CURRENT WATER RESOURCES CONDITIONS and FRIMPTER METHOD INPUT PARAMETERS

United States Geologic Survey (USGS) Website:
For groundwater data measured from wells throughout Massachusetts, including Real-Time, Active, and Historical information, and to find the current conditions, type in this link below which will take you directly there: https://newengland.water.usgs.gov/web_app/GWW/GWW.html

A map of New England wells will come up showing the general range of water levels relative to normal conditions. Make sure in the legend in the upper right-hand corner of the map that the only well types to be checked off are the first two. "Continuous, Climate Response Network" and "Periodic, Climate Response Network." In order to obtain detailed measurements and monthly averages for a particular well, simply click on the well and then click on the link "see site graph and statistics" for the graph that shows the current conditions. If you click on the link on that page listed as "View Data on Monitoring Location Page," you will get the actual measurements over time by hovering your cursor over the measurements.

Frimpter Method Input Parameters
In order to obtain groundwater level information for use in the Frimpter Method to calculated the estimated seasonal high groundwater level, type in this link: https://rconnect.usgs.gov/MA-high_gw/ Click on the nearest well in the same geologic formation as at the site and a pop-up box will appear with the aquifer type, OWmax, and OWr values. These values are also included in a table as you scroll down the page and include the Sr value as well. Click on the "link to data" for more information. A slightly different methodology is applied to sites on Cape Cod. Select this link for a step-by-step menu on how to determine estimated seasonal high groundwater for Cape Cod and Island wells: Estimating High Groundwater Levels | Cape Cod Commission.

EXPLANATION OF Sr VALUE DETERMINATIONS USED IN MASSACHUSETTS FRIMPTER EQUATION

Frimpter Equation Sr Values For Use In Massachusetts – Revised 10/1/24

Statement of Purpose: Evaluation of Scientific Investigations Report 2020-5036 "Updating Data Inputs, Assessing Trends, and Evaluating a Method to Estimate Probable High Groundwater Levels in Selected Areas of Massachusetts" for the purpose of recommending Sr, OWr, and OWmax values for use in the Frimpter Equation.

Background

In a 1980 report by Michael Frimpter, titled Probable High Ground-Water Levels on Cape Cod, Massachusetts – Open File Report 80-1008, a methodology was presented to estimate probable high groundwaters in Massachusetts. This method is based on the theory that the ratio of the rise from current to probable high groundwater divided by the estimated maximum annual groundwater level range at a site of interest is equal to

the ratio of the rise from current to recorded high groundwater divided by the maximum recorded annual groundwater-level range at an index well. The method uses a groundwater measurement from an observation well at a test site, groundwater measurements from an index well in the USGS Climate Response Network of observation wells, and a distribution of maximum annual groundwater-level ranges from wells in similar geologic and topographic settings. The estimated depth to probable high groundwater for the observation well at the test site can be expressed mathematically as follows (all units are in feet):

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

Where: Sh = estimated depth below ground surface (bgs) to probable high groundwater level at the site
Sc = measured depth bgs to groundwater at the site
Sr = estimated upper limit of the annual range of groundwater levels in a particular zone where the site is located
OWc = measured depth bgs to groundwater in the index well (collected on the same day that Sc is measured) which is used to correlate with the water levels at the site
OWmax = recorded minimum depth bgs to groundwater level at the index well which is used to correlate with the water levels at the site
OWr = recorded upper limit of annual range of groundwater levels at the index well which is used to correlate with the water levels at the site

All of the equation variables with the exception of Sr can be determined from either published scientific data or observed groundwater levels at the site of interest. Sr, the range of water level fluctuation at the site of interest, is determined by regression analysis by which the maximum range of water levels for wells in similar geographic or geohydrologic environments were arranged in ascending order of magnitude and plotted against their percentage of the total number of wells in that environment. Historically Sr has been determined by using a 5% exceedance value (i.e., a value exceeding 95% of all other values) for a given regression curve for the three different groups of wells evaluated in Frimpter's 1980 report (wells located in till, sand and gravel wells located in valley flats, and sand and gravel wells located on terraces).

In a 2020 report by the USGS, titled Updating Data Inputs, Assessing Trends, and Evaluating a Method to Estimate Probable High Groundwater Levels in Selected Areas of Massachusetts – (Janet Barclay and John Mullaney) SIR 2020-5036, the Frimpter Method was updated by evaluating the potential changes to the method resulting from forty years of additional groundwater-level data and the expansion of the network of wells for monitoring groundwater levels. The report analyzed groundwater levels from 153 wells, 119 of which were included in the final list. For analyses, wells were grouped by surficial deposit (glacial till or stratified drift) and topographic setting. Two broad topographic-settings were used for the till wells (near stream and upland) and two groups were used for the stratified-drift wells (valley and hill). Note that till wells near streams were not evaluated in the 1980 report.

Implementation of the Frimpter method requires an estimate of the annual groundwater-level range from a distribution of the maximum annual groundwater-level ranges for wells in similar geologic and topographic settings. Historically Sr has been estimated by using the value representing the 95th percentile of the maximum range values for the three different groups of wells evaluated in the 1980 report (sand and gravel wells located in

valleys, sand and gravel wells located on terraces, and wells located in till). This resulted in an Sr value of 4.2 ft. for sand and gravel wells located in valley flats, 10 ft. for sand and gravel wells located on terraces, and 17 ft. for wells located in till. In this study, the distribution of maximum groundwater-level ranges was updated with an additional 40 years of water level data. Distributions of the 90th-percentile of annual groundwater-level ranges were also generated for each of the four different groups of wells evaluated (glacial till wells located near stream and in upland areas, and stratified-drift wells located in valleys and upland areas). The 90th-percentile of annual ranges distribution filters out water years with the largest water-level ranges which avoids the use of annual ranges that may have been anomalously high.

Assessment of Proposed Revisions to Frimpter Method

Based on the data presented in the 2020 report, Drinking Water Program's Technical Services was tasked with determining acceptable Sr values for each of the four well groups. The focus of that assessment was comparing the percent of wells failing to predict high water level at specific percentages of the chronological period of record for specific vertical height thresholds above the predicted depth to probable high groundwater (Sh). These calculations were conducted using the USGS index wells as the sites of interest for calculating Sh. Failure rates for each well group were assessed for Sh calculations using Sr values selected for each well group from a) the maximum range values (maximum OWr values), and b) the 90th percentile of maximum range values (Per90) (90th percentile of OWr values) for that well group. For both the maximum annual range of values and the Per90 annual range of values, the failure rates were determined for the following exceedance values: 95th percentile, 85th percentile and 75th percentile of the maximum and Per90 annual range values.

For each of the four well groups, the individual Frimpter calculations of Sh for the maximum annual range of values approach used Sr values selected from a plot of the maximum OWr values; the maximum OWr value for the selected index well; and the shallowest recorded depth to groundwater level for the index well for OWmax. The Sh calculations for the Per90 annual range of values approach used Sr values selected from a plot of the 90th percentile OWr values; the 90th percentile OWr value for the selected index well; and the 90th percentile shallowest recorded depth to groundwater level for the index well as the OWmax value (i.e. 90% of recorded water levels are deeper than the 90th percentile shallowest recorded depth to groundwater level.

The assumption was that any well with any observed depth to water level of less than 6 feet would require a mounded soil absorption system (SAS) to maintain the minimum required vertical separation distance between the bottom of the SAS and the actual depth to high water level. Wells with no observed depths to water of less than 6 feet were assumed to never fail to meet the minimum required 4-foot vertical separation distance between the bottom of the SAS and high water level regardless of the calculated Sh value [i.e. assumptions are that ground surface will not be lowered upon completion of construction and base of SAS will be approximately 2 feet below existing pre-construction (and post-construction) ground surface]. The percent of wells in any well group failing to meet any of the selected criteria represent the percent of all wells in that well group (both wells that would have required a mounded SAS system and those that would not have required any mounding).

The analysis consisted of determining the percent of wells in each of the four groups of wells that failed to maintain each of the following vertical separation distances between the bottom of the SAS that would have been determined based on the calculated Sh value and the observed monthly depth to water measurements for the period of record: 4 feet, 2 feet, and 0 (zero) foot (i.e. water level rose to or above the base of the SAS). The following chronological frequencies of failure criteria were assessed for each of the three vertical separation distances:

- once every 20 months or >/= 5% of the time;
- once every 100 months or >/= 1% of the time; and
- once every 200 months or >/= 0.5% of the time.

The above scenarios were further subdivided into all Sh values and maximum Sh (Max Sh) values. All Sh values included up to 25 randomly selected times during wet and dry periods for which USGS applied the Frimpter method to calculate an Sh value for a given well. Max Sh values are the deepest calculated depth to water of all 25 Sh values that USGS calculated for the well. See the attached spreadsheet showing all results.

For each of the following four well groups, Technical Services' recommended Sr value is predicated on the assumption that the Sr value provides a reasonable balance between maintaining sufficient vertical separation distances between the base of the SAS and the Estimated Seasonal High Groundwater (ESHGW) elevation and minimizing the number of mounded systems that will require a greater volume of imported Title 5 sands than would be necessary (i.e. at sites where the Frimpter calculated depth to high groundwater is significantly shallower than the actual depth to high groundwater). A table showing the percent of wells failing to meet the 4-, 2-, and 0-foot separation distances at frequencies of greater than once every 20 months (1.7 years), once every 100 months (8.3 years), and once every 200 months (16.7 years) for the recommended Sr value is provided below for each of the well groups. See the attached spreadsheet to see all results for all six of the Sr values analyzed for each well group and for the percent of wells failing to meet the vertical separation distances,

<u>Proposed Changes to Frimpter Method</u>

Stratified Drift Wells on Hills:
For the 38 stratified drift wells located on hills (TopoGroup = SD:Hill) our analysis reviewed results for Sr values that ranged from 7.96 ft. (using a plot of Per90 OWr values and Sr selected as the 75th percentile of the Per90 OWr values) to 13.76 ft. (using a plot of maximum OWr values and, Sr selected as the 95th percentile OWr value). The current Sr value being used for wells in this topographic setting, assuming the use of the 95th percentile value, is 10 ft. Based on our analysis of the recent USGS data, Technical Services is recommending that the Sr value for stratified drift wells located on hills be 7.96 ft which represents the 75th percentile of the Per90 annual range values for this well grouping. This Sr value and Per90 approach is the least conservative of the six methods reviewed but results in a maximum of 3% of wells failing to maintain 0 foot of vertical separation under any of the three rates of failure frequency categories.

The following table of results for stratified drift wells on hills is based on Frimpter calculations for Sh using the Per90 approach and an Sr value of 7.96 feet, representing the 75th percentile range value from the Per90 plot of annual ranges for this well group:

Frequency of failure to maintain specified vertical separation distance	Using all 25 Sh values or only the deepest of the 25	% wells failing to maintain 4 ft vertical separation	% wells failing to maintain 2 ft vertical separation	% wells failing to maintain 0 ft vertical separation
>/= 5% (5% = once per 20 months)	All Sh values	16%	3%	0%
	Only deepest Sh values	26%	8%	0%

>/= 1% (1% = once per 100 months)	All Sh values	24%	5%	0%
	Only deepest Sh values	34%	8%	3%
>/= 0.5% (0.5% = once per 200 months)	All Sh values	29%	8%	0%
	Only deepest Sh values	37%	8%	3%

Stratified Drift Wells in Valleys:
For the 41 stratified drift wells located in valleys (TopoGroup = SD:Valley) our analysis reviewed results for Sr values that ranged from 4.25 ft. (using a plot of Per90 OWr values and Sr selected as the 75th percentile of the Per90 OWr values) to 7.07 ft. (using a plot of maximum OWr values and Sr selected as the 95th percentile OWr value). The current Sr value being used for wells in this topographic setting, assuming the use of the 95th percentile exceedance value, is 4.2 ft. Based on our analysis of the recent USGS data, Technical Services is recommending that the Sr value for stratified drift wells located in valleys be 4.25 ft which represents the 75th percentile of the Per90 annual range values for this well grouping. This Sr value and Per90 approach is the least conservative of the six methods reviewed but results in none of the wells failing to maintain 0 foot of vertical separation under any of the three rates of failure frequency categories.

The following table of results for stratified drift wells in valleys is based on Frimpter calculations for Sh using the Per90 approach and an Sr value of 4.25 feet, representing the 75th percentile range value from the Per90 plot of annual ranges for this well group:

Frequency of failure to maintain specified vertical separation distance	Using all 25 Sh values or only the deepest of the 25	% wells failing to maintain 4 ft vertical separation	% wells failing to maintain 2 ft vertical separation	% wells failing to maintain 0 ft vertical separation
>/= 5% (5% = once per 20 months)	All Sh values	12%	0%	0%
	Only deepest Sh values	24%	0%	0%
>/= 1% (1% = once per 100 months)	All Sh values	22%	0%	0%
	Only deepest Sh values	54%	0%	0%
>/= 0.5% (0.5% = once per 200 months)	All Sh values	34%	0%	0%
	Only deepest Sh values	56%	2%	0%

Till Wells Near Streams:
For the 8 till wells located in valleys (TopoGroup = Till:Near Stream) our analysis produced Sr values that ranged from 5.13 ft. (using a plot of Per90 OWr values and Sr selected as the 75th percentile of the Per90 OWr values) to 9.38 ft. (using a plot of maximum OWr values and Sr selected as the 95th percentile OWr value). There is no current Sr value for till wells near steams since this group of wells was not evaluated in the 1980 USGS report. Based on our analysis of the recent USGS data, Technical Services is recommending that the Sr

value for till wells located in uplands be 7.44 ft which represents the 95th percentile of the Per90 annual range values for this well grouping. This Sr value and Per90 approach is in the mid-range of the six methods reviewed and results in none of the wells failing to maintain 0 foot of vertical separation under any of the three rates of failure frequency categories.

The following table of results for till wells near streams is based on Frimpter calculations for Sh using the Per90 approach and a Sr value of 7.44 feet, representing the 95th percentile range value from the Per90 plot of annual ranges for this well group:

Frequency of failure to maintain specified vertical separation distance	Using all 25 Sh values or only the deepest of the 25	% wells failing to maintain 4 ft vertical separation	% wells failing to maintain 2 ft vertical separation	% wells failing to maintain 0 ft vertical separation
>/= 5% (5% = once per 20 months)	All Sh values	13%	13%	0%
	Only deepest Sh values	25%	13%	0%
>/= 1% (1% = once per 100 months)	All Sh values	13%	13%	0%
	Only deepest Sh values	38%	13%	0%
>/= 0.5% (0.5% = once per 200 months)	All Sh values	38%	13%	0%
	Only deepest Sh values	63%	13%	0%

Till Wells in Uplands:
For the 32 till wells located in uplands (TopoGroup = Till:Uplands) our analysis produced Sr values that ranged from 12.39 ft. (using a plot of Per90 OWr values and Sr selected as the 75th percentile of the Per90 OWr values) to 16.74 ft. (using a plot of maximum OWr values and Sr selected as the 95th percentile OWr value). The current Sr value being used for wells in this topographic setting, assuming the use of the 95th percentile exceedance value, is 17 ft. Based on our analysis of the recent USGS data, Technical Services is recommending that the Sr value for stratified drift wells located in valleys be 16.74 ft which represents the 95th percentile of the maxium annual range values approach for this well grouping. This Sr value and maximum annual range approach is the most conservative of the six methods reviewed and is recommended because the percent of wells failing to meet the various vertical separation distances between base of SAS and groundwater level for the three different frequency of failure categories is not ideal even for this most conservative approach. This results in a maximum of 9% of wells failing to maintain 0 foot of vertical separation under any of the three rates of failure frequency categories.

The following table of results for stratified drift wells on hills is based on Frimpter calculations for Sh using the maximum annual range approach and an Sr value of 16.74 feet, representing the 95th percentile range value from the plot of maximum annual ranges for this well group:

Frequency of failure to maintain specified vertical separation distance	Using all 25 Sh values or only the deepest of the 25	% wells failing to maintain 4 ft vertical separation	% wells failing to maintain 2 ft vertical separation	% wells failing to maintain 0 ft vertical separation
>/= 5% (5% = once per 20 months)	All Sh values	22%	6%	0%
	Only deepest Sh values	53%	22%	3%
>/= 1% (1% = once per 100 months)	All Sh values	44%	22%	0%
	Only deepest Sh values	63%	28%	9%
>/= 0.5% (0.5% = once per 200 months)	All Sh values	50%	22%	3%
	Only deepest Sh values	69%	28%	9%

SUMMARY: All of the equation variables with the exception of Sr can be determined from either published scientific data or observed groundwater levels at the site of interest. After reviewing the 2020 report by the USGS, titled <u>Updating Data Inputs, Assessing Trends, and Evaluating a Method to Estimate Probable High Groundwater Levels in Selected Areas of Massachusetts</u> – (Janet Barclay and John Mullaney) SIR 2020-5036, and after detailed calculations of percent failures made by Technical Services staff from this new USGS data, we have recommended the following Sr values to be used in the Frimpter Equation for the 4 different geologic and topographic settings found in Massachusetts:

- **Stratified drift wells on hills: 7.96 feet**
- **Stratified drift wells in valleys: 4.25 feet**
- **Till wells near streams: 7.44 feet**
- **Till wells in uplands: 16.74 feet**

Data Analysis for Determination of Massachusetts Sr Values

					percent of wells with >/= 5% failure rate (once per 20 months)						percent of wells with >/= 1% failure rate (once per 100 months)						percent of wells with >/= 0.5% failure rate (once per 200 months)					
					All Sh values			max Sh values			All Sh values			max Sh values			All Sh values			max Sh values		
Stats Type	Sr Exceedance Percent	Sr value	TopoGroup	Total # of wells in Topo Group	< 4 ft vertical separation	< 2 ft vertical separation	flooded SAS	< 4 ft vertical separation	< 2 ft vertical separation	flooded SAS	< 4 ft vertical separation	< 2 ft vertical separation	flooded SAS	< 4 ft vertical separation	< 2 ft vertical separation	flooded SAS	< 4 ft vertical separation	< 2 ft vertical separation	flooded SAS	< 4 ft vertical separation	< 2 ft vertical separation	flooded SAS
Max	95	13.76	SD: Hill	38	5%	0%	0%	8%	3%	0%	8%	3%	0%	11%	3%	0%	8%	3%	0%	11%	3%	0%
Max	85	10.77	SD: Hill	38	5%	3%	0%	13%	3%	0%	13%	3%	0%	18%	5%	0%	16%	3%	0%	18%	5%	0%
Max	75	9.3	SD: Hill	38	11%	3%	0%	18%	8%	0%	18%	5%	0%	18%	8%	0%	18%	5%	0%	24%	8%	0%
Per90	95	12.41	SD: Hill	38	8%	0%	0%	16%	3%	0%	11%	3%	0%	21%	3%	0%	16%	3%	0%	21%	3%	0%
Per90	85	9.39	SD: Hill	38	13%	3%	0%	21%	3%	0%	18%	3%	0%	24%	8%	0%	21%	5%	0%	29%	8%	0%
Per90	75	7.96	SD: Hill	38	16%	3%	0%	26%	8%	0%	24%	5%	0%	34%	8%	3%	29%	8%	0%	37%	8%	3%
Max	95	7.07	SD: Valley	41	0%	0%	0%	5%	0%	0%	5%	0%	0%	12%	0%	0%	10%	0%	0%	17%	0%	0%
Max	85	6.1	SD: Valley	41	2%	0%	0%	10%	0%	0%	10%	0%	0%	15%	0%	0%	12%	0%	0%	20%	0%	0%
Max	75	5.52	SD: Valley	41	2%	0%	0%	10%	0%	0%	12%	0%	0%	17%	0%	0%	15%	0%	0%	22%	0%	0%
Per90	95	5.39	SD: Valley	41	5%	0%	0%	15%	0%	0%	15%	0%	0%	34%	0%	0%	22%	0%	0%	39%	0%	0%
Per90	85	4.68	SD: Valley	41	7%	0%	0%	22%	0%	0%	20%	0%	0%	44%	0%	0%	27%	0%	0%	51%	2%	0%
Per90	75	4.25	SD: Valley	41	12%	0%	0%	24%	0%	0%	22%	0%	0%	54%	0%	0%	34%	0%	0%	56%	2%	0%
Max	95	9.38	Till: Near Stream	8	13%	13%	0%	13%	13%	0%	13%	13%	0%	25%	13%	0%	13%	13%	0%	38%	13%	0%
Max	85	7.85	Till: Near Stream	8	13%	13%	0%	13%	13%	0%	13%	13%	0%	25%	13%	0%	13%	13%	0%	38%	13%	0%
Max	75	6.93	Till: Near Stream	8	13%	13%	0%	13%	13%	0%	13%	13%	0%	25%	13%	0%	13%	13%	0%	50%	13%	0%
Per90	95	7.44	Till: Near Stream	8	13%	13%	0%	25%	13%	0%	13%	13%	0%	38%	13%	0%	38%	13%	0%	63%	13%	0%
Per90	85	5.89	Till: Near Stream	8	13%	13%	0%	25%	13%	0%	38%	13%	0%	50%	13%	0%	38%	13%	0%	63%	13%	0%
Per90	75	5.13	Till: Near Stream	8	13%	13%	0%	38%	13%	0%	38%	13%	0%	63%	13%	0%	38%	13%	0%	75%	13%	0%
Max	95	16.74	Till: Upland	32	22%	6%	0%	53%	22%	3%	44%	22%	0%	63%	28%	9%	50%	22%	3%	69%	28%	9%
Max	85	15.21	Till: Upland	32	28%	9%	0%	59%	28%	9%	53%	22%	0%	69%	28%	13%	56%	25%	9%	72%	28%	13%
Max	75	14.3	Till: Upland	32	31%	9%	0%	63%	28%	13%	56%	25%	6%	72%	31%	13%	59%	25%	9%	78%	31%	13%
Per90	95	14.39	Till: Upland	32	38%	9%	0%	63%	31%	9%	59%	28%	6%	78%	34%	9%	59%	28%	9%	78%	41%	13%
Per90	85	13.14	Till: Upland	32	41%	13%	0%	66%	34%	9%	59%	31%	6%	78%	41%	16%	66%	34%	9%	78%	44%	16%
Per90	75	12.39	Till: Upland	32	47%	16%	0%	69%	34%	13%	59%	31%	6%	78%	44%	16%	69%	38%	9%	81%	44%	16%

StatsType: Max indicates that Sr values were taken from plots of the maximum range values (Owr) for all wells in the "TopoGroup" category.
Per90 indicates that Sr values were taken from plots of the 90th percentile of maximum of range values (OWr) for all wells in the "TopoGroup" category.
water level range values for each USGS well are based on calendar year, not the maximum range in any given 365 day period of time.

Sr ExceedancePercent: indicates the percentile value that the Sr value was selected from in order to run the calculations.
Example: "95" indicates that the Sr value represents the 95th percentile of the plot of all ranges for each USGS well in the "TopoGroup" category
(i.e. 95 % of the ranges for the "TopoGroup" category are less than the Sr value selected.

TopoGroup: indicates the combination of aquifer type and landscape setting.
SD = stratified drift (no distinction between fine sands and sand and gravel).
till = glacial till (no distinction between lodegement till vs. ablation till vs. ground moraine).

total # of wells in Topo Group: The number of wells in the "TopoGroup" for which calculations were run.