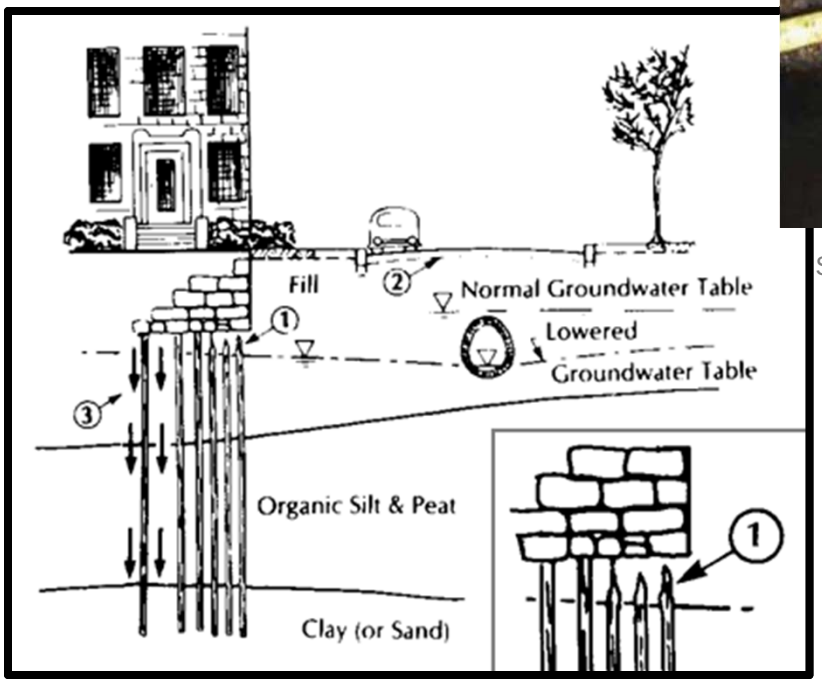
Filling of Back Bay





Images: bostongroundwater.org

Why is groundwater elevation important in Back Bay?



Source: Aldrich and Lambrechts, 1986

Source: Vatovec and Kelley, 2007

Project Objectives

Objectives:

(1) Determine if recharge best management practices (BMPs) have had a significant (positive) impact on groundwater levels

(2) Can we predict expected increase in groundwater levels due to existing and future recharge BMPs?

What approaches are needed?

- Statistical methods to enable hypothesis tests
- Methods must preserve groundwater dynamics

Tufts

Background

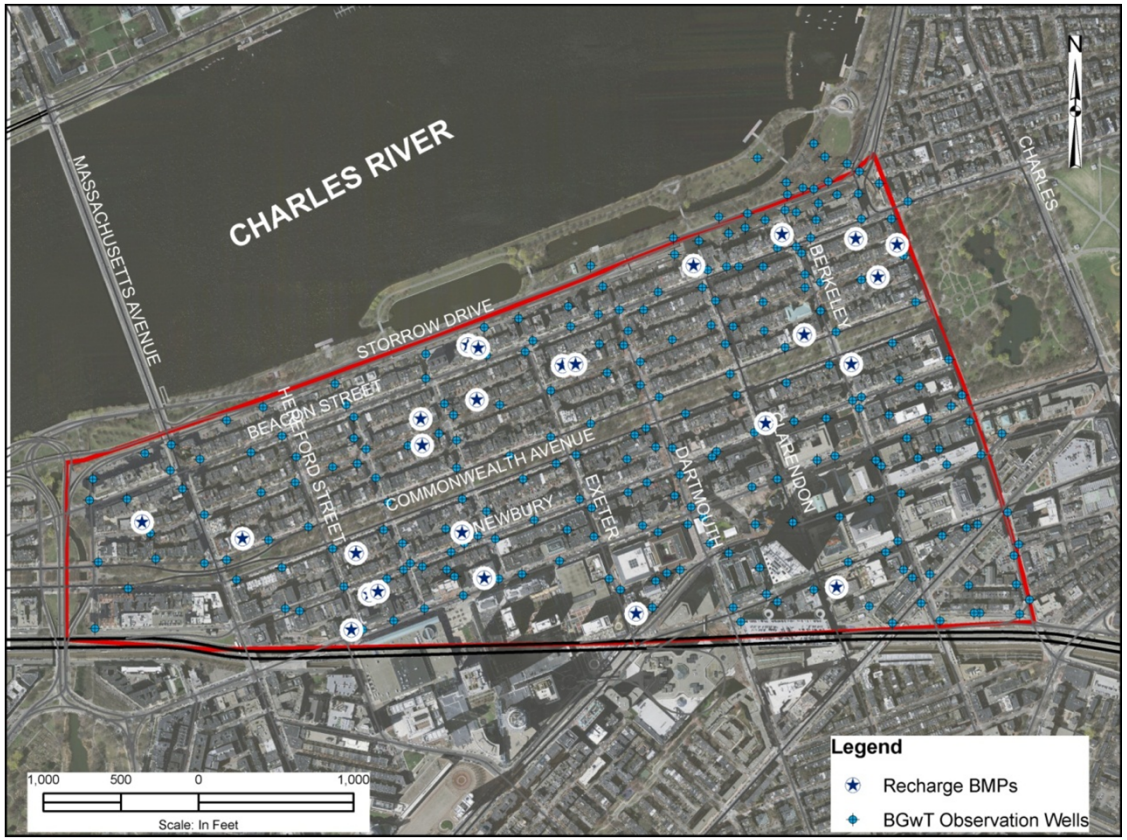
Hodgson (1978) – Water Budget Approach

$$\mathbf{GW_t = GW_{t-1} + SR + UR - UD - P - T}$$

- GW_t: groundwater level at time t
- GW_{t-1}: previous groundwater level
- SR: surface recharge
- UR: groundwater recharge
- UD: Underground discharge
- P: Pumping discharges
- T: Transpiration

Tufts

What Makes This Project Possible? DATA



Study Area:

234 Observation wells
1999-2010

24 BMP's totaling 9,050 cubic feet
(out of total of 79 BMP's)

Tufts

Methodology

- Use all existing data on wells and BMP's
- Exploit multivariate statistical method
  - Well elevations depend on many factors
  - Enables hypothesis tests
- Ensure model is consistent with (physical) water balance
- Special attention to validation

Tufts

Multivariate Statistical Model

Back Bay Regional Model

Model Coefficient

Model Error

$$GW_t = \beta_0 + \beta_1 GW_{t-k} + \beta_2 P + \beta_3 k + \beta_4 PET_1 + \beta_5 \sum BMP + \varepsilon_t$$

Explanatory Variable Description	Variable Name	Data Source	Units
Observed GW elevation at time t	GW_t	BGwT	ft
GW elevation k days prior to GW_t	GW_{t-k}	BGwT	ft
Precipitation over k days	P	NCDC	ft
Time Lag between well observations	k	BGwT	day
Potential evapotranspiration	PET	NCDC	ft/day
Recharge BMP Variable	∑BMP	BGwT/GIS	ft^3/ft

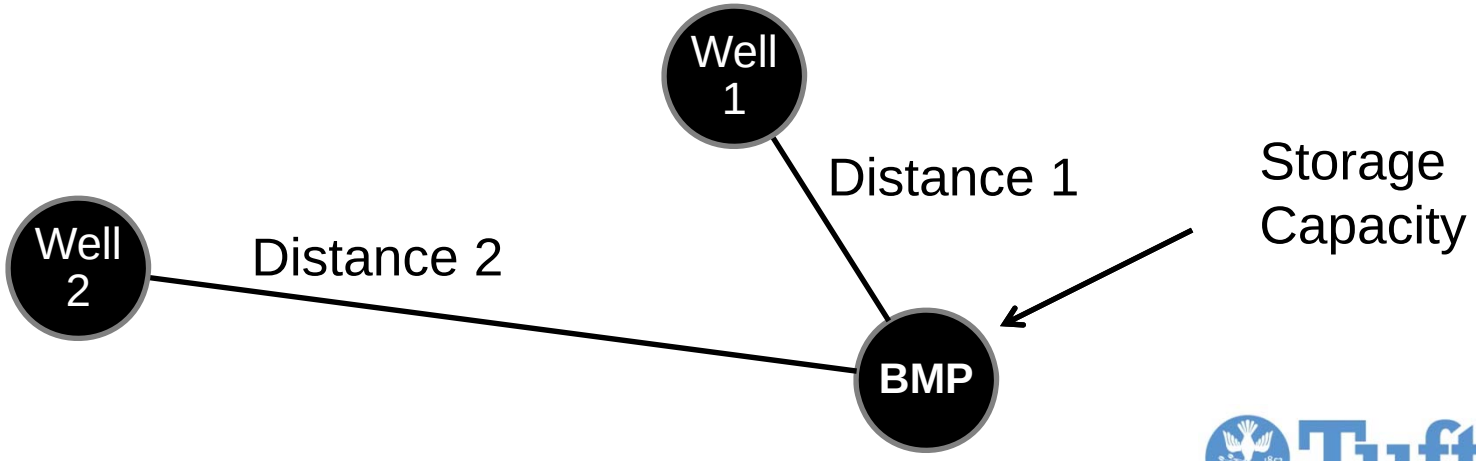
Tufts

Recharge BMP Variable: BMP*CAP/D

$$BMP = \begin{cases} 0 \text{ if BMP not installed} \\ 1 \text{ if BMP installed} \end{cases}$$

$$CAP = \text{Capacity of Recharge BMP } (ft^3)$$

$$D = \text{Distance from Well(i) to BMP(i)}$$



Tufts

Back Bay Regional Model

Regional Model: Superposition

$$GW_t = \beta_0 + \beta_1 GW_{t-k} + \beta_2 P + \beta_3 k + \beta_4 PET_1 + \beta_5 \sum BMP + \varepsilon_t$$

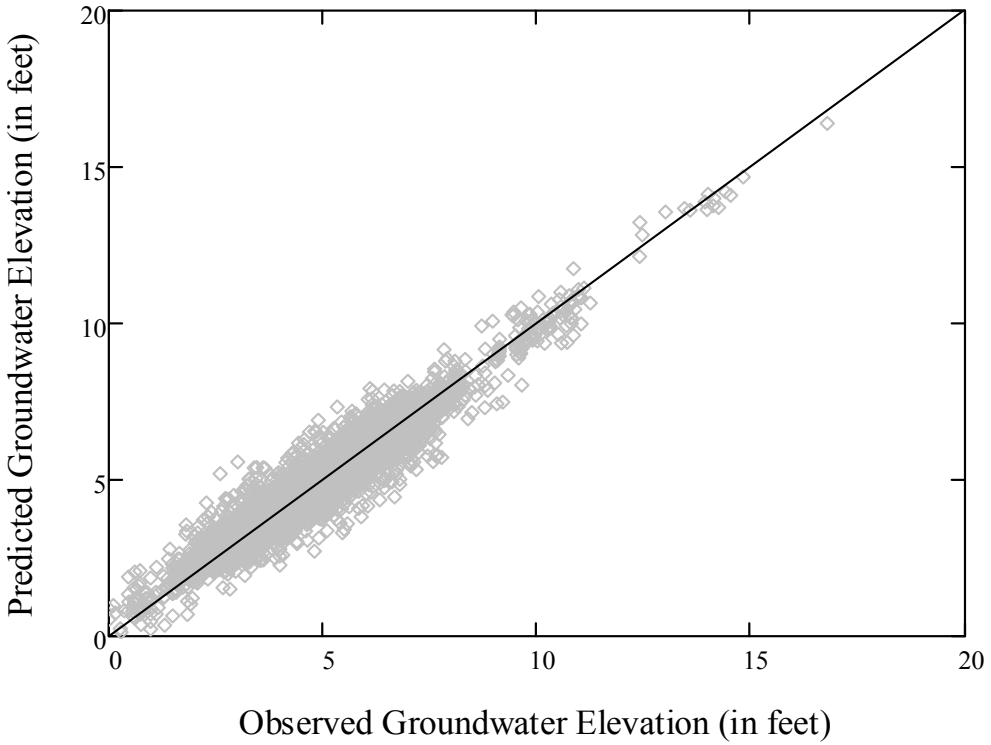
Model	β_0	β_1	β_2	β_3	β_4	β_5	Adj-R^2	Pred-R^2	NSE	SE	PRESS
1	0.36 (16.6)	0.93 (234.3)					87.5%	87.5%	0.88	0.52	2151.
2	-0.16 (-7.33)	0.94 (273.5)	0.83 (48.4)				90.6%	90.6%	0.91	0.46	1683
3	0.12 (5.23)	0.94 (281.8)	1.19 (52.9)	-0.009 (-25.4)			91.2%	91.2%	0.92	0.45	15911
4	0.28 (11.9)	0.95 (303.6)	1.24 (59.5)	-0.01 (-31.1)	-389.2 (-21.7)		92.4%	92.4%	0.92	0.41	1345
5	0.24 (10.5)	0.95 (324.5)	1.25 (64.0)	-0.01 (-31.7)	-401.0 (-24.0)	0.016 (5.85)	93.4%	93.4%	0.92	0.38	1091

Tufts

Back Bay Regional Model
Results

$$GW_t = 0.24 + 0.95GW_{t-k} + 1.25P - 0.01k - 400.99PET_1 + 0.016\sum BMP$$

Comparison of Predicted and Observed Groundwater Elevations



A BMP of capacity 1 feet^3 located 1 foot away from a well, will increase well elevation by 0.016 feet

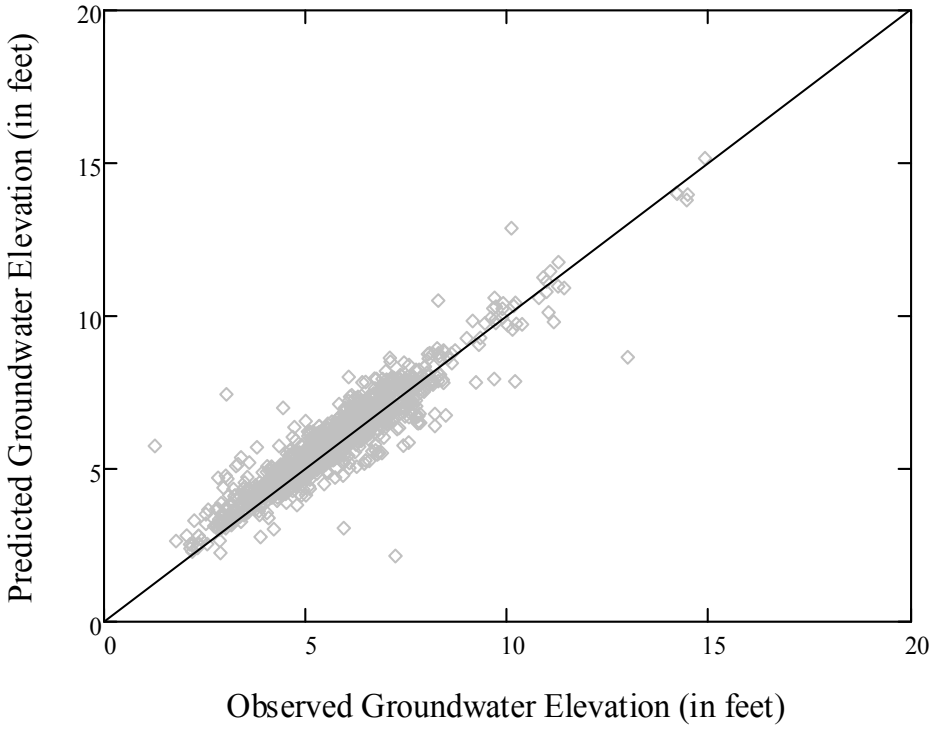
Tufts

Back Bay Regional Model

Results – Blind Sample Validation (Oct 2009 – June 2010)

$$GW_t = 0.24 + 0.95GW_{t-k} + 1.25P - 0.01k - 400.99PET_1 + 0.016\sum BMP$$

Comparison of Predicted and Observed Groundwater Elevations
Blind Sample Validation



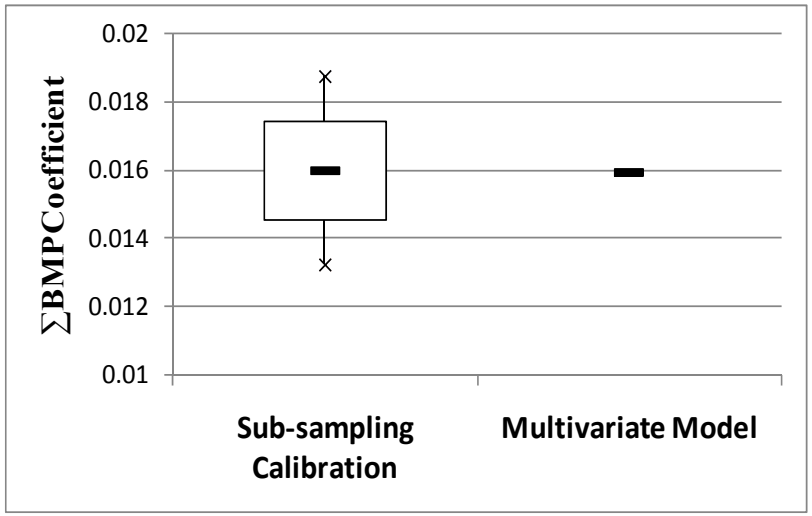
Tufts

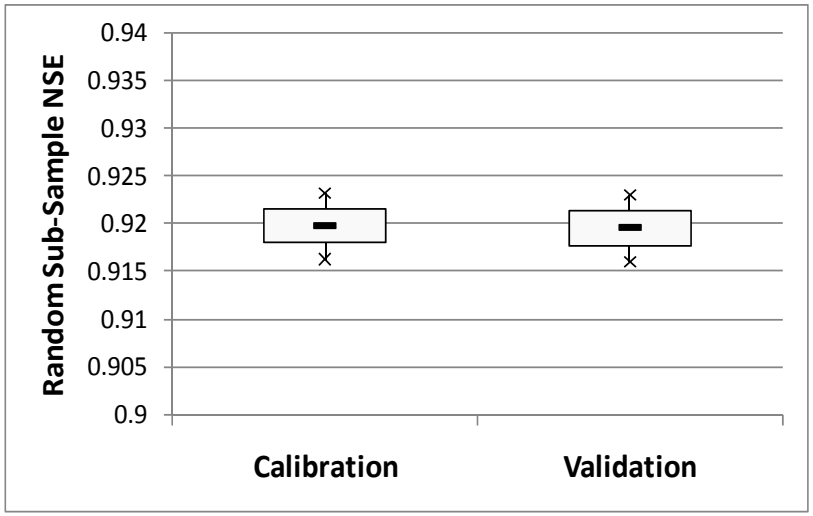
Back Bay Regional Model

Cross Validation Results

Repeated Validation Using 50% of Sample to Fit Model and the other 50% to Test model

Nash Sutcliffe Efficiency and BMP Model Coefficient
Cross- Validation Results

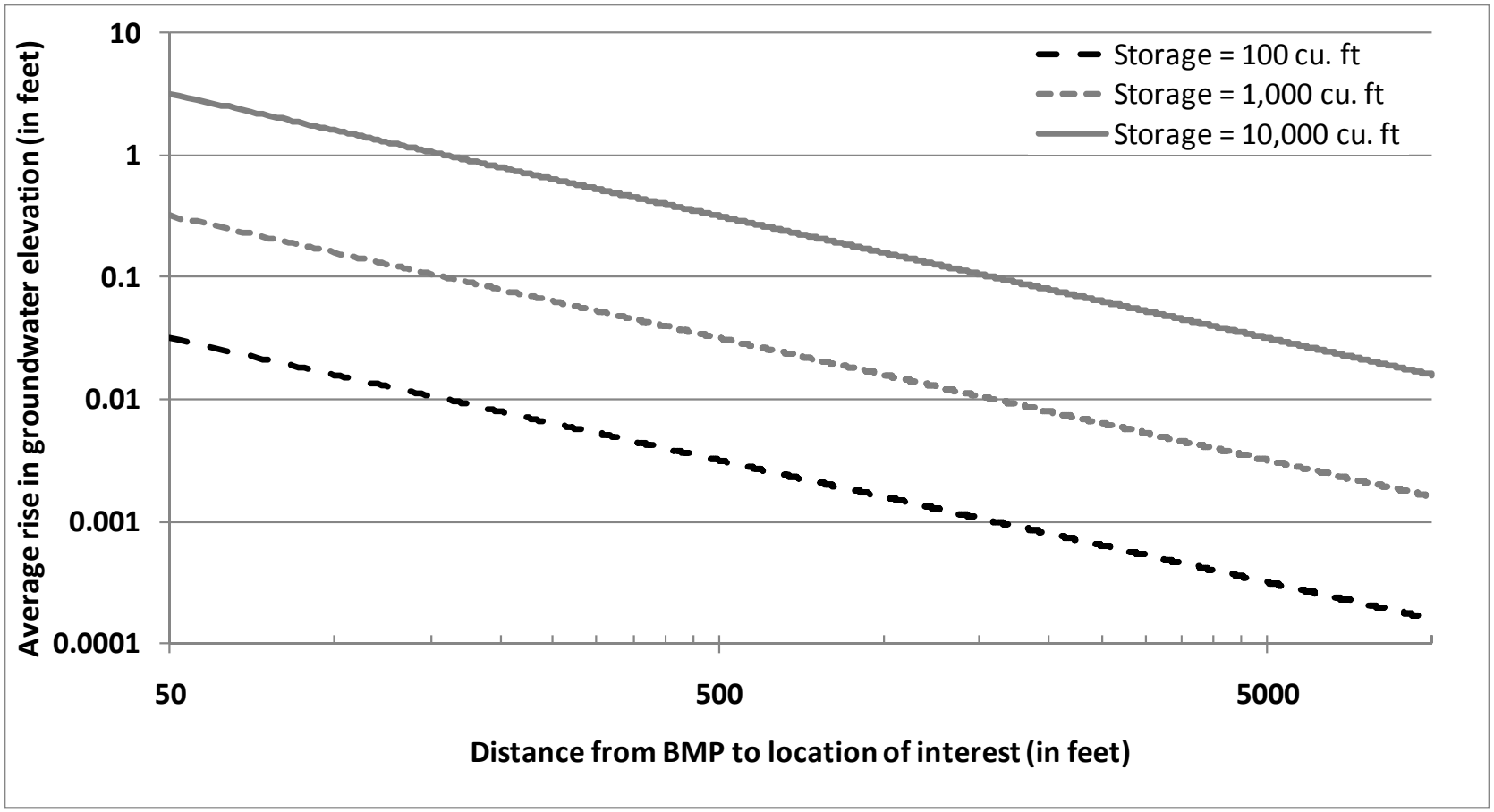




Tufts

Model Application – Holding Everything But BMP's Constant

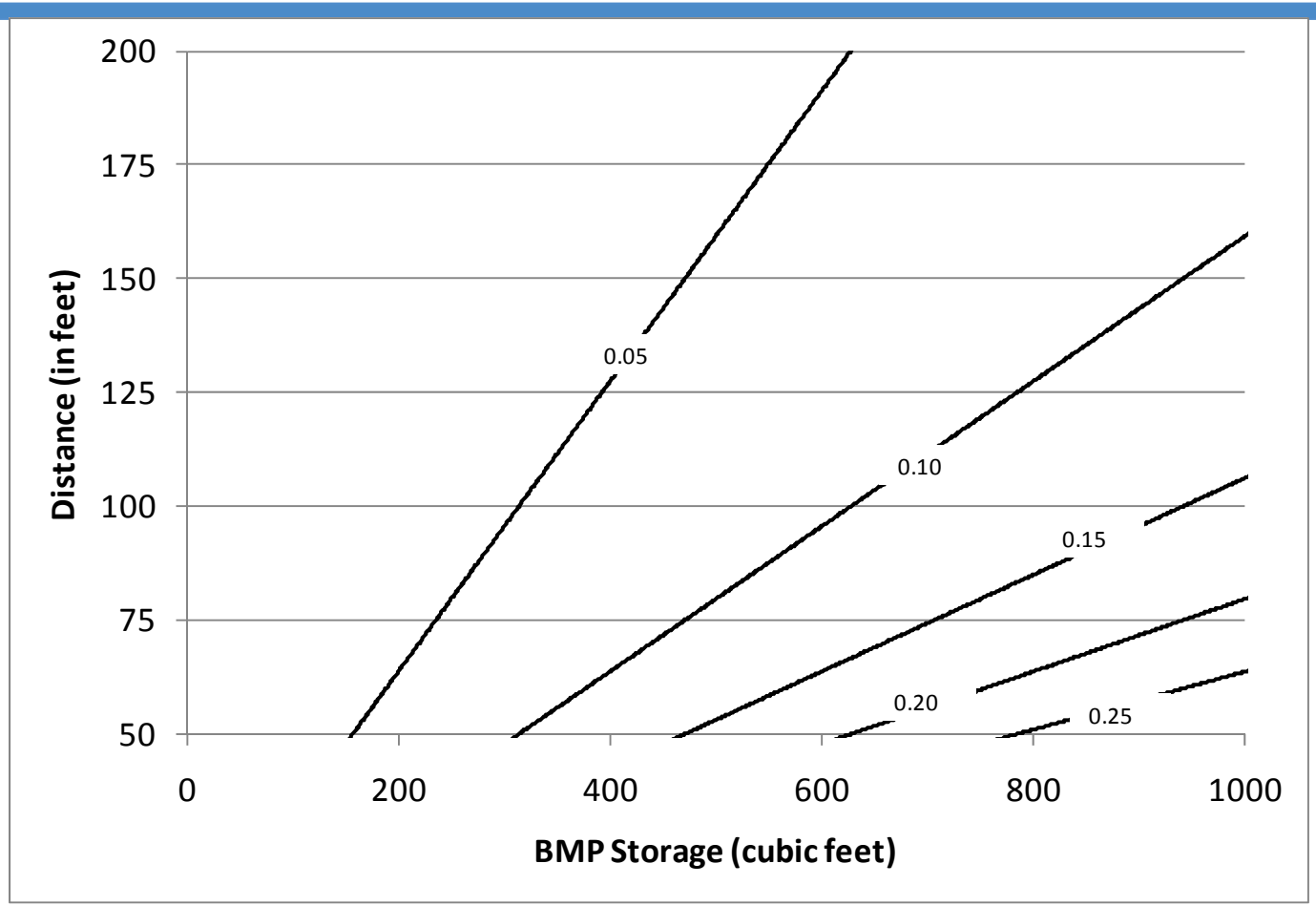
$$GW_t = 0.24 + 0.95GW_{t-k} + 1.25P - 0.01k - 400.99PET_1 + 0.016\sum BMP$$



Tufts

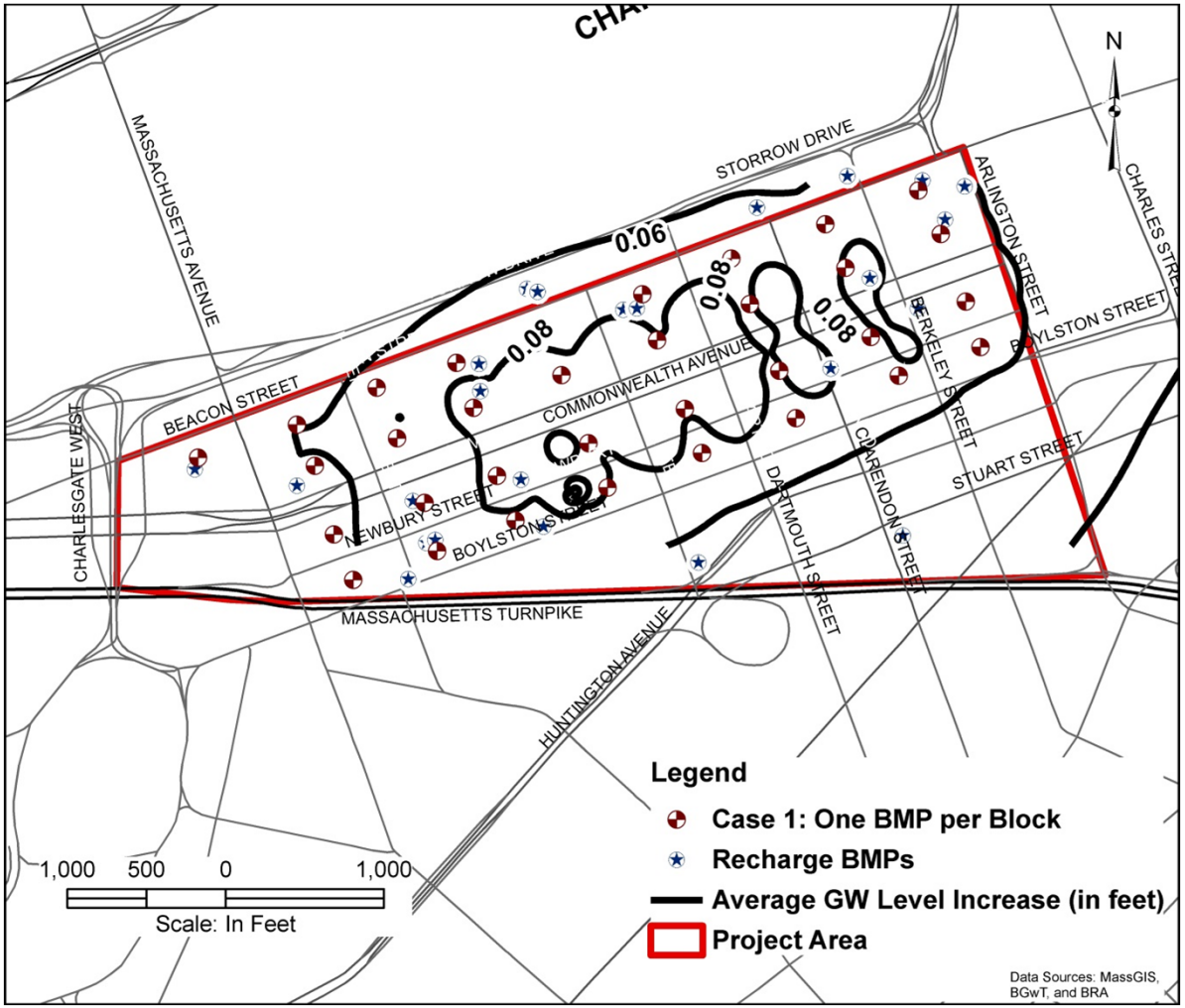
Model Application – Holding Everything But BMP's Constant

$$GW_t = 0.24 + 0.95GW_{t-k} + 1.25P - 0.01k - 400.99PET_1 + 0.016\sum BMP$$



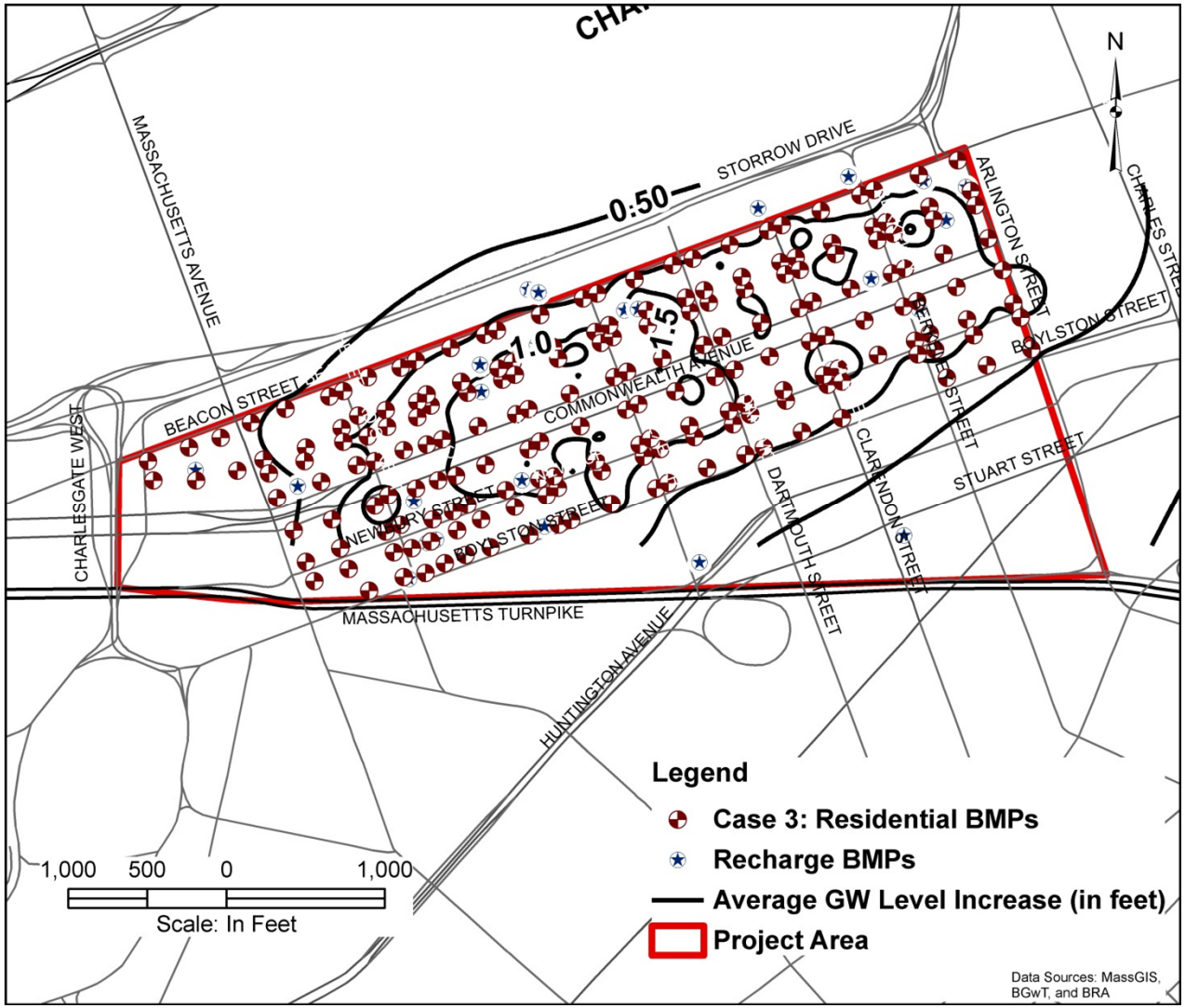
Tufts

Case 1: Single recharge BMP per block; located centrally; 280 ft^3 capacity



Tufts

Case 3: BMPs placed at approximately every 10th building; approximately 6 BMPs per block; 280 ft³ capacity



Tufts

Back Bay Regional Model
Summary

- Recharge BMP variables have small but statistically significant and positive impact on groundwater levels
- Model developed can predict the average increase in groundwater level resulting from a system of recharge BMP's given their locations and capacities
- Model developed can be used as a planning tool to aid in the siting future recharge BMP's

Tufts

Questions?

Acknowledgments:
-Boston Groundwater Trust (Elliott Laffner and Christian Simonelli)
-BGwT Technical Advisory Committee

Tufts