The “Frimpter” Method for Determining High Groundwater Levels in Massachusetts

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USGS

Massachusetts Environmental Health Association, March 5, 2025

U.S. Geological Survey

The USGS is one of 11 bureaus in the Department of Interior – Doug Burgum Secretary

Established by the Organic Act in 1879

We have no regulatory or management responsibilities

Guided by our Fundamental Science Practices

USGS Director (Vacant)

Almost 8,200 employees in offices across the Nation with headquarters in Reston VA

Bureau of Trust Funds Administration

USGS Mission and Vision

The **USGS mission** is to monitor, analyze and predict current and evolving dynamics of complex human and natural Earth system interactions and to deliver actionable information at scales and timeframes relevant to decision makers.

Vision Statement: Lead the Nation in 21st-century integrated research, assessments, and prediction of natural resources and processes to meet society's needs.

Mission Areas, Science Centers, Regions

- Partnerships with stakeholders developed at every level
- USGS often works directly with local and regional partners including tribes, states, municipalities, academia, other federal agencies, etc.

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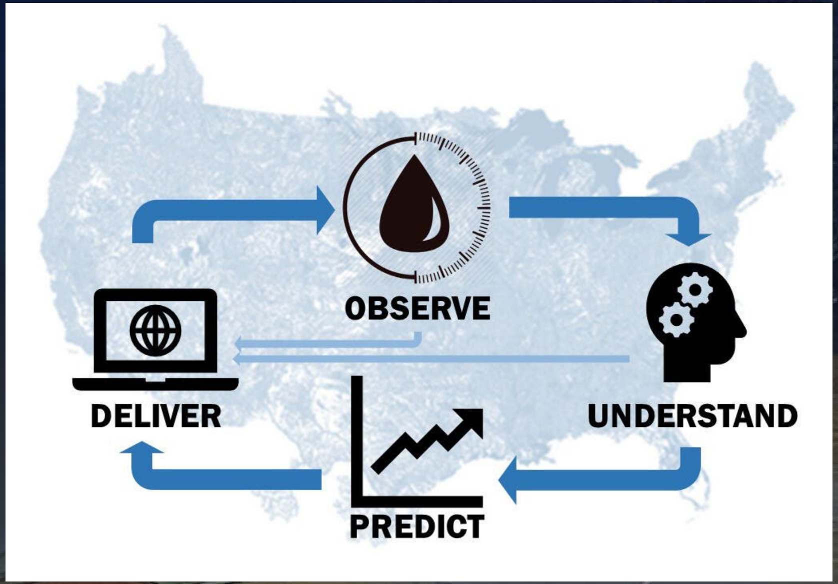
Water Resources Misson Area Headquarters

The essence of the USGS Water Science Strategy is built on the concept of "water availability," defined as the spatial and temporal distribution of water quantity and quality, as related to human and ecosystem needs, as affected by human and natural influences.



The WMA has 5 HQ Divisions that work to observe, understand, predict, and deliver water science by building new capabilities, tools, and delivery systems to meet the Nation's water-resource needs.

- Observing System Division (OSD)
- Laboratory and Analytical Services Division (LASD)
- Earth System Processes Division (ESPD)
- Integrated Modeling and Prediction Division (IMPD)
- Integrated Information Dissemination Division (IIDD)

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USGS WMA Division Directors

Overview of the New England WSC

- Five office locations
- Over 180 staff
- Hydrologic Technicians, Hydrologists, Physical Scientists, Biologists, Administrative Staff, IT Specialists, Technical Specialists, and Program Managers
- Staff range from early-career students and recent graduates to internationally-recognized experts

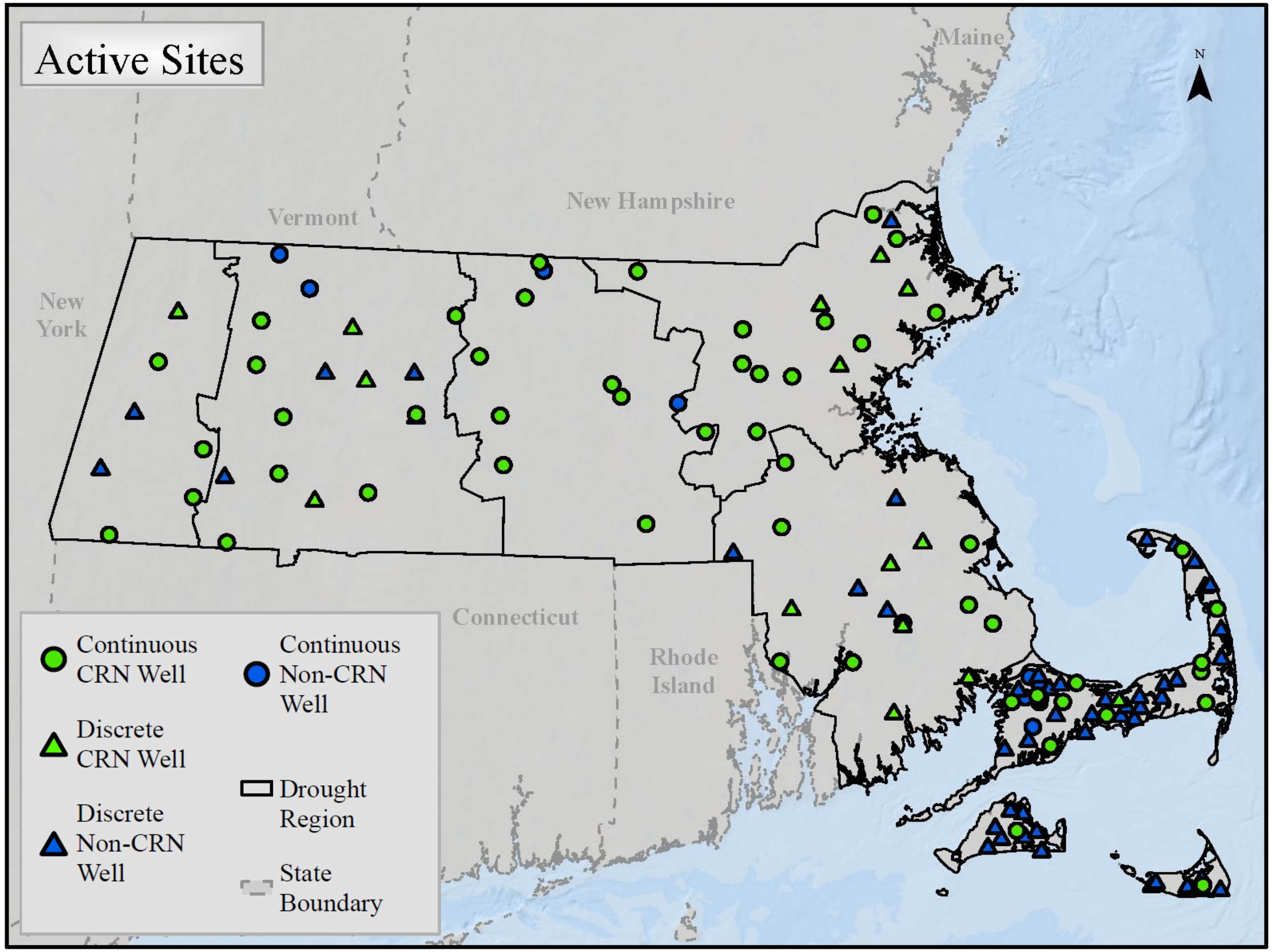
- Over 140 Cooperators
- About 600 real-time and over 300 routine monitoring locations
- Over 50 ongoing studies
- 46 scientific publications and countless data points (tens of millions) released in Federal Fiscal Year 2023

www.usgs.gov/centers/new-england-water-science-center

USGS Groundwater Level Network

Completing an installation of real-time monitoring equipment

Massachusetts Groundwater Network



Cooperators and Partners

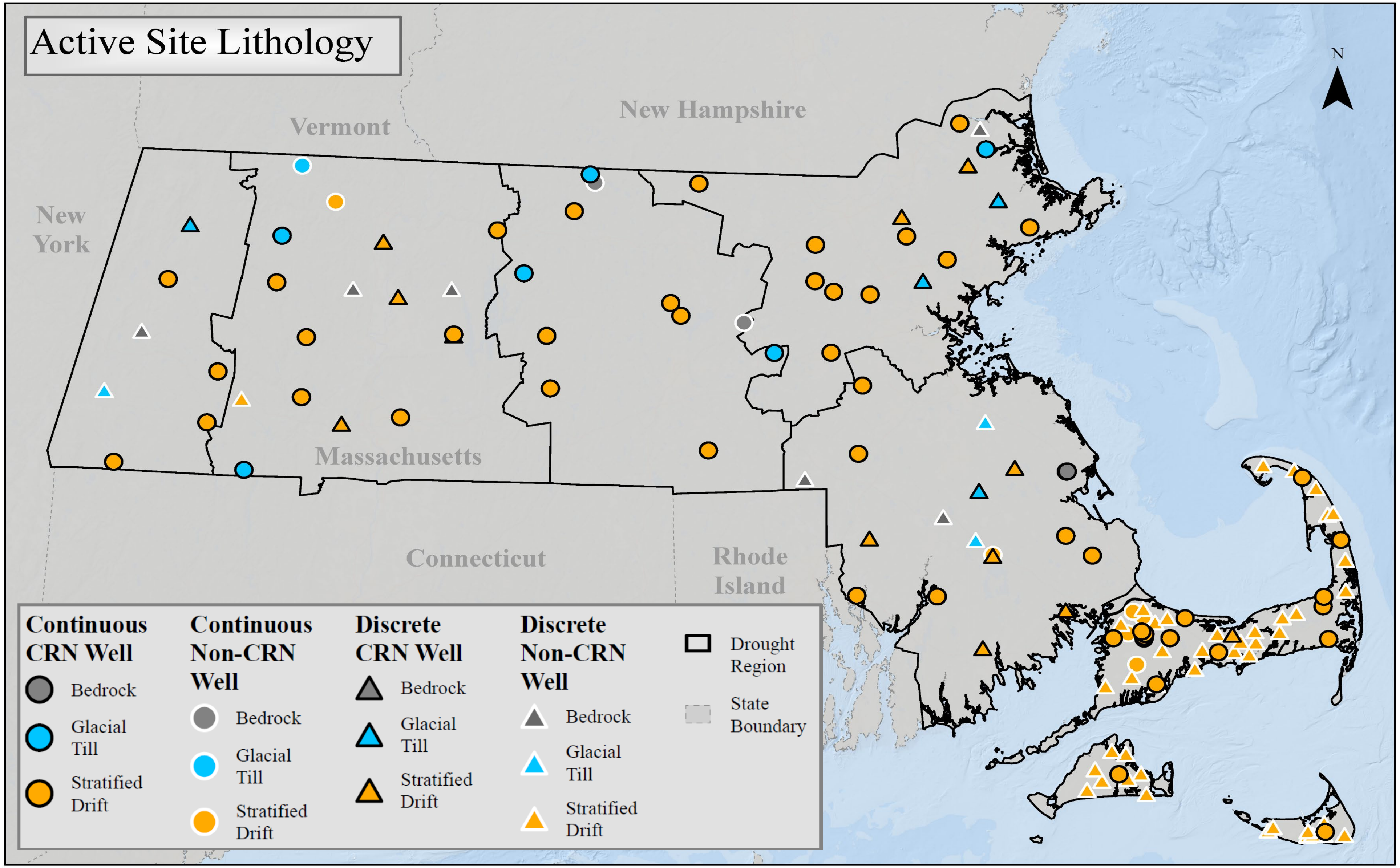
- **Massachusetts Department of Conservation and Recreation**
- **Massachusetts Department of Environmental Protection**
- **Cape Cod Commission**
- **U.S. Army**

*CRN wells continue to be upgraded to real time continuous monitoring

Climate Response Network ([Caldwell and Fine, 2024](#))

USGS science for a changing world

COMMONWEALTH OF MASSACHUSETTS

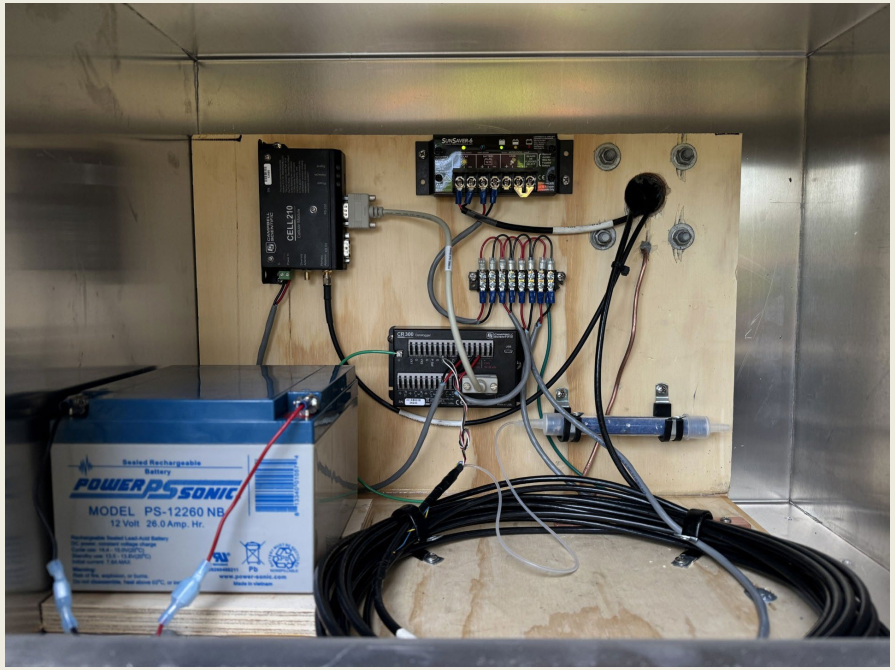


*CRN wells continue to be upgraded to real time continuous monitoring

USGS science for a changing world

Commonwealth of Massachusetts

EXAMPLE OF USGS GROUNDWATER LEVEL MONITORING SITE IN ANDOVER



USGS

Mike Frimpter 1934 - 2021

- **U.S. Army**
- **Williams College**
- **Boston University, PhD**
- **U.S. Geological Survey 1963 – 66**
- **University of Wisconsin 1966 – 71**
- **U.S. Geological Survey 1971 – ~94 Chief, Massachusetts Office**

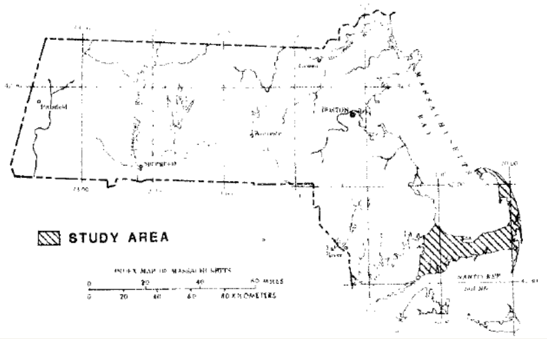
USGS

Original Reports on the Method

R+D
File Copy
TSB
Westborough

PROBABLE HIGH
GROUND-WATER LEVELS
ON CAPE COD, MASSACHUSETTS

U.S. GEOLOGICAL SURVEY
Water-Resources Investigations
Open-File Report 80-1008



PROBABLE HIGH GROUND-WATER LEVELS IN MASSACHUSETTS

By Michael H. Frimpter

U.S. GEOLOGICAL SURVEY

Water Resources Investigations 80-1205

Open-File Report 80-1205

Prepared in cooperation with the

COMMONWEALTH OF MASSACHUSETTS

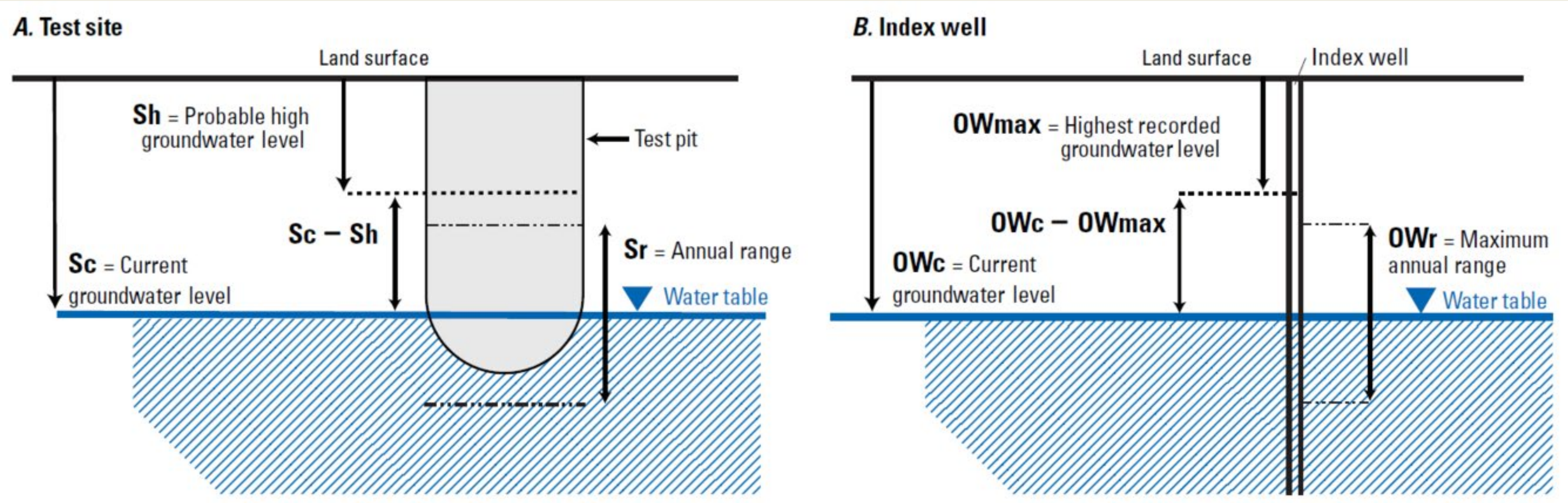
DEPARTMENT OF ENVIRONMENTAL QUALITY ENGINEERING

March 1981

The Frimpter Equation

$$Sh = Sc - \frac{Sr}{OWr}(OWc - OWmax)$$

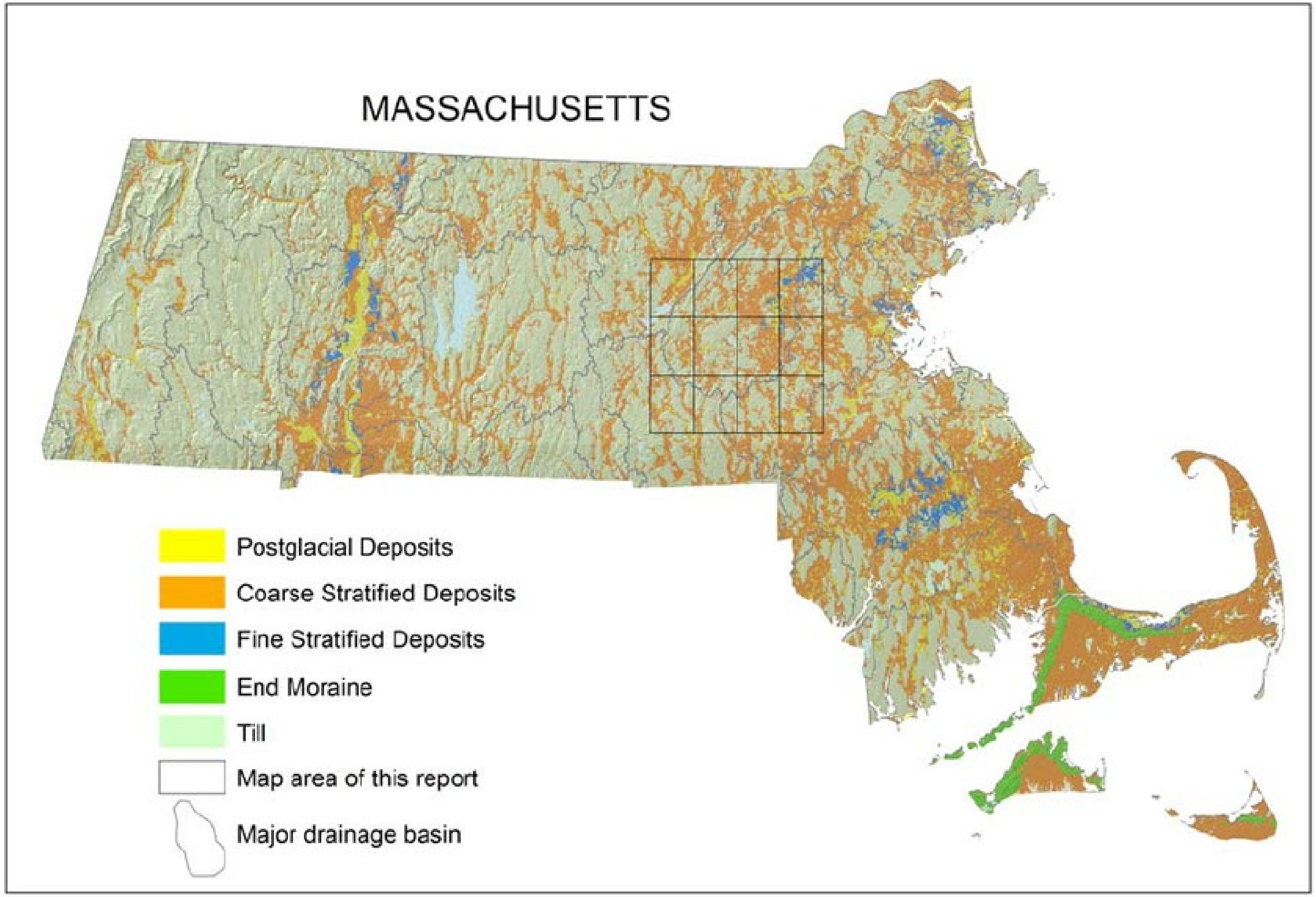
- Sh = the estimated depth below land surface to the high groundwater level
- Sc = measured depth to groundwater at site of interest
- Sr = estimated maximum annual range at the site of interest
- OWc = measured depth to groundwater at index well (same date)
- OWmax = recorded minimum depth to groundwater at index well
- OWr = maximum annual range in groundwater level at the index well



USGS

Surficial Geology

OWr varies by surficial geology and position in the landscape or setting



From Stone and Stone, 2006

Maximum annual range in water level in glacial till

Frimpter, 1981

Excluding Cape Cod

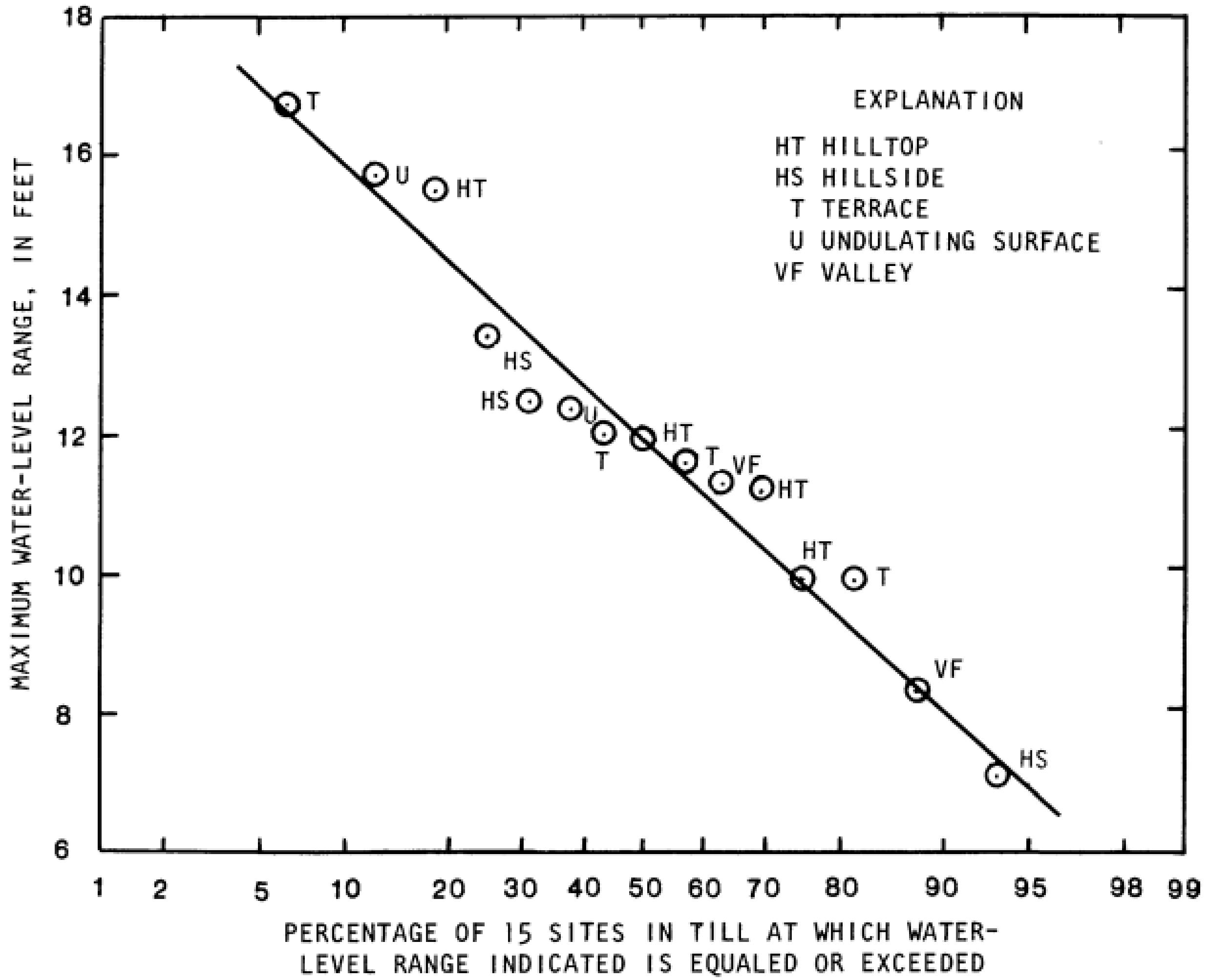


Figure 8.--Probability of water-level range in till

USGS

Maximum annual range in water level in stratified drift (sand and gravel)

Frimpter, 1981

Excluding Cape Cod

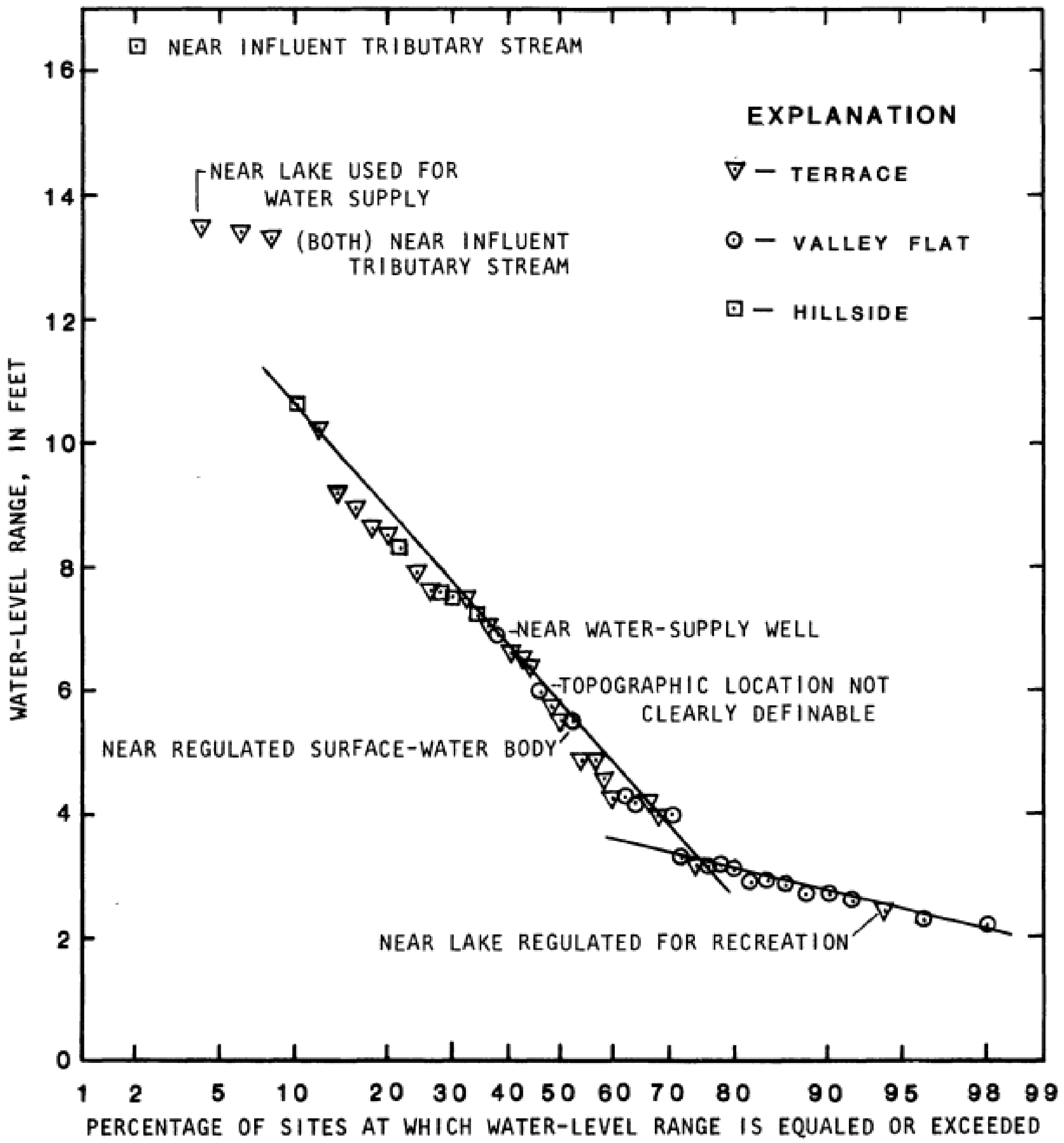


Figure 10.--Probability of water-level range in sand and gravel showing terrace and valley flat subgroups

USGS

Selection of Sr in the original Frimpter method

10 ft on sand and gravel and terraces

Excluding Cape Cod

Frimpter, 1981

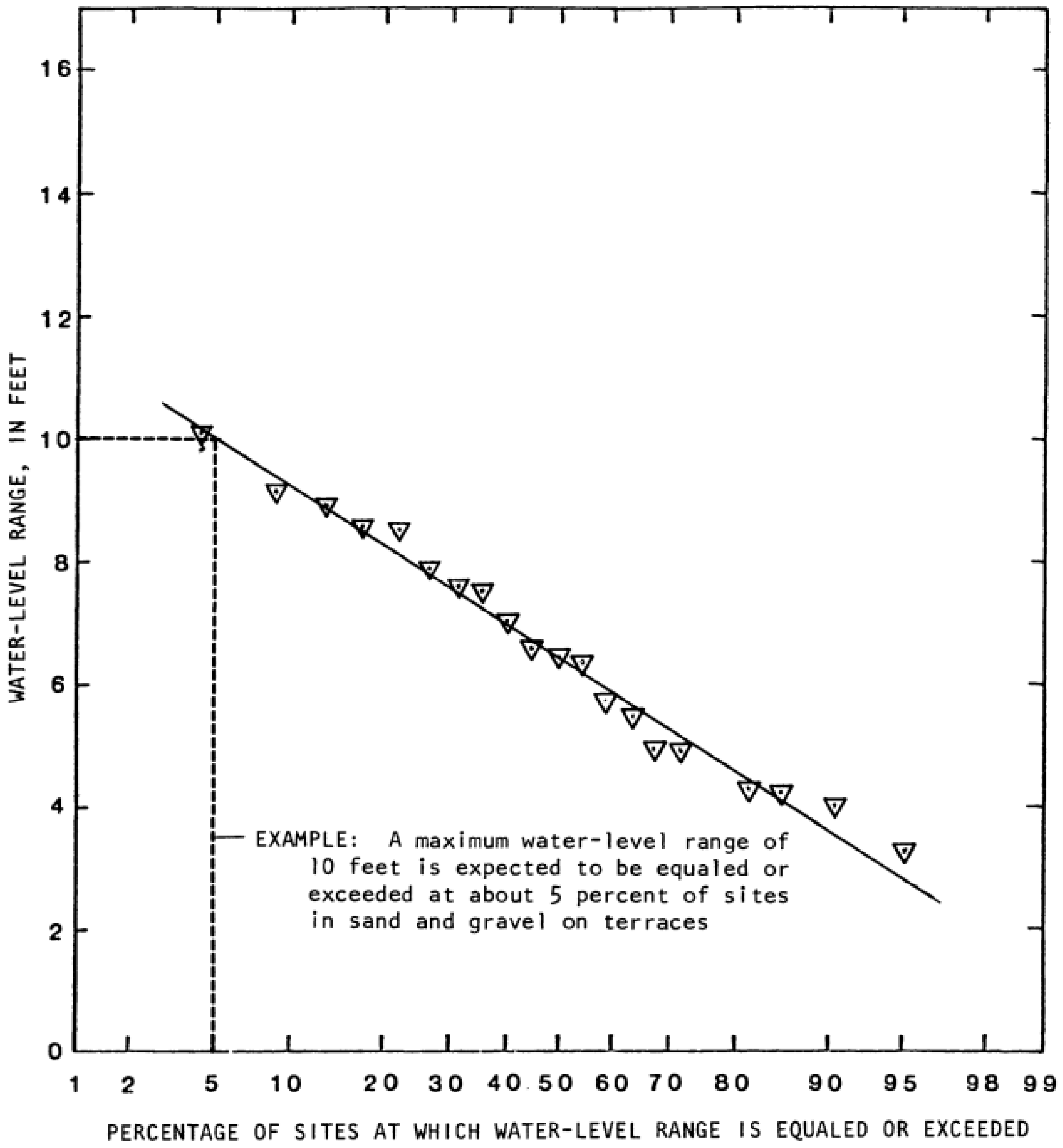


Figure 11.--Probability of water-level range in sand and gravel on terraces

Selection of Sr in the original Frimpter method

4.2 feet sand and gravel and on valley flats

Excluding Cape Cod

Frimpter, 1981

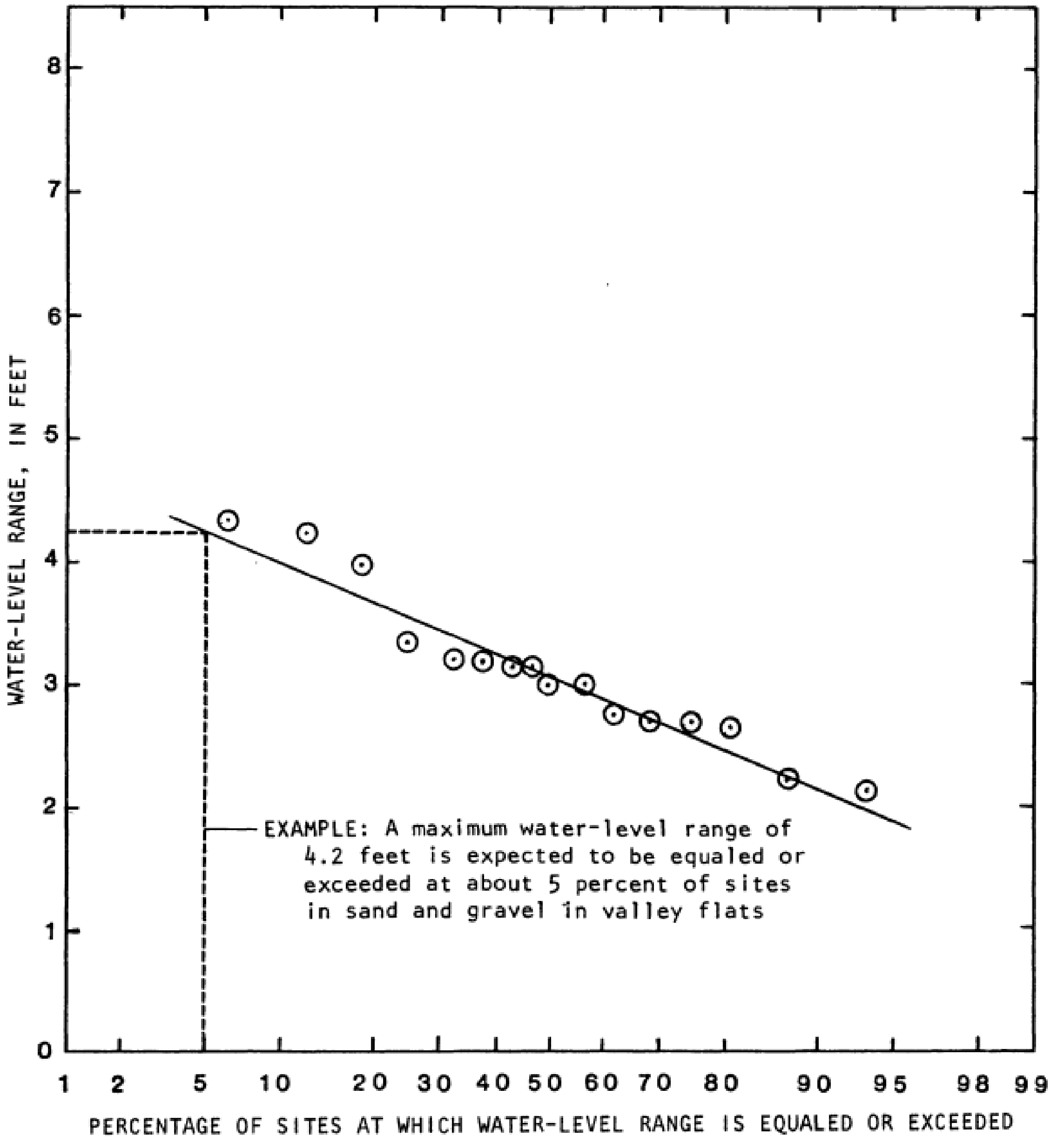


Figure 12.--Probability of water-level range in sand and gravel in valley flats

USGS 2020 report to evaluate and update the Frimpter method

Barclay and Mullaney, 2020

USGS

USGS
science for a changing world

Prepared in cooperation with the Massachusetts Department of Environmental Protection

Updating Data Inputs, Assessing Trends, and Evaluating a Method To Estimate Probable High Groundwater Levels in Selected Areas of Massachusetts

Scientific Investigations Report 2020–5036

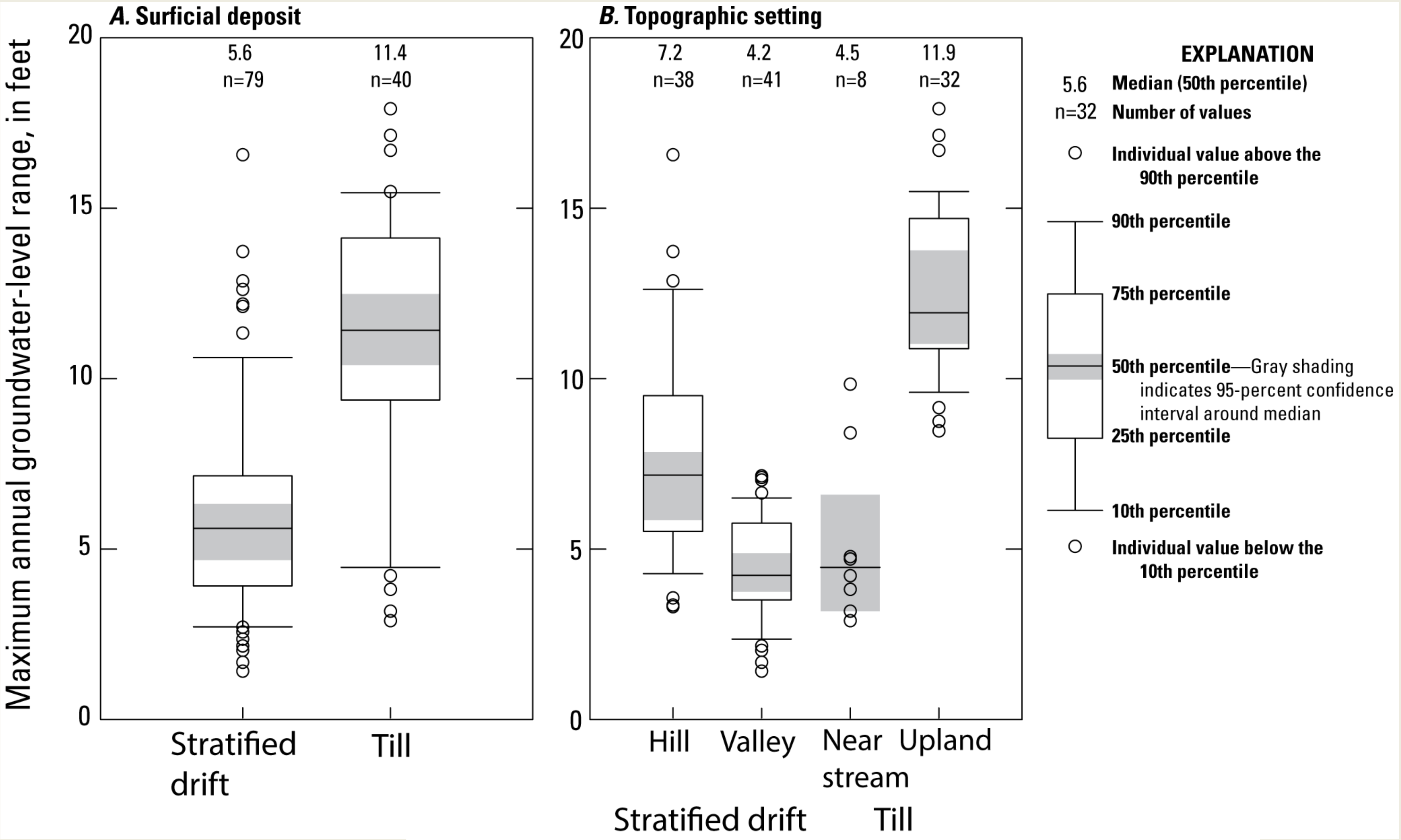
Annual range in updated Frimpter method

Based on Barclay and Mullaney (2020)

and

EXPLANATION OF Sr VALUE DETERMINATIONS USED IN MASSACHUSETTS FRIMPTER EQUATION Frimpter Equation Sr Values For Use In Massachusetts – Revised 10/1/24 (MassDEP)

Excluding Cape Cod

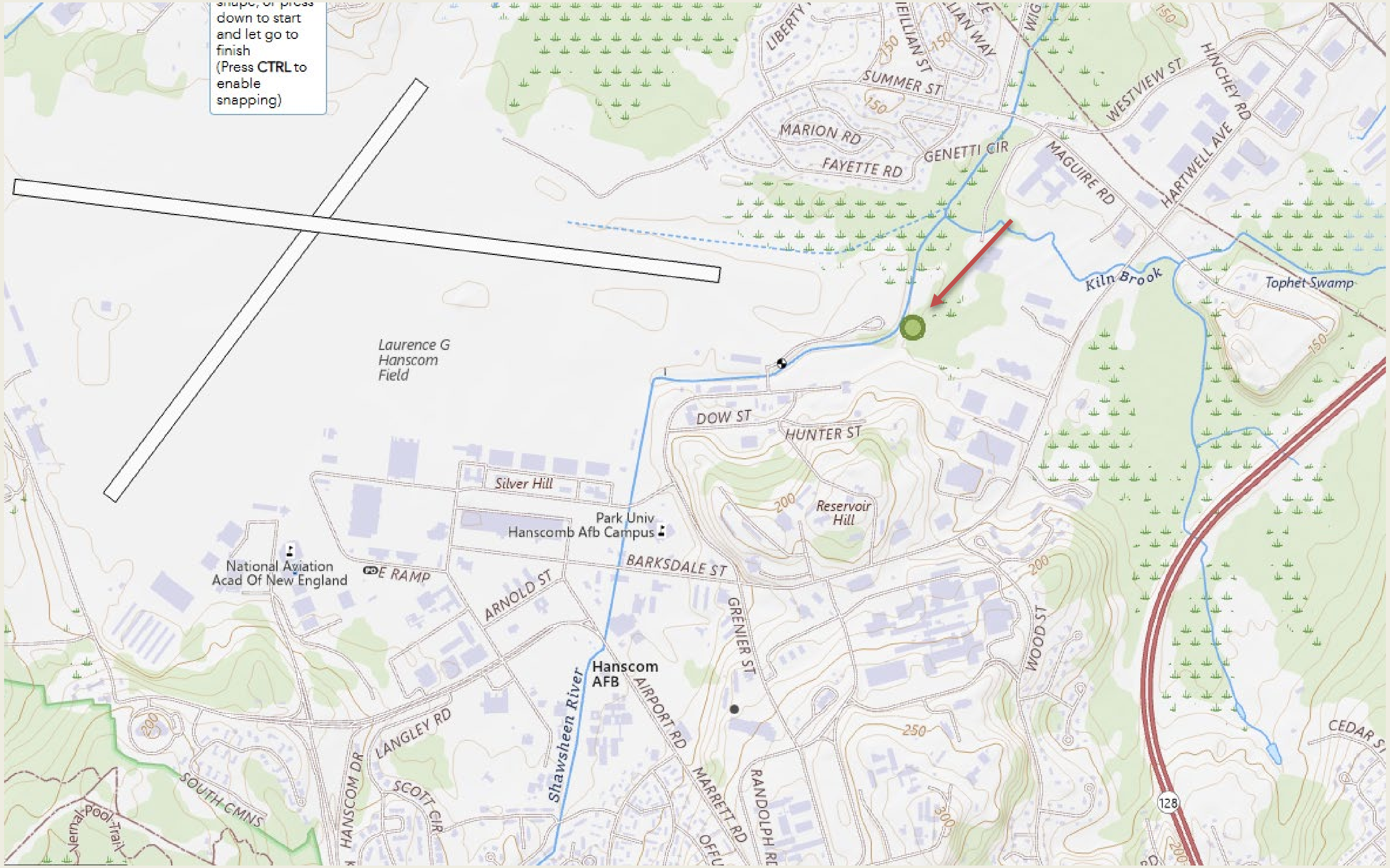


Updated Values from MassDEP analysis

OwMax and OWr	Sr
*90th pct	•Stratified drift hills: 7.96 feet
*90th pct	•Stratified drift in valleys: 4.25 feet
*90th pct	•Till near streams: 7.44 feet
100th pct (max)	•Till in uplands: 16.74 feet

USGS

Example High Groundwater Calculation Bedford, MA

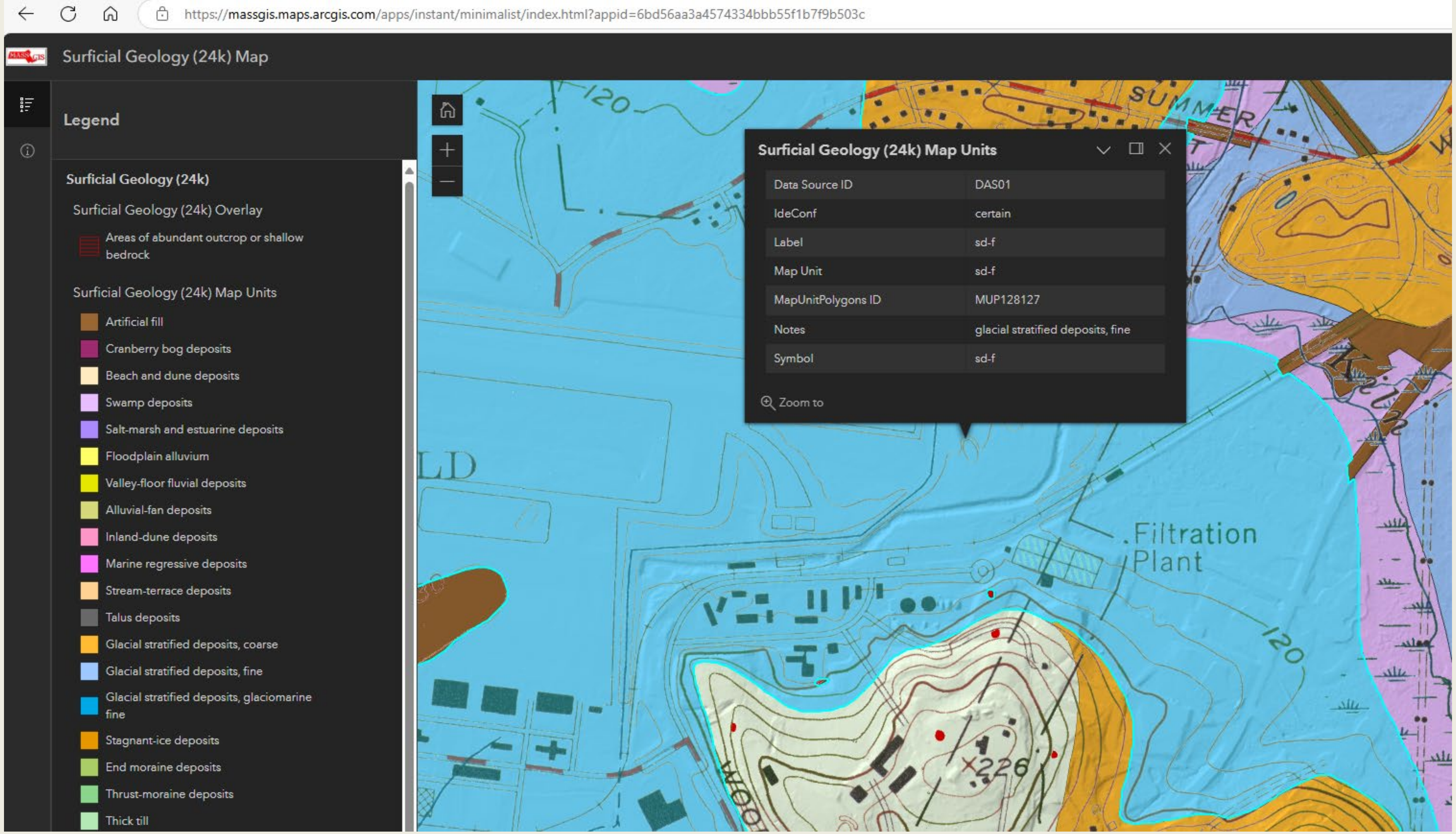


Sc = 10.90 feet below land surface on May 15, 2024

$$Sh = {\color{red}Sc} - \frac{Sr}{OWr}(OWc - OWmax)$$

USGS

Surficial Geology



[MassGIS Data: USGS 1:24,000 Surficial Geology | Mass.gov]

Stone and others (2018)

Choose stratified drift (valley) for well selection and Sr determination

USGS

Recently Updated Web Site with Values for Frimpter method
Closest well in same geology and setting is Lexington 104

https://rconnect.usgs.gov/MA-high_gw/MA_high_gw.html

An official website of the United States government Here's how you know

USGS science for a changing world

Determining High Groundwater Levels in Massachusetts

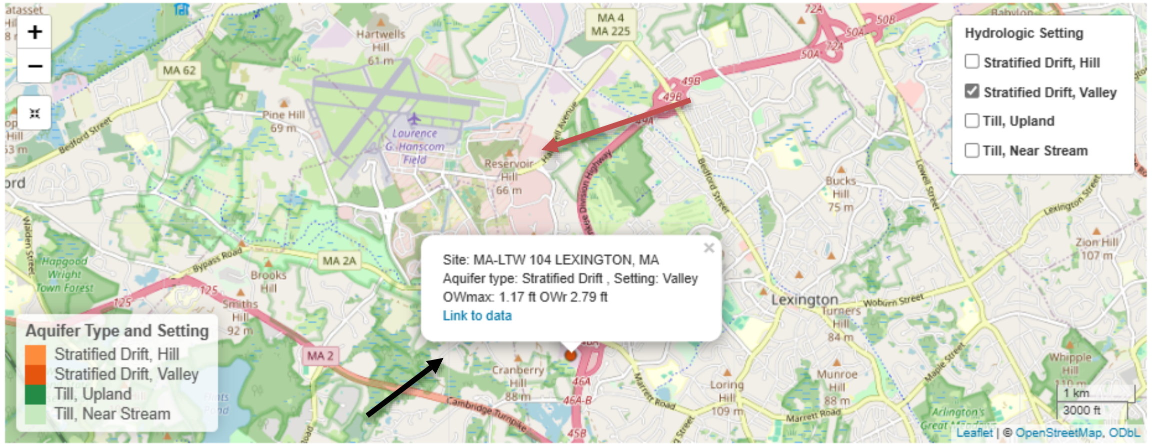
The map and table on this web page provide information on wells in the New England Observation-Well Network which have been used as index wells in the calculation of high groundwater levels, commonly known as the "Frimpter Method." Values of highest groundwater level, or the 90th percentile of groundwater levels (OWMax), and maximum or 90th percentile of annual range (OWr) in water level are based on monthly and daily measurements from the beginning of the record through **September 30, 2023.** Sr (the estimated annual range at a test site) values reported here are provided by the Massachusetts Department of Environmental Protection.

The original methodology for determination of high groundwater levels in mainland areas west of Cape Cod is in the report: Probable High Ground-Water Levels in Massachusetts. A more recent report: Updating Data Inputs, Assessing Trends, and Evaluating a Method To Estimate Probable High Groundwater Levels in Selected Areas of Massachusetts is also available through the USGS Publications Warehouse.

For Cape Cod, a slightly different method is used to estimate high groundwater levels.

The updated methodology for using the values shown below is available from MassDEP (external site).

Map



Copy Excel

Search: lexington

Table with statistics for use in estimation of high groundwater levels, [Values in feet below land surface datum, OWmax, high groundwater level used for particular setting; Sr, the estimated annual range at a test site (provided by the Massachusetts Department of Environmental Protection); OWr, maximum annual range or 90th percentile of the annual range, depending upon the setting; Start Date is the date of the first water-level measurement for the site; and Start Date (daily data) is the first day with continuously recorded data.] Statistics for these wells as of: 2023-09-30.

Site Number	Station Name	Aquifer Type	Setting	Start Date	Start Date (daily data)	Sr	OWmax	OWr	Link to Data
422627071154002	MA-LTW 104 LEXINGTON, MA	Stratified Drift	Valley	1964-12-01	2022-12-06	4.25	1.17	2.79	Link

Previous 1 Next

https://rconnect.usgs.gov/MA-high_gw/

$$Sh = Sc - \frac{Sr}{OWr}(OWc - OWmax)$$

Sr = 4.25, OWmax = 1.17, OWr = 2.79

https://waterdata.usgs.gov/nwis/dv?referred_module=sw&site_no=422627071154002

USGS 422627071154002 MA-LTW 104 LEXINGTON, MA

PROVISIONAL DATA SUBJECT TO REVISION

Available data for this site | Time-series: Daily data | GO

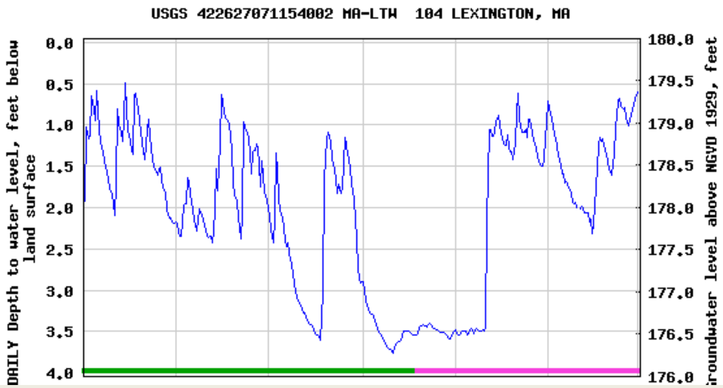
Click to hide station-specific text

NOTE: The precipitation data for this station are temporary and will only be displayed for 120 days.Time series of 15-minute or cumulative daily values WILL NOT be available for retrieval following the 120-day display period. Although the instrumentation is calibrated at least once/year, the temporary classification means that documtated routine inspections and other quality assurance measures are not performed that would make the data acceptable for archival, retrieval, or future use in general scientific or interpretive studies.

Available Parameters	Period of Record	Output format	Days (365)	
☐ All 1 Available Parameters for this site		○ Graph		GO
☑ 72019 Water level, depth LSD(Mean)	2022-12-06 2025-03-01	○ Graph w/ stats	-- or --	
		○ Graph w/ meas	Begin date 2024-03-01	
		○ Graph w/ (up to 3) parms		
		◉ Table	End date 2025-03-01	
		○ Tab-separated		
		○ Tab-separated w/ meas		

[Summary of all available data for this site](#)
[Instantaneous-data availability statement](#)

Depth to water level, feet below land surface



Add up to 2 more sites and replot for "Depth to water level, feet below land surface"

Add site numbers Note

Enter up to 2 site numbers separated by a comma. A site number consists of 8 to 15 digits

GO

https://waterdata.usgs.gov/nwis/dv?cb_72019=on&format=html&site_no=422627071154002&legacy=&referred_module=sw&period=&begin_date=2024-03-01&end_date=2025-03-01

Daily Mean Depth to water level, feet below land surface

DATE	Mar 2024	Apr 2024	May 2024	Jun 2024	Jul 2024	Aug 2024	Sep 2024	Oct 2024	Nov 2024	Dec 2024	Jan 2025	Feb 2025	Mar 2025
1	1.88[A]	1.20[A]	2.17[A]	0.72[A]	2.01[A]	3.52[A]	2.90[A]	3.50[A]	3.48[P]	1.10[P]	0.71[P]	1.77[P]	0.60[P]
2	1.92[A]	1.32[A]	2.20[A]	0.85[A]	2.10[A]	3.55[A]	3.01[A]	3.51[A]	3.52[P]	1.17[P]	0.80[P]	1.51[P]	
3	1.03[A]	1.35[A]	2.30[A]	0.92[A]	2.26[A]	3.58[A]	3.14[A]	3.53[A]	3.54[P]	1.23[P]	0.92[P]	1.24[P]	
4	1.10[A]	0.65[A]	2.35[A]	0.95[A]	2.42[A]	3.60[A]	3.18[A]	3.54[A]	3.54[P]	1.25[P]	1.02[P]	1.15[P]	
5	1.17[A]	0.61[A]	2.34[A]	1.01[A]	2.12[A]	3.34[A]	3.23[A]	3.54[A]	3.50[P]	1.12[P]	1.12[P]	1.19[P]	
6	1.13[A]	0.82[A]	1.98[A]	1.13[A]	1.34[A]	3.00[A]	3.27[A]	3.54[A]	3.49[P]	1.28[P]	1.16[P]	1.16[P]	
7	0.64[A]	0.95[A]	1.95[A]	1.31[A]	1.54[A]	1.66[A]	3.29[A]	3.52[P]	3.50[P]	1.33[P]	1.26[P]	1.30[P]	
8	0.80[A]	1.08[A]	1.95[A]	1.70[A]	1.89[A]	1.17[A]	3.33[A]	3.47[P]	3.50[P]	1.32[P]	1.37[P]	1.37[P]	
9	0.95[A]	1.21[A]	1.64[A]	1.84[A]	2.03[A]	1.08[A]	3.38[A]	3.43[P]	3.54[P]	1.42[P]	1.48[P]	1.43[P]	
10	0.59[A]	1.33[A]	1.69[A]	1.92[A]	2.13[A]	1.15[A]	3.42[A]	3.43[P]	3.53[P]	1.22[P]	1.59[P]	1.54[P]	
11	0.82[A]	1.41[A]	1.85[A]	2.12[A]	2.25[A]	1.19[A]	3.47[A]	3.42[P]	3.47[P]	0.85[P]	1.59[P]	1.57[P]	
12	1.06[A]	1.05[A]	2.02[A]	2.25[A]	2.40[A]	1.41[A]	3.51[A]	3.43[P]	3.48[P]	0.62[P]	1.70[P]	1.61[P]	
13	1.22[A]	0.93[A]	2.16[A]	2.38[A]	2.48[A]	1.46[A]	3.55[A]	3.45[P]	3.52[P]	0.91[P]	1.69[P]	1.35[P]	
14	1.33[A]	1.14[A]	2.22[A]	2.10[A]	2.43[A]	1.65[A]	3.59[A]	3.41[P]	3.50[P]	1.02[P]	1.72[P]	1.03[P]	
15	1.43[A]	1.27[A]	2.29[A]	0.96[A]	2.55[A]	1.82[A]	3.62[A]	3.40[P]	3.47[P]	1.08[P]	1.79[P]	0.90[P]	
16	1.52[A]	1.41[A]	2.16[A]	1.07[A]	2.69[A]	1.72[A]	3.65[A]	3.42[P]	3.48[P]	1.09[P]	1.82[P]	0.70[P]	
17	1.56[A]	1.50[A]	2.01[A]	1.09[A]	2.82[A]	1.78[A]	3.68[A]	3.45[P]	3.50[P]	1.06[P]	1.93[P]	0.68[P]	
18	1.67[A]	1.58[A]	2.10[A]	1.18[A]	2.91[A]	1.83[A]	3.70[A]	3.47[P]	3.49[P]	1.15[P]	1.96[P]	0.77[P]	
19	1.76[A]	1.61[A]	2.16[A]	1.34[A]	3.03[A]	1.76[A]	3.72[A]	3.48[P]	3.48[P]	0.93[P]	1.93[P]	0.80[P]	
20	1.84[A]	1.54[A]	2.21[A]	1.59[A]	3.08[A]	1.15[A]	3.75[A]	3.48[P]	3.49[P]	0.93[P]	2.00[P]	0.79[P]	
21	1.97[A]	1.51[A]	2.28[A]	1.33[A]	3.13[A]	1.25[A]	3.77[A]	3.49[P]	3.45[P]	1.01[P]	---	0.90[P]	
22	2.09[A]	1.67[A]	2.34[A]	1.31[A]	3.19[A]	1.35[A]	3.70[A]	3.51[P]	2.15[P]	1.18[P]	2.02[P]	0.97[P]	
23	1.71[A]	1.76[A]	2.36[A]	1.23[A]	3.23[A]	1.41[A]	3.66[A]	3.51[P]	1.06[P]	1.25[P]	1.98[P]	1.01[P]	

OWc =
2.29

$$Sh = Sc - \frac{Sr}{OWr}(OWc - OWmax)$$

Calculating High Groundwater

$$Sh = Sc - \frac{Sr}{OWr}(OWc - OWmax)$$

- Sh = the estimated depth below land surface to the high groundwater level
- Sc = measured depth to groundwater at site of interest
- Sr = estimated maximum annual range at the site of interest
- OWc = measured depth to groundwater at index well (same date)
- OWmax = recorded minimum depth to groundwater at index well
- OWr = maximum annual range in groundwater level at the index well

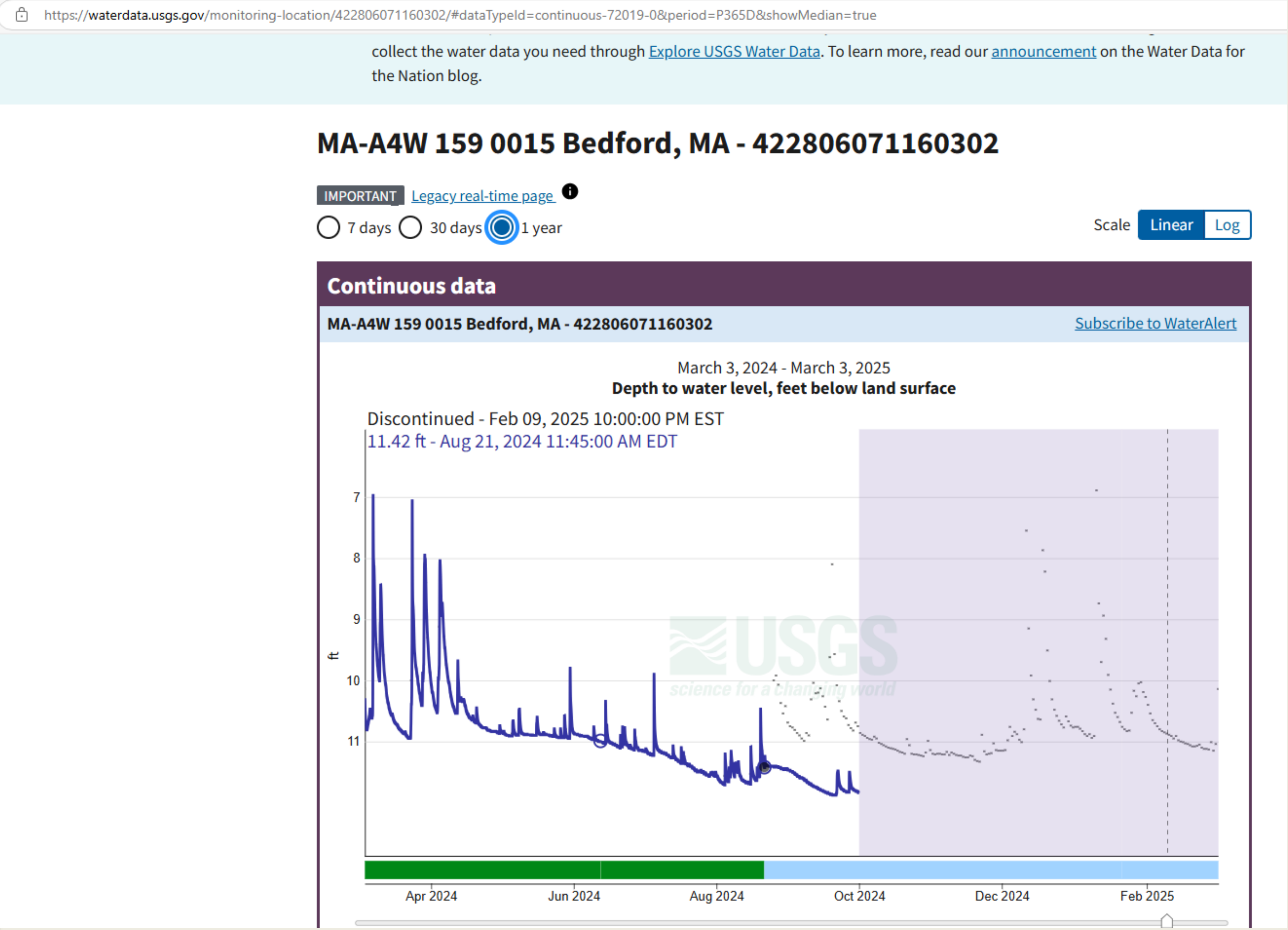
$$Sh = 10.90 - \frac{4.25}{2.79}(2.29 - 1.17)$$

Sh = 9.19 ft below land surface

USGS

Groundwater-Level Measurements at site

https://waterdata.usgs.gov/monitoring-location/422806071160302/#dataTypeId=continuous-72019-0&period=P365D&showMedian=true

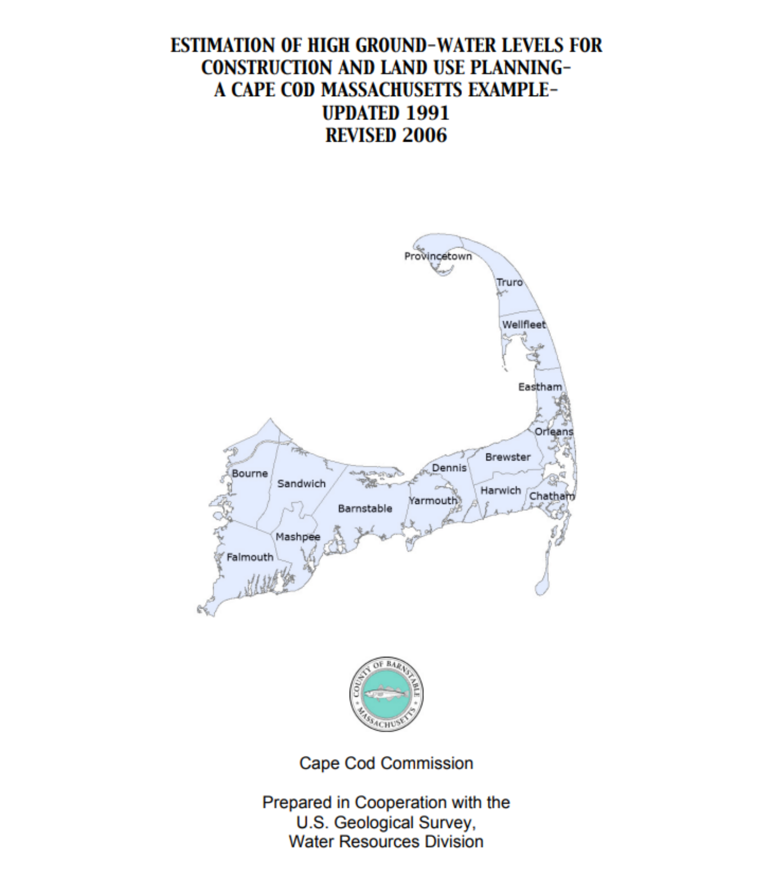


USGS

Frimpter Method Use on Cape Cod

Frimpter and Belfit, 2006

- Sr values determined from mapped zones of annual range with polygons associated with each index well



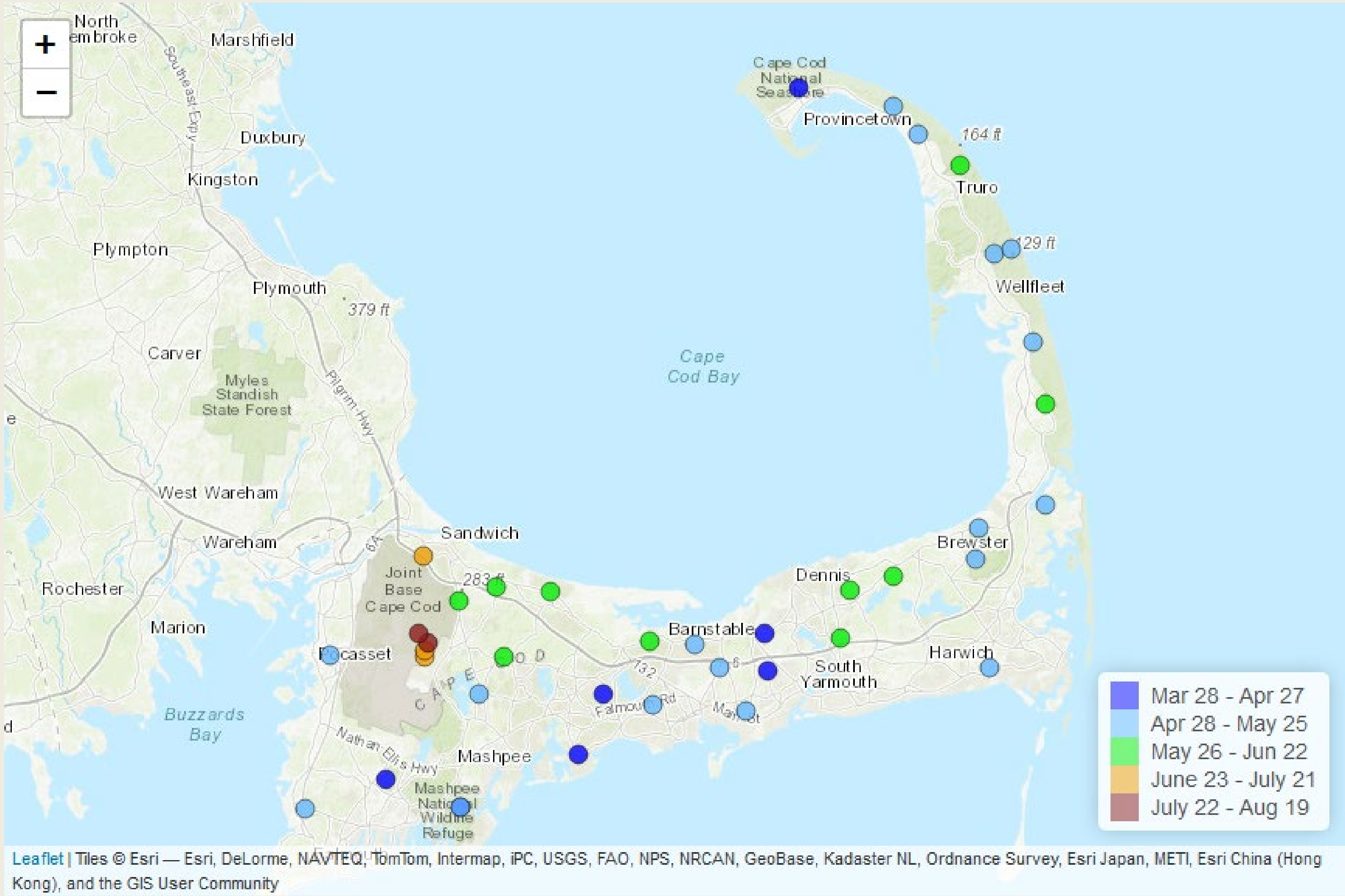
USGS

Median Timing of High Groundwater Levels 2004 - 2023

Typical timing of high groundwater varies considerably Factors include:

Position in the flow system (within or edge of lens or near coast)

Unsaturated-zone thickness



Preliminary Information-Subject to Revision. Not for Citation or Distribution.

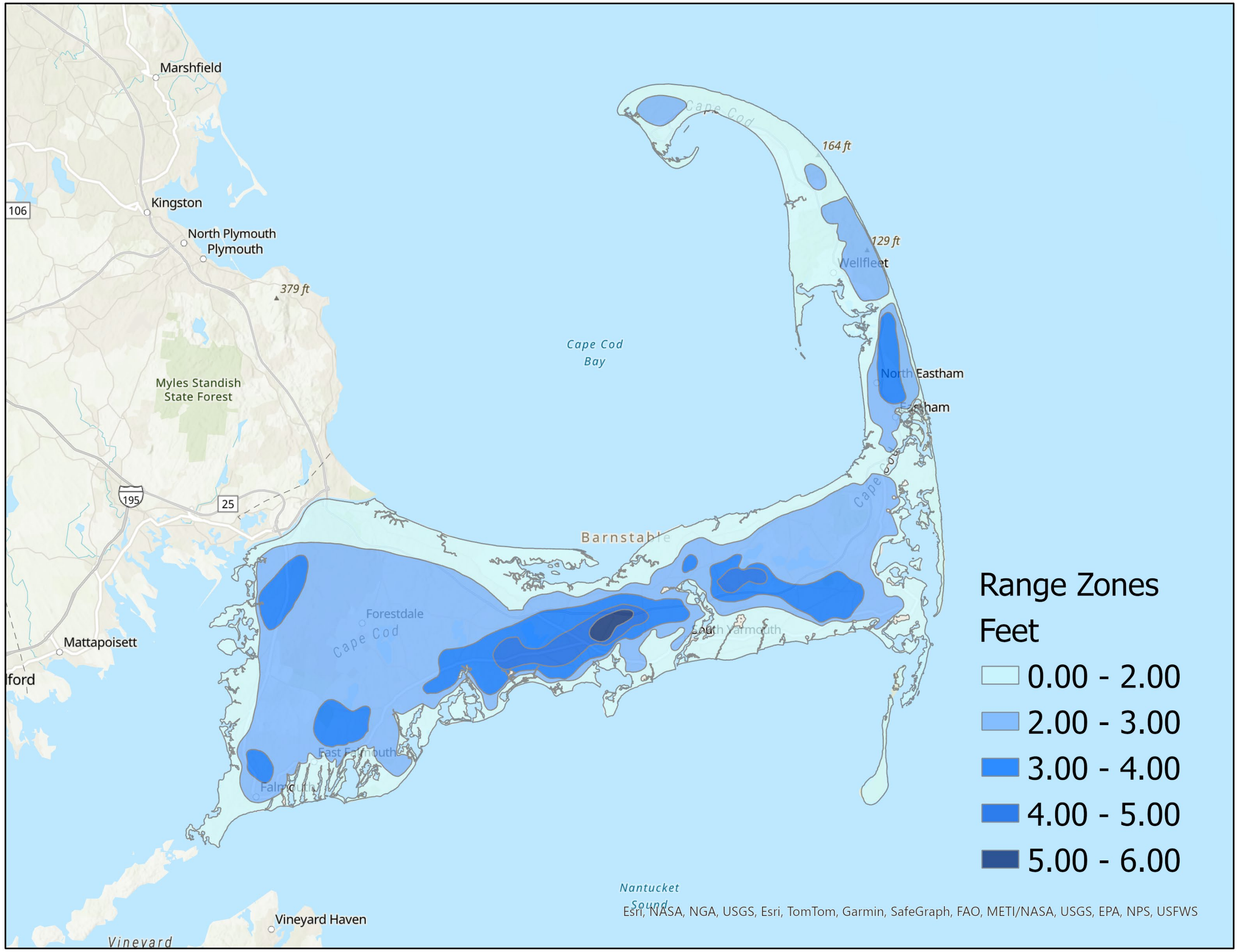
USGS

Zones of GW Level Range and Index Wells

The Upper Limits of the Range in these zones is used as Sr in the Frimpter Equation

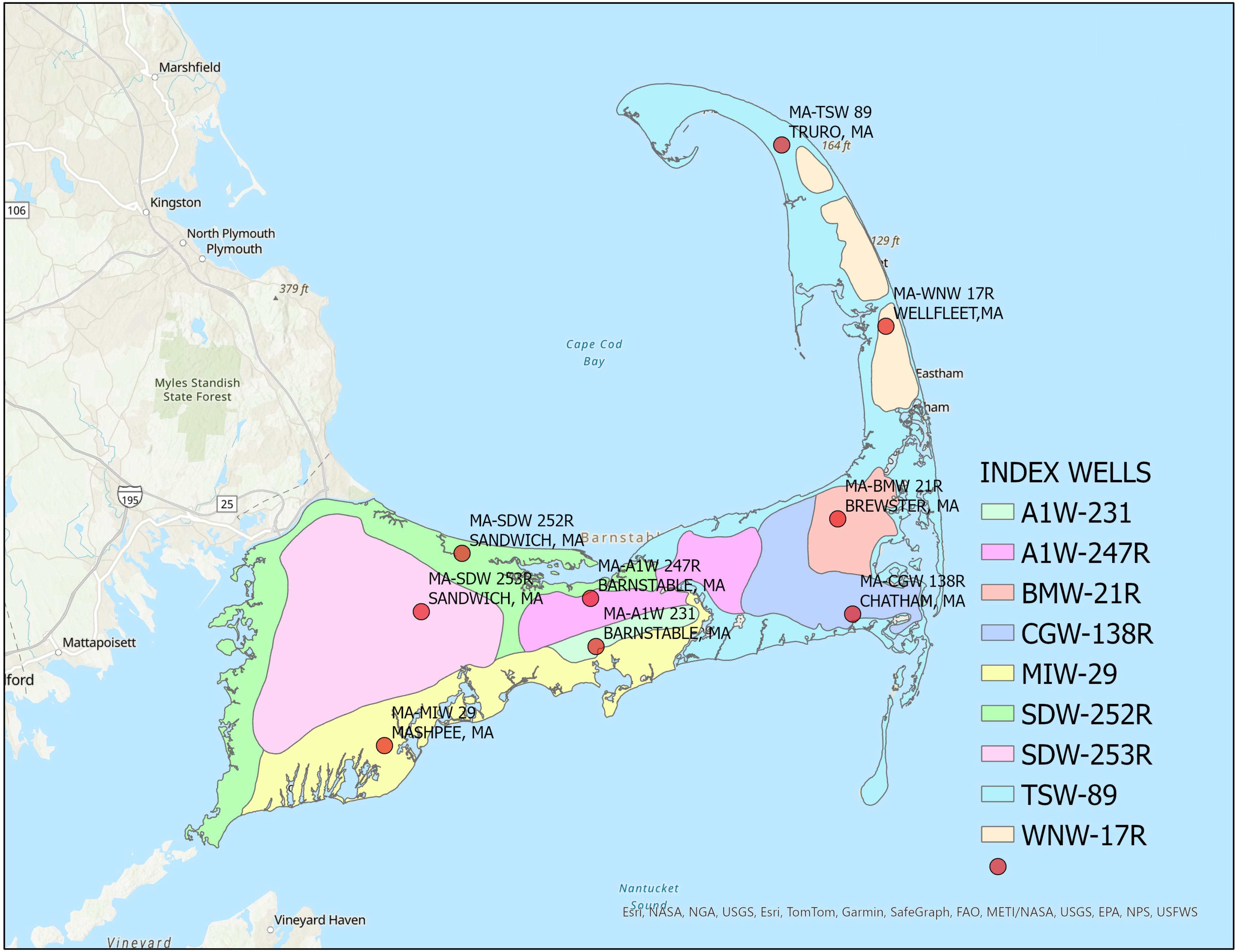
Zone	Sr (ft)
A	2
B	3
C	4
D	5
E	6

Frimpter and Fischer, 1983



USGS

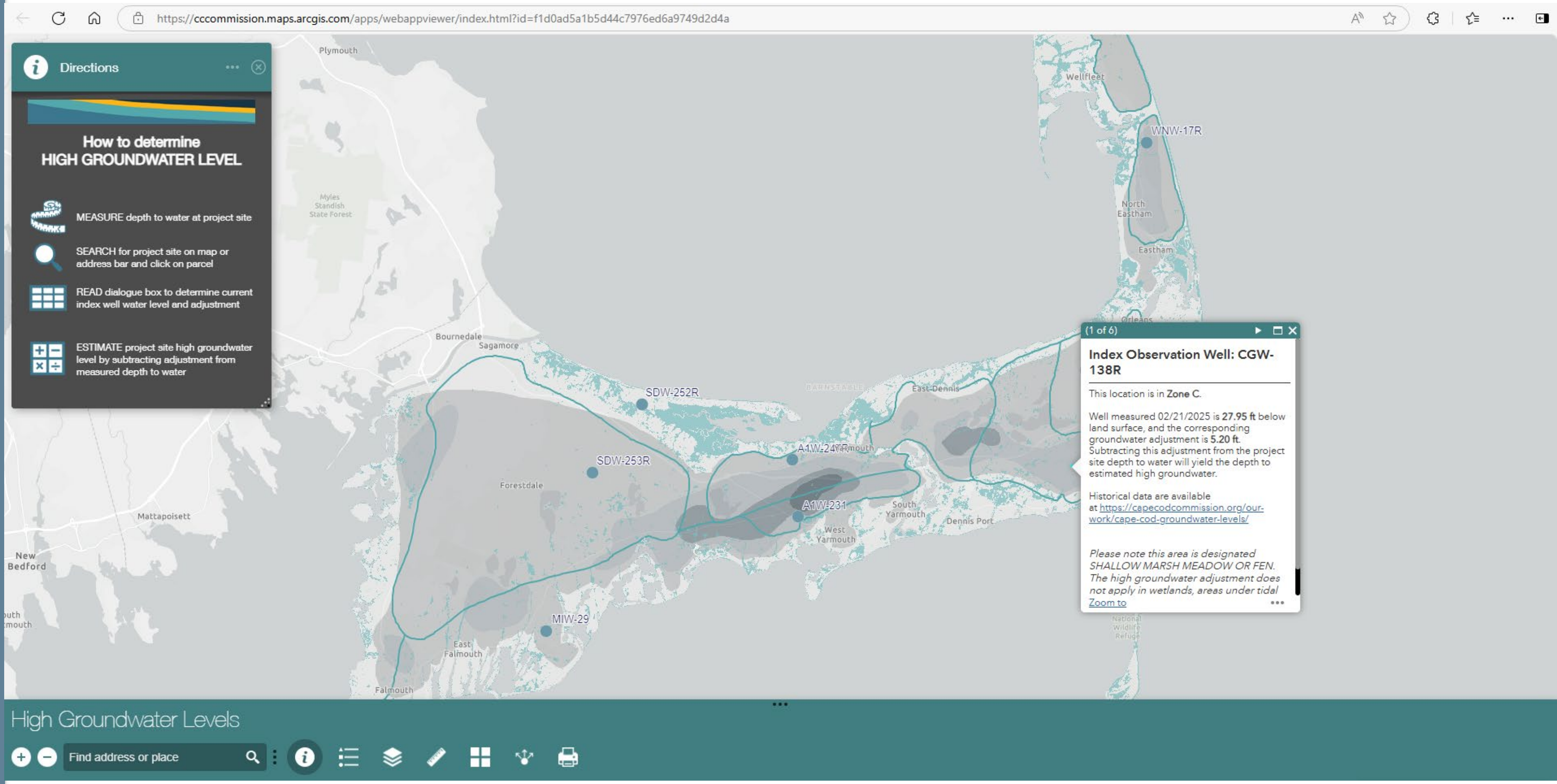
Zones for USGS Index Wells



Frimpter and Fischer, 1983

USGS

Cape Cod Commission Web Tool



https://www.capecodcommission.org/our-work/estimating-high-groundwater-levels/

USGS

Frimpter report and tables

ESTIMATION OF HIGH GROUND-WATER LEVELS FOR CONSTRUCTION AND LAND USE PLANNING- A CAPE COD MASSACHUSETTS EXAMPLE-
UPDATED 1991
REVISED 2006

Cape Cod Commission

Prepared in Cooperation with the
U.S. Geological Survey,
Water Resources Division

Potential Water-Level Rise (feet) for Index Well- Reference Table

Following Technical Bulletin 92-001, estimations of high groundwater levels are needed for construction and land use planning on Cape Cod. Using the appropriate index well and water-level range zone, water-level adjustment is provided, defined as Step 4 in the High Ground Water-Level Computation Form.

Index Well: **AIW231**

Index Well Depth to Water (feet below land surface)	Water-Level Range Zone Adjustments (ft)				
	Zone A	Zone B	Zone C	Zone D	Zone E
24.1	0	0	0	0	0
24.2	0.1	0.1	0.1	0.1	0.2
24.3	0.1	0.1	0.2	0.3	0.3
24.4	0.2	0.2	0.3	0.4	0.5
24.5	0.2	0.3	0.4	0.5	0.6
24.6	0.3	0.3	0.5	0.7	0.8
24.7	0.3	0.4	0.6	0.8	0.9
24.8	0.4	0.5	0.7	0.9	1.1
24.9	0.4	0.5	0.8	1.1	1.2
25.0	0.5	0.6	0.9	1.2	1.4
25.1	0.5	0.7	1	1.3	1.5
25.2	0.6	0.7	1.1	1.5	1.7
25.3	0.6	0.8	1.2	1.6	1.8
25.4	0.7	0.9	1.3	1.7	2
25.5	0.7	0.9	1.4	1.9	2.1
25.6	0.8	1	1.5	2	2.3
25.7	0.8	1.1	1.6	2.1	2.4
25.8	0.9	1.1	1.7	2.3	2.6
25.9	0.9	1.2	1.8	2.4	2.7
26.0	1	1.3	1.9	2.5	2.9
26.1	1	1.3	2	2.7	3
26.2	1.1	1.4	2.1	2.8	3.2
26.3	1.1	1.5	2.2	2.9	3.3
26.4	1.2	1.5	2.3	3.1	3.5
26.5	1.2	1.6	2.4	3.2	3.6
26.6	1.3	1.7	2.5	3.3	3.8
26.7	1.3	1.7	2.6	3.5	3.9
26.8	1.4	1.8	2.7	3.6	4.1
26.9	1.4	1.9	2.8	3.7	4.2
27.0	1.5	1.9	2.9	3.9	4.4
27.1	1.5	2	3	4	4.5
27.2	1.6	2.1	3.1	4.1	4.7
27.3	1.6	2.1	3.2	4.3	4.8

$$\mathrm{Sh} = \mathrm{Sc} - \underbrace{\frac{\mathrm{Sr}}{\mathrm{OWr}}(\mathrm{OWc} - \mathrm{OWmax})}_{\text{“Water-Level Adjustment”}}$$

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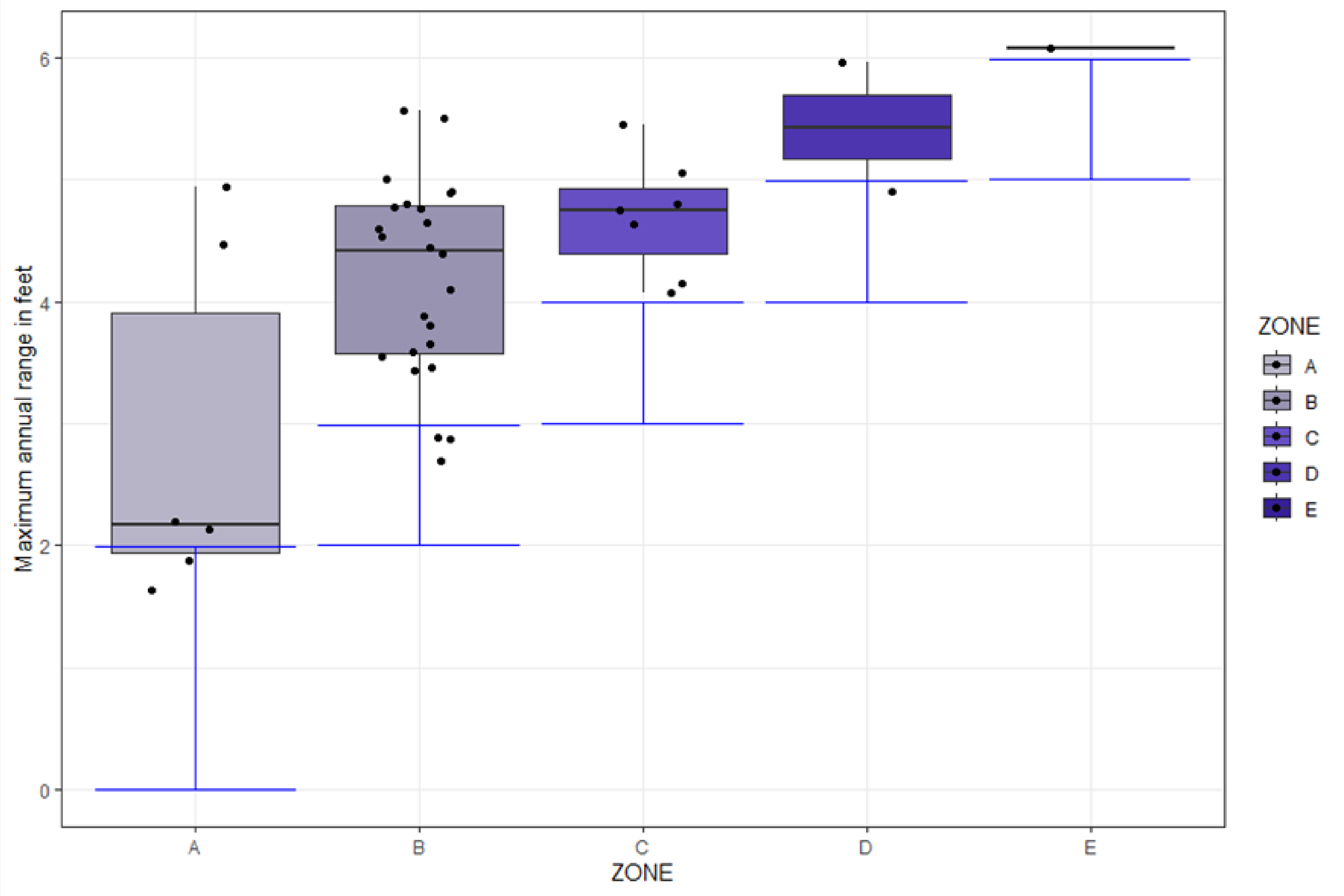
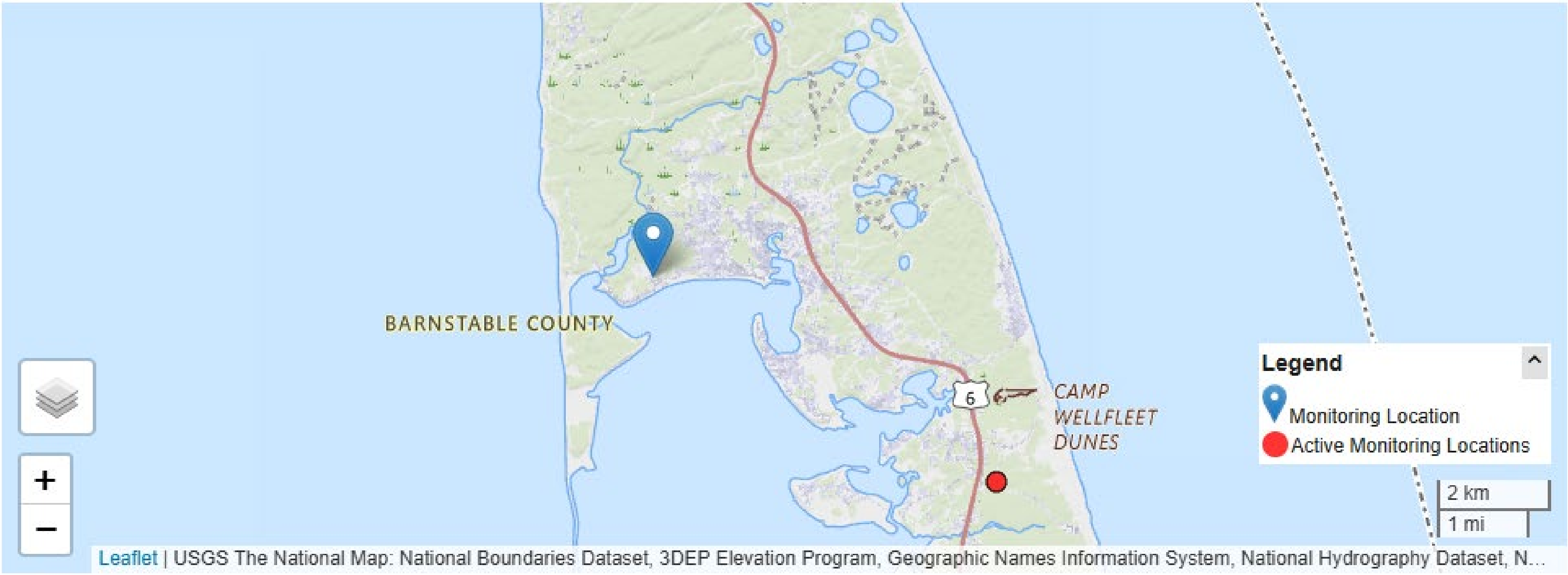
Evaluation of the Frimpter Method on Cape Cod

- Discussing possible update with the Cape Cod Commission
  - Statistics for OWmax and OWr need updating
  - Mapped ranges don't match data in zones
  - Would be good to re-visit the zones for Sr
- Currently used method is lacking detailed documentation
- Method detail needed in areas close to the coastline



USGS

Example to illustrate the challenges of using the Frimpter method in coastal areas



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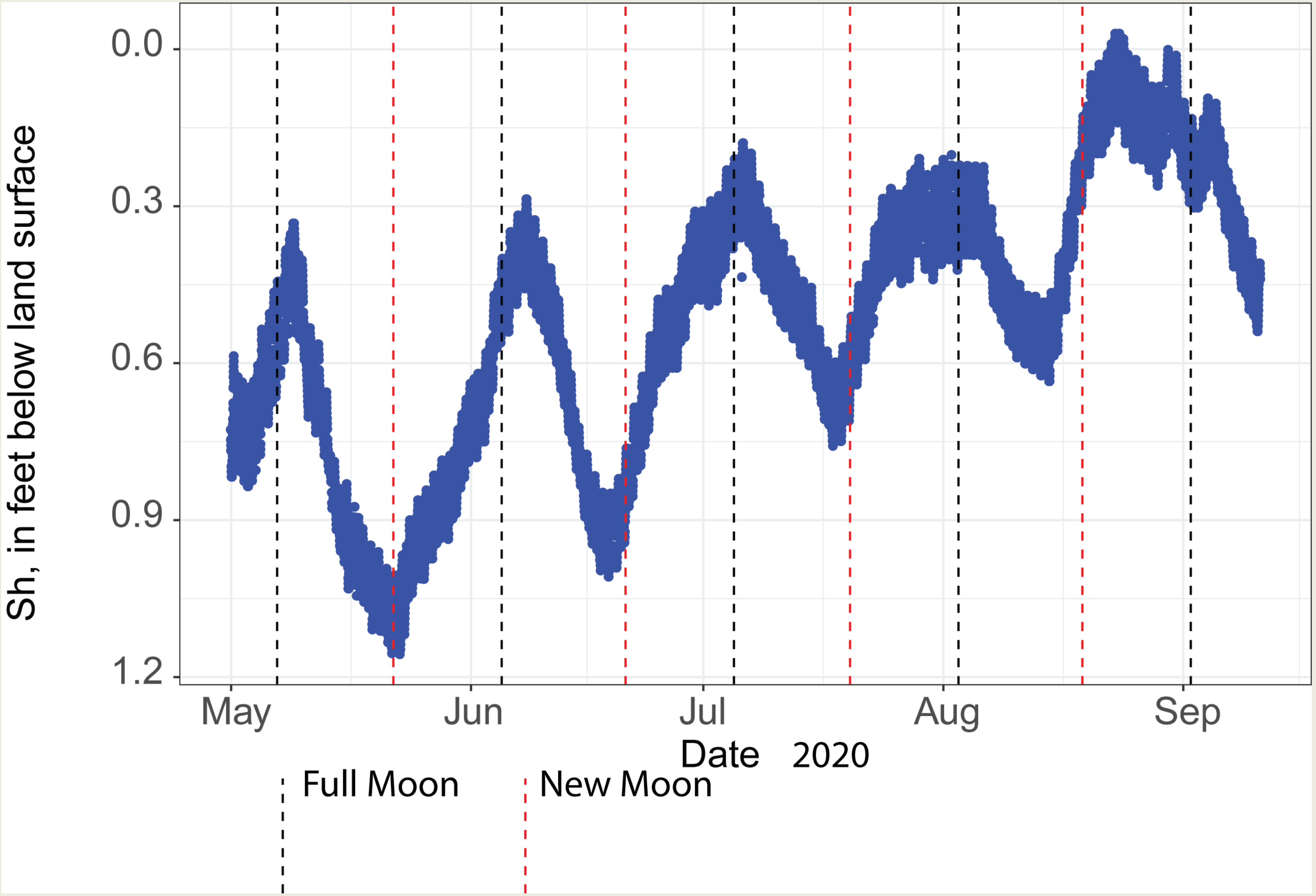
Frimpter method in near-coast areas

- Sh calculations using 15-minute data at a tidal groundwater site



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Questions?

Stratified Drift – Valley Setting

Links to information on the methods to determine high groundwater levels and data sources

- USGS New England Water Science Center
- Updating Data Inputs, Assessing Trends, and Evaluating a Method To Estimate Probable High Groundwater Levels in Selected Areas of Massachusetts
- Determining High Groundwater Levels in Massachusetts (recent updates, latest values to use on Massachusetts Mainland here)
  - MassDEP guidance for changes to the Frimpter Method
- Massachusetts Surficial Geology
- Groundwater Levels in New England
- Cape Cod Commission – High Groundwater Levels

- Historical Reports on Methods of Estimating High Groundwater in Massachusetts
  - Probable high ground-water levels in Massachusetts
  - ESTIMATION OF HIGH GROUND-WATER LEVELS FOR CONSTRUCTION AND LAND USE PLANNING, CAPE COD MASSACHUSETTS UPDATED 1991, REVISED 2006

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