OARS River Report Card—Grade Calculation

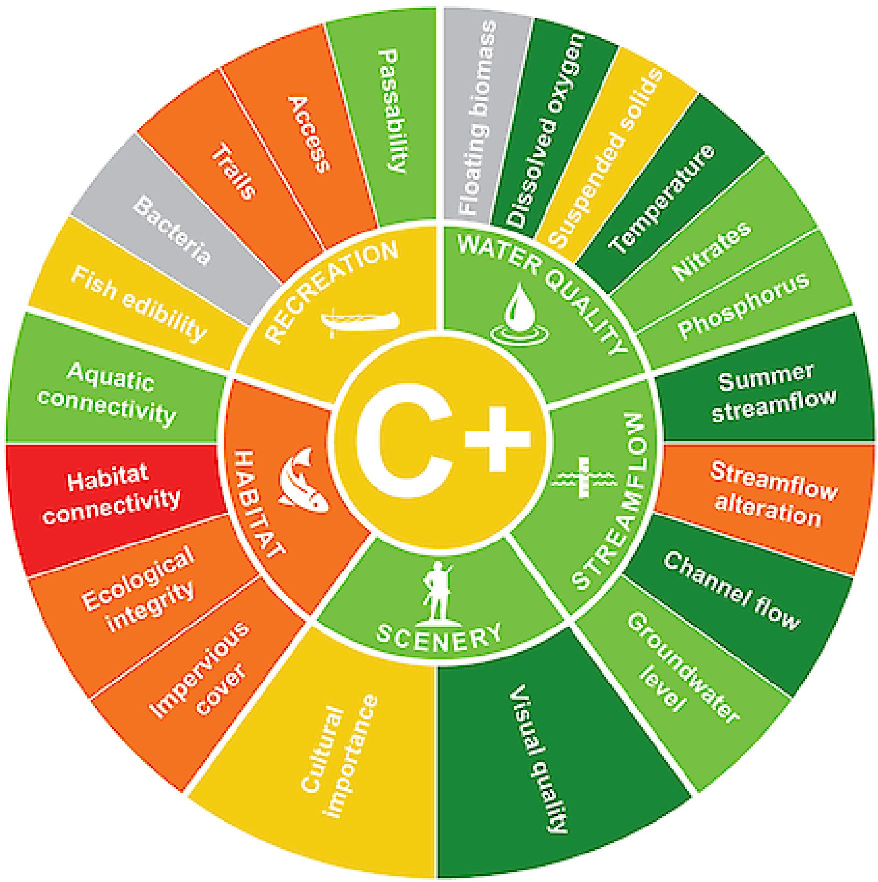
Original by S. Flint (June 2019), Updated by B. Wetherill

Contents

Overview

The grade calculation method described here is used as the data integration mechanism for OARS' River Report Card. The goals of the Report Card project are to characterize the health of the river ecosystem and to provide timely, accurate information to a wide audience on a regular basis. The Sudbury, Assabet, and Concord River Report Card is posted on the OARS' webpage (through the University of Maryland's page). We expect that the overall grade for the watershed will be calculated biennially. Some of the individual indicator or value scores will be calculated more frequently (e.g. the water quality score may be calculated for each sampling date).

Example Report Card Graphic:



Background

An Eco-Health Report Card (or environmental index) is designed to bring information from multiple data sources together into a single number, like a grade, that can be understood at a glance. Much of the initial work developing water quality indices was done in the 1970's and early 1980's. The University of Maryland Center for Environmental Science's (ECS) Integration and Application Network's report cards extend the concept of water quality indices to include a wider range of ecosystem health indicators, and, importantly, involve stakeholders in identifying important values that should be captured in their report card. This first Report Card will focus on the mainstem rivers of the basin (Assabet, Sudbury, and Concord Rivers) but will include some indicators that reflect conditions throughout the subbasins (e.g. the Index of Ecological Integrity or percent impervious throughout the basin).

In 2018, OARS partnered with the University of Maryland Center for Environmental Science to initiate a river report card for the region. To start the process, two workshops were held at Great Meadows National Wildlife Refuge on February 28th and March 1st, 2018, with key stakeholders from all three river basins. The initial workshop elicited what stakeholders value about the rivers, and the subsequent workshop focused on ways to measure those values, and identifying potential data sources. The top values identified were: water quality, water quantity, habitat/wildlife, recreation, economy, and cultural significance. Discussed below are: river sections, assessment categories, potential data sources, scoring, and calculation of the final grade.

River Sections

The Sudbury, Assabet, and Concord river watershed is divided into six sections for evaluation and reporting: Upper Assabet, Lower Assabet, Upper Sudbury, Lower Sudbury, Upper Concord, and Lower Concord.

Assessment areas are based on the NRCS HUC-12 subbasins modified to break out the Lowell Lower Concord section. Sections stats are described below:

Assabet River (basin area 178 square miles; 44% of the watershed area)

- Upper Assabet: Headwaters to Elizabeth Brook (HUC-010700050201, and HUC-010700050202)
    - Basin area: 89.9 square miles; 51% of the Assabet basin
    - Includes OARS' sampling sites ABT-301, ABT-237, and ABT-144
    - Mainstem river miles: 24.9
- Lower Assabet: Elizabeth Brook to Egg Rock (HUC-010700050203, and HUC-010700050204)
    - Basin area: 88.0 square miles; 49% of the Assabet basin
    - Includes OARS' sampling sites ABT-077, ABT-062, and ABT-026
    - Mainstem river miles: 9.5

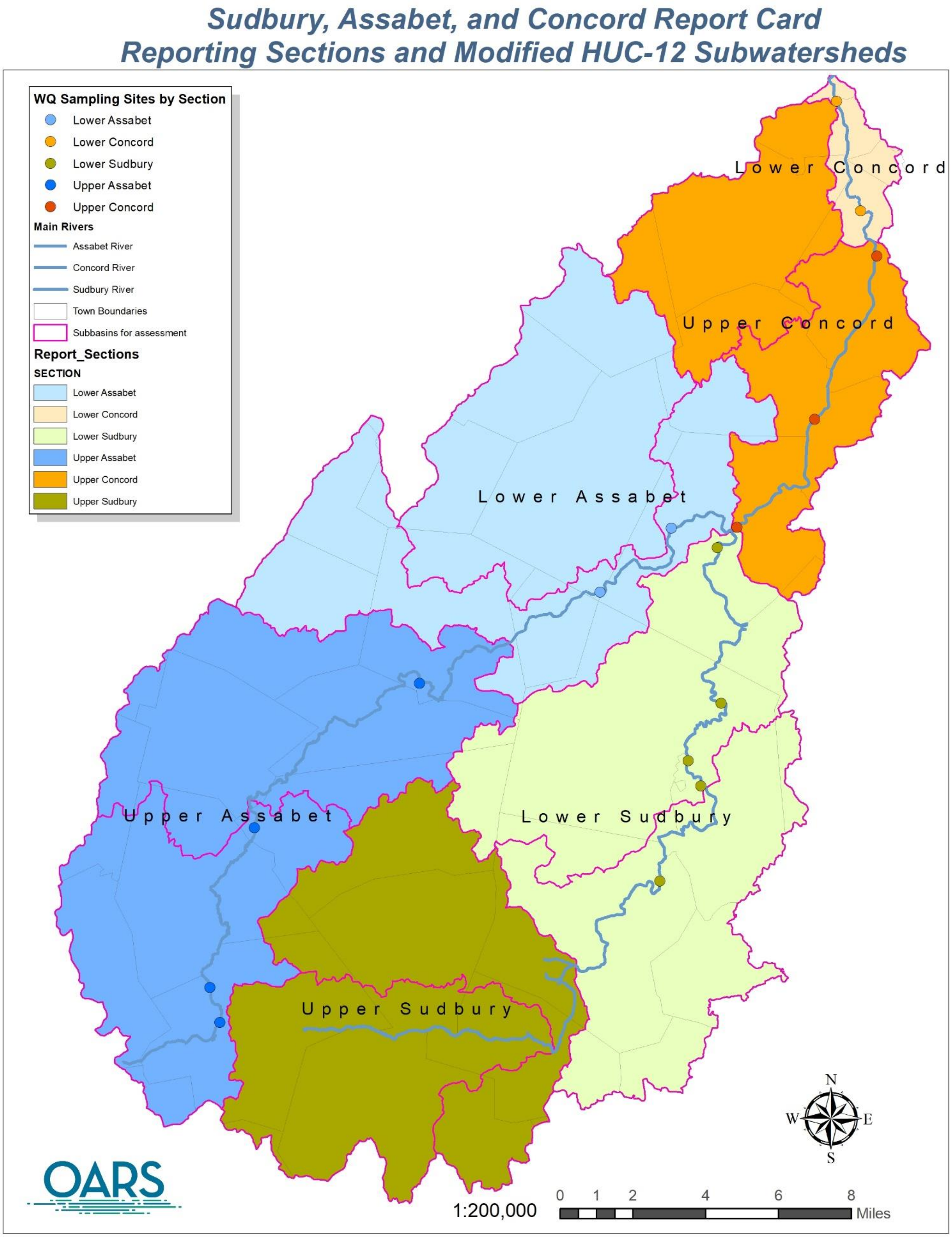
Sudbury River (basin area 163 square miles; 41% of the watershed area)

- Upper Sudbury: headwaters to outlet of Stearns Reservoir (HUC-010700050101, and HUC-010700050102)
    - Basin area: 74.7 square miles; 46% of the Sudbury basin
    - Includes OARS' sampling sites SUD-236 and SUD-293
    - Mainstem river miles: 11.3
- Lower Sudbury: outlet of Stearns Res. to Egg Rock
    - Basin area: 87.8 square miles; 54% of the Sudbury basin
    - Includes OARS' sampling sites SUD-144, SUD-096, SUD-086, SUD-064, and SUD-005
    - Mainstem river miles: 21.7

Concord River (basin area 59.9 square miles; 15% of the watershed area)

- Upper Concord: Egg Rock to Talbot Dam, North Billerica (HUC-010700050205 and HUC-010700050206 minus the Lower Concord)
    - Basin area 53.9 square miles; 90% of the Concord basin
    - Includes OARS' sampling sites CND-161, and CND-110
    - Mainstem river miles: 10.5
- Lower Concord: from North Billerica to Lowell
    - Basin area: 6.1 square miles; 10% of the Concord basin (Designated HUC-010700050207 for this analysis only; extracted from HUC-010700050206)
    - Includes OARS' sampling sites CND-045, and CND-009
    - Mainstem river miles: 5.8

Figure 1: Watershed and Reporting Sections



Values, Indicators, and Scoring Criteria

The Sudbury, Assabet and Concord River Report Card grading assesses five overall values: **water quality**, **water quantity** (streamflow), **wildlife habitat**, **cultural and scenic**, and **recreation**. The economic value of the rivers was also identified as an important value but was not used in this version of the report card; potential indicators for economic value include the value of recreational boating and fishing, tourism, and flood claims.

Each value is assessed using measurable indicators with criteria against which to judge the indicator. Grades have been calculated for each value for each river section: upper and lower Assabet, upper and lower Sudbury, and upper and lower Concord Rivers. The overall river health grade was then calculated for each section, each river, and the overall watershed.

The individual values, indicators, criteria, and grade calculations are described below.

Value: Water Quality

Data source: OARS water quality field data from 16 sites between May 1st and September 30th.

The Water Quality Score uses the Water Quality Index developed in 2002 as part of OARS' StreamWatch project in collaboration with United State Geological Survey (USGS), the Massachusetts Division of Fisheries and Wildlife, and the Massachusetts Audubon Society. OARS' Water Quality Index is modeled after earlier water quality indices (Ott, 1978; Cude, 2001; Hallock, 2002) and with subindex scoring curves appropriate to local conditions. Individual scoring curves were developed for streams with different designations: cold-water fisheries, warm-water fisheries, and warm-water aquatic life. Cold-water fisheries are found only in tributary and headwater streams and are not among the sampling sites included in the index. A score for floating biomass was added to the water quality indicators based on floating aquatic biomass assessments performed by OARS in three impoundments of the Assabet River.

Table 1 (below) summarizes the indicators and scoring criteria used in the water quality index. The indicators were selected for relevance to fish habitat, relative ease of measurement, and availability of information against which to judge current conditions. Indicator scores were developed using the criteria listed in Table 1 and scoring curves were drawn with best-fit equations. Field data results are converted to indicator scores using those equations. Calculated scores of <1 or >100 are rounded to 1 or 100 respectively.

Time period: The WQI was designed mainly for summer conditions when river habitat is most stressed. For the Report Card analysis, the water quality index is calculated for samples taken between May 1st and September 30th at 15 mainstem sampling sites (Table 2). Sampling SOPs, data handling, and quality control for the water quality monitoring program is documented in Quality Assurance Project Plan for OARS' Water Quality and Quantity Monitoring Program.

Table 1: Water Quality Indicators and Scoring Criteria

Value	Indicator	Scoring Criteria (on a scale of 1 - 100)
Water Quality	DO concentration (minimum)	Massachusetts Water Quality Standards (WQSs) for cold water fisheries and warm water fisheries; fish tolerances; EPA criteria; EPA Ecoregion XIV data
	DO % saturation (min)	
	Temperature	Mass WQSs for cold and warm water fisheries, published fish tolerances
	~~pH*~~	~~Mass WQSs; EPA Gold Book criteria; published fish tolerances~~
	Total phosphorus	EPA Ecoregion XIV data
	Nitrates **	EPA Ecoregion XIV data
	Total Suspended Solids	Washington state data; published fish tolerances; Mass DEP criteria
	Biomass	OARS biomass assessment for the Assabet River impoundments

*Decided not to use the pH score in the Report Card because pH hasn't been a problem and the high scores give the impression of better water quality.
**In 2020, decided to reduce nitrate monitoring to only the most downstream sites in each section, to measure exported nitrate.

Table 2: OAR water quality sampling locations

River	**Site Name**	Town	OARS Site #	Lat/Long (decimal degrees)	Sampling Months	USGS Gage locations	Stream Designation *
Concord	Rogers Street	Lowell	CND-009	42.635909/-71.301809	May-Sept	USGS Gage	Warm
Concord	Lowell Street	Billerica	CND-045	42.466452/-71.355724	June-Aug		Warm
Concord	Rte 225	Bedford	CND-110	42.50916/-71.313342	June-Aug		Warm
Concord	Lowell Rd. Bridge	Concord	CND-161	42.466452/-71.355724	May-Sept		Warm
Assabet	Rte 2	Concord	ABT-026	42.465938/-71.391128	May-Sept		Warm
Assabet	Rte 62 (Canoe access)	Acton	ABT-062	42.440765/-71.429409	June-Aug		Warm

Assabet	USGS Maynard Gage	Maynard	ABT-077	42.432356/-71.449407	May-Sept	USGS Gage	Warm
Assabet	Rte 62 (Gleasondale)	Stow	ABT-144	42.404519/-71.526349	June-Aug		Warm
Assabet	Robin Hill Road	Marlborough	ABT-237	42.346645/-71.614691	June-Aug		Warm
Assabet	Route 9	Westborough	ABT-301	42.283169/-71.638509	May-Sept		Warm
Sudbury	Rte 62 (Boat House)	Concord	SUD-005	42.458253/-71.366318	May-Sept		Aquatic
Sudbury	Sherman Bridge Road	Wayland	SUD-064	42.396454/-71.364422	May-Sept		Aquatic
Sudbury	River Road	Wayland	SUD-086	42.373980/-71.381739	May-Sept		Aquatic
Sudbury	Route 20	Wayland	SUD-096	42.363441/-71.374828	May-Sept		Aquatic
Sudbury	Sudbury Landing	Framingham	SUD-144	42.325616/-71.397487	May-Sept	USGS Gage	Aquatic
Sudbury	Chestnut Street	Ashland	SUD-236	42.257609/-71.454952	June-Aug		Warm
Sudbury	Fruit Street	Southborough	SUD-293	42.267362/-71.552384	May-Sept		Cold

* Stream designations: Warm/Cold = warm/cold-water fishery, Aquatic = warm-water aquatic life

** The original Water Quality Index included ABT-312, but this was excluded because it is more like a tributary.

*** SUD-236 and SUD-293 were added in 2021.

Indicators included for Water Quality:

- Total Phosphorus
- Nitrate
- Total Suspended Solids
- Dissolved Oxygen
- Water Temperature
- Biomass

Indicators considered but not used for Water Quality:

chlorophyll. Chlorophyll-*a* is sampled only on the Sudbury River.

Indicator = Nutrients (total phosphorus and nitrate)

While nutrients have an indirect effect on the quality of fish habitat they are important indicators of potential for eutrophication, which is a serious problem in the much of the region. The overgrowth of algae and macrophytes leads to large diurnal changes in dissolved oxygen and pH levels which affect fish habitat. Both total phosphorus and nitrates are used to indicate potential for eutrophication. Total phosphorus (TP) and nitrate (NO_3) scores are based on EPA Ecoregion XIV data for Subregion 59 (the Northeast US) (EPA 2000). Nitrate was used as a surrogate for the more comprehensive measure total nitrogen which is not consistently measured in the watershed. Nitrite is generally a small proportion of the measured nitrate + nitrite concentration; nitrite is not measured in the watershed.

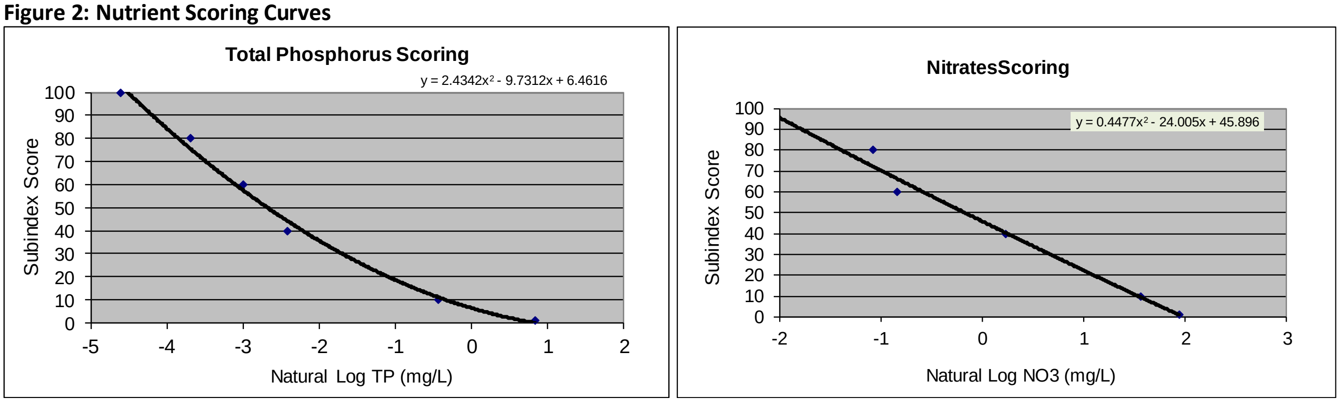
As of the 2020 Report Card (based on 2019 data), it was decided that Nitrate is primarily a concern with regard to downstream export to marine estuaries. It is not considered to be a limiting nutrient in fresh water rivers. Therefore, to save cost, nitrate monitoring was reduced to only the furthest downstream site in each river section. Nitrate indexes are not included in the WQI calculations for other sites.

Note that the Nitrate/Nitrite scoring curve used for the Report Card is different than the curve used for the Water Quality Index prior to 2018. The previous curve was based on numbers that could not be corroborated with any known reference material (0.10, 0.28, 0.39, 0.54, 3.10, 10.60).

Table 3: Nutrients Scoring Criteria

Total phosphorus scoring curve			
TP (mg/L)	Ecoregion XIV subregion 59 summer data statistic (EPA, 2000)	Natural Log	Index
0.010	TP 5th percentile	-4.605170186	100
0.025	TP 25th percentile	-3.688879454	80
0.05	TP median	-2.995732274	60
0.09	TP 75th percentile	-2.407945609	40
0.65	TP 95th percentile	1.871802177	10
2.3	maximum TP for Ecoregion XIV (all subregions)	1.945910149	1
Nitrate/nitrite (N) scoring curve			
NO3 (mg/L)	Ecoregion XIV subregion 59 summer data statistic (EPA, 2000)	Natural Log	Index
0.11	NO3/NO2 5th percentile	-2.207274913	100
0.34	NO3/NO2 25th percentile	-1.078809661	80
0.43	NO3/NO2 median	-0.84397007	60
1.25	NO3/NO2 75th percentile	0.223143551	40
4.77	NO3/NO2 95th percentile	1.562346305	10
6.93	Maximum NO3/NO2 for Ecoregion XIV (all subregions)	1.935859813	1

Figure 2: Nutrient Scoring Curves

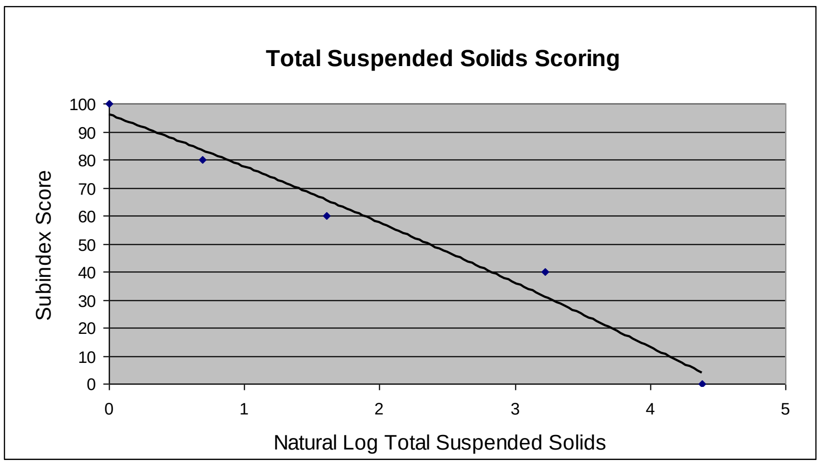


Indicator = Total Suspended Solids

Excess suspended solids can have a direct effect on fish, as gill damage, behavioral changes, lowered resistance to disease, and blanketing spawning gravels (Caux et al., 1997). Ecoregion XIV data for suspended solids are not available, so until ecoregion-specific data are available this subindex is based on the long-term summertime data for Washington State's coastal region (Hallock, 2002), published levels affecting fish health (reviewed in Caux et al., 1997), and the Massachusetts DEP criteria for protection of aquatic life. The Washington State data were used in the absence of a similar local database in the literature.

Total suspended solids scoring curve			
TSS (mg/L)	Description & Citation	Natural Log TSS	Score
1	20th percentile Washington Coastal Region (Hallock 2002)	0	100
2	50th percentile Washington Coastal Region (Hallock 2002)	0.693147181	80
5	80th percentile Washington Coastal Region (Hallock, 2002)	1.609437912	60
25	No evidence of harmful effects on fisheries below 25mg/L (Caux etal., 1997); Mass DEP criteria for aquatic life protection (MDEP 2003)	3.218875825	40
80	upper limit of good to moderate fisheries (Caux et al., 1997)	4.382026635	0

Figure 3: TSS Scoring



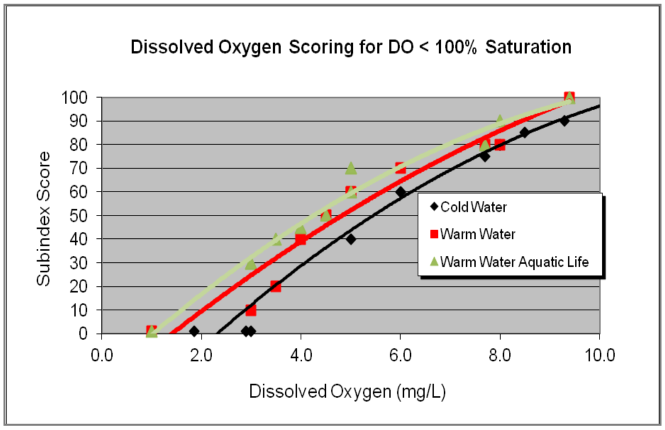
Indicator = Dissolved Oxygen (DO)

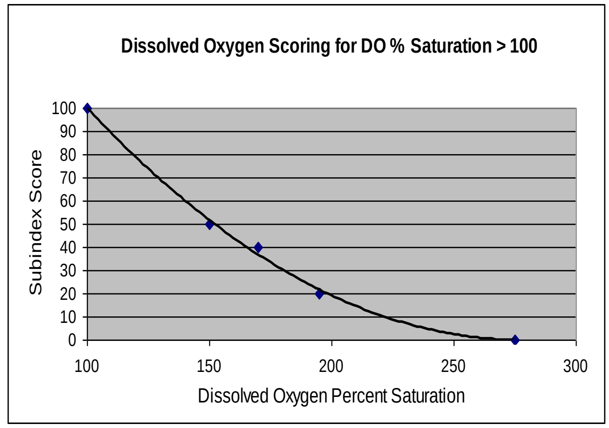
The dissolved oxygen subindex is based on published fish tolerances (Oregon DEQ, 1995), the Massachusetts Water Quality Standards (Mass WQS 1993), EPA recommended criteria (EPA, 1986), and EPA Ecoregion XIV subregion 59 data. If dissolved oxygen is below 100% saturation, the DO subindex is calculated from concentration with separate curves for cold-water, warm-water, and “Aquatic Life” designated streams. If the dissolved oxygen concentration is above 100% the score is calculated based on saturation to address concerns of gas bubble trauma, swim bladder over-inflation, and respiratory distress in fish caused by high total dissolved gas concentration (Oregon DEQ, 1995).

Table 4: Dissolved Oxygen Scoring Criteria

Dissolved oxygen scoring curve for warm-water fisheries with DO < 100% saturation		
DO (mg/L)	Description & Citation	Score
1.0	Acute mortality for crappie (Oregon DEQ, 1994)	1
3.0	Acute mortality (EPA, 1986), critical oxygen tension for largemouth bass (Oregon DEQ, 1994)	10
3.5	Severe impairment (EPA, 1986)	20
4.0	Moderate impairment (EPA, 1986)	40
4.5	Swimming performance reduced in largemouth bass (Oregon DEQ, 1994)	50
5.0	Slight impairment (EPA, 1986)	60
5.0	Massachusetts Water Quality Standards for warm-water fisheries	60
6.0	No impairment (EPA, 1986), reduced growth rates in bass (Oregon DEQ, 1994)	70
7.7	25th percentile calculated from Ecoregion XIV subregion 59 data (June - Sept)	80
8.0	Onset of O_2-dependent metabolism in brown bullhead (Oregon DEQ, 1994)	80
9.4	75th percentile calculated from Ecoregion XIV subregion 59 data (June - Sept)	100
Dissolved Oxygen scoring curve for Warm Water "Aquatic Life" Streams with DO < 100% saturation		
1.0	Acute mortality for crappie (Oregon DEQ, 1994)	1
3.0	Acute mortality (EPA, 1986), critical oxygen tension for largemouth bass (Oregon DEQ, 1994)	30
3.0	MA Water Quality Standard for Class B "Aquatic Life" (not less than 3.0mg/L any time)	30
3.5	Severe impairment (EPA, 1986)	40
4.0	Moderate impairment (EPA, 1986)	45
4.5	Swimming performance reduced in largemouth bass (Oregon DEQ, 1994)	50
5.0	MA WQS "Aquatic Life" not less than 5.0mg/L at least 16 hrs/day	60
5.0	Slight impairment (EPA, 1986)	70
7.7	25th percentile calculated from EPA Ecoregion XIV subregion 59 data (Jun - Sept)	80
8.0	Onset of O_2-dependent metabolism in brown bullhead (Oregon DEQ 1994)	90
9.4	75th percentile calculated from EPA Ecoregion XIV subregion 59 data (Jun - Sept)	100
Dissolved oxygen scoring curve for DO > 100% saturation		
100	Good conditions (EPA, 1986)	100
150	Increased mortality in salmon (Oregon DEQ, 1994)	50
170	Swim bladder over-inflation in surface waters (Oregon DEQ, 1994)	40
195	Gas bubble trauma in rainbow trout (Oregon DEQ, 1994)	20
275	Acute mortality in steelhead salmon (Oregon DEQ, 1994)	1

Figure 4: Dissolved Oxygen Scoring





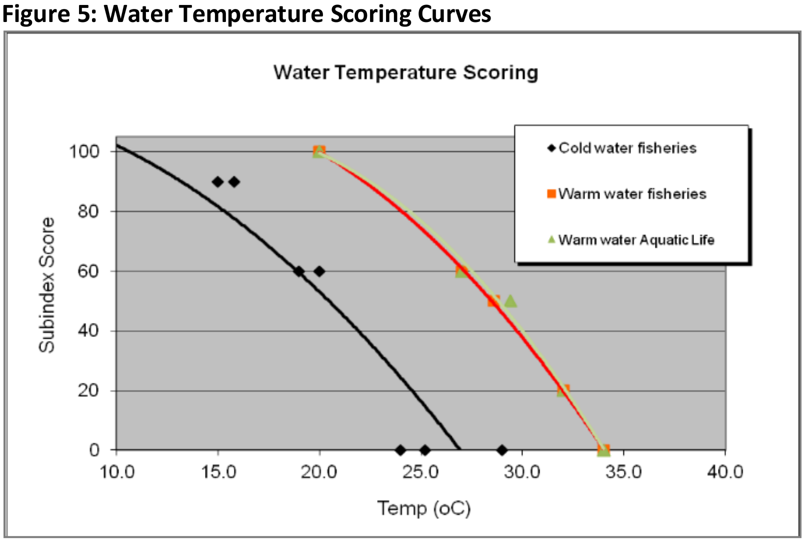
Indicator = Water Temperature

The water temperature thresholds are based on published fish tolerances (Oregon DEQ, 1995; McCullough, 1999; McCullough et al., 2001), the Massachusetts Water Quality Standards (Mass WQS, 1993), and EPA recommended criteria (EPA, 1986). Separate curves are drawn for cold-water, warm-water, and “Aquatic Life” designated fisheries.

Table 5: Water Temperature Scoring Criteria

	Temperature scoring curve for warm-water resources	
20	Mass WQS cold (Mass WQS, 1993)	100
27	Maximum for growth in black crappie (EPA, 1986)	60
28.6	Mass WQS for warm water fisheries (Mass WQS, 1993)	50
32	Maximum for growth of largemouth bass (EPA, 1986)	20
34	Maximum for survival of largemouth bass (EPA, 1986)	1
Temperature scoring curve for warm-water aquatic life resources		
20	Mass WQS cold (Mass WQS, 1993)	100
27	Maximum for growth in black crappie (EPA, 1986)	60
29.4	Mass WQS for warm water fisheries (Mass WQS, 1993)	50
32	Maximum for growth of largemouth bass (EPA, 1986)	20
34	Maximum for survival of largemouth bass (EPA, 1986)	1
Temperature scoring curve for cold-water resources		
8.0	Washington DEQ 2001	100
15.0	Average optimum for growth of brook trout (McCullough 2001)	90
15.8	Average optimum for growth of rainbow trout (McClough 2001)	90
19.0	Maximum for growth of brook trout (EPA 1986)	60
20.0	Mass WQS cold water fisheries	60
24.0	Maximum for survival of rainbow and brook trout (EPA 1986)	0
25.2	Maximum for survival of brown trout (McCullough 1999)	0
29	Maximum for growth of blacknose dace & yellow perch (EPA 1986)	0

Figure 5: Water Temperature Scoring Curves



Indicator = Biomass

Excessive growth of aquatic plants is a recognized problem in the watershed and particularly in impoundments of the Assabet River. Reduction in aquatic biomass was a key goal of the nutrient TMDL for the Assabet and one of the metrics for evaluating water quality. The TMDL states "For the purpose of this TMDL, a substantial reduction in total biomass of at least 50% from July 1999 values is considered a minimum target for achieving designated uses". (MADEP, 2004)

OARS surveys biomass annually within the watershed, but only in three impoundments on the Assabet. Despite the limited coverage, it is a sufficiently important metric for the Assabet that it is included as a water quality indicator. OARS has conducted biomass surveys between mid-August and early September (the peak of the growing season) since 2005 in the Hudson, Gleasondale, and Ben Smith impoundments. The visual surveys are conducted by OARS staff from a kayak or canoe. Each impoundment is divided into observation grids and the percent area covered by vegetation recorded along with other observations as detailed by Flint (2006). The visual recordings are then used to estimate total biomass in kilograms in each impoundment per Flint (2006) and assessed as a percentage of the biomass estimated for 1999 by ENSR (2001) (Table 6). The assigned score is 100 minus the percentage of the average biomass from 1999. Thus, if the biomass is measured as greater than or equal to 100% of the 1999 biomass, the grade is zero; if the biomass is 45%, the grade is 55; and if there is zero biomass, the grade is 100. The Ben Smith score is assigned to the Lower Assabet and the average of Hudson and Gleasondale scores is assigned to the Upper Assabet.

Two adjustments to the 1999 baseline biomass estimate from ENSR were considered, but subsequently reversed. First, per Flint (2006), the Ben Smith impoundment was reduced to account for the smaller area surveyed by OARS in 2005/2006. However, since OARS expanded its survey area in 2007 to match ENSR, this adjustment is no longer necessary. Second, there was a question of whether the ENSR estimate should be reduced to exclude the edges of the impoundments. In 2020, OARS decided to survey only the central areas of the impoundments. The edges were excluded for several reasons: because the objective of the survey was really to track biomass growing in the central portions not that collecting along the edges; because the edges included large portions of exposed land making the floating estimates misleading; and to make the survey more time efficient. However, it was decided that the ENSR survey approach probably most closely matched the new OARS approach without edges, so this adjustment also is not necessary. All OARS survey estimates prior to 2020 were adjusted to match this approach and exclude edge grids.

Table 6: Biomass Estimates for July 1999 (ENSR, 2001)

1999 Biomass (kg)	Ben Smith Impoundment (Lower Assabet)*	Gleasondale Impoundment (Upper Assabet)	Hudson Impoundment (Upper Assabet)
Original ENSR, 2001	93,600	83,000	118,000
~~Adjusted by Flint, 2006~~	~~73,008~~	~~83,000~~	~~118,000~~

* Per Flint (2006), the baseline biomass for the Ben Smith Impoundment was re-scaled for the somewhat smaller area surveyed by OARS (in 2005-2006) versus that surveyed by ENSR. However, in subsequent surveys, OARS expanded the Ben Smith survey area to match ENSR.

Calculating the Water Quality Score

Water Quality Score calculation consists of four steps:

(1) Calculate an indicator score for each indicator and sample day and site from the rating curves.
(2) Aggregate the indicator scores into a water quality index score for each sample day/site using a harmonic mean (Equation 1). For the Water Quality Score we assumed that all indicators are about equally important in supporting aquatic life in a stream, thus any low-scoring indicator should be heavily weighted as is accomplished by using the harmonic mean (e.g. a stream with all good scores except dissolved oxygen should not score well overall).
(3) Calculate the average of the water quality index scores for each river section for the year (May-Sep). This is the Section Water Quality Index.
(4) If there is a Biomass score, calculate the weighted average of the Water Quality Index and the Biomass score for each river section. Use a weighting of 75% for WQI and 25% for Biomass. This is the Section Water Quality Score.
(5) Calculate the area-weighted average of the section scores for each river.
(6) Calculate the area-weighted average of the river scores for the whole watershed.

Steps 1-3 above can be calculated with a single query in the OARS Water Quality Database: "Water Quality Index by River Section" (qryIndex_sections).

Equation 1: Harmonic Mean

$$\text{Harmonic Mean} = \frac{n}{\sum_{i=1}^{n} \frac{1}{x_i}}$$

For the harmonic mean calculation, n is the number of indicators evaluated, and x_i represents each indicator score.

Value: Streamflow

Data sources include: daily mean streamflows at the USGS gages on the Assabet River at Maynard, the Sudbury River at Saxonville, and the Concord River at Lowell; and groundwater levels from the USGS groundwater monitoring well in Acton.

The Water Quantity Score is based on assessment of summer streamflows, annual variability of streamflows, and groundwater levels.

Table 7: Streamflow and Groundwater Scoring

Value	Indicators	Scoring Criteria (on a scale of 1 - 100)
Streamflow	Summer Streamflows	Tennant method flow recommendations for summer conditions; 40%, 30%, and 10 % of mean annual discharge ((Q_{MA}) create "good," "fair," and "poor" habitat conditions, respectively (Tennant , 1976).
		StreamStats-calculated August median flows "good"
		StreamStats-calculated 7Q10 flows "very poor"
		R2Cross criteria (SITE SPECIFIC – this was done for tributary sites); 3/3 criteria and 2/3 criteria ()
	Annual Variability of Streamflows	Deviation of Indicators of Hydrologic Alteration from a "least altered" gage record: monthly median flows for January, April, August, and October; annual 7-day and 3-day minimum flows; low-pulse count; low-pulse duration.
	Groundwater levels from USGS Acton well	Long term records for the Acton well; quartiles of the monthly statistics

Indicators included for Streamflow:

- Summer streamflows
- Annual flow variability
- Groundwater levels

Indicators considered but not used for Streamflow:

Channel Flow Status (OARS' field observations) – this was removed from the Report Card in 2023 because visual estimates were not consistent enough for statistics.
Water withdrawals (state records)
% Effluent in the Streamflow (EPA records)
Groundwater depletion (USGS reports and Massachusetts Sustainable Water Initiative)

Indicator = Summer Streamflows

Low flows (particularly summertime streamflows) are one of the primary constraints on maintaining aquatic habitat health. Streamflow scoring curves are based on criteria from several methods for evaluating summertime streamflows for habitat protection (Tennant method, August median flows, 7Q10 flows, and R2Cross criteria). The various criteria are assigned scores (as shown in the example in Table 8) and a best fit line to those points is used to create a scoring curve (for example in Figure 6). Thus, the final scoring curve represents a composite of the various criteria for evaluating streamflow. Streamflows for each river are scored for each mean daily reading from May 1 to September 30 (the expected low-flow period), then the daily scores are averaged for the summer for each river, and annual averages are averaged to calculate a 5-year average. The following formulas have been established for calculating scores for each river:

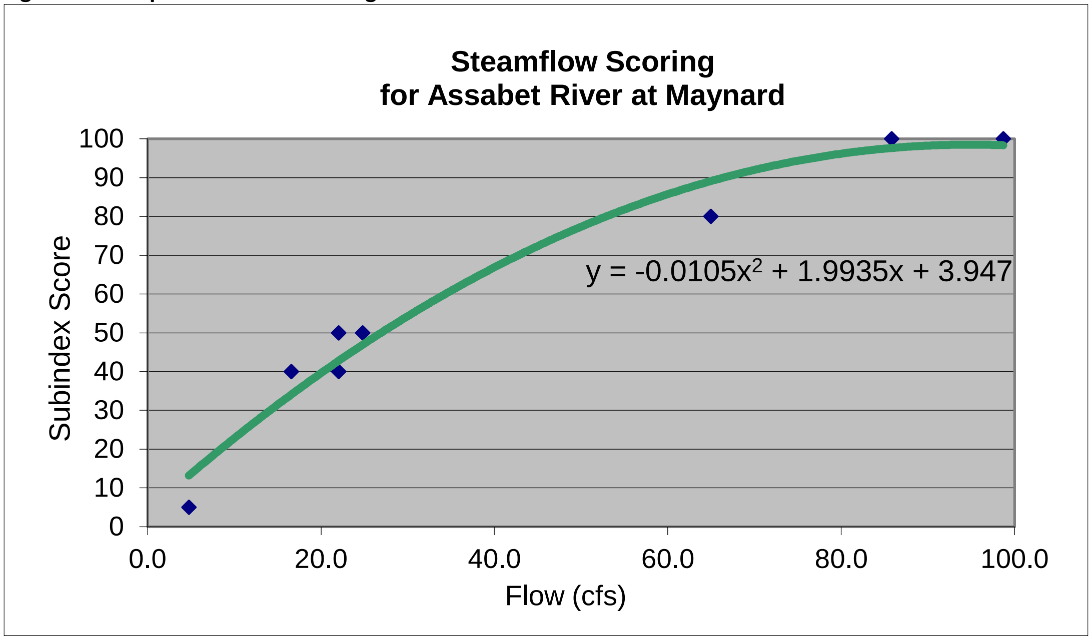
- Assabet: score = -0.0105*flow^2 + 1.9935*flow + 3.947
- Sudbury: score = -0.0126*flow^2 + 2.1816*flow + 3.947
- Concord: score = -0.0009*flow^2 + 0.5781*flow + 3.947

Table 8: Example Streamflow Scoring Criteria

Streamflow scoring curve – Assabet River			
Flow (cfsm)	Flow (cfs) [cfsm x drainage area 116 sq.mi.]	Statistic (Parker et al., 2004) (StreamStats)	Score
0.851	98.72	R2Cross 3/3 criteria (median of 6 Assabet sites)	100
0.74	85.84	Tennant 40% of mean annual flow (median of 6 regional gages)	100
0.56	64.96	Tennant 30% of mean annual flow (median of 6 regional gages)	80
0.214	24.82	Wetted perimeter (median of 6 Assabet sites)	50
0.19	22.04	StreamStats August median flow (median 10 project streams)	50
0.19	22.04	Tennant 10% of mean annual flow (median of 6 regional gages)	40
0.14	16.59	R2Cross 2/3 criteria (median of 6 Assabet sites)	40
0.04	4.76	StreamStats 7Q10 (median 10 project streams)	5

- A Tennant method analysis, which sets recommended flows based on analysis of long-term flow records of *unaltered gages*, was conducted on the combined long-term records of six USGS stream gaging stations in eastern Massachusetts (Parker et al., 2004).
- R2Cross and Wetted Perimeter: R2Cross identifies the minimum level of water needed to let fish pass through shallow riffles. Wetted Perimeter is based on the concept that because most river channels are U-shaped, it is most important to keep the rounded bottom of the U covered with water. R2Cross and Wetted Perimeter analyses conducted at riffles on six streams in the Assabet River watershed yielded median values of 0.851 cubic feet per square mile (cfsm) for R2Cross analysis using 3/3 criteria, 0.143 cfsm for R2Cross analysis using 2/3 criteria, and 0.214 cfsm for Wetted Perimeter analysis (Parker et al., 2004).
- August median and 7Q10 flows were calculated from the USGS long-term record for the mainstem gages (Assabet at Maynard, Sudbury at Saxonville, and Concord at Lowell). The 7Q10 is an estimation of the average 7-day low flows expected to recur once every 10 years. The 7Q10 flows would be expected to provide very poor habitat.
- Measured daily streamflows above the curve maximum (97.27 cfs in the example in Table 8) are assigned a grade of 100. Streamflows below the minimum (4.69 cfs in Table 8) are assigned a value of 1.

Figure 6: Example streamflow scoring curve



Indicator = Annual Flow Variability

Recognizing that a full range of natural flows is needed to maintain the ecological integrity of a stream system, the Report Card assesses the annual hydrographs for the rivers against the major components of a flow regime (magnitude, frequency, duration, timing, and rate of change). As stated by Weiskel et al. (2010), "natural streamflow regimes help to create and maintain the range of habitat properties required for diverse, well-functioning aquatic communities and ecosystems" (Poff and others, 1997). Aquatic ecosystem integrity depends upon the maintenance of an appropriate degree of streamflow variability (Richter and others, 1996). In Massachusetts, natural flow regimes vary substantially in both time and space, and as a function of climate, surficial geology, and hydrologic position in a drainage basin (Armstrong and others, 2001; 2008)." Armstrong et al. (2011) further state "Fish community responses to flow alterations include loss of sensitive species, reduced diversity, altered assemblages, and dominant taxa, reduced abundance, and increases in non-native species… More than three decades of research have illustrated the effects of water withdrawals, the damming and channelization of streams, and urbanization on aquatic communities, including fish."

Assessment: The Nature Conservancy's "Indicators of Hydrologic Alteration" (IHA) software (The Nature Conservancy 2009) is used to compare the last 10 years of record from the USGS gages on the Assabet River at Maynard, Sudbury River at Saxonville, and Concord River at Lowell with the long-term gage record from a gage in the same basin-drainage group identified as "least altered" by Armstrong et al. (2008). The least altered, northern runoff-dominated streams considered for comparison include: Squannacook River near West Groton, MA; Beaver Brook in Pelham, NH; Stony Brook in Temple, NH; Contocook River in MA; Tarbell River in Winchendon, MA; and South Branch Piscataquog near Goffstown, NH. Of these streams, the Squannacook River was selected as most similar to our rivers in terms of watershed area and percent stratified drift per stream length.

Data source: USGS National Water Information System mean daily streamflows for the Sudbury, Assabet, Concord, and Squannacook Rivers.

Score Calculation Steps:
1. Download the mean daily streamflow data from the USGS National Water Information System site for Squannacook River Gage (01096000, Period of Record starting from 10/1/1950), Assabet River Gage (01097000, 10 years), Concord River Gage (01099500, 10 years), and Sudbury River Gage (01098530, 10 years). All data should start with Oct. 1 and end with Sep. 30 for water-year calculations. It is best to use R for the download.
2. Save each downloaded file as a 2-column text file with date and flow.
3. In the IHA software, import the .txt data file(s) and run the analysis for each gage for the desired time period: full period of record for the Squannacook, most recent 10 years of record for Assabet, Sudbury, and Concord River gages.
    a. Import each data file
    b. Create a project for each river
    c. Add and run a new analysis in each project (use wizard for single period, parametric analysis)
4. Export the table of results to Excel for analysis. Normalize the streamflow data for all rivers to the Assabet River drainage (116 sq.mi.) to compare results.
5. Calculate the percent alteration between "least altered" (Squannacook) and the Assabet, Concord and Sudbury Rivers for various IHA statistics:
    a. Potential Alteration (%) = Absolute value ((Affected / Least Altered -1) * 100)
    b. The following statistics recommended by Weiskel et al. (2010) were used:
        i. Median January flow
        ii. Median April flow

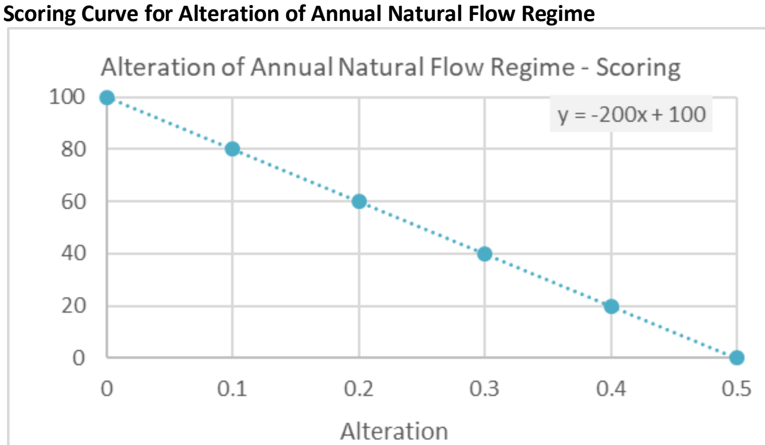
iii. Median August flow
iv. Median October flow
v. Annual 7-day minimum flow
vi. Annual 1-day minimum flow
vii. Annual 3-day maximum flow (added to capture potential changes in flooding due to climate change)
viii. Low-pulse count
ix. Low-pulse duration

6. Compute the linear average of the absolute values of the Potential Alteration percentages for the eight statistical measures as the overall Percent Alteration for the river.
7. Based on the literature[1], the report card score is calculated following the scheme shown in Table 9 and Figure 7.

Table 9: Annual Variability Scoring

Percent Alteration	Description	Score
< 10 %	Near Natural	100
10 - 20%	Least Altered	80
20 - 30%	Altered	60
30 - 40 %	Highly Altered	40
> 40%	Extensively Altered	0

Figure 7: Scoring Curve for Alteration of Annual Natural Flow Regime



[1] Armstrong et al. (2001) showed fish community affects: "The quantile regression plots indicate that (1) as many as seven fluvial-fish species are expected in streams with little flow alteration or impervious cover [<10% alteration in flow], (2) no more than four fluvial-fish species are expected in streams where estimated percent alteration of August median flow from groundwater withdrawals exceeds 50% or the percent area of impervious cover exceeds 15 percent, and (3) few fluvial fish remain at high rates of withdrawal (approaching 100 percent) or high rates of impervious cover (between 25 – 30%)." Weiskel et al. (2010) shows flow alteration as: <10% potential alteration is "near-natural;" 10 – 20% is "least altered;" 20 – 40% is "altered;" >40% is "extensively altered."

Indicator = Groundwater levels

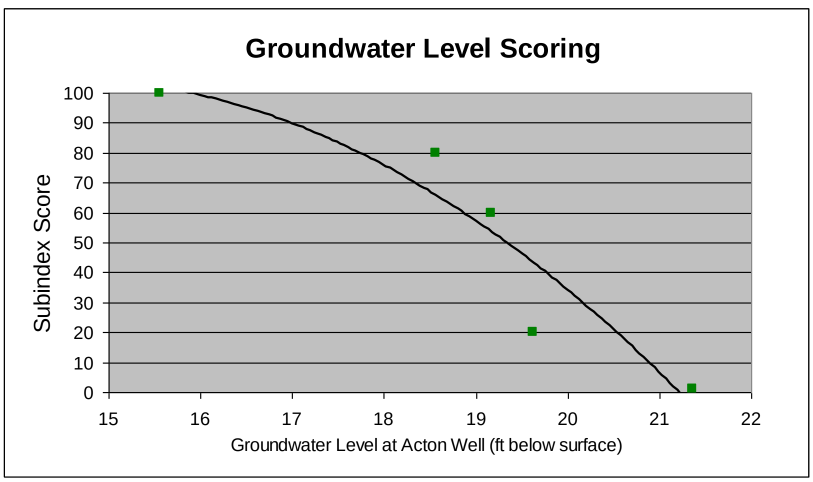
Groundwater provides the summertime baseflow in New England streams and would be expected to respond more slowly to changes in precipitation levels.

Score calculation: Real-time readings from a groundwater monitoring well in the watershed (USGS MA-ACW 158) are available on the USGS web page (http://waterdata.usgs.gov/nwis/uv/). Late summer (Aug 1 to Sept 30) groundwater levels are scored against the medians of the long-term record quartiles for June, July, August, and September and minimum and maximum reading for June - September. Because groundwater levels in New England drop naturally over the summer, the groundwater index readings would be expected to drop over the course of the summer.

Table 10: Groundwater level scoring criteria

Groundwater levels scoring curve for Acton MA-ACW 158 Acton, MA (period of record Jan 1965 – Sept 2001)						
Historic groundwater level statistics	Groundwater level (ft below surface)					
	June	July	August	Sept	**June - Sept**	Score
Highest monthly reading	15.55	16.56	17.71	18.60	**15.55**	100
Upper quartile	17.48	18.15	18.97	19.50	**18.56**	80
Median	18.06	18.89	19.43	19.85	**19.16**	60
Lower quartile	18.85	19.40	19.85	20.15	**19.63**	20
Lowest monthly reading	20.34	20.62	21.00	21.36	**21.36**	1

Figure 8: Groundwater level rating for Acton Groundwater well



Value: Habitat

Landuse and human impacts throughout the watershed (not just directly abutting the rivers) affects river health and habitat. Conservation Assessment and Prioritization System (CAPS) is an ecosystem-based approach for assessing the ecological integrity of lands and waters developed by UMass Landscape Ecology Program (McGarigal, 2011). For this Report Card, the overall CAPS Index of Ecological Integrity scores scaled by watershed (IEI-W) was selected as indicators of habitat quality. Other indicators included are Aquatic Connectivity, a measure of dam and culvert density, and Percent Impervious Cover, sourced from MassGIS. An average value for each indicator is calculated for each river section and area-weighted averages are calculated for the overall watershed.

Indicators included for Habitat:

- Impervious cover
- Ecological Integrity
- Aquatic connectivity

Indicators considered but not used for Habitat:

The following were considered but not included in the Habitat score:

- Crossing and Culverts (North American Aquatic Connectivity Collaborative (NAACC) stream crossing database https://naacc.org/naacc_search_crossing.cfm) – This could be included in the Aquatic Connectivity metric – combined with dams. We decided not to include because we have no data about crossing type.
- CAPS Habitat and Aquatic Connectivity raw data – These were originally used in the 2018 Report Card, but they were replaced because they were duplicates of the Index of Ecological Integrity and overly complicated.
- Aquatic vegetation (OARS data – available for 3 impoundments of the Assabet River)
- Fish communities (Mass Division of Fisheries and Wildlife survey data)
- Macroinvertebrates (Mass Department of Environmental Protection survey data)
- % of the riverfront in permanent protection (datalayers from MassGIS, towns, Sudbury Valley Trustees)

Indicator = Impervious Cover

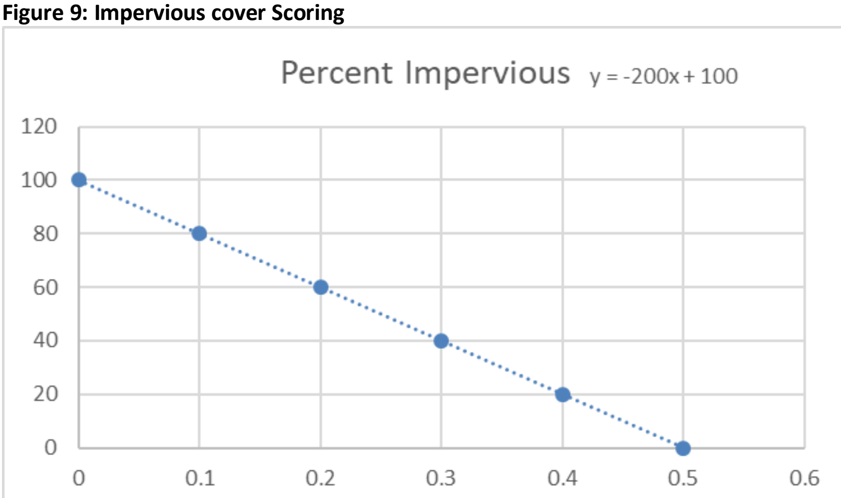
Data Source (2019): CAPS percent impervious data layer (2011). GIS "raw metrics" data downloaded from http://umasscaps.org/data_maps/data.html. Percent values in 30mx30m grids. Averages were calculated by river section using ArcGIS Spatial Analyst Zonal Statistics.
Date Source (2020->): MassGIS LandUse/LandCover data layer (2016). Downloaded from https://www.mass.gov/info-details/massgis-data-2016-land-coverland-use. Filtered for Class (Covercode) 2 Impervious and converted to 1mx1m raster. Total impervious area was calculated by river section using ArcGIS Spatial Analyst Zonal Statistics and divided by total area.

Land use and percent impervious are indicators of habitat integrity or disturbance. The effects of percent impervious in a watershed on fish assemblages has been studied. In 2011 a USGS study of fish and habitat (Armstrong et al., 2011) showed, among other things, that habitat for fish is severely impacted in watersheds with >15% impervious cover.

Table 11: Impervious cover Scoring

USGS description	% Impervious Metric	Grading Score
	0	100
< 10% near-natural	0.1	80
10 – 20% least altered	0.2	60
20 – 40% altered	0.3	40
20 – 40% altered	0.4	20
>40% extensively altered	0.5	0

Figure 9: Impervious cover Scoring



Indicator = Ecological Integrity

Data from a variety of sources were combined to calculate the CAPS Index of Ecological Integrity at each 30-meter grid point state-wide. Over 40 indicators are used in the analysis, including many that are particularly relevant to watershed health: estimates of habitat loss, total impervious and % impervious surface adjacent to wetlands, road traffic, dams, habitat connectedness, aquatic habitat connectivity, flow gradient and volume, and development.

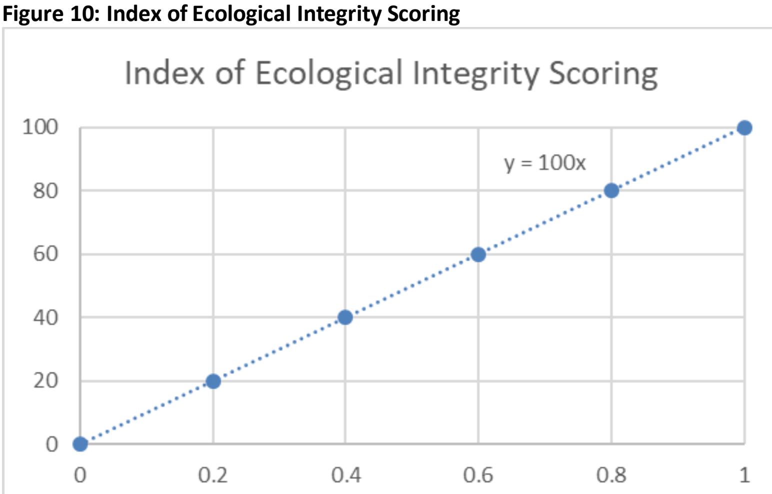
Data source: CAPS GIS data downloaded from http://umasscaps.org/data_maps/data.html Standard Results

For the Report Card, mean CAPS IEI-W scores (0 -1) are calculated for each river section in the watershed using Spatial Analyst Zonal Statistics in ArcGIS; results are exported to Excel and IEI-W scores converted to grading scores. Average grading scores are calculated for each section and area-weighted average scores are calculated for each river and then the whole watershed.

Table 12: Index of Ecological Integrity Scoring

IEI-W Score Range	Grading Score
0-0.2	0
0.2-0.4	20
0.4-0.6	40
0.6-0.8	60
>0.8	80
1	100

Figure 10: Index of Ecological Integrity Scoring



Indicator = Aquatic Connectivity

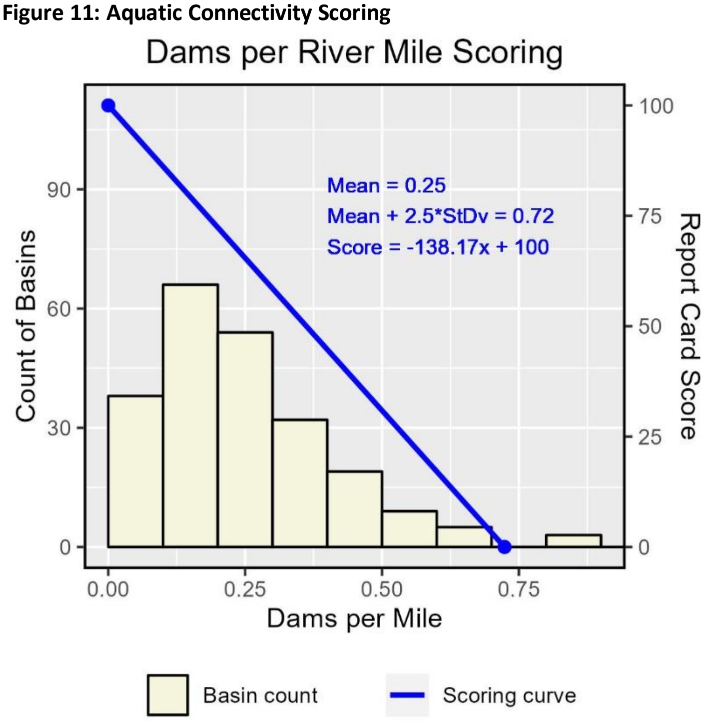
Aquatic Connectivity considers the resistance from dams or other similar connectivity impediments for aquatic organisms. OARS has inventoried all dams within the watershed to calculate a density per river mile for the Report Card. We considered including culverts and stream crossings in the measure, but there is insufficient data available on crossing types.

Data Sources: The list of dams is sourced from the MassGIS Dams layers (https://www.mass.gov/info-details/massgis-data-dams), which is derived from the Mass Office of Dam Safety's dam safety database. River miles are calculated from the USGS Hydrography 1:100K layer. The 100K layer was used to identify the extent of streams included and was adjusted to replace ponds with flowlines for linear calculation.

Following logic like that used in the Tennessee River Basin Report Card (TRBN, 2017), the scoring rubric for Aquatic Connectivity was based on the statistical distribution of dams/river mile densities in all of the NRCS HUC 12 basins in Massachusetts. For all 212 HUC 12 basins in MA, dams per river mile per basin was calculated, and the mean and standard deviation were derived from the full set. See Figure 11 for a histogram of the basins. Following the Tennessee River Basin Report Card logic, a scoring line was drawn from zero dams/river mile (perfect score) to the mean plus 2.5 standard deviations (worst score). This line encompasses almost the full range of dams/river mile ratios in Massachusetts. We are using this line for scoring our report card sections: Score = -138.17 * DpRM + 100.

To calculate our scores, the dams per river mile ratio is calculated in GIS for each of our report card sections. Only active dams are included, and only streams from the 100K hydrography layer are used for river miles. This is then converted to a report card score per report section.

Figure 11: Aquatic Connectivity Scoring



Value: Recreation

Data sources: OARS field data on access points and passage around dams, GIS data on walking and bicycling trails (from Sudbury Valley Trustees, towns, OARS, and OpenStreets), Office of Dam Safety records, USGS National Hydrography Dataset flowlines, and OARS bacteria field data.

Recreational values of the rivers were assessed as: (1) number of access points (put-ins) per mainstem river mile; (2) passability (number of dams per river mile with consideration of the difficulty of passage); (3) number of miles of walking trails within 200 feet (61 meters) of the mainstem rivers, (4) fish edibility based on Department of Public Health fish consumption advisories, and (5)bacterial contamination. River miles were calculated by summing all mainstem stream reaches in the USGS National Hydrography Database flowlines data layer using ArcMap software.

Indicators included for Recreation:

- Passability
- River access
- Trails in riverfront area
- Bacterial contamination
- Fish edibility

Indicators considered but not included for Recreation:

The following were considered but not included in the Recreation score:

- Cyanobacteria (not currently sampled by OARS)
- Recreational use (boating, hiking, or fishing counts)
- Access to river via public transport
- Riparian buffer vegetation (within 200'riverfront area) as a scenic metric for non-urban segments
- Camping along the rivers
- Waterfront amenities such as river walks/waterfront dining, or other indices for urban waterfront areas

Indicator = Passability

Passage around dams for recreational boaters is an important quality for extended boat trips. OARS is working with dam owners to improve passage options.

Data sources: OARS field observations, Office of Dam Safety, and USGS National Hydrography Dataset flowlines for the mainstem river miles.

OARS volunteers assessed recreational passage around dams on the mainstem rivers. Dams were scored (0 – 2) for each of five criteria according to the scheme in Table 13: dam intactness, ownership, ease of access, length of portage, and road crossings in portage. The best possible score for an individual dam would be zero (e.g. the dam is breached and passage is safe, public, and easy). The worst score would be ten (2x5) (e.g. the dam is intact, private, and difficult to portage around). Scores for all the dams in a river section were summed and divided by number of river miles in the section to give a dam-score per river mile. Finally, a grading curve was developed for dam-scores per river mile assuming that zero dams per river mile is ideal and more than one difficult-to-portage dam per river mile is poor (Table 14), and a best fit line was used to create a scoring curve (Figure 12) for overall "passability" of the river section. Scores are calculated as follows: Score = 1.32 * DSpRM^2 – 23.11 * DSpRM + 100.4.

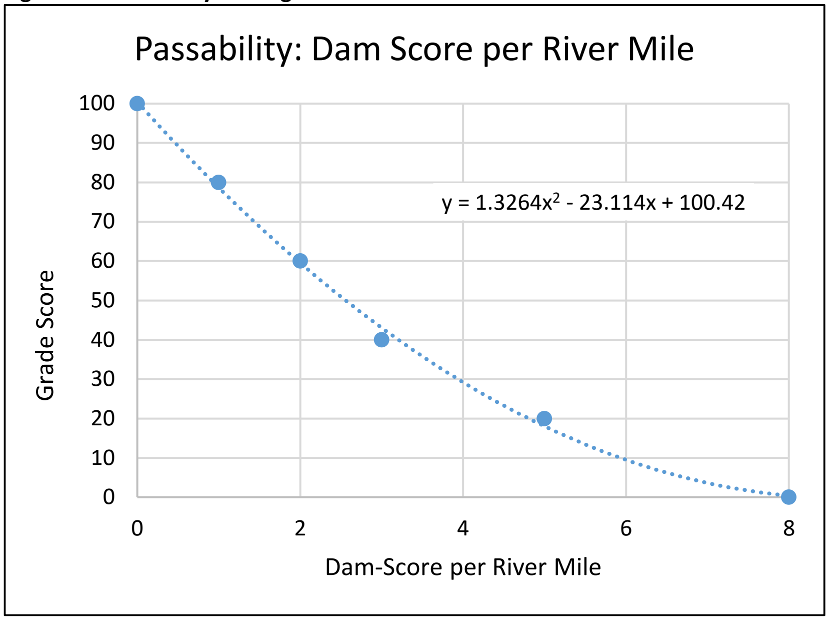
Table 13: Individual Dam Portage Scoring

Category	Description	Points
PORTAGE	Breeched dam (no portage needed)	0
	Breeched need portage/good portage	1
	Intact dam (portage needed)	2
OWNERSHIP	(no portage needed)	0
	Public	1
	Private	2
EASE OF ACCESS	(no portage needed)	0
	good access/easy pullout	1
	difficult access	2
PORTAGE LENGTH	(no portage needed)	0
	<400 ft	1
	>400 ft	2
ROAD CROSSINGS ON PORTAGE	(no portage needed)	0
	path (no roads)	1
	roads	2
	POTENTIAL SCORE (BEST-WORST)	0-10

Table 14: Passability Scoring

Dam-Score / River Mile	Grade	General Description
0	100	No dams blocking recreational passage
1	80	
2	60	Some partial barriers to recreational passage
3	40	
5	20	
8	0	Some complete barriers to recreational passage/ river mile

Figure 12: Passability Scoring



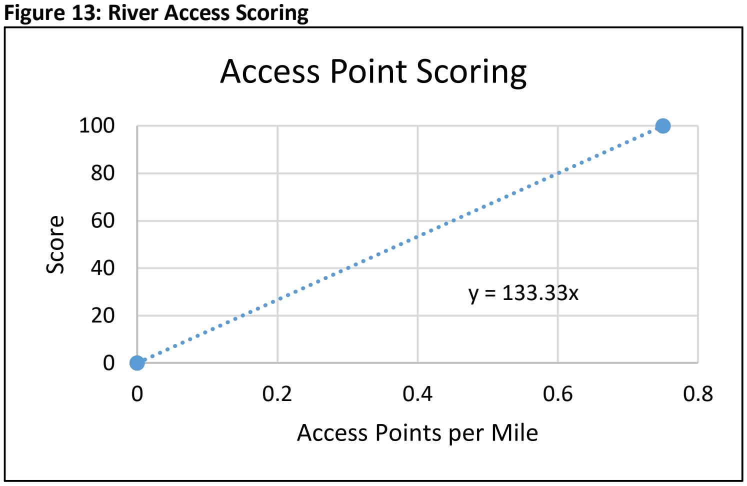
Indicator = River Access

Public access points are key to promoting recreation on the rivers. OARS works with the local towns and landowners to develop and formalize access points along the mainstem rivers. Both launching sites and picnic landings are important for recreational users.

Data source: OARS field observations of access points, and USGS National Hydrography Dataset flowlines for the mainstem river miles.

River access (boating put-ins and landings) was assessed as number of public access points per river mile. Assuming that one access point per 1.3 river-miles (a little less that one access per mile) is ideal and zero is too few, scores were calculated for each river section as follows: score = access points/river-mile * 133.3. Weighted average scores were calculated for the rivers and the overall watershed.

Figure 13: River Access Scoring



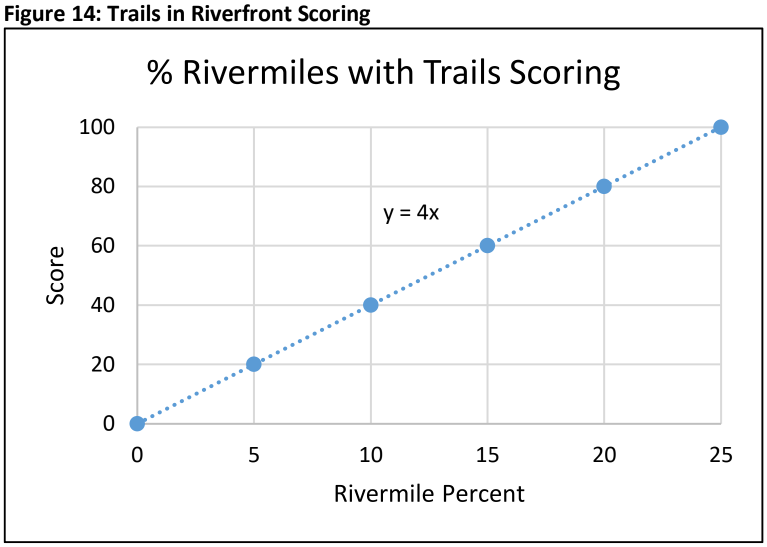
Indicator = Trails in the Riverfront Area

Trails along the river provide river access and enjoyment for all sorts of passive recreation (walking, birding, fishing, bicycling). OARS works with local towns and landowners to develop and formalize trails along the rivers. We promote trails in the whole watershed, but we are particularly interested in trails that provide access to the rivers and views of the rivers.

Data source: GIS data for walking and multipurpose trails (MassGIS trails, Sudbury Valley Trustees maps, Town trail maps, MAPC Trailmap, Strava heat map) – OARS "Trails-near-mainstems" data layer; USGS National Hydrography Dataset flowlines for mainstem river miles.

The metric for trails within 200 feet of the mainstem rivers was calculated in ArcGIS by creating a 200-ft buffer around the mainstem rivers (including a 200-ft buffer around impounded sections) and intersecting that buffer area with the trails layer. Then, the flowline lengths of all the segments of the rivers that contain trails within 200 feet are measured and added up, and this total is divided by the total river miles for each report section. Scoring assumed that having riverfront trails in 25% of the river-miles is good (100% would be ideal but is likely not achievable). Figure 14 shows the scoring curve.

Figure 14: Trails in Riverfront Scoring



Indicator = Bacterial Contamination

Data source: OARS bacteria sampling field data from 6 sites and 15 summer sampling events.

Bacterial contamination is the primary indicator of recreational health safety of water bodies. Fecal Indicator Bacteria *E. coli* and Enterococcus are measured worldwide in recreational water bodies, such as ocean beaches, fresh water lakes, and rivers, to decide whether the water is safe for swimming or boating. *E. coli* is monitored in fresh water, and Enterococcus is monitored in all water. The EPA (EPA 2012) has established thresholds for primary contact (bathing) and secondary contact (boating). For *E. coli*, these thresholds are …

	Single Sample	Geometric Mean
Primary contact	235 CFU/100mL	126 CFU/100mL (most recent 5 samples)
Secondary contact	1260 CFU/100mL (10% of samples)	630 CFU/100mL (previous 6 months)

The EPA has also designed a method for calculating report card grades that is used by both CRWA and MyRWA. They calculate an annual compliance rate for each river section. Then they calculate a 3-year rolling average from the annual rate. The compliance rate is calculated as the average of the % of samples meeting the swimming criteria (235 cfu) and the % of samples meeting the boating criteria (1260 cfu). Grades are assigned per the following rubric:

Grade	A+	A	A-	B+	B	B-	C+	C	C-	D+	D	D-	F
Compliance	95%	90%	85%	80%	75%	70%	65%	60%	55%	50%	45%	40%	<40

For this report card, OARS is applying this same grading method, with a 5-year rolling average, and indexing the results to align with the report card indexes as follows:

Grades	OARS Indexes	EPA compliance percentages
A+	96-100	95% to 100%
A	86-95	90% to 95%
A-	81- 85	85% to 90%
B+	76-80	80% to 85%
B	66-75	75% to 80%
B-	61-65	70% to 75%
C+	56-60	65% to 70%
C	46-55	60% to 65%
C-	41-45	55% to 60%
D+	36-40	50% to 55%
D	26-35	45% to 50%
D-	21-25	40% to 45%

Indicator = Fish Edibility

Fish edibility is important to the “fishable” Class B goal for the rivers and is a particular factor with the SuAsCo rivers due to mercury from the Nyanza Superfund Site in the Sudbury River. The Massachusetts Department of Public Health publishes fish consumption advisories for the state.

Data source: Massachusetts Department of Public Health fish consumption advisories. https://www.mass.gov/info-details/freshwater-fish-consumption-advisory-lookup-table

Score calculation: Scoring was based on the most restrictive advisory published for each mainstem river section. Prior to 2023, DPH used advisory codes as outlined in Table 15. In 2023, DPH started listing advice for both sensitive and general populations, which can be matched to the advisory code descriptions. The advisory codes are assigned grades according to level of restriction as shown in Table 15. These grades are used as the Report Card grades and the middle score for each grade range is entered into the Report Card weighted average calculations (e.g. 50 for a C).

Table 15: Fish Consumption Advisories from Mass DPH

Grade	DPH Advisory Codes	Description
A		*No such water bodies in MA*
C	(no advisory)	*the P1 advisory applies to all water bodies in MA based on atmospheric deposition of mercury (use P1 (species) as least restrictive)*
C	P1 (species)	Children younger than 12 years of age, pregnant women, women of childbearing age who may become pregnant, and nursing mothers should not eat any of the affected fish species (in parenthesis) from this water body.
C-	P1 (all species)	Children younger than 12 years of age, pregnant women, women of childbearing age who may become pregnant, and nursing mothers should not eat any fish from this water body.
D+	P3 (species)	The general public should limit consumption of affected fish species (in parenthesis) to two meals per month.
D	P4	The general public should limit consumption of non-affected fish from this water body to two meals per month.
D	P2 (species)	The general public should not consume any of the affected fish species (in parenthesis) from this water body.
D-	P5	The general public should limit consumption of all fish from this water body to two meals per month.
F	P6	No one should consume any fish from this water body.

Value: Scenery

Indicators included for Scenery:

- Visual quality
- Cultural importance

Indicators considered but not included for Scenery:

The following were considered but not included in the Cultural / Scenic score:

- Trash
- Soundscapes
- Public interface

Indicator = Visual Quality

The *scenic quality* assessment process identifies and describes visible elements of the viewed landscape and rates the scenic quality of the view.

Indicator = Cultural Importance

The *view importance* assessment identifies and describes key attributes of the viewpoint or viewed landscape and rates the importance of the view to NPS and the visitor experience.

The cultural and scenic values of eleven views in the watershed were rated using the National Park Service's Visual Resource Inventory methodology. The National Park Service (NPS) Visual Resource Inventory (VRI) is a systematic process to identify scenic values and importance to NPS visitor experience and interpretive goals, for views within and extending beyond NPS units. The NPS VRI includes two primary processes that lead to ratings for scenic quality and view importance: the scenic quality assessment and the view importance assessment. Mark Meyer and Holly Salazer from the Park Service provided training and help adapting the VRI to river views. The views within the SuAsCo's Wild and Scenic sections will be added to the NPS VRI database. A full description of the Visual Resources Inventory methodology is available online (http://blmwyomingvisual.anl.gov/vr-inventory/nps/).

Views in the Sudbury, Assabet and Concord River watershed were selected to be representative of views within the various river sections. Views are identified, mapped, described, and evaluated in a way that seeks to represent the visitor's experience. Each view is mapped and described from the viewers' perspective and is evaluated to capture two distinct facets of a view: what is its scenic quality, and how important is it to the visitor experience?

Views assessed (view panoramas in Appendix B):

- Upper Assabet River:
  - view upstream from the Hudson Library, Hudson;
- Lower Assabet River:
  - view from the Ice House Landing dock, Maynard;
  - view near the Nashoba Brook / Assabet River confluence, Concord.
- Upper Sudbury River (added in 2020):
  - Mill Pond Park in Ashland;
  - Stearns Reservoir Dam in Framingham.
- Lower Sudbury River:
  - view downstream from Sherman's Bridge, Wayland;
  - view upstream from boathouse at Fairhaven Bay, Lincoln;
  - view from downstream from the South Bridge Boathouse dock.
- Upper Concord River:
  - view from the river access at Bartlett's Landing, Billerica;
  - view downstream from North Bridge, Concord.
- Lower Concord River:
  - view downstream from the East Merrimack Street bridge, Lowell;
  - view of the Faulkner dam and upstream, Billerica;
- (Three Rivers Confluence: view of Egg Rock and river's confluence from the Old Calf Pasture, Concord. This view was not included in the Report Card scoring, because it belongs to all three rivers.)

Data source: OARS / River Stewardship Committee / NPS Visual Resources Inventory survey data.

Score calculation:
At each site, at least four evaluators independently scored the view on each of the attributes called for on the View Description & Scenic Quality Data form (TM_03) and the View Importance Data form (TM_08). The individual scores were averaged in the field to create a consensus rating for each Scenic Quality and View Importance factor. Still in the field, those ratings were summed to calculate totals for each of the sub-categories: Landscape Character Integrity, Vividness, Visual Harmony, View Importance, Viewed Landscape Importance, and View Concern.

In the office, the consensus ratings were transcribed from the field sheets to the *SCORECALC_Scenic&Cultural* Excel spreadsheet *VRI Scoring* tab. For each site, Scenic Quality and View Importance totals were calculated by adding the three corresponding sub-category totals. Then for each river segment, Scenic Quality and View Importance totals were averaged and converted to percent of the possible score. The maximum VRI score in each category is 45. These percentages were taken as the Report Card scores for Scenic Quality and View Importance.

Other Values Considered

Economy

River-based economy values were not included in this report card.
Potential indicators include: visitation/use, tourism-based business, and tourism-based employment.

- Economic impacts:
    - provisioning services like fisheries, pollination, and food production
    - regulating services like flood control, clean water, carbon sequestration, etc.
    - cultural services like recreation and tourism
    - hedonic valuation, i.e. changes in land values
- Economic modeling (which would require a consulting economist); US F&W used IMPLAN software to evaluate economic impacts of restoration; how restoration cycled through the local economy and spurred more local spending (multiplier effect).

OVERALL INDEX CALCULATION

Aggregating the Indicator Scores:

"The aggregation process is one of the most important steps in calculating any environmental index. Here is where most of the simplification (reduction of information) takes places, and here is where most of the distortion is likely to be introduced" (Ott, 1978).

A variety of approaches to aggregating the indicator scores have been used in published indices. Each method suffers some limitation(s). The simpler methods (the linear sum, weighted linear sum, arithmetic mean, and weighted product) tend to "eclipse" low scoring indicators in the aggregation process. Calculating a harmonic mean of the indicator scores allows low-scoring indicators to be more heavily weighted in the overall index.

Several approaches have been used in this Report Card scoring: harmonic mean for the water quality indicators, simple averages for other indicators, and area-weighted averages for aggregating river section scores.

For OARS' Water Quality Index, indicator scores are aggregated using a harmonic mean (reciprocal of the arithmetic mean of the reciprocals—see Equation 1). For the Water Quality Index, we assumed that all indicators are about equally important in supporting aquatic life in a stream, thus strongly weighting any low-scoring indicator accurately reflects its effect on habitat in the overall score. For all other Values (Streamflow, Habitat, Scenic/Cultural, Recreation) a simple average of the indicator scores is used.

Area-weighted averages were used to aggregate the section and watershed scores for each indicator and value. The Overall scores for each river are also calculated as area weighted averages of the overall section scores. However, for the Sudbury, the river overall score is calculated as a straight average of the river-level Value scores, because many of the Upper Sudbury indicators have no data. We will switch the Sudbury to the normal approach as soon as we start calculating all of the Upper Sudbury indicators.

Letter grades were assigned using a 100-point scale with 20-point breaks (Table 16). Since this scheme does not follow the typical academic system (e.g. <60 is a "D"), we do not present the numeric scores in the public-facing part of the Report Card.

Table 16: Letter Grade Scale

Grades	Points	Description
A+	95-100	Very Good
A	85-94	Very Good
A-	80-84	Very Good
B+	75-79	Good
B	65-74	Good
B-	60-64	Good
C+	55-59	Moderate
C	45-54	Moderate
C-	40-44	Moderate
D+	35-39	Poor
D	25-34	Poor
D-	20-24	Poor
F	0-19	Very Poor

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Oregon Department of Environmental Quality Water Quality Index
https://www.oregon.gov/deq/wq/Pages/WQI.aspx

Other EcoHealth Report Cards:
https://ecoreportcard.org/