WATER QUALITY OF TRIBUTARIES IN THE WACHUSETT WATERSHED 1998 – 2007

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Massachusetts Department of Conservation and Recreation
Division of Water Supply Protection
Office of Watershed Management

Abstract:
This ten-year water quality summary examines physical, chemical, and biological trends at tributary stations throughout the Wachusett Reservoir watershed from 1998 through 2007. Water quality has improved in many tributaries due to construction of sewers, replacement of poorly functioning septic systems, use of best management practices at significant agricultural sites, and control of stormwater. The report adds to the Division of Water Supply Protection's understanding of the range of factors that impact water quality and suggests monitoring and research directions for the next ten years.

Acknowledgments:
This report was written by Lawrence Pistrang, Environmental Analyst with the Department of Conservation and Recreation, Division of Water Supply Protection, Office of Watershed Management's Wachusett/Sudbury Operational Section. Dave Getman, Frank Battista, and Kelley Freda assisted with sampling and analysis. The Massachusetts Water Resources Authority staff at the Southborough and Deer Island labs provided additional analysis. Jenny Pistrang helped with initial data organization and interpretation. Joel Zimmerman gave formatting and editing support.

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1. INTRODUCTION

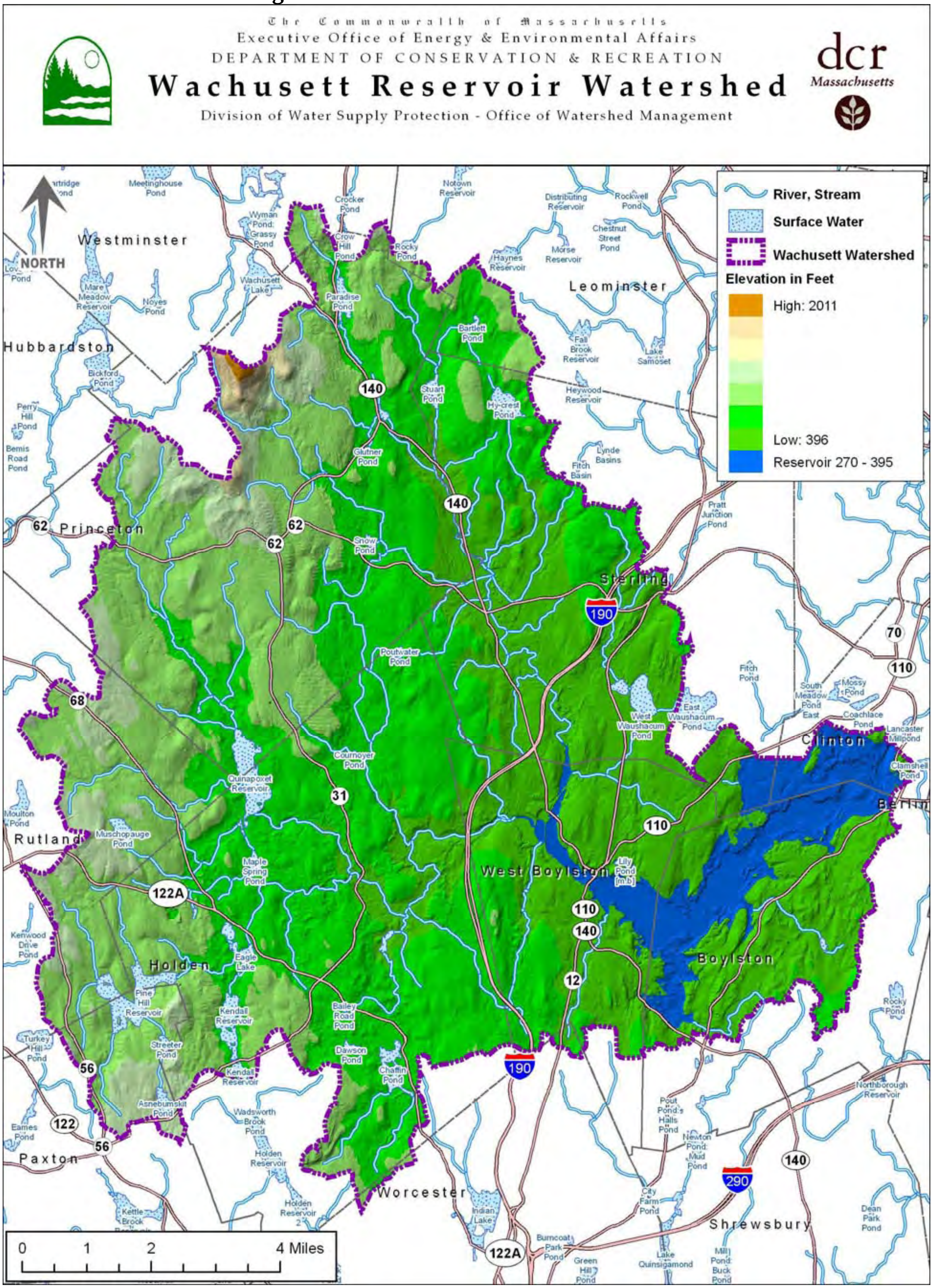
Chapter 372 of the Acts of 1984 established the Department of Conservation and Recreation Division of Water Supply Protection Office of Watershed Management (originally known as the Metropolitan District Commission Division of Watershed Management). The Division was created to manage and maintain a system of watersheds and reservoirs and provide pure water to the Massachusetts Water Resources Authority (MWRA), which in turn supplies drinking water to approximately 2.5 million people in forty-six communities.

The overall mission and both short and long term goals of the Division require the routine sampling of tributaries within the watershed (see Figure 1). Water quality sampling helps identify tributaries with water quality problems and ensures compliance with state and federal water quality criteria for public drinking water supply sources. Bacterial monitoring of tributaries provides an indication of sanitary quality and helps to protect public health. Division staff also sample to understand the responses of tributaries to a variety of physical, chemical, and biological inputs, and to assess the ecological health of the watershed.

Routine water quality sampling in the Wachusett watershed has been conducted since 1988 by Division staff. Analysis has taken place in the field, in Division facilities in Clinton and West Boylston, and at the MWRA Southborough and Deer Island laboratories. Data are compiled and published by Division staff each March as part of an annual water quality report. Major tributaries have been sampled on a regular basis for twenty years, but many of the other tributaries have been sampled with varying frequency and the list of parameters has changed as well. The Division published a comprehensive ten year summary in 1998 that attempted to analyze the physical, chemical, and biological data collected and to discuss any obvious water quality trends. This second ten year summary will examine the period between 1998 and 2007 and look for ongoing trends, changes related to specific watershed protection efforts including the expansion of sewers, and water quality impacts linked to seasonal patterns or precipitation events. Water quality will also be compared to the previous ten year period.

Individual chapters will address water quality at each sampling station. The report will conclude with an overall summary and conclusion for each of the most significant parameters as well as a look forward towards the next ten years.

Figure 1: Wachusett Reservoir Watershed



2. PHYSICAL, CHEMICAL, AND BIOLOGICAL SAMPLING

Samples were collected from sixty-one stations on thirty-six tributaries during the ten year period covered by this report. Only a subset of stations was sampled each year (Table 1). A variety of parameters were measured, with fecal coliform, conductivity, macroinvertebrates, nutrients, and metals providing the most useful data sets for water quality assessment and trend analysis. All data collected are available in a series of annual water quality reports (MDC/DCR, 1999 – 2008).

Sixteen stations on eleven tributaries were sampled all ten years and three others were sampled in all but one of the years. Six stations were sampled only during 1999 and 2000 to confirm conditions documented in the previous ten year report.

Fecal coliform has remained the primary parameter for monitoring water quality especially as it relates to public health, although future reports will instead interpret *E. coli* data to reflect a shift in state water quality standards. The interpretation of fecal coliform data and the generation of annual statistics require an understanding of the common distribution of bacterial populations. Correct application of statistical measures requires a symmetrical distribution of measured data, but fecal coliform concentrations often vary by several orders of magnitude after a rain event or during the summer, and annual data sets are generally characterized by having many low values and a few very high ones. Arithmetic means calculated are often much higher than the median and can lead to incorrect assessments of annual water quality.

Although state regulations have until very recently referenced arithmetic mean as the standard, DCR staff have used annual median and more recently geometric mean to help interpret water quality trends. The reasoning behind this decision is summarized in the following excerpt from Standard Methods:

> "It is usually necessary to convert skewed data so that a symmetrical distribution resembling the normal distribution results. An approximately normal distribution can be obtained from positively skewed data by converting numbers to their logarithms. If the logarithms of numbers from a positively skewed distribution are approximately normally distributed, the original data have a log-normal distribution. The best estimate of central tendency of log-normal data is the geometric mean. The geometric mean is equal to the antilog of the arithmetic mean of the logarithms. Therefore, although regulations or tradition may require or cause microbiological data to be reported as an arithmetic mean or median, the preferred statistic for summarizing microbiological data is the geometric mean."
>
> (Standard Methods, 17th edition, 1989, pg. 9-21)

Sampling for fecal coliform and for physical and chemical parameters was supplemented by the collection of macroinvertebrate samples at seventeen stations on thirteen tributaries. Streams are dynamic systems, and grab samples that measure a selected set of parameters at a single moment in time obtain a static picture of a rapidly fluctuating environment. Biotic communities have the ability to integrate the effects of short-term environmental stresses and can reflect impacts of intermittent or low level contamination. The Division collects aquatic macroinvertebrates due to their general abundance, relative ease of sampling and identification, and sessile nature.

Table 1:
SAMPLING STATIONS (1998-2007)

STATIONS	1998	1999	2000	2001	2002	2003	2004	2005	2006	2007
1. Airport		x	x							
2. Asnebumskit (Mill)	x	x	x				x	x	x	x
3. Asnebumskit (Prin)		x	x				x	x	x	x
4. Bailey		x	x							
5. Ball	x	x					x	x	x	x
6. Beaman 1		x	x			x				
7. Beaman 2						x	x	x	x	x
8. Beaman 3						x	x	x	x	x
9. Beaman 3.5							x	x	x	x
10. Boylston	x, bio	x	x	x, bio	x	x	x	x	x	x
11. Chaffins (Malden)	x, bio	x	x				x	x	x	x
12. Chaffins (Poor Farm)							x	x	x	x
13. Chaffins (Unionville)	x, bio	x	x				x	x	x	x
14. Chaffins (Wachusett)							x	x	x	x
15. Cold		x	x							
16. Cook	x	x, n	x, n	x, n	x, n	x, n	x, n	x, n	x, n	x, n
17. EWachusett (140)	x, bio	x	x	bio (3)			x	x	x	x
18. EWachusett (31)		x	x				x	x	x	x
19. EWachusett (Bull)							x	x	x	x
20. French	x	x, n	x, n	x, n	x, n	x, n	x, n	x, n	x, n	x, n
21. Gates 1	x, bio	x, n	x, n	x, bio (3), n	x, n	x, n	x, n	x, n	x, n	x, n
22. Gates 2	x, bio	x	x	x, bio	x	x	x	x	x	x
23. Gates 3	x	x	x	x	x	x	x	x	x	x
24. Gates 4	x	x	x	x, bio	x	x	x	x	x	x
25. Gates 6	x	x	x	x	x	x	x	x	x	x
26. Gates 9	x	x	x	x	x	x	x	x	x	x
27. Governor		x	x							
28. Hastings	x	x	x	x	x	x	x	x	x	x
29. Hog Hill							x	x	x	x
30. Houghton		x	x				x	x	x	x
31. Jordan Farm	x	x, n	x, n	x, n	x, n		x, n	x, n	x, n	x, n
32. Justice	x	x	x				x	x	x	x
33. Keyes (Gleason)	x	x	x				x	x	x	x
34. Keyes (Hobbs)							x	x	x	x
35. Keyes (Onion)							x	x	x	x
36. Landfill		x	x							
37. Malagasco	x, bio	x, n	x, n	x, bio, n	x, n	x, n	x, n	x, n	x, n	x, n
38. Malden	x, bio	x, n	x, n	x, bio, n	x, n	x, n	x, n	x, n	x, n	x, n
39. Muddy	x, bio	x, n	x, n	x, bio, n	x, n	x, n	x, n	x, n	x, n	x, n
40. Oakdale		x	x				x	x	x	x
41. Quinapoxet (CMills)					x, n-m12	x, n-m12	x, n-m12	x, n-m12	x, n-m12	x, n-m12
42. Quinapoxet (dam)	x, bio	x, n12	x, n12	x, bio (3), n12		x	x	x	x	x
43. Quinapoxet (Mill St)	x			bio			x	x	x	x

STATIONS	1998	1999	2000	2001	2002	2003	2004	2005	2006	2007
44. Rocky	x	x	x				x	x	x	x
45. Rocky (East Branch))	x	x, n	x, n	x, n	x, n		x, n	x, n	x, n	x, n
46. Scanlon	x	x	x	bio			x	x	x	x
47. Scarlett	x	x	x				x	x	x	x
48. Scarlett (Rt12)							x	x	x	x
49. Stillwater (62)							x	x	x	x
50. Stillwater (sb)	x	x, n12	x, n12	x, bio (3), n12	x, n-m12	x, n-m12	x, n-m12	x, n-m12	x, n-m12	x, n-m12
51. Swamp15	x	x	x				x	x	x	x
52. Trout	x, bio	x	x	bio (3)			x	x	x	x
53. Unnamed		x	x							
54. Warren Tannery		x	x				x	x	x	x
55. Waushacum (Connelly)							x	x	x	x
56. Waushacum (filter bed)							x	x	x	x
57. Waushacum (Fairbanks)							x	x	x	x
58. Waushacum (Prescott)	x	x	x	x, bio	x	x	x	x	x	x
59. Waushacum (WWP)							x	x	x	x
60. WBoylston	x, bio	x, n	x, n	x, bio, n	x, n	x, n	x, n	x, n	x, n	x, n
61. Wilder	x	x	x				x	x	x	x

Key:
x = fecal coliform/conductivity (weekly)
n = nutrients (2-8 times per year)
bio = biomonitoring (May)
bio (3) = biomonitoring (May/July/Oct)
n12 = nutrients (monthly)
n-m12 = nutrients and metals (monthly)

Wachusett staff collected routine water quality samples weekly throughout the ten year period. Sampling stations are described at the beginning of each of the sixty-one station chapters that follow. Each tributary station scheduled for sampling was visited throughout the entire year, although samples were not collected at some stations during low flow or no-flow conditions. Temperature and conductivity were measured in the field using a Hydrolab Surveyor III (1998), YSI Model 30 conductivity meter (1999-2000, 2004-2007) or Corning CD-30 conductivity meter (2001-2003). Changes in instrumentation may have impacted conductivity measurements and will be addressed later in this report.

Weekly grab samples were collected for fecal coliform analysis and delivered on ice to the MWRA Southborough Lab for filtration. Samples were collected 2 – 8 times per year from nine stations and analyzed at the MWRA Deer Island Lab for alkalinity, conductivity, ammonia, nitrate-nitrogen, nitrite-nitrogen, total phosphorus, total silica, dissolved silica, UV-254, total suspended solids, and total organic carbon. Monthly samples for the same parameters plus metals were collected from the Quinapoxet and Stillwater Rivers. Depth measurements were done at these stations to calculate flow using previously established rating curves. Sample collection and analyses were conducted according to Standard Methods for the Examination of Water and Wastewater 20th Edition (1998).

Precipitation data from NOAA weather stations in Worcester and Fitchburg, from the USGS station on the Stillwater River in Sterling, and from a staff monitored rain gauge in West Boylston were compiled daily to help interpret water quality data.

Macroinvertebrate samples were collected in May 1998 and in May, July, and October 2001 using a one-minute kick technique. Bottom substrates in a stream riffle area were disturbed using hands and feet for one minute upstream of a hand-held rectangular net. The macroinvertebrates collected in the net were placed in a small pan and a one hundred organism subsample randomly removed for identification. Samples were preserved in the field with 70% ethyl alcohol. Specimens were sorted and identified to the lowest practical taxonomic level (usually genus or species) using available references. All sampling and identification was done by a Division aquatic biologist.

Two reference stations were selected with a healthy, diverse macroinvertebrate community. Samples and sampling stations in the Wachusett watershed were compared with these reference stations to determine if macroinvertebrate populations were impacted and if impacts were the result of pollutants or poor habitat.

Five metrics were calculated at each sampling location and compared to the metrics calculated at the two reference stations. The ratios of the sampling site metrics to the reference site metrics were calculated and given scores based on EPA biological condition scoring criteria to produce an assessment of the level of impairment. Metrics used were number of taxa, the Hilsenhoff biotic index, number of mayfly/stonefly/caddisfly (EPT) taxa, ratio of EPT taxa to chironomid midges, and percent contribution of the dominant taxonomic group. A description of these metrics and how to interpret them is available in the first ten year summary report published in 1998.

3. SAMPLING STATION SUMMARIES

Each of the sixty-one sampling stations with multiple years of data from the period between 1998 and 2007 are addressed separately in the chapters that follow. A description of the station, flow information (if available), land use of the contributing area, and sampling history precede summaries of water quality. Fecal coliform and conductivity data are assessed for each station, and nutrients, metals, and macroinvertebrates are discussed if data were available. Fecal coliform data are examined in the greatest detail, with a discussion of seasonal differences, impacts from precipitation events, and long term trends.

3.1 AIRPORT BROOK

Water quality samples were collected just downstream of Greenland Road approximately 500 yards from the Stillwater River. The stream is ten feet in width at this sampling location and is very slow moving, with extensive areas of surrounding swampland. Flow under the road is in twin 36" culverts. Fecal coliform and conductivity samples were collected weekly in 1999 and 2000, although intermittent flow limited collection in the summer of 2000. A total of 78 samples were collected and analyzed. Nutrient, metals, and macroinvertebrate samples have not been collected in this subbasin, and there is no information on flow.

Four samples had been collected for fecal coliform and conductivity analysis in 1989. No additional samples were collected during the previous ten year period (1988-1997).

The Airport Brook subbasin is comprised of 525 acres of forest and open land (65%), residential development (18%), and agriculture use (14%). The remaining area is covered by wetlands and a section of the Sterling Airport. The percentages of residential development and agriculture use are both higher than the watershed average, as is the percentage of impervious cover (6.8%).

All annual fecal coliform metrics showed slight improvements in 2000 (see Table 2), although this appears to have been related to the lack of late summer or fall samples collected in that year. The geometric mean of seasonally grouped samples collected during the winter (January-March), spring (April-June), and summer (July-September) of 1999 and 2000 were nearly identical.

Table 2:
AIRPORT BROOK – FECAL COLIFORM AND CONDUCTIVITY

YEAR	88-97	98	99	00	01	02	03	04	05	06	07
fecal – median	3		21	11							
fecal – geomean	4		15	10							
fecal – %>20	25		50	40							
fecal – %>100	0		8	3							
(total samples)	(4)		(48)	(30)							
conductivity	89		99	107							

Seasonally grouped samples exhibited significant differences at this station and at every other sampling station in the watershed. All metrics at Airport Brook were lowest during the winter months, with a geometric mean of only 5 cfu/100mL. In sharp contrast, the geometric mean during the summer months was greater than 50 cfu/100mL, and more than 90% of all samples collected during this season contained more than 20 cfu/100mL. Elevated fecal coliform during the summer months is the normal condition at sampling stations throughout the watershed, and appears related to a natural reduction in flow and subsequent concentration of bacteria in the tributaries.

Only limited storm event data were collected and therefore nothing conclusive can be stated about the water quality impacts of storm events on Airport Brook. It is likely, however, that any contaminants entering the tributary would be at least partially removed due to the presence of extensive wetlands.

Annual conductivity values have been fairly consistent although they did appear to increase slightly (Table 2). This has been a common pattern at almost every sampling station in the watershed and may reflect a slight decline in water quality or simply be an artifact of changes in monitoring equipment, sampling frequency, and weather conditions.

Upstream residential development and the resultant high percentage of impervious cover are likely impacting water quality, although wildlife could also be a source of fecal coliform. Beaver activity was noted, with most indications of presence at or in close proximity to the Stillwater River.

Data suggest that water quality in this small tributary is adequate even though land use is less than ideal. Additional sampling is unnecessary.

3.2 ASNEBUMSKIT BROOK

3.2.1 Mill Street

Water quality samples were collected just upstream of the Mill Street Bridge approximately 150 yards upstream of the Quinapoxet River. The stream is approximately fifteen feet in width at this sampling location, flowing rapidly over large boulders and areas of bedrock. Samples for fecal coliform and conductivity were collected weekly in 1998, 1999, and 2000, and again from 2004 through 2007. A total of 336 samples were collected and analyzed. Macroinvertebrate samples were collected in May of 1998 and 2001 at a location approximately 100 yards upstream from the primary sampling station. Nutrient and metals samples were not collected from this segment of Asnebumskit Brook and no information on flow has been collected.

A total of 160 samples were collected for fecal coliform and conductivity analysis between 1988 and 1995. Macroinvertebrate samples were collected from this tributary in 1988, 1989, and 1990 at a location approximately 100 yards upstream from the primary sampling station.

The Asnebumskit Brook subbasin is comprised of 707 acres of forest and open land (54%), residential development (41%), agriculture use (4%), and commercial development (1%). Nearly all of the residential development is on parcels of one half acre or less. The percentage of residential development is much higher than the watershed average and is one of the highest in the watershed, as is the percentage of impervious cover (14.2%). Land within 400 feet of the brook is predominantly covered by forest or open land, however, especially downstream near the sampling station, which helps mitigate any threats from contaminants.

Fecal coliform metrics have been relatively stable with some improvement throughout the ten year period (see Table 3). The last two years of sampling resulted in some of the best water quality data of the past twenty years. Annual median values assembled in five year groupings showed a steady improvement (40/31/25/23); the percentage of samples exceeding 20 cfu/100mL did the same (66/60/54/49).

Table 3:
ASNEBUMSKIT BROOK (Mill Street) – FECAL COLIFORM AND CONDUCTIVITY

YEAR	88-97	98	99	00	01	02	03	04	05	06	07
fecal – median	25-59	31	19	20				30	23	20	20
fecal – geomean	n/a	28	15	17				27	30	25	23
fecal – %>20	50-78	64	50	48				57	50	41	47
fecal – %>100	13-44	14	2	14				13	24	24	13
(total samples)	(160)	(50)	(50)	(50)				(46)	(42)	(51)	(47)
conductivity	127-177	191	186	190				274	229	210	217

Seasonally grouped samples exhibited differences at this station and at every other sampling station in the watershed, although they appeared less significant at Mill Street station. Fecal coliform concentrations were generally low in the winter, increasing in the spring and summer, and then dropping slightly in the fall. Other stations in the watershed often showed a more dramatic improvement in water quality in the fall.

One of the difficulties interpreting fecal coliform data is that summarized data can be greatly influenced by variable conditions. Poor water quality in the fall appears to be related to impacts from storm events. When only dry weather samples were considered, the geometric mean of fall samples was as low as that of the winter samples, and the percentage of samples exceeding 20 cfu/100mL was less than at any other time of year. Using either dry weather samples, wet weather samples, or all samples collected, water quality is worst in the spring and summer.

Regardless of the season, wet weather samples have water quality that is dramatically worse than dry weather samples. Annual median values of dry samples during the seven years of sampling were between 10 and 23 cfu/100mL, while annual median values of wet weather samples from the same period were between 80 and 230 cfu/100mL. Between 80 and 100% of all wet weather samples exceeded 20 cfu/100mL, and at least 40% exceeded 100 cfu/100mL. The maximum percentage of dry weather samples exceeding these two thresholds were 54% and 15%.

Annual conductivity values increased significantly in 2004, but then declined and remained fairly uniform for the past three years. Mean conductivity for the current ten year period was 44% higher than for the previous ten year period, but that is actually a smaller increase than the watershed average of 56% (determined by using ten tributaries that have been sampled consistently for the past twenty years). Steadily increasing conductivity has been observed at nearly all sampling stations in the watershed and may reflect a decline in water quality or simply be an artifact of changes in monitoring equipment or weather conditions.

Conductivity measured at this station was remarkably uniform throughout the year, usually without an increase during the summer that is common in most other tributaries. It appears that reduction in stream flow during the summer may also reduce the input of contaminants. Elevated levels were seen occasionally during the winter, most likely the result of salt applications to roadways following storms. Samples collected upstream at Princeton Street were very different in character, with sharply elevated conductivity measured during the summer.

Macroinvertebrate samples were collected in May of 1998 and 2001 using a one-minute kick technique. The stream is between four and five yards in width at the sampling station which is approximately 100 yards upstream from the primary water quality sampling station. The substrate consists primarily of sand and gravel and is not ideal for comparison with the reference station at Trout Brook, but is within the acceptable range.

A sample collected in 1998 showed no impairment when compared to the reference station, and the sample from 2001 showed only slight impairment. Samples collected in 1988, 1989, and 1990 also showed only slight impairment when compared to the reference station. Most metrics fell within the ranges recorded at the reference station. The dominant species in all samples was one of the Ephemerellidae mayflies, usually *Ephemerella dorothea*. Other than the dominant group, the insect population in this stream usually seems to consist of many species in small numbers, indicative of a healthy environment.

It is important to note that both Warren Tannery Brook and Eagle Lake discharge to Asnebumskit Brook upstream of the primary sampling station. There are a number of sources of contamination within both of these subbasins, including substantial residential development which could be impacting Asnebumskit Brook. There is also considerable development and a variety of other potential threats in the headwater region of Asnebumskit Brook, and a sampling station in that area has poor water quality (Chapter 3.2.2). Much of the land bordering on the downstream portion of Asnebumskit Brook is owned by the Division and serves as a protective buffer, however, and water quality has improved.

An expansion of the municipal sewer system within developed areas of this subbasin has led to an increase in sewer connections, and may help explain the apparent water quality improvements detailed previously. Fecal coliform contamination from existing septic systems and from sewer overflows remains a threat, although stormwater transport of contaminants is the primary threat to water quality in this subbasin. Regular sampling at the Mill Street station should continue to help document further improvements, and additional sampling locations should be established upstream to help determine the sources of contamination near the headwaters.

3.2.2 Princeton Street

Water quality samples were collected just upstream of Princeton Street about 2.5 miles upstream of the sampling station described in Chapter 3.2.1. The stream is between fifteen and twenty feet wide at the Princeton Street sampling location, flowing slowly over large boulders and areas of sand and silt. Samples for fecal coliform and conductivity were collected weekly in 1999 and 2000, and again from 2004 through 2007. A total of 295 samples were collected and analyzed. No samples for macroinvertebrates, nutrients, or metals were collected from this segment of Asnebumskit Brook during this time period, and no information on flow is available. A number of additional samples were collected from upstream locations during the past few years to try and locate a persistent source of fecal coliform.

A total of 22 samples were collected for fecal coliform and conductivity analysis in 1991. A small number of sediment samples for metals were collected a short distance downstream following a sewer overflow. An attempt to collect macroinvertebrate samples at the same location was not successful due to a lack of quality habitat.

This sampling station is located close to the headwaters of Asnebumskit Brook in an area of residential development with parcels of one half acre or less. There are a number of homes in close proximity to the brook. Domestic animals and wildlife are common and a probable source of fecal coliform. Asnebumskit Brook flows out of Eagle Lake, which at times has a substantial resident population of Canada geese, and the brook flows beneath Route 122A which at times has harbored a substantial number of roosting pigeons. Residents of Holden use Eagle Lake as a swimming location during the summer months. There is also some commercial development and a golf course within the subbasin.

Fecal coliform concentrations have been very high during the ten year period (see Table 4), although there are some signs that water quality might be improving. During three of the last four years of sampling, less than three quarters of the samples exceeded 20 cfu/100mL and less than half exceeded 100 cfu/100mL. While this is still very poor water quality, it is a marked improvement from the results of 1999 and 2000. An expansion of the municipal sewer system within developed areas of this subbasin has led to an increase in the percentage of homes connected to the sewer, and may explain the apparent water quality improvements.

Table 4:
ASNEBUMSKIT BROOK (Princeton Street) –
FECAL COLIFORM AND CONDUCTIVITY

YEAR	88-97	98	99	00	01	02	03	04	05	06	07
fecal – median	149		465	231				70	50	360	60
fecal – geomean	n/a		384	281				82	73	228	64
fecal – %>20	77		100	90				74	58	82	63
fecal – %>100	62		80	67				47	48	67	39
(total samples)	(22)		(50)	(48)				(47)	(50)	(51)	(49)
conductivity	100		167	152				242	193	172	176

Seasonally grouped samples exhibited pronounced differences at this station, similar to what was seen at most other sampling stations in the watershed. The annual geometric means of winter samples (January-March) were always less than 100 cfu/100mL. Annual geometric means of summer samples (July-September) were always greater than 350 cfu/100mL and in one year was as high as 2026 cfu/100mL.

Unlike most other sampling stations, water quality at Asnebumskit Brook (Princeton Street) does not appear to be strongly influenced by storm events. Annual median values of dry samples during the seven years of sampling were between 49 and 354 cfu/100mL, while annual median values of wet weather samples from the same period were only slightly higher at between 90 and 982 cfu/100mL. Between 39% and 80% of all dry weather samples exceeded 100 cfu/100mL. The percentage of wet weather samples exceeding this threshold ranged from 33% to 78%. The source of fecal coliform contamination at this station appears not to be related to or transported by stormwater runoff.

Flow in Asnebumskit Brook near this station is very slow to nonexistent during the summer, and it appears that there may be a population of fecal coliform bacteria surviving in the sediment beneath the pools of warm nutrient rich water. The presence of wild animal tracks (raccoons) suggests a possible source, as does the proximity of domestic animals (dogs) to the brook. During a storm event, there likely is an increased input of bacteria, but it appears to be balanced by the additional flow which dilutes the concentration.

Annual conductivity values reached a maximum in 2004, but then declined sharply in 2005 and again in 2006 to approach levels previously seen during 1999 and 2000. Conductivity measured at this station was sharply elevated during the summer.

Samples collected from the Princeton Street station had much higher concentrations of fecal coliform than did samples from the Mill Street station, with annual geometric mean values between two and twenty-five times higher (Table 5). The differences between the stations were greatest in 1999 and 2000. Although bacteria concentrations were always higher at the Princeton Street station, conductivity was always lower which suggests a source of fecal coliform that is not human. Human waste from sewers or septic systems usually is very high in conductivity. Continued efforts should be made to determine the source of contamination, possibly by using alternative indicators.

Table 5:
ASNEBUMSKIT BROOK – ANNUAL GEOMETRIC MEAN FECAL COLIFORM AND ANNUAL MEDIAN CONDUCTIVITY

STATION	1999	2000		2004	2005	2006	2007
Princeton Street – annual geometric mean	384	281		82	73	228	64
Mill Street – annual geometric mean	15	17		27	30	25	23
Princeton Street – annual median conductivity	167	152		242	193	172	176
Mill Street – annual median conductivity	186	190		274	229	210	217

3.3 BAILEY BROOK

Water quality samples were collected downstream of Beaman Road in Sterling, approximately 800 yards before it discharges into the Stillwater River. The stream is less than three feet in width at this sampling location. The brook upstream of the sampling station flows out of a man-made pond owned by a rod and gun club and passes through a large wetland before crossing under the road.

A total of 91 fecal coliform and conductivity samples were collected weekly and analyzed during 1999 and 2000. Samples for nutrient, metals, and macroinvertebrate have not been collected in this subbasin, and there is no information on flow.

Four samples were collected for fecal coliform and conductivity analysis in 1989. No additional samples were collected during the previous ten year period (1988-1997).

The Bailey Brook subbasin is comprised of 343 acres of forest and open land (86%) and low or medium density residential development (14%). Much of the subbasin is owned by the Division and permanently protected. Nearly all of the medium density residential development is located in a single neighborhood downstream of the sampling station.

Table 6:
BAILEY BROOK – FECAL COLIFORM AND CONDUCTIVITY

YEAR	88-97	98	99	00	01	02	03	04	05	06	07
fecal – median	2		1	1							
fecal – geomean	2		3	2							
fecal – %>20	25		10	10							
fecal – %>100	25		0	0							
(total samples)	(4)		(41)	(49)							
conductivity	29		25	29							

Water quality in this subbasin is among the best in the watershed, although additional sampling should be done downstream of Beaman Road near the mouth of the tributary to determine if there are any water quality problems caused by the medium density residential development. Samples from Bailey Brook currently meet State Class A Water Quality Standards.

Water quality showed a slight decline during the summer, with fecal coliform concentrations above 20 cfu per 100mL in more than 25% of samples collected in July, August, and September. Nearly 30% of samples collected throughout the year during or within twenty-four hours of a storm event contained more than 20 cfu per 100mL. Fecal coliform concentrations never exceeded 100 cfu per 100mL, however, regardless of season or weather conditions, except for a single sample in 1989 likely impacted by wildlife.

Conductivity levels were uniform throughout each year and were very low, indicative of runoff from undeveloped watersheds and much lower than those recorded from the reservoir itself.

3.4 BALL BROOK

Water quality samples were collected just downstream of Route 140 approximately 200 yards from the confluence of Ball Brook and the Stillwater River. The stream is approximately three feet wide at this sampling location. A total of 239 samples were collected weekly and analyzed for fecal coliform and conductivity between 1998 and 2007. Samples for nutrient, metals, and macroinvertebrate have not been collected, and there is no information on flow from this brook.

A total of 32 samples were collected previously for fecal coliform and conductivity analysis in 1989 and 1993. No other bacteria or conductivity samples were collected during this previous ten year period (1988-1997).

The Ball Brook subbasin is comprised of 481 acres of forest and open land (69%), residential development (25%) and agriculture (5%). The percentage of residential use is relatively high and much of it is within 400 feet of the brook, with over thirty percent of this sensitive area covered with single family homes. The amount of impervious cover in the subbasin is less than previously thought and is the same as the watershed average (5.4%). The threat from stormwater runoff should not be significant.

Ball Brook flows out of Poutwater Pond in Holden, and travels through thick wetlands, across backyards of homes, through woodlands, under Route 62, through a farm pond, and under Route 140 through twin 36" pipes, discharging eventually into the Stillwater River. During the late summer and fall the brook is generally dry in many sections.

Table 7:
BALL BROOK – FECAL COLIFORM AND CONDUCTIVITY

YEAR	88-97	98	99	00	01	02	03	04	05	06	07
fecal – median	3-10	4	3					5	10	10	10
fecal – geomean	n/a	5	4					15	12	13	17
fecal – %>20	22-25	18	16					29	24	28	27
fecal – %>100	0-11	8	0					15	3	2	14
(total samples)	(32)	(38)	(38)					(41)	(38)	(47)	(37)
conductivity	44-53	47	54					78	80	78	75

Water quality at this station as measured by fecal coliform is very good, with annual geometric mean fecal coliform values of less than 20 cfu per 100mL, but water quality appears to have declined slightly since the 1990s. The cause for this decline is unknown. The change in water quality appears to have occurred between 1998/1999 and 2004. Water quality since 2004 has been very consistent and still good.

Seasonally grouped samples exhibited pronounced differences at this station, similar to what was seen at most other sampling stations in the watershed. The annual geometric means of winter samples (January-March) were never greater than 10 cfu/100mL, while the annual geometric means of summer samples (July-September) ranged from six to 241 cfu/100mL. Less than 25% of winter samples exceeded 20 cfu/100mL, but during the summer months the percentage of samples exceeding that benchmark ranged from 33-100%. Spring and fall samples generally had water quality that fell between the two extremes.

The proximity of developed areas to the tributary suggests potential problems with stormwater even though impervious surfaces throughout the subbasin are not in excess of ten percent. The percentage of wet weather samples containing more than 20 cfu/100mL is considerably higher than that of dry weather samples. Annual percentages of wet weather samples containing more than 20 cfu/100mL range from 33-56%; the percentage of dry samples with more than 20 cfu/100mL was only 7-24%.

Conductivity levels at this station were very low and generally consistent throughout the year. Conductivity levels in this range are indicative of runoff from undeveloped watersheds and are similar to those recorded from the reservoir itself. The increase in conductivity between 1999 and 2004 (Table 7) was less than the average increase in tributary conductivity observed across the watershed.

Water quality in this subbasin is better than in most of the other subbasins in the watershed, but fecal coliform levels periodically are higher than desirable. A detailed investigation has not yet been carried out to determine the sources of the problem, but wild or domestic animals are likely suspects. The sampling station is a considerable distance downstream from much of the residential development and it is possible that the stream is actually being polluted but most contaminants are being naturally filtered as the water moves downstream through a series of wetlands and ponds. Water quality samples should be collected immediately downstream of the residential development to check for any contamination.

3.5 BEAMAN POND BROOK

3.5.1 Beaman Pond Brook (1)

This was the primary sampling station on Beaman Pond Brook in 1995, 1996, 1997, 1999, and 2000. Samples were collected approximately 100 yards from the shore of the reservoir just upstream of the access road at Gate 27. The stream is only two feet wide at this sampling location and was dry a significant portion of the year. A total of 52 samples were collected for fecal coliform and conductivity analysis during the ten year period covered by this report, 16 in 1999, 21 in 2000, and 15 in 2003. During the previous ten year period a total of 92 samples were collected. No macroinvertebrate samples have been collected from this tributary because of low flows and inadequate substrate, and no samples for nutrients or metals have been collected. There are no flow data available for this tributary.

The primary sampling station was shifted 150 yards upstream to Beaman Pond Brook (2) to take advantage of more consistent flow in 2003. Results are presented in Chapter 3.5.2. Sampling continued at Beaman Pond Brook (1) as well during 2003, but was then discontinued.

The Beaman Pond Brook subbasin is comprised of 373 acres of forest and open land (54%), residential development (30%), agriculture use (5%), and commercial development (6%). Nearly all of the residential development is on parcels of one half acre or less. The percentage of residential development is much higher than the watershed average and is one of the highest in the watershed. The percentage of impervious cover (12.4%) is greater than the percentage at which watersheds begin to show the impact of non-point source runoff and increased stormwater pollution.

Table 8:
BEAMAN POND BROOK (1) – FECAL COLIFORM AND CONDUCTIVITY

YEAR	88-97	98	99	00	01	02	03	04	05	06	07
fecal – median	10-86		21	51			190				
fecal – geomean	n/a		22	47			119				
fecal – %>20	42-78		50	76			80				
fecal – %>100	12-36		19	38			60				
(total samples)	(92)		(16)	(21)			(15)				
conductivity	386-624		422	597			967				

Most samples were collected during the late winter or spring when there was adequate flow in the brook. Water quality appears to have declined at this station, although it is difficult to assess using annual metrics since sample collection was so irregular and infrequent. There are several possible sources upstream including failing or poorly designed septic systems, wild or domestic animals (including horses and dogs), and problems with the new municipal sewer system. The high percentage of impervious cover is a likely mechanism for transport of contaminants to the brook.

3.5.2 Beaman Pond Brook (2)

Water quality samples were collected at this station located approximately 250 yards from the shore of the reservoir in 2003, 2004, 2005, 2006, and 2007 to take advantage of a more regular flow pattern. A total of 181 samples were collected for fecal coliform and conductivity analysis. The brook is about five feet wide and slow moving with a soft mud bottom. There are a number of single-family homes adjacent to the brook, and at least one property houses a large dog with access to the water. Two additional sampling stations were established upstream on this tributary (Chapters 3.5.3 and 3.5.4) to help determine exactly what was causing elevated fecal coliform concentrations. No samples for nutrients or metals have been collected, and macroinvertebrate sampling was not done because of low flows and inadequate habitat.

Water quality as measured by fecal coliform and conductivity was very poor in 2003, with both fecal coliform and conductivity median values among the highest in the watershed. A special investigation with additional sampling stations was initiated and a cooperative effort with the

West Boylston Board of Health helped locate a failing septic system close to the brook. Repairs were made and fecal coliform concentrations and conductivity did drop.

Table 9:
BEAMAN POND BROOK (2) – FECAL COLIFORM AND CONDUCTIVITY

YEAR	88-97	98	99	00	01	02	03	04	05	06	07
fecal – median							110	85	30	50	10
fecal – geomean							75	64	30	38	29
fecal – %>20							74	69	52	62	45
fecal – %>100							52	45	16	23	17
(total samples)							(27)	(42)	(44)	(39)	(29)
conductivity							924	774	708	571	575

Secondary sampling stations located upstream of the primary station and described in the following chapters appear to show that the main source of contamination is near the headwaters, although the annual summary statistics shown in Table 10 can be impacted by variations in flow and seasonality of sample collection. Due to the small amount of flow in Beaman Pond Brook and the frequent but irregular periods throughout the year when samples cannot be collected at one or more stations on this tributary, it is difficult to make conclusive statements about water quality trends.

Table 10:
BEAMAN POND BROOK FECAL COLIFORM (all stations)

SAMPLING LOCATION	2003	2004	2005	2006	2007
	geomean	geomean	geomean	geomean	geomean
Beaman Pond Brook #2 (primary station)	75	64	30	38	29
Beaman Pond Brook #3 (below pond)	136	67	47	57	48
Beaman Pond Brook #3½ (above pond)	no data	134	42	86	52

Seasonally grouped samples exhibited pronounced differences at this station, similar to what was seen at most other sampling stations in the watershed, although samples not collected due to low or no flow conditions may have influenced data interpretation. No annual geometric mean of winter samples (January-March) exceeded 20 cfu/100mL, while no annual geometric mean of spring samples (April-June) was less than 20 cfu/100mL. Summer samples, though infrequently collected, had annual geometric means of between 164 cfu/100mL and 321 cfu/100mL. Fall samples had annual geometric means between 37 cfu/100mL and 58 cfu/100mL.

The difference between dry weather samples and wet weather samples is also very clear. The annual geometric mean of dry samples ranged from 15 to 46 cfu/100mL; the annual geometric mean of wet samples ranged from 99 to 363 cfu/100mL. A high percentage of impervious area in the subbasin likely exacerbates the impacts from storm events.

Turbidity measurements taken in 2006 help illustrate the negative impacts caused by stormwater runoff. Wet weather mean turbidity was more than 200% higher than dry weather mean turbidity. Many of the other tributaries did not show such a significant increase, especially those with large areas of undeveloped lands and a lower percentage of impervious surfaces.

The dramatic drop in conductivity at this station over the past five years was only noted at a select number of locations throughout the watershed. In almost every case, lower conductivity was linked to a reduction in a human source of fecal coliform, either by repair of septic systems or an increase in the number of parcels connected to the municipal sewer. The new municipal sewer system in West Boylston now serves part of this subbasin, and a total of 108 homes and businesses (nearly half of all parcels) had been connected as of July 2008.

3.5.3 Beaman Pond Brook (3)

A total of 165 samples were collected at this station during 2003, 2004, 2005, 2006, and 2007 for fecal coliform and conductivity analysis. No samples for nutrients or metals have been collected, and macroinvertebrate sampling was not done because of low flows and inadequate habitat. The station is located just downstream of Route 110 and below the outlet of a small pond. The stream is about four feet wide, is very shallow with a sandy bottom, and often is littered with trash from the road. A property with horses and dogs is located upstream of this pond and is bisected by Beaman Pond Brook.

Table 11:
BEAMAN POND BROOK (3) – FECAL COLIFORM AND CONDUCTIVITY

YEAR	88-97	98	99	00	01	02	03	04	05	06	07
fecal – median							150	70	30	80	55
fecal – geomean							136	67	47	57	48
fecal – %>20							73	69	59	57	61
fecal – %>100							58	40	28	43	36
(total samples)							(26)	(35)	(39)	(37)	(28)
conductivity							897	705	673	519	565

Water quality as measured by fecal coliform and conductivity was extremely poor in 2003, with fecal coliform and conductivity median values among the highest in the watershed. A special investigation using alternative indicators led to the determination that much of the fecal coliform was likely coming from horses living upstream and adjacent to the brook. The animals were moved from the site and fecal coliform concentrations did drop. The animals returned to the site the following year, but best management practices were in place and fecal coliform counts did not immediately rise. The subsequent decline in water quality in 2006 may have been the result of stormwater flowing across the site and carrying bacteria from a dog run and from the horses. Flow patterns were altered to redirect stormwater and water quality improved.

Seasonally grouped samples exhibited very clear differences at this station, although low flow and no flow conditions sometimes meant that samples were not collected and may have impacted data interpretation. The annual geometric mean of winter samples (January-March) never exceeded 24 cfu/100mL, while the annual geometric mean of spring samples (April-June) was between 29 cfu/100mL and 149 cfu/100mL. Summer samples, though infrequently collected, had annual geometric means of between 135 cfu/100mL and 492 cfu/100mL. Fall samples had annual geometric means between 115 cfu/100mL and 432 cfu/100mL.

The difference between samples collected during dry weather and wet weather is quite striking as well. The annual geometric mean of dry weather samples ranged from 25 to 83 cfu/100mL; the annual geometric mean of wet samples ranged from 94 to 337 cfu/100mL. Annually 7-57% dry weather samples contained more than 100 cfu/100mL, while 58-83% of all wet weather samples exceeded this threshold.

Water quality has certainly shown improvement at this station, but intermittent problems persist. Horses and dogs are no longer probable sources following the addition of vegetated buffers and improvements to site drainage. A muskrat lived in the pond in the past, although it has not been seen for several years. Other species of wildlife could also be a source of contamination. There has also been at least one instance where electrical failure led to an overflow of a sewer pump which might have discharged to the brook. The source of fecal coliform contamination in this subbasin remains illusive and further investigations are warranted.

3.5.4 Beaman Pond Brook (3.5)

A total of 128 samples were collected at this station for fecal coliform and conductivity analysis during 2004, 2005, 2006, and 2007. This station was added in an attempt to isolate the source of elevated fecal coliform concentrations in the brook. No samples for nutrients or metals have been collected, and macroinvertebrate sampling was not done because of low flows and inadequate habitat. The station is located just upstream of a small pond adjacent to Route 110. The stream is only a foot or two wide and is very shallow. It flows through a property with horses and dogs, although the animals are excluded from the brook and the immediate area.

Table 12:
BEAMAN POND BROOK (3.5) – FECAL COLIFORM AND CONDUCTIVITY

YEAR	88-97	98	99	00	01	02	03	04	05	06	07
fecal – median								175	40	130	40
fecal – geomean								134	42	86	52
fecal – %>20								81	62	62	69
fecal – %>100								58	27	51	31
(total samples)								(26)	(37)	(39)	(26)
conductivity								676	675	517	539

Sample results from three stations on Beaman Pond Brook during 2004 clearly indicated that the primary source of contamination of the brook was located near the headwaters of this tributary, with a median fecal coliform concentration at the upstream station twice as high as the median concentration at the other two stations (Table 10). This focused attention on the small horse farm immediately upstream of this station, and led to significant enhancements at the site which were discussed in Chapter 3.5.3. The best management practices and site modifications resulted in the water quality improvements documented in Tables 11 and 12.

Seasonal differences and impacts from storm events at this station were similar to those noted at Beaman Pond Brook (2) and Beaman Pond Brook (3). Water quality at all stations on this brook and in most tributaries in the watershed was best during the winter months (January-March), declining in the spring (April-June), dramatically worst during the summer (July-September), and improving somewhat in the fall (October-December). Samples collected during or within twenty-four hours of a rain event had a geometric mean fecal coliform concentration between four and five times higher than dry weather samples.

It is important to note that any assessment of water quality trends at the stations on Beaman Pond Brook must be tempered by the understanding that annual summary statistics are impacted by the number of samples and by the timing of these samples. Flow in this tributary is irregular and the collection of samples is not consistent from year to year or season to season. Poor annual statistics may be a function of how many samples were collected during the summer months (or how few were collected during the winter when water quality was better), or may be related to whether or not the year had an abnormal number of sampled storm events.

3.6 BOYLSTON BROOK

This small stream was sampled just downstream of Route 70 near the junction with French Road. The stream is less than three feet wide at this sampling location and was previously straightened and lined with wood and stone to increase flows to the reservoir, which is approximately 400 yards to the northwest. A total of 419 samples were collected for fecal coliform and conductivity analysis during the ten year period covered by this report. Macroinvertebrate samples were collected from this station until 1990, but because of the historic modifications to the substrate, samples after 1990 (including the samples from 1998 and 2001) were collected from a location about 100 yards downstream which had not been modified. No samples for nutrients or metals have been collected from this tributary, and no information on flow has been collected.

A total of 266 samples were collected for fecal coliform and conductivity analysis between 1989 and 1997. Macroinvertebrate samples were collected from this sampling station in 1989 and 1990 and at the new location approximately 100 yards downstream from the primary sampling station in 1992, 1994, and 1996.

The Boylston Brook subbasin is comprised of 141 acres of forest and open land (60%), low density residential development (25%), and agriculture use (3%). Nearly all of the remaining land is covered by open water or wetlands. The percentage of residential development is much higher than the watershed average, but because it is all on large parcels the percentage of impervious cover (11.1%) is below what might be expected.

Annual fecal coliform metrics have been relatively stable throughout the ten year period except for an abrupt decline in water quality in 2003 and 2004 (see Table 13). Water quality actually was rather poor during the winter of 2002 with a seasonal geometric mean (31 cfu/100mL) that was three times higher than normal, but because there was only a single sample collected that summer (a season when water quality tends to be considerably worse than normal), the overall metrics for the year do not reflect the decline. An investigation that used alternative indicators was initiated and the problem determined to be of human origin. Inadequate or failing septic systems in close proximity to the brook (and to the sampling station) were suspected, and repairs were made that appeared to alleviate the problem. The geometric mean of samples collected between January and March of 2003 (16 cfu/100mL) was only half that of the previous winter, but an abundance of summer samples including six taken after storm events resulted in annual metrics that appeared very poor compared to previous years. The geometric mean of winter samples continued to drop in 2004, but again there was plenty of flow throughout the summer and many samples with very high fecal coliform concentrations were collected, so annual metrics remained poor. During 2005, only four samples were collected during the summer and annual metrics were much improved.

Water quality appeared to decline again in 2007, with elevated fecal coliform concentrations in the winter and spring. Only three samples were collected during the summer, but all were during storm events and had very poor water quality. A lower than normal number of samples collected during the fall when water quality tends to improve also had a negative impact on overall metrics for the year.

Data from this station is quite illustrative of the difficulties of using annual metrics to describe water quality trends. Elevated concentrations recorded during the summer are often the result of reduced flows and the subsequent concentration of contaminants, but if flow is greatly reduced and samples cannot be collected for extended periods, annual water quality might actually appear to improve. When flow does persist throughout the summer, the additional samples collected often contain high concentrations of fecal coliform which can negatively impact annual statistics. The frequency and intensity of sampled storm events can also significantly alter annual statistics since fecal coliform concentrations can increase by several orders of magnitude following rain.

Table 13:
BOYLSTON BROOK – FECAL COLIFORM AND CONDUCTIVITY

YEAR	88-97	98	99	00	01	02	03	04	05	06	07
fecal – median	4-37	15	12	19	10	10	40	25	10	10	20
fecal – geomean	n/a	12	11	12	16	17	39	30	19	17	27
fecal – %>20	24-61	43	34	43	41	31	55	50	41	33	35
fecal – %>100	6-33	14	14	9	13	18	25	28	10	8	18
(total samples)	(266)	(42)	(35)	(47)	(32)	(39)	(56)	(46)	(39)	(49)	(34)
conductivity	169-255	227	230	259	403	465	448	411	360	367	315

Seasonally grouped samples exhibited significant differences at this station and at most sampling station in the watershed, although there was some variability from year to year as described in the preceding paragraphs. Fecal coliform concentrations were generally low in the winter, increased in the spring and summer, and then dropped in the fall. The number of samples collected during the summer months ranged from a single sample in 2002 to a high of fourteen samples in 2003. When summer samples were collected, water quality was very poor as shown in the following table.

Table 14:
BOYLSTON BROOK – RANGE OF SEASONAL METRICS

	WINTER	SPRING	SUMMER	FALL
fecal – median	1 – 20	5 – 65	51 – 415	5 – 15
fecal – geomean	2 – 31	4 – 51	66 – 258	7 – 24
fecal – %>20	8 – 44	0 – 69	80 – 100	0 – 45
fecal – %>100	0 – 38	0 – 33	20 – 100	0 – 27

Regardless of the season, water quality of wet weather samples at this station was dramatically worse than that of dry weather samples. The annual geometric mean of dry samples during the ten years of sampling was 25 cfu/100mL or less each year, while the annual geometric means of wet weather samples from the same period were between 20 and 475 cfu/100mL. Less than half of dry weather samples collected each year contained more than 20 cfu/100mL, while more than half (and in some cases 100%) of wet weather samples exceeded 20 cfu/100mL.

Annual conductivity values increased significantly in 2001, 2002, and 2003, but conductivity increased at all stations during these years. These increases have been linked to the use of a new field conductivity meter during that three year period. Annual conductivity at this station and most others declined following a return to an earlier piece of monitoring equipment. The percentage drop in Boylston Brook was one of the largest observed with a 23% decline from 2004 to 2007.

The mean conductivity in Boylston Brook for the current ten year period was 84% higher than for the previous ten year period, considerably more than the average watershed increase of 56% as determined by using ten tributaries that have been sampled consistently for the past twenty years.

Years with little rainfall often result in higher conductivities due to low flow conditions, and winter storm events can lead to elevated levels due to the application of salt on icy roadways, so the use of annual statistics for conductivity can be just as misleading as with fecal coliform data. Annual data were examined to look for periods of relative stability and annual conductivity then grouped and summarized. The periods of 1988-1992, 1998-2000, and 2006-2007 exhibited little change throughout the watershed and were therefore used to detect trends. The increase in conductivity at the ten tributaries continuously monitored from the earliest period (88-92) to the latest (06-07) was 83%. The increase in Boylston Brook was a nearly identical 85% and therefore probably not indicative of any unusual problem.

Macroinvertebrate samples were collected from Boylston Brook during May of 1998 and 2001 and previously in the spring during five years between 1989 and 1996. The samples collected in 1989 and 1990 showed severe impairment when compared to the reference station, although this was probably due at least in part to poor habitat. The sampling location was moved approximately 100 yards downstream in 1992. Calculated metrics at this new location reflect moderate impairment in all years except 1996.

Table 15:
BOYLSTON BROOK – MACROINVERTEBRATE ASSESSMENT

YEAR	TAXA	EPT	EPT/chiro	HBI	% DOMIN	IMPAIRMENT
1989	6	3	9	3.89	43	severe
1990	15	8	35	2.56	46	severe
1992	10	8	>108	1.90	26	moderate
1994	10	7	99	1.80	63	moderate
1996	12	9	106	1.28	40	slight
1998	13	10	48	1.76	31	moderate
2001	10	8	>100	1.86	35	moderate
89-01	19-28	13-18	10->100	1.02-1.62	14-23	REF STATION

The dominant taxon for each sampling season was *Isoperla*, a medium sized predaceous stonefly which comprised 26-63% of the insect community. Small herbivorous mayflies and stoneflies were also present each year. Total taxa and EPT taxa were less than half that of the reference station, but even at the new sampling location the stream is very small and shallow and might be expected to have less diversity than at a larger stream like the reference station.

Historical water quality improvements at this station appear significant, probably due to repairs of nearby septic systems. More than half of all samples collected exceeded 20 cfu/100mL during the early 1990s. The percentage has dropped to less than fifty in all years except 2003 and 2004. The number of samples exceeding 100 colonies per 100mL also decreased significantly, as has annual median fecal coliform concentration. Macroinvertebrate samples may also show an improvement in water quality, but there have been none collected during or following the period of poor water quality in 2002-2004. Additional sampling should be done at this station to determine if water quality improvements have in fact taken place.

If water quality does not continue to improve, or if macroinvertebrate samples suggest that the stream is still being impacted by unknown contaminants, a second detailed investigation of the Boylston Brook subbasin should take place. Alternative indicators or new innovative methods should be used to determine if bacterial contamination is from humans or from wildlife. Nearby septic systems should again be investigated as a potential source of contamination.

3.7 CHAFFINS BROOK

3.7.1 Malden Street

The primary sampling location on Chaffins Brook is at the outlet of Unionville Pond upstream of Wachusett Street in Holden (Chapter 3.7.3). Samples were also collected weekly from a station just above Malden Street in Holden to help locate specific sources of contamination and to determine the water quality of the brook upstream of Unionville Pond. This sampling station is within an undeveloped wooded area just below a beaver dam that is periodically breached. The brook is approximately ten feet wide at this sampling location.

Samples were collected in 1998, 1999, 2000, 2004, 2005, 2006, and 2007. A total of 345 samples were collected for fecal coliform and conductivity analysis. Thirty-eight samples were collected previously in 1995. No samples for nutrients or metals have been collected from this station. Macroinvertebrate sampling was done in 1998 and previously in 1992, 1994, and 1996.

The Chaffins Brook subbasin is comprised of over 1500 acres of forest and open land (56%), residential development (34%), commercial development (5%), an industrial area (2%), and small amounts of open water, wetlands, and agriculture. Much of the residential development is on parcels of less than an acre (medium density) and is responsible for a percent impervious cover of 15.9% that is one of the highest in the watershed.

Table 16:
CHAFFINS BROOK (Malden Street) – FECAL COLIFORM AND CONDUCTIVITY

YEAR	88-97	98	99	00	01	02	03	04	05	06	07
fecal – median	48	35	31	15				20	20	10	30
fecal – geomean	n/a	37	31	21				22	24	19	26
fecal – %>20	74	70	68	45				39	38	35	53
fecal – %>100	24	20	14	12				13	18	14	12
(total samples)	(38)	(50)	(50)	(49)				(46)	(50)	(51)	(49)
conductivity	228	237	231	235				311	293	239	266

Annual fecal coliform metrics improved throughout the ten year period except for an apparent decline in water quality in 2007. The increase in annual median and geometric mean was largely the result of an unusual number of fall samples with more than 20 cfu/100mL and may not be indicative of a significant water quality decline. The number of samples that contained more than 100 cfu/100mL did not increase and was actually at an all time low.

Seasonally grouped samples exhibited some differences although less so than at a number of the sampling stations in the watershed. Fecal coliform concentrations were generally low in the winter, increased in the spring and summer, and then dropped in the fall. Water quality remained poorer than usual in the fall of 2007 as described in the previous paragraph.
Regardless of the season, water quality of wet weather samples at this station was dramatically worse than that of dry weather samples, with all metrics showing no overlap between the two groups (Table 17). As with almost every station in the watershed, water quality during or soon after storm events is much worse than at all other times, regardless of season or adjacent land use.

Table 17:
CHAFFINS BROOK (Malden Street) – FECAL COLIFORM (wet versus dry)

	wet weather samples	dry weather samples
fecal – annual median	60 – 230	3 – 26
fecal – annual geomean	83 – 183	16 – 33
fecal – annual %>20	77 – 100	22 – 65
fecal – annual %>100	33 – 75	7 – 28

Annual conductivity values at this station did not increase as much as at many of the others in the watershed. Annual medians in 1998, 1999, and 2000 were nearly identical and only slightly higher than what had been recorded in 1995. The annual median in 2004 was significantly higher, but values in the three years that followed were lower (Table 16). A comparison of annual values from 1998-2000 with those from 2006-2007 (which excludes abnormally dry years) showed an increase of only 8%. The average increase at stations in the watershed was 40%, with some stations having increases as high as 100%.

Macroinvertebrate samples were collected from the Malden Street station in May of 1992, 1994, 1996, and 1998. Habitat was comparable to many other locations in the watershed so it is likely that any differences noted are due to impacts from pollutants. Samples on Chaffins Brook were also collected from the primary sampling station below Unionville Pond and are discussed later in Chapter 3.7.3.

Table 18:
CHAFFINS BROOK (Malden Street) – MACROINVERTEBRATE ASSESSMENT

YEAR	TAXA	EPT	EPT/chiro	HBI	% DOMIN	IMPAIRMENT
1992	13	9	13	3.03	25	moderate
1994	19	13	15	3.16	37	moderate
1996	14	12	>102	1.56	33	slight
1998	21	14	11	2.71	14	moderate
88-98	19-28	13-19	10-95	1.02-1.54	14-41	REF STATION

Water quality conditions in Chaffins Brook changed dramatically during the spring of 1991. An application of pesticide inadvertently reached the tributary through the storm drainage system and killed thousands of fish and almost all of the macroinvertebrates. Although samples collected downstream showed severe impairment, samples from the Malden Street station illustrated a relatively quick recovery. The samples collected in 1992 and 1994 showed moderate impairment when compared to a reference station, reflected by low numbers of taxa and elevated HBI scores. The macroinvertebrate community appears to have recovered from the pesticide release, although impacts from other pollutants are still suggested. A sample collected in 1996 showed only slight impairment, with HBI scores much better than in previous years, but a sample from 1998 showed moderate impairment once again. The number of taxa has increased, but some of the species present are more tolerant of polluted waters and result in an elevated HBI score. This is often the case immediately downstream of beaver dams (one is present here) and may not indicate a significant decline in water quality.

The sampling station at Malden Street supports a healthy, diverse population of macroinvertebrates, with several species of mayflies, stoneflies, and caddisflies present. Dominant species include the small mayfly *Ephemerella rotunda*, the predaceous stonefly *Isoperla*, the black fly *Simulium venustum*, and the filter-feeding caddisfly *Hydropsyche betteni*. No sample has been collected since 1998, however, and conditions should be checked again to make sure water quality has not declined.

A preliminary look at data from 2008 suggests that the decline in water quality noted in 2007 has not been reversed. Sampling should continue through 2009 to see if this trend is maintained. It would also be useful to collect macroinvertebrates in 2009 and to closely examine the surrounding area and watershed upstream of the sampling station to aid in the interpretation of water quality and help determine the source of any problems. An updated environmental quality assessment of this section of the Wachusett watershed is scheduled for 2009.

Once sufficient information has been compiled and problems identified and resolved, this station can likely be dropped from routine sampling, especially since Unionville Pond downstream filters out most contaminants. A comparison of water quality at the four stations on Chaffins Brook is presented in Chapter 3.7.3

3.7.2 Poor Farm Brook

The primary sampling location on Chaffins Brook is at the outlet of Unionville Pond upstream of Wachusett Street in Holden (Chapter 3.7.3). Samples were collected weekly from a station on Poor Farm Brook (a tributary to Chaffin Pond) just below Newell Road in Holden to investigate the water quality of the headwaters of Chaffins Brook. The brook is approximately six feet wide at this sampling location and relatively slow-moving with a sandy bottom.

Water quality samples were collected in 2004, 2005, 2006, and 2007. A total of 193 samples were collected for fecal coliform and conductivity analysis. No samples for nutrients or metals have been collected from this station, and no macroinvertebrate sampling has been done due to low flows and inadequate substrate.

The Chaffins Pond subbasin is comprised of 2512 acres of forested and open land (64%), residential development (23%), commercial and industrial areas (4%), and small amounts of open water, wetlands, and agriculture. This sampling station is upstream of all of the commercial and industrial development, however, and the contributory drainage is almost entirely from forest or residential development.

Table 19:
CHAFFINS BROOK (Poor Farm Brook) – FECAL COLIFORM AND CONDUCTIVITY

YEAR	88-97	98	99	00	01	02	03	04	05	06	07
fecal – median								10	20	20	25
fecal – geomean								23	28	22	30
fecal – %>20								41	46	45	50
fecal – %>100								22	30	10	22
(total samples)								(46)	(50)	(51)	(46)
conductivity								113	125	97	115

Water quality as measured by annual fecal coliform and conductivity metrics has been relatively uniform over the past four years. No changes in water quality during the winter, spring, or summer were observed, but fecal coliform concentrations did increase during the fall of 2007. The same trend was noted at a downstream station at Malden Street (Chapter 3.7.1).

Samples grouped by season or weather condition exhibited strong differences. Water quality in the winter months was very good with less than ten percent of these samples containing more than 20 cfu/100mL. Up to half of all spring and fall samples contained more than 20 cfu/100mL, while more than three quarters of summer samples exceeded this threshold. The differences between wet and dry samples were even more striking as illustrated in Table 20.

Table 20:
CHAFFINS BROOK (Poor Farm Brook) – FECAL COLIFORM (wet versus dry)

	wet weather samples	dry weather samples
fecal – annual median	85 – 230	5 – 10
fecal – annual geomean	82 – 103	15 – 23
fecal – annual %>20	67 – 90	34 – 46
fecal – annual %>100	40 – 62	2 – 19

Annual conductivity values at this station were unchanged over the four year period and suggest that water quality is stable. Sampling at this location can likely be discontinued after a few additional years to confirm conditions.

3.7.3 Unionville Pond

This is the primary sampling station on Chaffins Brook and was the only sampling station on the brook until 1995. It is located just upstream of Wachusett Street at the outlet of Unionville Pond. The stream is several yards wide at this sampling location and is slow moving as it leaves the pond except during times of high water following storm events or snow melt. The surrounding area is mostly wooded and is partially owned by the Division, although there are a number of single family homes along Union Street and Wachusett Street near the pond.

Water quality samples were collected at this station in 1998, 1999, 2000, and from 2004 through 2007. A total of 345 samples were collected for fecal coliform and conductivity analysis. No samples for nutrients or metals have been collected. Macroinvertebrate sampling was done in 1998.

A total of 103 samples were previously collected for fecal coliform and conductivity analysis between 1989 and 1997. Macroinvertebrate samples were collected in 1989, 1989, 1992, 1994, 1996, and 1998 and from the boulder-filled mossy stream channel approximately 50 feet downstream of the primary sampling station.

A special investigation of Chaffins Brook was initiated in 1995 and replicated in 1998, 1999, and 2000. Samples were collected weekly from an upstream station just above Malden Street to help locate specific sources of contamination and to determine the water quality of the brook upstream of Unionville Pond. Regular weekly sampling at this station has continued since 2004. A description and a discussion of results were described previously in Chapter 3.7.1.

Samples have also been collected since 2004 from two additional upstream stations on Chaffins Brook. Data from Chaffins Brook (Poor Farm) and Chaffins Brook (Wachusett) are presented in Chapter 3.7.2 and Chapter 3.7.4.

The Chaffins Brook subbasin is comprised of 1581 acres of forest and open land (56%), a large amount of residential development (34%), commercial activities (5%), an industrial area (2%), and small amounts of open water or wetlands (2%) and agriculture (1%). The percentage of residential development (primarily medium density) is much higher than the watershed average and is responsible for a percent impervious cover of 15.9%.

Annual fecal coliform metrics have been relatively stable throughout the ten year period and are indicative of good water quality (see Table 21). Water quality actually improved slightly with the best annual values recorded during 2007. Unlike nearly all other sampling stations in the watershed, there did not appear to be seasonal differences in water quality. The geometric mean of samples collected during the winter months was nearly identical to that of samples collected during the summer. In many stations in the watershed the geometric mean of summer samples is often as much as ten times higher than the geometric mean of winter samples. Samples from the spring and fall were also comparable. The pond is likely acting as a settling basin and removing a significant proportion of the bacteria and other contaminants before they reach the sampling location.

Table 21:
CHAFFINS BROOK (Unionville Pond) – FECAL COLIFORM AND CONDUCTIVITY

YEAR	88-97	98	99	00	01	02	03	04	05	06	07
fecal – median	6-17	10	5	3				5	5	5	5
fecal – geomean	n/a	9	6	6				10	12	11	8
fecal – %>20	33-47	36	24	20				15	24	20	8
fecal – %>100	0-21	6	4	6				7	6	8	2
(total samples)	(103)	(50)	(50)	(49)				(46)	(50)	(51)	(49)
conductivity	152-218	208	219	212				286	268	231	242

The presence of the pond was unable to completely buffer the impacts from storm events, as wet weather samples still contained significantly more fecal coliform than dry samples. All metrics showed a dramatic difference between wet and dry samples (Table 22).

Table 22:
CHAFFINS BROOK (Unionville Pond) – FECAL COLIFORM (wet versus dry)

	wet weather samples	dry weather samples
fecal – annual median	10 – 90	2 – 8
fecal – annual geomean	13 – 54	4 – 9
fecal – annual %>20	11 – 75	5 – 27
fecal – annual %>100	11 – 50	0 – 3

Conductivity levels were generally highest during the summer when flows were lowest and contaminants were concentrated, although sometimes conductivity remained elevated during the fall and early winter and other years conductivity was relatively constant throughout the year. Conditions in Unionville Pond obviously played an important role in determining conductivity in Chaffins Brook. Elevated levels were occasionally seen during the winter, most likely the result of salt applications to roadways following storms.

The mean conductivity in Chaffins Brook below Unionville Pond during the period covered by this report was only 26% higher than for the previous ten year period, considerably less than the average watershed increase of 56%, although this is almost certainly due in part to the fact that Chaffins Brook was not sampled during 2001-2003 when an alternative meter was used and conductivities were much higher in almost every tributary. Annual conductivity data from 1988-1992, 1998-2000, and 2006-2007 were unimpacted by weather variations or equipment bias and can therefore be used to detect trends. The increase in annual conductivity at the ten tributaries continuously monitored from the earliest period (88-92) to the latest (06-07) was 83%. The increase in Chaffins Brook below Unionville Pond was only 42% and is reflective of stable water quality.

Table 23 presents annual geometric mean fecal coliform data and median conductivity data for the four sampling stations on Chaffins Brook. The three upstream stations had very similar fecal coliform numbers during most years, but the downstream station below Unionville Pond always contained considerably less than the other three. This is likely due to the filtering effect of the pond as suggested earlier. Conductivity data do exhibit some differences, with the lowest conductivity found at Poor Farm Brook which is upstream of a significant portion of residential development and all of the commercial and industrial areas. Additional stormwater runoff from developed areas is a source of elevated conductivity, and the pond would not filter out dissolved salts as it does bacteria.

Table 23:
CHAFFINS BROOK – FECAL COLIFORM AND CONDUCTIVITY

YEAR	98	99	00	01	02	03	04	05	06	07
fecal – geometric mean										
Unionville Pond	9	6	6				10	12	11	8
Malden Street	37	31	21				22	24	19	26
Wachusett Street							26	30	15	17
Poor Farm Brook							23	28	22	30
conductivity										
Unionville Pond	208	219	212				286	268	231	242
Malden Street	237	231	235				311	293	239	266
Wachusett Street							216	197	173	189
Poor Farm Brook							113	125	97	115

Macroinvertebrate samples were collected from Chaffins Brook (Unionville Pond) during May of 1998 and previously in the spring during five years between 1988 and 1996. Samples were collected approximately 50 feet downstream of the primary sampling station. The presence of a large pond immediately upstream of the sampling station often has a significant impact on macroinvertebrate populations and makes it very difficult to compare a station such as this with a reference station. Large numbers of a few filter-feeding species tend to dominate pond outlet communities, feeding on algae and other organic materials. The effects of human induced enrichment of the brook are often masked.

Samples collected in 1988 and 1989 showed moderate impairment, with unbalanced populations, low numbers of taxa, and elevated HBI scores (indicating the presence of more tolerant species). This is the natural condition below a pond outlet, however, and did not necessarily reflect significant problems upstream. Conditions changed dramatically in the spring of 1991. An application of pesticide reached the brook and killed thousands of fish and most macroinvertebrates. Samples collected in 1992, 1994, and 1998 showed severe impairment. The stream remains dominated by the filter-feeding caddisfly *Hydropsyche betteni*, a species tolerant of the elevated levels of organic material expected at a pond outlet. Two other filter feeders which were present in large numbers prior to the pesticide release (the caddisfly *Macrostemum* and the black fly *Simulium vittatum*) are now very uncommon. There are very few predators present, and almost no mayflies and stoneflies.

Macroinvertebrate samples were also collected from the Malden Street station in May of 1992, 1994, 1996, and 1998 (Table 24). Samples collected following the pesticide spill showed only moderate impairment, with a more rapid recovery than at the Unionville Pond station. Additional details can be found in Chapter 3.7.1.

Table 24:
CHAFFINS BROOK – MACROINVERTEBRATE ASSESSMENT

YEAR	TAXA	EPT	EPT/chiro	HBI	% DOMIN	IMPAIRMENT
1988 U	8	4	54	6.25	60	moderate
1989 U	17	8	11	4.29	38	moderate
1992 U	15	5	3	5.64	40	severe
1994 U	13	7	15	4.82	33	severe
1996 U	11	7	11	4.85	55	inadequate sample
1998 U	11	6	8	5.63	44	severe
1992 M	13	9	13	3.03	25	moderate
1994 M	19	13	15	3.16	37	moderate
1996 M	14	12	>102	1.56	33	slight
1998 M	21	14	11	2.71	14	moderate
88-98	19-28	13-19	10-95	1.02-1.54	14-41	REF STATION

U = Unionville Pond M = Malden Street

Water quality at this station is better than at most others in the watershed, although this may be primarily due to the filtering provided by Unionville Pond. No macroinvertebrate samples have been collected since 1998 to determine if the population has recovered from the release of pesticide, or to see if other factors might be impacting the aquatic insect community. Samples should be collected in the spring of 2009 or in subsequent years.

3.7.4 Wachusett Street

The primary sampling location on Chaffins Brook is at the outlet of Unionville Pond upstream of Wachusett Street in Holden (Chapter 3.7.3). Samples were also collected weekly during 2004, 2005, 2006, and 2007 from a station on Wachusett Street just downstream of the WPI Alden Labs facility in Holden to investigate the water quality upstream on Chaffins Brook. The brook is approximately ten feet wide at this sampling location and relatively slow-moving, with a rocky and sandy bottom.

A total of 195 samples were collected for fecal coliform and conductivity analysis. No samples for nutrients or metals have been collected from this station, and no macroinvertebrate sampling has been done due to low flows and inadequate substrate.

Table 25:
CHAFFINS BROOK (Wachusett Street) – FECAL COLIFORM AND CONDUCTIVITY

YEAR	88-97	98	99	00	01	02	03	04	05	06	07
fecal – median								25	20	10	10
fecal – geomean								26	30	15	17
fecal – %>20								50	46	30	39
fecal – %>100								15	22	6	6
(total samples)								(46)	(50)	(50)	(49)
conductivity								216	197	173	189

Water quality as measured by annual fecal coliform and conductivity metrics has been relatively uniform over the past four years with a slight improvement suggested (Table 25). Samples grouped by season exhibited strong differences similar to those observed at many of the sampling stations in the watershed. Water quality in the fall and winter months was very good with a geometric mean of no more than 20 cfu/100mL. The geometric mean of spring and summer samples ranged from 19 cfu/100mL to 82 cfu/100mL.

The differences between wet and dry samples were even more striking as illustrated in Table 26. Annual median, geometric mean, and the percentage of samples greater than 20 cfu/100mL and 100 cfu/100mL of samples collected during or within twenty-four hours of a rain event of at least 0.20 inches were all significantly higher than that of samples collected during dry weather.

Table 26:
CHAFFINS BROOK (Wachusett Street) – FECAL COLIFORM (wet versus dry)

	wet weather samples	dry weather samples
fecal – annual median	30 – 400	10 – 20
fecal – annual geomean	37 – 183	11 – 19
fecal – annual %>20	56 – 85	20 – 43
fecal – annual %>100	11 – 62	3 – 11

Annual conductivity values at this station declined slightly during the four year period. If water quality continues to improve, sampling at this location can likely be discontinued after a few additional years to confirm conditions.

3.8 COLD BROOK

Cold Brook (and Governor Brook) are the two headwater tributaries of Trout Brook. They meet just south of Mason Road in Holden where Cold Brook flows from the north and Governor Brook flows from the northeast under Sterling Street. This area is occasionally flooded from beaver activity.

Cold Brook flows under Mason Road through two 36" culverts after passing over the dam at Cournoyer Pond. The sampling station is located just downstream of Mason Road, approximately 750 feet upstream of the point where Cold Brook and Governor Brook meet and nearly two miles upstream from the Quinapoxet River. The brook is about six feet in width at this sampling location. One hundred samples were collected for fecal coliform and conductivity analysis during 1999 and 2000; 12 monthly samples had been collected previously in 1989. No samples for nutrients, metals, or macroinvertebrates have been collected from this tributary, and no information on flow has been collected.

The Cold Brook subbasin is comprised of 769 acres of forest and open land (71%), low density residential development (19%), and agriculture use (9%). The percentage of low density residential development is more than twice the watershed average, but because most of the development is on parcels of two acres or more and because almost none of the development is within 400 feet of the tributary or the pond, the percentage of impervious cover (5.1%) is less than the watershed average and stormwater runoff is not considered a problem. Agricultural land use is higher than in most watershed subbasins and includes land on the eastern shoreline of the pond immediately upstream of the sampling station, but no negative water quality impacts have been detected.

Table 27:
COLD BROOK – FECAL COLIFORM AND CONDUCTIVITY

YEAR	88-97	98	99	00	01	02	03	04	05	06	07
fecal – median	2		5	3							
fecal – geomean	n/a		5	5							
fecal – %>20	0		22	26							
fecal – %>100	0		2	6							
(total samples)	(12)		(50)	(50)							
conductivity	74		86	78							

Monthly measurements of fecal coliform never exceeded the Class A Surface Water Quality Standard for fecal coliform of 20 colonies per 100mL during 1989. Approximately one fourth of the samples collected weekly during 1999 and 2000 exceeded the standard, but water quality remained among the best in both the district and watershed-wide. Elevated summertime fecal coliform concentrations are believed to be due to a concentration of contaminants caused by reduced tributary flows, a common condition throughout the watershed.

Conductivity levels were fairly uniform throughout each of the sampling years, and were quite low. Low conductivity levels such as those shown in Table 27 are indicative of runoff from undeveloped watersheds and are similar to those recorded from the reservoir itself.

Even though water quality in this subbasin is among the best in the watershed, differences in fecal coliform concentrations between wet and dry samples are obvious. Less than 20% of all samples collected during dry weather contained more than 20 cfu/100mL, while more than half of the samples collected during or after a rain event contained more than 20 cfu/100mL (Table 28).

Table 28:
COLD BROOK – FECAL COLIFORM (wet versus dry)

	wet weather samples	dry weather samples
fecal – annual median	27 – 34	1 – 5
fecal – annual geomean	21 – 28	4 – 5
fecal – annual %>20	60 – 75	17 – 18
fecal – annual %>100	0 – 20	2 – 3

There are no apparent problems with water quality in Cold Brook, although some contaminants might be filtered out by Cournoyer Pond. No samples have been collected upstream near the two large residential developments in Princeton, and sampling in that area should be considered for the future.

3.9 COOK BROOK

Cook Brook travels through the densely developed Pinecroft neighborhood of West Boylston and Holden and empties into a large wetland near Interstate 190. This area previously was thought to be the headwaters of Gates Brook but changes in municipal drainage, beaver dam construction, and modifications by a landowner resulted in flow patterns being altered with much of the flow now entering Malden Brook. Flow does still intermittently travel from Cook Brook to Gates Brook as well.

The Pinecroft area (Cook Brook) has been studied since 1998 to document the positive impacts of sewering on water quality in a small urbanized tributary to the Wachusett Reservoir. Initial sampling established baseline and stormwater nutrient and bacteria levels. Samples were also collected in two similarly sized subbasins with different land uses (agriculture, undeveloped) for comparative purposes. Weekly sampling of the three subbasins continued through 2007.

Sampling on Cook Brook has taken place at several locations, but the only one where sampling took place with any regularity was the station near Wyoming Street in Holden. A total of 477 samples for fecal coliform and conductivity have been collected from Wyoming Street in the past ten years. Samples for nitrate-nitrogen and total phosphorus were collected irregularly (2-11 times per year) from 1999 through 2007. No samples for metals or macroinvertebrates have been collected from this tributary, and only a limited amount of information on flow has been compiled.

Calculated statistics on land use in the Cook Brook subbasin are not currently available, although percent impervious is assumed to be high. Much of the area is covered by dense residential development with small areas of commercial and agricultural use. Numerous problems with septic systems were identified and led to the expansion of the sewer and eventual connection to many residences in the area.

Annual fecal coliform metrics in 1998 were indicative of poor water quality (Table 29). Water quality improved dramatically in the following two years as homes were connected to the sewer, but there was an abrupt decline in 2001. Water quality was much better again in 2002 and 2003 and it was initially believed that 2001 might be a statistical anomaly and that sewer connections were having a positive impact on water quality, but all fecal coliform metrics declined in the years that followed even as the percentage of homes connected to the sewer exceeded 80%. It is clear that either annual fecal coliform metrics are not always the best measure of water quality trends or perhaps that water quality in Cook Brook has not improved significantly even though sewers are now predominantly in use.

Table 29:
COOK BROOK – FECAL COLIFORM AND CONDUCTIVITY

YEAR	88-97	98	99	00	01	02	03	04	05	06	07
fecal – median		41	25	18	50	20	20	30	70	40	50
fecal – geomean		59	30	23	42	19	34	36	74	35	44
fecal – %>20		70	55	48	53	35	49	53	69	61	64
fecal – %>100		34	21	22	40	12	18	22	35	25	24
(total samples)		(50)	(42)	(50)	(40)	(43)	(51)	(49)	(51)	(51)	(50)
conductivity		290	355	373	486	520	515	453	411	368	357

The poor water quality noted in 2001 was likely due to the fact that there were only two samples collected during the fall, a season when fecal coliform concentrations in watershed tributaries tend to be lower. The absence of fall samples usually results in higher annual concentrations. Inconsistent sampling patterns due to low flow can bias annual fecal coliform metrics. The same explanation cannot be used for the increasingly poor water quality seen during the past four years as samples were collected nearly every week throughout the year.

A number of alternative theories have been advanced. The elimination of septic systems and removal of much of the wastewater from the subbasin via municipal sewers might have resulted in reduced groundwater and reduced stream flow which could then lead to higher concentrations of fecal coliform. Division staff have been investigating the possibility that dog feces could be a significant and increasing source of fecal coliform contamination in this and other subbasins.
Seasonal differences were present but slightly different from those observed at other sampling stations in the watershed. Fecal coliform concentrations were low in the winter and remained low during the spring. Concentrations increased in the summer, and remained elevated during the fall. In most other sampling stations concentrations were lowest in the winter, highest in the summer, but were also higher during the spring and fall. Seasonal data did not show any trends over the ten year period.

Table 30:
COOK BROOK – RANGE OF SEASONAL METRICS

	WINTER	SPRING	SUMMER	FALL
fecal – median	5 – 90	13 – 50	40 – 175	10 – 230
fecal – geomean	7 – 78	21 – 73	41 – 213	11 – 164
fecal – %>20	8 – 75	43 – 75	62 – 100	10 – 82
fecal – %>100	0 – 42	8 – 42	15 – 55	0 – 64

Regardless of the season, water quality of wet weather samples at this station was dramatically worse than that of dry weather samples. The annual geometric mean of dry samples during the ten years of sampling was 35 cfu/100mL or less each year, while the annual geometric means of wet weather samples from the same period were between 60 and 497 cfu/100mL. Less than 65% of dry weather samples collected each year contained more than 20 cfu/100mL, while at least

65% (and in some cases 100%) of wet weather samples each year exceeded 20 cfu/100mL. Less than a fourth of dry samples contained more than 100 cfu/100mL; 45%-100% of wet samples exceeded this benchmark.

Annual conductivity values increased steadily from 1998 through 2000, and then rose dramatically in 2001 and 2002. Conductivity increased at all watershed stations during the latter two years and the increases have been linked to the use of a new field conductivity meter. Annual conductivity at this station and most others declined following a return to an earlier piece of monitoring equipment, but conductivity at Cook Brook continued to drop each year through 2007. Nineteen of the thirty-seven stations monitored during that period exhibited a decline in annual conductivity, but only seven dropped by twenty percent or more. Annual conductivity in Cook Brook dropped twenty-one percent from 2004 to 2007. It is interesting to note that nearly all other stations with a similar drop in conductivity were located in areas with new or expanded sewers or where septic systems had been recently repaired. This will be examined in greater detail in section 4.2.

Conductivity during the periods of 1998-2000 and 2006-2007 exhibited little change at stations throughout the watershed. Comparison of period averages have been used to help detect trends. The average increase in conductivity at the thirty stations that were monitored during those time periods was 39%. The increase in Cook Brook was only 7% (the lowest recorded) and certainly suggests water quality improvements relative to the other sampling stations in the watershed.

Although fecal coliform data do not show clear water quality improvements, it is not surprising that conductivity data present a different picture. All single family homes in the subbasin used septic systems in 1998, but by the end of 2007 nearly 83% of residences were connected to the municipal sewer. The negligible rise in average median conductivity while most other streams were showing much greater increases suggest a reduction in pollutant loading, the likely result of so many homes being connected to the sewer.

Table 31:
COOK BROOK – NUTRIENT MEAN CONCENTRATIONS (mg/L)

	2000	**2001**	**2002**	**2003**	**2004**	**2005**	**2006**	**2007**
Nitrate-nitrogen	4.25	3.55	4.51	3.34	3.09	2.82	2.69	2.50
Total phosphorus	0.027	0.029	0.026	0.021	0.056	0.041	0.013	0.016

Nutrient samples were collected as part of an ongoing study to evaluate the impacts of sewering on water quality. Concentrations remain higher in Cook Brook than in any other tributaries sampled during the year, but annual mean nitrate-nitrogen concentrations have dropped steadily since 2002 (Table 31). Concentrations of total phosphorus in Cook Brook were also at their lowest levels during the past two years. The apparent improvements in water quality as shown by nutrient and conductivity data would support the conclusion that fecal coliform contamination from human sources has been significantly reduced, but that an alternative source such as dog feces still remains and needs to be addressed.

A special investigation was initiated in 2006 to try to determine the cause of unexplained fecal coliform spikes. Additional samples were collected and extensive field work was done. The results did not identify a specific bacterial source, although one area appeared to have a higher bacteria concentration each time it was sampled. During field investigations, it was noted that this same area had a thick, dense algal mat, skunk and raccoon sign, and a large number of dogs. It was confirmed that there were fifty seven dogs licensed in the neighborhood which drained to this area of the stream. This neighborhood, as well as two others along this stretch of the tributary has been targeted for an ongoing dog waste collection initiative.

3.10 EAST WACHUSETT BROOK

3.10.1 Route 140

This is the primary sampling station on East Wachusett Brook. Samples were also collected from two upstream stations which are described in Chapters 3.10.2 and 3.10.3. East Wachusett Brook originates on Wachusett Mountain to the northwest and travels a significant distance through protected forests and fields, low density residential development, and agricultural areas before eventually reaching extensive wetlands bordering the Stillwater River in Sterling.

East Wachusett Brook passes beneath Route 140 through a new ten foot box culvert. Samples were collected just downstream of the road approximately 500 yards before the brook discharges into the Stillwater River. Samples for fecal coliform and conductivity were collected weekly in 1998, 1999, 2000, 2004, 2005, 2006, and 2007. A total of 344 samples have been collected and analyzed. Macroinvertebrate samples were collected at this station during the spring, summer, and fall of 2001. No samples for nutrients or metals have been collected.

A total of 159 samples were collected previously for fecal coliform and conductivity analysis between 1988 and 1997. Macroinvertebrate samples were collected in 1989, 1989, 1990, 1992, 1994, and 1996 at this station, and at upstream locations near a gravel pit during 1988, 1990, and 2001. The stream is approximately ten feet in width at the primary sampling station with a substrate consisting primarily of boulders, cobble, gravel, and sand. The habitat at both the primary station and the upstream stations was found to be very good, with excellent bottom substrate, a good diversity of flow and depth types, little or no scouring, and stable banks. Canopy cover is partly shaded to partly open. Because of the excellent habitat, the relatively undeveloped watershed, the healthy and diverse macroinvertebrate population, and relatively low levels of contaminant, this station was chosen as one of two macroinvertebrate reference stations for the Wachusett watershed.

The East Wachusett Brook subbasin is comprised of 4181 acres of forest and open land (81%), low density residential development (10%), agriculture (7%), and small amounts of open water and wetlands (1%). A large gravel pit in the subbasin was recently converted into a recreational complex of grass fields, basketball court, a small building, and an unpaved parking lot. The percent impervious cover of 3.4% is much lower than the watershed average and problems from stormwater runoff are unlikely, although some erosion and sedimentation has been documented.

Land use within 400 feet of the stream is similar to overall land use percentages, although agricultural development was less common with a majority of farms found in upland areas away from water.

Annual fecal coliform metrics have been relatively stable throughout the ten year period and are indicative of good water quality (Table 32). Water quality had appeared to decline slightly in the mid 1990s but improved at the end of the decade and metrics approached or reached historic levels in 2007.

Table 32:
EAST WACHUSETT BROOK (Route 140) – FECAL COLIFORM AND CONDUCTIVITY

YEAR	88-97	98	99	00	01	02	03	04	05	06	07
fecal – median	7-31	15	22	13				20	25	10	5
fecal – geomean	n/a	15	27	10				19	22	16	12
fecal – %>20	17-64	42	51	31				39	50	33	22
fecal – %>100	4-24	14	27	2				8	13	10	8
(total samples)	(159)	(50)	(45)	(51)				(49)	(48)	(51)	(50)
conductivity	75-104	97	109	94				122	121	102	111

Fecal coliform concentrations were generally low during the winter, spring, and fall, with elevated levels during the summer. This pattern is common to many of the tributaries in the Wachusett watershed and is probably due to reduced flows and the resultant concentration of contaminants. During several years flows were reduced to a trickle, and samples with very high concentrations of fecal coliform were collected immediately following the resumption of measurable flow. Elevated fecal coliform was also recorded periodically following storm events in the spring and fall, and all metrics of wet weather samples were dramatically higher than those of dry weather samples.

Conductivity levels remain fairly uniform throughout the year at this station with slight increases during the summer (reduced flows) and during the late winter and spring following storm events. There have been no significant changes in conductivity levels over the past twenty years. The minor increases in annual conductivity are in fact among the smallest recorded in the watershed.

The mean conductivity in East Wachusett Brook (Route 140) during the ten year period covered by this report was only 15% higher than for the previous ten year period, considerably less than the average watershed increase of 56%, although this is due in part to the fact that East Wachusett Brook was not sampled during 2001-2003 when an alternative meter was used and recorded conductivities were much higher in almost every tributary. Annual conductivity data sets from 1988-1992, 1998-2000, and 2006-2007 appear free of equipment bias and impacts from abnormal weather, and can therefore be used to detect trends. The increase in annual conductivity at the ten tributaries continuously monitored from the earliest period (88-92) to the latest (06-07) was 83%. The increase in East Wachusett Brook (Route 140) was only 19%.

Samples from two upstream stations suggest that water quality as measured by fecal coliform is remarkably uniform throughout East Wachusett Brook. The annual geometric mean at Route 140, Bullard Road, and Route 31 during the past four years ranged from 10-22 cfu/100mL, with slightly higher concentrations usually recorded at the downstream Route 140 station. There were some differences in annual conductivity which will be addressed in the following chapters.

Macroinvertebrate samples were collected from East Wachusett Brook in 1988, 1989, 1990, 1992, 1994, 1996, and 2001 at the primary station, and at upstream locations near a gravel pit during 1988, 1990, and 2001. All samples were collected using a one-minute kick technique. Samples prior to 2001 were all collected in May; samples from the primary station were also collected in July and October during 2001. The primary station (Route 140) was chosen as a reference for the watershed.

Samples collected from East Wachusett Brook were always very similar, with high numbers of total taxa and EPT taxa, very low HBI scores (indicating the presence of pollution intolerant species), and balanced populations as reflected by low percent dominance. The overall assessment of the biotic community was excellent as expected at a reference station. An increase in pollution tolerant chironomid midges in 1992, 1994, and 1996 is reflected in Table 33 by reduced EPT**:**chironomid ratios. An increase in fecal coliform concentrations was also noted during this period and suggests a temporary decline in water quality, but conditions had improved in 2001.

Table 33:
EAST WACHUSETT BROOK – MACROINVERTEBRATE ASSESSMENT

YEAR	TAXA	EPT	EPT/chiro	HBI	% DOMIN	IMPAIRMENT
1988	19	14	>97	1.27	24	REF STATION
1989	19	12	>80	1.16	20	REF STATION
1990	22	16	91	0.98	21	REF STATION
1992	30	19	22	1.39	16	REF STATION
1994	24	15	14	1.18	28	REF STATION
1996	30	22	24	1.27	24	REF STATION
2001	27	18	>100	1.62	16	REF STATION
2001-July	20	13	47	1.36	31	REF STATION
2001-October	19	12	91	3.39	40	REF STATION
1988upstream	16	14	>106	1.38	45	non-impaired
1990upstream	25	17	>68	1.48	28	non-impaired
2001upstream	24	15	26	1.69	19	non-impaired
2001upstream	18	10	39	1.40	19	slight

Macroinvertebrate samples were collected from the primary station three times during 2001 to look for possible seasonal differences. The spring sample was dominated by pollution intolerant mayflies including *Ephemerella dorothea*, *Ephemerella rotunda*, and *Epeorus* sp. A sample collected during the summer had fewer taxa present and was dominated by the filter-feeding caddisflies *Hydropsyche sparna* and *Dolophilodes* sp. This was not necessarily indicative of a decline in water quality but likely the result of the early summer emergence of many of the mayfly species. The fall sample was dominated by the mayfly *Habrophlebiodes americana*, a species tolerant of nutrient enriched water.

Macroinvertebrate samples collected from the upstream stations were very similar in composition to the reference samples and reinforce the idea that water quality is uniformly good throughout the entire length of East Wachusett Brook.

There are several parcels in the subbasin with farm animals. Seven properties have horses, although most house only a few and there are only seventeen present in the subbasin. There is one farm with twenty cows and an undetermined number of goats and chickens. A student from Wachusett Regional High School did a study of the impacts of the large farm several years ago, collecting fecal coliform samples from East Wachusett Brook above and below the property during a variety of weather conditions. Most of the data were inconclusive, but it did appear that the farm was not a significant source of contamination to the brook. There are active populations of beaver in several locations throughout the subbasin, but it does not appear that they are having negative impacts on water quality either. No immediate actions in the subbasin are necessary.

3.10.2 Route 31

A special investigation of East Wachusett Brook was initiated in 1999 and replicated in 2000. Samples were collected weekly from an upstream station just below Route 31 to determine water quality near to the headwaters. The brook is less than ten feet wide at this location and flows over a substrate of boulders, cobble, gravel, and sand. Regular weekly sampling at this station has continued since 2004 and 298 samples for fecal coliform and conductivity analysis have been collected. No samples for metals or nutrients were collected and no flow information is available. Macroinvertebrate samples were collected in 1988, 1990, and 2001.

The sampling station is surrounded by protected land and there is only a small amount of low density residential development upstream. The Town of Princeton DPW yard is nearby and salt contaminated runoff appears to have reached the brook in the past. Salt deposits in bottoms sediments and adjacent to the brook remain an intermittent source of very high conductivity.

Table 34:
EAST WACHUSETT BROOK (Route 31) – FECAL COLIFORM AND CONDUCTIVITY

YEAR	88-97	98	99	00	01	02	03	04	05	06	07
fecal – median			2	5				5	5	5	5
fecal – geomean			4	3				10	10	10	10
fecal – %>20			20	6				18	18	16	14
fecal – %>100			0	0				8	2	6	8
(total samples)			(50)	(50)				(49)	(49)	(51)	(49)
conductivity			133	111				141	141	129	171

Fecal coliform data from this station are indicative of excellent water quality that has been mostly unchanged since 1999 (Table 34). Rare occurrences of high fecal coliform (>100 cfu/100mL) have been noted since 2004. Nearly all instances of elevated fecal coliform occur during the summer months when flows are low and contaminants are concentrated, or during or following rain events in any season.

Table 35:
EAST WACHUSETT BROOK (Route 31) – FECAL COLIFORM (wet versus dry)

	wet weather samples	dry weather samples
fecal – annual median	11 – 160	2 – 5
fecal – annual geomean	8 – 53	3 – 8
fecal – annual %>20	29 – 67	2 – 17
fecal – annual %>100	0 – 60	0 – 5

Annual conductivity is always slightly higher at this station than at the primary station at Route 140, but was significantly higher (>50%) in 2007. Throughout much of the year there is no difference between the two stations, but each summer there is an extended period of time when conductivity measured at the Route 31 station rises abruptly by an order of magnitude or more. This has not been linked to rain events or direct runoff but instead appears to be due to a historic release of salt to the brook and the surrounding area. During summer low flow conditions, there seems to be movement of salt or salt contaminated groundwater into the tributary from in-stream sediment or an existing source in the adjacent stream banks. The elevated annual conductivity in 2007 is not necessarily indicative of a decline in water quality but might simply reflect a longer period of low flow.

There are no significant problems with water quality at this location, and conditions seem to be stable. Elimination of sampling at Route 31 should be considered.

3.10.3 Bullard Road

Samples were collected weekly from this station just above Bullard Road to help characterize water quality in East Wachusett Brook upstream of the primary sampling station (Chapter 3.10.1). The brook is ten feet wide at this location and flows over a substrate of boulders, cobble, gravel, and sand. Regular weekly sampling at this station began in 2004 and a total of 198 samples for fecal coliform and conductivity analysis have been collected. No samples for metals, nutrients, or macroinvertebrates were collected and no flow information is available.

The sampling station is within a forested area with some low density residential development upstream. The brook meanders through woodlands behind residential homes and flows under Bullard Road through two culverts. The brook also receives water from Snow Pond through two culverts and over a dam a short distance upstream of the Bullard Road sample station.

Annual fecal coliform data from this station are indicative of excellent water quality and have been very stable for the past four years (Table 36). As is the case with many of the sampling stations in the Wachusett watershed, there is a noticeable decline in fecal coliform metrics during the summer months. Water quality of samples collected during or immediately after a significant (>0.2 inches) storm event is nearly always much worse than that of samples collected during dry weather.

Table 36:
EAST WACHUSETT BROOK (Bullard Road) –
FECAL COLIFORM AND CONDUCTIVITY

YEAR	88-97	98	99	00	01	02	03	04	05	06	07
fecal – median								10	10	10	10
fecal – geomean								13	12	12	13
fecal – %>20								27	24	24	22
fecal – %>100								8	4	4	4
(total samples)								(49)	(49)	(51)	(49)
conductivity								133	140	116	146

Annual conductivity has also been relatively stable, with some likely impacts from upstream. There is not a significant difference between this station and others on the brook, and sampling at this location can be discontinued in the future.

3.11 FRENCH BROOK

French Brook was previously sampled just downstream of Route 70 immediately to the west of Tahanto Regional High School and about a half mile from the shore of the reservoir (Gate 9). The brook was modified by beaver activity ten years ago and formed a large ponded area upstream and downstream of the road, and the sampling location was shifted approximately 600 yards closer to the reservoir to its current position near Gate 10. The brook is about four feet wide at this sampling location. Surrounding land use is primarily undisturbed woodland and forest roads, although a few single-family homes are present.

A total of 467 samples for fecal coliform and conductivity analysis and forty-seven samples for nitrate-nitrogen and total phosphorus have been collected from French Brook during the ten year period covered by this report. The brook passes through a constructed weir and staff gauge measurements are recorded each week. The USGS provides updated rating curves to allow staff to determine flow.

During the previous ten year period a total of 323 samples were collected for fecal coliform and conductivity analysis. Macroinvertebrate samples were collected in 1988, 1989, and 1990, but sampling was discontinued after 1990 due to the presence of poor habitat and because the high school has used this site for educational programs and consequently impacted the macroinvertebrate community.

Samples were also collected from two additional stations on French Brook in 1989 and 1995 to try to further define sources of contamination. No samples have been collected from these locations since 1995.

The French Brook subbasin consists of 1375 acres of forest and open land (72%), low density residential development (12%), open water and wetlands (12%), agriculture use (4%), and a small area of commercial development (<1%). Land use and calculated percent impervious cover (6.4%) are comparable to watershed averages.

Annual fecal coliform metrics have been relatively stable throughout the ten year period with a possible improvement in the last few years as illustrated in Table 37 on the following page. Annual median and geometric mean values do not show any discernable pattern, but the percentage of samples that exceed 20 cfu/100mL each year dropped to historic lows in 2005, 2006, and 2007. Sixty-four percent of samples exceeded 20 cfu/100mL from 1988 through 1992. This dropped to forty-six percent for 1993-1997, thirty-eight percent from 1998-2002, and only thirty-two percent in 2003-2007.

Table 37:
FRENCH BROOK – FECAL COLIFORM AND CONDUCTIVITY

YEAR	88-97	98	99	00	01	02	03	04	05	06	07
fecal – median	8-56	14	10	10	5	10	20	15	10	5	10
fecal – geomean	n/a	16	13	10	16	14	28	17	14	11	14
fecal – %>20	31-86	45	41	46	32	28	49	38	27	24	25
fecal – %>100	8-36	19	11	5	11	5	25	12	10	4	10
(total samples)	(323)	(47)	(37)	(37)	(37)	(39)	(55)	(58)	(51)	(55)	(51)
conductivity	82-125	102	110	108	132	159	158	168	230	164	169

Annual water quality metrics at this station are sometimes impacted by variations in flow. There was little or no flow for an extended period (10-14 weeks) during the summers of 1999-2002, a time of year when contaminants are concentrated and bacteria numbers usually increase. Collection of a small number of summer samples can appear to improve annual metrics, although it was not true in this case.

Seasonally grouped samples exhibited significant differences at this station and at most sampling station in the watershed. Fecal coliform concentrations were generally low in the winter, were higher in the spring and fall, and reached their highest during the summer. The number of samples collected during the summer months ranged from two samples in 1999 to a high of fourteen samples in 2003. When summer samples were collected, water quality was very poor as shown in Table 38.

Table 38:
FRENCH BROOK – RANGE OF SEASONAL METRICS

	WINTER	SPRING	SUMMER	FALL
fecal – median	2 – 7	5 – 50	10 – 110	5 – 70
fecal – geomean	3 – 10	10 – 44	15 – 146	6 – 60
fecal – %>20	0 – 23	23 – 71	33 – 91	9 – 60
fecal – %>100	0 – 8	6 – 33	0 – 64	0 – 47

Water quality of wet weather samples at this station was much worse than that of dry weather samples. The annual geometric mean of dry samples during the ten years of sampling was 18 cfu/100mL or less each year, while the annual geometric means of wet weather samples from the same period were between 19 and 171 cfu/100mL. Other annual fecal coliform metrics showed similar differences (Table 39).

Table 39:
FRENCH BROOK – FECAL COLIFORM (wet versus dry)

	wet weather samples	dry weather samples
fecal – annual median	10 – 240	5 – 10
fecal – annual geomean	19 – 171	8 – 18
fecal – annual %>20	38 – 83	14 – 41
fecal – annual %>100	0 – 73	2 – 14

The overall percentage increase in conductivity noted was close to the average observed at the ten tributaries continuously monitored from 1988 through 2007. Annual conductivity values increased significantly in 2001, 2002, and 2003, but conductivity increased at all stations during these years. These increases have been linked to the use of a new field conductivity meter during that three year period. Annual conductivity at most other stations dropped following a return to an earlier piece of monitoring equipment, but remained high in French Brook. It is unclear what caused the unusually high annual value recorded in 2005. Conductivity of French Brook for three of the past four years has been very consistent (Table 37).

Samples for nitrate-nitrogen and total phosphorus were collected irregularly (2-11 times per year) from 1999 through 2007. Nutrient samples collected from French Brook always contained one of the lowest annual mean concentrations of nitrate-nitrogen measured in the watershed, but had the highest annual mean concentration of total phosphorus in five of the nine years. The annual mean recorded in 2003 and 2005 was higher than the EPA recommended limit of 0.05 mg/L and potentially could increase algal growth in the reservoir.

Table 40:
FRENCH BROOK – NUTRIENT MEAN CONCENTRATIONS (mg/L)

	1999	**2000**	**2001**	**2002**	**2003**	**2004**	**2005**	**2006**	**2007**
Nitrate-nitrogen	0.098	0.100	0.122	0.102	0.017	0.113	0.103	0.067	0.094
Total phosphorus	0.027	0.043	0.048	0.022	**0.059**	0.033	**0.056**	0.036	0.041

The presence of agricultural operations and active wildlife populations were considered a threat to water quality in the previous assessment of this station. Several of the agricultural operations have ceased to exist, and there are currently only two properties in the subbasin that house livestock. Two horses are housed at a farm on Cross Street where sheep were previously also present. The animals are fenced more than one hundred feet from a large pond and no longer can access the water directly. The other property with animals contained two horses and a cow. Runoff from the paddock used to flow directly into a stream, but improved drainage has diverted the flow and it does not appear that any of these locations are a potential threat to water quality.

Populations of beaver and muskrat have been identified at a number of locations in this subbasin, although trappers have removed some problem individuals. A large dam across the stream just below Route 70 necessitated the relocation of the staff gauge used for flow measurements. The release of water to the reservoir from a failed dam led to water quality concerns several years ago. Although negative water quality impacts are expected when populations of aquatic mammals are present, there is also the potential for positive impacts. Beaver ponds that remain unbreached can serve as a settling basin and filter out potential contaminants, and may be one of the reasons that water quality appears to be improving in French Brook.

Regular sampling of French Brook has occurred without interruption since 1988 and will be maintained in the future for historical purposes and because it is a direct tributary and close to the Cosgrove intake. Additional water quality sampling at upstream locations was done in the past to attempt to determine the source of fecal contamination, but none has been necessary in the past decade and none is planned for the future. Wildlife control activities have improved water quality in this tributary. Beaver populations should be monitored regularly and individuals removed if necessary to protect water quality.

3.12 GATES BROOK

3.12.1 Gates Brook (1)

Gates Brook 1 is located just downstream of the Division's Gate 25 fire access road crossing. This is the primary sampling station on Gates Brook although samples have been collected regularly from five other sampling stations each year since 1995. Data from these upstream stations are compared and contrasted with data from the primary station in this chapter and are also discussed in greater detail in the five chapters that follow.

Samples at the primary station are collected approximately 150 feet upstream of the reservoir. The stream is between ten to fifteen feet wide and flows through a four foot culvert beneath the road. A staff gage is located at the sampling station and the USGS provides updated rating curves to enable calculation of flow. A total of 516 samples were collected for fecal coliform and conductivity analysis on a weekly basis for the past ten years. Macroinvertebrate samples were collected from this station in May of 1998 and in May, July, and October of 2001. Samples for nitrate-nitrogen and total phosphorus were collected irregularly (2-11 times per year) from 1999 through 2007. No samples for metals have been collected since 1996.

A total of 336 samples were previously collected for fecal coliform and conductivity analysis between 1989 and 1997. Macroinvertebrate samples were collected in 1988, 1989, 1990, 1992, 1994, and 1996.

The Gates Brook subbasin as originally defined (including the Cook Brook subbasin) consists of 1645 acres of residential development (41%), forest and open land (34%), open water and wetlands (10%), agriculture use (6%), and commercial and industrial development (4%). This basin has the lowest percentage of forested and open land in the watershed and not surprisingly has one of the highest percentages of impervious surfaces (15.4%). It is the only subbasin in the watershed where residential development covers more of the subbasin than forest and open land.

Shifts in land use have led to an increase in percent impervious cover in this subbasin. The total amount of residential development has increased only slightly, but there has been an increase in high density development as areas of low density development are converted. Water quality impacts from stormwater are likely due to the high percentage of impervious cover. The extent of development and associated alterations to the land adjacent to Gates Brook has made it necessary to construct a substantial stormwater conveyance system including many culverts to help control drainage. A new municipal sewage system was installed as well and many homes and businesses have been connected during the past ten years. It should be noted that water quality at the primary station on Gates Brook could be impacted by water from Scarlett Brook. A description of water quality of Scarlett Brook, which has a considerable amount of commercial development and the highest percentage of impervious cover in the watershed, can be found in Section 3.29.

Annual fecal coliform metrics have been relatively stable throughout much of the ten year period (Table 37). Water quality was noticeably better than during the previous ten years following the completion of the new municipal sewer, but fecal coliform concentrations did not continue to drop as expected even as more and more homes were connected. There was no discernable pattern for any of the annual fecal coliform metrics. This does not necessarily mean that water quality did not improve as the result of the new sewer, but may simply suggest that annual fecal coliform metrics are not the best measures of detecting water quality improvements.

Table 41:
GATES BROOK (1) – FECAL COLIFORM AND CONDUCTIVITY

YEAR	88-97	98	99	00	01	02	03	04	05	06	07
fecal – median	19-59	20	19	24	20	10	20	30	20	20	30
fecal – geomean	n/a	25	17	42	24	17	32	27	23	27	41
fecal – %>20	46-86	50	38	52	46	35	42	51	38	46	57
fecal – %>100	10-27	18	8	27	15	8	21	18	18	15	27
(total samples)	(336)	(50)	(48)	(52)	(52)	(49)	(52)	(57)	(53)	(54)	(49)
conductivity	369-569	466	494	506	721	812	790	752	821	702	732

Seasonally grouped samples exhibited significant differences at most other sampling stations in the Wachusett watershed but showed no strong seasonal trends at Gates Brook 1. All metrics were similar during each of the four seasons (Table 42). Water quality was strongly impacted by weather conditions, however, with water quality of wet weather samples much worse than that of dry weather samples (Table 43). An examination of wet weather samples from this station provides one of the few instances where water quality appears to have improved slightly over the past decade, although the trend reversed in 2007 with declines noted in all metrics. It is unclear what caused this recent decline in water quality, although median annual flows in Gates Brook were nearly twice the norm in 2007 (Table 44) and may reflect increased stormwater runoff.

Table 42:
GATES BROOK (1) – RANGE OF SEASONAL METRICS

	WINTER	SPRING	SUMMER	FALL
fecal – median	10 – 69	10 – 70	10 – 40	3 – 40
fecal – geomean	11 – 61	13 – 99	16 – 99	5 – 72
fecal – %>20	25 – 75	23 – 62	31 – 69	8 – 62
fecal – %>100	0 – 42	0 – 38	8 – 38	0 – 38

Table 43:
GATES BROOK (1) – FECAL COLIFORM (wet versus dry)

	wet weather samples	dry weather samples
fecal – annual median	30 – 595	10 – 20
fecal – annual geomean	39 – 696	12 – 23
fecal – annual %>20	62 – 100	25 – 45
fecal – annual %>100	23 – 80	2 – 14

Table 44:
GATES BROOK (1) – MEDIAN ANNUAL FLOW (cfs)

year	1998	1999	2000	2001	2002	2003	2004	2005	2006	2007
flow	1.70	1.63	2.06	1.50	2.30	3.20	2.30	3.17	2.30	4.31

The overall percentage increase in conductivity noted was very close to the average observed at the ten tributaries continuously monitored from 1988 through 2007. Annual conductivity values increased significantly in 2001, 2002, and 2003, but conductivity increased at all stations during these years. These increases have been linked to the use of a new field conductivity meter during that three year period. Annual conductivity at most stations in the watershed dropped significantly following a return to the original monitoring equipment, but remained elevated in Gates Brook and peaked in 2005 before declining in 2006 and 2007. Conductivity at Gates Brook 1 for three of the past four years has been very consistent (Table 41).

Samples for nitrate-nitrogen and total phosphorus were collected irregularly (2-11 times per year) from 1999 through 2007. Annual mean concentrations of nitrate-nitrogen samples collected from Gates Brook were among the highest measured in the watershed each year, but annual mean concentration of total phosphorus were highest only once. The annual mean concentration of total phosphorus recorded in 2001 was higher than the EPA recommended limit of 0.05 mg/L and potentially could increase algal growth in the reservoir.

Concentrations of both nutrients seem to be dropping (Table 45) and may reflect positive results of connections to the new municipal sewer system. By the end of 2007 nearly eighty percent of all homes in the subbasin had been connected to the sewer, and both nitrate-nitrogen and total phosphorus annual mean concentrations were at historic lows.

Table 45:
GATES BROOK (1) – NUTRIENT MEAN CONCENTRATIONS (mg/L)

	1999	**2000**	**2001**	**2002**	**2003**	**2004**	**2005**	**2006**	**2007**
Nitrate-nitrogen	1.87	1.83	1.68	1.55	2.97	1.65	1.50	1.39	1.10
Total phosphorus	0.024	0.034	**0.059**	0.032	0.021	0.022	0.034	0.019	0.018

Macroinvertebrate samples were collected in May of 1988, 1989, 1990, 1992, 1994, 1996, 1998, and 2001 at the primary station using a standard one-minute kick technique. Samples were also collected from Gates 2, Gates 3, and Gates 4 during many of those years. Samples collected from the primary station almost always showed moderate to severe impairment when compared to the reference station (Table 46). Macroinvertebrate samples collected from upstream stations always showed severe impairment with low numbers of total taxa and unbalanced populations

Pollution-tolerant chironomid midges initially replaced populations of the mayfly *Ephemerella*, but the mayflies were present again in 1998 and 2001 along with filter feeding caddisflies and water quality appeared to be improving. Sampling should be done in upcoming years to continue to document improvements in water quality.

Table 46:
GATES BROOK (1) – MACROINVERTEBRATE ASSESSMENT

YEAR	TAXA	EPT	EPT/chiro	HBI	% DOMIN	IMPAIRMENT
1988	8	6	16	1.96	50	moderate
1989	6	4	51	2.00	56	moderate
1990	9	6	4	1.93	24	moderate
1992	10	5	2	2.79	38	severe
1994	12	8	7	2.02	36	severe
1996	8	6	1	3.46	47	severe
1998	13	10	49	1.07	42	moderate
2001-May	14	7	4	3.44	36	moderate
2001-July	21	11	3	2.92	16	slight-moderate
2001-Oct	14	11	>100	1.67	33	slight
88-01	19-28	13-19	10 - >100	1.02-1.62	14-41	REF STATION

Fecal coliform concentrations at the primary station are often quite high, especially during storm events. Gates Brook historically has been one of the most highly contaminated streams in the watershed due to dense residential development, untreated stormwater runoff from roads and commercial areas, a high percentage of impervious cover, and poorly functioning septic systems. Mean turbidity during storm events is nearly five times higher than during dry weather, one of the largest differences seen in Wachusett tributaries.

A number of special investigations to locate sources of pollutants in the Gates Brook subbasin have been done in response to elevated bacteria concentrations and impaired macroinvertebrate populations. The most significant of these has been the collection of weekly fecal coliform and conductivity samples from five additional stations on Gates Brook.

Samples collected appear to show significant differences in water quality at the six stations in most years. Samples collected from all upstream stations regularly contained more fecal coliform than samples collected from Gates 1 (Table 47). The results from the upstream stations were quite variable which suggests that multiple sources of fecal coliform exist, although Gates 4 and Gates 6 generally had the highest annual median and often had the highest daily value especially during the late spring, summer, and fall when bacteria levels were elevated at most stations in the brook. Data from the five upstream stations are discussed in greater detail in Chapters 3.12.2, 3.12.3, 3.12.4, 3.12.5, and 3.12.6. Staff will continue to search for specific sources including failing septic systems, stormwater discharge pipes, or animal populations and will initiate remedial actions wherever possible. An effort to identify all stormwater discharges to this tributary is currently underway.

Table 47:
GATES BROOK – FECAL COLIFORM (geometric mean at all stations)

	1998	1999	2000	2001	2002	2003	2004	2005	2006	2007
Gates 1	25	17	42	24	17	32	27	23	27	41
Gates 2	62	75	76	56	45	77	29	54	44	72
Gates 3	53	59	76	40	40	45	33	30	39	66
Gates 4	99	95	86	73	45	54	40	45	49	94
Gates 6	60	108	76	105	49	55	50	58	40	87
Gates 9	22	54	40	33	27	29	42	28	32	49

There are currently no known threats from agricultural operations or wildlife in this subbasin, but wastewater and stormwater remain significant problems. The new sewer is helping to remediate wastewater issues, although conclusive water quality improvements have not been obvious. Data analysis will continue to look for water quality trends.

The town of West Boylston addressed some stormwater problems in conjunction with the sewer project. Some drainage problems were corrected during street reconstruction but additional work could be done. The Division is considering the possibility of developing some type of in-stream treatment on Division property upstream to help remove pollutants carried in stormwater.

3.12.2 Gates Brook (2)

Gates Brook 2 is the first of five upstream stations on this tributary and is located just downstream of Route 140 in West Boylston and about 4000 feet upstream of the reservoir. The stream is ten to fifteen feet wide and flows through a four foot concrete box culvert beneath the road. Immediately downstream from the Route 140 crossing, there is a 12" concrete pipe which discharges stormwater from Route 140 directly into Gates Brook and can potentially impact water quality of samples collected at this location. A total of 524 samples were collected for fecal coliform and conductivity analysis on a weekly basis for the past ten years. Macroinvertebrate samples were collected from this station in May of 1998 and 2001. No samples for nitrate-nitrogen, total phosphorus, or metals have been collected and no flow data are available.

A total of 242 samples were collected for fecal coliform and conductivity analysis between 1988 and 1997. Macroinvertebrate samples were collected in 1988, 1989, 1990, 1992, and 1996.

The Gates Brook subbasin was described previously in Chapter 3.12.1 and consists primarily of residential development and forest and open lands. Much of the forested land in the subbasin is downstream of Gates Brook 2 and the portion of the subbasin that drains directly to this station is urban with a high percentage of impervious surfaces. Some stormwater management basins are present to treat runoff from recently redeveloped sites and small sections of roadway. Scarlett Brook, which has a considerable amount of residential and commercial development and the highest percentage of impervious cover in the watershed, joins Gates Brook from the west approximately 1000 feet upstream of Gates Brook 2. This brook and its subbasin are described separately in Chapter 3.29.

Table 48:
GATES BROOK (2) – FECAL COLIFORM AND CONDUCTIVITY

YEAR	88-97	98	99	00	01	02	03	04	05	06	07
fecal – median	60-81	48	61	49	50	40	50	30	60	40	70
fecal – geomean	n/a	62	75	76	56	45	77	29	54	44	72
fecal – %>20	82-98	70	82	63	73	63	68	52	61	67	76
fecal – %>100	36-42	36	38	33	33	28	37	26	27	20	37
(total samples)	(242)	(50)	(50)	(52)	(52)	(54)	(59)	(50)	(51)	(55)	(51)
conductivity	415-622	494	509	528	750	808	810	769	841	715	791

Annual fecal coliform metrics have been relatively stable throughout much of the ten year period (Table 48, Figure 2). Water quality was noticeably better than during the previous ten years following the completion of the new municipal sewer, but fecal coliform concentrations did not continue to drop as much as expected. There was no strong pattern for any of the annual fecal coliform metrics, although geometric mean and the percentage of samples exceeding both 20 and 100 cfu/100mL all trended slightly downward as illustrated in Figure 2.

Seasonally grouped samples exhibited obvious differences at Gates Brook 2 and at most other stations in the Wachusett watershed, although the differences at this station were not as pronounced as at some others. Water quality metrics were worst during the summer months as expected, with the maximum geometric mean more than three times higher than during the spring or fall and seven times higher than during the winter months. There were no strong seasonal trends at Gates Brook 1. Water quality at Gates Brook 2 was also impacted by weather conditions, with water quality metrics of wet weather samples much worse than those of dry weather samples (Table 49).

Water quality of wet weather samples from this station appear to have improved over the past decade. Ninety percent or more of wet weather samples exceeded 20 cfu/100mL through 2001, but this percentage has been exceeded only twice since then. Increased numbers of connections to the sewer and better control of stormwater runoff are possible reasons for the noticeable water quality improvement.

The overall percentage increase in conductivity from 1998-2000 to 2006-2007 (48%) was slightly higher than the average increase at thirty representative watershed tributaries (40%). Annual conductivity values increased significantly at Gates 2 in 2001, 2002, and 2003, but conductivity increased at all stations during these years. These increases have been linked to a new field conductivity meter in use during that three year period. Annual conductivity throughout the watershed dropped significantly following a return to the original monitoring equipment, but remained elevated in Gates Brook and declined at Gates Brook 2 only during 2006 (Table 48).

Figure 2: GATES BROOK (2) – FECAL COLIFORM TRENDS

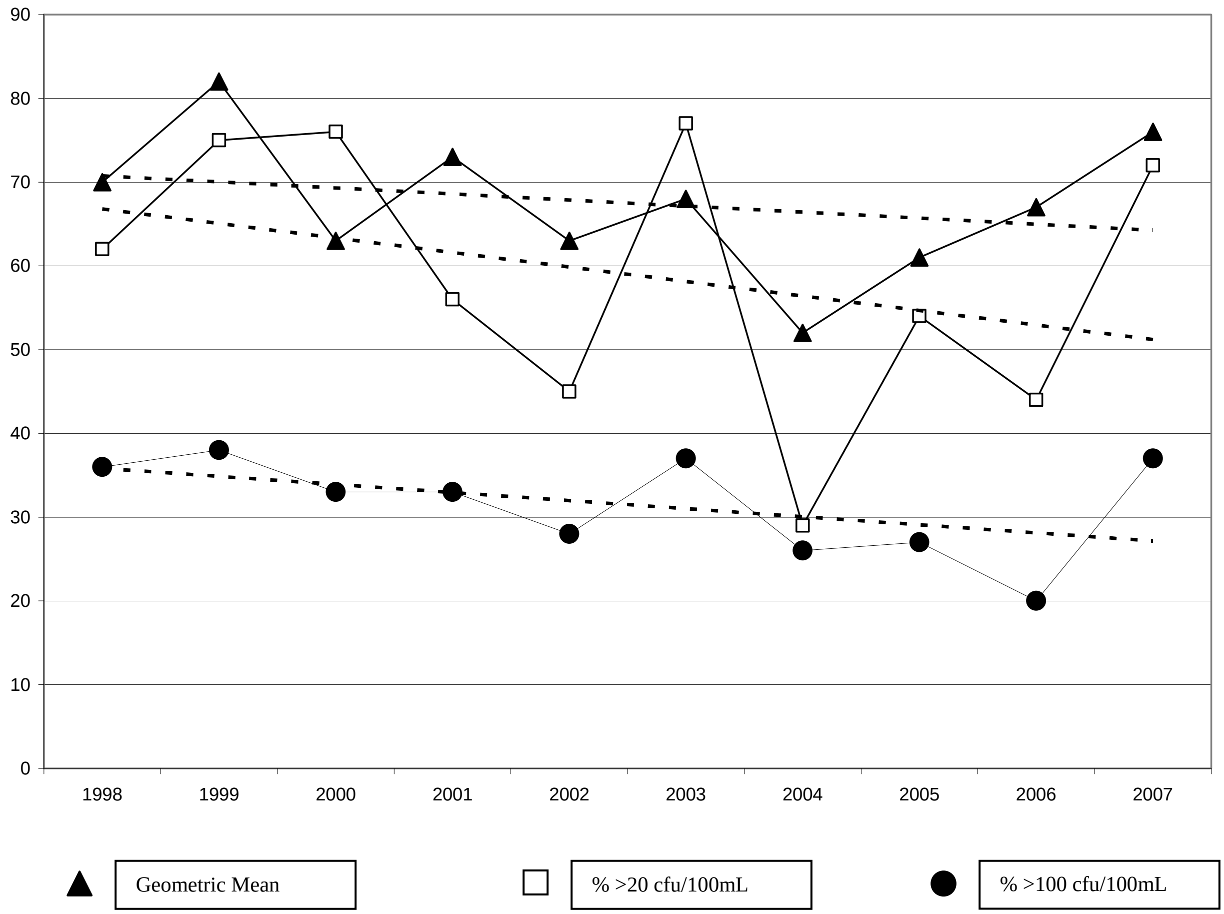


Table 49:
GATES BROOK (2) – FECAL COLIFORM (wet versus dry)

	wet weather samples	dry weather samples
fecal – annual median	80 – 975	25 – 55
fecal – annual geomean	82 – 961	25 – 67
fecal – annual %>20	67 – 100	50 – 80
fecal – annual %>100	46 – 91	10 – 35

Macroinvertebrate samples were collected in May of 1988, 1989, 1990, 1992, 1996, 1998, and 2001 at Gates Brooks 2 using a standard one-minute kick technique. Samples collected from this and other upstream stations always showed severe impairment with low numbers of total taxa and unbalanced populations. Sampling will continue in the future to document any improvements in water quality.

Continued efforts to control stormwater, encourage connections to the municipal sewer, repair any failing septic systems outside of the sewer area, and search for other sources of pollutants should help improve water quality.

3.12.3 Gates Brook (3)

Gates Brook 3 is the second of five upstream stations on this tributary and is located on the east side of Worcester Street in West Boylston approximately 400 yards upstream of Gates Brook 2. The stream is ten feet wide and flows beneath the road just downstream of the sampling station. It remains underground for a short stretch, then re-emerges, and combines with Scarlett Brook behind the Wal-Mart Plaza. A total of 514 samples were collected for fecal coliform and conductivity analysis on a weekly basis for the past ten years. No samples for nitrate-nitrogen, total phosphorus, or metals have been collected and no flow data are available. Macroinvertebrate samples have not been collected from this station within the past ten years.

A total of 191 samples were collected for fecal coliform and conductivity analysis between 1989 and 1997. Macroinvertebrate samples were collected in 1988 and 1992. Samples collected from this station showed severe impairment with little diversity and unbalanced populations.

The Gates Brook subbasin was described previously in Chapter 3.12.1. The area in the subbasin that drains directly to Gates Brook 3 consists primarily of residential and commercial development and has a high percentage of impervious surfaces with associated stormwater runoff problems.

Annual fecal coliform metrics have been relatively stable throughout much of the ten year period with some improvement noted until the final two years (Table 50). Water quality was initially better than during the previous ten years following the completion of the new municipal sewer, and fecal coliform concentrations continued to drop until increasing significantly during 2006 and again in 2007. Even with the increase in fecal coliform concentrations, annual geometric mean and the percentage of samples exceeding both 20 and 100 cfu/100mL trended slightly downward for the ten year period.

Table 50:
GATES BROOK (3) – FECAL COLIFORM AND CONDUCTIVITY

YEAR	88-97	98	99	00	01	02	03	04	05	06	07
fecal – median	41-83	41	47	50	30	40	30	30	20	45	80
fecal – geomean	n/a	53	59	76	40	40	45	33	30	39	66
fecal – %>20	70-96	76	82	74	54	61	56	56	43	63	73
fecal – %>100	22-49	20	34	40	29	31	21	20	18	20	43
(total samples)	(191)	(50)	(50)	(50)	(52)	(49)	(57)	(50)	(51)	(54)	(51)
conductivity	436-685	541	537	557	761	905	907	859	920	841	861

Seasonally grouped samples exhibited clear differences at Gates Brook 3 and at most other stations in the Wachusett watershed. Water quality metrics were worst during the summer months, with the maximum geometric mean nearly ten times higher than during the winter months. Water quality at Gates Brook 3 was even more strongly impacted by weather conditions, with water quality metrics of wet weather samples much worse than those of dry weather samples (Table 51).

Table 51:
GATES BROOK (3) – FECAL COLIFORM (wet versus dry)

	wet weather samples	dry weather samples
fecal – annual median	80 – 730	20 – 60
fecal – annual geomean	70 – 594	23 – 53
fecal – annual %>20	69 – 100	37 – 80
fecal – annual %>100	38 – 82	5 – 39

Water quality of wet weather samples from this station appear to have improved over the past decade. Ninety percent or more of wet weather samples exceeded 20 cfu/100mL in all but one year through 2003, but this percentage has not been approached since then. Increased numbers of connections to the sewer and better control of stormwater runoff are possible reasons for the noticeable water quality improvement.

The overall percentage increase in conductivity (56%) from 1998-2000 to 2006-2007 was higher than the average increase at thirty representative watershed tributaries (40%) and a greater increase than noted at the two downstream Gates Brook stations (47%, 48%). This is suggestive of declining water quality and is disturbing in light of the fact that significant effort and expense has been directed towards improving conditions in this tributary. Annual conductivity values increased significantly in 2001, 2002, and 2003, but conductivity increased at all stations during these years. These increases have been linked to the use of a new field conductivity meter during that three year period. Annual conductivity throughout the watershed dropped significantly following a return to the original monitoring equipment, but remained elevated in Gates Brook and never declined at Gates Brook (3) or the three stations upstream (Tables 50, 52, 55, and 57). Annual conductivity at these four upstream stations was significantly higher than at Gates Brook 2 and Gates Brook 1 each year although the cause remains unknown.

3.12.4 Gates Brook (4)

Gates Brook 4 is the third of five upstream stations on this tributary and is located on the west side of Worcester Street in West Boylston just south of Pierce Street and approximately one half mile upstream of Gates Brook 3. The stream is ten feet wide and flows through a high density residential neighborhood along Worcester Road downstream of Gates Brook 6. This section of the tributary is most vulnerable to non-point source pollution as it flows in a straight-lined channel behind numerous residences and under several streets with only a narrow buffer of trees and shrubs between the homes and the brook. Some drainage improvements have been made along the brook to help prevent impacts from stormwater. These include rip-rap sedimentation basins which collect stormwater prior to discharge into the brook as well as rip-rap swales along Worcester Street to reduce scouring and sedimentation of the brook.

A total of 515 samples were collected for fecal coliform and conductivity analysis on a weekly basis for the past ten years. No samples for nitrate-nitrogen, total phosphorus, or metals have been collected and no flow data are available. Macroinvertebrate samples were collected from this station in May of 2001.

A total of 168 samples were collected for fecal coliform and conductivity analysis in 1989, 1995, 1996, and 1997. Water quality was very poor. Macroinvertebrate samples were collected in 1989 and showed severe impairment with little diversity and unbalanced populations.

The Gates Brook subbasin was described previously in Chapter 3.12.1. The area in the subbasin that drains directly to Gates Brook 4 consists primarily of dense residential and commercial development with a high percentage of impervious surfaces.

Annual fecal coliform metrics have been relatively stable since 2000 but conditions declined in 2007 (Table 52). Water quality from 2000 through 2006 was better than during the previous twelve years and likely reflects a major effort to repair or replace aging septic systems or to connect to the new municipal sewer. The unexplained decline in water quality in 2007 was not a common occurrence across the watershed although it was true at all stations on Gates Brook. Median annual flows in Gates Brook were nearly twice the norm in 2007 (see Table 44) and may reflect increased annual stormwater runoff which could easily lead to poor water quality, although wet weather water quality actually improved as discussed below.

Table 52:
GATES BROOK (4) – FECAL COLIFORM AND CONDUCTIVITY

YEAR	88-97	98	99	00	01	02	03	04	05	06	07
fecal – median	74-144	100	82	48	60	50	35	55	40	50	100
fecal – geomean	n/a	99	95	86	73	45	54	40	45	49	94
fecal – %>20	87-98	94	94	77	75	60	56	64	64	64	77
fecal – %>100	43-58	48	42	40	37	30	33	28	30	33	49
(total samples)	(168)	(50)	(50)	(53)	(52)	(50)	(52)	(50)	(50)	(55)	(53)
conductivity	472-713	570	587	573	796	930	895	860	946	907	901

Seasonally grouped samples from Gates Brook 4 exhibited differences but less so than seen at most other stations in the Wachusett watershed. Water quality metrics were worst during the summer, but conditions were often nearly as bad during the spring and fall. Water quality at Gates Brook 4 was much more strongly impacted by weather conditions, with water quality metrics of wet weather samples much worse than those of dry weather samples (Table 53).

Table 53:
GATES BROOK (4) – FECAL COLIFORM (wet versus dry)

	wet weather samples	dry weather samples
fecal – annual median	125 – 1045	20 – 77
fecal – annual geomean	134 – 574	29 – 87
fecal – annual %>20	71 – 100	47 – 93
fecal – annual %>100	57 – 100	19 – 45

Water quality of wet weather samples from this station has improved over the past decade, and in fact the decline in overall water quality in 2007 appears to be due to increases in dry weather bacterial concentration. The percentage of wet weather samples exceeding 100 cfu/100mL has been very steady since 2004 and much less than in previous years, while the percentage of dry weather samples rose dramatically in 2007 to a ten year maximum (Table 54).

Table 54:
GATES BROOK (4) – FECAL COLIFORM (% > 100cfu/100mL)

YEAR	98	99	00	01	02	03	04	05	06	07
‘wet’ samples	100	100	80	82	57	89	67	63	62	62
‘dry’ samples	30	37	30	24	19	21	23	24	24	45

The overall percentage increase in conductivity (57%) from 1998-2000 to 2006-2007 was higher than the average increase at thirty representative watershed tributaries (40%) and a greater increase than noted at the two downstream Gates Brook stations (47%, 48%). This is similar to the increases noted at Gates 3 and Gates 6. Annual conductivity values increased significantly in 2001, 2002, and 2003, but conductivity increased at all stations during these years due to the use of a new field conductivity meter during that three year period. Annual conductivity throughout the watershed dropped significantly following a return to the original monitoring equipment, but remained elevated in Gates Brook and never declined at Gates Brook 4 or the other three upstream stations (Tables 50, 52, 55, and 57).

Continued efforts to control stormwater, encourage connections to the municipal sewer, and search for other sources of pollutants should help improve water quality.

3.12.5 Gates Brook (6)

Gates Brook 6 is the fourth of five upstream stations on Gates Brook and is located just upstream (south) of Lombard Avenue in West Boylston approximately one half mile upstream of Gates Brook 4. The stream is only five feet wide at this sampling location and very slow moving with a muddy bottom. Gates Brook bifurcates a short distance upstream with one branch flowing out of the south from large wetlands on the east and west sides of Worcester Street in Worcester. The primary branch enters from the west and emanates from two distinct wetland systems located to the east and west of I-190. It flows behind a large parking lot and under Danielian Road and turns to the east and crosses under Route 12. One section of the brook was put in an extended culvert and buried to allow for parking lot expansion.

A total of 513 samples were collected for fecal coliform and conductivity analysis on a weekly basis for the past ten years. No samples for nitrate-nitrogen, total phosphorus, or metals have been collected and no flow data are available. Macroinvertebrate samples have not been collected from this station due to a lack of suitable substrate.

A total of 168 samples were collected for fecal coliform and conductivity analysis in 1989, 1995, 1996, and 1997. Water quality at this station has been among the worst in the watershed for many years.

The Gates Brook subbasin was described previously in Chapter 3.12.1. The area in the subbasin that drains directly to Gates Brook 6 is dense residential and commercial development and has a high percentage of impervious surfaces with associated stormwater runoff problems.

Most annual fecal coliform metrics did not show any clear pattern throughout the ten year period. Some improvement was noted, especially during 2002-2006, but all annual water quality metrics declined in 2007 (Table 55) as was noted at all Gates Brook stations. Water quality often was no better than during the previous ten years, although the period from 2002-2006 was initially encouraging. The water quality decline in 2007 has not been explained.

Table 55:
GATES BROOK (6) – FECAL COLIFORM AND CONDUCTIVITY

YEAR	88-97	98	99	00	01	02	03	04	05	06	07
fecal – median	44-92	92	103	60	115	50	35	50	70	40	80
fecal – geomean	n/a	60	108	76	105	49	55	50	58	40	87
fecal – %>20	68-76	62	82	74	71	59	60	66	67	60	78
fecal – %>100	34-50	46	50	42	54	39	33	32	39	33	45
(total samples)	(168)	(50)	(50)	(53)	(52)	(49)	(52)	(50)	(51)	(55)	(51)
conductivity	476-697	557	617	603	805	962	921	885	1007	891	961

Seasonally grouped samples exhibited clear differences at Gates Brook 6 and at most other stations in the Wachusett watershed. Water quality metrics were much worst during the summer months, with the lowest summertime geometric mean (175 cfu/100mL) nearly three times higher than the highest recorded during the fall or winter months. Nearly all samples collected during the summer contained more than 20 cfu/100mL regardless of weather conditions. Water quality at Gates Brook 6 was even more strongly impacted by weather conditions, however, with water quality metrics of wet weather samples very much worse than those of dry weather samples as illustrated in Table 56.

Table 56:
GATES BROOK (6) – FECAL COLIFORM (wet versus dry)

	wet weather samples	dry weather samples
fecal – annual median	120 – 1170	7 – 100
fecal – annual geomean	151 – 1153	26 – 88
fecal – annual %>20	77 – 100	49 – 80
fecal – annual %>100	50 – 100	21 – 46

Water quality of wet weather samples from Gates 6 appear to have improved over the past decade. One hundred percent of wet weather samples exceeded 100 cfu/100mL in 1998 and 1999, but less than ninety percent exceeded that threshold in the period from 2000-2003 and less than seventy percent have exceeded 100 cfu/100mL since then. Increased sewer connections and better control of stormwater runoff are possible reasons for the water quality improvement.

The overall percentage increase in conductivity (56%) from 1998-2000 to 2006-2007 was higher than the average increase at thirty representative watershed tributaries (40%) and a greater increase than noted at the two downstream Gates Brook stations (47%, 48%). It was nearly identical to the increases noted at Gates 3 and Gates 4. Annual conductivity at Gates 6 was higher than at the other five Gates Brook stations in nine of the ten years sampled. Annual conductivity values increased significantly in 2001, 2002, and 2003, but conductivity increased at all stations during these years. These increases have been linked to the use of a new field conductivity meter during that three year period. Annual conductivity throughout the watershed dropped significantly following a return to the original monitoring equipment, but remained elevated in Gates Brook and never declined at Gates Brook 6 or the other three upstream stations (Tables 50, 52, 55, and 57), reaching a historic maximum at all but one of the Gates Brook stations in 2005.

A number of potential causes for the decline in water quality have been postulated, including the presence of large numbers of dogs in backyards in close proximity to the brook as well as a drop in stream flow and concurrent concentration of contaminants due to removal of recharge from disconnected septic systems. Continued efforts to control stormwater, encourage connections to the sewer, and search for other sources of pollutants should help improve water quality.

3.12.6 Gates Brook (9)

Gates Brook 9 is the station closest to the headwaters of this tributary and is located downstream of Woodland Street in West Boylston approximately 600 yards upstream of Gates Brook 6. The stream is ten feet wide and flows through woodlands bordered by residential development. Flow originates from wetlands near I-190 and passes through agricultural land before reaching the sampling station. A large wetland near I-190 fed by Cook Brook (Chapter 3.9) was previously thought to be the headwaters of Gates Brook but changes in municipal drainage, beaver dam construction, and modifications by a landowner resulted in flow patterns being altered with much of the flow now entering Malden Brook. Flow does still intermittently travel from Cook Brook to Gates Brook as well.

A total of 512 samples were collected for fecal coliform and conductivity analysis on a weekly basis for the past ten years. No samples for nitrate-nitrogen, total phosphorus, or metals have been collected and no flow data are available. Macroinvertebrate samples have not been collected from this station. A total of 167 samples were collected previously for fecal coliform and conductivity analysis in 1989, 1995, 1996, and 1997.

The Gates Brook subbasin was described previously in Chapter 3.12.1. The area in the subbasin that drains directly to Gates Brook 9 is a combination of residential development and farmland with both crops and livestock. The percentage of impervious surfaces is higher than might be expected due to the presence of I-190.

Annual fecal coliform metrics presented a mixed message during the ten year period (Table 50). Annual median was markedly lower in 1998 and from 2001-2006, but then increased to a historic high in 2007. Geometric mean fluctuated between a low in 1998 and a high in 1999 with no discernible trend, and the percentage of samples exceeding 20 and 100 cfu/100mL gave equally unclear information. All water quality metrics declined in 2007 as they did at all of the other Gates Brook stations. Annual metrics appear too broad to accurately portray what is happening at a tributary station, and the data must be examined more closely to identify any trends present.

Table 57:
GATES BROOK (9) – FECAL COLIFORM AND CONDUCTIVITY

YEAR	88-97	98	99	00	01	02	03	04	05	06	07
fecal – median	37-46	19	47	47	20	20	30	50	30	20	80
fecal – geomean	n/a	22	54	40	33	27	29	42	28	32	49
fecal – %>20	58-62	46	74	58	48	49	56	65	53	45	57
fecal – %>100	16-32	14	32	32	35	24	13	31	18	29	43
(total samples)	(167)	(50)	(50)	(53)	(52)	(49)	(52)	(49)	(51)	(55)	(51)
conductivity	399-671	515	523	508	805	912	823	815	908	843	907

Seasonally grouped samples exhibited clear differences at Gates Brook 9 and at most other stations in the Wachusett watershed, regardless of weather conditions. Water quality metrics were worst during the spring and summer months in both dry and wet weather. Wet weather samples were always much worse than dry weather samples during all seasons, with the worst dry weather metrics almost always better than the best wet weather metrics (Table 58.

Table 58:
GATES BROOK (9) – FECAL COLIFORM (wet versus dry)

	wet weather samples	dry weather samples
fecal – annual median	100 – 485	10 – 55
fecal – annual geomean	68 – 353	11 – 46
fecal – annual %>20	64 – 100	30 – 72
fecal – annual %>100	46 – 100	2 – 39

Water quality of wet weather samples from this station appear to have improved over the past decade, with all fecal coliform metrics trending downward. The opposite was true with the dry weather samples. This pattern was noted at all six stations on Gates Brook but was not common at other sampling stations in the watershed.

The overall percentage increase in conductivity (70%) from 1998-2000 to 2006-2007 was much higher than the average increase at thirty representative watershed tributaries (40%) and a greater increase than noted at the two downstream Gates Brook stations (47%, 48%) and at the other three upstream Gates Brook stations (56%, 57%, 56%). Gates Brook 9 was one of only seven sampling stations where conductivity rose by more than ten percent in the past four years. Annual conductivity values increased significantly in 2001, 2002, and 2003, but conductivity increased at all stations during these years. These increases have been linked to the use of a new field conductivity meter during that three year period. Annual conductivity throughout the watershed dropped significantly following a return to the original monitoring equipment, but remained elevated in Gates Brook and never declined at Gates Brook (9) or the other three stations upstream (Tables 50, 52, 55, and 57). Annual conductivity at these four upstream stations was significantly higher than at Gates Brook (2) and Gates Brook (1) each year although the cause remains unknown.

Improvements to stormwater management and additional connections to the sewer have likely had positive impacts on water quality at this station, but the increase in annual conductivity and in dry weather fecal coliform concentrations is troubling. A reduction in stream flow and the resultant concentration of contaminants would explain both increased conductivity and increased fecal coliform, so it is possible that the positive impacts of eliminating septic systems may be hidden because of the loss of recharge and subsequent reduction in flow. Median annual flow in 2007 was very high, but this was due primarily to a number of significant storm events. Water quality during storm events has actually improved during the past ten years, and it is possible that fecal coliform annual load has decreased even though annual fecal coliform metrics have increased. This will be addressed in detail in Chapter 4.1.

3.13 GOVERNOR BROOK

Governor Brook and Cold Brook (described in Chapter 3.8) are the two headwater tributaries of Trout Brook. The two meet just south of Mason Road in Holden where Governor Brook flows from the northeast under Sterling Road and Cold Brook flows from the north under Mason Road.

The sampling station on Governor Brook is located approximately one half mile upstream of the junction of the two tributaries, just downstream of Sterling Road. The brook is about six feet wide at this sampling location and flows over large moss-covered boulders and rubble. Surrounding land use is primarily undisturbed woodland and fields, although a few single-family homes are present. The brook upstream is braided and complex due in part to the historic practice of ditching and draining to encourage flow.

A total of 86 weekly samples for fecal coliform and conductivity analysis were collected from Governor Brook during 1999 and 2000. No samples were collected during the summer of 1999 due to low flow. No samples for nutrients were collected, and macroinvertebrate sampling was not done because of low flows and inadequate habitat. Eleven monthly samples were collected previously in 1989.

The Governor Brook subbasin is one of the largest in the Wachusett watershed and consists of 2589 acres of forest and open land (85%), agriculture use (9%), and a small amount of low density residential development (5%). Much of the agriculture and residential development is not within 400 feet of the tributary. Percent impervious cover (1.7%) is much less than the watershed average and one of the lowest in the watershed. Impacts from non-point source runoff and stormwater pollution are unlikely.

Fecal coliform levels were low during the winter and spring, and then increased slightly at the beginning of the summer. This pattern is common to many of the tributaries within the Wachusett watershed, and is probably the result of concentration of contaminants due to lower flows. All fecal coliform metrics are representative of very good water quality during all three years of sampling (Table 59). Conductivity levels were fairly uniform throughout each of the sampling years, and were very low, indicative of runoff from an undeveloped watershed and similar to those recorded from the reservoir itself.

Table 59:
GOVERNOR BROOK – FECAL COLIFORM AND CONDUCTIVITY

YEAR	88-97	98	99	00	01	02	03	04	05	06	07
fecal – median	8		1	5							
fecal – geomean	n/a		3	6							
fecal – %>20	45		16	24							
fecal – %>100	9		0	8							
(total samples)	(11)		(37)	(49)							
conductivity	65		48	53							

Water quality of wet weather samples at this station was much worse than that of dry weather samples, but was still much better than in nearly every other tributary in the watershed. The annual median and geometric mean of wet weather samples were 23-46 cfu/100mL, while those of dry samples from the same period were never more than 4 cfu/100mL. Samples collected during dry weather almost never contained more than 100 cfu/100mL, but up to thirty percent of wet weather samples exceeded that benchmark.

The presence of agricultural is a potential threat to water quality, but the largest property in this subbasin was purchased by the Division in 1997 for watershed protection purposes. The two parcels were estimated to contain about 382 acres. The original owner retains a deeded personal right to continue to hay, fertilize, and reseed the farm fields subject to a two-hundred-foot buffer area from any existing tributary, stream or other water source. A large number of cows previously present have been removed from the site.

No active populations of beaver or muskrat were noted in the subbasin during recent stream surveys, but beaver were present immediately downstream of the junction of Cold and Governor Brooks. The presence of wildlife in the subbasin presents the most likely threat to water quality.

With very little impervious surface, limited development, and no known problems, water quality of this tributary is expected to remain very good. No additional routine sampling is necessary.

3.14 HASTINGS COVE BROOK

There are two distinct tributaries that flow into Hastings Cove, but only the tributary to the west is referred to as Hastings Cove Brook. The tributary to the east is unnamed and has never been sampled. The sampling station on Hastings Cove Brook is located downstream of Route 70 and very close to the shore of the reservoir. The steam is only about two feet wide at this point and slow moving. A total of 426 samples for fecal coliform and conductivity analysis were collected weekly during the ten year period covered by this report. No samples for nutrients or metals were collected. Macroinvertebrates were collected in the spring of 2001.

A total of 137 samples were collected previously in 1989, 1995, 1996, and 1997. Samples were collected monthly in 1989 and weekly during the other three years. A macroinvertebrate sample was collected in 1989 but results from that year were inconclusive due to poor habitat.

The Hastings Cove Brook subbasin consists of 389 acres of forest and open land (77%), low density residential development (14%), open water and wetland (8%), and a very small amount of agriculture use (1%). Many of the homes have been built since 1991 when only 4% of the subbasin was residential development. Percent impervious cover (3.6%) is considerably less than the watershed average and impacts from non-point source runoff and stormwater pollution are unlikely.

Water quality has been extremely consistent throughout the past decade and for several years before as well, with very low fecal coliform concentrations during the winter and spring and only brief increases at the end of the spring or during early summer. Single samples with very high fecal coliform concentrations are collected occasionally, suggesting an intermittent source of contamination such as wild animals. All fecal coliform metrics are representative of very good water quality (Table 60), although annual metrics at this sampling station can be occasionally biased due to missing samples. The number of samples collected yearly ranged from thirty-five to fifty-two due to low flows in the summer and sporadic inaccessibility due to snow and ice during the winter.

Table 60:
HASTINGS COVE BROOK – FECAL COLIFORM AND CONDUCTIVITY

YEAR	88-97	98	99	00	01	02	03	04	05	06	07
fecal – median	1-35	9	3	5	5	7	20	5	10	5	5
fecal – geomean	n/a	8	6	5	15	12	20	12	14	9	13
fecal – %>20	8-58	32	22	18	31	28	36	22	29	21	36
fecal – %>100	3-25	4	3	6	14	6	11	12	10	4	14
(total samples)	(137)	(47)	(36)	(49)	(35)	(36)	(45)	(50)	(41)	(52)	(35)
conductivity	59-110	69	61	82	101	119	109	90	116	87	87

Seasonally grouped samples show only minor differences and those were possibly biased by infrequent sample collection. Water quality metrics were slightly worst during the summer, but conditions were often nearly as bad during the spring and fall. Water quality in Hastings Cove Brook was more strongly impacted by weather conditions, although even that was much less obvious than was seen at most other stations. Maximum annual metrics of wet weather samples were higher than those of dry weather samples, but overall the water quality of wet weather samples was only moderately worse than dry weather samples. Forty percent of the wet weather samples collected during the past ten years regardless of season contained more than 20 cfu/100mL; twenty-three percent of dry weather samples exceeded that benchmark.

Conductivity levels were fairly uniform throughout each of the sampling years, and were very low, indicative of runoff from an undeveloped watershed and similar to those recorded from the reservoir itself. The overall percentage increase in conductivity (23%) from 1998-2000 to 2006-2007 was much less than the average increase at thirty representative watershed tributaries (40%) and suggests that impacts to the tributary are minor and not increasing at a significant rate. Annual conductivity values did increase significantly in 2001, 2002, and 2003, but conductivity increased at all stations in the watershed during these years. These increases have been linked to the use of a new field conductivity meter. Annual conductivity throughout the watershed dropped significantly following a return to the original monitoring equipment, including in Hastings Cove Brook. Annual conductivity has been very similar throughout the past four years with a slight increase in 2005 due to a number of missing samples during the winter when conductivity tends to be lowest.

The macroinvertebrate population was moderately impaired with low numbers of taxa and pollution intolerant indicator species, but this was likely a function of stream size rather than upstream pollution.

A survey for beaver and muskrat populations located good habitat for both species and three unoccupied bank dens were noted between Linden Street and the reservoir. An active beaver population was identified upstream of Linden Street in the summer of 2000, but the beaver were removed and have not returned. Muskrat have been seen in the reservoir cove at the mouth of the brook.

Stormwater runoff has not been identified as a significant problem in the Hastings Cove Brook subbasin. The percentage of impervious cover remains low, and turbidity measurements taken in 2006 and 2007 were generally low during both dry and wet weather.

There has been a significant amount of development with low density residential development increasing from 4% to 14% of the subbasin, but the threat from additional development appears to be limited due to topography, wetlands, and frontage requirements.

Water quality of both wet and dry weather samples from this station has been unchanged for a number of years and remains very good. Both fecal coliform and conductivity are among the lowest in the watershed each year and are not likely to increase. Routine sampling will continue indefinitely, however, as this tributary is the closest to the Cosgrove Intake and therefore very important to monitor. Any additional development should be closely watched and appropriate direction provided.

3.15 HOG HILL BROOK

Hog Hill Brook flows into the Quinapoxet River approximately ½ mile upstream from the Wachusett Reservoir. Flow enters from the north as a seasonal discharge from Clay Bottom Pond (an old mill impoundment) under a former railroad bed now part of the Central Mass Rail Trail. During low flow conditions in the summer and fall, most or all of the flow is contained in Clay Bottom Pond. The brook continues upstream to Laurel Street where samples were collected from 2004 through 2007. The steam is about five feet wide at this point and surrounded primarily by woodlands with some single family dwellings. A total of 179 samples for fecal coliform and conductivity analysis were collected weekly. No samples for nutrients, metals, or macroinvertebrates were collected.

A total of 33 samples were collected previously in 1990 and 1991 from an upstream location north of Legg Road. Sample collection was biweekly and was very inconsistent due to low flow. Data from this period cannot be compared to the more recent sampling as there is an extensive system of wetlands and stormwater basins between the two sampling points.

The Hog Hill Brook subbasin consists of 948 acres of forest and open land (80%), low and medium density residential development (7%), roadways (7%), agriculture use (4%), and open water and wetland (3%). Interstate 190 bisects the subbasin and is responsible for much of the impervious area, but runoff from the highway is directed into retention basins for treatment prior to discharge to the brook and should not have a significant negative impact. Overall percent impervious cover (5.5%) is nearly identical to the watershed average and impacts from non-point source runoff and stormwater pollution are unlikely.

Bacteria numbers been extremely consistent for the past four years (Table 61), with very low fecal coliform concentrations during the winter and slightly higher concentrations during the spring, summer, and fall. Water quality of Hog Hill Brook was strongly impacted by weather conditions, although annual metrics of wet weather samples were not as bad as at many other stations (Table 62).

Table 61:
HOG HILL BROOK – FECAL COLIFORM AND CONDUCTIVITY

YEAR	88-97	98	99	00	01	02	03	04	05	06	07
fecal – median	28-54							10	10	10	10
fecal – geomean	n/a							14	19	14	16
fecal – %>20	60-62							30	37	24	39
fecal – %>100	5-23							11	14	8	12
(total samples)	(33)							(46)	(43)	(49)	(41)
conductivity	53-54							207	224	148	162

Table 62:
HOG HILL BROOK – FECAL COLIFORM (wet versus dry)

	wet weather samples	dry weather samples
fecal – annual median	50 – 120	5 – 10
fecal – annual geomean	37 – 81	9 – 13
fecal – annual %>20	70 – 89	13 – 30
fecal – annual %>100	38 – 56	0 – 6

Annual median conductivity in Hog Hill Brook peaked in 2005 during a year of near record high precipitation and a time when fifteen other stations in the watershed recorded their highest ever annual conductivity as well. Annual conductivity in Hog Hill Brook was dramatically lower during the following two years, an improvement unmatched at most other sampling stations. Comparable improvements were noted primarily at stations where septic system repairs or new sewer connections were prevalent.

A parcel with a proposed subdivision and two agricultural parcels including a large pig farm have been purchased by the Division and are no longer threats to water quality. Fecal coliform appears to be unchanged and at low concentrations, and conductivity has improved in the past two years. Water from Hog Hill Brook only intermittently reaches the Quinapoxet River and the Wachusett Reservoir. Routine sampling of this tributary will be discontinued in 2009.

3.16 HOUGHTON BROOK

Houghton Brook originates in large forested wetlands on a large Division-owned property in Sterling former known as the Kristoff Farm. The brook flows behind residential homes and then passes through a beaver pond and under Route 140 towards the Stillwater River to the east.

The sampling station on Houghton Brook is located just upstream of Route 140. During the sampling period addressed by this report there was intermittent beaver activity immediately upstream and flow was often impeded by a large active dam. The steam is about three feet wide at this point and has a soft muddy bottom. A total of 290 samples for fecal coliform and conductivity analysis were collected weekly during 1999, 2000, and 2004-2007. No samples for nutrients or metals were collected, and macroinvertebrate sampling was not done because of low flows and inadequate habitat. A total of 95 samples were collected previously for fecal coliform and conductivity in 1989, 1990, 1992, and 1993.

The Houghton Brook subbasin consists of 662 acres of forests and open land (60%), agriculture land use (22%), low and medium density residential development (11%), and roads (6%). Much of the agricultural area has been purchased by the Division, and a private dump in the subbasin was closed and capped in 1987. Percent impervious cover (6.2%) is slightly higher than the watershed average.

The presence of beaver has likely had both positive and negative impacts to water quality at this sampling station. The construction of a dam across the brook and creation of a pond held back large amounts of water and helped settle out particulate matter and fecal coliform. The rising water level may have inundated nearby septic systems, however, and the beaver themselves were an additional source of fecal coliform.

Water quality did not show any clear pattern and in fact there was little difference between wet and dry weather samples due to the buffering effect of the pond and dam. Water quality did appear to decline in 2007 (Table 63), but that may have been in part due to the scarcity of samples collected that year during the early fall when water quality tends to improve.

Table 63:
HOUGHTON BROOK – FECAL COLIFORM AND CONDUCTIVITY

YEAR	88-97	98	99	00	01	02	03	04	05	06	07
fecal – median	16-43		13	29				10	15	20	40
fecal – geomean	n/a		22	22				18	24	25	36
fecal – %>20	44-52		47	57				43	44	47	57
fecal – %>100	19-31		29	23				12	24	18	26
(total samples)	(95)		(45)	(53)				(49)	(50)	(51)	(42)
conductivity	209-273		291	346				578	620	604	582

Seasonally grouped samples did show differences, with water quality metrics much worst during the summer and quite good during the winter (Table 64). The concentration of contaminants during the dry summer months is common in most watershed tributaries and is likely caused by reduced flow.

Table 64:
HOUGHTON BROOK – RANGE OF SEASONAL METRICS

	WINTER	SPRING	SUMMER	FALL
fecal – median	1 – 10	16 – 70	70 – 435	5 – 45
fecal – geomean	3 – 11	26 – 47	77 – 316	6 – 32
fecal – %>20	0 – 23	46 – 77	85 – 100	0 – 67
fecal – %>100	0	8 – 46	38 – 88	0 – 17

As discussed earlier, the presence of the beaver dam may have reduced the impacts of wet weather on water quality by delaying the transport of contaminants downstream. Few storm impacted samples were collected during four of the six years, so annual metrics of wet and dry samples were only compared during 2005 and 2006, two years when wet weather samples were collected on at least thirteen occasions. Maximum annual metrics of wet weather samples those years were slightly higher than those of dry weather samples (Table 65).

Table 65:
HOUGHTON BROOK – FECAL COLIFORM (wet versus dry, 2005-2006)

	wet weather samples	dry weather samples
fecal – annual median	25 – 30	10
fecal – annual geomean	32 – 49	20 – 21
fecal – annual %>20	50 – 62	42
fecal – annual %>100	23 – 29	16 – 22

Annual conductivity did not vary significantly over the past four sampling years, but was quite high and much higher than had been recorded in previous years. The overall percentage increase (86%) from 1998-2000 to 2006-2007 was more than twice the average increase at thirty representative watershed tributaries (40%) and the second highest increase in the watershed. The increase in conductivity occurred at the same time as the increase in beaver activity.

Beaver have had an obvious impact on water quality at this station although several have been killed by automobiles and the local population may be in decline. Agricultural activity certainly has the potential to impact water quality as well, although the largest property is now owned by the Division. There is a small farm adjacent to the brook just downstream of Route 140. As many as ten cows have been observed at this location, although a recent inspection noted only six cows and an area for horses. There is a fence that keeps the animals from physically getting into the water, but the stream bottom appears very different than in other stretches of the brook. No samples have been collected downstream of this site as the routine sampling station is located approximately fifty feet upstream.

Water quality of both wet and dry weather samples at this station has not changed much over the past few years. This small tributary discharges into the Stillwater River and any water quality impacts are certainly mitigated by the sheer volume of the receiving water. Routine sampling of this station will be discontinued although samples will be collected if the beaver activity increases and water quality impacts are suspected. The Division should also consider special sampling downstream of the small farm to make sure that there are no impacts from the animals.

3.17 JORDAN FARM BROOK

Jordan Farm Brook has been sampled since 1998 as part of a study to document positive impacts of sewering on water quality in a small urbanized tributary (Cook Brook). Land use in the Jordan Farm Brook subbasin is predominantly agricultural and water quality data from the brook were compared with data from Cook Brook and from a small tributary in an undeveloped subbasin (Rocky Brook – East Branch). Initial sampling established baseline and stormwater nutrient and bacteria levels. Weekly sampling of the three subbasins has continued through 2007.

Sampling on Jordan Farm Brook took place just upstream of Route 68 in Rutland, downstream of the large agricultural operation for which the tributary is named. The brook is narrow and very shallow. During most years there is a period during the summer or fall when flow is insufficient for sampling. A total of 320 samples for fecal coliform and conductivity were collected during the past ten years, although no samples were collected during 2003. Samples for nitrate-nitrogen and total phosphorus were collected irregularly from 1999 through 2007. There have been no samples for metals or macroinvertebrates collected from this tributary, and only limited information on flow has been compiled.

Calculated statistics on land use in the Jordan Farm Brook subbasin are not currently available, although percent impervious is assumed to be low. The subbasin is forested with a significant amount of land in agricultural use (livestock). Agricultural activities utilize best management practices and are not believed to be a significant threat to water quality.

Water quality in this tributary has not exhibited a clear pattern during the past decade, with most annual metrics neither increasing nor declining, although in most years water quality was much better than in a majority of sampling stations throughout the watershed. Inconsistent sampling patterns due to low flow can bias annual fecal coliform metrics, and low flows during summer months often reduced the total number of samples (Table 66). No strong seasonal patterns were noted, although this may also have been impacted by irregular sampling.

Table 66:
JORDAN FARM BROOK – FECAL COLIFORM AND CONDUCTIVITY

YEAR	88-97	98	99	00	01	02	03	04	05	06	07
fecal – median		27	19	6	25	5		7	10	10	10
fecal – geomean		23	16	8	25	8		16	39	19	13
fecal – %>20		55	40	21	50	10		29	41	36	26
fecal – %>100		18	10	11	17	3		18	24	16	5
(total samples)		(38)	(30)	(38)	(24)	(31)		(34)	(37)	(50)	(38)
conductivity		58	82	113	107	133		111	126	126	136

Water quality in Jordan Farm Brook was strongly impacted by weather conditions. Maximum annual metrics of wet weather samples were much higher than those of dry weather samples (Table 67). Only twenty-five percent of dry weather samples collected during the past ten years contained more than 20 cfu/100mL while nearly sixty-five percent of the wet weather samples exceeded that benchmark.

Annual conductivity levels were very low in 1998 and 1999 (Table 66), indicative of runoff from an undeveloped watershed and even lower than those recorded from the reservoir itself, but values more than doubled to a historic maximum in 2007. The overall percentage increase in conductivity (55%) from 1998-2000 to 2006-2007 was higher than the average increase at thirty representative watershed tributaries (40%). This possibly reflects impacts from the agricultural operation upstream but could also be due in part to reduced flows (a concentration of dissolved salts) and irregular sampling. Annual conductivity values are definitely trending upwards and reached a historic maximum in 2007, but remain considerably lower than what is measured in many of the other tributaries in the watershed.

Table 67:
JORDAN FARM BROOK – FECAL COLIFORM (wet versus dry)

	wet weather samples	dry weather samples
fecal – annual median	5 – 1120	5 – 17
fecal – annual geomean	13 – 570	4 – 19
fecal – annual %>20	29 – 100	4 – 46
fecal – annual %>100	17 – 71	0 – 14

Samples for nitrate-nitrogen and total phosphorus were collected irregularly (2-11 times per year) from 1999 through 2007 from Jordan Farm Brook and from two other locations (Cook Brook, Rocky Brook – East Branch) as part of an ongoing study to evaluate impacts of sewers on water quality. Concentrations of both parameters have remained fairly constant in Jordan Farm Brook during the ten years (Table 68). Total phosphorus concentrations appear to be trending higher but remained below 0.05 mg/L except during 2005 when a single very high concentration measured in the spring (0.277 mg/L) resulted in a much higher than normal annual mean. Nitrate-nitrogen concentrations were much higher and were only exceeded by samples from Cook Brook and West Boylston Brook.

Concentrations of nitrate-nitrogen and total phosphorus in Rocky Brook (East Branch) have remained very low and nearly unchanged over the past ten years (Chapter 3.27), but have dropped steadily in Cook Brook (Chapter 3.9) since 2002. Because nutrient concentrations have remained relatively unchanged in Jordan Farm Brook and in Rocky Brook (East Branch) but have dropped to historic lows in Cook Brook, it appears that there is clear evidence of the positive impacts of connections to the new municipal sewer system. Sampling will continue for several years to further document any additional improvements.

Table 68:
JORDAN FARM BROOK – NUTRIENT MEAN CONCENTRATIONS (mg/L)

	1999	**2000**	**2001**	**2002**	**2003**	**2004**	**2005**	**2006**	**2007**
Nitrate-nitrogen	1.91	2.69	1.97	1.82		1.33	1.47	1.72	1.95
Total phosphorus	0.023	0.015	0.020	0.011		0.030	**0.095**	0.037	0.027

3.18 JUSTICE BROOK

Justice Brook originates from the smaller of two ponds bisected by Justice Hill Road in Sterling and flows through mainly undeveloped woods to the sampling station downstream of Route 140 on the Sterling/Princeton line. The brook is three to four feet wide and flows slowly in a fairly straight path through the woods until it approaches Route 140 where it gets much wider and the rate of flow increases.

The sampling station on Justice Brook is located just downstream of Route 140, approximately 200 yards above the point where it joins with Keyes Brook and becomes the Stillwater River. The stream is between seven and ten feet wide at this sampling location. Samples were collected weekly during 1998, 1999, 2000, and 2004 – 2007. A total of 350 samples were collected for fecal coliform and conductivity analysis. No samples for nutrients, metals, or macroinvertebrates were collected from this station during the ten year sampling period.

A total of 251 samples for fecal coliform and conductivity were collected during the previous decade (1988 – 1997). Macroinvertebrate samples were collected in 1988, 1989, and 1990.

The Justice Brook subbasin consists of 3182 acres of forests and open land (86%), low density residential development (8%), agriculture (4%), and open water and wetlands (2%). Much of the land remains in private ownership although a significant portion of the headwater area upstream of the pond is part of the state-owned Leominster State Forest. Percent impervious cover (2.4%) is one of the lowest in the watershed.

Water quality was excellent and unchanged throughout the sampling period and has been since sampling began in 1989 (Table 69). Fecal coliform and conductivity remained very low. Justice Brook does not have any obvious water quality problems.

Table 69:
JUSTICE BROOK – FECAL COLIFORM AND CONDUCTIVITY

YEAR	88-97	98	99	00	01	02	03	04	05	06	07
fecal – median	0-3	1	2	2				5	5	5	5
fecal – geomean	n/a	3	3	2				9	8	9	6
fecal – %>20	0-15	10	4	0				8	10	14	2
fecal – %>100	0-5	2	0	0				4	2	2	0
(total samples)	(251)	(50)	(50)	(50)				(49)	(50)	(51)	(50)
conductivity	29-49	35	45	43				54	52	46	50

Seasonally grouped samples showed only very minor differences, with water quality metrics slightly higher during the summer. There were only small differences between dry weather and wet weather samples as well, much less than at any other sampling station in the watershed but still noticeable (Table 70).

Table 70:
JUSTICE BROOK – FECAL COLIFORM (wet versus dry)

	wet weather samples	dry weather samples
fecal – annual median	2 – 20	1 – 5
fecal – annual geomean	3 – 31	2 – 8
fecal – annual %>20	0 – 33	0 – 11
fecal – annual %>100	0 – 22	0

Macroinvertebrate samples were historically collected from this tributary in 1988, 1989, and 1990 using a one-minute kick technique. The stream has a substrate consisting primarily of bedrock, boulders, and cobbles, with many of the rocks covered with moss. Samples collected in all three years showed little or no impairment as was expected in a stream with excellent water quality. No additional samples have been collected.

Water quality in this subbasin meets Class A Surface Water Quality Standards, but fecal coliform levels still are occasionally elevated. Much of the subbasin is undeveloped, with known populations of beaver and muskrat in the ponds and wetlands. There are some single family homes and areas of agriculture, but all potential sources except wildlife are located at or upstream of Stuart Pond, so it is possible that any contamination is being removed due to sedimentation. The watershed below the pond is almost entirely undeveloped forested land. Infrequently elevated fecal coliform levels are probably caused by stormwater transport of bacteria from wild animal populations rather than from poorly sited agricultural operations or faulty septic systems.

Water quality has been very good for a number of years and there is no indication that conditions will change. Much of the land remains undeveloped forest and the small amounts of residential development and agriculture are either a distance from the tributary or well managed and not considered a threat. This station can be eliminated from routine sampling.

3.19 KEYES BROOK

3.19.1 Gleason Road

This is the primary sampling location on Keyes Brook, one of the two tributaries that combine to become the Stillwater River. The brook flows behind homes along Route 140 in Princeton at the base of a steep hill and into a small pond just upstream of Gleason Road. It then passes through two five foot openings under Gleason Road and over an expanse of exposed bedrock and large boulders. The brook is approximately ten feet wide at this location although it is sometimes considerably smaller depending on the time of year.

Weekly samples were collected downstream of Gleason Road during 1998, 1999, 2000, and 2004 – 2007 approximately 1000 yards above the point where it joins with Justice Brook. A total of 349 samples were collected for fecal coliform and conductivity analysis. No samples for nutrients, metals, or macroinvertebrates were collected from this station during the current ten year sampling period.

A total of 103 samples for fecal coliform and conductivity were collected during the previous decade (1988 – 1997). Macroinvertebrate samples were collected in 1989 but results were difficult to interpret due to poor substrate (bedrock) and this tributary was not sampled again.

Two other stations on Keyes Brook (Hobbs Road, Onion Patch) were sampled in 2004 – 2007 to help locate specific sources of contamination and to determine the water quality of the brook upstream. These sampling stations are described in the following two chapters (3.19.2, 3.19.3).

The Keyes Brook subbasin is comprised of over 3200 acres of forest and open land (84%), low density residential development (10%), and small amounts of open water, wetlands, and agriculture. The large amount of forested land, widely scattered residential development, and absence of any large commercial or industrial areas are responsible for a percent impervious cover of 3.1% that is one of the lowest in the watershed.

Fecal coliform metrics were relatively stable during the sampling period and in fact were very similar to data from the previous ten years, although water quality did appear to decline slightly during 1998-1999 (Table 71). Most metrics were higher during these years, a result of elevated fecal coliform concentrations during the spring and summer. Septic systems at a number of homes on small parcels close to the brook in East Princeton have had problems in the past and could have been the source of additional fecal coliform. These issues have all been resolved and water quality has been very good for the past four years.

Table 71:
KEYES BROOK (Gleason Road) – FECAL COLIFORM AND CONDUCTIVITY

YEAR	88-97	98	99	00	01	02	03	04	05	06	07
fecal – median	5-6	16	15	10				5	5	10	5
fecal – geomean	n/a	15	13	8				13	9	14	10
fecal – %>20	16-27	36	40	20				29	14	29	14
fecal – %>100	0-5	6	10	6				12	0	4	6
(total samples)	(103)	(50)	(50)	(50)				(49)	(49)	(51)	(50)
conductivity	55-81	63	79	63				89	85	69	77

Seasonally grouped samples exhibited some differences although less so than at a number of the sampling stations in the watershed. Fecal coliform concentrations were generally low in the winter, increased during the spring and summer, and then dropped in the fall. This was likely caused by a reduction in flow during the warmer, dry months in the middle of the year.

Water quality of wet weather samples at this station was worse than that of dry weather samples (Table 72), but there was less difference than seen at a number of other stations in the watershed. Twenty-one percent of dry weather samples collected during the past ten years contained more than 20 cfu/100mL while fifty percent of the wet weather samples exceeded that benchmark.

Table 72:
KEYES BROOK (Gleason Road) – FECAL COLIFORM (wet versus dry)

	wet weather samples	dry weather samples
fecal – annual median	12 – 150	5 – 15
fecal – annual geomean	12 – 69	8 – 13
fecal – annual %>20	21 – 80	7 – 40
fecal – annual %>100	0 – 56	0 – 11

Water quality of wet weather samples was particularly bad in 2004 compared to most other years, although the water quality of wet weather samples in 2007 was also poor. Comparison of annual wet weather metrics is difficult because of differences in the number, season, and magnitude of rain events each year, but the water quality decline of storm samples in 2004 appears significant. No explanation has been postulated.

Conductivity levels in Keyes Brook were very low, with an annual mean less than 100 µmhos/cm. Measurements this low are indicative of runoff from undeveloped watersheds and are lower than those recorded from the reservoir. Annual conductivity values at this station did not increase as much as at many of the other stations in the watershed. Annual medians were very similar throughout the sampling period and only slightly higher than historical values (Table 71). A comparison of annual values from 1998-2000 with those from 2006-2007 showed an increase of only 7%. The average increase at stations in the watershed was 40%, with some stations having increases of more than 100%.

Table 73 presents annual geometric mean fecal coliform data and median conductivity data for the three sampling stations on Keyes Brook. There are only slight differences between the three stations with very similar fecal coliform numbers during most years and conductivity only slightly lower at Hobbs Road than at the other two stations. This is not surprising as much of the watershed has similar land use and there are no significant differences between the sampling locations.

Table 73:
KEYES BROOK – FECAL COLIFORM AND CONDUCTIVITY

YEAR	2004	2005	2006	2007
fecal – geometric mean				
Gleason Road	13	9	14	10
Onion Patch	9	8	20	13
Hobbs Road	18	15	11	13
conductivity				
Gleason Road	89	85	69	77
Onion Patch	87	82	70	80
Hobbs Road	77	79	63	70

There are seven parcels with horses in the subbasin and some are located on steep slopes near wetland resources, but all were inspected and no actual problems have been identified. A number of single-family homes previously had septic system problems and required variances to Title 5, including one property where a tight tank was installed, but none have been linked recently to elevated fecal coliform concentrations. Erosion problems have been noted at several locations along Routes 31 and 140, with road runoff and sediment deposition, although turbidity data suggest that very little reaches the brook. There is an old illegal disposal site upstream of the sampling station where hazardous materials used to be buried. Water samples were collected by the DEP in 1983 from local wells but no contaminants were found, and the site is no longer considered a threat. Due to the lack of obvious problems and the consistent good water quality, this station and the others on Keyes Brook can likely be dropped from routine sampling.

3.19.2 Hobbs Road

The primary sampling location on Keyes Brook is located just downstream of Gleason Road in Princeton (Chapter 3.19.1). Samples were also collected weekly from a station just below Hobbs Road to help locate any sources of contamination closer to the headwaters. This sampling station is within a lightly developed residential area with widespread forests and some beaver activity. The brook is approximately eight feet wide at this sampling location.

Weekly samples at Hobbs Road were collected from 2004 through 2007 at a site approximately 1.5 miles upstream of the primary sampling location. A total of 200 samples were collected for fecal coliform and conductivity analysis. No samples for nutrients, metals, or macroinvertebrates have been collected from this station.

Fecal coliform and conductivity metrics were very stable during the four years of sampling with possibly a slight improvement observable (Table 74). Most metrics at this station were very similar to those from the other two stations on Keyes Brook (see Chapter 3.19). Water quality at this sampling station has been very good for the past four years as expected in a subbasin with limited upstream development.

Table 74:
KEYES BROOK (Hobbs Road) – FECAL COLIFORM AND CONDUCTIVITY

YEAR	88-97	98	99	00	01	02	03	04	05	06	07
fecal – median								10	10	10	7
fecal – geomean								18	15	11	13
fecal – %>20								37	34	14	24
fecal – %>100								14	4	2	8
(total samples)								(49)	(50)	(51)	(50)
conductivity								77	79	63	70

Seasonally grouped samples exhibited some differences (Table 75) although less so than at a number of the sampling stations in the watershed. Fecal coliform concentrations were very low in the winter, increased during the spring and summer, and then dropped in the fall. Much of the elevated fecal coliform during the warmer months appears to be the result of storm events as all metrics of dry weather samples show very minimal seasonal differences.

Table 75:
KEYES BROOK (Hobbs Road) – RANGE OF SEASONAL METRICS

	WINTER	SPRING	SUMMER	FALL
fecal – median	5	5 – 31	10 – 60	5 – 10
fecal – geomean	6 – 8	10 – 31	13 – 54	9 – 12
fecal – %>20	0 – 8	15 – 67	23 – 77	8 – 18
fecal – %>100	0 – 8	0 – 17	0 – 38	0 – 9

Water quality of wet weather samples at this station was worse than that of dry weather samples (Table 76), although differences were less significant than those observed at most other stations in the watershed and similar to the small differences noted at the two other Keyes Brook stations

(Tables 72 and 78). Twenty-one percent of dry weather samples collected during the past ten years contained more than 20 cfu/100mL while just fewer than fifty percent of the wet weather samples exceeded that benchmark.

Table 76:
KEYES BROOK (Hobbs Road) – FECAL COLIFORM (wet versus dry)

	wet weather samples	dry weather samples
fecal – annual median	20 – 70	5 – 7
fecal – annual geomean	22 – 99	8 – 13
fecal – annual %>20	38 – 67	5 – 31
fecal – annual %>100	7 – 44	0 – 8

Conductivity levels at this station were very low, indicative of runoff from undeveloped watersheds and lower than those recorded from the reservoir. Annual median conductivity values at this station were unchanged throughout the sampling period (Table 74).

Due to the lack of obvious problems and the consistent good water quality, this station and the others on Keyes Brook can be dropped from routine sampling.

3.19.3 Onion Patch

The primary sampling location on Keyes Brook is located just downstream of Gleason Road in Princeton (Chapter 3.19.1). Samples were also collected weekly from 2004 through 2007 from a station just below the Onion Patch to help locate any sources of contamination closer to the headwaters. This sampling station is behind a small commercial area at the outlet of the Onion Patch, a large open water body surrounded almost entirely by forest. The commercial property consists of a package store and a garage, and is the site of a small dump that accepted hazardous waste in the past. There is also evidence of beaver activity in the area.

Weekly water quality samples were collected from 2004 through 2007 at the Onion Patch pond outlet approximately 800 yards upstream of the primary sampling station at Gleason Road and about a mile downstream from the Hobbs Brook station (Chapter 3.19.2). The brook is ten feet wide at this sampling location but expands during periods of high flow. A total of 199 samples were collected for fecal coliform and conductivity analysis. No samples for nutrients, metals, or macroinvertebrates have been collected from this station.

Fecal coliform and conductivity metrics were relatively stable during the four years of sampling although fecal coliform concentrations did appear to increase slightly in 2006 and 2007 (Table 77). Most metrics at this station were very similar to those from the other two stations on Keyes Brook (see Chapter 3.19.1). Water quality at this sampling station has remained good for the past four years as expected in a subbasin with limited upstream development.

Table 77:
KEYES BROOK (Onion Patch) – FECAL COLIFORM AND CONDUCTIVITY

YEAR	88-97	98	99	00	01	02	03	04	05	06	07
fecal – median								5	5	10	10
fecal – geomean								9	8	20	13
fecal – %>20								17	12	35	30
fecal – %>100								2	4	22	10
(total samples)								(48)	(50)	(51)	(50)
conductivity								87	82	70	80

Similar to the other two sampling stations on Keyes Brook, seasonally grouped samples exhibited only small differences. Fecal coliform concentrations were generally low in the winter, increased in the spring and summer, and then dropped in the fall. Water quality of wet weather samples at this station was worse than that of dry weather samples (Table 78), although differences were less significant than those observed at most other stations in the watershed and similar to the small differences noted at the two other Keyes Brook stations (Tables 72 and 76). Eighteen percent of dry weather samples collected during the past ten years contained more than 20 cfu/100mL while forty-four percent of the wet weather samples exceeded that benchmark.

Table 78:
KEYES BROOK (Onion Patch) – FECAL COLIFORM (wet versus dry)

	wet weather samples	dry weather samples
fecal – annual median	5 – 110	5 – 10
fecal – annual geomean	10 – 61	8 – 17
fecal – annual %>20	21 – 80	8 – 32
fecal – annual %>100	0 – 60	3 – 21

Conductivity levels at this station were very low, indicative of runoff from undeveloped watersheds and lower than those recorded from the reservoir. Annual median conductivity values at this station were unchanged throughout the sampling period (Table 77).

Signs of old beaver and muskrat activity have been noted throughout the subbasin, and an active beaver population was identified within the Onion Patch. Flocks of ducks and geese have also been observed using the pond. Wildlife is the most likely cause of the recent increase in fecal coliform, but is not of great concern due to the distance from the reservoir.

Due to the lack of significant problems and the consistent good water quality at this location and downstream, all stations on Keyes Brook will be dropped from routine sampling.

3.20 LANDFILL BROOK

Landfill Brook originates in a wetland in Holden and flows west and then northwest to the Quinapoxet River, passing under River Road in a 24” culvert. The surrounding area is forest and open meadow (capped landfill). Water quality samples were collected from this tributary just below River Street approximately 150 feet from the Quinapoxet River. The stream is about six feet in width at this sampling location. Samples were collected weekly in 1999 and 2000 and a total of 100 samples were collected for fecal coliform and conductivity analysis. Forty-six samples were collected previously in 1989 and 1993. Macroinvertebrate sampling was done in 1989, 1998, and 2001. No samples for nutrients or metals have been collected from this station.

The subbasin is comprised of 134 acres of forest and open land (79%), a large area of roadways and industrial use (19%), and a small amount of open water and wetlands (2%). The industrial use includes a portion of the Holden municipal landfill (now closed and capped) and a large sand and gravel pit. Interstate 190 extends along the entire eastern edge of the subbasin. The percentage of impervious cover (7.5%) in the subbasin is higher than the watershed average (5.4%) but no problems with stormwater have been identified.

Fecal coliform concentrations were usually very low, increasing slightly in the summer, although the summer increase was less striking than that observed in most tributaries in the watershed. Annual fecal coliform metrics were similar in 1999 and 2000 and virtually identical to historic data. Water quality as measured by fecal coliform is quite good at this station (Table 79).

Table 79:
LANDFILL BROOK – FECAL COLIFORM AND CONDUCTIVITY

YEAR	88-97	98	99	00	01	02	03	04	05	06	07
fecal – median	4		5	3							
fecal – geomean	n/a		5	5							
fecal – %>20	0-26		12	20							
fecal – %>100	0-2		0	8							
(total samples)	(46)		(50)	(50)							
conductivity	154-161		165	170							

Weather conditions had a strong impact on water quality although even wet weather samples from this station often had better water quality than dry weather samples from many of the other sampling stations in the watershed. Dry weather samples from Landfill Brook had excellent water quality. Annual metrics of wet weather samples were 5-10 times higher (Table 80).

Table 80:
LANDFILL BROOK – FECAL COLIFORM (wet versus dry)

	wet weather samples	dry weather samples
fecal – annual median	37 – 40	2 – 4
fecal – annual geomean	17 – 28	3 – 4
fecal – annual %>20	50 – 60	9 – 10
fecal – annual %>100	0 – 20	0 – 5

Annual conductivity values at this station have been extremely consistent which is not surprising as land use in the contributory subbasin has remained the same for the past twenty years. Conductivity levels were highest during the spring and then dropped during the summer, increasing slightly during the fall and winter. This pattern was unlike that seen in any other tributary in the watershed. Conductivity levels tend to rise in the summer due to the concentration of contaminants caused by reduced flow. Proximity to the Holden landfill and flow from a large wetland receiving runoff from the highway may be impacting groundwater and surface water quality and quantity and causing these unusual conductivity measurements.

Macroinvertebrate samples were collected in May of 1989, 1998, and 2001 using a one-minute kick technique. An assessment of potential habitat at this sampling station was not done, but substrate and flow seemed adequate and comparable to other tributaries. Samples collected in all three years showed only slight impairment when compared to the reference station. The dominant taxa include two small mayfly species (*Ephemerella dorothea* and *Epeorus sp.*), a small stonefly (*Amphinemoura wui*.), and a web-spinning caddisfly (*Dolophilodes* sp.).

Table 81:
LANDFILL: BROOK – MACROINVERTEBRATE ASSESSMENT

YEAR	**TAXA**	**EPT**	**EPT/chiro**	**HBI**	**% DOMIN**	**IMPAIRMENT**
1989	20	14	81	2.09	45	slight
1998	23	18	82	1.34	27	non-impaired
2001	21	13	>100	1.49	24	slight
89-01	19-28	13-18	10->100	1.02-1.62	14-23	REF STATION

Stormwater runoff was not identified as a significant problem in this subbasin due to the lack of development, even though the percentage of impervious cover was higher than the watershed average because of extensive paved areas associated with the highway. Stormwater from Interstate 190 is collected in retention basins and many of the contaminants removed before the water filters into the brook.

Problems with stormwater runoff were noted during the capping of the Holden landfill during the late 1980s. Large quantities of clay were washing off of the site, down the entrance road, and into the brook. The contractor responsible utilized gravel berms and haybales with filter fence to keep silt-laden water on site.

Due to consistent good water quality and an absence of existing problems or threatened growth, this station can likely be dropped from routine sampling.

3.21 MALAGASCO BROOK

Malagasco Brook flows into the reservoir at South Bay from the east, passing through a townhouse complex and originating from a large swamp adjacent to a nursery. This tributary was sampled at a point approximately 100 yards from the shore of the reservoir near the end of West Temple Street in Boylston. The brook is about six feet wide at this sampling location. Surrounding land use is primarily undisturbed woodland, although a few single-family homes are located nearby.

A total of 551 samples for fecal coliform and conductivity analysis and fifty-nine samples for nitrate-nitrogen and total phosphorus have been collected from Malagasco Brook at this station during the ten year period covered by this report. A staff gage is located at the sampling station and the USGS provides updated rating curves to enable calculation of flow. Macroinvertebrate samples were collected from this tributary in May of 1998 and 2001. No samples for metals have been collected since 1992.

During the previous ten year period a total of 340 samples were collected for fecal coliform and conductivity analysis and macroinvertebrate samples were collected during 1988, 1989, 1990, 1992, 1994, and 1996.
Fecal coliform samples were also collected from four upstream stations on Malagasco Brook during 2003 (and had been from three of the same stations in 1995) to try to further define sources of contamination. A brief description of these sampling stations is presented at the end of this chapter.

The Malagasco Brook subbasin consists of 563 acres of forest and open land (53%), residential development (26%), open water and wetlands (21%), and a small amount of agriculture use. Seven percent of the residential development is identified as high density. A large multi-unit housing complex with more than one hundred units in twenty-four buildings is the most significant development in the subbasin. Loss of forested and open land for residential development has increased the percentage of impervious cover to near ten percent and problems with stormwater runoff are a concern. A filter curtain was installed at the mouth of the brook to help reduce transport of particulate materials into the reservoir.

Annual fecal coliform metrics have been relatively stable throughout the ten year period with a slight improvement of most metrics as illustrated in Table 82. Annual metrics in 2003 were much higher than normal, but this was due to a change in sampling that year which involved the collection of a larger number of samples with emphasis on storm events. When the additional samples were excluded and only weekly samples considered, annual median was 20 cfu/100mL. Metrics in all years except 2003 were considerably lower than what was measured prior to 1998.

A source of contamination was located and removed in 1997 and water quality has improved noticeably since that time.

Table 82:
MALAGASCO BROOK – FECAL COLIFORM AND CONDUCTIVITY

YEAR	88-97	98	99	00	01	02	03	04	05	06	07
fecal – median	16-82	26	33	26	20	20	65	20	20	25	20
fecal – geomean	n/a	28	31	18	29	23	57	26	26	29	24
fecal – %>20	44-82	52	59	58	46	41	65	46	44	50	41
fecal – %>100	21-46	32	20	12	29	27	40	20	17	22	12
(total samples)	(340)	(50)	(49)	(50)	(52)	(49)	**(88)**	(56)	(52)	(54)	(51)
conductivity	159-266	200	213	181	375	359	334	298	370	352	**449**

Seasonally grouped samples exhibited significant differences at this station and at most sampling station in the watershed. Fecal coliform concentrations were very low in the winter, were higher in the spring and fall, and reached their highest during the summer (Table 83). The increase in fecal coliform in the summer is most likely due to the reduction in flow and the subsequent concentration of bacteria in the brook. The annual geometric mean summer flow in Malagasco Brook was consistently low at 0.16 – 0.80 cfs, with an average of 0.47 cfs. Annual geometric mean winter flow ranged from 0.74 – 4.48 cfs with an average of 2.07 cfs. Spring flows were slightly less than winter flows (0.74 – 2.90, 1.82 cfs) while fall flows were more comparable to summer flows (0.41 – 1.37, 0.77 cfs).

Table 83:
MALAGASCO BROOK – RANGE OF SEASONAL METRICS

	WINTER	SPRING	SUMMER	FALL
fecal – median	2 – 9	20 – 91	20 – 240	5 – 60
fecal – geomean	4 – 10	26 – 59	32 – 267	9 – 63
fecal – %>20	0 – 31	43 – 69	38 – 100	8 – 75
fecal – %>100	0 – 8	8 – 46	15 – 92	0 – 25

Water quality of wet weather samples at this station was much worse than that of dry weather samples during all seasons except in winter when most storm events involved snow and ice rather than rain. One hundred percent of all wet weather samples collected after April 1st each year contained more than 20 cfu/100mL. Seasonal geometric means of wet weather samples from 2003 (the only year when enough storm events were sampled to determine seasonal wet weather metrics) ranged from 92 to 684 cfu/100mL. Seasonal geometric means of dry weather samples were usually less than 50 cfu/100mL except during the summer. The annual geometric mean of dry samples during the ten years of sampling was 33 cfu/100mL or less each year, while the annual geometric means of wet weather samples from the same period were between 36 and 234 cfu/100mL. Other annual fecal coliform metrics showed similar differences (Table 84).

Table 84:
MALAGASCO BROOK – FECAL COLIFORM (wet versus dry)

	wet weather samples	dry weather samples
fecal – annual median	45 – 280	10 – 33
fecal – annual geomean	36 – 234	15 – 33
fecal – annual %>20	50 – 96	32 – 60
fecal – annual %>100	14 – 73	3 – 30

The mean conductivity in Malagasco Brook for the current ten year period was 72% higher than for the previous ten year period, considerably more than the average watershed increase of 56% as determined by using ten tributaries that have been sampled consistently for the past twenty years. Years with little rainfall often result in higher conductivities due to low flow conditions, and winter storm events can lead to elevated levels due to the application of salt on icy roadways, so the use of annual statistics for conductivity can be misleading. Annual data were examined to look for periods of relative stability and annual conductivities grouped and summarized. The periods of 1988-1992, 1998-2000, and 2006-2007 exhibited little change throughout the watershed and were therefore used to detect trends. The increase in conductivity at the ten tributaries continuously monitored from the earliest period (88-92) to the latest (06-07) was 83%. The increase in Malagasco Brook was 141% (an increase of 86% since 1998-2000) and appears indicative of a possible problem that was not obvious by looking at fecal coliform numbers.

Annual conductivity values increased significantly in 2001, 2002, and 2003, but conductivity increased at all stations during these years. These increases have been linked to the use of a new field conductivity meter during that three year period. Annual conductivity at most other stations dropped following a return to an earlier piece of monitoring equipment, but declined only briefly in Malagasco Brook and then increased to a historic maximum in 2007 (Table 83).

Samples for nitrate-nitrogen and total phosphorus were collected irregularly (2-11 times per year) from 1999 through 2007. Nutrient samples collected from Malagasco Brook always contained more nitrate-nitrogen than all but the three tributaries in densely developed neighborhoods with known septic system problems (Gates Brook, West Boylston Brook, Cook Brook) and the tributary most impacted by livestock (Jordan Farm Brook). Annual mean concentration of total phosphorus was usually low and only narrowly exceeded the EPA recommended limit of 0.05 mg/L in 2005 (Table 85).

Table 85:
MALAGASCO BROOK – NUTRIENT MEAN CONCENTRATIONS (mg/L)

	1999	**2000**	**2001**	**2002**	**2003**	**2004**	**2005**	**2006**	**2007**
Nitrate-nitrogen	0.650	0.689	0.721	0.245	0.735	0.737	0.596	0.687	0.735
Total phosphorus	0.034	0.031	0.037	0.029	0.024	0.033	**0.057**	0.025	0.027

Macroinvertebrate samples were collected in May of 1988, 1989, 1990, 1992, 1994, 1996, 1998, and 2001 using a standard one-minute kick technique. Samples collected during 1988 and 1989 showed only slight impairment when compared to the reference station. Samples from 1990 and 1992 showed moderate impairment with a shift towards more pollution tolerant species such as chironomid midges. Samples collected in 1994, 1996, and 1998 indicated severe impairment of Malagasco Brook, with unbalanced populations and obvious impacts from organic enrichment reflected by biotic index scores of 3.00 or higher. A source of contamination was located and removed in 1997 and water quality (as measured by fecal coliform) improved greatly. The macroinvertebrate sample collected in 2001 was moderately to severely impaired, but some improvements were noted as the stream began to recover. A species of filter-feeding caddisfly (*Diplectrona modesta*) replaced most of the pollution tolerant chironomids and biotic index scores were lowered (Table 86).

A special study was initiated on Malagasco Brook during 1995 to help locate any sources of contamination. Samples collected from a headwater station receiving runoff from a commercial nursery regularly contained higher concentrations of fecal coliform than samples from downstream stations. There was a definite improvement in water quality at downstream stations, with the best water quality (though still poor) at the primary station near the mouth of the brook. It was clear that the primary source of contamination was at the headwaters, and additional investigations helped determine that the probable source was a large mulch pile on the nursery property. The owner of the nursery cooperated with the Division and the pile was removed in the fall of 1997. Fecal coliform concentrations were sharply lower in the brook for the remainder of the year.

Table 86:
MALAGASCO BROOK – MACROINVERTEBRATE ASSESSMENT

YEAR	TAXA	EPT	EPT/chiro	HBI	% DOMIN	IMPAIRMENT
1989	21	13	13.5	2.77	18	slight
1992	16	8	1.8	3.72	17	moderate
1994	17	9	2.7	3.44	34	severe
1996	17	9	0.7	4.05	55	severe
1998	16	9	0.4	4.55	57	severe
2001	13	5	1.6	3.03	37	moderate-severe
88-01	19-28	13-19	10 - >100	1.02-1.62	14-41	REF STATION

Fecal coliform samples were collected from four upstream stations during 2003 to continue to look for sources of contamination. A total of 144 samples were collected from Malagasco Brook from locations upstream, within, and downstream of the large townhouse development. Initial analysis appeared to implicate townhouse septic systems as a source of elevated fecal coliform in the brook, but further sampling determined that this was not the case. No clear source was ever identified, but water quality did not continue to decline and there was no immediate need to investigate further. The unusually elevated annual conductivity seen in 2007 suggest that conditions may be declining again and a decision whether to reinvestigate upstream sources will be made following interpretation of the 2008 sampling data.

Stormwater runoff was identified as a significant problem in this subbasin. A stormwater study singled out the Malagasco Brook subbasin as an impacted area based on elevated concentrations of fecal coliform and nitrate-nitrogen. The study recommended in-stream treatment using a riser pipe to detain water at the West Temple Street crossing within the townhouse development, but this was never implemented. A second suggestion to install a filter curtain similar to the one in Gates Brook Cove was acted upon during the spring of 1999. This system was calculated to remove 50-80% of the bacteria and to reduce turbidity levels by 70-80%.

Nearly ten percent of the watershed is covered by impervious surfaces. Turbidity measurements from 2006 illustrated negative impacts from stormwater runoff. Wet weather mean turbidity was nearly 200% higher than dry weather mean turbidity. Many of the other tributaries in the watershed did not show such a significant increase, especially those flowing through large areas of undeveloped lands.

It is not clear if water quality in Malagasco Brook is stable, improving, or declining. Additional macroinvertebrate samples should be collected to help answer this question. If water quality has not improved, the entire length of stream should be resampled to help determine the location of any sources of contamination. The status of the filter curtain should be determined and if still functional an updated assessment of removal efficiency should be completed.

3.22 MALDEN BROOK

The headwaters of Malden Brook are a large wetland just south of Lee Street in West Boylston. Drainage from the wetland flows north under Lee Street through two 24" corrugated metal pipes and continues north through protected open space owned by the Town of West Boylston, past a large housing development constructed in the eighties, and then through areas of forest, wetland, agricultural use, and residential development before flowing down a constructed spillway and discharging under Thomas Street into the Quinapoxet Basin of the Wachusett Reservoir. The brook was sampled just upstream of the spillway at a point approximately thirty feet from the reservoir.

A total of 521 samples for fecal coliform and conductivity analysis and fifty-eight samples for nitrate-nitrogen and total phosphorus have been collected from Malden Brook at this station during the ten year period covered by this report. The stream is approximately six feet in width at this location. A staff gage is located at the sampling station and the USGS provides updated rating curves to enable calculation of flow. Macroinvertebrate samples were collected from this tributary in May of 1998 and 2001.

During the previous ten year period a total of 341 samples were collected for fecal coliform and conductivity analysis and macroinvertebrate samples were collected during 1988, 1989, 1990, 1994, and 1996.

The Malden Brook subbasin consists of 1216 acres of forest and open land (65%), residential development (20%), agriculture (8%), roadways (6%), and a small amount of wetlands (1%), although much of the area of roadway (I-190) is actually outside of the subbasin. Six percent of the residential development is identified as medium density. Agricultural use is higher that the watershed average of 6%.

Annual fecal coliform metrics have been relatively stable throughout the ten year period without any obvious changes (Table 87) or clear patterns even though a new municipal sewage system was installed and many homes (40%) have been connected during the past five years.

Table 87:
MALDEN BROOK – FECAL COLIFORM AND CONDUCTIVITY

YEAR	88-97	98	99	00	01	02	03	04	05	06	07
fecal – median	14-47	32	21	10	20	10	10	30	10	20	30
fecal – geomean	n/a	27	22	12	23	15	14	30	17	20	31
fecal – %>20	33-82	58	52	35	42	35	27	53	33	38	53
fecal – %>100	4-22	26	16	6	19	4	8	17	13	15	20
(total samples)	(341)	(50)	(50)	(51)	(52)	(49)	(51)	(58)	(54)	(55)	(51)
conductivity	131-179	158	160	166	212	186	258	204	208	187	205

There does appear to have been some improvement over time at this station. Fecal coliform annual median values were examined in five year groupings to eliminate single year fluctuations and help identify trends. During the first five years of sampling (1988-1992) the average annual median was 28 cfu/100mL. In each of the three five year periods that followed the average annual median was between 19 cfu/100mL and 22 cfu/100mL. Sixty percent of all samples collected contained more than 20 cfu/100mL during 1988-1992; this dropped to just over fifty percent for the following five year period. Only forty-one percent of samples from 2003 to 2007 contained more than 20 cfu/100mL.

Seasonally grouped samples exhibited noticeable differences at this station, although they were not as dramatic as at other sampling stations in the watershed. Fecal coliform concentrations were lowest in the winter, were higher in the spring and fall, and reached their highest during the summer (Table 88), although the summer maximums were considerably less than those recorded from many of the other tributaries in the watershed. Summer flows in Malden Brook usually averaged 0.5 – 2.0 cfs, while flows in the spring were often five to ten times higher. Low flows can result in the concentration of bacteria in the brook and help explain the seasonal differences illustrated in the table below.

Table 88:
MALDEN BROOK – SEASONAL METRICS

	WINTER	SPRING	SUMMER	FALL
fecal – geomean (range)	5 – 20	8 – 64	21 – 99	4 – 41
fecal – geomean (average)	10	26	58	17
fecal – %>20 (range)	7 – 54	8 – 69	50 – 100	8 – 58
fecal – %>20 (average)	20	44	74	31

Fecal coliform concentrations of wet weather samples at this station were higher than those of dry weather samples, although the differences were not as pronounced as at some others. Seventy percent of all wet weather samples but only thirty percent of dry weather samples collected contained more than 20 cfu/100mL. Thirty-six percent of all wet samples but only nine percent of dry samples contained more than 100 cfu/100mL. Other metrics illustrated below in Table 89 show similar differences.

Table 89:
MALDEN BROOK – FECAL COLIFORM (wet versus dry)

	wet weather samples	dry weather samples
fecal – annual median	17 – 140	5 – 30
fecal – annual geomean	13 – 125	10 – 25
fecal – annual %>20	29 – 100	19 – 53
fecal – annual %>100	0 – 64	0 – 17

Conductivity levels in Malden Brook are usually remarkably uniform throughout the year, with no large increase during the summer as seen in most other tributaries. Elevated levels were seen occasionally during the winter, most likely the result of salt applications to roadways following storms, but summer increases of both conductivity and of fecal coliform were much less than what was observed in other parts of the watershed.

The mean conductivity in Malden Brook for the current ten year period was only 31% higher than for the previous ten year period, considerably less than the average increase of 56% in ten tributaries that have been sampled consistently for the past twenty years. Fluctuations in annual rainfall and frequency of winter storm events and associated salt applications can strongly influence annual statistics for conductivity. Annual data were closely examined to look for periods of relative stability that could be combined and summarized. The periods of 1988-1992, 1998-2000, and 2006-2007 exhibited little change throughout the watershed and were therefore used to detect trends. The increase in conductivity at the ten tributaries that were continuously monitored from the earliest period (88-92) to the latest (06-07) was 83%. The increase in Malden Brook was only 40% and indicative of much better water quality relative to the other sampling stations in the watershed.

Conductivity did increase significantly in 2001, 2002, and 2003, but conductivity increased at all stations during these years, and the increase in Malden Brook was less than what was observed elsewhere. The increases have been linked to the use of a new field conductivity meter during that three year period. Annual conductivity at this station declined only slightly following a return to an earlier piece of monitoring equipment, but has remained constant for the past four years with no further increases.

Samples for nitrate-nitrogen and total phosphorus were collected irregularly (2-11 times per year) from 1999 through 2007. Nutrient samples collected from Malden Brook always contained low concentrations of nitrate-nitrogen and initially contained elevated annual concentrations of total phosphorus. Annual mean concentrations of total phosphorus exceeded the EPA recommended limit of 0.05 mg/L in four years (Table 90), and individual samples did as well on a number of occasions during 1999, 2000, 2001, and 2005. Concentrations of nitrate and total phosphorus appear to be declining. Nearly forty percent of all homes in the subbasin have been connected to the sewer and this appears to be enough to produce measurable improvements.

Table 90:
MALDEN BROOK – NUTRIENT MEAN CONCENTRATIONS (mg/L)

	1999	**2000**	**2001**	**2002**	**2003**	**2004**	**2005**	**2006**	**2007**
Nitrate-nitrogen	0.516	0.637	0.653	0.235	0.450	0.468	0.386	0.356	0.452
Total phosphorus	**0.069**	**0.053**	**0.058**	0.019	0.023	0.032	**0.057**	0.023	0.027

Data on ammonia, silica, total suspended solids, total organic carbon, and UV-254 have also been collected over the past five years. All data were within normal ranges and are comparable to other tributaries within the watershed.

Macroinvertebrate samples were collected in May of 1988, 1989, 1990, 1994, 1996, 1998, and 2001 using a standard one-minute kick technique. Samples collected from 1988 through 1996 showed only slight or no impairment when compared to the reference station (Table 91). This tributary historically has maintained a healthy, diverse population dominated by the small omnivorous mayfly species *Ephemerella dorothea*, *Ephemerella rotunda*, and *Epeorus* spp. Large predaceous stoneflies were always present, and twelve different varieties of caddisfly have been identified. The sample collected in 1998 showed moderate impairment due primarily to a larger than normal population of pollution tolerant limnephilid caddisflies. Fecal coliform concentrations were higher in 1998 than at any other time during the ten year period and this appears to have been reflected by the macroinvertebrate population. A sample collected in 2001 showed no impairment.

Table 91:
MALDEN BROOK – MACROINVERTEBRATE ASSESSMENT

YEAR	TAXA	EPT	EPT/chiro	HBI	% DOMIN	IMPAIRMENT
1988	23	15	41	1.67	33	non-impaired
1989	29	16	9	1.74	39	slight
1990	20	12	>95	1.21	23	non-impaired
1994	30	18	29	1.82	21	slight
1996	20	14	14	1.01	42	non-impaired
1998	22	13	43	2.70	34	moderate
2001	25	15	39	1.80	18	non-impaired
88-01	19-28	13-19	10 - >100	1.02-1.62	14-41	REF STATION

There is one agricultural site in this subbasin that has a large number of animals. Division staff have been working with the owner to obtain a conservation restriction on a portion of this property as well as helping with grant applications to install BMPs such as fencing at critical areas of the farm. Malden Brook did have other significant agricultural activity near its headwaters in the past, some with large numbers of livestock, but most of these parcels were either purchased by the DCR or have since ceased agricultural operations and are no longer a water quality threat.

During the most recent stream surveys, beaver activity was noted at various areas along the stream including two sites south of Lee Street on Malden Brook Farm, Edwards Pond on Malden Street, and upstream of Route 140 where the brook enters Thomas Basin. Muskrat can be assumed to occupy these same areas. Aquatic mammals are a potential source of bacterial contamination but also help contain some contaminants by constructing dams that restrict flow and allow settling of particulate materials.

Homeowners should be encouraged to connect to the municipal sewer system where available, although many of the homes in this subbasin do not have this option and must use individual septic systems. Outreach efforts to convince dog owners to pick up after their pets, especially in the area around Pine Arden Drive, could have noticeable positive impacts on water quality.

3.23 MUDDY BROOK

Muddy Brook flows from the west into South Bay under Route 140. The brook originates from a large wetland within the industrial area of West Boylston and from drainage along the railroad tracks, and passes the closed and capped West Boylston landfill before entering the Wachusett Reservoir.

This tributary was sampled just upstream of Route 140 near the edge of the reservoir. The brook is about six feet in width and appears clear to the naked eye, although it usually carries a much higher than average load of fine particulate matter. A staff gage is located at the sampling station and the USGS provides updated rating curves to enable calculation of flow.

Samples have been collected biweekly or weekly for fecal coliform and conductivity for the past nineteen years. A total of 514 samples were collected weekly during the past ten years. An additional 340 were collected from 1989 through 1997. There have been fifty-six samples for nitrate-nitrogen and total phosphorus collected since 1998, and macroinvertebrate samples were collected from this tributary in May of 1998 and 2001 and previously during 1988, 1989, 1990, 1994, and 1996. Samples for metals analysis were taken in 1991 and 1996.

The Muddy Brook subbasin is shown as consisting of 534 acres of forest and open land (61%), residential development (17%), agriculture (6%), industrial development (3%), and a large area of open water and wetlands (12%). Nearly half of the residential development is identified as high density development. The presence of high density residential development and the large industrial area is the reason for a percent impervious cover of 9.4%, much higher than the watershed average. Although much of the impervious cover is located in the headwater area, the high subbasin percentage is suspected to be the cause of problems with stormwater runoff and of persistent elevated turbidity in Muddy Brook.

Annual fecal coliform metrics have been relatively stable throughout the ten year period and are among the lowest of the developed subbasins (Table 92). Fecal coliform concentrations tend to be lower in this tributary because the agricultural and industrial areas and almost all of the residential development in this subbasin are located in the headwaters and contaminants are naturally filtered out long before they reach the sampling station near the reservoir.

Table 92:
MUDDY BROOK – FECAL COLIFORM AND CONDUCTIVITY

YEAR	88-97	98	99	00	01	02	03	04	05	06	07
fecal – median	6-46	19	11	9	10	10	20	20	10	5	10
fecal – geomean	n/a	20	9	9	15	15	19	19	17	13	25
fecal – %>20	29-77	44	38	34	33	27	45	41	40	33	33
fecal – %>100	4-17	24	10	2	10	10	10	15	10	7	24
(total samples)	(340)	(50)	(50)	(50)	(52)	(49)	(51)	(54)	(52)	(55)	(51)
conductivity	122-174	148	143	131	162	165	179	138	147	148	158

Fecal coliform concentrations have also likely been reduced by the construction of a municipal sewer during the last decade. Connections to the sewer occurred slowly at first with only three homes connected by the end of 2001, but over 80% of all homes in the subbasin are now using the sewer to dispose of sanitary waste.

Seasonally grouped samples exhibited noticeable differences at this station, although they were not as dramatic as at other sampling stations in the watershed. Fecal coliform concentrations were lowest in the fall and winter, higher in the spring, and reached their highest during the summer (Table 93), although the summer maximums were considerably less than those recorded from many of the other tributaries in the watershed. Summer flows in Muddy Brook were often very low and may have been responsible for the concentration of bacteria.

Table 93:
MUDDY BROOK – SEASONAL METRICS

	WINTER	SPRING	SUMMER	FALL
fecal – geomean (range)	2 – 13	5 – 32	27 – 119	5 – 27
fecal – geomean (average)	8	15	63	11
fecal – %>20 (range)	0 – 38	8 – 43	62 – 100	0 – 58
fecal – %>20 (average)	18	30	77	20

Fecal coliform concentrations of wet weather samples at this station were higher than those of dry weather samples, although the differences were not as pronounced as at many others of the tributaries in the watershed. Only 57% of wet weather samples collected during the ten year period contained more than 20 cfu/100mL. This was less than twice the number of dry weather samples that exceeded this threshold. Twenty-eight percent of all wet samples but only eight percent of dry samples contained more than 100 cfu/100mL. Other metrics illustrated below in Table 94 show similar differences.

Table 94:
MUDDY BROOK – FECAL COLIFORM (wet versus dry)

	wet weather samples	dry weather samples
fecal – annual median	3 – 140	5 – 20
fecal – annual geomean	4 – 120	8 – 19
fecal – annual %>20	33 – 85	19 – 40
fecal – annual %>100	0 – 62	0 – 18

Conductivity in Muddy Brook changed very little throughout the ten year sampling period and was only slightly higher than what had been recorded during the previous decade. Summer increases were smaller than what were observed in most other tributaries. Elevated levels were rarely seen during the winter, probably because any upstream salt applications were a great distance from the sampling station.

The mean conductivity in Muddy Brook for the current ten year period was only 10% higher than for the previous ten year period, considerably less than the average increase of 56% in ten tributaries that have been sampled consistently for the past twenty years. Annual conductivity data can be strongly influenced by fluctuations in total rainfall and frequency of winter storm events and associated salt applications. Annual data were closely examined to look for periods of time with relative stability that could be combined and summarized. The periods of 1988-1992, 1998-2000, and 2006-2007 exhibited little change throughout the watershed and were therefore used to detect trends. The increase in conductivity at the ten tributaries that were continuously monitored from the earliest period (88-92) to the latest (06-07) was 83%. The increase in Muddy Brook was only 19% and was the smallest increase of any tributary in the watershed.

The only noticeable increase in conductivity took place in 2001, 2002, and 2003, but conductivity increased at all stations during these years. These increases have been linked to the use of a new field conductivity meter during that three year period. Annual conductivity at this station and most others declined following a return to an earlier piece of monitoring equipment.

Samples for nitrate-nitrogen and total phosphorus were collected irregularly (2-11 times per year) from 1999 through 2007. Annual mean concentrations of nitrate-nitrogen and total phosphorus were usually very low (Table 95). Annual mean concentrations of total phosphorus only exceeded the EPA recommended limit of 0.05 mg/L in 2001, but individual samples were higher during 1999, 2001, and 2005, often in the fall. Three of the six samples containing elevated concentrations of total phosphorus were collected during or immediately following storm events.

Table 95:
MUDDY BROOK – NUTRIENT MEAN CONCENTRATIONS (mg/L)

	1999	**2000**	**2001**	**2002**	**2003**	**2004**	**2005**	**2006**	**2007**
Nitrate-nitrogen	0.123	0.136	0.193	0.076	0.086	0.075	0.097	0.100	0.113
Total phosphorus	0.020	0.016	**0.074**	0.032	0.011	0.024	0.042	0.014	0.015

Metals samples analyzed from this tributary in 1992 contained measurable concentrations of aluminum, arsenic, copper, lead, and zinc. Monthly samples collected for iron during 1996 found an annual mean concentration in the brook of 0.62 mg/L with a maximum recorded value of 1.47 mg/L. Zinc and lead were again detected at low levels. Samples from monitoring wells at the adjacent capped landfill occasionally contain arsenic. The landfill or runoff from the upstream industrial area may be the source of metals in the Muddy Brook.

Macroinvertebrate samples were collected in May of 1988, 1989, 1990, 1994, 1996, 1998, and 2001 using a standard one-minute kick technique. Samples collected each year showed moderate impairment when compared to the reference station (Table 96). Only half as many total taxa were present as in the reference stream and many of those were organisms more tolerant of pollution. This was originally suspected to have been the result of impacts from toxic contaminants entering the stream upstream in the industrial area or from the adjacent landfill, but it has recently been determined to be more likely due to the continuous presence of elevated turbidity from the power line right-of-way.

Table 96:
MUDDY BROOK – MACROINVERTEBRATE ASSESSMENT

YEAR	TAXA	EPT	EPT/chiro	HBI	% DOMIN	IMPAIRMENT
1988	10	7	10	2.80	27	moderate
1989	13	8	45	2.93	31	moderate
1990	13	9	87	2.82	20	moderate
1994	15	10	43	2.47	25	moderate
1996	13	8	27	1.94	33	moderate
1998	13	10	>100	2.38	46	moderate
2001	13	6	42	2.05	35	moderate
88-01	19-28	13-19	10 - >100	1.02-1.62	14-41	REF STATION

One of the agricultural sites in this subbasin was once considered one of the twelve worst in the watershed. The owner of the property boarded ten horses on a small, steeply sloped, barren parcel with no manure storage area and very limited additional space. The owner now houses only a few of his own horses on the property, several best management practices have been implemented, and there are no plans to restart the boarding operation. No problems were noted at the site during the most recent inspection in 2006, and the property is no longer considered a water quality threat.

Wildlife could be the source of elevated bacteria in this subbasin. A field survey for beaver and muskrat found good habitat at a number of locations and active beaver sign in two wetlands, as well as a beaver pond with many ducks present. Fecal coliform concentrations in this tributary are generally low, but periodic episodes with elevated concentrations may be associated with wildlife populations.

Additional chemical testing of the brook may be necessary to determine if metals are entering the brook from the industrial area or the landfill. A station upstream of the landfill would need to be added.

Problems with elevated turbidity in this tributary are ongoing. Mean turbidity of samples collected during dry weather was 4.7 NTU, more than two times higher than any other tributary in the watershed. Wet weather turbidity averaged 6.3 NTU, and the small increase suggests that elevated turbidity in Muddy Brook was not exclusively a stormwater issue. Wet weather turbidity in many of the other brooks in the watershed was much higher (as much as nine times higher) than dry weather turbidity. Control of activities on the power line access road should help eliminate the primary source, and the Division may consider use of a filter curtain in the cove at the mouth of the brook to help remove particulate matter.

3.24 OAKDALE BROOK

The Oakdale Brook subbasin is located predominately within the town of West Boylston with a small portion to the north situated in Sterling. Three areas within the subbasin have been identified as headwaters, a large wooded swamp near Hosmer Street in West Boylston, a shrub swamp in Sterling, and groundwater breakout in the southern portion of the subbasin near Laurel Street.

The sampling station on Oakdale Brook is located just downstream of Waushacum Street near Route 140, approximately 400 yards from the shore of the Stillwater Basin. The stream is only a few feet wide at this sampling location. Samples were collected weekly during 1999, 2000, and from 2004 – 2007. A total of 300 samples were collected for fecal coliform and conductivity analysis. No samples for nutrients or metals were collected from this station during the ten year sampling period, and macroinvertebrate sampling was not done because of low flows and inadequate habitat.

Four samples for fecal coliform and conductivity were collected previously during 1989. Fecal coliform concentrations were low in three of the four samples but the sample collected in the fall contained more than 1000 cfu/100mL.

The Oakdale Brook subbasin is predominately medium-density residential development with the remaining area undeveloped forested and open land. The subbasin contains of 330 acres of forests and open land (46%), low and medium density residential development (40%), agriculture (7%), roadways (6%), and open water and wetlands (1%). Residential development is more than three times the watershed average, with less than half of the subbasin remaining undeveloped. Near brook conditions are even worse. More than half of all land within 400 feet of Oakdale Brook is occupied by residential development, with less than a third remaining forested or open. Percent impervious cover (15.2%) in the subbasin is one of the highest in the watershed, with impacts from non-point source runoff and increased stormwater pollution expected. Water quality problems have been noted.

Water quality in Oakdale Brook as measured by fecal coliform and conductivity historically has been quite poor, worse than all but the most contaminated of the tributaries in the Wachusett watershed. Improvement has been noted in the past few years, however, as reflected by all annual metrics (Table 97). The reduction in fecal coliform concentrations and drop in annual conductivity has occurred during a period of years when a number of homes previously served by individual septic systems have been connected to the new municipal sewer. No homes within this subbasin were connected to the sewer at the beginning of 2003, but thirty percent had been connected by 2005 and another twenty percent were tied in by the end of 2007. This appears to be a clear example of water quality improvements related to sewering.

Table 97:
OAKDALE BROOK – FECAL COLIFORM AND CONDUCTIVITY

YEAR	88-97	98	99	00	01	02	03	04	05	06	07
fecal – median	34		64	45				50	40	20	35
fecal – geomean	71		50	50				49	38	31	34
fecal – %>20	75		69	67				65	61	49	54
fecal – %>100	25		35	35				37	27	27	20
(total samples)	(4)		(48)	(51)				(49)	(51)	(51)	(50)
conductivity	294		389	446				774	751	686	584

Seasonally grouped samples exhibited noticeable differences at this station, similar to those at other sampling stations in the watershed. Fecal coliform concentrations were lowest in the winter, higher in the spring, and reached their highest during the summer before declining again in the fall (Table 98).

Table 98
OAKDALE BROOK – SEASONAL METRICS

	WINTER	SPRING	SUMMER	FALL
fecal – geomean (range)	8 – 18	14 – 138	44 – 381	16 – 176
fecal – geomean (average)	12	43	178	79
fecal – %>20 (range)	8 – 46	31 – 100	69 – 100	27 – 91
fecal – %>20 (average)	26	60	92	66

Fecal coliform concentrations of wet weather samples at this station were higher than those of dry weather samples, although the differences were not as pronounced as at other tributaries in the watershed. Wet weather samples were twice as likely as dry weather samples to have elevated fecal coliform concentrations. Fifty-one percent of wet weather samples and twenty-six percent of dry weather samples contained more than 100 cfu/100mL. Eighty-six percent of all wet samples and fifty-six percent of dry samples contained more than 20 cfu/100mL. Annual median and annual geometric mean show similar differences (Table 99).

Table 99:
OAKDALE BROOK – FECAL COLIFORM (wet versus dry)

	wet weather samples	dry weather samples
fecal – annual median	36 – 220	10 – 70
fecal – annual geomean	42 – 241	21 – 51
fecal – annual %>20	71 – 100	44 – 67
fecal – annual %>100	0 – 71	15 – 38

Annual conductivity data can be strongly influenced by fluctuations in total rainfall and frequency of winter storm events and salt applications. Annual data were closely examined to look for multiple year periods with relative stability that could be summarized and used to identify trends. The periods of 1998-2000 and 2006-2007 exhibited little change throughout the watershed and can be used for this purpose. The increase in conductivity from 1998-2000 to 2006-2007 in Oakdale Brook was 52% which was higher than average. Conductivity actually had increased by a much larger percentage with a maximum annual mean of 774 recorded in 2004. Conductivity declined by 25% from 2004 to 2007, one of the largest declines in the watershed and a likely reflection of water quality improvement brought about by increased connections to the municipal sewer system.

Water quality in this subbasin does not meet Class A Surface Water Quality Standards, but fecal coliform levels appear to be dropping. All agricultural sites with animals have been inspected by staff and have been determined not to pose a water quality threat. Beaver sign has been noted at two areas along the brook, but the most likely sources of contamination are single family homes and stormwater runoff. Sampling of the brook should be continued to further document water quality improvements and to help link these improvements to an increase in the number of sewer connections.

3.25 QUINAPOXET RIVER

3.25.1 Canada Mills

The section of the Quinapoxet River monitored by this sampling station extends from the first River Road crossing upstream of the Holden Landfill to the Wachusett Street (Route 31) crossing. This stretch of the river also receives flow from seven other subbasins.

Samples were collected near the USGS water quality monitoring facility just upstream of the Canada Mills crossing on River Road in Holden. The river is more than thirty feet wide at this sampling location with a substrate consisting primarily of boulders, gravel, and sand. Samples are also collected regularly from both an upstream (Mill Street) and downstream location (circular dam), and data from these locations will be addressed in the following two chapters. A total of 491 fecal coliform and conductivity samples have been collected weekly or twice weekly from Canada Mills since 2002. Samples for nitrate-nitrogen, total phosphorus, and metals were collected monthly from 2002 through 2007. No samples for macroinvertebrates have been collected since 1992, but macroinvertebrates samples have been collected at both upstream and downstream sites within the past ten years.

Water quality data at this station is supplemented by a continuous water quality monitoring station established and maintained by the USGS. Temperature, conductivity, and flow are recorded throughout the year at fifteen minute intervals. Real-time data are available on-line at http://waterdata.usgs.gov/nwis/uv?01095375.

Residential development in the Quinapoxet River (Canada Mills) subbasin is more than twice the watershed average. The subbasin consists of 1138 acres of forest and open land (63%), low and medium density residential development (28%), agriculture use (8%), and small amounts of open water, wetlands, and industrial development. The residential development is primarily located near the center of Holden and is the reason for the higher than average percentage of impervious cover. The Division does own more than 20% of the subbasin including a significant portion of the land within 400 feet of the river which helps reduce impacts from stormwater runoff.

Annual fecal coliform metrics have been fairly stable since sampling began in 2002 (Table 100). No long term trends were noted. Fecal coliform levels were low during the winter, increased sharply in the spring and summer, and remained moderately elevated through the fall. Many tributaries in the Wachusett watershed show a similar pattern probably related to concentration of contaminants during low flow conditions. Periodic spikes related to storm events were noted.

Table 100:
QUINAPOXET RIVER (Canada Mills) – FECAL COLIFORM AND CONDUCTIVITY

YEAR	88-97	98	99	00	01	02	03	04	05	06	07
fecal – median						40	45	50	30	20	30
fecal – geomean						33	36	40	30	19	27
fecal – %>20						59	58	58	52	46	51
fecal – %>100						16	25	33	19	10	15
(total samples)						(49)	(52)	(80)	(105)	(105)	(100)
conductivity						302	259	226	198	166	177

Seasonally grouped samples exhibited significant differences at this and most other sampling stations in the Wachusett watershed. All metrics were very low during the winter months, high during the spring and summer, and somewhat elevated in the fall (Table 101).

Table 101:
QUINAPOXET RIVER (Canada Mills) – RANGE OF SEASONAL METRICS

	WINTER	SPRING	SUMMER	FALL
fecal – median	5	20 – 100	60 – 140	10 – 40
fecal – geomean	7 – 9	24 – 104	40 – 182	15 – 32
fecal – %>20	0 – 15	46 – 100	69 – 100	27 – 55
fecal – %>100	0	12 – 48	12 – 60	0 – 25

Water quality was strongly impacted by weather conditions, with water quality of wet weather samples much worse than that of dry weather samples (Table 102). The Quinapoxet River is a large tributary with many contributing smaller streams, and impacts from precipitation events are not always seen immediately at the Canada Mills sampling station since contaminated water from the smaller tributaries may take additional time to reach the river. Water quality of samples collected forty-eight hours after storm events is presented in the table below and as expected is intermediary between dry weather and wet weather samples.

Table 102:
QUINAPOXET RIVER (Canada Mills) – FECAL COLIFORM (wet versus dry)

	wet weather samples	samples 48hrs after	dry weather samples
fecal – annual median	80 – 190	20 – 90	10 – 29
fecal – annual geomean	71 – 284	19 – 52	14 – 28
fecal – annual %>20	73 – 100	43 – 90	35 – 53
fecal – annual %>100	23 – 78	0 – 36	2 – 22

Annual conductivity values were elevated in 2002 and 2003, but conductivity increased at all stations during these years. These increases have been linked to the use of a new field conductivity meter during that three year period. Annual conductivity has dropped significantly since the initial measurement in 2002 (Table 100).

Conductivity was often slightly elevated during the winter and then declined during the spring and early summer, increasing during the late summer and remaining high during the fall and early winter. It appears that the reduction in stream flow during the summer may also reduce inputs of dissolved contaminants (especially from contributing smaller tributaries) although the opposite usually occurs in most watershed tributaries and sometimes was the case at this sampling station as well.

Samples for nitrate-nitrogen and total phosphorus were collected monthly from 1999 through 2007, with samples prior to 2002 collected downstream at the circular dam. Data from the downstream site are described in Chapter 3.25.2 but are very similar to the results recorded from Canada Mills. Annual mean concentrations of nitrate-nitrogen samples were low to moderate compared to other watershed tributaries and did not change significantly over the six year sampling period. Annual mean concentration of total phosphorus was high in both 2002 and 2007 but low in other years (Table 103). Initial analysis of more recent data suggests that annual mean concentration of total phosphorus will be low in 2008 as well. The high annual mean recorded in 2007 exceeded the EPA recommended limit of 0.05 mg/L and was due to very high concentrations in two samples (January, September) both unrelated to storm events. No source of the elevated total phosphorus concentrations has been identified.

Table 103:
QUINAPOXET RIVER (Canada Mills) – NUTRIENT MEAN CONCENTRATIONS (mg/L)

	1999	**2000**	**2001**	**2002**	**2003**	**2004**	**2005**	**2006**	**2007**
Nitrate-nitrogen				0.427	0.336	0.311	0.270	0.309	0.325
Total phosphorus				0.046	0.024	0.024	0.020	0.025	**0.073**

Macroinvertebrate samples were collected in May 1990 and 1992 but have not been collected since. The samples collected in the nineties showed slight to no impairment when compared to the reference station, and had high numbers of total taxa and EPT taxa, low HBI scores indicating the presence of pollution intolerant species, and balanced populations. The dominant species was *Drunella cornuta*, a small mayfly which feeds by scraping algae off rocks and leaves. The strong-swimming filter-feeding mayfly *Isonychia sayi* and the web-spinning, filter-feeding caddisfly *Chimmara* spp, were also common. The population appeared balanced and stable. Additional macroinvertebrate samples have been collected downstream near the circular dam sampling station and will be discussed in the next chapter.

Water quality data for this subbasin has not declined during the six years of sampling but fecal coliform concentrations remain higher than desirable. Water quality at this sampling station is impacted by any pollutants that enter the river from Asnebumskit, Chaffins, Swamp 15, and Warren Tannery Brooks, as well as by direct stormwater discharges upstream from areas with dense development. Division staff have attempted to identify all sources of contamination and to work to reduce impacts through source reduction or remediation.

There are a number of agricultural sites within this subbasin, but none of them appear to threaten water quality. Problems with improper manure storage and inadequate stormwater management have been resolved. No active populations of beaver or muskrat were noted during recent stream surveys. Wastewater problems are being eliminated as more homes connect to the expanded municipal sewer.

Problems related to stormwater have been closely monitored and Division staff worked with town officials to ensure that significant problems were avoided during construction of the new elementary school on Bullard Street. There are a number of stormwater basins that discharge to wetlands or streams in this subbasin and control of these discharges should remain a priority.

3.25.2 Dam

This was the primary sampling station on the river from 1988 until 2002. Sampling continued on a weekly basis from 2003 to the present, but the primary station was moved upstream to Canada Mills (described previously in Chapter 3.25.1). An additional sampling station on the river, located near the headwaters in an area of very limited development (Mill Street), is described in Chapter 3.25.3. Water quality at the three stations is compared within this chapter.

This section of the Quinapoxet River extends from the mouth of the river at Thomas Basin in West Boylston to River Road in Holden, a distance of about three miles. The Quinapoxet River (dam) sampling station receives water from more than a third of the Wachusett watershed and also receives direct flow from Trout Brook, Landfill Brook, and Hog Hill Brook.

The mouth of the river is wide and slow moving except during times of high flow following storm events, snow melt, or a release from the Quabbin Reservoir through the Quabbin Aqueduct. Just upstream from the mouth is an accretion dam that collects sediment before it reaches the reservoir. The sampling station is immediately upstream of this accretion dam off of River Road in West Boylston. Upstream from the dam the river is rocky with a fairly steep gradient and stream channel more than fifty feet wide. The substrate is mainly boulders and large rubble. Both stream banks are wooded with steep slopes and mostly owned by the Division.

A total of 441 samples have been collected for fecal coliform and conductivity analysis on a weekly basis over the past ten years, although no samples were collected in 2002. Macroinvertebrate samples were collected from this station in May of 1998 and in May, July, and October of 2001. An additional sample was collected at a riffle a short distance upstream during May 2001. Samples were collected for nitrate-nitrogen, total phosphorus, and metals in 1999, 2000, and 2001, but no flow data are available. Nutrient and metals samples after 2001 were collected upstream near the USGS monitoring station and are discussed in Chapter 3.25.1.

A total of 392 samples were collected for fecal coliform and conductivity analysis between 1988 and 1997. Macroinvertebrate samples were collected in 1988, 1989, 1990, 1992, 1994, and 1996.

The Quinapoxet River (dam) subbasin is made up primarily of forest and open lands. The subbasin consists of 1473 acres of forest and open land (86%), low and medium density residential development (6%), lands used for industrial development or transportation (6%), agriculture use (2%), and small amounts of open water and wetlands. The percentage of impervious cover (5.8%) is nearly identical to the watershed average (5.4%) and problems with stormwater runoff are not expected. The subbasin does receive flow from a total of thirteen other subbasins, however, including some with significant amounts of medium density residential development and construction activity. There have been documented cases of negative impacts of stormwater on water quality.

Fecal coliform levels were generally low during the late winter and early spring, increasing in the summer and remaining slightly elevated throughout the fall. Periodic spikes related to storm events were noted. A number of the tributaries in the Wachusett watershed show a similar pattern due to concentration of contaminants during low flow conditions, although fecal coliform concentrations in many tributaries drop significantly in the fall when flows increase.

Annual fecal coliform metrics have been fairly stable during the past ten years and most were within historic bounds established during the 1980s and 1990s (Table 104). Water quality did appear to improve slightly toward the end of the period, with historically low annual medians and geometric means recorded in 2006 and 2007.

Table 104:
QUINAPOXET RIVER (dam) – FECAL COLIFORM AND CONDUCTIVITY

YEAR	88-97	98	99	00	01	02	03	04	05	06	07
fecal – median	12-22	17	15	17	20		30	20	20	10	10
fecal – geomean	n/a	16	17	21	28		37	19	24	17	17
fecal – %>20	33-51	46	40	46	42		60	43	38	31	31
fecal – %>100	0-12	10	8	22	27		29	10	21	14	9
(total samples)	(392)	(50)	(50)	(50)	(52)		(35)	(61)	(47)	(51)	(45)
conductivity	103-189	143	164	152	240		230	184	193	167	184

Seasonally grouped samples exhibited smaller differences than at most other sampling stations in the Wachusett watershed. All metrics were very low during the winter months, slightly elevated during the spring and fall, and high in the summer (Table 105).

Table 105:
QUINAPOXET RIVER (dam) –SEASONAL METRICS

	WINTER	SPRING	SUMMER	FALL
fecal – geomean (range)	5 – 13	18 – 35	24 –159	9 – 24
fecal – geomean (average)	8	27	60	16
fecal – %>20 (range)	0 – 29	31 – 62	54 – 100	22 – 42
fecal – %>20 (average)	12	47	70	30

Water quality was strongly impacted by weather conditions, with water quality of wet weather samples much worse than that of dry weather samples (Table 102). More than half of all samples collected during wet weather contained more than 100 cfu/100mL. Only a very small percentage of dry weather samples (less than ten percent) contained more than 100 cfu/100mL.

Table 106:
QUINAPOXET RIVER (dam) – FECAL COLIFORM (wet versus dry)

	wet weather samples	dry weather samples
fecal – annual median	59 – 310	10 – 20
fecal – annual geomean	33 – 266	10 – 22
fecal – annual %>20	56 – 100	22 – 48
fecal – annual %>100	22 – 100	0 – 20

Conductivity levels in the Quinapoxet River above the circular dam were similar to measurements from other tributaries in the Wachusett watershed, with elevated levels during the summer and lowest levels in the winter. This seasonal pattern is most likely the result of a concentration of contaminants during low flow periods. Occasional elevated conductivity in the fall appears to be the result of dry weather conditions that keep flow levels below normal.

Annual conductivity has increased slightly in this tributary (Table 104) but less so than in many of the other streams and rivers in the watershed. The mean conductivity for the current ten year period was 44% higher than for the previous ten year period, less than the average watershed increase of 56% in ten tributaries that have been sampled consistently for the past twenty years. Years with little rainfall often result in higher conductivities due to low flow conditions, and winter storm events can lead to elevated levels due to the application of salt on icy roadways, so the use of annual statistics for conductivity can be misleading. Annual data were closely examined to look for multiple year periods with relative stability that could be summarized and used to identify trends. The periods of 1998-2000 and 2006-2007 exhibited little change throughout the watershed and can be used for this purpose. The increase in conductivity from 1998-2000 to 2006-2007 at this sampling station was only 15%, much lower than average. Conductivity increased dramatically at all stations during 2001-2003, but these increases have been linked to the use of a new field conductivity meter during that three year period. Annual conductivity in the Quinapoxet River and at most others stations declined following a return to an earlier piece of monitoring equipment. In all other years annual conductivity has almost always been within the historic range.

Samples for nitrate-nitrogen and total phosphorus were collected monthly from this station in 1999, 2000, and 2001. Nutrient and metals samples after 2001 were collected upstream and were discussed in Chapter 3.25.1. All samples collected prior to 1999 were analyzed using inadequate detection limits and provide little additional information.

Annual mean concentrations of nitrate-nitrogen samples were low (0.263–0.467 mg/L) compared to other watershed tributaries and were nearly identical to annual means recorded during the following six years at the upstream Canada Mills sampling station. Annual mean concentration of total phosphorus was high in 1999 and 2000 (and in 2007 upstream) exceeding EPA recommended limits of 0.05 mg/L but no source has been identified.

Macroinvertebrate samples were collected from this tributary in 1988, 1989, 1990, 1992, and 1994 at a location approximately 500 yards upstream. Samples were collected just above the dam in May of 1996 and 1998 and in May, July, and October 2001. Additional macroinvertebrate samples were collected upstream from the Canada Mills sampling station (Chapter 3.25.1) and just below the Holden landfill in 1990 and 1992. A macroinvertebrate sample was also collected from the Mill Street sampling station (Chapter 3.25.3) in 2001.

All samples collected from the four Quinapoxet River stations showed slight to no impairment when compared to a reference station, with high numbers of total and EPT taxa, high numbers of pollution intolerant species, and fairly balanced populations. Dominant species included *Drunella cornuta* and *Pseudocleon* spp, two small mayflies which feed by scraping algae off rocks and leaves, and *Dolophilodes* spp, a web-spinning, filter-feeding caddisfly. Six to eight mayfly species were present at each site each year, some in small numbers. A diverse population of Hydropsychidae caddisflies was also resident, with a total of nine species in this family alone. Differences in macroinvertebrate populations collected below the landfill site and from the other three sites were very minor. Only slight impacts were noted at the landfill site, probably the result of less habitat variety and a moderate amount of scouring and deposition rather than elevated nutrient concentrations or toxic effects. Although visible seepage from the landfill was observed entering the river, the amount appeared insignificant relative to the total flow in the Quinapoxet River and visible signs of the landfill discharge could not be detected a short distance downstream.

The macroinvertebrate population in this portion of the Quinapoxet River did not appear to change significantly during the past twenty years. No seasonal differences were noted in the three samples collected during 2001.

Samples have been collected at three separate locations on the Quinapoxet River to help locate specific sources of fecal coliform contamination. Samples were collected at all three sites in 2004, 2005, 2006, and 2007 and data are compared in Table 107.

Table 107:
QUINAPOXET RIVER – FECAL COLIFORM (range of metrics at all stations)

	median	geomean	%>20	%>100		conductivity
Mill Street	10	10-12	18-29	0-4		110-129
Canada Mills	20-50	19-40	46-58	10-33		166-226
Dam	10-20	17-24	31-43	9-21		167-193

Water quality at the Mill Street station as measured by fecal coliform and conductivity was very good, reflective of the surrounding land use and level of protection found at the headwaters of the river. A description of this sampling station and the contributory subbasin can be found in Chapter 3.25.3. Water quality downstream at Canada Mills was significantly worse and appears impacted by residential development and inputs from several tributaries that pass through a variety of land uses. The river passes through an extensive stretch of protected forest before reaching the downstream sampling station at the circular dam, and bacteria concentrations are reduced through natural remediation (die off) but remain higher than at the source. There is no reduction in conductivity as the water travels downstream.

A property on Manning Street was determined to have problems with improper storage of manure, but the property was sold in 1990 and all horses and manure were removed. There are currently no known threats from agricultural operations, wildlife, or stormwater runoff in this lower reach of the river. Basins on Interstate 190 retain much of the runoff from the highway, although they should be inspected and maintained on a regular basis. Substantial amounts of sand are washed off of River Street and into the Quinapoxet River during and following each winter, but the accretion dam just below the sampling location has collected much of the sediments moving downstream.

A portion of the Holden municipal landfill is located in this subbasin. The landfill is closed and capped, but breakout has been observed flowing into the Quinapoxet River. Samples of the breakout have been collected and analyzed, and samples were collected from the river as well. Elevated concentrations of lead, zinc, and arsenic were found in the leachate; copper was also present but at lower levels than detected in an upstream sample in the river. A number of other metals and volatile organic compounds were also present. Although the presence of these contaminants was disturbing, the volume of the contaminated flow was very small in comparison to the flow in the Quinapoxet River (1:150), and it was the opinion of the EPA that water quality of the river was unimpaired. Macroinvertebrate samples collected above and below the site supported this assessment. Leachate from the landfill should be retested to make sure that levels of contaminants are not increasing.

Staff will continue to search for specific sources including failing septic systems, stormwater discharge pipes, or animal populations and will initiate remedial actions wherever possible. The Division should consider the removal of years of accumulated sediment from the accretion dam near the mouth of the river.

3.25.3 Mill Street

This section of the Quinapoxet River extends from the Quinapoxet Reservoir dam at Princeton Street in Holden to the bridge at Mill Street. The Quinapoxet Reservoir receives flow from a large area of Princeton and Rutland, but only a small portion of the water flows over the spillway into the Quinapoxet River. Most of the water in the Quinapoxet Reservoir is utilized by the City of Worcester for water supply purposes.

The sampling station is located just upstream of Mill Street in Holden about a mile and a half from the outlet of the Quinapoxet Reservoir and two and a half miles upstream of the sampling station at Canada Mills. The stream is fifteen feet wide and surrounded by undeveloped forested land. A total of 247 samples were collected for fecal coliform and conductivity analysis on a weekly basis, mostly over the past four years. Macroinvertebrate samples were collected from this station in May of 2001. No samples for nitrate-nitrogen, total phosphorus, or metals have been collected and no flow data are available.

A total of 22 samples were collected for fecal coliform and conductivity analysis in 1991. Additional samples have been collected at two other locations on the river and are discussed in Chapters 3.25.1 and 3.25.2.

This large subbasin of 1564 acres contains primarily of forest and open land (87%) with lesser amounts of agriculture (6%) and low density residential development (6%). The Division owns slightly more than fifty percent of this subbasin. Percentage impervious cover (3.0%) is one of the lowest in the watershed.

Samples collected at the Mill Street station were free of influences from other tributaries and reflect water quality conditions of a relatively undeveloped subbasin. Water quality in this subbasin as measured by fecal coliform concentrations was very good and among the best in the watershed.

Table 108:
QUINAPOXET RIVER (Mill Street) – FECAL COLIFORM AND CONDUCTIVITY

YEAR	88-97	98	99	00	01	02	03	04	05	06	07
fecal – median	7	4						10	10	10	10
fecal – geomean	n/a	4						11	12	10	12
fecal – %>20	14	16						21	24	18	29
fecal – %>100	0	0						2	4	0	2
(total samples)	(22)	(50)						(47)	(50)	(51)	(49)
conductivity	72	86						119	129	110	113

Seasonally grouped samples exhibited only minor differences at this station, with bacteria concentrations low throughout the year. Fecal coliform concentrations were lowest in the fall and winter, higher in the spring, and reached their highest in the summer (Table 109), although the summer maximums were considerably less than those recorded from nearly all other tributaries in the watershed.

Table 109:
QUINAPOXET RIVER (Mill Street) – SEASONAL METRICS

	WINTER	SPRING	SUMMER	FALL
fecal – geomean (range)	3 – 9	4 – 14	13 – 22	1 – 13
fecal – geomean (average)	6	10	17	9
fecal – %>20 (range)	0 – 15	8 – 33	23 – 50	0 – 33
fecal – %>20 (average)	8	21	39	18

Weather conditions also had much less impact on water quality than at other locations, and wet weather samples from this station often had better water quality than dry weather samples from other sampling stations in the watershed. Dry weather samples from the Mill Street station had excellent water quality. Annual metrics of wet weather samples were only 3-5 times higher.

Table 110:
QUINAPOXET RIVER (Mill Street) – FECAL COLIFORM (wet versus dry)

	wet weather samples	dry weather samples
fecal – annual median	6 – 30	2 – 5
fecal – annual geomean	7 – 30	3 – 10
fecal – annual %>20	23 – 67	11 – 23
fecal – annual %>100	0 – 11	0 – 3

Annual conductivity has increased slightly in this tributary (Table 108) but less so than in many streams and rivers in the watershed. Annual conductivity remains quite low and is reflective of the undeveloped surroundings.

Macroinvertebrate samples were collected from this tributary in May 2001. The sample showed no impairment when compared to a reference station, with high numbers of total and EPT taxa, high numbers of pollution intolerant species, and a balanced population. Dominant species included *Drunella cornuta* and *Ephemerella dorothea,* two small mayflies which feed by scraping algae off rocks and leaves.

There are a number of small agricultural operations in the subbasin and some evidence of beaver activity present, but neither is considered to be a significant threat to water quality.

A major incident involving wastewater did take place in the subbasin during 1990. Domestic sewage was dumped into a pile of woodchips on Elmwood Avenue in an attempt to avoid disposal charges at the sewage treatment plant. A review of company records determined that up to 70,000 gallons of sewage had been disposed of illegally. Groundwater was tested and found to be highly contaminated with fecal coliform bacteria. The DEP required the owner to remove all of the contaminated woodchips, install several monitoring wells, and pay a fine. The owner has recently agreed to pay a substantial fine and complete the remediation activities. Division staff should monitor the situation and confirm that all actions are completed.

Minor problems with erosion and stormwater runoff were noted during sewer expansion in this subbasin. No other stormwater issues are expected due to the low percentage of impervious surfaces present, and additional routine sampling is unnecessary.

3.26 ROCKY BROOK

Rocky Brook originates from Hy-Crest Pond in Sterling and flows through Division-owned forests and light residential development until eventually entering the wetlands system bordering the Stillwater River. A second branch of Rocky Brook joins the main tributary from the east on Division property south of Justice Hill Road. This smaller branch has been sampled since 1998 and is described in Chapter 3.27.

The primary sampling station on Rocky Brook is located on the upstream side of Beaman Road approximately 1000 yards from the Stillwater River. The brook is about six feet wide, and the water is clear. Samples were collected weekly from 1998 – 2000 and from 2004 – 2007. A total of 346 samples were collected for fecal coliform and conductivity analysis. No samples for nutrients or metals were collected from this station during the ten year sampling period, and macroinvertebrate sampling was not attempted due to low flows.

Samples for fecal coliform and conductivity were collected irregularly during 1989, 1992, and 1993. Annual median fecal coliform concentrations were relatively low and conductivity was very low with an annual mean never exceeding 65 µmhos/cm. Values that low are indicative of runoff from undeveloped watersheds and are lower than those recorded from the reservoir.

The Rocky Brook subbasin contains of 1607 acres of forests and open land (77%), a significant amount of agriculture (10%), low density residential development (7%), and open water and wetlands (7%). Percent impervious cover (2.0%) in the subbasin is one of the lowest in the watershed, with no impacts from non-point source runoff and increased stormwater pollution expected.

Water quality in Rocky Brook as measured by fecal coliform and conductivity has been quite good in the past, but a slight upward trend of all metrics was noted during the last ten years. Maximum values were recorded in 2006 or 2007 for annual median, geometric mean, and the percentage of samples exceeding 20 cfu/100mL and 100 cfu/100mL (Table 111). Annual mean conductivity also reached an historical maximum in 2007. Despite the apparent decline, water quality in Rocky Brook remains better than in many tributaries in the Wachusett watershed.

Table 111:
ROCKY BROOK – FECAL COLIFORM AND CONDUCTIVITY

YEAR	88-97	98	99	00	01	02	03	04	05	06	07
fecal – median	5-8	5	10	5				10	15	20	10
fecal – geomean	n/a	8	15	6				12	19	19	19
fecal – %>20	20-32	29	43	20				16	38	43	35
fecal – %>100	8-11	8	16	2				8	8	8	17
(total samples)	(75)	(49)	(49)	(50)				(49)	(50)	(51)	(48)
conductivity	50-65	55	66	63				79	86	74	92

Fecal coliform concentrations exhibited no strong patterns throughout the year, with only slight increases in the spring and summer. Spring and summer geometric means were usually 3-5 times higher than fall and winter geometric means. Differences between samples collected during wet and dry weather were more significant (Table 112) but less so than at some other stations in the watershed.

Table 112:
ROCKY BROOK – FECAL COLIFORM (wet versus dry)

	wet weather samples	dry weather samples
fecal – annual median	10 – 480	4 – 10
fecal – annual geomean	17 – 210	5 – 15
fecal – annual %>20	44 – 80	10 – 43
fecal – annual %>100	0 – 60	2 – 15

Annual conductivity remained very low, although there was a steady upward trend and a maximum annual value was recorded in 2007. The increase in conductivity from 1998-2000 to 2006-2007 was 35%, less than the watershed average. The periods of 1998-2000 and 2006-2007 exhibited little change throughout the watershed and are used for comparative purposes. Annual conductivity in Rocky Brook is as low as or lower than what has been recorded in the reservoir.

There is no clear explanation why water quality in this subbasin should be declining. There are a number of agricultural sites in the subbasin including nine with animals, but each was inspected by staff and determined not to pose a water quality threat. No beaver or muskrat were observed, but a temporary population of ducks on a small pond north of the Beaman Road sampling station does cause occasional problems. There are not many single-family homes in the subbasin and wastewater problems are not considered to be a significant threat. Stormwater is also not a threat due to the very small amount of impervious surfaces present.

3.27 ROCKY BROOK (East Branch)

The east branch of Rocky Brook has been sampled since 1998 to serve as a control site for a study of the positive impacts of installing sewers. This sampling station is located just upstream of Justice Hill Road in Sterling. Flow is generally very low or nonexistent during the summer. The stream meanders throughout woodlands and receives limited sunlight, and the substrate is moss covered rocks. The small contributory subbasin is almost entirely undeveloped forest and the only potential negative impacts to water quality are from wildlife.

The Pinecroft area in Holden and West Boylston (Cook Brook) has been studied since 1998 to document the positive impacts of sewering on water quality in a small urbanized tributary to the Wachusett Reservoir. Initial sampling established baseline and stormwater nutrient and bacteria levels. Samples were collected at Rocky Brook (East Branch) and from a small agricultural subbasin for comparative purposes. A total of 312 weekly samples have been collected from Rocky Brook for fecal coliform and conductivity analysis. No samples were collected from this station during 2003. Samples for nitrate-nitrogen and total phosphorus were collected irregularly (2-11 times per year) during the ten year sampling period. No samples for macroinvertebrates or metals have been collected and only a limited amount of information on flow has been compiled.

Calculated statistics on land use in the Rocky Brook (East Branch) subbasin are not currently available, but most of the subbasin is undeveloped forest and percent impervious is very low. Water quality is the best in the watershed and nearly always meets Massachusetts Class A Surface Water Standards. Annual water quality as measured by fecal coliform was unchanged throughout the sampling period except for a slight increase in 2005 (Table 113).

Seasonal differences were nearly nonexistent with fecal coliform concentrations remaining low throughout the year, due partially to the fact that very few samples were collected during the summer when bacteria numbers often increase. Differences between samples collected during dry and wet weather were also minor, with even wet weather samples meeting Class A Surface Water Standards.

Table 113:
ROCKY BROOK (East Branch) – FECAL COLIFORM AND CONDUCTIVITY

YEAR	88-97	98	99	00	01	02	03	04	05	06	07
fecal – median		1	1	1	5	5		5	5	5	5
fecal – geomean		1	1	2	5	6		5	10	6	6
fecal – %>20		0	0	11	0	3		3	21	5	9
fecal – %>100		0	0	5	0	0		0	8	0	0
(total samples)		(40)	(30)	(38)	(21)	(32)		(36)	(39)	(44)	(32)
conductivity		20	26	39	41	53		56	59	51	53

Annual conductivity did increase significantly from 1998 through 2002, and then has remained unchanged through 2007. Conductivity increased at all watershed stations during the past ten years, although in most cases by a smaller percentage than at Rocky Brook (East Branch). Even with a doubling of annual conductivity, values are still very low and much less than what are measured each year in the Wachusett Reservoir.

Nutrient samples were collected as part of the ongoing study to evaluate the impacts of sewering on water quality. Concentrations of both nitrate-nitrogen and total phosphorus in Rocky Brook are extremely low (Table 114) and reflect baseline conditions in undeveloped forests. Concentrations remained unchanged throughout the sampling period. A drop in nutrient concentrations in Cook Brook (Chapter 3.9 – Table 31) is therefore likely due to a specific reduction in a source of pollutants and not simply a reflection of a widespread watershed trend. This would support the conclusion that contamination of Cook Brook from human sources has been significantly reduced by the introduction of sewers.

Table 114:
ROCKY BROOK (East Branch) – NUTRIENT MEAN CONCENTRATIONS (mg/L)

	1999	**2000**	**2001**	**2002**	**2004**	**2005**	**2006**	**2007**
Nitrate-nitrogen	<0.005	<0.005	0.007	0.019	0.011	0.017	0.008	0.009
Total phosphorus	0.007	0.006	0.016	0.012	0.013	0.016	0.007	0.010

Sampling of Rocky Brook (East Branch) has continued through 2008 and 2009 to continue the comparison between the three subbasins as sewer connections continue and during a shift from fecal coliform to *E. coli* as the parameter of interest. Sampling will likely be discontinued in 2010 or 2011 once sufficient data have been collected.

3.28 SCANLON BROOK

The Scanlon Brook subbasin is located within the towns of Sterling and Holden. This small stream was sampled downstream of Route 140 just before it passes under Crowley Road about 250 yards upstream of the Stillwater River. The stream is about six feet in width at this location. A total of 318 fecal coliform and conductivity samples were collected weekly in 1998-2000 and 2004-2007. Macroinvertebrate samples were collected in 2001. No nutrient or metals samples have been collected from this tributary and no flow information is available.

Eighty-three samples for fecal coliform and conductivity were collected previously during 1989, 1990, 1992 and 1993. Macroinvertebrate samples were collected in 1990, 1994, and 1996. Fecal coliform and conductivity data were indicative of very good water quality, but macroinvertebrate populations were moderately impaired which suggests water quality problems.

The Scanlon Brook subbasin consists of 829 acres of forests and open land (73%), medium density residential development (13%), agriculture (12%), and a small amount of low density residential development (2%). Agricultural use is twice the watershed average, and medium density residential development is among the highest in the watershed. Much of the residential development is within a single subdivision in Sterling but is fortunately not in close proximity to the brook. Only five percent of land within 400 feet of a water resource in this subbasin is occupied by homes. Percent impervious cover (4.1%) in the subbasin is low and impacts from non-point source runoff and stormwater are not expected.

Water quality in Scanlon Brook as measured by fecal coliform and conductivity historically has been quite good, but all metrics showed a water quality decline toward the end of the latest sampling period (Table 115).

Table 115:
SCANLON BROOK – FECAL COLIFORM AND CONDUCTIVITY

YEAR	88-97	98	99	00	01	02	03	04	05	06	07
fecal – median	2-4	2	1	1				5	5	10	10
fecal – geomean	n/a	4	3	3				13	15	20	16
fecal – %>20	8-25	18	13	8				28	28	37	27
fecal – %>100	0-15	2	0	0				9	13	20	17
(total samples)	(83)	(45)	(38)	(50)				(47)	(46)	(51)	(41)
conductivity	40-57	50	64	72				94	88	83	84

Seasonally grouped samples exhibited clear differences at this station, similar to those at other sampling stations in the watershed. Fecal coliform concentrations were low in the winter, higher in the spring and fall, and reached their highest during the summer (Table 116).

Table 116:
SCANLON BROOK – SEASONAL METRICS

	WINTER	SPRING	SUMMER	FALL
fecal – geomean (range)	1 – 6	2 – 17	8 – 113	2 – 19
fecal – geomean (average)	4	10	69	8
fecal – %>20 (range)	0 – 8	0 – 38	23 – 92	0 – 50
fecal – %>20 (average)	2	25	60	13

Annual fecal coliform concentrations of wet weather samples at this station were sharply higher than those of dry weather samples (Table 117). Wet weather samples were much more likely to have highly elevated fecal coliform concentrations than dry weather samples. Twenty-five percent of wet weather samples but only five percent of dry weather samples contained more than 100 cfu/100mL.

Table 117:
SCANLON BROOK – FECAL COLIFORM (wet versus dry)

	wet weather samples	dry weather samples
fecal – annual median	10 – 670	1 – 7
fecal – annual geomean	8 – 205	2 – 14
fecal – annual %>20	29 – 80	5 – 26
fecal – annual %>100	0 – 60	0 – 13

Annual conductivity data increased at this station over the ten year period as it did at all stations in the watershed, but less so than the watershed average. An annual maximum was reached in 2004. Conductivity declined by 11% from 2004 to 2007 and seems to have stabilized at a level comparable to those recorded in the reservoir.

Macroinvertebrate samples were collected from this tributary using a one-minute kick technique. An assessment of potential habitat was done during 1990 to determine if any differences seen between the macroinvertebrate population at this station and a reference station with high quality habitat and a healthy, diverse macroinvertebrate population were due to pollutants or variations in physical habitat. The habitat was found to be comparable to the reference station, with a substrate consisting primarily of rubble, gravel, and some bedrock, moderately stable banks, and only minor amounts of scouring and deposition. Samples collected in all four years showed moderate impairment compared to the reference station, reflected by low numbers of total taxa and EPT taxa and by slightly elevated HBI scores indicating the presence of more pollution tolerant species. There were no mayfly species present in 2001 and a significant reduction of caddisflies as well. Flow characteristics of this tributary may be limiting the macroinvertebrate population.

There are no known problems with agricultural activities, wildlife, septic systems, stormwater, or hazardous materials in the subbasin, but fecal coliform concentrations appear to be increasing and macroinvertebrates are moderately impaired. Water quality sampling should continue and additional parameters may need to be considered to help determine what is impacting the brook.

3.29 SCARLETT BROOK

The Scarlett Brook subbasin is located within the town of West Boylston. There are two sampling stations in the subbasin, one of which is discussed in more detail in Chapter 3.30. The primary sampling station is located just upstream from the junction of Scarlett and Gates Brooks, immediately after it emerges from a culvert under the Wal-Mart parking lot. The stream is ten feet wide at this sampling location. Samples were collected weekly from 1998-2000 and from 2004 – 2007. A total of 352 samples were collected for fecal coliform and conductivity analysis. No samples for nutrients or metals were collected from this station during the ten year sampling period, and macroinvertebrate sampling was not done because of low flows and poor habitat.

A total of 179 samples for fecal coliform and conductivity were collected previously during 1989, 1990, and from 1995-1997. Water quality during that period was very poor.

The Scarlett Brook subbasin is very highly developed, with more industrial and commercial development than any other subbasin in the watershed. The subbasin is 320 acres of forest and open land (58%), residential development (20%), commercial and industrial development (18%), and small areas of agriculture and open water and wetlands. The combination of industrial and commercial development and the high concentration of medium and high density residential development are responsible for the high percentage of impervious cover (24.7%). No other subbasin has as much impervious cover and stormwater problems are inevitable.

Water quality in Scarlett Brook as measured by fecal coliform and conductivity historically has been quite poor, but improvements have been noted recently. Most annual metrics from the latest ten year period are at the low end or below the range of values recorded during the previous decade (Table 118). Water quality has been fairly consistent for the past ten years, even as a significant percentage of homes previously served by individual septic systems have been connected to the new municipal sewer. No homes within this subbasin were connected to the sewer at the beginning of 2001, but seventy-eight percent were tied in by the end of 2007. Most water quality improvements occurred prior to sewering, however, and are likely reflective of the increased efforts to repair improperly functioning septic systems. There has been a reduction in the percentage of samples that exceed certain benchmark values. The percentage of samples that contained more than 100 cfu/100mL reached historic lows in the final two years of sampling, and the percentage that contained more than 20 cfu/100mL was less than historic values in all seven years sampled during this most recent period.

Seasonally grouped samples exhibited noticeable differences at this station, but slightly less than those at other sampling stations in the watershed. Fecal coliform concentrations were lowest in the winter, higher in the spring, and reached their highest during the summer before declining again in the fall (Table 119).

Table 118:
SCARLETT BROOK – FECAL COLIFORM AND CONDUCTIVITY

YEAR	88-97	98	99	00	01	02	03	04	05	06	07
fecal – median	26-68	31	11	40				20	30	30	40
fecal – geomean	n/a	43	22	37				26	40	33	29
fecal – %>20	64-74	60	42	55				47	56	59	55
fecal – %>100	23-34	26	20	29				20	29	18	16
(total samples)	(179)	(50)	(50)	(51)				(49)	(52)	(51)	(49)
conductivity	257-414	335	379	382				491	670	662	497

Table 119:
SCARLETT BROOK – SEASONAL METRICS

	WINTER	SPRING	SUMMER	FALL
fecal – geomean (range)	3 – 20	17 – 82	41 – 295	15 – 71
fecal – geomean (average)	13	43	108	31
fecal – %>20 (range)	8 – 38	38 – 69	69 – 85	27 – 69
fecal – %>20 (average)	22	59	80	52

Fecal coliform concentrations of wet weather samples at this station were strikingly higher than those of dry weather samples (Table 120), with almost no overlap in the range of metrics. Fifty-eight percent of wet weather samples contained more than 100 cfu/100mL; only fifteen percent of dry weather samples exceeded this benchmark.

Table 120:
SCARLETT BROOK – FECAL COLIFORM (wet versus dry)

	wet weather samples	dry weather samples
fecal – annual median	105 – 230	11 – 30
fecal – annual geomean	24 – 245	18 – 31
fecal – annual %>20	60 – 100	38 – 54
fecal – annual %>100	50 – 71	8 – 23

Annual conductivity was much higher than in previous years in 2004 and then increased again in 2005, remaining high in 2006 before declining in 2007 (Table 118). No explanation has been developed for the sharp increase. Annual conductivity increased by almost sixty percent from 1998-2000 to 2006-2007, higher than the watershed average.

Water quality in this subbasin remains poor, but fecal coliform concentrations have dropped since the previous ten year period. Additional connections to the new municipal sewer should lead to further water quality improvements, but problems with stormwater may be masking most positive changes. Stormwater runoff was identified as a significant problem in this subbasin, primarily due to the high percentage of impervious surfaces. Wet weather mean turbidity was more than five times higher than dry weather mean turbidity. Many of the other tributaries in the watershed did not show such an obvious difference. Significant remedial efforts are needed to reduce problems associated with stormwater in this subbasin and in the adjacent Gates Brook subbasin. The option of structural controls on Division property should be considered.

3.30 SCARLETT BROOK (Route 12)

The Scarlett Brook subbasin is located within the town of West Boylston. The primary sampling station in the subbasin was discussed in detail in Chapter 3.29. A second sampling station was added in 2004 to help determine if contamination was from upstream locations or was primarily associated with stormwater inputs from the Wal-Mart parking lots.

The secondary sampling station is located upstream of Route 12 where flow is contained in a small ditch next to a grassy parking area. The stream is only a few feet wide and is often dry during the summer months. Samples have been collected weekly since 2004. A total of 164 samples were collected for fecal coliform and conductivity analysis. No samples for nutrients or metals were collected from this station during the sampling period, and macroinvertebrate sampling was not done because of low flows and poor habitat.

Land use of the Scarlett Brook subbasin was described in the previous chapter. Land use within this smaller subsection of the subbasin is similar but has less commercial development and a smaller percentage of impervious cover.

Water quality at this station appears to have declined. All annual fecal coliform metrics were better during 2004 than in any of the subsequent three years (Table 121). Water quality was worse during the spring and summer and during wet weather. Wet weather samples were exceptionally bad during 2007 with all seven samples containing more than 100 cfu/100mL.

Table 121:
SCARLETT BROOK (Route 12) – FECAL COLIFORM AND CONDUCTIVITY

YEAR	88-97	98	99	00	01	02	03	04	05	06	07
fecal – median								10	30	40	37
fecal – geomean								20	44	49	44
fecal – %>20								41	55	69	66
fecal – %>100								20	24	27	34
(total samples)								(41)	(42)	(49)	(32)
conductivity								285	249	242	257

It was assumed that water quality measured at the Route 12 station would be better than at the downstream station because of fewer potential sources of contamination, but this was not the case. Water quality as measured by fecal coliform was slightly worse at the Route 12 station which, in spite of the name, does not receive runoff from Route 12. Stormwater runoff from Route 12 and from the Wal-Mart parking lots does not appear to be high in fecal coliform. Impacts from stormwater runoff were reflected by sharply higher annual conductivity measured at the downstream station (491 – 670 μmhos/cm) as compared to that measured at the Route 12 station (242 – 285 μmhos/cm).

Water quality at the Route 12 station was worse than at the downstream station during the winter, summer, and fall, but was nearly identical during the spring. There were no significant differences between sampling stations when samples were grouped by weather conditions.

Negative water quality impacts to Scarlett Brook (Route 12) are almost certainly caused by wildlife, with geese a likely source. Low conductivity suggests a non-human source. Geese are known to frequent the grounds of the Wachusett Country Club which is upgradient of the sampling station. Although routine sampling of this station is not going to continue beyond 2008, special sampling should take place following an attempt to locate and remove the source of bacteria.

3.31 STILLWATER RIVER

3.31.1 Route 62

The Stillwater River combines flow from Justice and Keyes Brooks and travels southeast between Sterling and Princeton, passing beneath Route 62 and eventually entering the Wachusett Reservoir through the Stillwater and Thomas Basins. The Stillwater River is one of the two largest tributaries to the reservoir and drains approximately thirty percent of the watershed. There are a number of named and unnamed tributaries to the river.

Water quality samples have been collected from the Stillwater River for more than twenty years. The primary sampling station is located just below the steel bridge at Muddy Pond Road and is described in detail in Chapter 3.31.2. A second sampling station was established to help locate any upstream sources of contamination. This station is located just downstream of Route 62.

The sampling station at Route 62 is in a slow moving stretch of the river. Stormwater enters the river upstream of the sampling station and the bottom of the river is covered by sand and mud. The river is approximately thirty feet wide. A total of 200 samples have been collected for fecal coliform and conductivity analysis on a weekly basis beginning in 2004. No samples for metals, nutrients, or macroinvertebrates were collected from this station, but samples for all three were collected at the primary station downstream. A total of 130 samples were collected for fecal coliform and conductivity analysis previously in 1989, 1992, 1993, and 1995.

Land use statistics for the Route 62 subbasin were compiled by combining information from the eleven defined subbasins that comprise the drainage basin. A total of 16,485 acres drain to the Route 62 sampling station. Eighty percent of the area is forested or open land. Slightly more than eleven percent is residential development (mostly low density) and between five and six percent is covered by agriculture.

The percentage of impervious cover throughout the contributory area (4.1%) is less than the watershed average (5.4%), but this includes eleven separate subbasins and does not preclude problems with stormwater runoff in smaller areas with a higher percentage of impervious cover. Some stormwater problems have been noted near the sampling station.

Annual fecal coliform metrics have been fairly consistent during the four years of sampling and at the low end of historic data (Table 122). Samples grouped by season or by weather condition showed the usual watershed pattern, with elevated metrics during the spring and summer or following rain events.

Table 122:
STILLWATER RIVER (Route 62) – FECAL COLIFORM AND CONDUCTIVITY

YEAR	88-97	98	99	00	01	02	03	04	05	06	07
fecal – median	6-49							20	30	20	15
fecal – geomean	n/a							25	26	27	22
fecal – %>20	40-62							45	54	49	44
fecal – %>100	16-30							16	16	18	14
(total samples)	(130)							(49)	(50)	(51)	(50)
conductivity	62-77							97	109	87	97

Conductivity levels at this sampling station were similar to those observed in the reservoir itself. Annual conductivity has increased slightly but at a rate comparable to that observed at many other stations throughout the watershed. There has been no change in annual conductivity during the past four years.

Water quality at Route 62 has historically been slightly worse than at the primary station, but water quality at the two stations has been very similar since 2004. An assessment of the differences between the two stations and what it might mean is included in Chapter 3.31.2.

Beaver impoundments have been observed both upstream and downstream of the sampling station. Geese have been observed in the quiet open water areas upstream. During periods of high water following snow melt or significant storm events the river expands beyond its banks and may occasionally approach septic system leach fields. Stormwater is probably the greatest threat to water quality, and staff should consider means to delay or treat discharges prior to their reaching the river.

Agricultural activity was identified as a potential source of contamination, but all sites in the subbasin have been visited and are not considered a threat at this time. Staff will revisit all sites in the future to make sure that best management practices are still in use.

3.31.2 Steel Bridge

The Stillwater River is one of the two largest tributaries to the Wachusett Reservoir and drains approximately thirty percent of the watershed. Water quality samples have been collected from the Stillwater River for more than twenty years. The primary sampling station is located just below the steel bridge at Muddy Pond Road. A second sampling station was established to help locate any upstream sources of contamination and is located just downstream of Route 62. Water quality at the two stations is compared within this chapter.

The Stillwater River combines flow from Justice and Keyes Brooks in Princeton and travels southeast, passing beneath Route 62 and to the west of the Sterling Airport. Surrounding land below this point is part of the Stillwater River (steel bridge) subbasin described in this chapter. There are also a number of named and unnamed tributaries to the river as well as periodic discharges from an oxbow pond, a peat bog, and several stormwater basins along Interstate 190.

The primary sampling station on this tributary is just downstream of the steel bridge on Muddy Pond Road in Sterling. The river is about forty feet in width at this sampling location. Samples for fecal coliform and conductivity analysis were collected weekly from 1998-2003, and twice weekly from 2004-2007. A total of 735 samples have been collected.

Monthly samples were collected for nitrate-nitrogen, total phosphorus, and a variety of metals from 1999-2007. Depth measurements were done every fifteen minutes and flow data are available from the USGS monitoring station located near the bridge. Macroinvertebrate samples were collected from this station in May, July, and October of 2001. Another macroinvertebrate sample was collected about 50m downstream of the primary station in May 2001 to determine if road runoff was impacting the river.

A total of 385 samples were collected for fecal coliform and conductivity analysis between 1988 and 1997. Macroinvertebrate samples were collected in 1988, 1989, 1990, 1992, 1994, and 1996.

The Stillwater River (steel bridge) subbasin consists of 928 acres of forest and open land (53%), agriculture (18%), industrial development or transportation (17%), residential development (8%), and open water and wetlands (5%). Much of the industrial activity is associated with old gravel pits that are no longer in use. The percentage of impervious cover (8.4%) is considerably higher than the watershed average (5.4%) due to the presence of the interstate highway and the Sterling Airport. The subbasin does receive flow from a number of other subbasins, many with very low percentages of impervious cover, but there is little doubt that stormwater pollution is a significant threat and there have been documented cases of negative impacts of stormwater on water quality.

All of the land with industrial activity in this subbasin is located within 400 feet of the Stillwater River and its tributaries, as are a significant percentage of the roads, airport runways, and agriculture. The percentage of impervious cover within 400 feet of the river is even higher than the overall subbasin percentage.

All annual fecal coliform metrics at this station have been very consistent since 1988 (Table 123). Mean annual discharge has varied from a low of 32.2 cfs in 2002 to a high of 86.1 cfs in 2005 but has had no apparent effect on water quality.

Table 123:
STILLWATER RIVER (steel bridge) – FECAL COLIFORM AND CONDUCTIVITY

YEAR	88-97	98	99	00	01	02	03	04	05	06	07
fecal – median	12-32	40	20	22	25	20	30	40	30	20	20
fecal – geomean	n/a	28	16	17	30	25	31	33	27	26	24
fecal – %>20	33-63	58	49	51	50	45	52	55	52	50	48
fecal – %>100	9-30	32	10	10	31	22	23	25	19	15	17
(total samples)	(385)	(50)	(49)	(71)	(52)	(49)	(52)	(103)	(104)	(105)	(100)
conductivity	66-109	95	106	103	130	167	137	148	174	144	179

Seasonally grouped samples exhibited clear differences at this station, similar to those at other sampling stations in the watershed. Fecal coliform concentrations were generally low during the winter and early spring, increasing during the late spring and summer, and remaining somewhat elevated through much of the fall (Table 124).

Table 124:
STILLWATER RIVER (steel bridge) – SEASONAL METRICS

	WINTER	SPRING	SUMMER	FALL
fecal – geomean (range)	2 – 10	22 – 64	51 – 242	6 – 29
fecal – geomean (average)	7	39	117	15
fecal – %>20 (range)	0 – 23	46 – 83	77 – 100	25 – 48
fecal – %>20 (average)	9	64	95	31

Water quality was strongly impacted by weather conditions, with water quality of wet weather samples much worse than that of dry weather samples (Table 125). Concentrations increased following storm events and sometimes remained high for several days.

The Stillwater River is a large tributary with many contributing smaller streams, and impacts from precipitation events are not always seen immediately at the primary sampling station since contaminated water from the smaller tributaries may take additional time to reach the lower reaches of the river. Water quality of samples collected forty-eight hours after storm events is presented in Table 125 and as expected is intermediary between dry weather and wet weather samples.

Table 125:
STILLWATER RIVER (steel bridge) – FECAL COLIFORM (wet versus dry)

	wet weather samples	samples 48hrs after	dry weather samples
fecal – annual median (range)	9 – 280	10 – 135	10 – 24
(average)	102	47	19
fecal – annual geomean (range)	25 – 221	22 – 78	15 – 28
(average)	78	37	20
fecal – annual %>20 (range)	33 – 100	25 – 80	39 – 51
(average)	76	60	45
fecal – annual %>100 (range)	28 –89	14 – 63	8 – 24
(average)	43	25	14

The mean conductivity in the Stillwater River for the current ten year period was 61% higher than for the previous ten year period, slightly more than the average watershed increase of 56% as determined by using ten tributaries that have been sampled consistently for the past twenty years. Years with little rainfall often result in higher conductivities due to low flow conditions, and winter storm events can lead to elevated levels due to the application of salt on icy roadways, so the use of annual statistics for conductivity can be misleading. Annual data were examined to look for periods of relative stability and then grouped and summarized. The periods of 1988-1992, 1998-2000, and 2006-2007 exhibited little change throughout the watershed and were therefore used to detect trends. The increase in conductivity at the ten tributaries continuously monitored from the earliest period (88-92) to the latest (06-07) was 83%. The increase in the Stillwater River was 116% and seems indicative of a problem.

Conductivity increased sharply at all stations in the watershed during 2001, 2002, and 2003, and the Stillwater River was no exception. These increases have been linked to the use of a new field conductivity meter during that three year period. Annual conductivity at most stations declined following a return to an earlier piece of monitoring equipment, but did not drop at the Stillwater station and in fact reached historic maximums in 2005 and then again in 2007.

Samples for fecal coliform and conductivity analysis were collected at an upstream station on the Stillwater River to help determine the sources of contamination. Fecal coliform concentrations were initially higher at the mid river station below Route 62 than at the primary station at the steel bridge, but conductivity was always lower. Much of the land adjacent to the lower reaches of the Stillwater River is undeveloped and protected. The Route 62 station is also near a significant area of protected land, but there are a number of homes in close proximity as well as a significant wildlife population, and several tributaries with water quality problems discharge to the river only a short distance upstream.

Samples collected from 2004-2007 showed no real differences in fecal coliform concentrations between the two stations, but conductivity remained much higher at the downstream station. Very high conductivity water enters the river from Houghton Brook and may be responsible for elevated conductivity at Stillwater (steel bridge). Beaver activity near the bridge could also play a role.

Samples for nitrate-nitrogen and total phosphorus were collected monthly from this station from 1999-2007. Samples had been collected previously but detection limits were too high to provide useful information. Annual mean concentrations of nitrate-nitrogen samples during the past ten years were very low (0.119–0.273 mg/L) compared to other watershed tributaries. Annual mean concentration of total phosphorus was high in 2000, exceeding the EPA recommended limit of 0.05 mg/L, but was low to moderate (0.021–0.044) in all other years. The elevated annual mean in 2000 (0.083) was the result of a single very high measurement from February that has not been explained.

Macroinvertebrate samples were collected in 1988, 1989, 1990, 1992, 1994, 1996, and 2001 approximately 150 yards upstream from the primary sampling station using a one-minute kick technique. A second sample was collected in 1990 and in 2001 about 50 yards downstream of the primary station. Substrate at the upstream station consists primarily of boulders, cobble, gravel, and sand. Downstream is a mix of cobble and sand with increasing amounts of silt. The river is wide (approximately forty feet) and relatively slow moving, and canopy cover is open to partly open.

Samples collected from both stations showed slight to no impairment when compared to a reference station, and in fact during some years contained a greater number of total and EPT taxa and were more diverse than the reference station. Biotic index scores were higher than expected, although the reduced flows and reduced oxygen levels caused by beaver activity were the likely cause and does not necessarily reflect problems upstream.

Table 126:
STILLWATER RIVER – MACROINVERTEBRATE ASSESSMENT

YEAR	TAXA	EPT	EPT/chiro	HBI	% DOMIN	IMPAIRMENT
1988	28	19	24	2.15	16	slight
1989	27	19	8	2.90	23	slight
1990	28	19	11	2.29	12	slight
1992	34	23	6	2.39	15	slight
1994	29	21	85	1.98	18	none
1996	33	22	26	1.75	22	none
2001	31	16	15	2.68	17	none
1990dwnstr	24	17	15	2.17	13	slight
2001dwnstr	30	17	24	4.17	16	slight
2001July	29	20	17	2.30	14	none
2001Oct	25	16	>100	3.08	20	slight-none
88-01	**19-30**	**12-22**	**14 - >100**	**0.98-1.62**	**16-28**	**REF STATION**

Differences in macroinvertebrate populations collected above and below the steel bridge were very minor. Only slight impacts were noted downstream, probably the result of less habitat variety and deposition of silt due to stormwater runoff. The macroinvertebrate population in the Stillwater River did not appear to change significantly during the past twenty years. No obvious seasonal differences were noted in the three samples collected during 2001.

Only four active agricultural sites are listed in this subbasin, even though the land use coverage shows nearly one fifth of the subbasin as agriculture. The sites include a nursery, a vegetable farm, an extensive area of hayfields, and a parcel with four horses. No problems with agricultural activities have been noted.

Several areas of beaver activity were identified both upstream and downstream of the sampling station. The largest population is located just downstream of the steel bridge. The river used to be fast moving in this area with a substantial riffle area and a diverse insect population. A series of dams constructed downstream has slowed the flow of water and resulted in the deposition of large quantities of sand and silt. The river is now slow moving and the insect population has been impacted although remains healthy and diverse.

The Stillwater River subbasin was identified as likely to be impacted by unmanaged stormwater. A number of site specific best management practices were recommended including installation of a forebay at Muddy Pond Road to remove sediment. Stormwater management improvements were incorporated as part of the upgrade of the Muddy Pond Bridge (steel bridge) and conditions have improved.

There are few homes present with most located a great distance from any wetland resource. Only the high density residential development across from the airport is within 400 feet of the river, and this area is the only one likely to be the source of wastewater problems. Water quality data have not indicated any problems to date, but staff will continue to look for possible sources of contamination.

3.32 SWAMP 15 BROOK

This tributary flows into the middle section of the Quinapoxet River approximately one half mile upstream of the Canada Mills crossing in Holden. The brook enters from the southeast, flowing out of a wetland and under Harris Street in a three foot culvert. The sampling station is located immediately downstream of Harris Street and is a third of a mile from the Quinapoxet River.

The stream is about six feet in width at the sampling location. Samples were collected weekly during 1998 – 2000 and from 2004 – 2007. A total of 341 samples were collected for fecal coliform and conductivity analysis. No samples for nutrients or metals were collected from this station during the ten year sampling period, and macroinvertebrate sampling was not done because of low flows and inadequate habitat.

Thirty-nine samples for fecal coliform and conductivity were collected previously during 1989 and 1995.

The Swamp 15 Brook subbasin contains of 694 acres of forests and open land (77%), agriculture (11%), and low and medium density residential development (11%). The agricultural development is concentrated near the stream and wetlands, with forty-six of seventy-nine acres within 400 feet of a water resource. Percent impervious cover (3.9%) in the subbasin is low and impacts from non-point source runoff and increased stormwater pollution should be limited, but the proximity of agriculture to the resource areas increases the threat.

Water quality in Swamp 15 Brook as measured by fecal coliform historically was quite poor. Improvement has been noted in the past ten years, however, as reflected by all annual metrics (Table 127). The water quality improvements appear related to a concerted effort to reduce impacts from agricultural operations in the subbasin.

Table 127:
SWAMP 15 BROOK – FECAL COLIFORM AND CONDUCTIVITY

YEAR	88-97	98	99	00	01	02	03	04	05	06	07
fecal – median	53-79	21	21	12				10	30	20	20
fecal – geomean	n/a	36	23	17				26	28	26	30
fecal – %>20	50-77	50	50	45				43	52	39	49
fecal – %>100	37-50	32	18	16				30	20	18	16
(total samples)	(39)	(50)	(50)	(49)				(46)	(50)	(51)	(49)
conductivity	183-225	259	275	253				424	431	350	420

Seasonally grouped samples exhibited some differences at this station, although not as striking as those at other sampling stations in the watershed. Fecal coliform concentrations were lowest in the winter, higher in the spring, and reached their highest during the summer before declining again in the fall (Table 128). The summer increase was more pronounced in some years than in others.

Table 128:
SWAMP 15 BROOK – SEASONAL METRICS

	WINTER	SPRING	SUMMER	FALL
fecal – geomean (range)	4 – 17	16 – 73	50 – 178	10 – 61
fecal – geomean (average)	9	38	85	25
fecal – %>20 (range)	0 – 25	31 – 77	77 – 86	18 – 50
fecal – %>20 (average)	12	55	83	36

Fecal coliform concentrations of wet weather samples at this station were much higher than those of dry weather samples, probably due to the proximity of agriculture to the brook and the resultant impact during storm events. Wet weather samples were much more likely to have elevated fecal coliform concentrations. Sixty-six percent of all wet weather samples and only eleven percent of all dry weather samples contained more than 100 cfu/100mL. Annual median and annual geometric mean show similar differences (Table 129).

Table 129:
SWAMP 15 BROOK – FECAL COLIFORM (wet versus dry)

	wet weather samples	dry weather samples
fecal – annual median	70 – 515	8 – 20
fecal – annual geomean	52 – 378	10 – 27
fecal – annual %>20	56 – 100 (81%)	27 – 48 (39%)
fecal – annual %>100	33 – 100 (66%)	2 – 19 (11%)

Conductivity levels were remarkably uniform during some years, while in other years summer increases were observed. Annual conductivity has been relatively consistent during the past four years, but increased significantly since the previous ten year sampling period. Annual conductivity data can be strongly influenced by fluctuations in total rainfall and frequency of winter storm events and salt applications. Annual data were closely examined to look for multiple year periods with relative stability that could be summarized and used to identify trends. The periods of 1998-2000 and 2006-2007 exhibited little change throughout the watershed and can be used for this purpose. The increase in conductivity from 1998-2000 to 2006-2007 in Swamp 15 Brook was 47% which was similar to the average increase across watershed tributaries.

Water quality in this subbasin has improved in the past ten years. All agricultural sites with animals were inspected by staff and a number were determined to pose water quality threats. Horses were associated with seven of the sites, and an additional site housed a large number of pigs and cows. One of the sites was one of twelve agricultural operations in the watershed identified as significant based on proximity to the reservoir or due to the large numbers of animals present. Fourteen cows and fifteen horses were housed on a 12.5 acre site, and a small tributary ran through part of the pasture area. Manure storage was inadequate. Runoff from the manure pile and from field droppings was contaminating the stream. The Division purchased a buffer strip on either side of the stream and installed fencing to exclude the livestock. A sand filter was also constructed downstream to help remove contaminants. The Division provided funding for a manure storage shed and additional fencing and all have been constructed. Livestock numbers at this site have been reduced as well, and water quality impacts have been significantly reduced.

A second farm is considerably larger in area and at one time housed twenty-eight cows and five hundred pigs, but due to its location with respect to the stream and other wetland resources was not considered a serious problem. Fencing was used to keep the cows away from wetland areas, and a most of the animals were eventually sold.

Fencing and other best management practices have been used at additional agricultural sites in the subbasin and agriculture is no longer considered to pose water quality threats.

No active populations of beaver or muskrat were noted during recent stream surveys and wildlife is not thought to be a threat to water quality. Division staff are no longer concerned with wastewater or stormwater issues in the subbasin and routine sampling of the tributary can probably be discontinued. Agricultural operations will be inspected regularly to make sure that conditions do not decline.

3.33 TROUT BROOK

Trout Brook originates just south of Mason Road in Holden. Cold Brook (Chapter 3.8) and Governor Brook (Chapter 3.13) meet in a swampy area flooded by beaver activity and their combined flow becomes Trout Brook. The brook flows through forested areas owned by the Town of Holden and the Division until it reaches the Quinapoxet River.

The sampling station on Trout Brook is located just downstream of Manning Street approximately one quarter mile upstream of the Quinapoxet River. The stream is twelve feet in width at this location. Samples were collected weekly during 1990 – 2000 and from 2004 – 2007. A total of 341 samples were collected for fecal coliform and conductivity analysis. Macroinvertebrate samples were collected in May of 1998 and in May, July, and October of 2001. No samples for nutrients or metals were collected from this station during the ten year sampling period.

Samples for fecal coliform and conductivity were collected previously during 1988 – 1991, 1993, and 1995. A total of 165 samples were collected biweekly or weekly. Macroinvertebrate samples were collected in May of 1988, 1989, 1990, 1992, 1994, and 1996. Nutrient samples were collected during 1988 but data from that time period are not considered reliable due to high detection limits.

The Trout Brook subbasin contains a very high amount of forested and open land. Much of the subbasin is owned by the Division or protected as town open space by the Trout Brook Reservation. The subbasin contains of 1071 acres of forests and open land (90%), low density residential development (7%), and agriculture (3%). Land use within 400 feet of Trout Brook is almost completely covered by forest, open land, and wetlands. There are only five acres of residential development and two acres of agricultural development near the brook; no other areas near this tributary are developed and water quality should be very high. Percent impervious cover (2.5%) in the subbasin is one of the lowest in the watershed, and impacts from stormwater pollution are very unlikely. The two subbasins that drain into the Trout Brook subbasin have similar land use and should have similar water quality. Forests, open land, low density residential, and agriculture are the only land uses present in the Cold Brook and Governor Brook subbasins. Percentage impervious in both is very low and the threat from stormwater runoff is considered insignificant.

Water quality in Trout Brook as measured by fecal coliform and conductivity has been very good for a number of years, better than most of the tributaries in the Wachusett watershed. A slight decline in water quality was noted in 2005 and 2007, however, as reflected by most annual metrics (Table 130). Even with a slight decline, water quality remains very good.

Table 130:
TROUT BROOK – FECAL COLIFORM AND CONDUCTIVITY

YEAR	88-97	98	99	00	01	02	03	04	05	06	07
fecal – median	4-13	3	3	3				5	10	10	10
fecal – geomean	n/a	4	4	5				10	15	11	16
fecal – %>20	16-39	16	22	20				19	30	24	32
fecal – %>100	0-14	6	2	6				2	8	4	9
(total samples)	(165)	(50)	(46)	(50)				(47)	(50)	(51)	(47)
conductivity	48-67	61	60	59				68	83	64	68

Fecal coliform levels were generally uniform throughout the year, with slightly elevated values during the spring, summer, and fall (Table 131). The summer increase is presumably caused by concentration of contaminants due to low flows or due to increased wildlife activity in the warmer months, but was less striking than that seen in most other tributaries within the watershed.

Table 131:
TROUT BROOK – SEASONAL METRICS

	WINTER	SPRING	SUMMER	FALL
fecal – geomean (range)	2 – 6	6 – 20	12 – 29	2 – 22
fecal – geomean (average)	4	12	18	10
fecal – %>20 (range)	0 – 8	17 – 38	31 – 54	0 – 40
fecal – %>20 (average)	3	29	41	19

Fecal coliform concentrations of wet weather samples at this station were higher than those of dry weather samples, although less so than at many other sampling stations in the watershed. Fifty-six percent of wet weather samples contained more than 20 cfu/100mL and twenty-one percent contained more than 100 cfu/100mL. Only fifteen percent of all dry samples contained more than 20 cfu/100mL; only two percent of dry samples contained more than 100 cfu/100mL. Annual median and annual geometric mean show similar differences (Table 132).

Table 132:
TROUT BROOK – FECAL COLIFORM (wet versus dry)

	wet weather samples	dry weather samples
fecal – annual median	7 – 74	1 – 10
fecal – annual geomean	13 – 73	3 – 12
fecal – annual %>20	33 – 100	8 – 24
fecal – annual %>100	0 – 33	0 – 3

The mean conductivity in Trout Brook for the current ten year period was only 14% higher than for the previous ten year period, much less than the average watershed increase of 56%. Years with little rainfall often result in higher conductivities due to low flow conditions, and winter storm events can lead to elevated levels due to the application of salt on icy roadways, so the use of annual statistics for conductivity can be misleading. No samples were collected from Trout Brook during 1997 and 2001, both dry years with elevated conductivity. In order to eliminate bias caused by specific years, annual data were examined to look for periods of relative stability and then grouped and summarized. The periods of 1988-1992, 1998-2000, and 2006-2007 exhibited little change throughout the watershed and were therefore used to detect trends. The increase in conductivity at the ten tributaries continuously monitored for the past twenty years from the earliest period (88-92) to the latest (06-07) was 83%. The increase in Trout Brook was only 21% and seems to clearly show a lack of any significant water quality problems. The increase in annual conductivity from 1998-2000 to 2006-2007 was only 10% which is one of the smallest increases in the watershed. This consistency is likely due to the lack of development in the subbasin.

Macroinvertebrate samples were collected in May of 1988, 1989, 1990, 1992, 1994, 1996, and 1998, and in May, July, and October of 2001using a one-minute kick technique. This site was chosen as a reference station for the Southern Wachusett and Quinapoxet sanitary districts due to the large percentage of undeveloped watershed, the presence of a diverse macroinvertebrate population, and the relatively low levels of contaminants found in the water.

An assessment of potential habitat was done in 1990 to determine if differences between macroinvertebrate populations at this station and others were due to pollutants or variations in physical habitat. The habitat at the Trout Brook station was found to be very good, with a bottom substrate consisting of boulders, cobble, and gravel, a stable bank, almost no deposited fine sediments, and adequate depth and velocity.

Samples collected in May of all years were quite similar. This tributary maintained a healthy, diverse population dominated by the small mayfly species *Ephemerella dorothea* and *Drunella cornuta* or the small stoneflies *Amphinemoura wui* and *Leuctra* sp. Large predaceous stoneflies such as *Acroneuria* and *Isoperla* were usually present. There were no clear changes over time. Some samples contained a few more pollution tolerant chironomid midges than others, but no apparent trends were detected. There were some seasonal differences noted, however. The sample from July contained a reduced number of taxa including very few mayflies. The October sample included a larger number of pollution tolerant taxa. Neither is a cause for concern.

Table 133:
TROUT BROOK – MACROINVERTEBRATE ASSESSMENT

YEAR	TAXA	EPT	EPT/chiro	HBI	% DOMIN	IMPAIRMENT
1988	24	17	55	1.54	37	reference
1989	27	16	16	1.25	22	reference
1990	19	13	88	1.17	17	reference
1992	28	18	20	1.43	20	reference
1994	26	18	>88	1.02	14	reference
1996	24	13	10	1.47	23	reference
1998	27	19	95	1.19	41	reference
2001	30	19	11	1.68	25	reference
2001July	20	12	>100	1.37	24	reference
2001Oct	29	16	17	2.18	12	reference

All parameters examined suggest that Trout Brook is in good condition. Fecal coliform and conductivity data indicate no contamination from septic systems. The macroinvertebrate community is healthy and diverse, and shows no detrimental impacts from pollutants. The occasional increase in fecal coliform and conductivity during storm events appears unrelated to human activities and is likely the natural consequence of having a healthy wildlife population in an undeveloped subbasin.

The Trout Brook subbasin has only limited development and very good water quality. Sampling should continue in order to use this subbasin as a control for comparison with other subbasins throughout the watershed.

3.34 UNNAMED BROOK

Unnamed Brook flows through a large area of Division owned forested land in the northwest corner of Sterling. This small tributary was sampled downstream of Route 140 approximately 200 yards before it discharges into the Stillwater River. The stream is six feet in width at this sampling location. A total of 76 samples were collected weekly during 1999 and 2000 for fecal coliform and conductivity analysis. No samples for nutrients or metals were collected from this station and macroinvertebrate sampling was not done because of low flows. Three fecal coliform and conductivity samples were collected previously in 1989 (no sample was collected during the summer because the stream was dry).

The subbasin contains 417 acres of forests and open land (89%), low density residential development (10%), and agriculture (1%). Much of the forested land is owned by the Division and protected from development. The residential development is located along Elliot Road and Rowley Hill Road in the headwaters area, but most is more than 400 feet from the brook, with

97% of this sensitive area covered by forest. Percentage impervious in the subbasin is very low (2.0%) and is one of the lowest in the watershed.

Fecal coliform was never detected in 1989, and concentrations were very low during 1999 and 2000 as well. Water quality as measured by fecal coliform is excellent and ranked first among all streams sampled in the watershed.

Table 134:
UNNAMED BROOK – FECAL COLIFORM AND CONDUCTIVITY

YEAR	88-97	98	99	00	01	02	03	04	05	06	07
fecal – median	0		1	1							
fecal – geomean	0		3	3							
fecal – %>20	0		14	13							
fecal – %>100	0		3	3							
(total samples)	(3)		(37)	(39)							
conductivity	42		49	52							

Seasonal differences were noted, with fecal coliform concentrations higher during the summer when there was enough flow to collect a sample, but the differences were much less than what was observed at many other stations throughout the watershed. Concentration increased during and following storm events as well, although again the differences were much less pronounced than at stations with more contamination. Only thirty-three percent of all wet weather samples contained more than 20 cfu/100mL and only one sample contained more than 100 cfu/100mL.

Conductivity levels were uniform throughout the year and were among the lowest of all watershed tributaries. The annual conductivities observed are indicative of undeveloped forested areas and were considerably lower than those seen in the reservoir.

Water quality as good as this is possible only in areas with limited residential or agricultural development and virtually no activity close to wetland resources. Almost all residential development is more than 400 feet from the tributary, and the only agricultural site is a large apple orchard that is no longer in operation. There is almost certainly an active wildlife population in the subbasin, but no sign was identified during field inspections and aquatic mammals may not be present. Stormwater should not be a threat due to the extremely low percentage of impervious surfaces in the subbasin.

3.35 WARREN TANNERY BROOK

Water quality samples were collected from this tributary just downstream of Quinapoxet Street in Holden and just below an extensive wetland system, almost half a mile before it joins with Asnebumskit Brook and eventually flows into the Quinapoxet River. The stream is about six feet in width at the sampling location. Fecal coliform and conductivity samples were collected weekly in 1998, 1999, and 2004 – 2007. No nutrient or metals samples have been collected at this station, and no macroinvertebrate samples have been collected from this station because of low flows and inadequate substrate.

Samples for fecal coliform and conductivity were collected previously during 1989, 1993, and 1995. Samples were collected monthly in 1989 and weekly in 1993 and 1995. Water quality in 1989 was comparable to water quality observed during the past ten years, while water quality in 1993 and 1995 was not as good.

The Warren Tannery Brook subbasin contains 813 acres of forests and open land (60%), a large amount of residential development (28%), agricultural sites (8%), and small areas of commercial development and wetlands. Much of the residential development is classified as medium density. Land use within 400 feet of Warren Tannery Brook is more conducive to good water quality than total land use figures in the subbasin might suggest, with nearly 70% of this area covered by forest and only 12% (versus 23% overall) covered by medium density residential development.

Percent impervious cover (13.5%) in the subbasin is one of the highest in the watershed, with impacts from non-point source runoff and increased stormwater pollution expected. Wachusett Regional High School is located in the headwaters of this subbasin and was the site of a major renovation and expansion project. Severe stormwater problems were observed at the school and downstream of the site during construction.

Water quality in Warren Tannery Brook as measured by fecal coliform and conductivity has been stable throughout the sampling period (Table 135). Water quality problems caused by the expansion of the high school were reflected by elevated turbidity measurements but not by any increases in fecal coliform or conductivity.

Table 135:
WARREN TANNERY BROOK – FECAL COLIFORM AND CONDUCTIVITY

YEAR	88-97	98	99	00	01	02	03	04	05	06	07
fecal – median	16-40		19	12				15	10	10	20
fecal – geomean	n/a		14	10				19	19	20	22
fecal – %>20	36-62		44	42				39	42	35	49
fecal – %>100	9-35		16	10				11	12	16	8
(total samples)	(101)		(50)	(31)				(46)	(50)	(51)	(49)
conductivity	213-235		216	239				375	329	309	314

Seasonally grouped samples exhibited only minor differences at this station, much less than those at many of the other sampling stations in the watershed. Seasonal differences may have been buffered by the presence of a large wetland complex immediately upstream. Fecal coliform concentrations were lowest in the winter, higher in the spring, and reached their highest during the summer before declining again in the fall (Table 136).

Table 136:
WARREN TANNERY BROOK – SEASONAL METRICS

	WINTER	SPRING	SUMMER	FALL
fecal – geomean (range)	4 – 8	14 – 33	23 – 53	11 – 38
fecal – geomean (average)	6	24	43	20
fecal – %>20 (range)	8 – 23	45 – 69	31 – 77	25 – 60
fecal – %>20 (average)	11	55	61	44

Fecal coliform concentrations of wet weather samples at this station were much higher than those of dry weather samples, the likely result of rapid stormwater transport in a subbasin with a high percentage of imperious surfaces. Forty-four percent of wet weather samples but only five percent of dry weather samples contained more than 100 cfu/100mL. Seventy-nine percent of all wet samples and thirty-three percent of dry samples contained more than 20 cfu/100mL. Annual median and annual geometric mean show similar differences (Table 137).

Table 137:
WARREN TANNERY BROOK – FECAL COLIFORM (wet versus dry)

	wet weather samples	dry weather samples
fecal – annual median	32 – 160	6 – 15
fecal – annual geomean	23 – 176	8 – 17
fecal – annual %>20	57 – 100	22 – 40
fecal – annual %>100	14 – 100	0 – 9

Conductivity levels were fairly uniform throughout the year, with minor increases during the summer as noted in many other watershed tributaries. There have been no major changes in annual median conductivity since 1989. Annual conductivity data can be strongly influenced by fluctuations in total rainfall and frequency of winter storm events and salt applications, so annual data were closely examined to look for multiple year periods with relative stability that could be summarized and used to identify trends. The periods of 1998-2000 and 2006-2007 exhibited little change throughout the watershed and have been used for this purpose. The increase in conductivity from 1998-2000 to 2006-2007 in Warren Tannery Brook was 37%, comparable to the average watershed increase during the same period.

The Warren Tannery Brook subbasin has one of the highest concentrations of medium density development in the watershed and additional development is possible. Although sewers are available in this subbasin, some homes remain on individual septic systems and increases in fecal coliform and nitrates are possible if this development occurs. Connections to the sewer should be encouraged where available. Control of stormwater is also a significant issue and should be addressed wherever possible.

3.36 WAUSHACUM BROOK

3.36.1 Connelly Brook

Waushacum Brook (Connelly Brook) is the station closest to the headwaters of this tributary and is located upstream of Jewett Road in Sterling approximately 800 yards upstream of the Quag. The stream is approximately ten feet wide and flows through woodlands, agricultural areas, and residential development. There is a large contributory subbasin upstream which receives runoff from I-190.

A total of 163 samples have been collected for fecal coliform and conductivity analysis on a weekly basis beginning in 2004. No samples for nutrients, metals, or macroinvertebrates have been collected, and no flow data are available. Samples from this station were collected to help identify any possible contamination in the headwaters of Waushacum Brook.

The Upper Waushacum Brook drainage basin includes the Connelly Brook subbasin as well as Waushacum Brook (filter beds) and Waushacum Brook (West Waushacum Pond) described in Chapters 3.36.2 and 3.36.5. Land use in this drainage basin is similar to the watershed average in most categories, although medium density residential is twice the watershed norm. Much of the dense development is located in the highly developed center of Sterling, however, and the area that drains directly to Connelly Brook is primarily forest and open space, low density residential development, agriculture, and drainage basins of Interstate 190.

Annual fecal coliform metrics showed no obvious trend during the four year sampling period (Table 138). Fecal coliform concentrations did tend to be less than at many of the other sampling stations on Waushacum Brook, possibly the result of several beaver dams upstream that might serve to settle out any bacteria. A comparison of all of the sampling stations on Waushacum Brook will be included in Chapter 3.36.4.

Table 138:
WAUSHACUM BROOK (Connelly) – FECAL COLIFORM AND CONDUCTIVITY

YEAR	88-97	98	99	00	01	02	03	04	05	06	07
fecal – median								5	20	15	10
fecal – geomean								12	23	22	15
fecal – %>20								28	49	41	29
fecal – %>100								2	12	11	3
(total samples)								(43)	(41)	(44)	(35)
conductivity								409	430	403	360

Water quality metrics at this station were worst during the summer months, with good water quality during the winter, spring, and fall. Wet weather samples were slightly worse than dry weather samples, but much less so than at most other stations in the watershed (Table 139).

Table 139:
WAUSHACUM BROOK (Connelly) – FECAL COLIFORM (wet versus dry)

	wet weather samples	dry weather samples
fecal – annual median	10 – 70	5 – 20
fecal – annual geomean	11 – 59	12 – 18
fecal – annual %>20	20 – 75	27 – 41
fecal – annual %>100	0 – 29	0 – 8

Annual conductivity did not fluctuate much during the four years of sampling. It is difficult to draw conclusions using annual data from this station since samples were collected infrequently during the summer months when flow was reduced, but elevated conductivity does suggest that there are sources of contamination upstream.

A number of beaver dams have been observed upstream of the sampling station and are presumed to be supporting active populations. Beaver populations can be a source of both fecal coliform and of nutrients, but their dams and ponds serve to filter out some contaminants. Beaver in this subbasin are too distant from the reservoir to be considered a threat.

3.36.2 Filter Beds

Waushacum Brook (filter beds) is one of two headwater stations of this tributary and is located upstream of the filter beds in Sterling approximately 1000 yards upstream of the Quag and 1200 yards downstream of the center of town. The stream is only a few feet wide and is often dry during the summer and winter months.

A total of 145 samples have been collected for fecal coliform and conductivity analysis on a weekly basis beginning in 2004. No samples for nutrients, metals, or macroinvertebrates have been collected, and no flow data are available. Samples from this station were collected to help identify any possible contamination in the headwaters of Waushacum Brook.

The Upper Waushacum Brook drainage basin includes the filter beds subbasin as well as Waushacum Brook (Connelly Brook) and Waushacum Brook (West Waushacum Pond) described in Chapters 3.36.1 and 3.36.5. Land use in this drainage basin is similar to the watershed average in most categories, although medium density residential is twice the watershed norm. Much of the dense development is located in the filter beds subbasin, and the area that drains directly to this station is much more developed than the rest of the Upper Waushacum Brook drainage basin.

Annual fecal coliform metrics showed no clear trends during the four year sampling period (Table 140). Fecal coliform concentrations did tend to be lower than at some of the other sampling stations on Waushacum Brook, but this could have been due to the irregularity of sampling during the dry summer months. A comparison of all of the sampling stations on Waushacum Brook will be included in Chapter 3.36.4.

Table 140:
WAUSHACUM BROOK (filter beds) – FECAL COLIFORM AND CONDUCTIVITY

YEAR	88-97	98	99	00	01	02	03	04	05	06	07
fecal – median	n/a							20	10	10	10
fecal – geomean	n/a							23	33	19	22
fecal – %>20	n/a							47	45	31	38
fecal – %>100	n/a							11	26	17	24
(total samples)	0							(38)	(38)	(35)	(34)
conductivity	n/a							630	673	568	563

Water quality metrics at this station were worst during the spring and summer months, with much better water quality during the winter and fall. Wet weather samples were only slightly worse than dry weather samples, much less so than at other stations in the watershed (Table 141).

Table 141:
WAUSHACUM BROOK (filter beds) – FECAL COLIFORM (wet versus dry)

	wet weather samples	dry weather samples
fecal – annual median	7 – 80	5 – 15
fecal – annual geomean	15 – 147	15 – 24
fecal – annual %>20	17 – 77	28 – 43
fecal – annual %>100	0 – 46	6 – 25

Annual conductivity was highest during the first two years of sampling and then dropped in 2006 and 2007. It is difficult to draw conclusions using annual data from this station since samples were collected infrequently during the winter and summer months when flow was reduced, but annual conductivity as high as was recorded at this station suggests a significant source of contamination upstream. There have been a number of repairs of faulty septic system in the center of Sterling. Elevated conductivity could also be the result of runoff from the municipal yard immediately upstream where sand and salt are stored.

Active beaver populations have been observed on Waushacum Brook in the downtown Sterling area and it is assumed that muskrat occupy all of these same areas. A number of beavers were removed in 2007, but more remain. The threat from wildlife to the reservoir from this subbasin is considered low due to the distance from the reservoir and the presence of large downstream water bodies (West Waushacum Pond and the Quag) where bacteria and other contaminants presumably would settle out.

Stormwater problems were identified in this subbasin, but the issues were not determined to be significant due to the substantial travel time to the reservoir.

3.36.3 Fairbanks Street

Waushacum Brook has a large watershed that has been divided into two parts to simplify analysis. The Lower Waushacum Brook subbasin is defined as the watershed contributing to all branches of Waushacum Brook downgradient of West Waushacum Pond. This subbasin is almost evenly divided between the towns of Sterling and West Boylston.

Waushacum Brook emanates from West Waushacum Pond at Gates Road. This pond has a very large contributory area which has been described in Chapters 3.36.1, 3.36.2, and 3.36.5. The brook passes under Gates Road and then continues in a defined channel through a deciduous wooded swamp in the area of Twine and Campground Roads, flowing along and then beneath railroad tracks and eventually south to a culvert under Fairbanks Street where water quality samples were collected.

The sampling station is located just upstream of Fairbanks Street on the West Boylston/Sterling line approximately 1000 yards upstream of the primary sampling station on Prescott Street and 1200 yards downstream of West Waushacum Pond. The stream is only a few feet wide but contains water throughout the year. A total of 201 samples have been collected for fecal coliform and conductivity analysis on a weekly basis beginning in 2004. No samples for nutrients, metals, or macroinvertebrates have been collected, and no flow data are available.

A total of 115 samples were previously collected for fecal coliform and conductivity analysis in 1992, 1993, and 1995.

The Lower Waushacum Brook subbasin consists of 1691 acres of forest and open land (61%), residential development (24%), agriculture (7%), open water and wetlands (5%), and small amounts of commercial and industrial development (3%). Most land uses in the basin are similar to the watershed average, although residential development is significantly higher. Percent impervious cover (8.2%) higher than average and impacts from non-point source runoff and increased stormwater pollution are possible. Land use close to the tributary is similar to that noted throughout the subbasin. It should be noted that much of the water in the main branch of Waushacum Brook that flows through the Fairbanks Street station originates in the Upper Waushacum subbasin and enters the Lower Waushacum subbasin as discharge from West Waushacum Pond. The pond presumably acts as a settling basin and likely removes a significant percentage of the pollutants.

Annual fecal coliform metrics have been very stable throughout the four years of sampling and similar to historic values recorded during the 1990s (Table 142). Seasonally grouped samples exhibited noticeable differences at this station, with fecal coliform concentrations lowest in the winter, higher in the spring and fall, and highest during the summer. Water quality was also impacted by weather conditions, although the differences were not as pronounced as they were at many others tributaries in the watershed. Seventeen percent of dry weather samples and twenty-nine percent of wet weather samples contained more than 100 cfu/100mL. Forty-two percent of dry weather samples contained more than 20 cfu/100mL as did sixty-one percent of wet weather samples

Table 142:
WAUSHACUM BROOK (Fairbanks) – FECAL COLIFORM AND CONDUCTIVITY

YEAR	88-97	98	99	00	01	02	03	04	05	06	07
fecal – median	9-26							20	20	20	20
fecal – geomean	n/a							25	30	22	23
fecal – %>20	32-53							49	47	41	44
fecal – %>100	4-18							14	22	18	20
(total samples)	(201)							(49)	(51)	(51)	(50)
conductivity	154-207							406	397	378	333

Annual conductivity has dropped each year since reaching a historic maximum in 2004, but remains significantly higher than was measured during the previous decade. Annual conductivity data can be influenced by fluctuations in total rainfall and frequency of winter storm events, so annual data were closely examined to look for multiple year periods with relative stability that could be summarized and used to identify trends. The periods of 1988-1992 and 2006-2007 exhibited little change throughout the watershed and have been used for this purpose. The increase in conductivity from 1988-1992 to 2006-2007 at this sampling station was 131%, greater than what was observed at most watershed stations during the same period.

A survey for beaver and muskrat populations found several sites within this subbasin where these mammals were present. Two beaver and a large dam were removed from Waushacum Brook just upstream of Fairbanks Street in the spring of 2002. There are still active beaver sites all along Waushacum Brook from Gates Road to Prescott Street. Beavers are active around the area of the railroad tracks at Campground Road and Twine Road where they are constantly damming the culvert that flows under the tracks. They have caused property damage in this vicinity and are a likely source of fecal coliform contamination of Waushacum Brook.

Most of the residential development found in the Waushacum Brook subbasin was constructed prior to 1978 and are presumed to have antiquated septic systems such as cesspools. The most egregious is a neighborhood of homes on small parcels with a long history of septic system problems. The Sterling Campground area is similar to a condominium association in that the houses are owned by individuals but the land is owned by the Campground Meeting House Association. There are approximately seventy-five dwellings on fifty acres of commonly owned land, but the dwellings are concentrated in an area of approximately twenty acres, each on a parcel of a quarter acre or less. Additional growth in this neighborhood is unlikely, but the overcrowding has already led to problems with septic systems and stormwater runoff.

Although there are some obvious threats to water quality in this subbasin, few problems have been noted. The presence of beaver, while adding a source of fecal coliform, also helps to slow transport of certain pollutants downstream. Multiple stations on Waushacum Brook have not identified any major source of pollutants, and all but the primary station (described in Chapter 3.36.4) will be eliminated from routine sampling in the future.

3.36.4 Prescott Street

Waushacum Brook (Prescott Street) is the primary sampling station on this tributary and except for 1991 has been sampled regularly each year starting in 1988. Samples have also been collected regularly from four other sampling stations each year since 2004. Data from these upstream stations are compared and contrasted with data from the primary station in this chapter and are also discussed in greater detail in Chapters 3.36.1, 3.36.2, 3.36.3, and 3.36.5.

The sampling station is located in West Boylston downstream of Prescott Street, approximately 500 yards from the shore of the Stillwater Basin at the extreme northern end of the reservoir. The stream is slightly more than six feet in width at this sampling location and has just passed through a 48-inch culvert. A beaver dam was constructed just upstream of this sampling station in 1994. A total of 501 samples were collected for fecal coliform and conductivity analysis on a weekly basis for the past ten years. No samples for nutrients or metals were collected during that period, and no flow data are available. Macroinvertebrate sampling was done in May 2001 after the beaver dam was breached.

A total of 320 samples were previously collected for fecal coliform and conductivity analysis between 1988 and 1997. Macroinvertebrate samples were collected from this tributary in 1988, 1989, 1990, 1994, and 1996, but sampling was curtailed briefly due to the construction of a beaver dam and the subsequent decline in habitat.

Waushacum Brook has a large watershed that has been subdivided to simplify analysis. The Lower Waushacum Brook subbasin is defined as the watershed contributing to all branches of Waushacum Brook downgradient of West Waushacum Pond. This subbasin is almost evenly divided between the towns of Sterling and West Boylston. The Lower Waushacum Brook subbasin consists of 1691 acres of forest and open land (61%), residential development (24%), agriculture (7%), open water and wetlands (5%), and small amounts of commercial and industrial development (3%). Most land uses in the basin are similar to the watershed average, although residential development is significantly higher. Percent impervious cover (8.2%) higher than average and impacts from non-point source runoff and increased stormwater pollution are possible. Land use close to the tributary is similar to that noted throughout the subbasin. It should be noted that much of the water in the main branch of Waushacum Brook originates in the Upper Waushacum subbasin and enters the Lower Waushacum subbasin as discharge from West Waushacum Pond. The pond presumably acts as a settling basin and likely removes a significant percentage of the pollutants. The southern branch of Waushacum Brook receives runoff from a large percentage of the agricultural land in the subbasin.

Annual fecal coliform metrics have been relatively stable throughout the final nine years of this latest ten year period (Table 143). All metrics were elevated in 1998 but improved the following year. This improvement continued a trend previously observed at this sampling station. Fecal coliform data grouped into five-year intervals has been improving for twenty years. Median fecal coliform in the four five-year intervals has improved from 31 to 26 to 19 to a low of 18. The percentage of samples exceeding 20 cfu/100mL has dropped from 58 to 55 to 46 to 40.

Table 143:
WAUSHACUM BROOK (Prescott Street) – FECAL COLIFORM AND CONDUCTIVITY

YEAR	88-97	98	99	00	01	02	03	04	05	06	07
fecal – median	16-47	29	17	18	10	20	20	10	20	20	20
fecal – geomean	n/a	27	15	14	16	19	20	14	23	23	19
fecal – %>20	49-71	58	44	49	35	43	44	31	44	47	37
fecal – %>100	0-21	20	8	6	10	6	10	4	8	8	10
(total samples)	(320)	(50)	(50)	(51)	(52)	(49)	(50)	(49)	(50)	(51)	(49)
conductivity	162-262	224	260	267	435	420	454	400	381	376	364

Fecal coliform concentrations were generally low during the winter and early spring, and then increased significantly in the late spring. This pattern is common to many of the tributaries within the Wachusett watershed and is probably the result of concentration of contaminants due to lower flows. Fecal coliform concentrations did not continue to rise during the summer, however, with spring and summer metrics nearly identical. Fecal coliform did not always drop noticeably in the fall, which is also different than most tributaries. Elevated levels of fecal coliform were recorded occasionally throughout the year, often in association with storm events. Beavers have also been intermittently active just upstream from this sampling site which could certainly impact fecal coliform concentrations.

Seasonally grouped samples exhibited significant differences but the pattern was unlike that seen at many of the other sampling stations in the Wachusett watershed. Fecal coliform metrics in the spring and summer were very similar (Table 144). Water quality was also strongly impacted by weather conditions, with twenty-six percent of all wet weather samples but only five percent of dry weather samples exceeding 100 cfu/100mL.

Table 144:
WAUSHACUM BROOK (Prescott Street) – RANGE OF SEASONAL METRICS

	WINTER	SPRING	SUMMER	FALL
fecal – median	5 – 12	20 – 85	20 – 70	5 – 30
fecal – geomean	3 – 11	18 – 83	23 – 61	8 – 25
fecal – %>20	0 – 15	46 – 92	38 – 92	0 – 55
fecal – %>100	0 – 8	0 – 31	8 – 31	0 – 17

The overall percentage increase in conductivity noted was higher than the average observed at the ten tributaries continuously monitored from 1988 through 2007. Annual conductivity values were much higher in 2001, 2002, and 2003, but conductivity increased at all stations during these years. These increases have been linked to the use of a new field conductivity meter during that three year period. Annual conductivity at most stations in the watershed dropped significantly following a return to the original monitoring equipment, but dropped more slowly at this station.

The mean conductivity in Waushacum Brook for the current ten year period was 88% higher than for the previous ten year period, considerably more than the average watershed increase of 56% at the ten tributaries that have been sampled consistently for the past twenty years. Years with little rainfall often result in higher conductivities due to low flow conditions, and winter storm events can lead to elevated levels due to the application of salt on icy roadways, so the use of annual statistics for conductivity can be misleading. Annual data were searched carefully for periods of relative stability and annual conductivity and then grouped and summarized. The periods of 1988-1992, 1998-2000, and 2006-2007 exhibited little change throughout the watershed and were therefore used to detect trends. The increase in conductivity at the ten tributaries continuously monitored from the earliest period (88-92) to the latest (06-07) was 83%. The increase in Waushacum Brook was 120% which confirms a significant decline in water quality.

Macroinvertebrate samples collected in May of 1988, 1989, and 1990 showed slight to moderate impairment when compared to the reference station. Samples from 1994 and 1996 showed severe impairment, with reduced numbers of both total taxa and pollution-intolerant EPT (mayflies, stoneflies, and caddisflies), an elevated HBI score, increased presence of tolerant chironomid midges compared to intolerant EPT organisms, and an unbalanced population (percent dominance). The construction of a beaver dam immediately upstream of the sampling station in 1994 appears to have had a strong negative impact on water quality as it relates to the macroinvertebrate community.

There was a significant change in the macroinvertebrate population that reflects the gradual conversion of upstream stream habitat to a beaver pond. The dominant taxa for the first two sampling seasons included the omnivorous mayfly *Ephemerella* and two predators, the large stonefly *Paragnetina*, and a free-living caddisfly *Rhyacophila fuscula*. In 1990 the most common taxa observed were the mayflies *Baetis* and *Pseudocleon*, the predaceous stonefly *Isoperla*, and chironomid midges. The mayflies and chironomids are collector feeders, as are young instars of *Isoperla*. Collectors are often found to dominate the macroinvertebrate community below a pond outlet, utilizing algae and detritus as a food source.

No mayflies were collected in 1994. The two dominant species, which made up almost eighty percent of the community, were the small stonefly *Amphinemura nigritta* and the black fly *Simulium venustum*. Both are collectors and are generally more tolerant of organic pollution and low dissolved oxygen concentrations than the other species which had been found previously. A single mayfly was observed in 1996, with the community dominated by tolerant species including the filter-feeding caddisfly *Hydropsyche betteni*, chironomid midges, and black flies. Measurement of dissolved oxygen levels during the study period found average percent saturation in 1990 and 1992 of almost ninety percent. By 1995 the average percent saturation was only sixty-three percent, with single measurements as low as nineteen percent. Similar values were recorded in 1996 as well.

Following removal of the beaver dam, the macroinvertebrate population improved. Mayflies and other pollution-intolerant taxa were collected in 2001 and the tributary was upgraded to moderately impaired (Table 145).

Table 145:
WAUSHACUM BROOK (Prescott Street) – MACROINVERTEBRATE ASSESSMENT

YEAR	TAXA	EPT	EPT/chiro	HBI	% DOMIN	IMPAIRMENT
1988	21	14	24	1.78	46	slight
1989	14	9	29	1.94	20	moderate
1990	23	14	7	2.80	15	slight
1994	12	4	7	3.62	45	severe
1996	12	4	4	4.77	33	severe
2001	13	8	30	4.14	39	moderate
88-01	**19-30**	**12-22**	**14 - >100**	**0.98-1.62**	**16-28**	**REF STATION**

Waushacum Brook has a large watershed with a variety of potential threats including agriculture, wildlife, untreated stormwater runoff, and poorly functioning septic systems. Waushacum Brook (Prescott Street) is the primary sampling station on this tributary but samples have also been collected regularly from four other sampling stations beginning in 2004 to help identify actual sources of contamination.

Samples from the five stations show only minor differences in water quality (Table 146). The annual geometric mean fecal coliform concentration is lowest at the West Waushacum Pond station because the pond acts as a settling basin and removes many of the pollutants. Water quality is not as good at the Fairbanks Street and filter beds sampling stations because these are closer to sources of contamination, but the differences are not significant. The presence of numerous ponds and wetlands in the subbasin helps restrict the transport of pollutants and keeps downstream water quality from declining.

Table 146:
WAUSHACUM BROOK – FECAL COLIFORM (geometric mean at all stations)

	2004	2005	2006	2007
Prescott Street	14	23	23	19
Fairbanks Street	25	30	22	23
West Waushacum Pond	9	11	7	9
filter beds	23	33	19	22
Connelly Brook	12	23	22	15

The lack of variability between sampling stations suggests that monitoring water quality at the primary station is sufficient to document problems in this subbasin that threaten the reservoir.

Even though sampling in this subbasin can probably be curtailed at all but the primary station without jeopardizing protection efforts, it is clear that there are a number of threats that could potentially impact downstream resources especially if wetlands were damaged. There are a number of large agricultural operations in the subbasin, but all have been inspected and most are not considered a threat to water quality at this time. Inspections will continue on a regular basis. There are a number of active wildlife populations in this subbasin, and both wastewater and stormwater remain significant problems. The Division should remain aware of all issues and readdress any significant threats during the next environmental quality assessment of the area, currently scheduled for 2010.

3.36.5 West Waushacum Pond

This sampling station is located in the middle of the Waushacum Brook subbasin at the outlet of West Waushacum Pond. The land upstream of the sampling station is called the Upper Waushacum subbasin; downstream is known as the Lower Waushacum subbasin. Much of the water in the main branch of Waushacum Brook flows through West Waushacum Pond which serves as a natural settling basin and likely removes a significant percentage of any pollutants.

Samples are collected just downstream of the bridge over Gates Road, although beaver activity in the brook sometimes necessitates shifting the station location slightly to allow safe access. The stream is between ten to thirty feet wide depending upon the amount of flooding. A total of 201 samples were collected for fecal coliform and conductivity analysis on a weekly basis beginning in 2004. No samples for nutrients, metals, or macroinvertebrates have been collected, and no flow data are available.

The Upper Waushacum Brook subbasin includes the West Waushacum Pond subbasin as well as the Connelly Brook and filter beds subbasins described in Chapters 3.36.1 and 3.36.2. Land use in this basin is similar to the watershed average in most categories, although medium density residential is twice the watershed norm. Much of the West Waushacum Pond subbasin consists of protected open space, however, and there is very little development of any kind.

Table 147:
WAUSHACUM BROOK (WWPond) – FECAL COLIFORM AND CONDUCTIVITY

YEAR	88-97	98	99	00	01	02	03	04	05	06	07
fecal – median	n/a							5	5	5	5
fecal – geomean	n/a							9	11	7	9
fecal – %>20	n/a							16	18	12	18
fecal – %>100	n/a							4	12	0	0
(total samples)	0							(49)	(51)	(51)	(50)
conductivity	n/a							415	409	378	359

Annual fecal coliform metrics showed no clear trends during the four year sampling period (Table 147). Fecal coliform concentrations were the lowest of all of the sampling stations on Waushacum Brook, probably due to the settling effects of the pond and to the lack of threats in the subbasin. A comparison of all of the sampling stations on Waushacum Brook was included in Chapter 3.36.4.

Seasonally grouped samples showed only minor differences, with fecal coliform concentrations slightly elevated (but still low) during the summer months. Water quality was only slightly impacted by weather conditions as well. This was one of only a few stations in the watershed that did not exhibit strikingly higher fecal coliform concentrations during wet weather. Only nineteen percent of all wet weather samples and sixteen percent of dry weather samples exceeded 20 cfu/100mL.

Annual conductivity was highest during the first two years of sampling and then dropped in 2006 and 2007. It is difficult to draw conclusions using annual data from this station over a short period of time, but annual conductivity this high suggests a significant source of contamination upstream. There have been a number of repairs of faulty septic system in the center of Sterling. Elevated conductivity could also be the result of runoff from the municipal yard upstream where sand and salt are stored. West Waushacum Pond has the ability to remove certain particulate contaminants, but would have little effect on the dissolved salts that increase conductivity.

Water quality in this subbasin is very good even though there are a number of possible sources of contamination. Active beaver populations have been observed and it is assumed that muskrat occupy all of these same areas. There is clear evidence of dog walking around the pond even though the activity is currently prohibited. Stormwater problems were identified in the subbasin but the issues were determined to be insignificant due to the substantial travel time to the reservoir. The threat from wildlife to the reservoir is also considered low due to the distance from the reservoir and the filtering ability of West Waushacum Pond.

3.37 WEST BOYLSTON BROOK

West Boylston Brook flows into the reservoir from the southwest, passing under railroad tracks and Route 12. Flow originates in a series of wetlands with additional inputs from the stormwater drainage system and passes through a large area of dense residential development.

Water quality samples were collected approximately 100 yards from the shore of the reservoir inside of Gate 25.

This tributary was sampled just downstream of a culvert that carries flow under the railroad tracks near the West Boylston municipal yard. The brook is four feet wide and has a sandy bottom. There is often an odor of petroleum present. A staff gage and v-notch weir is located at the sampling station and the USGS regularly updates rating curves to enable calculation of flow.

Samples have been collected biweekly or weekly for fecal coliform and conductivity for the past nineteen years. A total of 517 samples were collected weekly during the past ten years. An additional 333 were collected from 1989 through 1997. There have been fifty-six samples for nitrate-nitrogen and total phosphorus collected since 1998, and macroinvertebrate samples were collected from this tributary in May of 1998 and 2001 but not previously due to problems with low flow and inadequate habitat. Samples for metals analysis were taken in 1992 and 1996.

The West Boylston Brook subbasin consists of 258 acres of forest and open land (35%), residential development (44%), agriculture (11%), commercial and industrial development (3%), and a large area of open water and wetlands (7%). Nearly half of the residential development is identified as medium density development. The subbasin has one of the lowest percentages of forested and open land in the watershed and the percent impervious cover of 14.6% is one of the highest in the watershed and nearly three times the watershed average. Unmanaged stormwater runoff is a problem. Mean wet weather turbidity (2.9 NTU) is more than four times higher than mean dry weather turbidity (0.67 NTU) in West Boylston Brook.

Fecal coliform concentrations were uniformly high throughout the year through 1996, with an annual median value in excess of 60 colonies per 100mL each year. Water quality was the worst of all Wachusett tributaries. Many Wachusett tributaries with high fecal coliform concentrations showed a strong seasonal pattern, with lower concentrations observed during the winter, early spring, and late fall and higher concentrations occurring during the summer. The lack of seasonal differences prior to 1997 suggests a constant source of contamination to the brook.

Table 148:
WEST BOYLSTON BROOK – FECAL COLIFORM AND CONDUCTIVITY

YEAR	88-97	98	99	00	01	02	03	04	05	06	07
fecal – median	31-100	31	37	40	50	40	30	50	60	70	60
fecal – geomean	n/a	39	33	61	48	40	49	48	64	55	70
fecal – %>20	66-98	56	66	69	63	55	59	65	74	74	69
fecal – %>100	24-47	36	22	38	31	33	22	32	30	33	39
(total samples)	(333)	(50)	(50)	(52)	(52)	(49)	(51)	(57)	(53)	(54)	(49)
conductivity	339-566	429	469	442	660	620	618	578	595	629	671

Fecal coliform concentrations in 1997 and beyond more closely matched the pattern seen in most Wachusett watershed tributaries. Concentrations were elevated during the summer when flows were reduced and were lower during the spring, fall, and winter. Annual median values were considerably lower than they had been. There appears to have been a sharp reduction in the amount of fecal coliform reaching the brook, which coincided with a focused effort to repair or replace inadequate septic systems. Annual median fecal coliform then began to increase following 2003, at the same time that the first homes began to connect to the new municipal sewer. It was initially thought that elimination of groundwater recharge led to the reduction of flow in this tributary and the concentration of contaminants, but annual flows actually increased in 2004 and remained high for the following three years. A third of the homes were connected to the sewer in 2005 and two thirds connected by the end of 2007. Annual median fecal coliform concentrations were 60 colonies per 100mL or higher in each of the past three years (Table 148).

In addition to the increasing annual metrics, seasonal patterns of fecal coliform concentrations also changed. Seasonal differences were barely noticeable during 2007, with geometric means of samples collected during the winter, spring, and fall nearly identical and all higher than the geometric mean of samples collected during the summer months. It is not clear what has caused this decline in water quality and why the high percentage of sewer connections has not resulted in a noticeable improvement.

Seasonally grouped samples exhibited noticeable differences at this station over the ten year period (Table 149), but as noted previously this was not the case during 2007 nor prior to 1997.

Table 149:
WEST BOYLSTON BROOK – SEASONAL METRICS

	WINTER	SPRING	SUMMER	FALL
fecal – geomean (range)	6 – 75	25 – 134	51 – 328	11 – 109
fecal – geomean (average)	30	62	156	41
fecal – %>100 (range)	0 – 43	0 – 54	23 – 77	0 – 36
fecal – %>100 (average)	16	30	57	22

Fecal coliform concentrations of wet weather samples at this station were much higher than those of dry weather samples. The difference was not clearly illustrated by the percentage of samples that contained more than 20 cfu/100mL because so many samples (more than sixty percent) exceeded this threshold. More than sixty percent of wet weather sample contained more than 100 cfu/100mL as well, while only twenty-two percent exceeded this threshold. Other metrics illustrated below in Table 150 clearly illustrate the decline in water quality during wet weather.

Table 150:
WEST BOYLSTON BROOK – FECAL COLIFORM (wet versus dry)

	wet weather samples	dry weather samples
fecal – annual median	40 – 530	16 – 60
fecal – annual geomean	62 – 484	22 – 57
fecal – annual %>20	60 – 100	41 – 77
fecal – annual %>100	31 – 100	10 – 32

The mean conductivity in West Boylston Brook for the current ten year period was 38% higher than for the previous ten year period, considerably less than the average watershed increase of 56% as determined by using ten tributaries that have been sampled consistently for the past twenty years. This is not indicative of a tributary with better water quality than others but is more likely a reflection of the very high conductivity that has been the norm since sampling began in the 1980s. Even with a smaller than average increase the conductivity in West Boylston Brook is higher than all other tributaries in the watershed except Gates Brook.

Years with little rainfall often result in higher conductivities due to low flow, and winter storm events can lead to elevated levels due to the application of salt on icy roadways, so the use of annual statistics for conductivity can be misleading. Annual data were examined to look for periods of relative stability and annual conductivity then grouped and summarized. The periods of 1988-1992, 1998-2000, and 2006-2007 exhibited little change throughout the watershed and were therefore used to detect trends. The increase in conductivity at the ten tributaries continuously monitored from the earliest period (88-92) to the latest (06-07) was 83%. The overall increase in West Boylston Brook was only 75% and initially did not appear indicative of any unusual problem.

There was a noticeable increase in conductivity in 2001, 2002, and 2003, but conductivity increased at all stations during these years. These increases have been linked to the use of a new field conductivity meter during that three year period. Annual conductivity at this and most other stations declined following a return to an earlier piece of monitoring equipment, but conductivity has increased each year since 2004 and reached a historic maximum in 2007.

Fifty-six samples for nitrate-nitrogen and total phosphorus were collected from West Boylston Brook at irregular intervals (2-11 times per year) from 1999 through 2007. Annual mean concentrations of nitrate-nitrogen were among the highest in the watershed each year, while annual mean concentrations of total phosphorus were usually very low (Table 151). The annual mean concentrations of total phosphorus slightly exceeded the EPA recommended limit of 0.05

mg/L in 2005, and individual samples were higher during 1999, 2001, and 2005. Each of the five samples containing elevated concentrations of total phosphorus were collected during or immediately following storm events. It is clear that stormwater runoff is an issue in this subbasin.

Table 151:
WEST BOYLSTON BROOK – NUTRIENT MEAN CONCENTRATIONS (mg/L)

	1999	2000	2001	2002	2003	2004	2005	2006	2007
Nitrate-nitrogen	2.41	3.18	2.88	1.95	3.40	2.93	1.95	2.21	2.05
Total phosphorus	0.030	0.019	0.032	0.018	0.031	0.018	0.051	0.018	0.025

Metals samples collected in 1992 detected aluminum (0.11 mg/L), zinc (0.032 mg/L), and lead (0.004 mg/L). Monthly samples collected for iron during 1996 found an annual mean concentration in the book of 0.39 mg/L. No additional sampling for metals has been done or is planned for the future.

Macroinvertebrate samples were collected in May of 1998 and 2001 using a standard one-minute kick technique. Samples collected each year showed extreme impairment when compared to the reference station (Table 152). Less than half as many total taxa were present as in the reference stream and many of those were chironomid midges that are very tolerant of pollution. A lack of adequate habitat certainly has an impact on macroinvertebrate populations in West Boylston Brook, but so do elevated turbidity during storm events, high concentrations of nitrates and fecal coliform, and the likely presence of additional contaminants from residential areas and roadways.

Table 152:
WEST BOYLSTON BROOK – MACROINVERTEBRATE ASSESSMENT

YEAR	TAXA	EPT	EPT/chiro	HBI	% DOMIN	IMPAIRMENT
1998	12	5	0.5	4.44	59	extreme
2001	11	6	0.4	4.71	65	extreme
88-01	19-28	13-19	10 - >100	1.02-1.62	14-41	REF STATION

A special study of West Boylston Brook was done previously in 1994 and 1995 as part of a detailed investigation of the subbasin. Twenty sampling locations on the brook and from the contributory storm drainage system were utilized to pinpoint sources of fecal contamination. Specific problematic septic systems were identified, and well as locations of both wild and domestic animal sources. Drainage patterns in the subbasin were mapped and used to help determine pathways of contamination. A concentrated remediation effort was initiated, with a combination of septic system repairs or replacement, a proposal for municipal sewers, stormwater improvements, and proposed agricultural setbacks for livestock. It is believed that this effort was eventually responsible for the improvement noted in this tributary. Additional studies have been done more recently using alternative indicators to help locate the latest source of contamination, but no conclusive results have been developed.

Agricultural sites within the subbasin are not considered threats to water quality. There is good habitat for both beaver and muskrat, but no animals or sign have been located recently and wildlife is unlikely to be a significant source of contamination. Two thirds of the homes in the subbasin have been connected to the sewer, and an earlier effort was made to repair failing septic systems, but continued efforts are necessary to remove any remaining wastewater problems.

Stormwater runoff remains the most important issue in this subbasin, due to the high percentage of older residential development and lack of large amounts of forest or open space. An earlier stormwater study recommended installation of sewers and the construction of an extended detention wet pond between Route 12 and the railroad tracks. The wet pond would have allowed pollutants to settle and associated wetland vegetation would have naturally removed contaminants as well. A forebay was proposed to pretreat runoff from the West Boylston Highway Department facility. Sewers have been constructed but the pond and forebay were never built due to lack of available land and high expected costs. An in-reservoir best management practice similar to the filter curtain used in Gates and Malagasco basins was also considered but never installed.

3.38 WILDER BROOK

The Wilder Brook subbasin is located entirely within the town of Sterling. The brook originates on the side of Rowley Hill and flows down a steep slope before passing through a number of residential areas and Division land, traveling behind a number of homes and under driveways before flowing under Wilder Road. Wilder Brook then passes through a large wetland and discharges into the Stillwater River north of Route 62.

Water quality samples were collected just downstream of Wilder Road, about 1000 yards before it meets the Stillwater River. The stream is less than three feet in width at this sampling location and dries up during the summer months. It also sometimes freezes completely during the winter. A total of 164 fecal coliform and conductivity samples were collected weekly in 1998 – 2000 and 2004 – 2007. No samples for nutrients or metals were collected from this station during the ten year sampling period, and macroinvertebrate sampling was not done because of low flows and inadequate habitat.

Fifty-seven samples were collected previously at this station during 1989, 1992, 1993, and 1995 although sampling was very irregular due to lack of flow and less than twenty samples were collected during three of the four years.

The Wilder Brook subbasin contains 831 acres of forests and open land (54%), low and medium density residential development (28%), agriculture (15%), and a small amount of open water and wetlands (2%). Both residential development and agriculture are present at more than twice the watershed average, with only slightly more than half of the subbasin remaining undeveloped.

The percentage of impervious cover is nearly identical to the watershed average even with the large amount of residential development present because much of the residential development consists of single family homes on large parcels.

Fecal coliform concentrations in Wilder Brook are high but erratic. Annual statistics are difficult to interpret due to variations in flow from year to year. Wilder Brook dries up each summer, and the length of time with no flow has a significant effect on annual data since fecal coliform levels are usually highest during the warmer months. This brook often freezes solid during the colder months, and the length of time without flow during the winter is also significant. Concentrations are often lowest during the winter and early spring, but if the tributary is frozen there can be no data collected during those times.

Water quality during the past ten years appears to have improved slightly over the previous ten year period (Table 153), but as indicated above this could simply be a factor of sample number and collection season. Water quality as measured by fecal coliform concentration has been poor enough historically to lead to an investigation of the brook. Samples were collected at numerous locations along the tributary during storm events and during dry weather in an attempt to isolate the source of fecal coliform. The original focus was on septic systems located close to the brook, but dogs and wildlife were eventually suggested as an alternative source of contamination.

Table 153:
WILDER BROOK – FECAL COLIFORM AND CONDUCTIVITY

YEAR	88-97	98	99	00	01	02	03	04	05	06	07
fecal – median	25-132	16	8	23				25	30	20	20
fecal – geomean	n/a	20	9	21				36	37	34	31
fecal – %>20	50-77	38	29	54				50	50	43	47
fecal – %>100	27-54	27	14	17				27	23	26	12
(total samples)	(57)	(26)	(14)	(24)				(22)	(26)	(35)	(17)
conductivity	85-109	89	61	114				127	132	110	129

Due to the irregularity of sample collection, assessment of seasonally grouped samples was not realistic, although it is likely that water quality was much poorer during the summer months. Differences in fecal coliform concentrations due to weather conditions were very clear, however. Fifty-seven percent of all wet weather samples contained more than 100 cfu/100mL. Only nine percent of dry weather samples contained more than 100 cfu/100mL. Annual median and annual geometric mean show similar differences (Table 154).

Table 154:
WILDER BROOK – FECAL COLIFORM (wet versus dry)

	wet weather samples	dry weather samples
fecal – annual median	50 – 3000	4 – 22
fecal – annual geomean	68 – 3000	5 – 24
fecal – annual %>20	60 – 100	18 – 53
fecal – annual %>100	33 – 100	0 – 18

Conductivity measurements were uniform throughout the year, with only minor increases from historic levels. Conductivity at this station was lower than at many other stations in the watershed, but missing summer data make assessment difficult. Low conductivity measurements recorded with elevated fecal coliform concentrations are usually indicative of a contamination source other than septic systems or sewers. Wildlife, farm animals, and dogs have been suggested as possible sources of contamination.

4. PARAMETER SUMMARIES

4.1 FECAL COLIFORM SUMMARY

Tributaries in the Wachusett watershed were ranked using four different fecal coliform metrics, annual median, annual geometric mean, and the percentage of weekly samples that exceeded 20 cfu/100mL or 100 cfu/mL each year. Not every station was sampled each year and a direct comparison of each of the sixty-one stations could not be done, but some very clear trends were established.

The stations with the worst water quality as measured by fecal coliform were Asnebumskit Brook (Princeton Street), all four stations on Beaman Pond Brook, five of the six stations on Gates Brook, West Boylston Brook, Oakdale Brook, Cook Brook, and both stations on Scarlet Brook. Each of these stations is located in a densely developed residential neighborhood with a history of septic system problems and uncontrolled stormwater runoff, and all but Asnebumskit Brook and Cook Brook are in the town of West Boylston.

Table 155:
WORST WATER QUALITY – FECAL COLIFORM

STATION	annual median	annual geomean	% samples >20	% samples >100
Asnebumskit Brook (Princeton Street)	206	184	78	58
Beaman Pond Brook (1)	87	63	69	39
Beaman Pond Brook (2)	57	47	60	31
Beaman Pond Brook (3)	77	71	64	41
Beaman Pond Brook (3½)	96	79	69	42
Cook Brook	36	40	56	25
Gates Brook (2)	50	59	68	32
Gates Brook (3)	41	48	64	28
Gates Brook (4)	62	68	73	37
Gates Brook (6)	70	69	68	41
Gates Brook (9)	36	36	55	27
Oakdale Brook	42	42	61	30
Scarlett Brook	29	33	53	23
Scarlett Brook (Route 12)	29	39	58	26
West Boylston Brook	47	51	65	32

Stations with good to excellent water quality included Bailey Brook, Justice Brook, Unnamed Brook, Landfill Brook, Rocky Brook (East Branch), Trout Brook, Cold Brook, Governor Brook, Scanlon Brook, Quinapoxet River (Mill Street), East Wachusett Brook (Route 31), two stations on Keyes Brook, Chaffins Brook (Unionville Pond), and Waushacum Brook (Waushacum Pond). These stations are generally located in undeveloped areas distant from the reservoir with limited sources of bacterial contamination. Three of the stations are immediately downstream of ponds which often tend to filter out many contaminants.

Bacteria concentrations tend to be much higher during or immediately following rain events at nearly all sampling stations. In many years, the median of storm impacted samples from Cook Brook, West Boylston Brook, all six stations on Gates Brook, and many of the Chaffins Brook stations was more than twenty times higher than the median of dry weather samples. Very large differences between wet weather and dry weather samples were noted at Jordan Farm Brook and Asnebumskit Brook (Mill Street) during each of the past three years and intermittently from Scarlett Brook and both stations on the Stillwater River.

Although significant impacts from storm events were common, there were a number of stations where median and geometric mean values of wet weather samples were similar to those of dry weather samples. Stations with very low bacteria concentrations and limited sources of bacterial contamination often did not show impacts from storm events. Ball Brook, Justice Brook, Hastings Cove Brook, Rocky Brook (East Branch), Cold Brook, Keyes Brook (Onion Patch), East Wachusett Brook (Route 31), and stations on Waushacum Brook fit this profile.

Four stations with poor water quality did not show impacts from storm events. Boylston Brook, Asnebumskit Brook (Princeton Street), Keyes Brook (Gleason), and Malagasco Brook contained elevated concentrations of fecal coliform during both dry and wet weather, suggesting a constant source of contamination.

Seasonal patterns were also very clear at most stations. Samples collected during the winter months (January-March) usually had the lowest concentrations of fecal coliform each year. Concentrations were higher in the spring and reached their highest during the summer months (July-September) before dropping in the fall. A reduction in stream flow during hot, dry weather likely causes the increase in fecal coliform concentrations. Although this pattern was the norm, there were a few stations where bacteria concentrations did not increase during the summer. Rocky Brook (East Branch) almost never contained many bacteria and concentrations remained extremely low throughout each year. The same was true at Chaffins Brook (Unionville Pond) where the buffering effect of the upstream pond also played a role. There was no increase during the summer in Wilder Brook in most years, but that was because this stream usually dries up and samples were not often collected during the summer months. This latter example illustrates the difficulty of looking at annual data without understanding exactly when and how many samples were collected each year. Annual data are not always representative of what is truly happening in the brook.

Samples collected from Gates Brook (1) also showed no strong seasonal trends, with all metrics similar during each of the four seasons. All other stations on Gates Brook exhibited the standard pattern with greatly elevated fecal coliform concentrations in the summer. Most other stations on Gates Brook showed significant variability from one year to the next, with annual medians ranging from 19 cfu/100mL to 115 cfu/100mL, but the annual median at Gates (1) remained between 10 cfu/100mL and 30 cfu/100mL. Gates Brook travels though a substantial area of undeveloped protected land that appears to remove bacteria between Gates (2) and Gates (1) and helps buffer the impacts of upstream contamination.

Stations that showed the greatest seasonal differences included Houghton Brook, Asnebumskit Brook (Princeton Street), Gates Brook (6), and the Stillwater River (steel bridge). The annual geometric means of winter samples at Asnebumskit Brook (Princeton Street) were always less than 100 cfu/100mL and usually less than 35 cfu/100mL, while the annual geometric means of summer samples were always greater than 350 cfu/100mL. Geometric mean values from the spring and fall were also much higher than those from the winter, but were considerably lower than summer values. No conclusive source of fecal coliform has yet been identified at this station.

Regardless of seasonal or weather related influences, there are some obvious trends when annual water quality data are grouped together. Fifty-four stations were sampled for several years during the most recent ten-year period and nine of them exhibited signs of improving water quality. Four stations had declining water quality, and forty-one neither improved nor declined. Sampling at seven additional stations was discontinued after two years of documenting good water quality.

Asnebumskit Brook (Princeton Street) improved significantly over the ten year period with much lower annual median fecal coliform in three of the past four years. Thirty-four new connections to the municipal sewer system likely helped, although water quality remains poor. Conductivity is lower than at most polluted stations, however, and the remaining sources of contamination are probably not human.

Three stations on Beaman Pond Brook showed improving water quality. The small contributing subbasin is now 36% sewered and problems at an agricultural site have been partially resolved. Two stations on Chaffins Brook also showed signs of improvement. Many of the homes in the area have been connected to the sewer, and water quality at all four stations on the brook is good.

Two stations on Gates Brook exhibited signs of improvement, especially between 2002 and 2006. Prior to this period less than 10% of the homes in the subbasin were connected to the sewer. Nearly half of the homes were connected by the end of 2002, and almost 75% had hooked up by the end of 2006. Stormwater controls were included in the sewer construction project, and wet weather water quality did improve at Gates 6 and Gates 9. Both stations showed an overall decline in water quality in 2007, however, highlighted by an extended period of elevated fecal coliform that began in May and extended through October. Annual average flow in Gates Brook was higher during 2007 than in any of previous nine years and may have helped carry additional bacteria into the brook.

Fecal coliform metrics clearly show water quality improvement in Oakdale Brook. A concurrent drop in annual conductivity suggests that this improvement is directly related to the increase in the number of homes previously served by individual septic systems that are now connected to the new municipal sewer. No homes in this subbasin were connected prior to 2004, but more than fifty percent had been connected by the end of 2007.

Four stations exhibited declining water quality even after efforts to locate and eliminate sources. Elevated concentrations of fecal coliform were recorded in Rocky Brook during 2006 and 2007, and conductivity reached annual maximums as well, but water quality remained better than in many of the watershed tributaries and no immediate action appeared warranted. Concentrations rose at the Scarlett Brook (Route 12) station, but low conductivity suggests a non-human source. Geese feeding upstream at the Wachusett Country Club and wildlife in surrounding woods are a likely source of the bacteria.

Water quality in West Boylston Brook improved initially following a focused effort to repair or replace inadequate septic systems. Annual median fecal coliform concentrations began to increase in 2004, ironically at the same time that the first homes in the subbasin began to connect to the new municipal sewer. It was suspected that elimination of groundwater recharge had reduced flows in West Boylston Brook with a resultant concentration of contaminants, but both annual and summer flows actually increased in 2004 and remained high for the following three years. While connections to the sewer have almost certainly reduced bacterial inputs to the brook, there are still a number of homes not connected (33%) and other sources such as wildlife and domestic animals may also contribute.

A similar pattern was observed in Cook Brook. Water quality was very poor in 1998 but improved each year as more and more homes were connected to the sewer. Conditions changed in 2003 and 2004 , with a decline in all fecal coliform metrics even as the percentage of homes connected to the sewer exceeded 80%. It is not clear what caused increasing concentrations of fecal coliform, but a number of theories have been advanced. The elimination of septic systems and removal of much of the wastewater from the subbasin via municipal sewers might have resulted in reduced groundwater and reduced stream flow which could then lead to higher concentrations of fecal coliform, although as described earlier there was actually an increase in flow in those tributaries with new sewers that reported flows. Division staff have also been investigating the possibility that dog feces could be a significant and increasing source of fecal coliform contamination in this and other subbasins.

Annual conductivity in Cook Brook dropped twenty-one percent from 2004 to 2007. Most other stations with a similar drop in conductivity also were located in areas with new or expanded sewers or where septic systems had been recently repaired. Annual mean nitrate-nitrogen concentrations have dropped steadily since 2002, and concentrations of total phosphorus in Cook Brook were also at their lowest levels during the past two years. The apparent improvements in water quality as reflected by nutrient and conductivity data would support the conclusion that fecal coliform contamination from human sources has been significantly reduced, but that an alternative source such as dog feces still remains and needs to be addressed.

Longer term trends were also examined, with data from 1998-2007 compared to data from the previous ten year period. Twelve of thirty-six stations sampled over the twenty year period exhibited noticeably improved water quality, with much lower annual median fecal coliform concentrations (Table 156). Water quality at the remaining twenty-four stations was unchanged or slightly improved. In no case was water quality worse than it had been during the previous ten years. This clearly illustrates the effectiveness of Division efforts to improve and maintain water quality in watershed tributaries. Construction and utilization of sewers, repair and replacement of outdated or poorly functioning septic systems, encouragement of the use of best management practices at significant agricultural sites, and stormwater management efforts have led to noticeable improvements in many locations and have prevented declines elsewhere.

Table 156:
WATER QUALITY IMPROVEMENTS – FECAL COLIFORM 1988 - 2007

STATION	1988-1997 mean of annual medians	1998-2007 mean of annual medians
Asnebumskit Brook (Mill Street)	37	23
French Brook	27	11
Gates Brook (1)	31	21
Gates Brook (2)	69	49
Gates Brook (3)	66	41
Gates Brook (4)	101	61
Malagasco Brook	45	23
Scarlett Brook	52	29
Swamp 15 Brook	66	20
Waushacum Brook (Prescott Street)	28	19
West Boylston Brook	77	47
Wilder Brook	74	20

An increase in the number of homes and businesses connected to municipal sewers has had a strong positive impact on water quality. Many parcels in the Asnebumskit Brook, Gates Brook, Scarlett Brook, and West Boylston Brook subbasins have been connected to the sewer within the past ten years and water quality has improved (Table 156). Stormwater management efforts in these subbasins have improved and individual septic systems that serve the unsewered parcels are maintained and repaired as needed.

There are no sewers in the French Brook subbasin, but a reduction in the number of farm animals and the removal of several beaver from the brook led to noticeable water quality improvements. Farm animals were allowed to remain in the Swamp 15 Brook subbasin, but vegetated buffers, fencing, manure management, and other best management practices were used to reduce impacts from horses and cows living near the brook.

Problems on Malagasco Brook were reduced after a lengthy investigation determined that mulch stored near the tributary was the source of bacteria. High concentrations of fecal coliform at Waushacum Brook (Prescott Street) were reduced when a beaver dam was breached and the animals chose to relocate upstream. The significant improvements on Wilder Brook were the result of septic system repairs as well as changes in annual flow that now leave the brook dry during much of the summer.

The use of fecal coliform to measure short term and long term water quality trends can be problematic. Results need to be carefully interpreted, with attention given to irregular sampling patterns, changes in flow from year to year, season to season, or even day to day, and the inherent variability of seasonal storm events and whether they are sampled or not. Regardless of what statistical methods are used, changes in other water quality parameters should be examined to help support any conclusions or to illuminate hidden trends.

Interpretation of fecal coliform data is also difficult because of the wide range of sources. These bacteria can originate from humans, from wildlife, from domestic animals, or even from insects or plant materials, and locating the source of elevated concentrations requires patience and persistence. Concentrations are dependent on specific conditions for growth, and conditions can change quickly. Fecal coliform bacteria washed into a tributary by winter rains might die off rapidly due to cold temperatures. Exposure to sunlight (ultraviolet radiation) kills bacteria, but warmer temperatures promote growth. Formulating how to summarize fecal coliform data and overcome multiple variables is a complicated and ongoing task.

The most important sources of fecal coliform bacteria in the Wachusett watershed are failing septic systems and animal waste, with stormwater the primary means of transport. As the watershed has become more urbanized, new sewer connections and improvements at agricultural operations have helped reduce the threat. Unfortunately, bacteria from farm animals and septic systems have been replaced by waste from domestic pets and leaking sanitary sewers. The fact that concentrations have actually declined in a number of tributaries is a testament to the efforts of the Division. A number of areas in the watershed have been targeted for an ongoing dog waste collection initiative, and water quality improvements have already been noted. Further efforts, especially related to stormwater management, should result in additional improvements throughout the watershed.

4.2 CONDUCTIVITY SUMMARY

Annual conductivity increased at all stations during the most recent ten and twenty year periods. Years with little rainfall often result in higher conductivities due to low flow, and winter storm events can lead to elevated levels due to the application of salt on icy roadways, so the use of annual statistics for analyzing conductivity trends can be misleading. Conductivity at nearly all stations was elevated during 1997 when annual rainfall was 33.8” (nearly 13” less than the average). Conductivity also increased significantly at all stations in 2001, 2002, and 2003. These increases have been linked to the use of a new field conductivity meter during that three year period. Annual conductivity at most stations declined following a return to an earlier piece of monitoring equipment. Even though it is clearly difficult to assess conductivity using annual data, the widespread upward trend cannot be ignored. Atmospheric deposition and stormwater transport are likely sources of the contaminants that are increasing conductivity in Wachusett tributaries.

In order to eliminate some of the confounding influences mentioned in the previous paragraph, sets of ten year averages were compared after removing data from the abnormally dry year of 1997 and the three year period (2001-2003) when a different field conductivity meter was used for data collection. Conductivity increased by seventy percent or more at seven stations, with an increase of greater than one hundred percent in both Houghton and Oakdale Brooks. Eleven stations exhibited a much smaller increase of less than forty percent, with a low of nine percent noted in Muddy Brook. A majority of the thirty-two stations examined fell between these two extremes. All comparisons are included in Table 157 on the next page.

It is interesting to note that if all data are used to compare the periods of 1988-1997 and 1998-2007, very similar conclusions can be drawn. The only significant differences are lower percent increases (less than sixty percent) at Scarlett Brook and Gates Brook (9).

Table 157:
LONG TERM CONDUCTIVITY TRENDS 1988 – 2007
(excluding 1997 and 2001-2003)

STATION	1988-1996 mean of annual means	1998-2007 mean of annual means	% increase
Asnebumskit Brook	148	214	44
Ball Brook	49	69	42
Beaman Pond Brook	423	608	44
Boylston Brook	182	310	71
Chaffins Brook	189	238	**26**
East Wachusett Brook	94	108	**15**
French Brook	93	150	61
Gates Brook (1)	400	639	60
Gates Brook (2)	421	664	58
Gates Brook (3)	439	731	67
Gates Brook (4)	479	763	60
Gates Brook (6)	484	789	63
Gates Brook (9)	400	717	79
Hastings Cove Brook	59	85	44
Houghton Brook	241	504	109
Justice Brook	35	46	**35**
Keyes Brook	65	75	**15**
Malagasco Brook	172	295	71
Malden Brook	145	184	**27**
Muddy Brook	133	145	**9**
Oakdale Brook	294	605	106
Quinapoxet River	121	170	40
Rocky Brook	59	74	**25**
Scanlon Brook	48	76	61
Scarlett Brook	287	488	70
Stillwater River	84	136	62
Swamp 15 Brook	204	345	69
Trout Brook	58	66	**14**
Warren Tannery Brook	223	297	**33**
Waushacum Brook	181	325	80
West Boylston Brook	395	545	**38**
Wilder Brook	98	109	**12**

Annual conductivity data were also examined for periods of relative stability and then grouped together and summarized. The periods of 1988-1992 and 2006-2007 exhibited little change throughout the watershed and were therefore used to detect trends. The increase in conductivity was greater than one hundred percent at seven tributaries (Houghton, Malagasco, Waushacum, Oakdale, Stillwater, Scarlett, and Swamp 15) and less than forty percent at five (Wilder, Muddy, East Wachusett, Trout, and Keyes).

Regardless of the methodology used, Houghton Brook, Malagasco Brook, Oakdale Brook, and Waushacum Brook had the largest increases in conductivity over the twenty year period. Increases in Houghton Brook and Waushacum Brook were likely due to beaver activity just upstream of the sampling location. The increase in Malagasco Brook has not yet been explained and there was no similar increase in fecal coliform concentrations. Conductivity in Oakdale Brook increased as fecal contamination from inadequate septic systems became more prevalent, but actually declined at the end of the twenty year period following the construction of a municipal sewer.

Much smaller increases were observed at Chaffins Brook, East Wachusett Brook, Justice Brook, Keyes Brook, Malden Brook, Muddy Brook, Rocky Brook, Trout Brook, Warren Tannery Brook, West Boylston Brook, and Wilder Brook. Many of these tributaries flow though areas with only limited development, while others have large ponds or extensive wetlands upstream of the sampling stations which help filter out contaminants.

The focus of this report, however, is on the ten-year period from 1998 through 2007. The average increase in conductivity between 1998-2000 and 2006-2007 was slightly more than fifty percent, with twelve stations exhibiting a much smaller increase of less than thirty percent (Table 158). Three stations had much higher increases in conductivity with the largest rise (102%) recorded in Malagasco Brook. It is interesting to note that greater than average long term increases illustrated in Table 157 for Boylston Brook, Oakdale Brook, Scarlett Brook, and Waushacum Brook were not seen during this more recent ten year period. This is likely the result of a concerted effort to repair inadequate septic systems and to connect homes to a new municipal sewer, although smaller increases in Waushacum Brook were probably due to a new beaver dam and pond that filtered out contaminants.

The final four years of the period were examined closely to look for positive impacts from recent efforts to improve water quality. Thirty-seven stations were sampled weekly throughout the period, and annual conductivity remained the same or increased at eighteen of them. The largest increases were noted at Malagasco Brook (51%), Jordan Farm Brook (23%), the Stillwater River (21%), Rocky Brook (16%), and West Boylston Brook (16%), all with historic annual maximum values during 2007. No obvious causes for these increases were identified, and in some cases the increase in conductivity was not matched by an increase in fecal coliform concentrations.

Annual conductivity declined by twenty percent or less at twelve stations in the watershed, and declined by more than twenty percent at seven others. Six of the seven stations with sharply lower conductivity (Asnebumskit Brook, Beaman Pond Brook, Boylston Brook, Cook Brook, Oakdale Brook, and the Quinapoxet River) are in areas with new sewers or where a concerted effort had been made to repair or replace old and inefficient septic systems.

Table 158:
CONDUCTIVITY TRENDS 1998 – 2007

STATION	1998-2000 mean of annual means	2006-2007 mean of annual means	% increase
Asnebumskit Brook	189	214	**13**
Ball Brook	51	77	51
Beaman Pond Brook	510	573	**12**
Boylston Brook	239	341	43
Chaffins Brook	213	237	**11**
Cook Brook	339	363	**7**
East Wachusett Brook	100	107	**7**
French Brook	107	167	56
Gates Brook (1)	489	717	47
Gates Brook (2)	510	753	48
Gates Brook (3)	545	851	56
Gates Brook (4)	577	904	57
Gates Brook (6)	592	926	56
Gates Brook (9)	515	875	70
Hastings Cove Brook	71	87	**23**
Houghton Brook	319	593	86
Jordan Farm Brook	84	131	55
Justice Brook	41	48	**17**
Keyes Brook	68	73	**7**
Malagasco Brook	198	401	102
Malden Brook	161	196	**21**
Muddy Brook	141	153	**9**
Oakdale Brook	418	635	52
Quinapoxet River	153	176	**15**
Rocky Brook	61	83	35
Scanlon Brook	62	84	35
Scarlett Brook	365	580	59
Stillwater River	101	162	59
Swamp 15 Brook	262	385	47
Trout Brook	60	66	**10**
Warren Tannery Brook	228	312	37
Waushacum Brook	250	370	48
West Boylston Brook	447	650	46
Wilder Brook	88	120	36

4.3 NUTRIENT SUMMARY

More than seven hundred samples were collected for ammonia, nitrate-nitrogen, nitrite-nitrogen, total phosphorus, total silica, UV-254, total suspended solids, and total organic carbon during the ten year period covered by this report. Many of the parameters were relatively constant and others were often below detection limits, but nitrate-nitrogen and total phosphorus did exhibit some very interesting trends and are discussed in detail in the following paragraphs.

Table 159
NITRATE-NITROGEN ANNUAL MEANS 1998 – 2007

DATE	COOK	FRENCH	GATES	JORDAN	MALAG	MALD	MUDDY	QUIN	ROCKY	STILL	WEST B
1999	3.82	0.098	1.87	1.91	0.680	0.516	0.123	0.263	<0.005	0.119	2.41
2000	4.25	0.100	1.83	2.69	0.689	0.637	0.136	0.324	<0.005	0.185	3.18
2001	3.55	0.122	1.68	1.97	0.721	0.653	0.193	0.467	0.007	0.273	2.88
2002	4.51	0.102	1.55	1.82	0.245	0.235	0.076	0.427	0.019	0.239	1.95
2003	3.34	0.017	2.97		0.735	0.450	0.086	0.336		0.214	3.40
2004	3.09	0.113	1.65	1.33	0.737	0.468	0.075	0.311	0.011	0.133	2.93
2005	2.82	0.103	1.50	1.47	0.596	0.386	0.097	0.270	0.017	0.163	1.95
2006	2.69	0.067	1.39	1.72	0.687	0.356	0.100	0.309	0.008	0.155	2.21
2007	2.50	0.094	1.10	1.95	0.735	0.452	0.113	0.325	0.009	0.185	2.05
mean	**3.40**	**0.091**	**1.73**	**1.86**	**0.647**	**0.461**	**0.111**	**0.337**	**0.009**	**0.185**	**2.55**

Annual mean nitrate-nitrogen is always highest in Cook Brook, Gates Brook, Jordan Farm Brook, and West Boylston Brook, and very low at stations on French Brook, Muddy Brook, and Rocky Brook (East Branch). Maximum concentrations were recorded throughout the year, almost always during dry weather and prior to 2004. The highest concentrations measured were in dry weather samples collected from Cook Brook (5.82 mg/L, February 2002) and from West Boylston Brook (5.00 mg/L, April 2001). Maximum concentrations from Rocky Brook (East Branch), the Quinapoxet River, and the Stillwater River were recorded following rain events.

Annual means remained within a consistent range for most tributaries during the nine years, but there were positive changes noted at three stations, all in areas where sewers have recently become available. Annual mean nitrate-nitrogen at Cook Brook, Gates Brook, and West Boylston Brook were at historic lows during 2005, 2006, and 2007 (Table 159), and preliminary data from 2008 suggest that the water quality improvements are continuing.

The EPA Water Quality Criteria for total phosphorus (0.05 mg/L) was developed to help prevent eutrophication of receiving water bodies. Annual mean total phosphorus concentrations in the eleven Wachusett tributaries were generally less than 0.05 mg/L, and the mean of the annual means over the nine year sampling period was less than 0.05 mg/L in all streams with a low of 0.011 mg/L in Rocky Brook (East Branch) and a high of 0.43 mg/L in the Quinapoxet River (Table 160). The annual mean did exceed 0.05 mg/L in three tributaries in 1999, 2000, and 2001, and in five streams during 2005. Annual mean was greater than 0.05 mg/L four times at Malden Brook, three times in the Quinapoxet River, and in Cook Brook and French Brook twice.

Maximum total phosphorus values for single samples at each of the tributaries greatly exceeded the EPA criteria in all but one instance, and nearly all of them (nine of eleven) were recorded during or immediately following a rain event, unlike what was observed with nitrate-nitrogen maximums. Transport of phosphorus on suspended sediment is the likely cause of the high concentrations associated with stormwater. Maximum values were recorded from Cook Brook (0.58 mg/L) and the Stillwater River (0.47 mg/L).

Table 160:
TOTAL PHOSPHORUS ANNUAL MEANS 1998 – 2007

DATE	COOK	FRENCH	GATES	JORDAN	MALAG	MALD	MUDDY	QUIN	ROCKY	STILL	WEST B
1999	0.089	0.027	0.024	0.023	0.034	0.069	0.020	0.066	0.007	0.028	0.030
2000	0.027	0.043	0.034	0.015	0.031	0.053	0.016	0.061	0.006	0.083	0.019
2001	0.029	0.048	0.059	0.020	0.037	0.058	0.074	0.047	0.016	0.044	0.032
2002	0.026	0.022	0.032	0.011	0.029	0.019	0.032	0.046	0.012	0.034	0.018
2003	0.021	0.059	0.021		0.024	0.023	0.011	0.024		0.039	0.031
2004	0.056	0.033	0.022	0.030	0.033	0.032	0.024	0.024	0.013	0.036	0.018
2005	0.041	0.056	0.034	0.095	0.057	0.057	0.042	0.020	0.016	0.021	0.051
2006	0.013	0.036	0.019	0.037	0.025	0.023	0.014	0.025	0.007	0.032	0.018
2007	0.016	0.041	0.018	0.027	0.027	0.027	0.015	0.073	0.010	0.021	0.025
mean	**0.035**	**0.041**	**0.029**	**0.032**	**0.033**	**0.040**	**0.028**	**0.043**	**0.011**	**0.038**	**0.027**

Total phosphorus annual means remained relatively unchanged for most tributaries during the nine years, but there were positive changes noted at two stations with a large number of new sewer connections. Annual mean total phosphorus at Cook Brook and Gates Brook were at historic lows during 2006 and 2007 (Table 160), and preliminary data from 2008 suggest that the water quality improvements are continuing. These same stations showed similar reductions in nitrate-nitrogen and provide a clear illustration of the water quality improvements possible with sewer construction.

Total phosphorus in Jordan Farm Brook appears to be increasing with a historic maximum annual mean in 2005 and higher than normal means in 2006 and 2007 as well. Conditions do not appear to have improved in 2008. An intermittent source of fecal contamination has not yet been identified and may be the cause of increasing concentrations of total phosphorus.

4.4 METALS SUMMARY

Samples for twenty metals were collected monthly or less frequently from the Stillwater River and Quinapoxet River beginning in 2002. The number of samples collected for each parameter ranged from thirty-seven to sixty-six. Three parameters (antimony, beryllium, and selenium) were never measured at concentration above the detection limit, and seven others (cadmium, chromium, lead, mercury, nickel, silver, and thallium) were rarely detected. The maximum, minimum, and mean values of the other ten parameters are shown in Table 161.

Table 161:
METALS (Maximum, Minimum, and Mean in mg/L) 2002 – 2007

	QUINAPOXET RIVER			STILLWATER RIVER		
Parameter	**Maximum**	**Minimum**	**Mean**	**Maximum**	**Minimum**	**Mean**
Aluminum	2.64	BDL	0.201	0.651	0.021	0.163
Arsenic	0.008	BDL	BDL	0.011	BDL	0.002
Barium	0.041	0.013	0.020	0.021	0.011	0.017
Calcium	12.1	4.78	7.84	16.7	2.90	6.91
Iron	3.17	0.134	0.461	1.88	0.035	0.476
Magnesium	2.24	0.98	1.49	2.95	0.63	1.24
Manganese	0.626	0.030	0.092	0.348	0.021	0.095
Potassium	3.64	1.19	1.72	2.93	0.84	1.45
Sodium	61.9	11.9	26.6	37.7	10.4	18.0
Zinc	0.027	BDL	0.007	0.025	BDL	0.006

Mean values for most metals sampled were similar in the two rivers, although a majority of the means were slightly higher in the Quinapoxet River, not surprising as the subbasins draining to the Quinapoxet River are much more developed than those draining to the Stillwater River. There were many more samples (43 of 61) with detectible concentrations of arsenic in the Stillwater River than in the Quinapoxet River (25 of 62), however, likely due to a naturally occurring band of arsenic and possibly to the historic presence of apple orchards.

Samples were also collected for silica, total organic carbon, total suspended solids, and UV-254 from eight or eleven stations depending upon the parameter. All results fell within normal and expected ranges. Watershed mean values for the four parameters were 8.43 mg/L (silica), 5.00 mg/L (TOC), 6.00 mg/L (TSS), and 0.248 A/cm (UV-254). Annual concentrations of total organic carbon appear to be dropping, and many of the samples for total suspended solids contained less than the detection limit.

4.5 MACROINVERTEBRATE SUMMARY

Macroinvertebrate samples were collected from thirteen stations on eleven tributaries during the spring of 1998 and from twenty-three stations on sixteen tributaries in the spring of 2001. Additional samples were collected from five tributaries during the summer and fall of 2001 to investigate possible seasonal differences in macroinvertebrate populations. Five metrics were calculated at each sampling location and compared to metrics calculated at two reference stations. The ratios of the sampling site metrics to two reference site metrics were calculated and given scores based on EPA biological condition scoring criteria to produce an assessment of the level of impairment. Metrics used were number of taxa, number of mayfly/stonefly/caddisfly (EPT) taxa, the ratio of EPT taxa to chironomid midges, the Hilsenhoff biotic index, and percent contribution of the dominant taxonomic group.

Metrics covered a wide range of values (Table 162), and the degree of impairment observed ranged from none (at reference stations as well as several others) to extreme. At most stations sampled there were no overall changes from 1998 to 2001, although some differences were observed and are discussed below.

Table 162:
MACROINVERTEBRATE ASSESSMENT

YEAR	# TAXA	# EPT	EPT/chiro	HBI	% DOMIN
1998 range of values	10 – 28	5 – 22	0.4 – >100	1.07 – 5.63	14 – 59
1998 Trout (ref)	27	19	95	1.19	41
2001 range of values	8 – 31	2 – 19	0.3 – >100	1.12 – 4.88	15 – 69
2001 Trout (ref)	30	19	10.5	1.68	25
2001 E.Wachusett (ref)	27	18	>100	1.62	16

Stations considered to have no impairment were those where metrics had at least an 83% agreement with the reference station. These stations included the two reference stations (Trout Brook, East Wachusett Brook), Asnebumskit Brook (1998), Landfill Brook (1998), Malden Brook (2001), the Stillwater River (2001), and the Quinapoxet River (1998 and 2001). Stations that were slightly impaired (54 – 79% agreement with the reference) included Asnebumskit Brook, East Wachusett Brook (upstream of the reference site), Landfill Brook, and the Stillwater River (all during 2001). A comparison of metrics from Scanlon Brook in 2001 placed this tributary on the boundary between slightly impaired and moderately impaired.

Moderate impairment was noted at five stations in 1998 and six stations in 2001. Agreement with the reference station was less than fifty percent and organic enrichment or the presence of other contaminants was likely. Boylston Brook, Chaffins Brook (Malden Street), Hastings Cove Brook, Gates Brook (1), Malden Brook, Muddy Brook, and Waushacum Brook were all moderately impaired during one or both years of macroinvertebrate sampling.

Malagasco Brook, Chaffins Brook (Unionville Pond), West Boylston Brook, and two upstream stations on Gates Brook were extremely impaired. Elevated nutrients, elevated turbidity, and poor habitat were prevalent at four of the five stations. Chaffins Brook (Unionville Pond) was impacted by an earlier spill of insecticide and upstream contaminants, but metrics also illustrate the negative effects caused by an upstream pond outlet (natural organic enrichment, higher temperatures, and reduced oxygen concentrations).

Conditions at Gates Brook (1) seemed to decline although the overall assessment of moderate impairment did remain. A shift in the dominant genus of mayfly from a pollution intolerant genus (*Ephererella*) to a pollution tolerant genus (*Baetis*) and an increase in the number of pollution tolerant chironomid gnats caused the biotic index value to triple. Continued movement in this direction would eventually lead to an assessment of extreme impairment. Conditions in Gates Brook do seem to be strongly influenced by season, however, (see below) and additional sampling should be done to determine if the decline is real or due to seasonal fluctuations.

A 1998 sample from Malagasco Brook was severely impaired, with an unbalanced population and impacts from organic enrichment reflected by a biotic index score of 4.55. A source of upstream contamination was located and removed in 1997 and water quality improved. The macroinvertebrate population took longer to recover. A sample collected in 2001 was between moderately and severely impaired. A species of filter-feeding caddisfly (*Diplectrona modesta*) replaced most of the pollution tolerant chironomids and the biotic index score lowered to 3.03.

A sample collected in 1998 from Malden Brook showed moderate impairment due primarily to a larger than normal population of pollution tolerant limnephilid caddisflies. Fecal coliform concentrations were higher in 1998 than at any other time during the ten year period. A sample collected in 2001 showed no impairment and very few limnephilid caddisflies were collected.

Samples were collected from five tributaries during the summer and fall of 2001 to investigate possible seasonal differences in macroinvertebrate populations. Samples from the Quinapoxet and Stillwater Rivers showed no seasonal differences at all, with similar numbers of total taxa and pollution-intolerant taxa and comparable biotic indices in spring, summer, and fall. Samples from the two reference stations (Trout Brook, East Wachusett Brook) did exhibit seasonal differences, with fewer taxa present during the summer and an increase in the number of pollution tolerant species (and biotic index) in the fall. Samples from Gates Brook (1) actually improved during the summer and appeared best in the fall, due primarily to a disappearance of pollution tolerant chironomids and a drop in the biotic index.

No macroinvertebrate samples have been collected since 2001, but water quality conditions in many of the tributaries has changed. Shifts in macroinvertebrate populations can help document improvements that might otherwise be overlooked. Stations on Boylston, Malagasco, Muddy, Gates, and Chaffins Brooks should be resampled in 2009 and 2010 to illustrate positive changes.

5. CONCLUSIONS - LOOKING FORWARD

Long term trends suggest that water quality in many watershed tributaries has improved. This clearly illustrates the effectiveness of Division efforts to improve and maintain water quality, but in no way suggests that the work of the Division is complete. Construction and utilization of sewers, repair and replacement of outdated or poorly functioning septic systems, encouragement of the use of best management practices at significant agricultural sites, and stormwater management efforts have led to noticeable improvements in many locations and have prevented declines elsewhere, but water quality in many tributaries is still not satisfactory. Additional sources need to be located and removed. An ongoing dog waste collection program should be continued and expanded. The use of alternative indicators or innovative techniques for source identification should be utilized. Clean drinking water is no longer considered an unlimited resource, and with the additional threats brought about by climate change it is crucial that every effort be made to protect and preserve what already exists. In order to refine understanding of bacteria trends, the Division has switched monitoring efforts from fecal coliform to the more specific *E. coli*, and the next ten-year summary report will look at trends of this parameter as well as a number of others. Publication is scheduled for the summer of 2019, and the report will hopefully document continued improvements to the water quality of the Wachusett watershed as well as be the final significant report by this author.