Is it Getting Hot in Here? A Mixed Methods Approach to Explaining "Suburban Drought" in Eastern Massachusetts

Author: Troy Hill '06 (First Reader: Colin Polsky, Second Reader: Robert Goble)

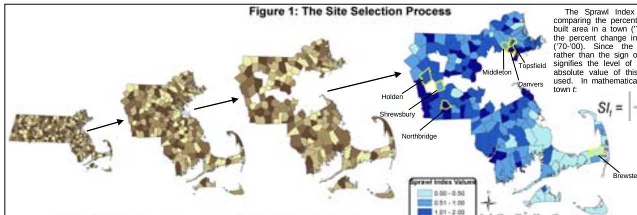
Introduction

Towns in eastern Massachusetts are implementing water restrictions in years with plentiful rainfall. This study attempts to explain this phenomenon using regression modeling and interview-based narratives. By focusing on suburbs of Boston and selecting 7 communities based on their degree of sprawl-style growth (a process described in Fig. 1), this study asks:

Is development affecting vulnerability to drought?

Vulnerability is understood to be a function of exposure, sensitivity, and adaptive capacity (the ability of a system to cope with a hazard). Drought, in this study, is taken to mean simply an inability of water supplies to meet demand. During the quantitative phase the focus was on attributing drought exposure (manifest in water restrictions) to climatic and non-climatic variables; during the qualitative phase this concept of vulnerability was fully operationalized. Drawing on quantitative and qualitative methods allowed a more robust analysis than would have been possible with a monomethod approach. Long-term planning and integration of land use and water management emerged as avenues for reducing vulnerability.

Figure 1: The Site Selection Process



Step 1: The towns must be from eastern Massachusetts. This criterion left 227 towns.

Step 2: Towns must supply their own water (i.e. be independent of the MWRA). This left 169 towns.

Step 3: A Sprawl Index was calculated, stratified into four categories and seven towns were selected.

The Sprawl Index is a ratio comparing the percent change in built area in a town ('71-'99) with the percent change in population ('70-'00). Since the magnitude rather than the sign of the value signifies the level of sprawl, the absolute value of this ratio was used. In mathematical terms, for town *t*:

$SI_t =$ [illegible]

Methods

Univariate Analysis

Univariate analysis was an important aspect of this study. Table 1 summarizes some of this; it shows that over the past 30 years there has been little appreciable change in summer-month climate. While there has been inter-annual variation in GDD season temperatures and precipitation, there has not been a dominant trend over time. Restrictions, however, have been increasing markedly (Fig. 3).

Examining these trends alongside data on water restrictions and knowledge gleaned from interviews offers similar insights. Northbridge serves as a good example: officials claim that climatic stress caused them to implement the 2002 restrictions, though Figure 2 shows that 2002 was not an abnormal year in one of the climatic variables used here (several drier years are circled in red). This suggests that Northbridge's sensitivity to climatic stress may be increasing. The role of development in that process merits serious consideration.

Figure 2: GDD Season Precipitation and Water Use Restrictions in Northbridge

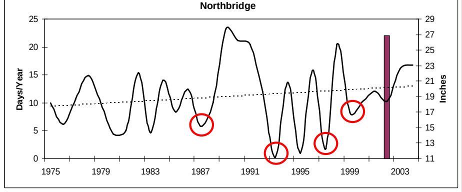
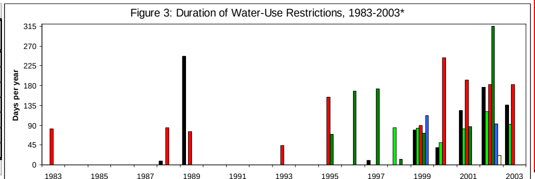


Table 1. Baseline Human-Environment Conditions

Town	*GDD**	*GDD_PRCP**	*Sprawl Index*	*Pop.Change ('70-'00)****	*Built Land Change ('71-'99) ‡*
Brewster	n.s.	n.s.	0.3	464%	137%
Middleton	+ **	n.s.	0.6	91%	57%
Shrewsbury	n.s.	n.s.	0.8	64%	49%
Holden	n.s.	n.s.	1.7	24%	41%
Topsfield	+ **	n.s.	1.8	18%	32%
Danvers	+ **	n.s.	4.3	-4%	15%
Northbridge	n.s.	n.s.	4.7	12%	56%

*trends over time (n.s.=not significant), **p<0.01, ***US Census, ‡EOEA

Figure 3: Duration of Water-Use Restrictions, 1983-2003*



*prior to 1983 no town had implemented restrictions

Multivariate Analysis

Six multivariate models were specified to test **two hypotheses:**

(1) That watering restrictions are increasing in duration, accounting for climate

This is tested by examining coefficient estimates for the YEAR variable. All of the statistically significant YEAR coefficients (4 out of the 6) are positive, indicating that water restrictions have been increasing in duration even after controlling for climatic variables (Table 3). My first hypothesis is validated.

(2) These increases are correlated with the amount of sprawl a town is experiencing

This is tested by examining the correlation between Sprawl Index values and the YEAR beta coefficients. Figure 5 shows that a positive correlation exists, but the results are not significant. This hypothesis is thus deemed inconclusive.

The data underpinning this analysis is detailed in Table 2. Five independent variables were constructed, one as a time dummy variable and four to represent different aspects of climate. One variable in particular merits further explanation. Growing degree days (GDDs) are a measure of heat stress for a plant's typical growth period. In this study GDDs were calculated to be relevant to dominant grass types in suburban lawns: fine fescue, Kentucky bluegrass and perennial ryegrass. The growing season for these grasses begins in early May and ends in late September, and increased GDDs will likely coincide with increased lawn watering. The formula for calculating GDDs is at right:

Table 2. Variable Descriptions and Data Sources

Variable			Definition	Source*
dependent variable		RSTXN_D	Number of days in a given year with water restrictions in effect	1
independent variables	non-climate	YEAR	Time dummy variable	1
	climate	SPRG_PRCP	accumulated monthly precipitation (inches) for months March-April	2
		GDD_PRCP	accumulated monthly precipitation (inches) for months May-September	2
		GDD	accumulated monthly growing degree days for months May-September	3
		WNTR2	accumulated monthly precipitation (inches) for months December-February	2

*Variables were constructed using the procedures outlined in the text and the following data sources:
1 = Town Selectmen Meetings Minutes, local newspapers, municipal documentation, communication with CWS managers, Boston Public and Gale Free Library archives, NewsBank, and Public Water Supply Annual Statistical Reports filed with the DEP
2 = DCR (2006)
3 = Northeast Regional Climate Center (2006)

$$GDD = \sum_{i=1}^{5} a_i\left(\frac{TMAX_i + TMIN_i}{2} - 60\right)$$

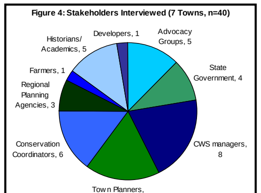
Where:
a_i = The number of days in month *i* (May through September),
$TMAX_i$ = The maximum temperature recorded for month *i*, and
$TMIN_i$ = The minimum temperature recorded for month *i*

Qualitative Analysis

Interviews with a range of stakeholders in the 7 selected towns were used to develop narratives regarding water use and management. Interviews explored regional development patterns, levels of communication between stakeholders, their decision-making processes, how they impacted water use and management, the degree of integration between land use and water planning; an investigation of the social processes and contexts that were unable to be explored in the regressions.

A total of 40 interviews were conducted, and Figure 4 shows the number from each stakeholder group. From the interviews, narratives were built detailing water use and management from regional and state-level perspectives. At its essence, the interview component uncovered a richness and depth left concealed by the regression models.

Figure 4: Stakeholders Interviewed (7 Towns, n=40)



House on Conservation Drive, Northbridge.

Brewster has over 1900 acres of conservation land.

Sources

American Rivers. 2003. "America's Most Endangered Rivers of 2003." Available at: http://www.americanrivers.org/site/DocServer/mermap.pdf?docID=678. Accessed 20 April 2006.

CHAPA (Citizens' Housing and Planning Association). 2006. "Fact Sheet on Chapter 40B: The State's Affordable Housing Zoning Law." Available at: http://www.chapa.org/40b_fact.html. Accessed 10 April 2006.

CZM (Coastal Zone Management). 2005b. "Water Management Act." Available at: http://www.mass.gov/czm/envpermitwatermanagementact.htm. Accessed 30 March 2006.

EOEA (Executive Office of Environmental Affairs). 1971/1999. "Land Use Datalayer." Available at: http://www.mass.gov/mgis/lus.htm.

US Census. 1970/2000. Population Data. Available at www.census.gov

For further information, contact Troy Hill at THill@Clarku.edu

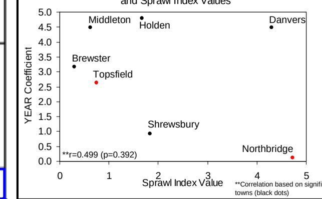
Quantitative and Qualitative Results

Table 3. Regression Results: OLS Models

Dependent variable: RSTXN_D		Brewster (coefficient estimate / t-statistic)	Northbridge (c.e. / t)	Shrewsbury (c.e. / t)	Holden (c.e. / t)	Middleton/ Danvers (c.e. / t)	Topsfield (c.e. / t)
Climate	SPRG_PRCP	-1.415	-0.206	-0.951	3.487	-4.405	-2.493
		-0.755	-0.722	-0.258	0.930	-1.270	-1.824
	GDD_PRCP	0.244	-0.083	4.612	4.148	-6.329*	-0.480
		0.203	-0.452	1.837	1.574	-2.037	-0.392
	GDD	0.132*	0.007	0.128	0.116	0.117	0.101
		2.053	0.512	0.718	0.580	0.600	1.309
	WNTR2	1.675	-0.145	-5.580	-0.730	1.0581	0.253
		1.163	-0.686	-1.738	-0.183	0.328	0.200
Non-climate	YEAR	3.174**	0.130	2.631*	4.790**	4.480**	0.930
		5.394	1.407	2.187	3.763	2.739	1.445
F-statistic	F-statistic	7.651**	0.620	3.483*	4.521**	2.750*	1.700
Fit	d.f.	24	24	24	24	24	24
	R^2 (Adjusted)	0.61 (0.53)	0.11 (-0.07)	0.42 (0.30)	0.49 (0.38)	0.36 (0.23)	0.26 (0.11)

*p<0.05, **p<0.01 (two-tailed tests)

Figure 5: Correlation between YEAR Coefficients and Sprawl Index Values



Lower Cape Cod Region

- ***Local dynamics: Land-use***
  - Numerous bylaws designed to minimize impact of development
    - 1-acre zoning, minimal grass cover
    - Explains poor performance of GDD_PRCP
  - Reg'l Planning Agency (RPA): Cape Cod Commission (CCC) shares burden of reviewing developments, guiding growth
- ***Local dynamics: Water resource management***
  - Very low water use (56 gpcd in 2005, 62.1 in 2004)
  - Water use heavily influenced by summertime population spikes
    - Explains GDD's significance and positive magnitude
  - Ability to engage in long-term planning
    - Benefit from the CCC's resources and technical expertise
- ***Regional challenges for water management***
  - Administrative load from regulatory agencies
  - Single source of water: Monomoy Lens
  - Reliance on septic systems: groundwater contamination (nitrates)
- ***Integration of land-use planning and water management***
  - Communication is constant, institutionalized, and highly effective
  - Water-related considerations are a top priority when planning
  - Positive YEAR coefficient is due to two main elements:
    - Meeting WMA-related conservation requirements
    - Evening out peak summertime demand

Greater Worcester Region

- ***Local dynamics: Land-use***
  - Rapid population growth occurring, due to nearby cities
  - Zoning is mostly 2-acre
  - Extensive residential development, especially recently
  - Limited resources have made long-term planning difficult
    - RPA: (Cent. Mass. Reg'l Planning Agency) provides limited, fee-based assistance
- ***Local dynamics: Water resource management***
  - High water use (Shrewsbury: 81 gpcd in 2003, 75 in 2004)
  - Demand heavily influenced by lawn irrigation systems
    - Surprising that climate variables didn't respond better
    - Reinforces positive YEAR variable
- ***Regional challenges for water management***
  - Development pressure: especially from 40B developments
  - Summertime lawn watering (contradicts model results)
  - "Catch-22" created by 40B and WMA withdrawal limits
    - Reinforces positive YEAR variable
  - Increasing administrative loads
- ***Integration of land-use planning and water management***
  - Communication and interactions occur, but are reactive, rather than anticipatory
  - Northbridge's CWS against restricting water use (explains poor model results)

Ipswich Region

- ***Local dynamics: Land-use***
  - Dominance of single-family residential zoning
    - Bedroom communities for Boston
    - Zoning is mostly 2-acre
  - Updating/reforming zoning has been slow
  - RPA: Metropolitan Area Planning Council performs mainly an educational function (e.g. workshops)
- ***Local dynamics: Water resource management***
  - Entirely dependent on Ipswich Watershed for water
  - Ipswich River is the 3rd most threatened river in the nation (American Rivers 2003)
    - Result of to recent withdrawals in the headwaters
      - Indicated by positive YEAR coefficient
- ***Regional challenges for water management***
  - Development patterns:
    - Contributes to positive YEAR coefficient
    - Complicate efforts to meet withdrawal permits
    - Summertime lawn watering is major issue
      - Indicated by negative GDD_PRCP coefficient
  - Obtaining water to handle new development
  - Administrative load from the state
- ***Integration of land-use planning and water management***
  - Mixed, more integrated now than has been historically
    - In Topsfield, most active and integrated; fewer years with restrictions (hence poor model results)

A typical home in Middleton.

State-level Narrative

State-wide legislation and demographic shifts also influence local water resources. Below is a sampling of some of these dynamics, which were common topics of discussion in the interviews. These formed the backdrop for local water management.

- **Water Management Act (WMA) (1985)**

  By limiting withdrawals and making permits contingent on conservation efforts, the WMA encourages demand-side management. Prior to 2004, withdrawal permits were based on past use. Many, and perhaps all towns will now be subject to a 65gpcd permit cap. The WMA was formed in response to intensely stressed watersheds. (CZM 2005)

- **Chapter 40B (1969)**

  If towns do not have enough affordable housing, 40B allows developers to bypass local bylaws to build it. Over the past 3 years, 30% of all housing in the state has been due to 40B, and 304 towns still have less than 10% affordable housing. 40B will continue influencing the landscape and water consumption in Massachusetts. (CHAPA 2006)

- **Growth in Real Estate Values and Population**

  Population growth in eastern Massachusetts was set in motion by a combination of rising property values near Boston and the construction of transportation infrastructure (e.g. the Massachusetts Turnpike, Interstate 495, etc.). This has encouraged people to move to the suburbs while still working in Boston, fueling the growth of populations and developed land in eastern Massachusetts (Table1).

Holden, summer 2004. Source: Polsky

Conclusions

Two key findings of this project are:

1) **Suburban droughts in eastern Massachusetts are increasing in duration, controlling for climate.**
2) **To mitigate development's impacts on vulnerability,**
   a) **Communication must occur between land use planning and water management processes, and**
   b) **That communication must lead to integration of those areas and contribute to long-term, anticipatory planning**

The data did not support the hypothesis that droughts are increasing along a sprawl gradient, though this may be due to the small sample size. There is a large amount of variation between towns and regions in how these different forces interact to shape vulnerability to drought. Development pressure can result in two main outcomes: it can be uncontrolled and lead to environmental degradation and increase vulnerability to drought (as in the Ipswich region), or it can be guided and focused (as in the Lower Cape), and have little negative impact on a site's vulnerability.

The question of whether development is affecting vulnerability to drought must be answered in the affirmative, and its effect is to increase vulnerability. The *nature and magnitude* of that effect is determined on a local scale; a function of available resources, the willingness (and, crucially, the ability) of a town to implement innovative bylaws and be responsive to changing pressures, historical factors (previous planning or lack thereof), amount of communication at the municipal and regional levels, and the role played by advocacy groups and RPAs.

Variation in these areas creates the complex tapestry that is local drought vulnerability, and helps explain why state-scale trends translate into different outcomes locally. Integration of land use planning and sustainable water use management may prove crucial to curtailing drought vulnerability; a disconnect in these areas has played a major role in the dire situation of the Ipswich region.

Future Directions

Extending the scale of this study to encompass more towns is the most natural next step. Methodologically, there remains the possibility of refining the models, possibly using a tobit or probit model, to account for the limited nature of the dependent variable. These avenues were explored, but no immediately obvious solution was forthcoming. Accounting for potential temporally-based model misspecifications due to serial autocorrelation should also take place, but was not able to be done for this project. On the qualitative side, judging the integration of land use and water planning was a complex task; finding a means of quantifying this or developing a set of criteria by which it is measured will help streamline future work.

Acknowledgments

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