Status of and Potential Impacts on Water Budget for the
Weir River Watershed

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ACEC	Area of Critical Environmental Concern
AWC	Aquarion Water Company of Massachusetts
cfsm	cubic feet per second per square mile
COE	U.S. Army Corps of Engineers
DEM-OWR	Massachusetts Department of Environmental Management Office of Water Resources
DEP or MADEP	Massachusetts Department of Environmental Protection
DFWELE	Massachusetts Division of Fisheries and Wildlife and Environmental Law Enforcement
EPA	U.S. Environmental Protection Agency
FEMA	Federal Emergency Management Agency
FEMA FIS	Federal Emergency Management Agency Flood Insurance Study
GIS	Geographic Information System
gpm	Gallons per minute
gpd	Gallons per day
IFIM	Instream Flow Incremental Methodology
LFPR	United States Geologic Survey Low Flow, Partial Record stream gage
MAWC	Massachusetts American Water Company (now Aquarion)
MBTA	Massachusetts Bay Transportation Authority
MCL	Maximum Contaminant Level
MEPA	Massachusetts Environmental Policy Act
MGD	Million Gallons per Day
MISER	Massachusetts Institute for Social and Economic Research
MWRA	Massachusetts Water Resources Authority
NFF	National Flood Frequency
NGVD	National Geodetic Vertical Datum
NPL	National Priority List
PCBs	Polychlorinated biphenyls
RAO	Response-Action Outcome
SCS	Soil Conservation Service (now known as the Natural Resource Conservation Service - NRCS)
SDWA	Safe Drinking Water Act
SVOCs	Semi-Volatile Organic Compounds
USDA	United States Department of Agriculture
USGS	United States Geologic Survey
UST	Underground Storage Tanks
VOCs	Volatile Organic Compounds
WWTP	Waste Water Treatment Plant

1.00 INTRODUCTION

1.10 AUTHORIZATION

The Massachusetts Department of Environmental Management (DEM) - Office of Water Resources (OWR) has contracted GZA GeoEnvironmental, Inc. of Newton Upper Falls, Massachusetts (GZA) to conduct a study on the Status of and Potential Impacts on the Water Budget for the Weir River watershed - DEM Contract 452. This study was conducted in conjunction with the Massachusetts Executive Office of Environmental Affairs (EOEA) Watershed Initiative, which gathers essential data and information needed for planning future watershed management. This report is subject to the Limitations in **Appendix A**.

1.20 PURPOSE

The purpose of this study was to prepare an inflow / outflow analysis for the Weir River watershed and its subbasins (i.e., study area). This analysis considered the potential human and natural influences which affect the overall water budget of the study area. Factors considered include, among others, climate and weather patterns, watershed characteristics, groundwater and surface water hydrology, local flora and fauna, water supply withdrawals, population, and anticipated growth. By analyzing the quantities of water entering and exiting the watershed, a water budget was estimated which accounts for available water resources in and around the Weir River and its tributaries. Such an analysis was conducted for both average and drought hydrologic conditions and used to evaluate current water supply withdrawals and draw conclusions as to potential future impacts of withdrawals on streamflow and growth within the watershed and surrounding water use areas.

The average and drought water budgets were then used to assist in assessing the stresses to the living aquatic resources of the watershed. Fish, macroinvertebrates, and wetland communities all require access to adequate water to flourish. By sampling and categorizing the types of aquatic flora and fauna present in the watershed, and evaluating the water resources available for aquatic plants and animals, potential stresses and risks were identified. By making estimates of growth and development in the watershed, the future state of the Weir River water budget was also evaluated. Such predictions give indications of the ability of the area's water resources to provide for continued water supply withdrawals while simultaneously supporting natural aquatic habitats and ecosystems.

This study was designed as a first step in assisting watershed planners, local governments, state regulators, private industry, and local stakeholders in identifying key water resources management issues in the Weir River watershed. As growth continues and demand expands, careful planning is needed to manage and protect the state's water resources in a sustainable and beneficial manner.

1.30 SCOPE

To meet the purposes of the project, the Weir River watershed study has been divided into five main tasks.

1.31 Gather and Review Existing Information

This task involved the collection and review of existing reports and data relevant to the study, as well as conducting interviews with key watershed stakeholders. Sources of such information include the DEM, DEP, the Towns of Hingham and Norwell, the Aquarian Water Company of Massachusetts (AWC) (formerly Massachusetts-American Water Company), the U.S. Geological Survey (USGS), and others. As a part of this task, a bibliography of pertinent sources has been produced and included in this report.

1.32 Develop Background and Site Description from Existing Information

Using the collected information, a general description of the watershed has been produced. This includes the delineation of the watershed and its subbasins as well as descriptions of the topographical, hydrological, and geological characteristics of the area. A description of development in the watershed has also been produced which encompasses information such as existing population, land usage, water supply, sewerage, and projected growth rates.

1.33 Hydrologic Impact Assessment

A general analysis of available hydrologic data has been conducted to develop basic statistical information about the water resources of the Weir River watershed. Available information has been summarized and displayed in various tables, figures, and GIS databases. Rainfall, flow rate, and other data have been analyzed to identify probability distributions and average values. Both surface water and ground water resources have been categorized, quantified, and described in terms of general water quality. Additional information on streamflow rates has been collected in the field to supplement existing data.

By combining the hydrologic analysis with information on the development and utilization of water resources in the Weir River watershed, catchment-wide water balance estimates were produced. The water balance accounts for inflows to and outflows from the watershed and describes, to a limited extent, the internal usage of the water. Along with the development of the water balance as it currently exists, additional budgets were prepared which examine the watershed in different states of development. Using the water balances, a model was created to assist in predicting average streamflow characteristics such as flow, depth, and velocity of the Weir River under different conditions, including the “virgin” watershed condition and projected future demand condition. The virgin condition refers to the watershed in its hypothetical “natural” state prior to modern human inhabitation and human-made development projects and withdrawals.

1.34 Living Aquatic Resources Assessment

Information on aquatic flora and fauna has been collected to determine the types of species present in the watershed. This data was supplemented with in-stream and wetland sampling. Information on the living aquatic resources was evaluated in conjunction with the Weir River streamflow model to assess the effects of different flow conditions on aquatic habitat and baseflow needs.

1.35 Conclusions

Based on analysis of the collected data, statistical summaries, and hydrologic models, several broad conclusions were developed regarding the sustainability of the water resources of the Weir River watershed. The general consequences of water use on available water supplies, living aquatic resources, and economic growth in the area are discussed. By predicting the most likely scenario for future water resources development, areas of interest and concern were identified for additional study by DEM, local government, and other stakeholders.

1.40 GENERAL LIMITATIONS

This report was prepared as per the scope and purpose developed by the DEM, which was discussed in Section 1.30. This study, and the parallel study in the Nashua watershed, are the first of their kind to be undertaken as a part of the Massachusetts Watershed Initiative (MWI). The goal of the MWI is to implement a watershed approach to outreach, research, assessment, planning, implementation, and evaluation. The MWI acknowledges as a key to successful program implementation the co-leadership roles of the state, watershed associations or other citizens groups, the business community, and municipalities. This report should be seen as a tool to be used by these stakeholders.

In general, the first portion of this report provides a broad overview of both the natural features of the watershed and the level of development. This information is intended to inform stakeholders as to what the water resources of the basin are and who the users and beneficiaries of these resources are. The second portion of the report presents the results of a generalized water balance and in-stream habitat study. This information is intended to be useful in identifying areas of concern within the basin, in terms of stresses on both water supplies and aquatic habitat. It is hoped that the data generated in the second portion of the report will spur discussion and interaction between stakeholders within the watershed regarding water resources allocation priorities.

It is important, however, to understand the limitations of this study. The water balance which was created is a generalized model using average conditions and large scale geographic data. Due to the lack of long term, watershed specific surface water and groundwater data, numerous parameters had to be inferred from information collected in nearby, similar watersheds. While this study used the techniques typical of Instream Flow Incremental Methodology (IFIM) studies, a full IFIM investigation was not undertaken. No detailed stochastic studies of water inflows and demands were conducted. No operational studies of water wells and reservoirs used by the water supply utilities were performed. While these types of investigations are generally used by water suppliers to evaluate the capacities of their systems to meet demand, the current report deals with the more qualitative interaction between water supply and the environment.

1.50 ACKNOWLEDGEMENTS

The project team would like to acknowledge the work and assistance of several individuals who were invaluable in the preparation of this study and report: Ms. Linda Marler and Mr. Mike Gildesgame of the Department of Environmental Management; Mr. Rich Kleiman, formerly of the Executive Office of Environmental Affairs; Mr. Jeff Bettinger and Ms. Joanne Norton of the Hingham Water Resources Task Force; Ms. Samantha Woods of the Weir River Watershed Association; Mr. Jack McGuiness of the Norwell Water Department; and Mr. Randy Sylvester and Ms. Eileen Commane of the Massachusetts-American Water Company. The Project team members from GZA were Peter Baril, Chad Cox, David M. Leone, Laurie Gibeau, Tim Briggs, and Chris Wright along with Brandon Kulik of Kleinschmidt Associates.

2.00 WATERSHED DESCRIPTION

2.10 PHYSICAL CHARACTERISTICS

2.101 General Watershed Description

The Weir River watershed is a part of the Weymouth and Weir River Subbasin which is in turn part of the Boston Harbor Basin. The Weymouth and Weir River Subbasin is designated as **19c** on the Massachusetts Water Resource Commission master list. The location of the Weir River watershed is shown in **Figure 2-1**. **Figure 2-2** shows an aerial orthophoto of the study area. **Figure 2-3** shows the limits of the watershed on a composite of USGS quadrangle base maps. The watershed is approximately 15 miles southeast of Boston and encompasses parts of Plymouth and Norfolk Counties. The Town of Hull is completely within the study area. The Town of Hingham is largely within the watershed study area, as are smaller portions of Cohasset, Weymouth, Norwell, and Rockland. Most of Hull is located on a peninsula which extends north into Massachusetts Bay. The total population living full-time within the watershed is approximately 30,000.

The total study area is approximately 23.4 square miles, but the sub-catchment contributing to the non-tidal portion of the Weir River is only 14.8 square miles (63 percent of total area.) The Weir River is fed by a number of tributaries, of which the most significant are Accord Brook and Plymouth River/Crooked Meadow River. The length of the Weir River is 5.5 miles to Hingham Bay and 2.6 miles to the end of the non-tidal portion at the Foundry Pond Dam. The lengths of the Accord Brook and the Plymouth/Crooked Meadow Rivers are about 5.8 miles and 3.7 miles, respectively. The Weir River drains into Hingham Bay after passing through a tidal portion below Foundry Pond. All the major watercourses in the watershed are low-gradient and in general have well defined channels, broad floodplains, and seasonally variable flow. The largest fresh water body of water in the study area is Accord Pond at the southern-most and highest elevation of the basin. Several other artificial impoundments and tidal ponds are also present. Prominent features of the watershed are presented in **Figure 2-4**.

The geology of the watershed is typical of the coastal areas of eastern Massachusetts where much of the soils are of glacial origin. The bedrock is typically Dedham Granite. The soil overlying the bedrock in the eastern portion of the watershed is typically glacial till of low hydraulic conductivity, while in the western portion, the soils consist of more stratified drift deposited as glacial outwash. Soil type is a major factor in the availability of groundwater for wetlands, streams, and water wells. Sand and gravel deposits have been and continue to be mined within the watershed. Numerous drumlins appear as high hills throughout the basin.

The largest land types within the watershed study area are vacant forested areas and residential developments. The Wompatuck State Park and George Washington Town Forest occupy a significant portion of the upper southeastern part of the watershed. In the past, the military used areas in and near the watershed for activities such as shipbuilding and munitions storage. Hingham Harbor currently supports a marina used primarily by sailboats and other small vessels. Population densities in Hingham are less than 1,000 per square mile, but in Hull the population density is over 3,500 per square mile. The majority of water use in the watershed is by residential users.

2.102 Location

The Weir River watershed is located in eastern Massachusetts in the area commonly referred to as the "South Shore" of the Massachusetts Bay. The locus of the watershed is shown on **Figure 2-1**. The majority of the watershed is within Plymouth County with a smaller portion extending into Norfolk County on both the east and west. The flow of the river is essentially south to north. The Weir River proper is formed by the confluence of several tributary streams as shown on **Figure 2-4**. The Plymouth/Crooked Meadow River and Fulling Mill Brook combine to form the Weir River with the Accord Brook confluence entering further downstream from the southeast. The southern boundary of the watershed is roughly along Route 3 and the northern boundary at the discharge into Hingham Bay.

There are two areas which do not contribute to the Weir River which are included in the study area. Runoff from much of the area around Hingham Harbor, including the west side of the World's End Reservation, drains directly into Hingham Harbor. Runoff from the Hull Peninsula flows not only into the Weir River, but also Hull Bay, Hingham Bay, and directly into the Massachusetts Bay. While these areas are not strictly part of the physical watershed of the Weir River, they are connected by proximity and utilization. The map coordinate limits of the watershed are defined in **Table 2-1** and are shown in **Figure 2-3**.

The watershed area is mapped on the "Weymouth, MA" and "Hull, MA" USGS 1:25,000 scale, 7.5 x 15 minute topographic quadrangles. Full watershed coverage on the USGS 7.5 minute topographic quadrangles requires the "Hull, MA," "Nantasket Beach, MA," "Weymouth, MA," and "Cohasset, MA" maps.

2.103 Watershed and Subbasin Areas

The Weir River watershed and its seven (7) main subbasins encompassing about 23.4 square miles, are shown on **Figure 2-3**. **Table 2-2** lists all relevant planar areas of the watershed. The bounds of the watershed were obtained from MassGIS as an ArcView shapefile and reviewed by GZA. According to the topography of the area, the watershed boundary as provided by MassGIS includes a small portion of land which does not contribute to the Weir River or its tributaries. This portion of the watershed, which accounts for about 3.91 square miles, drains directly into the bays. The drainage area of the Weir River from Accord Pond to the Hingham Bay, as delineated by GZA, is about 19.5 square miles. The suggested corrections to the Mass GIS base map are also shown on **Figure 2-3**.

Subbasin areas were obtained from MassGIS, with the subbasin boundaries delineated by the USGS based on existing USGS stream gages and drinking water supply sources. The

Weir River watershed has been divided into 7 subbasins including subbasins for the partial-record USGS stations above Foundry Pond (Subbasin 6) and at the Main Street culvert on the Crooked Meadow River (Subbasin 4), and the water supply sources of Accord Pond (Subbasin 1), Fulling Mill Pond (Subbasin 5), and the Accord Brook diversion (Subbasin 3). Details of the drinking water supply systems and sources will be presented in **Section 4.1**. The two remaining subbasins represent the Plymouth River (Subbasin 2) and the watershed beyond Foundry Pond (Subbasin 7). Note the suggested correction to the watershed involves only Subbasin 7. GZA utilized the MassGIS/USGS watershed delineations for subsequent hydrologic analyses. However, it is recommended that MassGIS/USGS refine the subbasins to reflect the Tidal and non-contributing areas of Subbasin 7, which does not appear to be associated with the water resources of the Weir River.

2.104 Topography

The topography of the watershed is defined by the coastal location and glacial-era history of the region. The general gradient of the watershed slopes in a general northerly direction to Hingham Bay. At the southern end of the study area, the highest point in the Accord Pond Basin is approximately 190 feet (58 meters) above the 1929 National Geodetic Vertical Datum (NGVD), and at the northern end the Weir River empties into Hingham Bay at Sea Level. The river distance between these two points is approximately 10 miles, making the average gradient of the Weir River / Accord Brook system approximately 0.0032 ft/ft. There are numerous drumlin hills within the watershed which form prominent landmarks and are also important as water tank locations. Several of the major hills and their maximum ground surface elevations are listed in **Table 2-3**.

2.105 Rivers and Streams

The main watercourse is the Weir River which flows into Hingham Bay and is divided into tidal and non-tidal sections by Foundry Pond Dam as shown in **Figure 2-4**. USGS maps show that the Weir River is formed just south of Hingham Center. Higher in the watershed, the channel bifurcates with Accord Brook draining the southeast portion of the watershed and Plymouth River/Crooked Meadow river draining the southwest. Eel Brook contributes to Plymouth River while Tower Brook and Fulling Mill Brook, which drains Fulling Mill Pond, flow directly into the Weir River. Smaller tributaries include Rattlesnake Run, which empties into the saltwater Straits Pond just south of Hull and Turkey Hill Run, which flows into the tidal portion of the Weir River. The major watercourses flow essentially year round, though there are sections of streams - especially Accord Brook - which go dry during some summer seasons. **Table 2-4** lists the rivers and streams in the Weir River watershed along with pertinent data.

The Weir River was dredged from Foundry Pond to Main Street during a project which occurred from circa 1954 to 1956. Limited information is available on the project, which was reportedly a town effort for flood control purposes[1].

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[1] Gale Associates, Inc., “Foundry Pond Diagnostic/Feasibility Study,” January, 1992.p.4.

2.106 Lakes and Ponds / Dams

There are a number of ponds within the Weir River watershed study area. Seven (7) named freshwater ponds appear on USGS maps of the area, along with one tidal pond. The majority of these ponds were artificially constructed. Accord Pond is the only major pond which is natural. The pond is a kettle pond, which is a depression formed when glacial outwash is deposited around a piece of ice left behind by a retreating glacier. When the ice chunk melts, the void left behind becomes the kettle lake. Accord Pond has also been modified by the addition of a dam, constructed by the entity now known as the Aquarion Water Company of Massachusetts (AWC) to increase its storage volume.[2]

Accord Pond is located in the far southern portion of the watershed at the head of Accord Brook and the highest elevation of the watershed. The pond is used for water supply and is therefore not normally available for other activities such as fishing or boating. Accord Pond is by far the largest of the two surface water storage sites in the watershed, the other being the Fulling Mill kettle ponds. The Massachusetts-American Water Company owns the pond area and maintains an intake pump station near the dam on the northern side of the lake. Further detail on the operations of Accord Pond is given in Section 4.21.

The other sources of surface water storage are the unnamed infiltration ponds at Fulling Mill. These seven (7) ponds were likely kettle ponds which were artificially enlarged. Water from Accord Brook is diverted via pipeline into these ponds where it is stored until withdrawn via infiltration trenches constructed beneath the ponds. Water is stored underground in a cistern, which is referred to as Fulling Mill Well. Fulling Mill Pond is not directly connected to this system, but does influence / is influenced by the groundwater level changes caused by the water supply system (i.e., water diverted from Accord Brook and/or withdrawn from the Fulling Mill Well).

Cushing Pond was created by the impoundment of the Plymouth River by a privately owned dam. The river flowing out of Cushing Pond is the Crooked Meadow River. The pond is used for recreational purposes.

Triphammer Pond is on Accord Brook, just upstream of the Brook's confluence with the Weir River. The Town of Hingham owns the dam and most of the surrounding area, while much of the other nearby land is either owned by the Metropolitan District Commission or is a part of Wompatuck State Park. The pond is said to have been created in 1680[3]. The spillway and outlet works have been recently repaired. The pond is used for recreation and as wildlife habitat. A fish ladder near the spillway has been constructed to allow for the upstream migration of

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[2] United States Army Corps of Engineers, New England Division, "Phase I Inspection Report: Accord Pond Dam," April 1979.

[3] New England Aquarium, "Management Report for Triphammer Pond," November, 1995.

anadromous fish such as alewife into the pond. Triphammer Pond is very shallow with an average depth of less than 3 feet.

Foundry Pond is on the Weir River and is impounded by an 11-foot high dam which forms the boundary between the tidal and non-tidal portions of the river. The pond (also called Forge Pond) was created in the late 1700s[4] and was used at various times by an iron foundry, a wool scouring plant, and an ice company. Since the 1950s, it has been used primarily for recreation and wildlife habitat and is owned by the Town of Hingham. A fish ladder at the dam allows anadromous fish to pass over the dam from the tidal section of the river into the pond and further upstream. Foundry Pond Dam was recently rehabilitated, with work completed on the spillway and low level outlet. The pond itself suffers from significant siltation and eutrophication problems. The Hingham Conservation Commission is currently investigating the possibility of dredging Foundry Pond.

Straits Pond is located between North Cohasset and Hull. A small dam separates the pond from the tidal portion of the Weir River. The dam is a control structure with automatically controlled gates that maintain the level of Straits Pond during the fluctuation of the Weir River and prevent excess tidal surge from causing high water in the pond.

Mill Pond, although part of the study area, is outside of the Weir River watershed and is located immediately south of Hingham Harbor. Hatch Pond is a small pond located east of Accord Pond. It appears to drain via wetlands into Accord Pond.

Table 2-5 lists the major ponds in the Weir River watershed study area along with pertinent information about each. **Table 2-6** presents data on the dams which impound the ponds.

2.107 Coves, Harbors, and Bays

The Weir River watershed borders on the coast and interacts with a number of tidal and marine water bodies. The Weir River discharges into Hingham Bay, which also receives the waters of the Weymouth Back River and the Weymouth Fore River. Hull Bay, which is south and west of the Hull Peninsula, is contiguous with Hingham Bay. Allerton Harbor is within Hull Bay. Hingham Harbor opens into Hingham Bay and is the site of a marina used primarily by small private and commercial vessels. Broad Cove empties into Hingham Harbor. Beyond Paddocks Island and the northern portion of Hull, Hingham Bay joins with the larger Massachusetts Bay.

The tidal portion of the Weir River is also used for navigation. A channel within the river provides access to the Town of Hull's Nantasket Pier. The minimum channel depth is currently approximately 6 feet below mean low water; however, on August 31, 1999, the U.S. Army Corps of Engineers issued public notice of a proposal to dredge the channel to increase the minimum depth to 10 feet.

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[4] Gale Associates, Inc. "Foundry Pond Diagnostic / Feasibility Study"

2.108 Tides and Coastal Features

The tidal range in the Weir River estuary is significant. The river below Foundry Pond Dam is subject to tidal action. Average tidal difference between mean low water and mean high water in the Weir River is approximately 12 feet. Tidal flats and salt marshes below the dam cover approximately half of the 950-acre total area. This tidal area along the Weir River below the dam, along with Straits Pond, was designated in 1986 as an Area of Critical Environmental Concern (ACEC).[5] The ACEC designation is further discussed in Section 2.111.

The Weir River watershed study area contains approximately 29.3 miles of coastline, including the banks of the tidal portion of the river. The shores of the Hull Peninsula account for most of this total. Numerous islands exist just offshore of the study area. The largest of these is Paddocks Island. Among the other islands are Hog (Spinnaker), Bumkin, Grape, and Langlee.

2.109 Geology

The Weir River watershed is underlain by four basic varieties of bedrock. These include Salem gabbro diorite and Dedham granodiorite[6], which are similar types of granite and are igneous rocks formed approximately 350 million years ago; the Mattapan volcanics are also igneous rocks; and the Roxbury conglomerate is a sedimentary stone. Within the study area there are numerous rock outcrops as well as areas where the bedrock is overlain by a thin layer of overburden soils. This is true mostly in the eastern portion of the watershed in the Cohasset area. Conversely, in the southern and western parts of the watershed, the depth to bedrock reaches a maximum of 90 feet[7]. Granite quarried from the Plymouth River areas has been used for many architectural applications.

Like much of the rest of New England, the surficial geology of the Weir River watershed was heavily influenced by glacial action during the last ice age. Glaciers in the Pleistocene Epoch deposited till onto the ground beneath the ice. This type of soil is generally compact, poorly sorted (well graded) material consisting of a wide range of clay, silt, sand, gravel, and cobbles. This type of material is generally quite dense and relatively impervious. The tall streamlined hills of the project area are drumlins composed primarily of till shaped by successive waves of glacial advance. As the glaciers retreated for the last time, about 10,000 years ago, they also deposited material in the form of outwash carried by meltwater. These formations are known as kames, eskers, and outwash deltas and plains.[8] Collectively these deposits are generally referred to as

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[5] Massachusetts DEM website, http://www.state.ma.us/dem/programs/acec/index.htm.

[6] Emerson, B.K. Geology of Massachusetts and Rhode Island. USGS Bulletin 597, Washington, 1917.

[7] Gale Associates, Inc. “Foundry Pond Diagnostic/Feasibility Study.” Jan. 1992.

[8] Hamblin, W. K. and Christiansen, E. H. Earth’s Dynamic Systems, 8th ed. Prentice Hall, NJ, 1998.

stratified drift because they are varying layers of well sorted (poorly graded) material. The velocity of flow determined the capacity of outwash water to carry soil particles of differing sizes. Seasonal and other climatic variation caused fluctuation in outwash flow velocities and therefore the size of soil particles deposited and carried away. In general, the stratified drift which filled the ancient valleys, such as the one under the Weir River, are composed of relatively coarse sands and gravels. These deposits are very pervious and generally favorable to the development of groundwater supplies. Much of the sand and gravel deposits in the Hingham area are thought to have been deposited in Glacial Lake Bouve, which covered much of Hingham, Weymouth, and Quincy[9]. Portions of the watershed adjacent to streams consist of floodplain alluvium. Alluvium is a term which refers to detrital material deposited permanently or temporarily by streams. It is an unconsolidated layer of gravel, sand, silt, and/or clay which applies to stream channels and floodplains. **Figure 2-5** shows the surficial geology of the watershed.

The surficial geology of the Weir River watershed is basically divided into two distinct sections along a line which runs north-south through the basin. The eastern section of the watershed is primarily till directly over bedrock. This type of stratigraphy generally leads to low infiltration and high runoff rates. Precipitation which falls on this area flows away in intermittent streams or collects in the valleys and lowlands where more pervious soils are common and wetlands form. The western sections of the watershed generally contain stratified drift deposits which are both wider in extent and deeper than on the eastern side. This material is much more conducive to infiltration and therefore supports productive aquifers. Groundwater outflow from these deposits supply baseflow to the streams of the watershed, though in some areas induced infiltration, causing discharge from the streams to the aquifer occurs during some periods of low precipitation and heavy pumping.

2.110 Soils, Land Use, and Hydrologic Characteristics

Soil types and land use classifications are an important part of the watershed description because they influence the amount and, often times, the quality of water which runs off into streams and rivers and infiltrates into the soil. Detailed soil types were obtained from the Soil Conservation Service (SCS) Soil Survey of Plymouth County. Land use classifications were obtained from MassGIS. Surficial geology coverage information, which generalizes soil types into sand and gravel, till and bedrock, and floodplain alluvium, was also obtained from MassGIS. **Figures 2-5** and **2-6** show surficial geology and land use for the watershed, respectively.

Sand and gravel deposits are common throughout the western portions of the watershed. Three dominant soil types, Quonset sandy loam, Merrimac sandy loam, and Hinckley gravelly loamy sand cover the majority of the well-drained sand and gravel watershed area. Till and bedrock are prevalent in the eastern portion of the watershed and typically are not as conducive to the infiltration of water as sand and gravel. Hollis-Charlton rocky, sandy loam, Gloucester very stony fine sandy loam, and Brockton extremely stony loam are the major soil types in this

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[9] Skehan, James W. Roadside Geology of Massachusetts. 2001.

area.[10] There is a relatively small amount of floodplain alluvium in the form of shallow and deep muck surrounding the Weir River and its tributaries. **Table 2-**7 lists, in general terms, the area and coverage of soils in the watershed. **Figure 2-7** graphically displays soil type distribution.

Land uses in the watershed are generally split into residential and wooded. Other pertinent land uses in the watershed include: urban open land, commercial land, wetlands, and recreational land. **Table 2-8** lists, in general terms, the area and coverage of land use in the watershed. **Figure 2-8** graphically displays land use distribution. Land use data was obtained from MassGIS. The data was compiled from aerial photography in 1990 and interpreted by the Resource Mapping Project at the University of Massachusetts at Amherst. Comparison of the land usage figures with the zoning data shown in Section 2.28 and on **Figure 2-9** show most of the land which is now wooded is actually zoned for residential use.

The nature of the soils and relatively undeveloped character of the western portion of the watershed result in the overall watershed being relatively well-draining with fairly high infiltration rates.

2.111 Flora and Fauna

The Weir River watershed provides habitat for a variety of flora and fauna. The watershed contains many important natural wildlife areas, including an Area of Critical Environmental Concern (as designated by the DEM), vernal pools, and rare species habitat. The river also provides for anadromous fish runs, allowing species of fish that live in the sea to return to inland waters to spawn. **Figure 2-10** shows sensitive environmental areas and wildlife habitats in the watershed contain in the MassGIS database including the following: Areas of Critical Environmental Concern, Outstanding Resource Waters, Shellfish Sampling Locations, Anadromous Fish Runs, Estimated Habitats for Rare Wildlife, and Massachusetts Certified Vernal Pools.

Vegetative cover of the Weir River watershed is dominated by forest land including the Wompatuck State Park and the Hingham Town Forest. **Figure 2-6** shows the land use characteristics of the watershed.

According to the Massachusetts Natural Heritage Atlas (1997-98), there are two certified vernal pools, two estimated habitats of rare wildlife, and one priority site of rare species habitat and exemplary natural community within the study area. In addition, the atlas shows estimated habitats of rare wildlife on Hog and Grape Islands, and priority sites on Hog, Grape, Paddocks, and Bumkin Islands.

The Weir River and its tidal flats downstream of the Foundry Pond Dam to the mouth of the river at Hingham Bay, including Straits Pond, have been designated as an Area of Critical

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[10] United States Department of Agriculture, Soil Conservation Service, “Soil Survey: Plymouth County, Massachusetts,” July, 1969.

Environmental Concern (ACEC)[11]. The approximately 950 acres of the Weir River ACEC contains one of the most extensive salt marsh systems in the greater Boston metropolitan area. The area around the ACEC is subject to development pressure. The size of the ACEC, unlike the many small pockets of marshland that dot the urban landscape, supports over 100 migratory and resident bird species, as well as numerous small mammals. An abundance of shellfish have been harvested historically, and continue to feed the bird populations. The marshes and flats are also nursery and feeding areas for a wide variety of finfish, including alewives, smelt, flounder, bluefish, and striped bass. Flood protection is provided by the flood plains of this estuarine system.

Although not included within the boundary of the ACEC, two important recreational areas abut the area: Nantasket Beach, a designated barrier beach, and "World's End," a park owned and managed by the private, non-profit organization "Trustees of Reservations."

Shellfish beds are located off the coastal portions of the study area and in the tidal section of the Weir River. The Weir River and Accord Brook support anadromous fish runs as far inland as Triphammer Pond, about 5 miles from the mouth of the Weir River.[12] A public fishery was established in the river by the legislature in 1805 on the basis of the smelt and alewife runs. The dams in the watershed have severely restricted the runs, but the fish ladders at Foundry Pond Dam and Triphammer Pond Dam are meant to make upstream fish passage possible. Fish sampling by the Massachusetts Division of Fisheries and Wildlife (DFW) in 1988 found Largemouth bass, Chain pickerel, Bluegill, Alewife, Black crappie, and Brown bullhead in Foundry Pond. The New England Aquarium sampled Triphammer Pond in the Fall of 1995 and found Largemouth bass, Bluegill sunfish, Pumpkinseed sunfish, Banded sunfish, Black crappie, Golden shiner, Chain pickerel, and Swamp darter. DFW reports from 1996 lists American eel and Redfin Pickerel as having been present in Accord Brook and American eel, Chain pickerel, Golden shiner, White sucker, Brown bullhead, Pumpkinseed sunfish, Bluegill sunfish, Smallmouth bass, Largemouth bass, and Yellow perch as having been found in Accord Pond. The DFW reports were included with a letter from DFW to the Hingham Conservation Commission which stated that Accord Brook, "probably sustained a wild brook trout population and possibly an alewife run before the area was developed."[13] Both the Plymouth River and the Weir River are listed by the DFW on its 1999 list of springtime "trout stocked waters."[14]

The area surrounding Accord Pond is classified as an Outstanding Resource Water under the Massachusetts Surface Water Quality Standards of 1995. According to 314 CMR 4.00: "Certain waters shall be designated for protection under this provision in 314 CMR 4.06(3) including Public Water Supplies [such as Accord Pond] (314 CMR 4.06(1)(d)1.). These waters constitute an outstanding resource as determined by their outstanding socioeconomic,

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[11] Secretary of the Executive Office of Environmental Affairs. Area of critical environmental concern – Weir River. http://www.state.ma.us/dem/programs/acec

[12] New England Aquarium, "Management Report for Triphammer Pond," November, 1995.

[13] Massachusetts Division of Fisheries and Wildlife, Steve Hurley Personal Correspondence, March 11, 1996.

[14] Massachusetts Department of Fisheries, Wildlife, & Environmental Law Enforcement, "Massachusetts Trout Stocked Waters, 2000," http://www.magnet.state.ma.us/dfwele/dfw/dfwsttrt.htm.

recreational, ecological and/or aesthetic values. The quality of these waters shall be protected and maintained." The GIS data layer was quality-checked by the DEP Wetlands Conservancy Program Staff.

2.20 DEVELOPMENT

2.21 History[15]

The first settlers in the study area were likely Native Americans of the Algonquian Nation. The earliest archeological evidence of human activity in Massachusetts dates to approximately 3,000 years ago. Among the earliest Europeans to immigrate to North America were the Pilgrims, who landed at Plymouth, just 30 miles south of the study area, in 1620. The Plymouth Colony established a post for trading with local Indians in the Hull area in 1621. By 1635, the Towns of Hingham and Weymouth had been incorporated. The area figured prominently in the War of Independence due to its strategic location and harbors. Revolutionary-era industries included fishing, shipbuilding, agriculture, mills, and commerce.

In the 19th Century, the areas around the shore were especially popular with tourists from Boston. At the same time, Rockland was famous for shoe manufacturing – it being said that the town's factories shod half the Union Army. With the start of the World War II, military-related industry became the most important activity in the study area and surrounding locales. Between 1942 and 1945, the Hingham Shipyard built 227 ships for the U.S. and British Navies. Many of the ships were LSTs (Landing Ship, Tank) used in the invasion of Europe at Normandy. At its height, the shipyard employed more than 23,000 workers. Military sites, including storage depots and air defense systems, continued to be located in the area throughout the years of the Cold War.

After the Second World War, the character of the area began to change with the suburban building boom of the 1950's. The towns in the watershed transitioned to residential communities supporting commuters working in the Boston area. Between 1950 and 1955, the population of Norwell almost doubled. Most of the area currently maintains a suburban residential character, but also retains significant areas of forest and park lands. These areas, along with activities on the shore, also attract summer visitors.

2.22 Cities and Towns

The study area overlaps two Massachusetts counties, Plymouth and Norfolk, and includes at least portions of six (6) municipalities: Hingham, Hull, Cohasset, Norwell, Rockland, and Weymouth. **Table 2-9** shows pertinent information regarding the areas of the towns of the Weir River watershed.

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[15] Historical information from facts contained in "Massachusetts Facts" website maintained by the Secretary of the Commonwealth and from "History" sections of Commonwealth Communities town websites.

2.23 Population

The total population within the watershed is difficult to accurately assess since the basin boundaries overlap portions of several municipal boundaries. However, based on the land area of each town within the watershed and its corresponding population density (as per the 2000 US Census population data and Mass. DHCD land area data), approximately 30,319 people live with the watershed / study area. This number increases during the summer due to seasonal residents in the Hull area where summer homes in the Nantasket Beach area cause a summertime increase in the population. Hull is the only community in the study area which exhibits significant seasonal population fluctuations[16]. Estimates of the seasonal population increase in Hull range from 4,500[17] to 6,000[18]. **Table 2-10** lists the 2000 US census figures for all towns connected to the study area.

Trends in the population of the area are tracked and used to make predictions for future growth. These predictions are made by organizations such as the Metropolitan Area Planning Commission (MAPC), the Massachusetts Institute for Social and Economic Research (MISER), and others. Projections by MAPC are listed in **Table 2-11**. The MAPC projected population within the study area (proportioned by the land area of each town within the study area boundaries) is 31,755 in the year 2010 and 32,602 in the year 2020.

The MAPC projections are reasonably similar to those developed by the DEM Office of Water Resources and cited in the 1990 Report on the Evaluation of the Hingham Water Company. DEM projected the combined population of Hingham and Hull (without regard to watershed boundaries) to be 33,100 in 2020, compared to the MAPC forecast of 33,843.

Examination of the population data presented above and in Table 2-11 shows that the overall population of the towns in and around the study area is expected to remain relatively constant for at least the next ten years (and possibly even the next twenty years.) When considered in total, neither large increases nor large decreases in population are forecast for the towns of the study area. From 2000 to 2020 the population of the six towns is projected to increase by a total of only 0.24%. For comparison, the MAPC 20-year (2000 to 2020) total growth estimate for the region is 8.67% or 0.84% annually. However, the population of the study area itself (proportioned by land area of each town within the boundary) is expected to grow by 7.53% or 0.37% annually. It is important to note, however, that the population of the study area is not necessarily the same as the number of consumers who draw water from the watershed. Because of imports or exports of water across the watershed boundary, the service population may be more or less than the actual population and may change at different rates. This will be further discussed under the section on Water Balance (Section 4.50).

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[16] DEM Office of Water Resources, "Draft: Weymouth and Weir River Basin Vol. I"

[17] Ibid.

[18] Massachusetts-American Water Company, "1998 Water Supply Questionnaire"

2.24 Economy

The health of the economy of the watershed study area is important for many reasons. The state of the economy can help predict trends in growth, suggest the need for development, and indicate an ability to pay for improved services, among others.

Table 2-12 is a list of economic indicators for the towns in and around the study area. The towns of Hingham, Cohasset, and Norwell all have median per capita incomes substantially above the state average, while Hull, Weymouth, and Rockland are all close to the state average. Another indicator of the relative prosperity of the communities of Hingham, Cohasset, and Norwell is the low percentage of total town revenue which is derived in the form of aid from the State of Massachusetts. These towns obtain an average of 10.4% of their total revenue from the State, whereas the other three towns receive an average of 29.1% of total revenue from the State.[19]

2.25 Industry

The main sectors of the economies of the towns in and around the study area are primarily wholesale and retail trade, finance, insurance, and real estate (42.5%) and government and services (38.9%) as shown in **Table 2-13**. Manufacturing and heavy industry account for a much less significant portion of employment (13.7%), and the industries of agriculture and mining account for very little employment (0.6%).

The commuter nature of much of the employment in the area is confirmed by noting that in 1990 there were 62,039 residents of the six towns listed as employed, but in 1993 only a total of 40,754 people (approximately two-thirds) are employed locally. There are 52% more employed workers in the towns in and around the study area than there are jobs in these same towns, suggesting that a significant number of residents work in other municipalities.

The three largest employers in Hingham (as of 1993) were The Talbots, C & S Administrative Services, and Russel Electric. In Hull, the three largest employers were Jake's Seafood, Riddle's Supermarket, and South Shore Catering. Super Stop and Shop, The Chart House (seasonal), and Webb Norfolk Conveyor were the three largest employers in Cohasset. The two largest employers in Norwell were Wearguard and Relocation Services and the three largest employers in Weymouth were the South Shore Hospital, the Town of Weymouth, and South Weymouth Naval Air Station. Finally, in Rockland, the three largest employers were the Rockland Trust Company, the Town of Rockland, and Boston Whaler.[20]

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[19] Commonwealth of Massachusetts, Department of Revenue, "FY2000 Estimated Receipts [State Aid Cherry Sheets]," 1999.

[20] Commonwealth of Massachusetts, Department of Housing & Community Development, "Community Profile," http://www.magnet.state.ma.us/cc/hingham.html.

Mining is a very small percentage of total employment, but it is worth noting that sand and gravel pits and rock quarries have been and continue to be operated in the study area. A number of the smaller ponds in the area may be abandoned gravel pits or quarries. The sand and gravel pits are scattered across the area of stratified drift surficial geology while the quarries are mostly in the southwestern portion of the study area.

The proposed redevelopment of the Hingham Shipyard will not significantly alter the industrial base of the region around the study area. The new development plan calls for residential units, retail space, and a hotel.[21]

2.26 Agriculture

Agriculture accounts for less than 1% of the total employment within towns in and around the study area. In Hingham and Hull, which make up the bulk of the watershed study area, 1985 Office of Environmental Affairs data lists only 422 acres of land as being used for agriculture. No cranberry bogs are shown on the USGS quad maps in Hingham or Hull, nor are any growers listed in the towns in the sixth edition of the Massachusetts Green Book. The Green Book does list Penniman Hill Farm in Hingham and Weir River Farm was observed to be located upstream of Foundry Pond.

In Plymouth County, the 1997 USDA Census of Agriculture states that crop sales account for 97% of the market value of agricultural products produced as opposed to 3% for livestock. The average size of a farm in Plymouth County in 1997 was 100 acres, and the average value of products sold per farm was $167,605. Statewide, less than 5% of land in farms is irrigated.

Based on the above general information, agriculture can be assumed to be only a minor contributor to the economy of the area and a minimal consumer of the water resources of the basin.

2.27 Transportation

The Weir River does not and has not supported significant navigation in the non-tidal portions of the river. Recreational boating in the ponds and channels above the Foundry Pond Dam is limited to very small, shallow draft boats; although the dredging upstream of Foundry Pond in the 1950's may have been done, in part, for navigation purposes. In the tidal portion of the Weir River, a channel from Hingham Bay allows access to the Town of Hull's Nantasket Pier. A proposed dredging project will increase the current 6 foot depth of the channel to 10 feet. Commuter boat service is available from Hingham Harbor to Rowes Wharf, Boston, by Boston Harbor Commuter Services and Mass Bay Lines.

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[21] The BSC Group, "Environmental Notification Form: Hingham Shipyard Redevelopment, Hingham, MA," July 31, 1998.

The Weir River watershed is considered within the Greater Boston Area, which has extensive rail, air, and highway facilities. State Route 128 (I-95) and Interstate Route 495 divide the region into inner and outer zones, which are connected by numerous "spokes" providing direct access to the airport, port, and intermodal facilities of Boston. The principal highways of the area are State Route 3, the Southeastern Expressway (Interstate 93), which connects Boston to the South Shore and the Cape, and State Routes 3A and 228. All towns in the study area are members of the Massachusetts Bay Transportation Authority (MBTA). Commuter rail service to South Weymouth is available on the MBTA Kingston/Plymouth line. The proposed Greenbush commuter rail line will extend service through Hingham Center and Cohasset. The proposed construction of the Greenbush line may have a significant impact of growth and development in the study area. The Bay Colony Railroad provides freight rail service to points in the area.

2.28 Zoning

Zoning ordinances in the towns in and around the watershed study area control land use and development. **Figure 2-9** shows a general zoning map for the study area based on information available from Mass GIS. The vast majority of the watershed (approximately 81 percent) is zoned for Residential use. Areas around public water supply sources are, in general, zoned as “Restricted” which reflects local open-space and/or drinking water protection bylaws. Land zoned as Restricted accounts for approximately 11 percent of the watershed. **Table 2-14** shows the general types of zoning designations and areas.

Hingham requires that new single family homes maintain a minimum lot size of 20,000 square feet. This restriction, along with other codes contained within the comprehensive plan, may limit population density in Hingham.

2.29 Growth and Development

Future growth and development in the area is expected to follow the same trends as the existing development. The predominance of areas zoned for residential development indicates that most future growth will continue to be oriented towards homes for commuters working in Boston and other urban centers. Total population within the six towns in and around the watershed is predicted to decline over the next 10 to 20 years, but the majority of that decline is due to population decreases in Weymouth. If Weymouth is excluded, then population is predicted to increase. Since Weymouth accounts for a very small portion of the watershed area and withdraws virtually no water from the watershed, water resources planning should account for expected population growth.

The planned Hingham Shipyard redevelopment project could be a source of significant growth for Hingham. While not within the study area, this project may draw water supply from the Weir River watershed through the Aquarion Water Company facilities. The Preferred Development Plan, as stated by the Environmental Notification Form filed under MEPA, states that 550 new residential units are to be developed, along with 259,000 square feet of retail space, 70,400 square feet of office space, and an 80 room inn. Assuming a low average for household size (2.5), this development could bring upwards of 1,400 new permanent residents to Hingham, an increase in population of approximately 6 percent.

Other redevelopment currently underway in the project area is occurring at the so-called Hingham Annex federal reservation. This land is owned by the U.S. Government and was used in the past for military purposes such as munitions storage and disposal. Environmental contamination of the area is currently being remedied. Upon completion of the clean-up, the land is expected to be turned over to the State as part of the Wompatuck State Park. It is unlikely that such a transfer will have significant demand on the water resources of the area, other than possible water quality improvements associated with the environmental clean-up efforts.

The redevelopment of the South Weymouth Naval Airstation in Weymouth will likely not have a direct effect on the water resources of the Weir River watershed, but it could lead to other development which could increase demand for water from the Weir River Basin. The proposed MBTA Greenbush commuter railroad, which will pass through Hingham, may also alter the development trends in the area and could bring more population to the area as options for commuting into Boston expand.

3.00 HYDROLOGY

3.10 THE HYDROLOGIC CYCLE

The hydrologic cycle represents the natural process in which water is continually circulated and transformed. **Figure 3-1** is a graphical representation of the various elements which comprise the hydrologic cycle. Precipitation falling on the land surface flows into streams or other bodies of water in the form of runoff and infiltrates into the ground. Water which infiltrates into the ground flows slowly through the subsurface and eventually discharges into rivers, lakes, or other bodies of water. Most of the water on earth is stored in streams, lakes, ponds, and, in particular, the ocean. The water is only stored temporarily before it returns to the atmosphere through evaporation. In addition, trees and other vegetation return water to the atmosphere through transpiration. The combined process of evaporation and transpiration is commonly referred to as evapotranspiration. As water evapotranspirates into the atmosphere, it condenses to form clouds where it eventually will precipitate back to the land surface as the cycle continues.

The cycle can be represented by the following equation:

$$P = (SW_R + GW_R) + ET$$

where: P = Precipitation
SW_R = Surface Water (Direct) Runoff
GW_R = Groundwater Runoff (i.e. baseflow)
ET = Evapotranspiration

3.20 HYDROLOGIC BACKGROUND – GENERAL CHARACTERISTICS

3.21 Climate Stations

GZA collected data from a variety of climate stations in and around the watershed to describe the hydrology of the Weir River watershed. Locally, the National Weather Service (NWS)operates hourly (i.e. recording) rain gages in Boston at Logan Airport; in Milton at the Blue Hill Observatory; and at the site of the former South Weymouth Naval Air Station. Other gages in the watershed are cooperative weather stations which record data on a daily basis. Cooperative stations, also referred to as non-recording stations, in or near the watershed include: Hingham, Cohasset, Beechwood, and Plymouth-Kingston.[22] **Table 3-1** lists the stations of interest in this study along with their period of record. The approximate location of the stations are presented graphically in **Figure 3-2**.

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[22] United States Department of Commerce, National Oceanic and Atmospheric Administration, National Climatic Data Center, “Cooperative Summary of the Day,” Volume 16, June, 1995.

3.22 Temperature

Detailed temperature information is most readily available for the recording climate gage in Boston/Logan Airport. Monthly average temperatures in Boston range from 73.5°F in July to 28.6°F in January. Monthly average maximum and minimum temperatures in Boston peak at 81.8°F in July and 21.6°F in January.[23] The temperature range in Hingham averages 71.5°F in July to 27.4°F in January.

3.23 Rainfall

Mean annual and monthly precipitation for the stations in and around the watershed is presented in **Table 3-2**. Stations located closest to the watershed in Hingham, Beechwood, and South Weymouth have similar mean annual and monthly precipitation. The mean annual precipitation using these three gages, including the water equivalent of snowfall, is 48.1 inches, indicative of the mean annual precipitation for the Weir River watershed. Typical monthly mean values for these gages are at their lowest in July at 3.18 inches and at their highest in November at 4.92 inches, but in general precipitation is distributed relatively evenly throughout the year without large monthly variation. Minimum monthly precipitation of 0.35 inches occurred in September, 1957. Maximum monthly precipitation of 18.56 inches occurred in August, 1955, and was associated with hurricanes. The mean annual precipitation in the region is 46.9 inches as computed from the records at the climate stations discussed above. The Cohasset station was not used in the computation of mean rainfall due to its short, 12-year period of record.

3.24 Snowfall

The mean annual (Jan. to Dec.) snowfall for the watershed is 47.7 inches as computed from the records of the climate station at Hingham. Peak mean monthly snowfall typically occurs in the month of February, averaging 13.8 inches. There has not been a recorded snowfall in the months of May, June, July, August, and September. The maximum monthly snowfall in Hingham of 42.7 inches occurred in February, 1969.

3.25 Evapotranspiration

The process of evapotranspiration is difficult to measure directly and is commonly computed as the remainder after all other gains and losses have been calculated (i.e., Precipitation minus Total Runoff). Monthly average temperature records were obtained for the City of Boston to quantify evapotranspiration in the Weir River watershed using the Thornthwaite equation[24]. The Thornthwaite equation relates evapotranspiration (ET), on a monthly basis, to air temperature and daylight duration but without regard to ground cover or vegetation. Theoretical mean monthly and annual evapotranspiration are presented in **Table 3-3**. The mean annual

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[23] United States Department of Commerce, National Weather Service, "Normals, Means, and Extremes: Boston, MA" http://tgsv5.nws.noaa.gov/er/box/climate/BOSTON__MA_____.html

[24] Chow, Ven Te, Ed. Handbook of Applied Hydrology. McGraw Hill, NYC. 1964.

evapotranspiration is computed to be about 26.5 inches. Monthly evapotranspiration values peak in July at 5.49 inches and are negligible when the average daily temperatures are below freezing in January and February. Thornthwaite calculations are presented in **Appendix C**.

The ET rates listed in **Table 3-3** are potential evapotranspiration rates. The amount of evapotranspiration which actually occurs is dependent upon the amount of water which falls as precipitation, and is available for uptake in the root zone. For example, the month of July has a potential evapotranspiration of 5.49 inches. However, if the amount of precipitation is only 1.0 inch and there is no significant water in the root zone, the actual ET will be much less than 5.49. In the months of June, July, and August, average potential ET (as shown in Table 3-3) exceeds average precipitation (as shown in Table 3-2) in the watershed area.

3.26 Extreme Events

The lack of a permanent USGS stream gage in the watershed makes quantifying past flood flows or drought events difficult. The Weir River watershed is located along the coast of New England, making it susceptible to hurricanes, ocean storms, and noreasters. The most significant flood in the area occurred in 1955 due to Hurricanes Connie and Diane. The hurricanes accounted for a large portion of the record-setting 18.56 inch rainfall in August of 1955. Several roads and bridges traversing the Weir River, Crooked Meadow River, and Plymouth River were overtopped during this storm by 3 to 5 feet.[25]

According to precipitation records, drought in the area was at its worst during a period in the mid-1960s. Minimum annual rainfall amounts throughout the basin occurred in 1965. The USGS operated a low-flow stream gage on the Weir River between 1969 and 1971 and between 1989 and 1991. The gage recorded a minimum flow in the Weir River, 0.3 miles upstream of Foundry Pond Dam, of 0.22 cubic feet per second (cfs) or 0.014 cfs per square mile (cfsm) in September of 1991.

3.30 SURFACE WATER HYDROLOGY

The Weir River watershed contains several streams and rivers including the Weir River, Crooked Meadow River, Plymouth River, Fulling Mill Brook, Tower Brook and Accord Brook. There are several ponds which are natural or have been formed by impounding these streams including Accord Pond on Accord Brook, Foundry Pond on the Weir River, Triphammer Pond on Accord Brook, Cushing Pond on the Plymouth River, Fulling Mill Pond on Fulling Mill Brook, and Straits Pond on an unnamed tributary of the Weir River. Estimates of the amount of water flowing into and out of these rivers and ponds will form a major portion of the hydrologic description of the watershed.

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[25] Federal Emergency Management Agency, "Flood Insurance Study for the Town of Hingham," June, 1986.

3.31 Streamflow

Streamflow records are the basis for estimation of water-supply potential and are used to estimate mean annual flows, frequency and duration of both high and low flows, and the magnitude and frequency of floods. The amount of flow in a stream depends on the size and topography of the upstream drainage area, precipitation, surficial geology, soil type, vegetation, evapotranspiration, storage of water, and the influence of development on the system. In areas where inadequate streamflow records exist, these watershed characteristics can be used to develop regional descriptions of ungaged watersheds and generate synthetic streamflow data.

The USGS has not maintained any permanent stream gages within the Weir River watershed. However, low flow, partial record (LFPR) gages were established by the USGS on the Weir River in order to estimate flow-duration and low flow frequency statistics. A low-flow, partial record stream gage was installed 0.3 miles above Foundry Pond on the Weir River during the summers of 1969 through 1971 and 1989 through 1991. An additional low-flow, partial record gage was installed at the culvert on Main Street on the Crooked Meadow River during the summers of 1969 through 1971 and 1994 through 1996[26]. **Figure 3-4** shows the location of stream gages in the watershed. USGS is also currently making monthly instantaneous flow measurements at the Rte. 3A bridge as part of a water quality monitoring project.

Flow-duration curves depict the average percentage of time that specific flow rates are equaled or exceeded at a particular site. **Table 3-4** contains the streamflow statistics which describe the flow-duration curve for the Weir River and Crooked Meadow River as calculated by the USGS using data from the LFPR gages, which are the only data available for these basins. Because this data only covers low flow conditions, it is not possible to use it to extrapolate flows greater than the 50 percent exceedence value. **Figure 3-3** shows the full-range flow-duration curves developed by GZA from USGS permanent gage data from several other similar watersheds in Massachusetts. These similar flow duration curves may be compared to the results obtained from the Weir Basin LFPR gages and used to extrapolate flows greater than the 50 percent exceedence. These other watersheds were selected based solely on similar watershed area and surficial characteristics (i.e., the percent of the watershed underlain by stratified drift, which can affect base flow) in the study area. Discrepancies between estimates for the Weir River and the other watersheds are potentially due to differences in water withdrawals, land use characteristics, stratified drift / soil types, water withdrawals and diversions, and regulation of flow by dams. **Table 3-5** lists other USGS gages located in similar watersheds. A flow of 23 cfs for the Weir River at its confluence with Hingham Bay was obtained for the 50 percent exceedence probability when using the regional regression estimate. This estimate is higher than the estimate of 13 cfs based on the LFPR given by the USGS for the Weir River above Foundry Pond;

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[26] USGS, "Streamflow Measurements, Basin Characteristics, and Streamflow Statistics for Low-Flow Partial Record Stations Operated in Massachusetts from 1989 Through 1996" Northborough, MA, 1999.

however, the LFPR estimate did not consider the entire Weir River drainage area (nor did GZA extrapolate the LFPR estimates in the USGS report to those of less than 50 percent exceedence). When considering flow data from different gages, it is often instructive to normalize data by dividing by the overall area drained. In this way total flow rates in cubic feet per second (cfs) are normalized to cubic feet per second per square mile (cfsm), thereby allowing a direct comparison of data from different gages. Accounting for the difference in drainage areas, the 50 percent flow for the Weir River at Hingham Bay per square mile of drainage area is 1.2 cfs/sq.mi. The LFPR estimate is 0.9 cfs/sq.mi.

A recent proposal to install a real-time USGS flow gage in the Weir River Basin has been indefinitely postponed due to budgetary constraints. Instead, two calibrated staff gages have been installed on the main channel of the Weir River. One staff gage has been placed at the Union Street Bridge and a staff gage at Route 3A has been recalibrated. Staff gages do not provide a continuous record of flows, but allow for instantaneous measurements based on observed depth of water in the channel. A watershed monitoring program has also proposed through an agreement between the Town of Hingham and the Massachusetts American Water Company (now Aquarion). This proposed program is to involve taking flow measurements and groundwater levels at various points in the watershed. **Figure 3-4** shows the location of sampling locations proposed for the watershed monitoring program. This information was obtained from the AWC and the Town of Hingham. In the interim, volunteers from the Weir River Watershed Association have taken intermittent readings from staff gauges installed at various locations in the watershed. This data was used to determine flow rates based on computed stage-discharge relations. The data and results of the Weir River Watershed Associations flow monitoring program are presented in Appendix E.

As part of the Foundry Pond Dam Feasibility Study, Gale Associates, Inc. took monthly flow measurements at the inlet and outlet of Foundry Pond from October, 1987 to November, 1988. A summary of their data can be found in **Table 3-6**. The duration of their flow measuring program is insufficient for use in calculating long-term streamflow statistics, in GZA's opinion.

The absence of a permanent flow gage in the Weir River Watershed has lead to a lack of extended duration flow data for the streams of the basin. In order to generate estimates of average monthly flows, GZA has made use of data from similar watersheds to derive estimated average monthly flows for streams of the Weir River basin. The methodology employed by GZA is discussed in Section 4.53.1 and the results are presented in **Table 4-15** and **Figure 4-4**.

3.32 Low Flows

Low flow discharges during dry weather are particularly important in computing safe yield calculations and determining impacts to watershed plant and animal life. Low flows in an area such as this are generally representative of baseflow or groundwater which is discharging to the stream through the soil. Of particular interest for many applications is the 7Q10 streamflow, or the average low flow rate for seven consecutive days which occurs once every ten years. The

7Q10 represents a lower boundary for water resource use and historically has been used to set wastewater discharge limits. The USGS calculated the 7Q10 at both of their LFPR stream gages. Their data, along with 7Q10 data calculated with the USGS computer program SWSTAT (Surface Water Statistics, USGS, April, 1998) using full-record USGS stream gages in similar watersheds are presented in **Table 3-7**. 7Q10 values obtained by the USGS are 0.02 cfsm at the Weir River in Hingham and 0.06 cfsm at the Crooked Meadow River in Hingham. Estimated 7Q10 values for the similar watersheds range from 0.01 cfsm to 0.05 cfsm, with the exception of the Neponset River gages which have values over 0.10 cfsm.

The 7Q10 value is not an appropriate technique for the establishment of recommendations for instream flows for maintaining aquatic habitat. The 7Q10 statistic was developed for use in designing and regulating wastewater treatment plants and does not address the flow requirements of fish.[27]

3.33 Floods

Due to the lack of USGS stream gages in the watershed, direct statistical analysis of flood flows is not possible. Historic flooding in the area was discussed previously in **Section 3.26**. In watersheds that are gaged, statistical analysis generally involves the analysis of several years of streamflow data. The Log Pearson Type III (LP3) method, first developed by Karl Pearson in 1930, is simply a curve fitting method known to fit many different shapes of observed sample frequency distributions. The LP3 distribution when presented in the probability density form usually has a bell shaped or (with some parameters) a J-shape. This method is best known for its ability to fit flood flow frequency. Frequency curves derived using LP3 or another curve fitting method are only an estimate of the population curve and not an exact representation. A streamflow record (for example) is only a sample of the total population and its prediction ability depends on the size of the sample. The larger the sample, the greater the prediction ability.

Regional regression estimates for ungaged sites in Massachusetts are done through the use of the USGS National Flood Frequency (NFF) computer program.[28] This program utilizes a regional regression equation for Eastern Massachusetts to quantify the 2, 5, 10, 25, 50, and 100 years floods. The results of the regression analysis and the results of flood frequency analyses for the similar watersheds are presented in **Table 3-8**. As seen from the table, the flood flows from the regression analyses are the same order of magnitude as those calculated from the similar watersheds using a Log Pearson III analysis.

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[27] Stalnaker, Clair, et. al. "The Instream Flow Incremental Methodology – A Primer for IFIM", National Biological Service Biological Report 29, March 1995.

[28] United States Department of the Interior, United States Geological Survey, "Nationwide Summary of U.S. Geological Survey Regional Regression Equations for Estimating Magnitude and Frequency of Floods for Ungaged Sites" 1993.

The 1986 Flood Insurance Study also used a USGS regional regression equation to estimate flood flows. The results of their analysis are presented in **Table 3-9**. The flood flows obtained by FEMA approximate the flows obtained with the NFF computer program.

In summary, the 10-year flood predicted by FEMA in Accord Brook in subbasin 3 is approximately 153 cfs and the 100-year flood flow is 480 cfs. At Foundry Pond at the downstream end of subbasin 6, the 10-year flood in the Weir River is 444 cfs and the 100-year flood flow is as much as 1,350 cfs.

3.34 GZA Flow Measurements

GZA visited the watershed on August 19, 1999, October 26, 1999 and April 12, 2000 to take flow measurements at eleven locations along the Weir River and its tributaries during periods of low, normal, and high flow. Flows were measured at selected locations primarily along Accord Brook and the Weir River. Flow measurement locations were chosen to provide a wide geographic distribution, and based on proximity to confluences and accessibility.

Flows were measured using a FloMate Flow Meter which records velocity. The primary technique that was utilized was the "Six-Tenths Depth Method" as described in the USGS paper "Measurement and Computation of Streamflow."[29] Velocity measurements were taken at stations along the stream cross section at 0.6 x depth. The 0.6 x depth velocity is used as the mean velocity in the vertical. USGS states that "Actual observation and mathematical theory have shown that the 0.6 x depth method gives reliable results." This method is recommended for depths between 0.3 ft and 2.5 ft. Very shallow water has been shown to cause underreporting of velocities, but USGS states, "From a practical standpoint, however, when it is necessary to measure velocities where water depths are as shallow as 0.3 ft., the 0.6 x depth method is used." In instances when water depths were greater than approximately 2.5 ft., the "Three-Point Method" was employed where velocities are observed at 0.2, 0.6, and 0.8 times depth. The stream was divided into multiple subsections based on the width of the stream and local features. Vertical velocity readings were taken at each subsection. Depths and widths were recorded at each subsection. Flow rates were then calculated by multiplying the mean vertical velocity by the cross-sectional area of the subsection and summing across the stream.

Quality Assurance / Quality Control procedures for the flow measuring program were established by GZA to provide for accuracy and constancy in the flow measurement program. Flow measurement locations were documented in text, on maps, and with photographs to provide for repeatability of the measurement locations. The velocity meter was zeroed as per the manufacturer's recommendations in a bucket in the morning prior to sampling and also checked for drift. After reducing the field data, flow measurements at each location were compared to observed flow rates upstream and downstream of a particular location. This allowed for a

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[29] Rantz, S.E. et. al. United States Department of the Interior, United States Geological Survey. "Measurement and Computation of Streamflow: Volume 1. Measurement of Stage and Discharge" Geological Survey Water-Supply Paper 2175, 1982.

continuity check to verify the reasonableness of the measured flow rate. Multiple flow rates taken over time at the same location were also compared to verify that the stage versus discharge relationship was appropriate.

The August 19, 1999 measurements were made in an effort to obtain data which would be generally representative of low flow conditions, as August is typically the time in which flows are lowest in streams in eastern Massachusetts. Precipitation in June of 1999 was well below normal (0.29 inches) at the Boston climate station, but rainfall in July (3.44 inches) was actually above normal. Precipitation in water year 1999 (October to September) was also slightly above normal (42.03 inches versus and average of 41.51 inches in Boston) as evident in the climatological data from the National Weather Service/National Climatic Data Center presented in **Appendix D**. Single rainfall events obviously can have a significant impact on flow rates. NOAA data also indicates that more than 0.6 inches of rain fell in the area in the five days preceding the flow measurement. Regression to baseflow can take much longer than this, particularly in watersheds as large as the Weir River with significant stratified drift surficial geology, as evidenced by the hydrograph for the Indian Head River during the same time. Therefore, flows in the lower Weir River watershed, particularly in the Weir River itself, may not have regressed to pure baseflow when the measurements were made. Flow data is presented in **Table 3-10** and the sampling locations are plotted in **Figure 3-4**. Flow measurement locations on Accord Brook were located at Route 53, Route 228, Prospect St. and South Pleasant St. Flow in the Crooked Meadow River was measured at the crossing of Main St., and flow in the Fulling Mill Brook was measured just downstream of the Fulling Mill Pond Dam. Flow Measurement locations on the Weir River included the crossings at Free St., Union St., and the driveway to the Weir River Farm. Flow measurements were also taken across the Weir River channel near Eastgate Lane and at the spillway of Foundry Pond Dam. The flow measurements at the dam made use of an assumed weir coefficient for the spillway, and are therefore subject to a certain level of uncertainty.

August flows in the Weir River ranged from 1.2 to 2.8 cfs and flow in the Crooked Meadow River was about 1.9 cfs at the culvert at Main Street. Accord Pond was below the spillway level and Accord Brook was dry in many locations during GZA's visit. Low flows between Routes 53 and 228, emanating from surface drainage and seepage from Accord Pond Dam, were measured to be about 0.1 cfs. The Accord Brook was not spilling over the diversion weir.

The October 26, 1999 measurements were considered representative of normal flow conditions. However, precipitation levels of September and October were several inches over normal precipitation levels (Appendix D). Data from the October round of flow measurement is presented in **Table 3-10**. In contrast with the August measurements, flow in the Weir River ranged from about 11 cfs to 31 cfs and flow in the Crooked Meadow River was about 3.4 cfs. Accord Brook continued to be dry in some locations since there was no flow past the Accord Brook diversion. A small amount of flow in Accord Brook between 0.3 and 0.9 cfs was measured at Route 228 (Main Street) and Route 53, respectively. Outflow from the fish ladder and spillway at Triphammer Pond was estimated to be about 1.9 cfs.

Flow measurements of April 12, 2000 were considered representative of average annual high flow conditions (not extreme flood flows). Typically, spring rainfall and snowmelt contribute to increased streamflow during March and April. However, the below average snowfall and precipitation from November to March may have produced less than the average annual high flow for April. Despite relatively dry conditions prior to our measurements, April flows were greater in magnitude than those of October (Table 3-10). Flow in the Weir River ranged from about 14.2 cfs to 36.5 cfs. Accord Brook showed a marked increase in flow as the diversion was overtopped and Accord Pond Dam was spilling. Flow in Accord Brook ranged from about 0.8 cfs at the Route 53 culvert to 1.5 cfs over the diversion dam and about 8.6 cfs at the Pleasant St. Culvert.

Based on the flow measurements taken by GZA in the Weir River watershed, preliminary rating curves have been developed for selected locations. These rating curves relate stage (water depth) to discharge (flow rate) in the stream. Using these relationships, flow rate at any given time at these locations may be approximated by measuring the maximum water depth in the stream and referring to the rating curve. GZA has developed rating curves for locations near road culverts which will be convenient for future flow monitoring programs by regulatory agencies, utilities, or volunteer groups. The rating curves are contained in **Appendix E**. The rating curves should be considered preliminary because they are based on a very limited amount of data. As additional data is collected, the rating curves should be updated.

In addition to the data collected by GZA, flow data has also been collected by the USGS and volunteers from the Weir River Watershed Association. The USGS operated a low-flow stream gage on the Weir River between 1969 and 1971 and between 1989 and 1991. The gage recorded low flows in the Weir River, 0.3 miles upstream of Foundry Pond Dam. In 1999, the USGS collected some limited flow and water-quality data for the Weir River at Route 3A in Hingham. The volunteer group began monitoring stream depths at various locations in the watershed beginning in 1999. Available data from these programs is contained in **Appendix E**.

GZA and others including the USGS have collected a limited amount of flow data in the watershed. However, the period of record and sample size is not sufficient to generate monthly flow patterns based on existing data. The GZA data was collected primarily for the purpose of developing cross-section flow rating curves for use in the aquatic habitat evaluation portion of the study. Simulated monthly flows in the watershed have been developed as part of the Water Balance and are further discussed in **Section 4.6**.

3.35 Storage

There are six major ponds in the Weir River watershed, all of which are impounded by dams. Accord Pond is the largest water body in the watershed with a maximum storage capacity at the top of its dam of 985 acre-feet or 321 Mgal, and the only one used as a drinking water supply. It is a natural kettle pond whose water level has been raised by a dam. The other ponds include: Foundry Pond, Triphammer Pond, Straits Pond, Cushing Pond, and Fulling Mill Pond. Pertinent pond data is summarized in **Table 2-5**.

Figure 3-5 shows the relationship between storage, elevation, and discharge for Accord Pond Dam. The pond, including the portion of the Great Pond which is not impounded by the dam, contains about 1,535 acre-feet of water, of which 845 acre-feet of water is usable due to the elevation of the water supply intake pipes. The maximum capacity of the spillway (i.e., discharge coincident with a water level at the top of the dam elevation) according to the 1979 U.S. Army Corps of Engineers Phase I Report is about 42 cfs.

3.36 Tides and River/Bay Interaction

The Weir River flows into Hingham Bay near World's End in Hingham and at the western shore of Hull. At this point, southward to Foundry Pond Dam, the river is influenced by the tides. Foundry Pond Dam effectively limits the tidal action from influencing the river to the north of the dam. The outlet of the Weir River is relatively protected from wave action by the Town of Hull to the northeast. The normal tidal range at full moon, according to local tide charts, is about 12 feet.

Flooding in the coastal areas above Foundry Pond Dam due to hurricanes or other ocean storms has been observed according to the FEMA FIS.[30] For example, the February 1978 storm, locally referred to as the "Blizzard of 1978," caused inundation of the low lying areas north of Foundry Pond Dam, as well as areas of Northern Cohasset including Crescent Beach at the northwest tip of Straits Pond.

3.40 GROUNDWATER HYDROLOGY

An important part of the hydrologic cycle occurs in the subsurface as groundwater moves through the saturated zone beneath the water table from areas of recharge to areas of discharge. Groundwater storage and circulation are affected by the earthen materials, both unconsolidated deposits and bedrock, which constitute the subsurface. Optimum water resources development and management require information on: the extent and hydrologic characteristics of subsurface materials, the amount of water available, and the groundwater flow system and its relation to the overall hydrologic cycle.

3.41 Aquifer Descriptions

Groundwater is water which infiltrates into the subsurface down to geologic layers called aquifers. Groundwater is most readily available in soils that have relatively large, uniform, and

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[30] Federal Emergency Management Agency, "Flood Insurance Study for the Town of Hingham," June, 1986.

interconnected pore spaces between soil particles. Typically, soils which exhibit these characteristics include “stratified drift” sand and gravel deposits. **Figure 2-5** shows the surficial geology of the watershed. Stratified drift is unconsolidated water-sorted material that is composed of interbedded layers of gravel, sand, silt, and clay. These materials were deposited during the deglaciation of the basin and generally occur in areas that served as drainage-ways for glacial meltwaters or sites of temporary glacial lakes.

Till is a non-stratified mixture of sediment deposited directly by glacial ice. Till and finer grained soils such as silt and clay are not usually conducive to the storage or withdrawal of groundwater and can limit the movement of groundwater in the subsurface. Groundwater can also exist in the fractures of bedrock which underlies unconsolidated deposits.

There are two different types of aquifers: confined and unconfined. Confined aquifers are overlain by a low-permeability layer of soil such as clay that does not allow for the efficient passage of water. The overhead confining layer in a confined aquifer allows for the development of pressure heads within the aquifer, such as are encountered at so-called “artesian” wells. Unconfined aquifers do not have such restrictions and extend all the way up to the water table. At the water table, the water pressure in the aquifer equalizes to atmospheric.

Much of the western portion of the Weir River watershed is underlain by sand and gravel deposits. Sand and gravel make up about 46 percent of the basin geology. Aquifers composed of this material are capable of supplying large quantities of water on a sustained basis. The major aquifer in the watershed is located in sand and gravel deposits and is unconfined. **Figure 3-6** shows the aquifers in the watershed. The high-yield portion of the aquifer can be separated into a northern and southern area. The first area, the northern part of the aquifer, underlies the central portion of the watershed south of Hingham center to an area between Fulling Mill Pond and the confluence of the Crooked Meadow River and Fulling Mill Brook. The second area, the southern portion of the aquifer, is located in the southern portion of the basin beneath Accord Brook near the border between the Towns of Hingham and Norwell. The extent of the southern portion of the aquifer indicates that the groundwater divide likely does not correspond to the surface water divide under the influence of pumping from municipal wells. This is commonplace in the Neponset, Weymouth, and Weir basins[31].

Hydrogeologic data is available in several USGS publications and available public water supply (Zone II) delineation studies. A Zone II delineation is typically required by the DEP for water withdrawals of 100,000 gpd or more. Zone II studies typically use 2- and 3-dimensional mathematical groundwater models to estimate the zone of contribution (recharge area) for a well pumping at its rated capacity for 180 days without recharge. A conceptual Zone II delineation has been performed for the AWC wells in the watershed by Talkington Edson Environmental Management, LLC (TEEM). In addition, a DEP-Approved Zone II has been completed for the

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[31] United States Department of the Interior, United States Geological Survey, Water-Resources Investigations Report 90-4144, “Water Resources of Massachusetts” 1992.

wells owned and operated by the Town of Norwell. In the absence of approved Zone II delineations, Interim Wellhead Protection Areas (IWPA) are adopted as the primary, protected recharge area for groundwater sources. The IWPA is not a reflection of the extent or shape of the actual aquifer. An IWPA is circular and its radius is proportional to the well pumping rate and ranges from a minimum of 400 feet and a maximum of ½ mile. Detailed information regarding the depth, movement, and the amount of water available in the aquifers obtained from these various sources is presented below.

3.42 Saturated Thickness

Saturated thickness can be an indication of the amount of water stored in an aquifer. **Figure 3-7** describes some of the important characteristics within a stratified drift aquifer. The saturated thickness of an aquifer, (b), refers to the depth of the aquifer from the water table to the bottom of an unconfined aquifer. Saturated thickness is typically determined by analyzing driller's logs of wells and test borings. Thickness is influenced by the geometry of the underlying bedrock. Commonly, bedrock is deeper at the center of a valley than at the sides. Therefore, saturated thickness is often at a maximum at the valley axis. Where all other conditions are equal, the amount of water an aquifer will store and yield will be higher for thicker aquifers.

Table 3-11 shows selected aquifer characteristics at each well location. The saturated thickness of the aquifer ranges from 40 feet to as much as 100 feet. The northern portion of the aquifer which contains the AWC's Downing and Free Street wells is very deep with a saturated thickness between 70 feet to 100 feet. The southern portion of the aquifer which contains the AWC's Prospect and Scotland Street wells is also deep, ranging from 60 feet to 80 feet. The wells owned and operated by the Town of Norwell are located in a portion of the aquifer which has a saturated thickness between about 20 feet to 50 feet.

3.43 Transmissivity

Transmissivity is a measure of how much water will flow through a unit width of the porous media of an aquifer under an unit hydraulic gradient. Transmissivity is the product of hydraulic conductivity of the aquifer material and the saturated thickness of the aquifer. Hydraulic conductivity, shown as K on **Figure 3-7**, is a property of soil which indicates its ability to convey water. Sands and other coarse-grained materials typically have larger values of K than other finer-grained materials. Transmissivity can be calculated as:

$$T = K \times b$$

where: T = Transmissivity (gal/day/ft)
K = Hydraulic Conductivity (gal/day/ft^2)
b = Saturated Thickness (ft)

and represents the volume of water moving through a one-foot wide vertical section of aquifer material per day with a gradient of one vertical foot per horizontal foot. Transmissivity can be calculated using pumping or aquifer tests. In the absence of pump test data, transmissivity can be estimated from well specific capacity data and water table drawdown or logs of wells and test holes.

Table 3-11 includes a listing of calculated and estimated transmissivities for each well location in the watershed. Typical transmissivities range from about 20,000 to 75,000 gpd/ft throughout each aquifer. The transmissivity value reported by the Conceptual Zone II report for the wells at Free Street were based on a yield evaluation report for the Free Street No.4 in 1982. Values reported for the Prospect and Scotland Street wells were calculated using pumping tests done when the wells were installed in the 1950s. Estimates of transmissivity were made for the Downing Street and Fulling Mill wells based on the soil type in the aquifer. Transmissivity for Norwell-owned wells were estimated based on hydraulic conductivity and saturated thickness data provided in the Zone II study, except for Well No. 10 which had a reported transmissivity value in the study.[32]

3.44 Storage and Storage Coefficients

Storage and storage coefficients relate to an aquifer's ability to yield water. Storage coefficients, along with transmissivity, can be used to estimate the water-table drawdown due to pumping wells, for any given time period or vice versa. The amount of water that can be withdrawn from an unconfined aquifer is only a fraction of the total storage and is derived from gravity drainage.

For unconfined aquifers such as in the Weir River watershed, storage coefficient, "S", is equal to the specific yield. The specific yield is defined as the volume of water that an aquifer releases from or takes into storage per unit area of aquifer per unit change in head and is expressed as a percentage of unit volume. Fine-grained materials have lower values of specific yield than coarse-grained materials such as sand and gravel. For stratified drift aquifers such as the one in the Weir River watershed, storage coefficients typically range from 0.05 to 0.30, depending on the grain size of the aquifer material and the time period. In many cases, a value of 0.20 is assumed to be a reasonable and possibly conservative value.

3.45 Gradients and Flow Patterns

Figure 3-8 illustrates the flow patterns that are typical within a stratified drift aquifer. In general, without considering the effects of groundwater pumping by the wells in the Weir watershed, the groundwater flow pattern is expected to trend from south to north, generally from topographic highs to low and discharging into rivers and streams. The hydraulic gradient can be

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[32] Reed, "Zone II Delineation, Grove St. Well Field, Norwell," September, 1994.

thought of as the groundwater equivalent of stream slope. Gradients for the AWC wells are shown in **Table 3-11**.

3.46 Recharge and Induced Infiltration

Natural recharge to aquifers is derived from precipitation that falls within the basin boundaries. The amount of water that infiltrates into the soil and reaches the saturated zone depends upon many factors, such as the intensity and duration of rainfall, soil types, vegetative cover, season, and land slope. Natural recharge from precipitation occurs mainly from October to April when groundwater runoff exceeds evapotranspiration. The amount of groundwater recharge occurring can also be affected by human activity in the watershed. Development can increase the amount of impermeable surface within a watershed and thereby reduce infiltration. Increased pumping of wells can reduce the amount of groundwater in storage and provide more space for recharge. Pumping can also reverse the water-table gradient near streams or other water bodes, causing surface water to move into the aquifer and toward wells. This process is called induced infiltration and the recharge resulting is called induced recharge. Artificial facilities for recharging aquifers (Fulling Mill Ponds) have also been constructed in the study area. These facilities include basins above the water table that collect stormwater runoff or surface water from streams and allow it to infiltrate into the saturated zone using infiltration galleries.

Natural recharge to stratified drift aquifers such as the Weir River aquifer consists of precipitation that infiltrates into subsurface and surface water that percolates into the stratified drift from adjacent till-bedrock uplands. Where pumping is greater than the natural recharge, there will be a resulting net decrease of water in storage and a corresponding decline in groundwater levels. These effects may be either seasonal, with wet weather infiltration restoring groundwater levels, or long-term if annual withdrawals outstrip overall annual recharge. Natural recharge can be estimated by measuring and summing the components of groundwater discharge over a period in which there is no net change in groundwater storage. The sum of groundwater runoff, evapotranspiration, and underflow accounts for the major part of groundwater discharge from areas where there is little or no pumpage and has been used as a conservative estimate of natural recharge. Hydrologic studies of several small drainage basins in the states of Massachusetts, Connecticut, and New York performed by the USGS suggest that a relationship exists between the amount of groundwater outflow from a small basin and the proportion of the stratified drift which is present underneath the basin.[33]

The average annual relationship is linear and can be expressed as:

$$Y = 0.6X + 35$$

where: Y = Groundwater outflow as a percentage of total runoff (%)
X = Percentage of total basin area underlain by stratified drift (%)

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[33] USGS, “Water Resources Inventory of Connecticut, Part 10, Lower Connecticut River Basin”, p. 37.

The total runoff is composed of the baseflow in a stream, which can be thought of as groundwater discharging to the stream through the soil, and the direct runoff which is a result of precipitation that is flowing overland by gravity into the stream.

Although recharge by induced infiltration and the factors controlling it are well known, it is difficult to evaluate quantitatively in the watershed. Estimates of recharge and infiltration are dependent on understanding the surface water-groundwater relationship and are further discussed in Section 4.50.

3.47 Bedrock Aquifers

Bedrock can also store water within fractures and joints. The quantity of water which can be withdrawn from bedrock on a regional basis is governed by the amount of recharge from precipitation and the ability of the bedrock aquifer to transmit water. Water transmission in bedrock is largely a function of the degree and connectivity of fractures and joints in the rock. These features are typically found at contacts between rock types and in fault zones. The major Ponkapoag fault runs through Hingham and Hull and forms the southern boundary of the Boston Bedrock Basin. This fault separates conglomerates in north Hingham and slates in Hull from the Dedham granite formation which underlies most of Hingham and Cohasset.[34] A study in the nearby Southeast Coastal Basin from Cohasset to Kingston completed in 1993 by the USGS examined yields of 133 bedrock wells throughout the basin[35]. The median yield of the wells was 6 gpm. Bedrock wells commonly supply adequate quantities of water for household use, but generally have insufficient yield for public water supply. However, the Source of Supply Study conducted for the MAWC in 1994 indicates that, "A typical bedrock well in the Hingham area drilled to a depth of 600 feet may be expected to yield between 100 gpm to 300 gpm."[36]

3.50 SURFACE-GROUNDWATER INTERACTION

In areas where surface and groundwater are both used for water supply, the connections between the two sources become more important. Surface water can infiltrate into the ground to recharge aquifers and groundwater can flow into streams or other water bodies. During dry weather, groundwater discharging into streams comprises the total amount of flow in the Weir River and its tributaries and is referred to as baseflow. Water supply withdrawals from aquifers can reduce base flows. Other factors may also reduce base flows. For example, paving and development can reduce the amount of groundwater recharge by causing water to run off rather than infiltrate, and inflow into storm and sanitary sewers can lower the groundwater table. Surface-groundwater interaction in the Weir River watershed is further discussed in Section 4.50.

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[34] Skehan, James W. Roadside Geology of Massachusetts. 2001.

[35] USGS, "Yields and Water Quality of Stratified-Drift Aquifers in the Southeast Coastal Basin, Cohasset to Kingston, Massachusetts", 1993.

[36] American Water Works Service Company, "Hingham Source of Supply Study", 1994.

3.60 WATER QUALITY

As water circulates through the hydrologic cycle, its natural water quality changes. In the atmosphere, water vapor dissolves dust, gases, and ocean salts and carries them to the land surface. On the surface, runoff picks up solids as it travels over land into streams and dissolves additional materials as it percolates through the soil into the water table. **Figure 3-9** shows the natural water quality in the hydrologic cycle. **Figure 3-10** shows the potential changes in the water quality in the hydrologic cycle due to the impacts of human activity. Water quality is closely related to water quantity. It is important to maintain good water quality to assure the safety of the drinking water supply, as well as to provide the necessary habitat for the proliferation of natural wildlife. Water quality was not directly addressed by this study, but the following sections summarize some of the relevant available information.

3.61 Surface Water Quality

3.61.1 Streams and Rivers

The water quality of streams and ponds results from the combined water quality of precipitation, overland runoff, and groundwater discharge. Based on the available data, the main surface water quality issue in the basin is increased phosphorous loading[37]. Water quality data taken from the Foundry Pond Dam Feasibility Study is presented in **Table 3-6**, which was also part of the flow measurement discussion in Section 3.3.1, and **Table 3-12**. **Table 3-6** contains the results of the monthly sampling done at Foundry Pond Dam in 1987-1988. Inlet station data is representative of water quality in the Weir River, while outlet station data is more indicative of pond water quality. Dissolved oxygen levels were highest during winter months, peaking in February at 12.6 mg/L, and lowest during summer, 5.2 mg/L in July. Phosphorous levels peaked in November and December, reaching a maximum level of 0.77 mg/L in December. **Table 3-12** shows the results of three sampling rounds done in October, November, and August of 1988. Sampling locations for the 1988 study included: Leavitt Street crossing of the Weir River near the town hall, Union Street crossing at Weir River near the high school, Route 228/Tower Brook Road crossing of the Tower Brook south of Cole Corner, Route 228/Friend Street crossing of Crooked Meadow River near the High St. Cemetery, and the Fulling Mill Pond outlet. Flow was at its highest during the August 1 sampling round, ranging from 5.5 cfs to 18.7 cfs – likely as a result of much higher than average rainfall in July of that year (7.62 inches at Logan Airport). Flow during the October and November sampling rounds was relatively lower, ranging from 0.35 cfs to 2.8 cfs in October and 0.6 cfs to 3.5 cfs in November. Dissolved oxygen concentrations ranged from 5.1 mg/L to 8.3 mg/L during August and 8.5 mg/L to 10.2 mg/L in November. Phosphate levels were highest in October and at the Tower Brook Road and Fulling Mill Pond locations at 0.23 mg/L and 0.303 mg/L respectively.

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[37] Gale Associates, Inc. "Foundry Pond Feasibility Study" Jan. 1992.

As indicated in **Table 3-13**, runoff from the more developed western portion of the watershed contributes a significantly greater annual phosphorous load than the predominately forested eastern half (62 kg/km^2/yr vs. 40 kg/km^2/yr). Tributaries with the highest values of phosphorous were, in order, Tower Brook, Fulling Mill Pond, and the Plymouth River. The 1988 study suggested more sampling was needed to locate the suspected sources of phosphorous loading. However, potential sources of phosphorous include lawn fertilizers, storm drainage, septic systems, and release from decaying leaf litter in adjacent wetlands during the fall and early winter. Phosphorous is an important indicator of water quality because it is typically the limiting nutrient in fresh water bodies.

Water quality data from the current USGS Weir River sampling program at Route 3A on the Weir River is contained in **Appendix E** and is the most up-to-date. These data are currently provisional and subject to revision. Measured dissolved oxygen peaked at 11.3 mg/l in January and was lowest in June. Total ammonia and organic nitrogen ranged between 0.33 and 0.666 mg/l (as N). Total Phosphorus ranged between 0.021 and 0.044 mg/l (as P). Of particular interest are the June 1999 USGS data which show elevated bacteria levels. Fecal coliform and E. coli levels were as high as 570 cols/100 ml and 410 cols/100 ml, respectively, during the sampling period.

3.61.2 Lakes and Ponds

Many of the ponds in the basin experience phosphorous overloading, including Triphammer Pond and Foundry Pond. Foundry Pond is very shallow and contains an emerging marsh. The shallow water leads to elevated temperatures and low dissolved oxygen levels which are stressful to fish and may lead to fish kills[38]. Triphammer Pond has similar problems with very low water levels. Much of Triphammer Pond is covered by aquatic vegetation during the summer months and there are algal blooms present around the dam area. Fulling Mill Pond is surrounded by 163 acres of land that are owned and protected by the AWC. Fulling Mill Pond has problems similar to Triphammer and Foundry Ponds: shallow depths and high nutrient loading from a large waterfowl population and runoff from Route 228 contributes to a significant amount of aquatic vegetation.[39] Nutrient loading in the ponds of the watershed may contribute to water quality problems which could degrade aquatic habitat within the ponds. These issues are, however, generally separate from the issue of the quality of the habitat in the streams and rivers of the watershed.

Accord Pond is currently the only surface water body used as a source of drinking water in the study area (though the well near Fulling Mill is also technically considered a surface water source.) Water quality testing for drinking water contaminants such as total coliform bacteria, manganese, color, turbidity, and sodium has taken place in the pond since the

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[38] Gale Associates, Inc. "Foundry Pond Feasibility Study", Jan. 1992.

[39] Gale Associates, Inc. "Foundry Pond Feasibility Study", Jan. 1992.

1960s by the Massachusetts Department of Public Health and the AWC and its predecessors. The water quality of the Pond has been relatively constant since monitoring began[40].

Total coliform bacteria in Accord Pond have exceeded water-quality standards to the extent that, in 1974, the Pond was temporarily discontinued as a water supply source. Values of 1000 per 100 mL are common in suburban and urban areas; levels of 300 per 100 mL were measured in Accord Pond. Raw water from Accord Pond is filtered and disinfected at AWC's treatment plant[41].

Manganese is listed as a Secondary Contaminant. The Secondary Maximum Contaminant Level (SMCL) for drinking water is 0.05 mg/l. SMCL standards are developed to protect the aesthetic qualities of drinking water and are not health based and are not legally enforceable. Data from the Accord Pond Water Supply study indicates manganese concentration as high as 0.11 mg/l[42]. Manganese is a naturally occurring element derived from rocks and is characteristically high in New England. The main problems with manganese are aesthetic and do not typically concern the health of the pond.

Color can be effected by the presence of algal blooms. Controlling algal blooms is the primary method of reducing color levels. Color typically varies seasonally because algal blooms typically occur during the mid- to late-summer. Color levels in Accord Pond have not exceeded drinking water standards since 1975. Turbidity levels in the pond have not exceeded drinking water standards since 1960.

In general, Accord Pond is slightly acidic, with pH values ranging between 5.7 and 7.3 (a pH of 7.0 is considered to be neutral). Most Massachusetts lakes and ponds exhibit slight acidity, presumably due to aerial pollutant deposition.[43] pH values below 5.0 are considered to be too acidic for most fish to survive.

Alkalinity is the quantitative capacity of water to react with hydrogen ions. It is important because it buffers pH changes that occur naturally as a result of plant activity in the pond. Components of alkalinity, such as carbonate and bicarbonate, may also bond with heavy metals and reduce their toxicity. Alkalinity levels in Accord Pond are low, averaging about 4.5 mg/L. The pond is therefore susceptible to pH fluctuations and heavy-metal contamination.

Hardness is a measure of dissolved metallic ions. In the majority of freshwater lakes, hardness is caused principally by calcium and magnesium ions. Accord Pond exhibits very low concentrations of these ions and is considered to be "soft." The low hardness of the water may be due to the absence of limestone-bearing strata in the watershed.

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[40] Metropolitan Area Planning Council, "Protecting the Accord Pond Supply", July 1981
[41] Metropolitan Area Planning Council, "Protecting the Accord Pond Supply", July 1981
[42] Ibid
[43] Ibid.

Nitrogen and phosphorous levels in Accord Pond, similar to the other waters in the Weir River watershed, indicate that there is substantial nutrient input. Nitrate levels have averaged about 0.2 mg/L which is an indication of nutrient-enriched conditions. Phosphorous levels fluctuated in the pond from 0.1 mg/L to 0.4 mg/L, according to data collected by the Massachusetts Department of Environmental Quality Engineering between the mid-1960's to 1980. These levels may lead to the eventual eutrophication of the pond, which would produce anaerobic conditions unsuitable for fish and increase the cost of treatment of water for water supply use. The source of the phosphorous and nitrogen loading in the watershed is unclear. Potential sources for these nutrients include septic systems, stormwater runoff, fertilizers, water fowl, and leaf litter. Overabundance of nutrients is considered to be a threat to water quality and may lead to the eutrophication of water bodies. More recent data would be useful in evaluating the current condition of Accord Pond in reference to nutrients.

3.62 Groundwater Quality

Groundwater is the major source of drinking water in the Weir River watershed and monitoring its quality is vital to maintaining a reliable water supply. The AWC has tested for 30 parameters for each of its wells. Results of the testing performed for the Conceptual Zone II Delineation are presented in **Table 3-14**. One of the major water quality problems is the elevated level of manganese present in the groundwater. The concentrations of manganese in raw groundwater have been historically higher than the secondary maximum contaminant level (SMCL) periodically for the majority of the AWC wells. Elevated concentrations of iron are also a problem with raw groundwater. These metals are naturally occurring and do not indicate contamination due to human activities. The water typically meets all other drinking water standards.

Safe Drinking Water Act (SDWA) Amendments passed in the early 1990's established provisions for the control of radionuclides such as radon within public water supplies. In New England, these compounds are very common and occur naturally due to the type of bedrock in the region. Radon levels in the groundwater at Free Street Well No.3 and the Prospect Street Well may be high enough to require treatment. A report prepared for the Massachusetts-American Water Company in 1992 states, "It should be noted that the level of radon found in the 1991 water analyses for the MAWC supplies would require treatment for removal, including the Free Street Well No. 3 and the Prospect Street Well, both of which previously required minimal water quality treatment."[44] The Massachusettts Drinking Water Office of Research and Standards Guideline Standard for radon-222 is currently 10,000 mg/l.[45]

The SDWA also set allowable levels for corrosivity of municipal water supplies. The intent of these standards is to regulate the amount of lead and copper that leach from piping systems into the water supply. Control of corrosivity is commonly accomplished by elevating the

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[44] Weston and Sampson, "Conceptual Review of Water Source Treatment and Operation Massachusetts American Water Company." 1992.

[45] Massachusetts Department of Environmental Protection, Spring 2001 Drinking Water Standards.

pH of water and with chemical treatment. Table 3-14 includes lead and copper levels in the AWC raw water supply.

3.63 Impacts of Human Activity on Water Quality

Potential sources of surface and groundwater contamination include underground fuel storage, wastewater, road salt, leachate, hazardous wastes, and pesticides. Contamination from these sources may be direct or via stormwater drainage. **Figure 3-11** shows the location of landfills, underground storage tanks (USTs), and groundwater discharge locations within the limits of the watershed.

Groundwater discharge points shown on the map indicate DEP-permitted discharges of sanitary sewage in excess of 10,000 gallons per day (gpd), discharges of non-contact cooling water, discharges from coin operated laundromats, car washes and treatment systems designed to remediate contaminated groundwater. There are two groundwater discharge points in the southern portion of the watershed, one car wash near Route 3 in Hingham and another facility just south of the Hingham town line in Norwell.

The town of Hingham operates a town landfill in an abandoned gravel pit northwest of Zion Hill. This site is just west of the boundary of the Weir River watershed, but may affect groundwater quality, since groundwater divides do not necessarily exactly coincide with surface watershed boundaries. The Town of Cohasset maintains a landfill in the northeast area of the basin. There is one additional landfill site in the watershed shown on the MassGIS data layer, **Figure 3-11.** Leachate is liquid waste resulting from water percolating through buried materials in sanitary landfills, waste impoundments, and other disposal sites. Leachate can contain inorganic and organic contaminants depending on the materials through which it is percolating.

Leakage of fuels stored in USTs can lead to groundwater contamination. There are over 50 facilities with USTs in the Town of Hingham. The Hingham fire department reportedly requires the installation of observation wells at new UST installations.[46] Older, unprotected steel tanks have an average life expectancy of 15 years in corrosive soils such as those present in Massachusetts. New tanks have better resistance to corrosion and better leakage control measures. To date, the wells operated by the AWC have not indicated contamination with volatile or synthetic organic contaminants.

GZA conducted a preliminary search of EPA-regulated RCRA facilities and DEP Bureau of Waste Site Cleanup locations in the watershed (Appendix B). Since the study area is not heavily industrialized, environmental contamination is limited. June 1997 site work at three service

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[46] Metropolitan Area Planning Council, "Town of Hingham Groundwater Protection Study," March 1987.

stations was listed as underway as required by DEP. Four additional sites were listed by the DEP for Failure to Meet Deadline.

The Hingham Annex, which is a US Army and Naval Reserve facility, is currently undergoing clean-up of materials related to military activities. The DEP lists such materials as petroleum, VOC's PCB's, metals, asbestos, and explosives as having been present on the site. The nearest EPA-listed National Priority List site near the basin is the South Weymouth Naval Air Station, roughly a mile southwest of the southern-most part of the basin. **Appendix B** contains a list of sites which appeared in the EPA regulated or DEP MCP database.

Approximately twenty percent of the Town of Hingham, in the northern portion of the watershed, is serviced by sanitary sewer. The remainder of the watershed area is serviced by individual on-site septic systems. **Figure 3-12** shows the area of Hingham which is served by the sewer system. Improper wastewater treatment or disposal can threaten the health of surface water supplies by introducing excessive nutrients that can lead to eutrophication of open water bodies. Bacterial contamination of surface water supplies is also a potential result of improper sewage disposal. Failure of septic systems can cause excessive nutrients, bacteria, and other contaminants to leach into groundwater. A 1983 Wastewater Management Study conducted by Metcalf and Eddy found numerous cases of septic system failures and frequent pump-outs in Hingham. These failures have not historically been serious nor numerous enough to impact the quality of groundwater in the watershed according to the data maintained by the AWC.

Deicing chemicals such as sodium chloride applied to streets during winter storms or stored in unprotected areas can wash off of pavements into water bodies or percolate into the groundwater. Elevated sodium concentrations can corrode distribution systems and negatively impact the health of consumers with high blood pressure and hypertension. Road salt used by the Town of Hingham is stored outside of the watershed. MassHighway maintains Routes 3, 3A, 53, and Derby Street and occasionally applies 100 percent salt during inclement winter weather. The Town of Hingham reportedly uses about 800 tons of salt in an average year. The sodium concentrations at the inlet of Foundry Pond were high during the Foundry Pond Feasibility Study. High sodium concentrations in the non-tidal portion of the basin can be attributed to direct road runoff.[47]

Pesticides and herbicides are chemical compounds used to control unwanted organisms such as insects, weeds, and rodents. Since the compounds vary depending upon their target, their potential water resources effects also vary greatly. Pesticides and herbicides can enter surface or groundwater by runoff or direct infiltration. Although pesticides are used in the watershed by residences, agricultural lands, and playground areas, there has been no evidence that pesticides associated with any of these land uses has impacted the quality of water.[48]

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[47] Gale Associates, "Foundry Pond Feasibility Study".

[48] Metropolitan Area Planning Council "Town of Hingham Groundwater Protection Study".

Hazardous wastes are wastes which are toxic, reactive, corrosive, or ignitable and include some of the materials mentioned above. There are no active hazardous waste sites registered with the EPA and on the National Priority List (NPL) within the Weir River watershed. The former South Weymouth Naval Air Station, located nearby the watershed, is the closest NPL site to the Weir River.

There are several non-NPL sites within the watershed including the former industrial military manufacturer at Hingham Annex which released oils, VOCs, PCBs, metals, SVOCs, explosives and asbestos from repair yards, surface and underground storage tanks. Site work is underway at this facility, according to MADEP. This site has been classified as a Tier IA under the Massachusetts Contingency Plan (MCP), which means it is a high priority site that requires a permit and the person undertaking response actions must do so under direct supervision of the MADEP. The site cleanup has entered Phase II, indicating that a comprehensive site assessment is taking place which will determine risks posed to public health, welfare, and the environment.

The former Army base on the grounds of Wompatuck State Park is a site which had non-oil hazardous discharges discovered in the mid-1980's. This site is awaiting a NPL decision and has been classified as a MCP Tier IB site. The western portion of Wompatuck drains into Accord Brook and the eastern portion drains into the Aaron River. The major contaminated area known as "the burning ground" served as a testing grounds for munitions and is located in the eastern portion of the park. A natural spring on the grounds of the park, which may be threatened by the contamination, is also located outside of the Weir River watershed.

Of the 61 listed EPA-regulated facilities in the Town of Hingham, only the PCC Merriman facility on Industrial Park Road south of Rout 3 is permitted for discharges to water and much of this site appears to drain to the south towards the Old Swamp River which is not tributary to the Weir River. A disposal site at the Litton Merriman Division facility, outside the southern boundary of the watershed, 100 Industrial Road in Hingham, released oil and hazardous wastes in the late 1980s. A Phase IV cleanup plan has been implemented at that site, which is the only EPA-regulated site in the watershed permitted to discharge to water according to the EPA Envirofacts database.

In July, 1995, there was a spill of potassium hydroxide (KOH) at the Free Street Well No.3 Pump Station. Approximately 500-600 gallons of KOH were released as a result of a pipe failure. KOH is used to treat groundwater for corrosivity by raising the pH of the water. The KOH was released to the surface and subsurface adjacent to the building, raising the pH of the surrounding soils to above background concentrations. A response action outcome (RAO) was filed with DEP in July 1996. An additional oil spill occurred on AWC property at the Fulling Mill Pump Station in September, 1997. The contaminated area involved soils west of the Fulling Mill Pump Station building. As a response action, the contaminated soils were removed, the groundwater encountered was pumped and treated, and the building demolished. A RAO was filed with DEP in November, 1997.

4.00 WATER SUPPLY AND WATERSHED WATER BALANCE

4.10 EXPLANATION OF WATER BALANCE

A water balance is a hydrologic accounting system which considers the amount of water deposited, withdrawn, and stored in a watershed. The deposits, or additions of water, include precipitation on the area and a minor amount of groundwater inflow from other basins. The withdrawals, or subtractions of water, consist of surface runoff, groundwater underflow, evapotranspiration, and diversions. The amount stored in the basin is in constant flux, however the natural change in storage in an average water year is assumed to be zero (i.e. steady-state). In equation form, the annual balance is as follows:

Total Inflow to Basin = Total Outflow from Basin + Change in Storage

where:

Total Inflow to Basin = Precipitation + Groundwater Inflow

Total Outflow from Basin = Evapotranspiration + Surface Runoff + Groundwater Underflow + Diversions

Change in Storage = Usually negligible on an average annual basis.

The water balance is an expression of the hydrologic cycle in the basin and an important part of the hydrologic description of the watershed. **Figure 4-1** is a conceptual illustration of a simplified water balance under natural conditions. When computed on a monthly basis, the water balance can illustrate the seasonal variation in precipitation, storage, and streamflow. It can also factor into evaluating the safe yields of drinking water supplies and the effects of human activity on the watershed and the habitat of aquatic life.

4.20 WATER SUPPLY SOURCES

To understand the water balance and the human impacts which may affect the hydrologic cycle, the sources of water supply in the watershed must be understood. Drinking water suppliers may influence the water balance through diversions and withdrawals from streams, ponds, and aquifers.

There are two major water suppliers in the watershed, Aquarion Water Company of Massachusetts (AWC) and the Town of Norwell. The AWC supplies the Towns of Hull and Hingham and portions of the Town of Cohasset. The Town of Norwell withdraws water for its own community use.

The Aquarion Water Company is owned by the Kelda Group, a private water and waterwater utility corporation based in the United Kingdom. In May 2002, Aquarion Water Company acquired the Hingham operation from the American Water Works Company, Inc. of Vorhees, New Jersey. Prior to being bought by Aquarion, the water supply company in Hingham was known as the Massachusetts-American Water Company (MAWC), and previous to that, the water works in Hingham were known as the Hingham Water Company. The Hingham Water Company was originally authorized to provide water to Hingham by a town charter passed in the 1880s. The first well at Fulling Mill Pond was installed in 1903 with a capacity of 800 gpm. Currently, the AWC owns and operates six wells in the watershed and withdraws water from Accord Pond. Accord Brook is diverted to Fulling Mill Pond via a small weir and underground pipeline and is also considered a surface water supply source by the MADEP.

The Commonwealth of Massachusetts passed the Water Management Act to control and allocate the water resources in the state and to ensure adequate resources for the present and future. In January, 1988, all water users had the opportunity to register their historic water use for the period 1981 to 1985. This registered an average day water use over that period that, if confirmed and approved by the state, became the “grandfathered” quantity allotted to the user. After the registration phase of the Act, the permitting process began in 1988. A permit is required if an existing or new user intends to or is using more than 100,000 gpd over the previously registered amount, if applicable. The registered and permitted withdrawal volumes for all suppliers within the Weir River watershed are shown in **Table 4-1** along with current water supply withdrawal points.

The AWC has registered for average annual withdrawals from the Weir River watershed of up to 3.51 MGD. This figure encompasses its six wells, the Accord Brook diversion, and withdrawals from Accord Pond.

The Town of Norwell withdraws water from four wells in the southern portion of the watershed, in the Grove Street area in the Town of Norwell. Norwell also owns and operates six additional wells in the South Coastal drainage basin. The wells in South Coastal basin account for the majority of Norwell’s water supply capacity; about 63 percent.

Under the Water Management Act, Norwell registered a withdrawal of 0.32 MGD from the wells in the Weir River watershed. In the early 1990s, Norwell was permitted to withdraw additional water from the Boston Harbor Watershed (Weir River Basin), over and above its registered amount. The permit allows for increasing withdrawals over time as shown below. Note that the figures presented are in addition to the registered 0.32 MGD.

1995:	0.24 MGD annually
2000:	0.35 MGD annually
2005:	0.38 MGD annually
2010:	0.40 MGD annually

As of 2000, the total registered and permitted withdrawals by Norwell in the Weir River watershed of up to 0.67 MGD annually are allowed. Based on the 0.40 MGD withdrawal permit from the watershed in 2010, the total registered and permitted average daily demand could be up to 0.72 MGD in year 2010 and beyond.

Water supply withdrawals by the two public water suppliers in the Weir River watershed have been evaluated based on data averaged over the five-year period between 1996 through 2000. The five-year average data is presented and used as per DEM guidelines in order to help remove variability which may be caused by climatic or other conditions. The effect of an anomalous year is reduced by averaging data and more representative statistics are produced.

According to the Public Water Supply Annual Statistics Reports from 1996 through 2000, the Town of Norwell withdrew an average of 0.46 MGD from their sources in the Weir River watershed. The withdrawn amount is 0.10 MGD below the permitted/registered value. Over the same five-year period the AWC (then MAWC) withdrew an average of 3.57 MGD from its supply sources in the watershed. This represents a 0.06 MGD average exceedence of AWC's registered withdrawal volume of 3.51 MGD. The registered withdrawal limit was exceeded in three of the five sample years years, as summarized below. In two years, 1998 and 1999, withdrawals exceeded registered limits by more than 100,000 gallons per day on average. This is the threshold under the Water Management act at which a new permit is required.

Aquarion Water Company Water Supply Withdrawals

Year	Average Daily Demand (MGD)
1996	3.46
1997	3.54 (exceeded registration)
1998	3.75 (exceeded registration by >100,000 gpd)
1999	3.63 (exceeded registration by >100,000 gpd)
2000	3.47

As a result of the exceedence in 1998, MAWC (now AWC) negotiated with DEP regarding an Administrative Consent Order (ACO) which went into effect in December 1999 stipulating remedial actions.

In light of the relatively small amount of water withdrawn from the watershed by Norwell in comparison to the AWC and since most of Norwell lies outside of the watershed, the following sections regarding the treatment, storage, and distribution of water in the watershed will focus on AWC operations.

4.21 Surface Water Sources

The AWC withdraws water from Accord Pond and diverts water from Accord Brook to the infiltration basins which feed the Fulling Mill well. Accord Pond has a usable capacity of 845 acre-feet and has been continually used for water supply purposes since 1979. There is a 16-inch intake from the pond which leads to a pumping station. The maximum pump capacity of the system to deliver water to the new treatment plant is now reportedly 1,500 gpm, by gravity alone the capacity is reportedly 300 gpm.[49]

Accord Brook is diverted by a 2-foot high concrete diversion weir into a pipeline which discharges into the Fulling Mill infiltration ponds. The diversion structure is located just upstream of South Pleasant Street (See **Figure 2-4**). There was a low-level outlet on the diversion dam which was closed at the time of GZA's visit. It is not known if the low level outlet is operable. There is a small screen chamber on the diversion and water flows through a 12-inch combination terra cotta, concrete drain and transite pipe which is 3,450 feet long. The diverted flow from Accord Brook empties into five of the Fulling Mill infiltration basins and is collected by the Fulling Mill well, which is described further below.

4.22 Groundwater Sources

Table 4-2 lists the wells of the Weir River watershed and their physical characteristics. **Figure 3-6** shows well locations and interim wellhead protection areas. The AWC operates six gravel-packed wells in the watershed: Downing Street, Free Street No.2, Free Street No.3, Free Street No.4, Prospect Street, Scotland Street, and Fulling Mill. The AWC does not own much of the land adjacent to Free Street No.4. As a result, the DEP has not approved its use as a water supply and it may only be used under emergency conditions.

The Fulling Mill well operates with a combination of surface and groundwater supplies and acts as a collection well. Constructed in 1903, the well has an estimated safe yield capacity of 615 gpm[50]. The well is located in the south central portion of town along the eastern side of Fulling Mill Pond. Water from Accord Brook is transmitted by pipeline to seven natural glacial ponds and gravel banks. Water is drawn through the banks by induced infiltration to perforated collection pipes installed within the banks. The infiltration pipe consists of 90 feet of 18-inch and 1,030 feet of 15-inch open jointed terra cotta pipe about 15 feet deep which runs along Fulling Mill Pond to a collection well near the pumping station. The Fulling Mill Well is a dug well, about 39 feet in diameter and 20 feet deep. The bottom seven feet of the well is constructed of open masonry, the outside of which is backfilled with graded gravel. The system was originally

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[49] Mr. Randy Sylvester, MAWC. Personal Communication, Aug. 19, 1999.

[50] Estimated Safe Yield Capacities based on operating experience. Not the same as pump capacity.

designed to take advantage of the natural water quality improvements offered by filtration through soil. The well is further recharged by Fulling Mill Pond, which is a human-made impoundment.

The Downing Street well was constructed in 1965 and is 64.5 feet deep. The well is located at Downing Street near Cole Corner in the north-central section of Hingham. The estimated safe yield capacity of the well is 215 gpm.

The wells located at Free Street were built between 1951 and 1982. The wells are located in a cluster with Free Street No.4 in the center, 440 feet west of Free Street No.2 and 220 feet north of Free Street No.3. The wells range in depth from 73 to 88.5 feet. The estimated safe yield capacities reported by AWC of Free Street wells 2,3, and 4 are 840 gpm, 160 gpm, and 460 gpm respectively.

The Prospect Street well was installed in 1971 to a depth of 58 feet. The well is located in the Liberty Plain section of Hingham at Prospect Street. The estimated safe yield capacity of the well is 180 gpm.

The Scotland Street well is located in the south-central portion of Hingham about 2,100 feet southeast of the Prospect Street well. The well was constructed in 1955 and is 45 feet deep. The estimated safe yeild capacity of the well is 670 gpm.

The Town of Norwell operates four wells in the Grove Street area, near the Hingham border which were constructed during a period from 1961 to 1985. The wells are located within a 0.15 mile radius of each other and are referenced as wells No.2, No.3, No.5, and No.10 according to DEP files. There is an existing Zone II Delineation dated 1994 for the wells which has been approved by the DEP. According to information provided by the Town of Norwell Water Department, the estimated safe yields range from 75 gpm to 250 gpm.

4.23 Water Treatment

Raw groundwater and surface water from Accord Pond, which is pumped by the AWC, is routed through their George W. Johnstone Water Treatment Facility which started up in April 1996. The treatment facility includes a filtration system and chemical treatment to remove iron and manganese. The system uses Superpulsator® clarifiers which remove suspended solids from the water. Chlorination and pH adjustment are also done at the plant.

The plant has a maximum capacity of 7.7 MGD and is located near the Fulling Mill well in Hingham. The average flow rate is reportedly approximately 4 MGD, according to a brochure on the facility prepared by the Massachusetts-American Water Company[51]. It should be noted however, that this figure is in excess of the quantity of water reported in the annual statistical summaries filed with MADEP, and may represent an approximation. The plant is staffed 24

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[51] MAWC, “The George W. Johnstone Water Treatment Facility.”

hours per day and critical aspects of the facility, including water quality, are electronically monitored via a Supervisory Control and Data Acquisition (SCADA) system which is also connected to the storage tanks and wells.

4.24 Storage

In addition to the natural storage of water provided by Accord Pond and the unique infiltration basin configuration of Fulling Mill, the AWC operates three storage tanks in Hingham and Hull. Storage tanks are located at Strawberry Hill in Hull, Turkey Hill, and Accord Pond (see **Table 4-3**). The tanks store water for use during times of peak demand. These tanks have a storage capacity of 3.25 million gallons. In addition to the tanks, the treatment plant provides clearwells for supplemental storage.

4.25 Distribution

The AWC has about 11,000 connections in Hingham, Hull, and Cohasset. About 10,000 of those connections are residential. The AWC maintains 215 miles of pipes and 1,084 fire hydrants. The AWC (then MAWC) supplied, on average, about 1.30 billion gallons of water per year to customers in the period between 1996 through 2000.

The AWC has two service system gradients, the main and the high systems. The high service system is supplied with water from the Scotland Street and Prospect Street wells, as well as the Accord Pond storage tank. The high system service area includes the southern portion of Hingham and the Liberty Plain area. The main service system makes up the majority of the AWC service area. This system is supplied by water from the other wells, including Free Street wells, Downing Street, and Fulling Mill. In addition, Accord Pond serves the main service system area.

4.26 Potential Additional Sources

To meet the water needs of a developing community, it may be necessary to explore additional sources of drinking water. The Town of Hingham, in particular, is facing large-scale development issues in the form of the Shipyard redevelopment and the potential addition of MBTA Commuter Rail infrastructure. Currently, the AWC and the Town of Norwell have water supply sources in the high yield portion of the aquifers along the Weir River and Accord Brook, as shown in **Figure 3-6**. The AWC also diverts flow from Accord Brook to the Fulling Mill infiltration basin for water supply purposes. Potential additional sources of water include the AWC-owned Fulling Mill Pond and the small high-yield aquifer located in the Mill Woods area of Hingham. Any substantial increased AWC water withdrawals from the watershed would likely require a Water Management Act permit, since it is currently, on average, withdrawing more than its registered volume of 3.51 MGD.

Fulling Mill Pond may be a limited source of surface water due to its small, 0.29 square-mile watershed and because of water quality issues. Fulling Mill Pond also is likely to already play a part in supplying the nearby large-diameter well. The difficulty AWC is encountering in obtaining permission from DEP to operate Free Street Well No. 4 is indicative of the challenges involved in establishing water supply withdrawals in developed areas. Land ownership (and environmental) issues are potential obstacles to further development of the aquifers around Free Street and Accord Brook. The small, currently unexploited aquifer below Mill Woods is located in a residential area within subbasin 2 near the Plymouth River and Cushing Pond. This area does not appear as densely populated as the aquifer below Free Street. USGS hydrogeologic maps indicate saturated thickness in the aquifer of up to 40 feet.

The Plymouth River subbasin (subbasin 2) is currently only lightly utilized for water supply purposes. It may be desirable to maintain this status quo for environmental reasons since the subbasin is now among the least impacted areas of the total watershed. However, flood skimming from the Plymouth River or limited withdrawals from Cushing Pond might be possible during wet periods of the year. Such a scheme could reduce groundwater withdrawals from other, more heavily impacted areas of the watershed and thereby help to mitigate reduction of in-stream baseflows later in the year. Many of the new developments planned in this subbasin are proposing shallow groundwater wells for irrigation purposes. Groundwater withdrawals from the Plymouth River subbasin may impact base flow into the Plymouth River.

Several other possibilities exist for augmenting water supply in the Weir River watershed. Additional surface water storage could be created to store excess runoff which is available in the winter and spring. The local water suppliers (AWC and Norwell) could connect to MWRA and purchase additional raw water originating from the Quabbin Reservoir. Finally, desalination could allow brackish water or even sea water to be used as a potable water source. A regional desalination facility is currently being proposed to treat water from the Taunton River to supply Brockton and other communities. All of these possible water supply sources offer the possibility of significantly enhancing the amount of water available, but would likely be expensive. The Town of Hull is also exploring the feasibility of a desalination facility in Hull, according to an article in The Patriot Ledger newspaper from April 24, 2002.

Source of Supply Alternatives are also discussed in the Source of Supply Study prepared for the Massachusetts-American Water Company in 1994. This study indicates that optimization of existing supply sources is an option, as well as purchased water, new source development, and demand management.

4.30 WATER DEMAND AND USE

Water from the Weir River watershed is used both within and outside the watershed for a variety of purposes. Some of the withdrawn water is recycled within the watershed in the form of return flows (i.e. recharge from septic systems, etc.) Other water is immediately exported from the watershed for use (e.g. portions of Hingham and Norwood outside of the watershed) or is removed from the basin for treatment after use (e.g. wastewater outflow from Hull and portion of

Hingham). In general only approximately 27 percent of water pumped from the Weir River watershed is expected to be returned to the watershed.

4.31 Service Area

Two public water suppliers withdraw water from the Weir River watershed in order to provide supply for different areas. The Aquarian Water Company (AWC) (formerly known as the Massachusetts-American Water Company) serves all of the Town of Hingham, all of the Town of Hull, and the northwest portion of the Town of Cohasset. The Town of Norwell Water Department uses wells within and near the watershed to supply the northwestern portion of the Norwell water distribution network. The portions of Rockland and Weymouth which are within the Weir River watershed are supplied from sources outside the basin.

4.32 Water Users And Service Population

Water is withdrawn from the Weir River watershed for use by domestic, commercial, industrial, and municipal users. Only a minimal amount of water is used for agricultural purposes, though domestic users do water their lawns with water from the public water systems. A search for registered/permitted users within the watershed was executed with the help of DEP. Virtually all water users receive their water from the two water utilities that operate in the watershed. Only one private commercial well is shown to be registered in the watershed according to the Massachusetts GIS data layer. The commercial well is located in the southwestern section of the watershed and belongs to a dining establishment on Route 228 (this source will be considered insignificant for the purposes of this study.) However, it is estimated that 125 residential units (approximately 398 persons) in Hingham are self-supplied. It appears from GZA's field observations that some residential users also withdraw water directly from streams and ponds for lawn watering.

The Cohasset Golf Club, an 18-hole private club, and the South Shore Country Club, an 18-hole public course, are within the study area and extract water for irrigation. Data obtained from the DEP Office of Watershed Management indicates that the Cohasset Golf Club withdraws from two irrigation sources: one irrigation well and a small 0.2 acre pond. The yearly water use was estimated to be 6.05 million gallons in 1997 and 1998, and 7.51 million gallons in 1999. Beginning in August 1999, the Cohasset Golf Club metered water use, including withdrawals of 3.6 million gallons in August, 1.45 million gallons in September, 0.34 million gallons in October, and 0.11 million gallons in November. The reported value for the 3-month period beginning August 1999 corresponds to about 59,000 gpd. Although this value would likely be higher and may exceed the 100,000 gpd standard for a required permit if May through July data were available, it remains a relatively minor water user in the watershed. Nonetheless, these demands have been factored into total watershed water use.

The South Shore Country Club is located within the limits of the study area in Subbasin 7, but outside of the physical Weir River drainage area as described in Section 2.103. Water sources for the South Shore Country Club include 3 irrigation wells and 2 surface water ponds. They report the following annual water usage: 16.8 million gallons in 1997, 13.4 million gallons in 1998, and 21.2 million gallons in 1999. Monthly breakdowns for 1999 were as follows: 0.7 million gallons in April, 1.5 million gallons in May, 4.5 million gallons in June, 5.8 million gallons in July, 5.5 million gallons in August, 2.5 million gallons in September, and 0.7 million gallons in October. The withdrawal volumes suggest that the Club may need of a Water Management Act permit for this level of water use. Withdrawal was above 100,000 per day in the peak three months 1999, but was slightly less than 100,000 per day when averaged over the entire period of pumping for 1999.

Information from the water suppliers regarding current population and percent coverage was used to estimate the service population of the water utility. The "adjusted service population" includes the seasonal population multiplied by an adjustment factor. **Table 4-4** shows service populations for the various water suppliers. The current total adjusted service population provided with water from the Weir River watershed is 38,014.

By using the population forecasts for the towns of the watershed developed by the Metropolitan Area Planning Commission (MAPC), the service population can be projected forward into the future as shown in **Table 4-5**. Service percentages where assumed to be constant (same as in **Table 4-4**). AWC states that it expects to reach 100 percent coverage of Hingham and Hull (i.e. providing water to all water users in the town), but high water rates suggest that private well users will continue to self supply. The seasonal population of Hull was taken to be 6,000 in the year 2000 based on the town census data reported in the Office of Water Resources Municipal Water Supply Questionnaire from 1998. An adjustment factor of 25% (as per the 1998 Questionnaire) is applied to the seasonal population to account for the fact that seasonal residents are not using water year-round. Using the MAPC data, the total service population of the Weir River watershed is projected to grow to 41,305 by the year 2020.

A number of development projects have recently been proposed within the watershed area. These are primarily within Hingham and include the Hingham Shipyard Redevelopment, the Black Rock Golf Community, and the Hingham Campus retirement community. If the additional residents of these proposed developments are added to the baseline population projections, then the service population by the year 2020 could increase to 48,005. Utilizing data from the Massachusetts EOEA build-out studies, the service population drawing water from the Weir River watershed at build-out has been computed to be as much as 53,586.

4.33 Total Water Use

The total amount of water withdrawn from the Weir River watershed is the sum of the withdrawals by the Massachusetts-American Water Company, the Norwell Water Department, the self-supplied private water users in Hingham, and the two golf courses. Total annual water supplied from the Weir River watershed for the years 1996 through 2000 is shown in **Table 4-6a**. Note that much of the data on self-supplied users and golf courses has been assumed using the typical values based guidance from DEP and elsewhere. Data on water use within the public supply systems was obtained through review of Public Water Supply Annual Statistical Reports filed by the suppliers with MADEP and contained in **Appendix K**. Water supply information has been averaged over the five year period between 1996 through 2000 in order to produce more representative data and reduce the effects of anomalous years. The five-year average quantities of water supplied from the Weir River watershed are shown in **Table 4-6b**.

In the five-years from 1996 through 2000, the average total water quantity withdrawn from the watershed by the AWC (then MAWC) was 1,304.44 million gallons per year, which is equivalent to an average daily demand (ADD) of 3.57 million gallons per day (MGD). This accounts for 100 percent of the total water use within the AWC system. During the same five-year period, Norwell pumped and average of 168.82 million gallons per year, or 0.46 MGD, from the Weir River watershed. This accounts for 46 percent of demand within Norwell's overall system. The self-supplied users within the watershed (including the golf courses) are assumed to have withdrawn an additional 31.03 million gallons per year or 0.08 MGD. Average total water withdrawals from the Weir River watershed therefore are estimated to be 1,504.29 million gallons per year, which is equivalent to an average daily demand of 4.12 MGD.

There is significant monthly variability to water use due to temperature, rainfall, air conditioner use, lawn watering, seasonal population change, and other factors. **Table 4-7** shows the average monthly usage of the main water suppliers / users in the Weir River watershed, based on DEP statistical reports. In general, demand is lowest in February and peaks between June and August. Typically, the maximum daily demand is also experienced in the summertime months. The annual maximum daily demands for 1996 through 2000 are shown on Table 4-6a and the average is presented on Table 4-6b. Average maximum daily demand in the AWC system was 6.14 MGD, producing a peaking factor of 1.72. The average maximum daily demand on the Norwell wells was 1.04, for a peaking factor of 2.26.

4.34 Distribution of Water Usage and Per Capita Consumption

Water supplied by the Aquarion Water Company and the Norwell Water Dept. goes to a variety of users. By far the largest single user group is residential (domestic) users, but other groups also purchase and utilize water. **Table 4-8** lists the estimated distribution of water deliveries to various groups by the two major water suppliers, averaged over the five years between 1996 through 2000. Residential users accounted for over 60 percent of total demand for water withdrawn from the watershed. "Unaccounted-for" demand (which is un-metered use or leakage) was the second largest category at 18.5 percent, followed by Commercial demand which was slightly over 12 percent. The large average overall "Unaccounted-for" distribution was primarily from the AWC system (average 20.3 percent over the five years). AWC's average "unaccounted-for" percentage was raised by the high rate in 1998 (25.8 percent), which may be somewhat anomalous. However, "unaccounted-for" water did not drop below 17.6

percent in either 1999 or 2000. **Figure 4-2** shows the distribution of water use among residential, non-residential, and unaccounted-for for the AWC system for 1996-2000.

With knowledge of the total amount of water delivered, the service population (which includes seasonal population), and the water supply distribution percentages, per capita demand for the Weir River watershed was computed. Two measurements of per capita demand are generally of interest: The actual residential per capita demand is a measure of the amount of water used by each individual resident drawing water from the watershed and is computed by dividing the volume of water delivered to residential customers by the service population. The gross (base) per capita demand is a measure of the total amount of water used by the community (including commercial user, industrial users, unaccounted-for water, etc.) to support each of its citizens. This figure is computed by taking the total amount of water used and dividing by the service population. **Table 4-9** lists the five-year average per capita demand for water from the various suppliers in the watershed. These figures represent the per capita demand of the population which actually draws water from the watershed. This group overlaps but is not the same as the population which lives within the watershed boundaries. The actual per capita demand figures should be similar for these two populations (residents supplied from the watershed versus residents living within the watershed). The watershed wide, average actual residential per capita use is 65.33 gallons per person per day (gal/per/day), and the overall gross system (base) per capita water use is 107.17 gal/per/day.

4.35 Water Rates

Knowledge of rates (tariffs) charged to water consumers by water suppliers can be an important factor in explaining and predicting rates of water demand. Water is acknowledged by many planners to be a price elastic commodity at all but the most minimal levels of consumption. In other words, demand for water will decrease per capita as the unit price increases. Price can therefore influence consumption of water and also be used as a management tool, though the latter may be difficult for political reasons. Price-based demand control may have reduced effectiveness in Hingham however. Written comments dated May 18, 2001 from CEI, a consultant hired by Massachusetts-American Water Company, state, “[M]any studies have shown that price does not affect consumption, especially in more affluent towns such as Hingham.”

There are several basic tariff structures generally used by water suppliers: flat fee, increasing block, decreasing block, etc. The water bill for an individual user may be determined based on frontage or other such indirect indicators, but the preferred method is by measuring actual consumption using a water meter for each customer. Sewer fees are also important because many times they are connected to water consumption.

The Aquarion Water Company meters 100 percent of its customers except for fire service connections. It uses a decreasing block rate structure to bill its customers, which means that the unit cost of water decreases for customers using large volumes of water. According to

1998 MWRA data, the average customer in Hingham paid $713.16 per year in water bills, and those who are connected paid $636.00 in sewer fees. The average annual cost of water to MWRA consumers in 1998 was $252.53; therefore the annual cost of water to customers of AWC was 2.82 times higher than MWRA average. AWC (then MAWC) rates increased 65.2% in 1996, which was the year the new water treatment plant went on line. According to the Boston Globe, 1999 average annual water fees in Hingham and Hull were $713 – the highest in metropolitan Boston area[52].

In 1998, a survey of businesses and residents was commissioned by the Hingham Planning Board for land use planning. Among other questions, the survey asked respondents to identify critical issues facing the Town of Hingham. The cost of water and sewer services was ranked as the number one critical issue by both business and residents of Hingham. Water and sewer costs were perceived as critical by 46 percent of business respondents and 58 percent of residential respondents. Lack of sewers in some areas of town and pollution of rivers / coastal waters were issues which also ranked in the top five.[53]

Since the AWC is a private water company, the Department of Telecommunications and Energy (DTE) has the ability to regulate the water company's rates. Currently, the DTE can allow declining block rates, but they are currently in discussion with the DEP about possibly eliminating them.

4.36 Water Use Trends and Projected Future Needs

Prediction of future water need is a difficult and often imprecise exercise. Estimating future need in general depends on the extrapolation of historical trends in population and water use, and is dependent on a number of base assumptions. Such extrapolations usually become less accurate as the prediction period is extended, due to influences that cannot be anticipated. A 1990 report commissioned by the Town of Hingham[54] to evaluate the Hingham Water Company compared various population and demand projections. Estimates of year 2000 population for the Towns of Hingham and Hull ranged from 32,700 (DEM) to 37,540 (Whitman & Howard) – a difference of 14.8 percent. Census data indicates the actual 2000 population of Hingham and Hull was 30,932. Projections of average daily demand varied from 3.88 MGD (DEM) to 4.51 MGD (Hingham Water Company). A certain amount of variability in various forecasts is due to use of different projection methodologies. This study will adopt the most current methodologies developed by the Massachusetts Water Resources Commission.

The Massachusetts Department of Environmental Management – Office of Water Resources (DEM-OWR) made water needs forecasts for the towns in the Weir River watershed in 1991 as part of the WRC/DEM River Basin Planning program. Once approved by the WRC, the forecasts can be used by water suppliers in their Water Management Act permit applications.

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[52] Franklin, James L. The Boston Globe, "Taking Water Seriously." May 21, 2000.

[53] The Jordan Group, "Town of Hingham - Survey of Businesses for Land Use Planning Study" July 31, 1999

[54] Weston & Sampson Engineers, Inc. "Evaluation of the Hingham Water Company." June, 1990.

DEM-OWR projected that average daily demand (ADD) in Hingham and Hull (includes all AWC customers) would be 3.62 MGD (1,321.30 MG per year) by the year 2000 and 3.79 MGD (1,383.35 MG per year) by the year 2010. These projections include an allowance for economic growth. The DEM-OWR forecast for year 2000 for AWC water use (3.62 MGD) compares favorably with the 1996-2000 average water use data (3.57 MGD). Hingham and Hull comprise most of the service population of the AWC, and AWC withdrawals currently account for almost 85 percent of the water taken from the watershed.

The projections made by DEM in the 1991 study were done with a methodology that is no longer utilized by DEM. The Massachusetts Water Resources Commission (MWRC) and DEM-OWR currently utilize two other methods for forecasting future water needs[55]. Method 1 is used for communities where three criteria are met: 1) Sufficient disaggregated water use data; 2) residential gallons per capita daily use (gpcd) of 80 or less; 3) unaccounted-for water factor of 15 percent or less. Method 2 is used when one or more of these criteria is not met. Water use in the overall Weir River watershed meets the first two criteria, but due to the high percentage of "unaccounted-for water" in the AWC system, the third criterion is not met. Method 2 was therefore chosen as the preferred forecasting technique.

In using the MWRC / DEM-OWR methods, population projections through 2020 from MAPC were used. Seasonal population in Hull was assumed steady at 6,000. Percent of population served in each community was held constant. As per MWRC / DEM-OWR procedures, projected per capita residential demand was held constant in future years.

It should be noted that the percentage of unaccounted-for water in the overall system is quite high in comparison to industry standards. The majority of the unaccounted-for water is in the AWC system (20.3% on average), while the Norwell system has a much lower percentage (8.1%). Method 1 may therefore be more appropriate for Norwell alone, but since the system was analyzed in aggregate, Method 2 is still preferred. In any event, the use of Method 1 forecast methodology for Norwell would result only a minor reduction in the 2020 overall forecast.

Based on Method 2, the total average daily demand for water supplied from the Weir River watershed is forecast to be 4.63 MGD in 2020, assuming population growth predicted by MAPC. The forecast indicates that average daily demand on the AWC system in the year 2020 may be expected to increase by 0.47 MGD (13.2 percent above current levels) to 4.04 MGD. Average daily demand on Norwell's Weir River basin wells is forecast to increase by 0.03 MGD (6.5 percent) to a total of 0.49 MGD. The remaining use is by self-supplied users and the existing golf courses. The results of the demand forecast procedure are shown in **Table 4-10**.

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[55] Massachusetts Water Resources Commission / DEM – OWR. "River Basin Planning Program – Generic Water Needs Forecasting Methodology." DEM – OWR Internal Document.

The projected 2020 watershed-wide average daily withdrawal rate of 4.63 MGD is based on the population forecasts from MAPC and past trends in the increase in non-residential demand. However, in the past two to three years, public announcements have been made regarding proposals for substantial development within the Weir River watershed. These proposed developments include the Hingham Shipyard redevelopment, the Black Rock Golf Community, the Hingham Campus retirement community, and others. These proposed projects are large enough to have required the filing of Environmental Notification Forms (ENFs) which were published in the Massachusetts Environmental Monitor. A list of proposed large developments in the Weir River watershed which have filed ENFs is contained in **Table 4-11**. Much of this development is likely beyond that anticipated by MAPC, therefore, these projects may represent additional demand beyond that predicted through the water needs forecasting methodology. The anticipated water needs of these projects are stated in the ENFs and are reported in Table 4-11b. The reported total combined average daily water use for these proposed projects is 0.85 MGD. Based on information contained in the ENFs, 0.50 MGD of this total is to be supplied from the Weir River watershed, including 0.24 MGD from the AWC system and 0.26 MGD from new irrigation wells. The remaining 0.35 MGD is expected to be supplied from the proposed Taunton River Water Supply Desalination Project. It should be noted however, that the Taunton River project currently lacks important permits which make its ultimate completion uncertain. The addition of the extra demand on Weir River sources which would be imposed by the projects could increase the 2020 average daily withdrawals from the Weir River watershed to 5.13 MGD. If the water currently expected to be provided by the Taunton River desalination project is also withdrawn from the Weir River, average daily withdrawals could reach as high as 5.48 by 2020.

Because there is no guarantee that any of these proposed developments will be constructed, GZA has used only the baseline demand forecast (4.63 MGD) to examine impacts of future water withdrawals on the watershed.

It is assumed that the additional volume of water will come almost exclusively from Subbasin 6, since the Free Street Wells have additional capacity according to the 1994 Source of Supply Study[56]. Other scenarios are possible, including new wells in southwest Hingham and water purchased from outside the watershed, but this seems the most reasonable. Based on the Method 2 results, total withdrawals from the watershed in 2020 (baseline forecast) will exceed the total registered and permitted limit of 4.23 MGD by 0.40 MGD or 9.5 percent.

According to USGS data for Massachusetts between 1990 and 1995, withdrawals for public supplies increased by approximately 1.5 percent in total while population also increased by approximately 1.5 percent over the same time period.[57] Therefore no appreciable change in per capita consumption was found to have occurred. This is generally consistent with the assumptions of the Method 2 forecast technique. USGS stated in 1990, "It seems likely that water

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[56] American Water Works Service Company, Inc. "Hingham Source of Supply Study", 1994.

[57] USGS, "Estimated use of water in the United States in 1995." http://water.usgs.gov/watuse

withdrawals for public supply and domestic uses will continue to increase as population increases. However, higher water prices and active water conservation programs may reduce the per capita use rate."[58] Based on the 1995 public supply use data for Massachusetts, this prediction appears to be generally accurate. The assumption of relatively static per capita use seems applicable to forecasts for water use in the Weir River watershed.

It should be noted, however, that in Hingham and Hull only, the average population growth rate between 1990 and 2000 was approximately 2.1 percent. During this time the demand for water from the Massachusetts American Water Company increased at a rate faster than population growth. In other words, there was an increase in gross (base) per capita consumption in Hingham and Hull in addition to a population increase. In 1990, the total demand for the year was 1,163 MG. The five-year average demand from 1996-2000 had increased to 1,304 MG per year. This is an increase of 12.1 percent in water consumption over the same decade when population increased by only 2.1 percent. This indicates an increase in gross (base) per capita demand. Increases in per capita water use may not continue into the future, due to increases in water costs, conservation measures, and limits on supply. If per capita demand does continue to increase, however, future total demand may exceed the Method 2 estimates presented above.

4.37 Recommendations For Water Conservation

An alternative to developing additional water supplies is to promote water conservation through improved efficiency and reduced consumer demand. Ongoing efforts at leak detection by the water utilities can reduce the amount of unaccounted for water which is lost before being used. Individual and business water users themselves can also improve their own water usage efficiency and thereby reduce demand. Low flow toilets and other plumbing fixtures have the potential to save water. More efficient lawn sprinkler systems or use of so-called gray water can significantly reduce water demand. Landscaping with plants which are less water intensive can reduce outdoor needs even further. Pricing schemes such as increasing block schedules can be used to discourage heavy water usage. "Water Bank" clauses can be attached to building permits which require proposed new demand to be balanced or exceeded by demand reductions elsewhere. As a result of the Administrative Consent Order issued by DEP, AWC has instituted a "Water Balance Program." AWC states that, "New development in Hingham, Hull and portions of North Cohasset will require the developer to find water savings in the communities, which will offset the water demand imposed by their projects." These offsets will likely be provided by retrofitting of low flow fixtures and other conservation measures.

Specific recommendations for water conservation measures are listed below. The Aquarion Water Company is currently promoting many of these concepts within its portion of the watershed, but action at the Town level may also be necessary to promote conservation.

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[58] USGS, "Estimated use of water in the United States in 1990 – Trends in Water Use." http://water.usgs.gov/watuse

Reducing Residential Water Consumption (In-home measures)

Data from the American Water Works Association shows that by installing water conservation measures inside the home, water consumption can be reduced by up to 32%. The following is a typical procedure for reducing in-home water consumption:

1. <u>Ensure that local bylaws support water conservation</u>:
   Review existing bylaws to ensure that they do not promote unnecessary water consumption, ensure that bylaws support federal maximum water-use requirements;

2. <u>Promote the idea of water conservation throughout the watershed</u>:
   Following the decision to implement a water conservation program the main challenge to overcome is changing peoples habits. The first part of this is education about the benefits of reducing water use. For example, New Englanders often find it hard to believe that there is insufficient water because of the amount of rain that falls in an average year. Education through the media or through schools can often be effective as a first step.

3. <u>Conduct water conservation audits</u>:
   Publicized by and running parallel to the education program, many cities have made water conservation audits easily available (e.g. by making evening and weekend audit appointments available in addition to regular working days). In some cities, these are free and provide customers with the opportunity to get free low flow-showerheads, faucet aerators, and hose nozzle heads installed, plus home-specific advice about further conservation measures that may be appropriate.

4. <u>Implement schemes to facilitate exchange of conventional fixtures for low-flow fixtures</u>.

Reducing Commercial Water Consumption

Commercial water users should be strongly encouraged to evaluate their water use practices for areas of potential improvement. While water consumption within this sector varies from one enterprise to another, water is mostly used for purposes such as cleaning and sanitation, cooling and heating, plumbing and landscape irrigation. Due to the nature of commercial buildings and their use, the majority of water savings can be brought about by changes such as:

- Retrofitting domestic plumbing fixtures (low-flow toilets, faucets etc) and checking for leaks

- Designing irrigation systems to maximize watering efficiency and avoid unnecessary watering
- Capturing, holding and using rainwater for irrigation
- Using Xeriscaping techniques (plants and grass species native to the area and therefore adapted to the local climate) for landscaping
- Parking lot and/or interstate median adaptations to minimize stormwater runoff to municipal drains and redirect runoff to water lowered planting beds and grassy swales
- Changes to practices in particular commercial businesses
- Examining commercial business types for potential water savings can lead to changes in practice and implementation of money and water saving devices. Effective metering allows easy monitoring of businesses that use large amounts of water. Examples of particular businesses that have made significant water savings include:
    - Car Washes: In Seattle, WA, a bus company reduced its freshwater consumption by 93 percent washes by reclaiming their water.
    - Hospitals: In Norwood, MA, retrofitting the hospitals sterilizers with a system that collects, cools, pumps and recirculates the cooling water saved 8 percent of the hospitals total water use.
    - Commercial kitchens: In Boston, reducing the flow rate of the food disposal system from 24 gallons per minute (gpm) to 6 gpm decreased water use by approximately 1.4 MG per year with a payback time of less than 2 weeks.

Reducing Outdoor Water Consumption

Targeting outdoor water use habits for residential and commercial properties with large lawns for education programs could result in significant water savings within the Weir River Watershed. Additional savings can be made by applying these techniques to public landscaped areas such as parks. Other options for encouraging water conservation outdoors includes raising water rates (and instituting tariff/reward systems for water conservation), implementing local ordinances aimed at reducing lawn over-watering, and/or requiring new developments to submit plans with water-wise design elements.

<u>Lawn Watering Techniques</u>:

- Promotion of optimum irrigation schedules can result in reduced water usage
- Most lawns only need watering once or twice a week, once they have adapted to less water.
- Once inch of water on the lawn is sufficient for 1-2 weeks
- The optimum time of day to water lawns to get maximum irrigation benefits is before or at dawn or after dark.
- Drip systems are much more efficient (and often cheaper) than sprinkler systems, where much water is lost to evaporation and runoff.

Xeriscaping: using plants native to the Northeast (and therefore adapted to rainfall patterns), using plants appropriate to the soil conditions, using efficient irrigation techniques is becoming more popular. These techniques have been shown to result in water savings of up to 50% compared with conventional landscaping practices and also result in water quality benefits due to reduced need for chemical fertilizers.

4.40 RETURN FLOWS

Return flow refers to water which remains in the watershed water balance after use. Return flows are available for additional re-uses within the basin and are not subtracted from the overall water budget. The quality of return flows may, however, restrict the possible uses of return flows in some cases if water is not adequately treated before discharge. Various types of return flows are discussed below. Return flows are later quantified in GZA water budget estimates (Appendix F).

4.41 Wastewater and Stormwater

Wastewater collection in the Weir River watershed is through a combination of public sewer systems and private septic systems. The proportion of population served by sewer systems varies by town and is shown in **Table 4-12**. In general, much of north Hingham and all of Hull are sewered. Less than half of Cohasset residents use septic systems, but all Norwell residents have septic systems. Virtually all of Weymouth and Rockland are connected to municipal sewers.

After water is used by consumers it is discharged to either a municipal sewer system or an on-site septic system, as described above. Wastewater which is collected by sewers is removed from the watershed. Wastewater treated by the MWRA Nut Island WWTP and the Hull WWTP is discharged directly to the Massachusetts Bay, and discharges from the Rockland WWTP do not re-enter the Weir River watershed. Once water enters the various sewage systems in the basin, it is essentially removed from the watershed without the possibility of further use. Sanitary sewers also may cause loss of groundwater due to infiltration and inflow. However, this effect is typically unimportant to flows in the streams and rivers of the Weir River basin since the sewered areas are in north Hingham and Hull, which are within the tidal portion of the watershed.

Wastewater treated using septic tanks and subsurface infiltration pits or leach fields is a different matter. Septic systems generally use small underground tanks to collect wastewater and treat it through sedimentation and biological action. After passing through the tank, the wastewater is removed by allowing it to infiltrate into the ground, usually through buried perforated pipes. Some of the water discharged from septic systems may be transpired by overlying plants, but most of it filters through the soil and infiltrates to the water table below. If the septic system is within the Weir River watershed, then the water is once again available for use as outflow to streams or as supply to be withdrawn from wells. The majority of the water is, in essence, recycled. This is reflected in GZA's water balance calculations. For the purposes of our water balance, we have employed a typical Massachusetts consumptive loss factor for municipal and residential use of 17.1 percent.[59] Consumptive loss is the portion of water demand which does not return to a septic or sewer system as waste water. For instance, some water is lost to evaporation from lawns and pools or is consumed in industrial processes.

The ultimate fate of wastewater is therefore important to the overall basin water balance. **Table 4-13** lists the quantities of wastewater that are assumed to reinfiltrate into Weir River watershed groundwater aquifers based on population, per capita consumption, sewer coverage, and a factor for consumptive uses such as lawn watering. Overall, approximately 42 percent of the watershed's population's wastewater is discharged via septic systems, resulting in an estimated 1.14 MGD return flow to the watershed. This accounts for approximately 27.6 percent of water withdrawn from within the watershed.

Stormwater and street drainage systems were observed during field reconnaissance throughout the watershed. Stormwater runoff appears to discharge to nearby streams (i.e., in-basin discharge). Stormwater is considered to be part of overall surface runoff in the water balance. The stormwater system is separate from the sanitary sewers.

4.42 Groundwater Outflows

The baseflow of the streams of the Weir River watershed is supplied by groundwater outflow. When rain or other water infiltrates into the soil, particularly in the areas of stratified drift, it serves to recharge the groundwater aquifers. Because most of these aquifers are shallow, unconfined aquifers, additional water is stored by means of a rise in the water table. When the water table and the ground surface intersect at a low area such as a streambed, water can re-emerge from the ground and become surface water flow. Groundwater outflow serves to stabilize the elevation of the water table, since more water will exit into streams as the water table rises. Over the long term and under natural conditions, it can be assumed that the overall quantity of groundwater stored in the aquifers is relatively constant. In such a case, it is reasonable to assume that all water which infiltrates into the watershed subsurface eventually re-surfaces, either as outflow to streams or direct outflow to the sea. Pumping of groundwater can affect this balance. The USGS description of the Boston Harbor Basin and the Weymouth and Weir River subbasin states, "Streamflow in many of the subbasins is affected by ground-water pumpage."[60] As water is extracted from groundwater aquifers and the water table is lowered by pumping, the amount of groundwater outflow can be reduced, stopped, or even reversed. When wells are pumped such that water from streams begins to recharge the groundwater, a situation known as "induced infiltration" is said to exist.

Groundwater outflow is difficult to directly measure, except at well-defined springs. As such, groundwater outflow is generally inferred by measuring streamflow before or significantly

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[59] Solley et al, "Estimated uses of water in the US in 1985" USGS Circular 1004, 1988.

[60] USGS, "Water Resources of Massachusetts" WRI-Report 90-4144, 1992.

after rain events. GZA's estimates of groundwater outflow, or baseflow, are provided in Section 4.50.

4.50 WATER BALANCE DEVELOPMENT AND SAFE YIELD ESTIMATE

Safe Yield is a hydrologic term with several different meanings. One common definition of Safe Yield is, "The maximum quantity of water which can be guaranteed during a critical dry period."[61] Knowledge of the safe yield associated with a water source (reservoir, aquifer, watershed, etc.) is important to prevent demand from exceeding the available and reliable supply. During periods when water is abundant, the available supply may far exceed the estimated safe yield, but during drought conditions supply will be reduced. Safe Yield generally represents the quantity of water which would be available under expected drought conditions.

Several estimates of the Safe Yield, as defined above, have been made for the Weir River watershed. The Town of Hingham commissioned a report in 1990 on what was then called the Hingham Water Company (now AWC) which estimated a safe yield for the system. A more recent and refined study was completed by the Massachusetts-American Water Company in 1994 following water shortages in 1993. The Water Resources Management Program has developed a safe yield estimate procedure, which was applied to the Weir River Watershed subbasins.

In this report, GZA has developed a detailed procedure to estimate safe yield using a monthly water balance. Because a major objective of this report is to examine the interaction between water supply demand and the environment, "safe yield" has been defined in this report to mean the amount of water which may be withdrawn while maintaining an acceptable level of aquatic habitat. The term "Aquatic Habitat Safe Yield" has been coined for this concept and is completely disparate from the water supply safe yield as used by the DEP for source approval. As per the DEM 452 scope of work, the water balance was performed for virgin, current, and future (growth) scenarios in both average and dry years. This report focuses on the "average year" conditions when discussing the Aquatic Habitat Safe Yield, but it should be remembered that typically "safe yield" estimates developed strictly for water supply reliability purposes assume conditions closer to the "dry year" scenario. The water balance incorporates the above information to formulate a hydrologic description of the watershed for each of the scenarios. Safe yield estimates appropriate for maintenance of aquatic life were then developed by GZA from the results of the water balance. Note the water balance developed for this project is simplified because it does not account for detailed processes of the hydrologic cycle, such as snowpack and soil moisture / storage; refer to the Limitations provided in Appendix A. This hydrologic information is intended to provide the basis by which the DEM, DEP, water purveyors, area communities, and other stakeholders will formulate future watershed management strategies.

4.51 Existing Safe Yield Estimates

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[61] Linsley, R.K. and Franzini, J.B. Water-Resources Engineering. McGraw-Hill. 1964.

The following subsections present information on Safe Yield estimates developed by others or developed using techniques created by others. GZA's estimate of Aquatic Habitat Safe Yield is presented in Section 5.50.

4.51.1 Town of Hingham Report (Weston & Sampson)

The Town of Hingham commissioned a report on its water system which was completed in June of 1990. The report was prepared by Weston & Sampson Engineers, Inc. and dealt with, among other issues, the estimated safe yield of the Hingham Water Company system (now owned and operated by AWC)[62]. The report estimates the safe yield of Accord Pond as approximately 0.4 MGD, using New England Water Works Association methodology. It states that storage in Accord Pond might provide additional water (up to 550 million gallons of active plus dead storage) in an emergency. The report indicates that overall surface water safe yield of the watershed (inclusive of Accord Pond) is approximately 3.0 MGD. This assumes withdrawals of all surface water in the Accord Pond and Brook subbasins above the Brook diversion point. The report cautions that "[M]ore historical data is required to statistically analyze the dependable streamflow of the Accord Brook." Groundwater yield was computed in a different manner. For groundwater resources, the Weston & Sampson report defined safe yield as "[T]he quantity of groundwater that can be reliably withdrawn without excessive drawdown that may cause contamination or impairment of the aquifer as a groundwater source." The groundwater safe yield estimates therefore are more indicative of local condition and well capacity than of overall water balance. Based on these criteria, groundwater safe yield was estimated as approximately 6.3 MGD. Accounting for both surface water and groundwater, the total Safe Yield of the Weir River watershed (subbasins 1 – 6) is given as between 9.1 to 9.3 MGD. The Weston and Sampson report states that the pumping from the Norwell wells in the watershed must also be supplied from this total.

It should be noted that the results of this report are in significant disagreement with the results reported in a later report by the parent company of the Massachusetts-American Water Company (see section 4.51.2). Given the disparity between the safe yield reported by Weston & Sampson and historic water usage, the total safe yield value of 9.1 MGD must be viewed with suspicion, in GZA's opinion.

4.51.2 Hingham Source of Supply Study Report (MAWC)

A more recent report was produced by the Massachusetts-American Water Company (now Aquarion Water Company of Massachusetts) entitled "Hingham Source of Supply Study, January 1994. This study reports a significantly estimated safe yield for the Hingham system (including Hull and North Cohasset). The report states, "[T]he total estimated safe yield of the Hingham water system's sources of supply, excluding Free Street Well No. 4 is

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[62] Weston & Sampson Engineers, Inc. "Evaluation of the Hingham Water Company System." June, 1990.

about 4.29 mgd… These amounts represent the estimated maximum production rates that could be sustained from the Water Company's approved sources of supply, including a repetition of the severe dry periods during the summer of 1993." It should be noted that the drought of record typically used to estimate safe yield in Massachusetts is the multi-year drought of the mid-1960's.

The report also states, "During the summer of 1993, the Water Company experienced an estimated deficit of 0.35 mgd, consisting of a 0.10 mgd safe yield surplus in the high service gradient and an estimated 0.45 mgd deficit from main service gradient supplies. Emergency use of Free Street Well No. 4 (whose estimated safe yield of about 0.66 mgd, is not included in these estimates) was a critical factor enabling the water company to avoid more serious shortages. Without Free Street Well No. 4, the safe yield deficit is projected to increase to 0.12 mgd…[based on projected summer average day demands in 2010]" Even larger deficits are expected by the report during summertime maximum demand days. It is noted in the report that, "During 1993, the total annual system delivery of 3.59 mgd exceeded the registered amount by 0.08 mgd, and was only 0.02 mgd below the amount for which a permit would have been required." The report also states that, "[D]uring the summer of 1993, Accord Brook ran dry…" and notes that the safe yield of Accord Brook is "zero."

In summary, the MAWC study reports the following values for the safe yield of the system:

Groundwater Wells:	2.97 MGD	(excludes Free St. #4)
Collection Well:	0.89 MGD	(Fulling Mill Pond)
Surface Water:	0.43 MGD	(Accord Pond)
SAFE YIELD:	4.29 MGD	
Emergency Source:	0.66 MGD	(Free St. Well #4)
EMERGENCY SAFE YIELD:	4.95 MGD	

4.51.3 Norwell Sources Safe Yield

The Town of Norwell's four wells in the watershed have also been assessed for their safe yield capacity. According to information provided by the Norwell Water Department, the combined safe yield of the four wells within the Weir River Watershed (Well Nos. 2, 3, 5, and 10) is 1.00 MGD. Information contained in earlier reports varies somewhat. The Zone II Delineation Study of the Grove Street Well Field commissioned by the Norwell Water Department and conducted Donald E. Reed in 1994 states that the combined safe yield of the four wells is 0.74 MGD. This rate was developed based on actual pumping rates in 1993. An earlier report by IEP Inc. prepared in 1988 lists slightly different values for the Weir River watershed wells.

4.51.4 Water Resources Management Program Safe Yield

The methods of estimating safe yield as specified in the DEP Massachusetts Water Resources Management Program regulations (310CMR36.00) were applied on a subbasin level. The safe yield is used to assess the impact of new withdrawals for water supply sources upon existing water resources. This allows regulatory agencies to evaluate the availability of water for new permit applications. GZA consulted Dr. Neil M. Fennessey, Professor of Hydrology of the University of Massachusetts at Dartmouth, who was instrumental in developing the safe yield guidelines in the regulations. According to the regulations, the following equation is used to estimate the average annual safe yield in a basin:

$$\text{Average Annual Safe Yield} = [E\,\{Q_{80}/Q_{81}\} - D_g\,Q_{min}]\,D_b / D_g$$

where:

$\mathbf{E\,\{Q_{80}/Q_{81}\}}$ = estimated daily streamflow for July through September, 1980-1981, cfsm
$\mathbf{D_g}$ = Drainage area of reference basin, mi^2
$\mathbf{Q_{min}}$ = Water Management reference streamflow, cfs
$\mathbf{D_b}$ = Subbasin drainage area, mi^2

For application to the Weir River Watershed, the closest USGS stream gage (Old Swamp River at Weymouth) was used to estimate an $E\{Q_{80}/Q_{81}\}$ of 1.05 cfsm and the corresponding D_g, the drainage area of the gage, 4.29 mi^2. A Q_{min} of 0.15 cfsm was chosen as recommended by the Massachusetts Division of Marine Fisheries. As shown in **Table 4-14**, The safe yield for each subbasin was subsequently estimated by substituting each respective drainage area for D_b.

4.52 Water Balance Methodology

The methods of estimating safe yield presented above are independent of time for the most part and do not provide a clear picture of the relationship between water demand and the aquatic environment. For this, a water balance is necessary. However, an average annual water budget model does not provide enough resolution to predict streamflow (and the baseflow component of total runoff) on a more refined, monthly basis. Detailed analyses using computer models such as HSPF (Hydrologic Simulation Program Fortran) require extensive amounts of watershed data, and calibration simulations which are not within the scope of this project. Therefore, GZA has used a simplified monthly water budget model to assist in the estimating seasonal values for aquatic habitat safe yield.

A water balance or budget is, at its simplest, an accounting of all water flowing into, out of, and/or stored within a watershed or subbasin. The water budget model used by GZA is a one-dimensional model with a monthly time step. A separate model has been applied to each subbasin and these are then linked. Inflow in the form of precipitation or streamflow is balanced against outflow which occurs as evapotranspiration, streamflow, or withdrawal. Estimating changes in overall storage, either surface water or groundwater are also possible. By accounting for all storage and transfer terms, and by varying the inputs and withdrawals, various drought and demand scenarios may be considered using the water balance model.

In developing the water balance model and the hydrologic characteristics of the Weir River watershed, GZA used general methodologies described in publications such as the USGS Water Resource Inventory Bulletins[63]. These publications have provided good general information on surface and groundwater resources.

A primary goal of this study and key rationale for developing the water balance is to examine how demand for water affects the quantity and quality of aquatic habitat based on flows at various times of the year. As will be further discussed in Section 5.30, a key factor in determining the suitability of a stream to provide aquatic habitat is the amount of flow within the stream. Therefore, one of the most important outputs from the water balance model is the quantity of flow expected to remain in the streams and rivers of the basin in each month, particularly in dry months.

Total streamflow is made up of two components, stormwater surface runoff and groundwater outflow (also called baseflow). For a small watershed such as the Weir River basin, the surface water component is often too transient and flashy in the summer months (on an average monthly basis) to be important for biologic activity. The quantity of streamflow contributed by average summer baseflow is likely to be a more accurate predictor of the typical <u>median</u> summer streamflow (which is the parameter preferred by USFWS in its New England ABF Policy). Thus we have, via simplified methods, developed a relationship between storage and groundwater baseflow (outflow).

Simply put, a means was needed to predict monthly baseflow (which will be used as a proxy for the typical median summertime streamflow) based on an estimate of monthly change in aquifer storage. By developing this relationship for an average year, under assumed "virgin" conditions on a subbasin level, GZA was able to develop a basic relationship between aquifer storage and baseflow. ("Virgin" conditions were defined as pre-development, no withdrawals.) GZA then evaluated how changes in aquifer storage due to pumping withdrawals may decrease total streamflow and potentially impact local aquatic biology. The analysis was carried out on a subbasin level. The model development process is presented below and the modeling implementation and results are described in Sections 4.53 and 4.54:

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[63] These reports include: Mazzaferro, D.L., Handman, E.H., Thomas, M.P., "Water Resource Inventory of Connecticut - Part 8 - Quinnipiac River Basin", prepared by USGS in cooperation with CTDEP, Connecticut Water Resource Bulletin No. 27 (1979).

- Known (or directly estimated) variables: Precipitation, Evapotranspiration, pumping withdrawals.
- Unknown variables: actual streamflow rates, actual basin-wide aquifer storage, monthly infiltration rates.

- **Step 1:** Estimate average monthly total stream flow rates in the ungaged, "virgin" Weir River watershed by using stream gage data from similar, nearby watersheds and normalizing for drainage area. As there are no permanent USGS streamflow gaging stations in the study area, use of flow data from other similar watersheds was necessary. The USGS gages used in our analyses were based on similar, relatively undeveloped (virgin) watersheds: Old Swamp River at Weymouth and Indian Head River at Hanover. Although useful for comparison purposes, the existing database of GZA, USGS, and other organization flow data cannot be used to confidently establish monthly average flow patterns due to limited periods of record. Continuously recording or daily stream gage data with long periods of record (i.e., sample size) were used to estimate flow patterns in the watershed. As with any other statistical endeavor, the larger the sample size, the higher the confidence in forecasting trends in the data. Monthly average flow estimates based on observed flow data with small and non-uniform sample sizes are susceptible to error based upon potentially extreme climate conditions (i.e., drought, flood), unforeseen conditions (water supply demand fluctuations), and/or flow measurement variability (human error, mechanical defects, etc.).

- **Step 2**: Derive average monthly baseflow rates in the "virgin" Weir River watershed through USGS program HYSEP (Hydrograph Separation). HYSEP takes average daily data from a USGS gage and estimates percent of total flow which is baseflow. Baseflow percentages from similar watersheds derived using HYSEP were normalized to cfsm and applied to the Weir River Watershed.

- **Step 3**: Calculate monthly water balance for average year climate conditions (precipitation). Input baseflows found in Step 2. Assume initial storage is zero (an arbitrary assignment). Storage values which are estimated in the process will be relative to this existing condition. Solve for monthly change in storage.

- **Step 4:** Plot Storage at time (t) vs. Baseflow at time (t+1). Use these 12 data points to develop what is essentially a "rating curve" of Storage vs. Baseflow.

- **Step 5:** Now the water balance evaluation can be performed for other scenarios (i.e. dry years, increased pumping, etc.), solving for resultant baseflow in the study stream. Together with the Jenkins Method for calculating streamflow depletion due to pumping wells[64], we can

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[64] C.T. Jenkins, "Computation of Rate and Volume of Stream Depletion by Wells," Techniques of Water-Resources Investigations of the USGS, Book 4, Chapter D1, 1977.

quantitatively evaluate (at least on a preliminary level) the relative impact pumping has on baseflow and whether the resultant flows are sufficient to sustain aquatic life.

A detailed description of the model spreadsheet entries is provided in **Appendix F**. In addition, the equations relating the pertinent parameters of the water balance (i.e., precipitation, evapotranspiration, runoff, baseflow, withdrawals, etc.) and copies of the model spreadsheets are in **Appendix F**.

4.53 Water Balance Discussion and Results

To start as simply as possible and to avoid complications introduced by water supply withdrawals and human impacts, the "pre-development" virgin condition was selected to develop the baseflow-storage relationship. The underlying assumptions and results of each step are presented below:

As per the scope of the study developed by DEM, the water balance model was used to examine several different scenarios. Three different developments scenarios were created and each of them was modeled under two different hydrologic conditions.

Development Scenarios:

- **Virgin Scenario**: Assumed natural conditions which existed before settlement and development of the area and withdrawals from the watershed.
- **Developed Scenario**: Water demand set at present (1998) level. See Section 4.33
- **Future Scenario:** Water demand forecast for the year 2020 by DEM-OWR Method 2. See Section 4.36.

It should be noted that the change in percent impervious cover in the watershed was not factored directly into the "developed" and "future" conditions. Although the promulgation of impervious areas can enhance surface runoff and impair local groundwater recharge, it is assumed to have a minor impact over the long term and over the entire extent of the watershed given the residential and moderately developed nature of the Weir River Basin.

The majority of the land use in the non-tidal (i.e., recharging) areas of the watershed are predominantly forested or large-lot residential. Land Classified as Urban, Commercial, or Industrial accounts for only 5 percent of the total watershed area. Many of the limited impervious areas in the residential areas, such as rooftops, driveways, or small parking lots, are not interconnected directly to large-scale drainage systems. While increases in impervious area will cause an increase of direct stormwater runoff from a site during a significant storm event, the effects of changes in infiltration characteristics (as represented by the SCS runoff curve number) is much less pronounced when the cumulative rainfall depth of a single event is small (2-inches or less). In an average year, small individual rainfall events are more common than the intense storms generally used in designing stormwater systems and make up the majority of precipitation. For these reasons, the cumulative effects of the increases in impervious area in the Weir River watershed are not likely to cause appreciably changes in the baseflow when compared to the "virgin" (i.e., baseline) condition, on an average monthly basis, and total streamflow will be unaffected.

Furthermore, the "virgin" condition flows were developed using similar watersheds as the Weir River basin at Old Swamp River in Weymouth and Indian Head River in Hanover. Since it is virtually impossible to find a truly undeveloped watershed in Southeastern Massachusetts from which to generate virgin flow estimates for an ungaged basin, it was judged appropriate to locate similar basins with a minimal amount of water supply withdrawals. The streamflow and baseflow data used for the simplified model were derived from these similar basins, and thus the effects of impervious areas are essentially built-in to the virgin model. The general method of using watersheds with minimal withdrawals to develop regression equations for ungaged basins was recently employed by the USGS in developing the StreamStats web application (USGS, WRI-00-4135).

Both of the similar watersheds contain continuous record USGS stream gages. Both of these basins are considered "natural" due to the lack of water supply withdrawals and other flow controls, and were used in the development or correlation process of the StreamStats regression equations (USGS, WRI 00-4135); however, both of these basins do have some development (residential, commercial, etc.) and thus more impervious area than under "virgin" conditions. In fact, Old Swamp River and Indian Head River watershed contain more urban and industrial land (22 percent and 17 percent respectively) than the Weir River watershed (5 percent). Further reduction in infiltration (and therefore baseflow) for the "current" scenario would be, in essence, "double-counting," in GZA's opinion. The "virgin" baseflows in the Weir River watershed therefore, if anything, underestimate the effects of present water supply withdrawals on current baseflows since the effects of impervious area are reflected in the flows from the two similar watersheds.

The effects of additional impervious area under future conditions has been discounted for all of the reasons stated above and because regulations require stormwater planning for new development which encourages infiltration of additional runoff generated by development.

Hydrologic Conditions:

- **Average Year Conditions:** Assumes that rainfall and all other climate inputs are equal to the long-term mean value.
- **Dry Year Conditions:** Assumes rainfall amounts that would likely occur in a 1 in 20 year drought, i.e. 95 percent exceedence. All other climate factions (ET, etc.) are assumed average and demand is the same as in the average year condition. See Section 4.53.6

4.53.1 Monthly Flow (Step 1)

Evaluating monthly flow begins in the similar watersheds (discussed in Section 3.31 and Table 3-5) that share some of the hydrologic, geographic, and land use characteristics of the Weir River watershed. Each watershed was investigated using MassGIS surficial geology and water supply data layers and compared to the "virgin" Weir River watershed. As shown on Figure 4-3a, the Old Swamp River at Weymouth and the Indian Head River at Hanover most resembled the virgin condition, with only one reported withdrawal point. The percent of stratified drift varied, however, from 26.4 percent in the Old Swamp River watershed to 59.9 percent in the Indian Head River watershed. These respective values lie below and above the amount of stratified drift in the Weir River Basin, which is 46 percent. The full period of record of daily flow data from the respective USGS stream gages was obtained from the USGS web site (www.usgs.gov). Data from similar watersheds was analyzed using the USGS computer program SWSTAT, which produced an average monthly streamflow value. The average monthly streamflow value for each watershed was normalized for drainage area, as shown in **Figure 4-4** and **Table 4-15**. The average monthly flow (cfsm) for each watershed is quite similar, despite the difference in the percentage of stratified drift underlying each basin. Average monthly flows peak in March, ranging from about 3.9 cfsm in the Indian Head River to about 3.8 cfsm in the Old Swamp River, and reach a minimum in July, ranging from 0.7 cfsm in the Indian Head River to 0.6 cfsm in the Old Swamp River. The average monthly flow in cfsm for the Weir River was estimated by taking the weighted average of the two flows based on percent stratified-drift. Lowest monthly values occur in the months of July, August, and September when the flow reaches a minimum of 0.6 to 0.7 cfsm. The peak monthly flow value occurs in March at 3.8 cfsm.

4.53.2 Baseflow Separation (Step 2)

Baseflow separation was accomplished with HYSEP (Hydrograph Separation, a USGS computer program) which accepts input in the form of average daily flows for a period of record and estimates the percentage of streamflow which is baseflow. The program relies on mathematical methods that mimic the methods of hand-separating baseflow from observed hydrographs.[65] The percentage of baseflow for the similar watersheds was applied to the Weir River watershed on a cfsm basis. **Figure 4-5** and **Table 4-15** shows the monthly Weir River streamflow and baseflow values for the virgin condition on a cfsm basis. Baseflow values are at a minimum of 37 percent of total flow, or about 0.3 cfsm, in the month of August. Highest baseflow is predicted to occur in March, when the baseflow is estimated as 62 percent of total flow, or approximately 2.3 cfsm. The results appear counter-intuitive at first glance, since it is widely accepted that baseflow represents the majority of total streamflow in the dry summer months. However, while total streamflows in August may consist of primarily groundwater outflow for the majority of days, relatively high-intensity summer precipitation events and tropical storms appear to enhance the magnitude of monthly average streamflow, especially in consideration of the low flows expected in summer. In this context, the HYSEP results (provided in Appendix F) may be more clearly understood. This is also further justification for the use of mean baseflow to establish minimum flow threshold recommendations.

4.53.3 Monthly Water Balance for the Study Area under Virgin Conditions (Step 3)

Once monthly streamflow and baseflow were estimated, the monthly water balance under virgin conditions for the entire 23.4 square-mile study area was evaluated. The results of the water balance were subsequently checked for reasonableness through comparison to expected and/or predicted values of streamflow and annual change in storage as discussed in previous sections. Using the methods of Section 4.10 and aforementioned USGS reference materials, inflow and outflow volumes were estimated and monthly changes in storage predicted. Refer to **Appendix F** for a detailed description of the water balance calculations. Key input parameters include monthly precipitation and monthly evapotranspiration estimates, as discussed in Section 3.23 and 3.25, respectively. The initial storage in the watershed was set to zero to represent an initial (arbitrary) condition. Estimating the actual storage of the watershed would require detailed hydrogeologic data and aquifer which are not available for the Weir River watershed.

Infiltration volumes and monthly storage changes were estimated using precipitation, evapotranspiration, streamflow, and baseflow information. Infiltration estimates were developed by subtracting the volume of runoff, which is equal to the difference in total streamflow and baseflow, from the volume of precipitation remaining after evapotranspiration. The monthly change in storage was then estimated as the difference between the infiltration volume and the baseflow volume.

As discussed in Section 4.10, there is assumed to be no change in storage on an average annual basis. Therefore, the total annual streamflow (or basin outflow composed of baseflow and surface runoff) should equal the volume of precipitation after evapotranspiration (resultant precipitation). However, since the analyses performed for baseflow and streamflow

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[65] Sloto and Crouse, "HYSEP: A Computer Program for Streamflow Hydrograph Separation and Analysis", USGS WRI 96-4040, 1996.

were based on estimates from USGS methodology and similar watersheds, the total annual streamflow was slightly different than our calculated resultant precipitation. Therefore, a "Correction Factor" was needed to balance the total annual streamflow and the resultant volume of precipitation. The Correction Factor (CF) is equal to the annual resultant volume of precipitation divided by the total annual streamflow. The CF is then applied to streamflow volumes to ensure our annual water balance for virgin conditions reflects steady-state storage conditions.

The CF for the study area under virgin conditions was about 0.96. This indicates that the estimate of the volume of resultant precipitation in the Weir River watershed was only about 4 percent below the estimate of total streamflow developed from USGS methods in the similar watersheds. Adjusting the streamflow amounts by CF resulted in an average annual change in storage of zero. The amount of storage in the basin was predicted to be below the initial condition (i.e. net storage deficit) from May to November and aquifer recharge was predicted to occur in the late autumn and winter months. The lowest adjusted total streamflow was estimated at 0.6 cfsm in the month of July and the lowest adjusted total baseflow was estimated at 0.2 cfsm in the month of August. Although it is not possible to compare predicted water balance flows with actual virgin condition values (since there is no stream gage data), the estimates obtained using this water balance methodology appear reasonable, in GZA's opinion.

4.53.4 Storage-Baseflow Relationship Development

The relationship between the amount of storage in the watershed and the resulting baseflow into streams was developed based on the virgin condition for the entire study area. The developed storage-baseflow rating curve was then investigated for statistical accuracy and applied to other scenarios, such as developed conditions. The absolute storage volume used by the model is arbitrary and does not necessarily represent the actual amount of groundwater in the aquifer. The storage-baseflow relationship is based on the change in storage from the initial arbitrary value.

The storage-baseflow relationship was developed by plotting the estimated monthly total storage against the estimated baseflow. A linear "best-fit" trend line was then fitted to the plot, as shown on **Figure 4-6(a)**. The square of the Pearson product moment correlation coefficient, commonly referred to as the "R-squared" value, and the correlation coefficient were calculated for the trend line. The R-squared value can be thought of as the proportion of variance in one set of variables attributable to the variance in another set of variables. The trend line exhibited good statistical association, with an R-squared value of 0.92 and a correlation coefficient of 0.96.

4.53.5 Developed Conditions: Baseflow Estimates and the Jenkins Method for Stream Depletion by Wells

The storage-baseflow relationship estimated for each subbasin was applied to the developed condition. Refer to **Appendix F** for a detailed description of the water balance methodology for the developed condition. The general approach is identical to the virgin water balance, with the exception of baseflow estimates and the addition of the Jenkins Method to predict stream depletion by wells.

Baseflow was estimated based on the equation of the trend line developed as discussed in the previous section. The total storage in the basin was set at zero at the start of the model, and a corresponding baseflow was computed. As total storage varied with each month, a revised baseflow was estimated and used in the subsequent month's water balance.

The impacts of well withdrawals were modeled using Jenkins Method, which provides a simple approach to estimate the effects of groundwater withdrawal on nearby streams. Jenkins Method allows for estimates of: 1) the rate of stream depletion at any time during the pumping period or the following non-pumping period, 2) the volume of water induced from the stream during any period, and 3) the effects of any pattern of intermittent pumping. This method was recently used in a similar study conducted on the Ipswich River Basin by the USGS.[66] Estimates of stream depletion are made through the use of a series of dimensionless curves and tables. Key input parameters include aquifer storativity and the transmissivity, the steady state pumping rate, pumping time, and the perpendicular distance from the pumping well to the stream. Jenkins Method calculations are provided in **Appendix F**. A summary of Jenkins Method calculations is presented in **Table 4-16** and **Table 4-17**. The depletion of the nearest stream was estimated for each pumping well based on the monthly pumping records from the 1998 DEP Public Water Supply Annual Statistics Report. An adjusted streamflow and baseflow rate was then estimated by subtracting the Jenkins volume of depletion due to pumping wells. On a watershed-wide basis, the most significant month for streamflow depletion is August, when 4.2 cfs is depleted from the collective streams of the watershed.

Accounting for stream depletion and well pumping, the annual change under average conditions in basin storage was estimated to be about 830 Mgal below initial conditions. Total streamflow was predicted to dip to a minimum of about 10 cfs in July and total baseflow was estimated at zero during August, September, October, and November. However, since the watershed-wide analysis was performed to simply check the rationality of the water balance model, it may not provide enough detail to estimate safe yield values. The model was therefore applied on a subbasin level.

To model 'future' conditions, accounting for increased levels of demand as described in Section 4.36, an additional 0.64 MGD was considered to be extracted from the watershed. Demand projections for the Town of Norwell are steady, such that increased demand in the basin will likely be from AWC. From discussions with AWC personnel and considering the age and configuration of their well system, GZA has assumed that the additional demand would

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[66] Kernell Ries, USGS via Telephone communication

be modeled as withdrawals from Free Street Well #4. Currently, this well is not approved for routine use by DEP; however, it is anticipated that AWC will eventually secure permission to do so. Free Street Well No. 4 is located in subbasin 6, along with AWC wells Free Street Nos. 2 and 3 and the Downing Street Well. A new Jenkins stream depletion rate was calculated for the subbasin in consideration of the increased pumping. Withdrawals from other subbasins were projected to remain constant from developed to future conditions.

4.53.6 Dry / Low Flow Conditions: Estimates of Rainfall and Streamflow

To apply the water balance model to dry climate conditions, rainfall estimates for extreme “dry” conditions were made based on data developed as discussed in Section 3.00. Annual rainfall data since 1900 from the Blue Hills observatory was analyzed and a cumulative probability function was generated, see **Figure 4-6(b)**. Based on the observed data, which is normally distributed, an expected annual precipitation depth was derived for “dry” conditions, assumed to occur when precipitation is less than or equal to the 95% exceedence value on the cumulative probability function. The 95% exceedence precipitation value used for the study area is 34.9 inches. This represents approximately 73% of the mean annual rainfall at the Blue Hills Station (47.8 in.). The Hingham rainfall gage has a smaller precipitation data set, but produces virtually the same results. Therefore to model low flow conditions within the water budget, average monthly precipitation input values were adjusted by a factor of 0.73.

The baseflow-storage relationship developed under average conditions is also considered to be valid for dry conditions. Total streamflow estimates were obtained by preserving calculated infiltration coefficients from the average conditions and/or percent of streamflow which is baseflow as calculated based on HYSEP estimates.

4.53.7 Limitations

Due to data collection and project scope limitations, the water balance model developed for application to the Weir River watershed is a simplified, monthly time-step model. As such, it is inappropriate to attempt to derive and evaluate the magnitude and frequency of extreme low flows, such as the 7Q10, through the use of the model. In addition, the model does not directly consider or differentiate between intricate hydrologic functions occurring within the watershed subbasins such as soil moisture conditions, areas of stream/well recharge vs. water table recharge, and septic system locations or return flow/recharge area geologic characteristics. Although the model does consider human impacts to the watershed through the use of the Jenkins method for estimating stream depletion due to pumping and by accounting for direct surface water withdrawals/diversions, it assumes that the physical alteration of the watershed and any land use changes occurring within the watershed from natural to developed and future scenarios are not of sufficient magnitude to have significant impacts on streamflow, on a monthly, watershed-wide basis. Of course, as development promulgates throughout a watershed, impervious areas increase. Such an increase may lead to reduced areas of potential infiltration which may have a negative impact on base flow.

4.54 Subbasin In-Stream Flows from the Water Balance

The water balance methodology discussed in Section 4.52 was applied on a subbasin level for virgin, developed, and future conditions. For the virgin condition, baseflow and total streamflow estimates developed as discussed in Sections 4.53.1 and 4.53.2 were converted to cfs by multiplying by each subbasin drainage area. The storage-baseflow relationship was then redeveloped for each subbasin with similar statistical success. Jenkins Method was also performed for each well in its respective subbasin and the results are summarized in **Table 4-17**. Water balance spreadsheets and storage-baseflow trend lines are provided in **Appendix F**. Summary tables of the water balance monthly results are provided in **Tables 4-18** to **4-24**. Note that baseflow and total streamflow values provided in the tables reflect incoming flow from other subbasins, when applicable. However, total storage is a subbasin-specific value.

In general, the water balance yields the most informative results for basins containing pumping wells, without surface water diversions or significant impoundments. In particular, Subbasins 3 (Accord Brook) and 6 (Weir River) show significant losses in storage and baseflow due to withdrawals. Other basins which do not contain large-scale water resources development, Subbasins 2 (Plymouth River), 4 (Crooked Meadow River), and 7 (Tidal) resemble virgin conditions, even under other development scenarios. Subbasins containing significant impoundments, Subbasins 1 (Accord Pond) and 5 (Fulling Mill), may overestimate total streamflows under developed conditions because the attenuation and flood storage provided by dams may be too detailed to integrate into the simplified monthly water balance model.

4.54.1 Subbasin One Water Balance: Accord Pond

The 0.76 square-mile Subbasin 1 (Accord Pond) contains one water supply source: Accord Pond. Water balance results are summarized in **Table 4-18a,b and Figure 4-7a,b** and calculations are provided in **Appendix F**. Under virgin conditions, the water balance predicts minimum baseflow of about 0.2 cfs in August. Total storage falls below initial conditions (i.e. net depletion in aquifer storage as compared to arbitrary January condition) from May to November. The developed condition accounts for the water supply withdrawals from storage, but does not model the affects of Accord Pond Dam on basin outflow. Since the withdrawals are reducing the amount of water stored in the basin, baseflow falls to zero cfs from July through December (a condition which has been observed in the field). The effects of Accord Pond Dam on stream flow are too detailed to incorporate in the simplified monthly water balance: the flow from the spillway is highly dependent on starting pond elevations and single-event rainfall. It is likely that actual total streamflow is less than predicted values; however, given this subbasins limited drainage area, the error generated by the flashy nature of Accord Pond Dam spillway overflows is likely insignificant relative to the month-to-month simplified water balance flow estimates. The total storage in the basin was predicted to be about 30 Mgal lower than initial conditions at the end of the 12 month period. The scenario remains constant from developed to future conditions since increased demand is considered to be satisfied from Free Street Well No. 4, which is outside the Accord Pond subbasin.

Under dry conditions, both baseflow and streamflow values fall to near zero under virgin conditions in September. The low flow conditions estimated for virgin conditions are exacerbated by withdrawals from storage under developed conditions (**Table 4-18b** and **Figure 4-7b**).

4.54.2 Subbasin Two Water Balance: Plymouth River

The 2.97 square-mile Subbasin 2 (Plymouth River), along with Subbasin 4 (Crooked Meadow River), does not contain significant water supply withdrawals according to the permitted and registered sources in the basin. Since water supply withdrawals are the major impact of developed and future conditions, the water balance model is relatively less significant in this subbasin. Water balance results are summarized in **Table 4-19a,b** and **Figure 4-8a,b** with calculations provided in **Appendix F**. Under virgin conditions, baseflow ranges from a minimum of 0.7 cfs in August to a maximum of 6.6 cfs in March. Streamflow values in the developed condition were not affected by the low withdrawal rate and baseflow numbers varied from virgin conditions as a result of the computed, linear storage-baseflow relationship. Total storage in the basin was predicted to fall below initial conditions by about 1.9 Mgal at the end of the year. The scenario remains constant from developed to future conditions since increased demand is considered to be satisfied from Free Street Well No. 4.

Under dry, virgin conditions, baseflows are estimated to fall to negligible levels in September and October. Since there are no large-scale withdrawals in the basin, virgin, developed and future conditions are similar (**Table 4-19b** and **Figure 4-8b**).

4.54.3 Subbasin Three Water Balance: Accord Brook

Subbasin 3 (Accord Brook) contains several water supply sources including the four Town of Norwell-owned wells and the AWC's Prospect and Scotland St. wells. The Accord Brook diversion is located at the outlet of the basin and diverts flow out of Subbasin 3 into Subbasin 5 (Fulling Mill). Since the diversion dam is located at the downstream outlet of Subbasin 3, it does not affect the water balance of upstream subbasins. The effects of the diversion are accounted for in Subbasin 5, which has been modeled to accept Subbasin 3 outflow. Water balance results are summarized in **Table 4-20a,b** and **Figure 4-9a,b** and calculations are provided in **Appendix F**. The minimum baseflow of 0.9 cfs under average, virgin conditions is predicted to occur in August. The maximum virgin baseflow, 8.4 cfs is predicted to occur in March. For developed and future conditions, the minimum baseflow drops to 0.0 cfs from July through December. Maximum baseflow, 6.5 cfs is estimated to occur in March. Total storage under developed and future conditions is expected to undergo depletion from April through December, reaching a deficit of about 341 Mgal at the end of the calendar year.

It is difficult to compare predicted flows under developed conditions to observed flows due to the presence of the Accord Brook diversion dam, which appears to have the capacity to divert the entirety of base flow to Subbasin 5 during a significant portion of the year based on the diversion dimensions and configuration. The predicted baseflow under developed conditions at the diversion dam for April is about 5.3 cfs, which resembles the 8.6 cfs of flow measured on April 12, 2000 at the culvert at South Pleasant Street. The culvert at South Pleasant Street is located a short distance downstream of the diversion, which was overflowing during the April flow measurement. Similarly, flows measured by GZA during August and October at various locations in Subbasin 3 seem to compare fairly well with predicted values. Sections of Accord Brook were dry during the August and October flow measurements, which is expected based on the water balance predictions of zero baseflow during this period. A flow of 1.2 cfs was measured on October 24, 1999 at the box culverts at Prospect Street, which is located about one mile upstream of the diversion dam. The water balance model predicts baseflows at the diversion dam for October as 0.0 cfs. Extensive average monthly flow data would be necessary to adequately verify the predicted flows from the water balance.

Under dry, virgin conditions, baseflow falls to near zero in September and October. (**Table 4-20b** and **Figure 4-9b**). Numerous groundwater withdrawals modeled in the developed and future condition reduce baseflow levels to zero from June to December and drop total streamflow to near zero in September. Under developed conditions, total net storage in the basin is estimated to fall about 394 Mgal below initial conditions when considering groundwater pumping.

4.54.4 Subbasin Four Water Balance: Crooked Meadow River

Subbasin 4 (Crooked Meadow River) receives incoming flow from the Plymouth River subbasin (Subbasin 2). It is similar to the Plymouth River subbasin because it does not contain large-scale permitted or registered water supply withdrawals. Water balance results are summarized in **Table 4-21a,b** and **Figure 4-10a,b** and calculations are provided in **Appendix F**. Under average, virgin conditions, baseflow ranges from a minimum of 1.2 cfs in August to a maximum of approximately 11.0 cfs in March. Streamflow values in the developed condition do not change because of the lack of withdrawals and baseflow numbers varied from virgin conditions as a result of the computed, linear storage-baseflow relationship. Cushing Pond Dam was not modeled because its storage effects are too detailed to incorporate in the simplified monthly water balance. Total storage in the basin was predicted to remain constant over an average annual basis.

The effects of Cushing Pond Dam decrease the significance of comparisons to observed flow. The predicted baseflow in August of 2.60 cfs is only slightly higher than the measured flow of 1.9 cfs at the box culvert under Main Street. The observed flow in October 1999 of about 3.4 cfs is higher than the predicted 0.92 cfs baseflow predicted by the model. Higher flows predicted by the model in April were not observed in the field, perhaps due to differences in modeled and actual precipitation (precipitation was slightly lower than normal over the winter and in the weeks prior to the measurement), the effects of the dam, and/or well pumping rates. The USGS operated a LFPR gage at the outlet of Subbasin 4, at the culvert under Main Street. Although the readings were not continuous, and were intended to be taken at times of low flow only, it is one of the few data sets available to check the reasonableness of the model. A comparison of USGS measured flowrates at the LFPR gage and estimated discharge is shown in **Table 4-21c**. The three measurements made in July appear to be somewhat lower than predicted values. However, in general, the measured and predicted flows match fairly well. It is important to note that to accurately verify the model, an extended period of flow observation, precipitation data, and withdrawal records are needed.

Baseflow reaches a minimum at or near zero in September and October during dry, virgin conditions (**Table 4-21b** and **Figure 4-10b**). Since there are no large-scale withdrawals in the basin, developed and future conditions resemble virgin conditions.

4.54.5 Subbasin Five Water Balance: Fulling Mill

The 0.29 square-mile Subbasin 5 (Fulling Mill) contains the Fulling Mill well, which is the lone major water supply source in the basin. Water balance results are summarized in **Table 4-22a,b** and **Figure 4-11a,b** and calculations are provided in **Appendix F**. Under average, virgin conditions, the model predicts baseflows ranging from about 0.1 cfs from July to September to 0.7 cfs in March. Developed and future baseflows generated by the subbasin itself are predicted to be at or near zero for much of the year. However, the developed condition is complicated by incoming flow from the Accord Brook diversion. The result of the diversion is a marked increase in total streamflow and baseflow from the virgin to developed condition. However, storage changes are considered only within the subbasin boundaries, which lead to an overestimate of the depletion of subbasin storage. Since flow from the Accord Brook diversion is not gaged, the amount of infiltrating surface water flow which is available for withdrawal by the Fulling Mill well is difficult to quantify. In essence, the 168 Mgal of storage depletion predicted by the model under developed conditions is not relative to initial virgin conditions but instead relative to the combined volume of water diverted from Accord Brook and the amount of storage in the subbasin.

For the dry condition, the model predicts virgin baseflow to range from 0.05 cfs in October to 0.25 cfs in April and May (**Table 4-22b** and **Figure 4-11b**). Inflow from the Accord Brook diversion increases total streamflow in developed and future conditions, but does not consistently supplement baseflow, since Accord Brook is modeled to run dry at times.

4.54.6 Subbasin Six Water Balance: Weir River

The 5.61 square-mile Weir River subbasin (Subbasin 6) contains three AWC water supply wells, excluding Free Street Well No.4, which is only used under emergency conditions. Increases in future demand have been assumed to be supplied from this wellfield. Water balance results are summarized in **Tables 4-23a,b** and **Figures 4-12a,b** and calculations are provided in **Appendix F**. It also receives inflow from each of the previous subbasins (1 through 5). Under average, virgin conditions, baseflow is predicted between 3.5 cfs in August and 32.6 cfs in March. The developed condition yields an estimate of baseflow between 0.9 cfs in October to 25.7 cfs in March. The total subbasin storage under developed conditions is predicted to be about 119 Mgal less than initial conditions at the end of the calendar year. For the future condition, added withdrawals from the assumed activation of Free Street Well Number 4 further reduce baseflow and storage. The developed and future baseflow estimates are lower than virgin conditions from August through December.

The outlet of the subbasin is at the Route 3A culvert, coincident with the location of the USGS LFPR gage. The comparison of modeled and measured flows is perhaps most accurately done at this location, since the river is free flowing and combines the flow from each of the subbasins. Under average climate conditions, the August baseflows are predicted to be 2.6 cfs. GZA-measured flows during August near the basin outlet were about 2.8 cfs. The USGS predicted an August median streamflow of 2.51 cfs using the LFPR gage data. Data collected from the LFPR gage and other data collected by the USGS during 1999 and 2000 at the same location is compared to estimated flows in **Table 4-23c**. As discussed earlier, if the precipitation prior to the flow measurement was considerably lower than normal or withdrawals were higher than expected, flows would be lower than expected in the model. Where USGS-measured flows were significantly lower than the predicted flows, "dry" weather estimates were included in **Table 4-23c**. Note that the reading of 0.22 cfs on July 18, 1991 is less than both the 99 percent exceedence value and the 7Q10 estimate according to the USGS estimate based on the LFPR data. The predicted flowrates in October were approximately 0.9 cfs of baseflow and approximately 12.6 cfs of total streamflow. GZA flow measurements in October were considerably higher at about 30.8 cfs. However, several storm events prior to this measurement, as discussed in Section 3.34, and any significant changes in water supply withdrawal volumes may account for this discrepancy. The GZA April flow measurement yielded about 36.8 cfs near the Subbasin 6 outlet. Predicted April flows range from a baseflow of about 24.5 cfs to an average total streamflow of approximately 42.0 cfs. In general, the limited amount of streamflow data collected by GZA and the USGS matches predicted values fairly well. To accurately verify the model, an extended record of precipitation, withdrawal, and flow data is needed.

Under virgin, dry conditions, baseflow is reduced dramatically from average conditions to as low as 0.06 cfs in October. Under both developed and future scenarios, baseflow is further reduced to about zero in September and October during dry conditions. Increased demand modeled in future conditions impacts Subbasin 6 as well, reducing baseflow (**Table 4-23b** and **Figure 4-12b**) by as much as about 0.5 cfs.

4.54.7 Subbasin Seven Water Balance: Tidal

Subbasin 7 is composed of the downstream limits of the study area and the water balance simulation was performed for the sake of completeness. The subbasin is tidally influenced and contains portions which do not actually contribute to the Weir River watershed.

There are no permitted or registered water supply sources within the basin and hydrogeologic data, as shown in **Figure 3-6**, indicate groundwater resources are not conducive to large-scale water supply development. This basin contains both golf courses, one of which (the South Shore Country Club) is actually outside of the physical drainage area of the Weir River. The golf course withdrawals were not modeled since the Cohasset Golf Club is a minor water-user which withdraws from only one well and one surface water source and the South Shore Country Club lies outside of the water resources of the Weir River watershed. Because of the noncontiguous nature of the watershed, the results for Subbasin 7 should not be considered to represent any portion of the Weir River. Water balance results are summarized in **Table 4-24a,b** and **Figure 4-13a,b** and calculations are provided in **Appendix F**. Under virgin conditions, the model indicates the minimum baseflow to be about 5.7 cfs in August. Under developed conditions, the minimum baseflow drops to about 2.5 cfs in October. Decreased flow under developed conditions was attributed to the cumulative effects of water supply withdrawals from other upstream (inflowing) subbasins. Baseflow increase error from virgin to developed and future conditions is a result of computed linear baseflow-storage relationship. Similar results are indicated by the water balance for dry conditions as for average conditions: decreased flow under developed conditions as compared to average conditions.

4.60 IMPLICATIONS

The water balance models indicate that, as expected, water withdrawals do lead to a reduction of baseflow, with a corresponding reduction in overall streamflow, in the streams and rivers of the Weir River watershed. The model also shows that there is a direct correlation between the amount of demand and the reduction of baseflows. The model predicts that under average conditions, many stream reaches within the basin could be expected to run dry for significant periods of time. The effects are most pronounced in Accord Brook and the Weir River. Anecdotal information from local residents, information contained in MAWC reports, GZA observations in 1999, and flow measurements by GZA and the Weir River Watershed Association validate this prediction. The model also indicates that under average conditions, a deficit in the amount of groundwater stored in the basin's aquifers is expected to result. The water balance predicts a total loss in storage within the watershed of about 750 Mgal during an average year based on current developed conditions. Annual groundwater recharge deficits under average conditions would be expected to be noticed in groundwater levels in the watershed. Groundwater level data provided by the MAWC (now AWC) appear to support this (see **Appendix E**). Examination of these graphs indicates that groundwater levels are typically reduced to minimum levels in the late summer (August – October) but generally recover during the winter and spring. However, the multi-year trend seems to indicate that the moving average of the groundwater levels is reduced over time at many of the wells, as evidenced by the declining minimum levels. Overall recovery after several years of such downward trends does, at least conceptually, appear to indicate that a wet year or a decrease in pumping is capable of restoring groundwater levels to previous maximums.

Greatest impacts are projected in Subbasins 3 and 6, which encompass the majority of water withdrawals. In subbasin 3, model results indicate baseflow, which was between about 1.0 and about 5.4 cfs under average virgin conditions, drops to negligible levels from July to December under average developed and future conditions. Similarly, in subbasin 6, average developed and future condition baseflow levels are reduced by as much as about 88 percent from the average virgin condition from July to December.

Again, as is intuitively expected, baseflow during dry conditions is predicted to be much less than during years with an average quantity of rainfall. It is interesting to note that, even under so-called virgin conditions, baseflow during extended drought conditions is predicted to fall to essentially zero in many cases.

The water balance model is a tool which allows analyses of all of the sub-basins of the watershed under various scenarios and conditions. The model quantifies the relationship between demand and baseflow. The next step to assessing the impacts of demand on the aquatic environment is to determine the relationship between median streamflow in the summer months (which is most closely approximated by baseflow within the water balance model) and aquatic habitat. Section 5.0 examines the streams of the watershed from an aquatic habitat perspective. The connection between median (typical) streamflow and useable habitat is established and recommendations are made regarding minimum acceptable baseflows. By combining the hydrologic and biologic information developed within body of this report, Aquatic Habitat Firm Yield values are estimated and presented in Section 5.50. General conclusions are offered in Section 6.00.

5.00 LIVING AQUATIC RESOURCES AND AQUATIC HABITAT SAFE YIELD

5.10 FISHERY RESOURCES

The waters of the Weir River Watershed have in the past supported a rich and diverse fish community. To evaluate the current status of the fisheries of the watershed, recent fisheries studies have been reviewed and a supplemental sampling program designed and implemented. The purpose of the report review (see Section 2.102) and supplemental sampling is to provide data for a qualitative description of the resident fish species within the watershed. This information may be used as a baseline to evaluate future changes in the watershed. Streamflows within the watershed have been evaluated based on suitability for a representative sample of those species of fish which are or should be present in the streams of the watershed. Information obtained from the Division of Fisheries and Wildlife on past sampling and historic fish populations is contained in **Appendix G**. Minimum streamflow requirements for representative species have been evaluated and compared to measured and predicted baseflows over a variety of hydrologic conditions. By combining the fisheries habitat needs criteria with the water balance hydrologic model developed in Section 4.0, an estimate has been made of the Aquatic Habitat Safe Yield of the Weir River watershed. This value represents the level of demand which may be sustained while balancing and maintaining the needs of the fisheries in the streams and rivers of the watershed.

The Living Aquatic Resources portion of this report was prepared jointly by GZA and its sub-consultant Kleinschmidt Associates (KA) of Pittsfield, Maine. Mr. Brandon Kulik of KA was the senior fisheries biologist. The methods used in this report are broadly similar to those used in Instream Flow Incremental Methodology (IFIM) studies. The scope of this project did not envision or call for a full-scale IFIM study. However, the information developed in this report could be expanded upon during a future IFIM study. Also the goals of the Living Aquatic Resources portion of this report are the same as that of a IFIM study. Specifically, the information presented here is intended to be used as, "[A] support system designed to help natural resources managers and their constituencies determine the benefits or consequences of different water management alternatives." [67]

5.11 Fishery Sampling Methodology

Fisheries sampling was conducted in the Weir River by biologists from GZA and Mr. Steve Hurley of the Massachusetts Division of Fisheries and Wildlife on September 11, 1999. The climate conditions preceeding the sampling event varied from lower than normal streamflows due to a very dry July and August to above normal streamflows due to large precipitation events triggered by tropical storms on or about September 10 and again on September 17. These conditions are not expected to have had an adverse impact on the validity of the sampling protocol. Sampling was done using backpack electroshock sampling techniques. Fish were

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[67] Bovee, Ken D. et. al. "Stream Habitat Analysis Using the Instream Flow Incremental Methodology". U.S. Geological Survey, BRD-1998-0004, 1998.

stunned, collected, cataloged, measured, and released. Eels were not measured, but approximate numbers were estimated. Sampling was only conducted in stream segments that were wetted at the time of sample collection. Sampling was conducted at eight locations within the watershed as listed below:

Weir River

1. Leavitt Street (Transect location W-2)
2. Weir River Farm / Route 228 (Transect Location W-3)

Accord Brook

3. Route 228 / Route 56 (Transect Location A-2)
4. Union Street – (Transect location A-3)
5. Pleasant Street – Upstream of Diversion

Plymouth River

6. Ward Street
7. Plymouth River Street – Plymouth River Common
8. Cushing Street – (unnamed tributary to Plymouth River)

5.12 Fishery Sampling Results

Fisheries sampling, in the locations listed above, was conducted in mid-September 1999. **Appendix G** contains the full results of the fish sampling program. The following fish species were collected:

1. Brown trout
2. Brook trout
3. largemouth bass
4. redfin pickerel
5. bluegill
6. pumpkinseed sunfish
7. American eel

The Massachusetts Division of Fisheries and Wildlife (MDFW) manages this river as a seasonal coldwater recreational fishery, based on (early spring) put and take trout stocking. Fish are stocked annually, and most fishing occurs in the river between Union Street downstream to Route 3A (S. Hurley, personal communication). Some of the stocked trout are not caught, and can hold over in portions of the watershed maintaining sufficient habitat and water quality throughout the year. In addition, MDFW fish sampling has detected brown trout reproduction, as evidenced by the presence of Young of Year (YOY) of this species collected near Leavitt Street, in the Weir River where in-stream flows are near their greatest.

The species sampled represent habitat generalists and/or species common to ponds and pools. However, this system is highly fragmented due to the presence of impounded reservoirs and dewatered reaches. As a result, a number of species indigenous to southeastern Massachusetts streams with lifestages dependent on riffle and run habitat were not detected by GZA. Species which would typically be expected to be relatively abundant in streams such as the Weir River, but were not found in the Weir River during GZA's sampling include:

1. Alewife
2. blueback herring
3. rainbow smelt
4. white sucker
5. tessellated darter

5.20 INVERTEBRATE SAMPLING

To assess whether the flow regime documented in Accord Brook has resulted in impairment of the ecological community of the brook, a bioassessment of macroinvertebrate communities within potentially impacted reaches of the brook was conducted in January, 2000. The proposed bioassessment was conducted in accordance with the recommendations of EPA's most recent revision of *Rapid Bioassessment Protocols for Use in Streams and Rivers*[68] (RBP).

Bioassessments of aquatic ecosystems are used to identify and characterize differences between ecosystems which are exposed to an environmental stressor, such as chemical discharge or nutrient enrichment, and reference ecosystems. Bioassessments use aquatic communities as sentinels of ecological impairment to natural resources. Among the most informative aquatic communities used in bioassessment studies are benthic (bottom-dwelling) macroinvertebrates. Most benthic macroinvertebrates are relatively sessile, and usually occur in great numbers and diversity. In addition, benthic macroinvertebrate communities are important food items for fish, and perform essential roles in the cycling of nutrients and organic matter. In combination, these properties make invertebrate communities ideal indicators of environmental impact.

In this bioassessment, benthic macroinvertebrate communities from two potentially impacted reaches of Accord Brook (AB-1 and AB-2 in subbasin 3) and two reference reaches from nearby Crooked Meadow Brook (CMB-1 and CMB-2 in subbasin 4) were sampled and compared to evaluate potential impacts from low flow conditions during summer months (see **Figure 3-4**). Sampling from these sites was believed to sufficient to produce data appropriate to the level of this study. The macroinvertebrate communities of potentially impacted portions of

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[68] EPA 841-D-97-002, Draft Revision - July 14, 1999.

Accord Brook (hereafter referred to as "study reaches") are also subject to non-flow related causes of potential impact (i.e., residential encroachment and reduction in riparian vegetation). The following sections describe field sampling efforts for benthic macroinvertebrates, laboratory taxonomic procedures, and data analysis techniques employed in the bioassessment.

5.21 Field And Laboratory Procedures

The interpretation of bioassessment results relies heavily upon the assumption that the environmental stressor of interest is the sole difference between unimpacted (reference) locations and study locations. This ideal situation rarely occurs in natural systems, which vary at macro- and micro-scales. The most important variables considered in the selection of reference sample locations for bioassessment are those that vary longitudinally along riverine ecosystems, such as bank vegetation characteristics, temperature, hydrology, and channel geomorphology.[69] The combined influences of these variables (along with a myriad of other environmental factors such as water chemistry) exert a strong influence on the invertebrate community structure of a river. This bioassessment documented habitat characteristics at each of the sampling reaches. The most important of these characteristics are described below.

5.21.1 Habitat Description

The study reaches of Accord Brook are dominated by runs (approximately laminar flow), without significant occurrence of pools or riffles. Riffles and runs are known to support the most diverse benthic macroinvertebrate communities, largely due to the dominance of stable cobble substrates and the high levels of dissolved oxygen associated with these flow regimes. The substrate of the Accord Brook reaches was composed primarily of gravel, with some accumulation of sand and silt. Organic debris (sticks, fallen leaves, and other coarse plant material) was abundant at both of the Accord Brook reaches. Aquatic mosses and other macrophytes were also common at both Accord Brook reaches.

Several accessible reaches of Crooked Meadow Brook were inspected to ascertain their suitability for comparison to Accord Brook. The most similar reaches were dominated by sequences of riffles (turbulent flow) and runs (approximately laminar flow), without significant occurrence of pools. The substrates of these reference reaches were dominated by gravel, sand, and cobble, with far less silt accumulation than in the Accord Brook reaches. The reference reaches also contained less aquatic vegetation and organic debris than the study reaches.

Habitat classifications were performed and documented in accordance with the RBP, and are included as **Appendix H**. The habitat classifications demonstrate that the reference locations selected are similar (but not identical) to potentially impacted locations. The habitats of each reach were scored using the criteria presented in the RBP. Habitat scoring criteria included

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[69] U.S. Environmental Protection Agency- SAB, 1993

the following characteristics: available substrate; substrate embeddedness; velocity/depth regime; sediment deposition; flow status; channel alteration; riffle frequency; bank stability; and riparian vegetation. Higher scores were assigned to more favorable habitat characteristics, and the scores for each characteristic were summed to derive an overall habitat score. The average Accord Brook habitat score (134.5) was lower than the average reference reach score of 162. The total scores indicate that the habitat quality in Accord Brook reaches is generally Suboptimal, while the habitat in the Crooked Meadow River reference reaches is generally Optimal (based on the EPA Rapid Bioassessment methodology.) The characteristics most responsible for this difference were the availability of substrate, riffle frequency and vegetative protection.

Figure 3-4 shows the locations of the sample reaches as well as the location of the reference reaches used to define background biological and chemical conditions for the study stream. These reaches were selected based on hydrological similarity to potentially impacted reaches.

5.21.2 Sampling Methods

The “Single Habitat Approach” described in the RBP was used to conduct the bioassessment. This method calls for the collection of composited samples from 100-meter reaches. Composites are composed of samples collected from riffles and runs representing different water velocities. Because the linear extent of the stream reaches was severely limited by residential properties, individual sample reaches established for this bioassessment were approximately 30-meters long. We established two 30-meter reference reaches (CMB-1 and CMB-2) in Crooked Meadow River to document the benthic macroinvertebrate community in an unaffected stream in the Weir River watershed. Two additional 30-meter reaches (AB-1 and AB-2) were established in a potentially impacted portion of Accord Brook to document the benthic macroinvertebrate communities in potentially impacted portions of the watershed.

Because water depths within the Study reach were less than 1.5 feet, samples were collected with a 0.5 mm mesh “Surber Sampler” (see photos in **Appendix H**). The sampler net was placed perpendicular to the bottom and 1 ft^2 of the substrate upstream of the net was manually lofted and brushed to dislodge benthic macroinvertebrates, which were trapped in the net as they floated downstream. This sampling method has the advantage of sampling the entire benthic community, whereas some other methods (e.g., kick-net) skew the collection towards larger, surface-dwelling organisms. The process was repeated in three riffle/runs within each 30-meter reach. Organisms from each of the three sub-samples were composited, preserved in 90 percent ethyl alcohol, and returned to GZA’s ecological laboratory for identification.

Standard water quality parameters were measured at each 30-meter reach at the time of sampling. These parameters included dissolved oxygen, temperature, specific conductivity and pH.

5.21.3 Laboratory Analysis

Macroinvertebrate samples were subsampled and sorted by a GZA biologist using a 10x to 70x stereo dissecting microscope. Random sub-sampling of approximately 100 organisms from each composited sample was conducted according to the recommendations of the RBP. Sub-sampling was conducted by evenly spreading out all of the material from a composite sample in a tray divided into a 4 x 3 grid. Based on a cursory examination, an appropriate number of individual grids (1 to 3) were randomly selected for microscopic evaluation and removal of organisms. After subsampling, organisms were sorted by taxonomic order[70] and were identified to the lowest practical taxonomic level.

5.22 Data Analysis Methods

Several analytical methods were used to characterize the macroinvertebrate communities sampled. Methods included several ecological indices related to community structure and health. Note that the presence of differences between macroinvertebrate sampling stations is not necessarily an indication of community structure impairment, and must be interpreted with consideration given to habitat characteristics and other potentially complicating variables. Analytical methods used for this bioassessment are described below.

5.22.1 Community Diversity and Evenness

The health of a biological community is often related to the number of different species represented (diversity) and the level of dominance exhibited by any one species (evenness). Several metrics which relate to both diversity and evenness were calculated.

Taxa Richness

Taxa Richness is simply the total number of taxa identified within a sample. The higher the Taxa Richness, the more diverse the community. Communities with greater diversity are generally considered to be healthier as compared to communities with lower diversity.

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[70] Taxonomy is the science of categorizing organisms according to body form and structure (which are generally presumed to relate to evolutionary ancestry), with the most basic taxonomic level being the species, and all higher taxonomic levels consisting of groups of species with similar characteristics. The higher taxonomic levels, in ascending order from species are genus, family, order, class, phylum, and kingdom. Criteria for placing organisms within a particular taxonomic group are increasingly broader as you move up the taxonomic levels, so that more species are included under each category. For this evaluation, most organism were identified to the family, or lower, and each uniquely named group of individuals will be referred to as a "taxon".

Percent Contribution of Dominant Taxon

The Percent Contribution of Dominant Taxon metric compares the abundance of the numerically dominant taxon to the total number of organisms in the sample and is calculated as

$$\frac{\textit{Total Abundance of all Taxa}}{\textit{Abundance of Dominant Taxon}}$$

In general, invertebrate communities which are dominated by one or a few taxa are indicative of environmental stress; therefore, the health of the community is considered to decrease with increasing Percent Contribution of Dominant Taxon values. Note that the results of this metric are dependent upon the overall level of taxonomic resolution on a sample-specific basis. Therefore, this metric has been calculated at the family level of taxonomic resolution.

Simpson's Index of Diversity

Simpson's Index of Diversity (Simpson, 1949) takes into account both taxa richness and taxa evenness (i.e., the equitability of taxa abundances; see Shannon's Index of Evenness below). The values generated by the index increase with increasing diversity. Although Simpson's Index is heavily influenced by the most abundant taxa in the sample, it has been shown that for samples containing more than 10 taxa, evenness plays an important role in determining the index value (May, 1975). The Simpson Diversity Index is calculated as:

$$D = \sum \frac{n_i (n_i - 1)}{N(N-1)}$$

where D = Diversity, n_i = the number of individuals in the $_i$th taxa, and N = abundance.

Shannon's Index of Diversity

Shannon's Index of Diversity can be referred to as an index of heterogeneity because it takes into account both taxa richness and taxa evenness. The values generated by the index increase with increasing diversity. The Shannon index is most significantly influenced by taxa richness, and is dependent upon the proportional abundances of individual taxa within a sample. Shannon's Index of Diversity is calculated as:

$$H' = -\sum \frac{n_i}{N} (\ln \frac{n_i}{N})$$

where H' = Diversity, and n_i and N are as noted above.

Shannon's Index of Evenness

"Evenness" in community ecology is a term that refers to the equitability between the abundance of each taxon within the community. Ultimate hypothetical evenness would be a community in which all species had the same abundance. Community health is considered to increase with increasing evenness because there is more balance among species with different ecological roles. Shannon's Index of Evenness is calculated by dividing Shannon's Index of Diversity by the natural log of taxa richness. The evenness index is expressed as a decimal between 0 and 1, with increasing values reflecting more even taxa distribution. Shannon's Index of Evenness is calculated by dividing Shannon's Index of Diversity by the natural log of taxa richness:

$$E = \frac{H'}{lnS}$$

where E = Evenness and S = taxa richness

5.22.2 Indices of Environmental Stress Within Benthic Communities

Two metrics were calculated which indicate whether the biological community is stressed by an environmental factor.

EPT/Chironomidae and EPT Index

The ratio of Ephemeroptera (mayflies), Plecoptera (stoneflies) and Trichoptera (caddisflies) abundance (EPT) to the sum of EPT and Chironomidae (midge) abundance was calculated for each sample. Many taxa within the EPT orders are sensitive to pollution, whereas Chironomidae taxa are generally considered to be pollution tolerant, therefore, the higher the ratio, the healthier a community is considered to be. This index describes communities with an unduly high proportion of Chironomidae as environmentally stressed. Another metric which focuses on pollution sensitive invertebrates is the EPT Index. This index is simply the total number of EPT taxa identified in a sample. As with the EPT/Chironomidae index, the higher the EPT Index the healthier the community is considered to be.

The result for each metric calculated for a study reach sample was compared to the range of results calculated for reference samples.

5.23 Results

Table 5-1 presents biological data for each of the six sample locations. **Table 5-2** presents the results of metrics. Note that many taxa were likely excluded from analysis by the subsampling method.

Metrics were evaluated by comparing results for potentially impacted areas to the range of metric results for the reference samples.

Estimated Macroinvertebrate Density

The density of macroinvertebrates for each sample reach was estimated by multiplying the number of organisms in subsampled grids by the inverse of the fraction of the benthic area represented by each grid. The average organism density at Crooked Meadow Brook reaches was 211 organisms per square foot. The average organism density at Accord Brook reaches was 602 organisms per square foot. This substantial difference in density is likely related to the flow regimes of the two streams, the amount of organic debris present, and the expected recruitment of organisms from the extensive wetlands immediately upstream of the Accord Brook reaches. Therefore, although the density estimates do not suggest flow-related impairment of the benthic community, the density estimates provide insight into the influence of a reach's position in the watershed on the benthic community.

Taxa Richness

As shown on **Table 5-2**, between 14 and 16 individual benthic macroinvertebrate taxa were identified in background samples. Samples from potentially impacted areas contained 8 taxa. Therefore, this important measure of taxonomic diversity may suggest that flow conditions have adversely impacted the benthic biota of the study reaches.

Percent Contribution of Dominant Taxon

The results of the "percent contribution of dominant taxon" metric were similar for all four samples. This metric does not suggest impairment of the benthic community of Accord Brook.

Simpson's Index of Diversity

Reference sample results for this metric ranged from 3.62 at CMB-2 to 5.51 at CMB-1. The Simpson's diversity of Study reach samples was substantially lower (mean =

3.12). This measure of taxonomic diversity suggests that flow conditions have adversely impacted the benthic biota of the study reaches.

Shannon's Index of Diversity

Reference sample results for this metric averaged 1.98, while the Study reach average was 1.34. This measure of taxonomic diversity suggests that flow conditions have adversely impacted the benthic biota of the study reaches.

Shannon's Index of Evenness

The average result of this measure of community evenness for Study reaches was slightly lower than the average result for Reference reaches. The magnitude of the difference is not sufficient to attribute impact due to flow conditions. This metric does not suggest impairment of the benthic community of Accord Brook.

EPT/Chironomidae and EPT Index

As previously noted, these two indices were developed to evaluate potential impacts associated with chemical and organic pollution, not flow-related impacts. However, because the habitat requirements of EPT taxa and Chironomids differ substantially, and because of the strong influence of flow regime on habitat composition, we calculated these metrics to evaluate the influence of habitat differences on community structure. The average Reference sample result for the EPT/Chironomidae metric was 0.68 compared to an average of 0.04 at Accord Brook. The average Reference sample result for the EPT metric was 6 taxa compared to 1.5 taxa at Accord Brook. Both of these metrics appear to imply adverse impacts to the benthic community of Accord Brook due to its irregular flow regime. Note that the sole Trichoptera taxa identified at Accord Brook was *Ironoquia*, a Limnephilidae species known to inhabit temporary stream and pools (Peckarsky et al., 1990; Merritt and Cummins, 1984). It is our opinion that the differences in EPT/ Chironomidae and EPT taxa metrics are associated with habitat differences between the brooks resulting from irregular flow at Accord Brook.

5.24 Conclusions

The bioassessment of Accord Brook and Crooked Meadow Brook documented substantial differences in the benthic macroinvertebrate communities of the two brooks. The taxonomic diversity of Accord Brook was substantially lower than that of Crooked Meadow Brook. Additionally, the composition of the benthic communities were substantially different. The benthic community of Crooked Meadow Brook was composed of typical lotic taxa (e.g. caddisfly larvae and riffle beetles). While the benthic community of Accord Brook was also composed primarily of lotic taxa, organisms typically associated with stagnant waters and temporary streams (e.g. Planarians and Encytraeid worms) were also common.

The differences in macroinvertebrate community structure between the two streams are likely related to habitat and substrate differences caused by flow regimes. Scoring of habitat parameters done as part of the habitat assessment indicates that the reaches of Accord Brook surveyed contained Suboptimal habitat while the reaches surveyed in the Crooked Meadow River contained Optimal habitat. During summer months, the flow of Accord Brook has been shown to dwindle and eventually cease, allowing deposition of silt and organic debris. During periods when Accord Brook dries completely, benthic organisms are unlikely to be present. As flow resumes in the brook, it is likely that substantial numbers of invertebrates drift downstream from the extensive wetlands at the headwaters of Accord Brook and quickly colonize the newly available habitat. In our opinion, it is likely that benthic macroinvertebrate community differences between Crooked Meadow Brook and Accord Brook are related to the intermittent flow regime of Accord Brook.

5.30 AQUATIC HABITAT SUITABILITY CRITERIA

5.31 Habitat Evaluation Criteria

The selection of evaluation species and lifestages is an important part of habitat evaluation. Although there are no absolutes, general guidance can be found in precedent. Bovee, *et al.* [71]recommend that species and lifestages selected for an instream flow assessment should reflect expressed fishery management objectives, and/or representative species representing use of specific habitats of interest (known as a "guild" approach). Bovee, *et al.*[72] also suggest that a mix of evaluation species should be used. Further, in New England, the USFWS (1994) states that:

> *"When selecting species for use as evaluation species in IFIM [Instream Flow Incremental Methodology] and related studies of water development project, obligate stream (lotic) species or lifestages should be utilized or recommended. Facultative species and/or lifestages should be carefully considered or, in some cases avoided as evaluation elements…. Staff should focus their review and evaluation on the habitat specialists within the stream system such as members of the riffle/run community…".*[73]

This is because not all mesohabitat types are equally susceptible to dewatering effects, and facultative (i.e. habitat generalists) may not provide an accurate barometer of low-flow habitat protection.[74] In the case of the Weir River basin, there is an expressed management objective for maintenance of a trout fishery. The scarcity, or potential absence, of riffle dwelling species in this watershed further suggests that obligate riffle/run dwelling species and lifestages

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[71] Bovee, *et al*., U.S. Fish and Wildlife Service. 1998.

[72] ibid.

[73] U.S. Fish and Wildlife Service, IFIM 1994.

[74] Bovee, *et al*., U.S. Fish and Wildlife Service. 1998

should also be considered in evaluating habitat and flow. There is also danger of selecting too many species, as this "*may facilitate getting the study started, but will ultimately make the analysis of alternatives more difficult.*" [75]

Based on these principles, reasonable species and lifestages for this analysis would logically be:

Species	**Life stage**	**Basis**
Brown trout	spawning	Management objectives exist, stream supports reproduction
Brown trout	juvenile	Management objectives exist, stream supports reproduction
Brown trout	adult	Management objectives exist, lifestage is stocked
White sucker	spawning	Obligate riffle/run dwelling species/lifestage
White sucker	juvenile	Obligate riffle/run dwelling species/lifestage
Tessellated darter	adult	Obligate riffle/run dwelling species/lifestage
Caddisfly or mayfly	larval	Obligate riffle/run dwelling species/lifestage

Note that *adult* white sucker are not listed. This is because that lifestage is a habitat generalist, which violates the governing principles noted above. Anadromous fish species such as smelt and alewife are also not listed since these species are generalists in both the spawning and juvenile lfestages. The limiting factor for this species is likely to depend more on fish ladder operability rather than habitat suitability. Warm water species such as bass are also excluded since they tend to favor the ponds rather than the streams.

The final selection of species and lifestages should also take into consideration availability of suitability index (SI) criteria. Established SI curves (which utilize stream flow and stream morphology parameters) exist for all lifestages of brown trout, white sucker, darter species, and stream insects, and have been used in other instream flow assessments at other locations.

5.32 Recommended Habitat Suitability Evaluation Criteria

In instream flow habitat assessments, habitat use is rated based upon a species- and lifestage-specific habitat Suitability Index (SI) rating curve, in which depth, substrate and velocity are independently assigned rating values on a scale from 0.0 to 1.0. These ratings are based on research literature, observations, and/or professional judgment.[76] These rating data are used to perform a composite assessment of habitat suitability, based on the observed or modeled sequence of primarily hydraulic characteristics (depth and velocity) found on each study transect. In some analyses, wetted substrate perimeter and cover are also evaluated.

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[75] ibid.

[76] Bovee, K.D. U.S. Fish and Wildlife Service. A guide to stream habitat analysis using the instream flow incremental methodology. Instream Flow Information Paper No. 12, Washington, DC. 1982

SI curves may be site-specifically developed if no other adequate data are available. Alternatively, these data are developed from literature or adapted from other SI curves used on similar, geographically proximate streams.

The SI shown in the following table appear to be suitable for use as inputs on the applicable SI criteria for each stream channel transect for which hydraulic data have been collected. These were obtained after review of a number of SI curves available from the literature and are used for the Weir River flow analysis. The detailed SI curves are attached as **Appendix I**. To assess the relationship of flow to habitat at specific stream locations in the Weir River watershed, the SI curves for each species were combined with the rating curves developed for the surveyed stream segments. This procedure and the results are discussed in Section 5.42 and 5.43, respectively.

Species	**Proposed SI Curve source**
Brown trout	Pennsylvania Fish and Boat Commission (1997)
White sucker	Twomey *et al*. 1984/NYSDEC
Tessellated darter	Ichthyological Associates, 1998
Caddisfly or mayfly	Vermont ANR "Waterbury IFIM Study" macroinvertebrate

Note that anadromous fish species such as smelt and alewife are not included in the species proposed for habitat evaluation. These species are important components of the Weir River Watershed fisheries communities but they are considered habitat generalists. Flow criteria that are appropriate for the proposed indicator species will be suitable for the common anadromous species. In addition, other factors, such as the functionality of the fish ladders at Foundry Pond Dam and Triphammer Pond Dam, may be more important in determining the capacity of the watershed to support anadromous fish.

1) Brown trout.

Brown trout are frequently studied in instream flow assessments in New England. Well-accepted SI curves are typically used in regional studies based on data from the Housatonic, Farmington and Deerfield rivers.[77] However, each of these rivers are relatively large, upland rivers, with greater channel depths, larger flow ranges, steeper gradients, and more boulder/cobble-dominated habitats than those of the Weir River. These factors would potentially bias suitability based on the distribution of adult and juvenile brown trout in these streams, especially relative to their selection of depth.

We therefore located curves based on observations of brown trout in smaller streams located in either southern New England or the mid-Atlantic. Data developed by Pennsylvania Fish and Boat Commission (1997) for juvenile and adult fish was collected on small (first through third order) lower gradient streams common to eastern

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[77] J. Warner, USFWS *and* R. Jacobsen, CTDEP, personal communications

Pennsylvania. These better reflect small stream habitat use for juvenile and adult life stages. Habitat suitability curves for spawning/incubation and fry lifestages are less sensitive to depth and localized substrate conditions, and therefore can be taken from more universal sources. Therefore, we use the Raleigh (1982) SI curves for these lifestages.

2) white sucker

SI curves developed for studies in New York and elsewhere in the mid-Atlantic have been used successfully in studies in the Northeast. These SI curves have been accepted for use in a wide range of small to large streams by the New York Department of Environmental Conservation, and reflect refinements over the standard USFWS "bluebook" curves presented by Twomey, *et al.* (1984).

3) tessellated darter

Tessellated darter is probably a good choice to represent overall riffle habitat use by small fish. Although general habitat preference information is available in the literature, no river-specific SI curves have been developed. However, SI curves have been developed from literature that have been accepted for use by the Connecticut Department of Environmental Protection for use in a small coastal stream.[78] These are the most geographically applicable SI curves available for this species.

4) Caddisfly/mayfly

Aquatic invertebrates are often used as bio-criteria in assessing stream health, as well as habitat suitability. A number of curves have been employed in recent years throughout New England. Because these are benthic organisms, the most important characteristics in selecting SI criteria are obtaining curves from rivers with comparable substrate from the source site to the target stream. A 1998 instream flow study on the Westfield River, Massachusetts used the so-called "Waterbury" macroinvertebrate curves. These were selected by the study team (including USFWS and Massachusetts DFW) after considering a spectrum of alternatives, based on the substrate and channel characteristics present at that site. Based on our August 1999 site visit, the Weir River appears to be dominated by similar channel materials (cobbles, gravels, fines in a series of low-gradient runs and shallow pools).

5.40 IN-STREAM FLOW NEEDS FOR AQUATIC WILDLIFE

The suitability of aquatic habitat for the evaluation species and other wildlife which inhabit the streams and rivers of the Weir River Watershed is closely tied to the stream flow. The in-stream

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[78] K. Jirka, Ichthyological Associates, personal communication

flow rate determines the depth, water velocity, and wetted perimeter at each specific stream section based on the hydraulic characteristics of that particular section. These parameters, in turn, affect the capacity of a section of stream to provide appropriate habitat for fish and other organisms. Low flow rates are of particular concern in regards to habitat suitability. When flow rates are low, depths, velocities, and wetted perimeter values may be reduced enough to cause stress to aquatic wildlife, and clearly fish cannot live in stream sections where there is no water at all. Low flows in streams and rivers can occur as a result of drought, impounding or diverting of upstream flow, induced infiltration due to groundwater pumping, or a combination of any or all of these.

5.41 Current Minimum Flow Threshold Recommendations

In recognition of the detrimental effects which low in-stream flows can have on aquatic wildlife, minimum streamflow thresholds have been recommended for the entire Weymouth and Weir River Basin, of which the Weir River watershed is a part. Recommendations to the Massachusetts Water Resources Commission from the Massachusetts Department of Environmental Management in 1991[79] provided for three minimum streamflow thresholds to be applied generically across the entire basin. These are:

(a) Year round, 0.15 cubic feet per second per square mile of drainage area (cfsm);
(b) March-May, 2.4 cfsm;
(c) mid-September to mid-October, 1.0 cfsm

The recommended flow rates are referred to as streamflow and presumably represent minimum instantaneous flow rate.

Another set of criteria which is generally applicable to the watershed is the U.S. Fish and Wildlife Service Aquatic Baseflow Policy (USFWS ABF). The New England Flow Policy was developed in 1981 as a water resources regulatory and planning tool for use by government agencies and others involved in water development. The following background for the Policy is presented by the USFWS in the Interim Regional Policy document:

> "The USFWS has used historical flow records for New England to describe stream flow conditions that will sustain and perpetuate indigenous aquatic fauna. Low flow conditions occurring in August typically result in the most metabolic stress to aquatic organisms due to high water temperatures and diminished living space, dissolved oxygen, and food supply. Over the long term, stream flora and fauna have evolved to survive these periodic adversities with[out] major population changes. The USFWS has therefore designated the median flow for August as the Aquatic Base Flow (ABF). The USFWS has assumed

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[79] Department of Environmental Management, Office of Water Resources. Recommendations to the Water Resources Commission, May 13, 1991.

> that the ABF will be adequate throughout the year, unless additional flow releases are necessary for fish spawning and incubation. We have determined that flow releases equivalent to historical median flows during the spawning and incubation periods will protect critical reproductive functions."[80]

The document goes on to state the USFWS personnel shall "recommend that the <u>instantaneous</u> flow releases for each water development project be sufficient to sustain indigenous aquatic organisms throughout the year." The following flow recommendations are presented in the Policy for rivers such as the Weir River where inadequate flow records exist. These flow recommendations have also been endorsed by the Massachusetts Division of Fisheries and Wildlife.[81]

(a) 0.5 cfsm for June to October,
(b) 1.0 cfsm for October to March,
(c) 4.0 cfsm for March to May,
(d) 1.0 cfsm for May and June.

The USFWS ABF recommendations must be carefully considered however. In a 1990 paper in the journal *Rivers*, Kulik states, "There has been a growing concern among water users and resource managers that the 0.5 cfsm value may not be a universally applicable approximation of unregulated median August flow in all New England streams."[82] There are several important criteria which the methodology used in selection streams for the calculation of the ABF including: 1) essentially unregulated stream; 2) minimum drainage area of 50 square miles; 3) minimum period of record on stream gage of 25 years; and 4) good or excellent quality gage data. The Weir River watershed would not have met these criteria and therefore may differ from the sample watersheds in important ways. In addition, the sample set was taken from all over New England while it has been shown that Massachusetts median August streamflows differ significantly from the 0.5 cfsm used in the USFWS ABF policy. According to USGS data, "The statewide median of the August median streamflow was 0.246 cubic foot per square mile (cfsm); however the median in the western region was 0.271 cfsm and the median in the eastern region was 0.197 cfsm. A third hydrologic region, the southeast coastal region, encompasses an area in which surficial geology is entirely stratified drift, and for which data were insufficient to determine August median streamflows."[83]

Table 5-3(a) indicates the total minimum in-stream flows which would be required to meet the MADEM / Massachusetts Water Resources Commission thresholds for each of the

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[80] U.S. Fish and Wildlife Service. Interim Regional Policy for New England Stream Flow Recommendations. Newton Corner, MA. 1981.

[81] Mass. Division of Fish and Wildlife. Todd Allan Richards, Personal Correspondence, Sept. 25, 2000

[82] Kulik, Brandon H. A Method to Refine the New England Aquatic Base Flow Policy. "Rivers" Vol.1 No. 1. pp 8-22. 1990.

[83] U.S. Geological Survey. August Median Streamflows in Massachusetts. Water-Resources Investigations Report 97-4190. Kernell G. Ries III. 1997.

subbasins in the Weir River Watershed and includes the predicted August median streamflows based on USGS regression analysis for Eastern Massachusetts. **Table 5-3(b)** indicates the total minimum in-stream flows which would be result from the USFWS ABF New England Flow Policy.

Another generalized method for determining flow criteria is the Tennant Method. This method was developed for use in the Western United States and uses percentages of average annual flow to describe the suitability of seasonal in-stream flow conditions for aquatic life. In 1999, Mr. Vernon Lang of the USFWS prepared an overview of the Interim Regional Policy for the New England Stream Flow Recommendations[84]. In this document, Lang compares the New England ABF recommendations to Tennant's criteria. The 0.5 csfm default for the ABF is about 26 percent of the average annual flow of the ABF reference stream. This falls between the poor habitat and fair habitat conditions postulated by Tennant. However, because Tennant's method was developed for use in very different geographic and hydrologic conditions, it is not generally applied in New England.[85]

These flow criteria listed above are general recommendations for use in the area of the Weymouth and Weir River watersheds and all of New England, respectively. To develop specific recommendations for the individual streams and rivers of the basin, it is necessary to do a stream-specific evaluation. Lang states, "Generally speaking, if site-specific studies have been properly coordinated, scoped, conducted, and reviewed, the tendency should be to use site specific over standard setting (ABF) data." The document goes on to say that, "Generally speaking, flow recommendations negotiated from IFIM studies tend to be lower than ABF values." Such an evaluation requires specific knowledge of the physical and hydrologic characteristics of the individual streams and rivers. Stream-specific evaluations were conducted at various locations along Accord Brook and the Weir River as detailed in Section 5.42 and 5.43.

5.42 Aquatic Habitat Evaluation Methodology

A site visit conducted during August 1999 revealed that predominate stream channel types consisted of shallow runs (smooth-flowing sections of the stream) and riffles (fast, turbulent, flowing sections of the stream), with few shallow pools (slow, wide, deeper sections of the stream). Other habitat types (e.g. steep rapids, deep pools and pocket water) were either absent or extremely rare. A total of six study sites were located on the Accord Brook (A-1 and A-2 in subbasin 3 and A-3 just beyond the subbasin divide in subbasin 6) and Weir River (W-1 through W-3 in subbasin 6) to account for representative habitat types (shown on **Figure 3-4**). Each study site was used to depict a typical or representative habitat type found in the subbasin. The total number of transects per study site varied from one to three, depending on observed

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[84] U.S. Fish and Wildlife Service. Questions and Answers on the New England Flow Policy. Vernon Lang. Concord, NH. May 11, 1999

[85] Stalnaker, Clair, et. al. "The Instream Flow Incremental Methodology – A Primer for IFIM", National Biological Service Biological Report 29, March 1995.

streambed complexity. This resulted in a total of thirteen transects (or cross sections) being employed. Most were placed in riffles and runs.

Habitat suitability was rated using standard suitability index (SI) curves. These were developed by evaluating existing and expected biota for the watershed, and subsequently obtaining applicable SI criteria for species representing a cross-section of aquatic resources (**Appendix I**), or habitat guilds.

Instream flow habitat analyses typically evaluate habitat based upon species- and lifestage-specific SI rating curve criteria, in which depth, substrate, and velocity are independently assigned rating values, based on research literature, observations, and/or professional judgment (Bovee, 1982). The Weir River study employs standardized field methods, habitat data inputs, and habitat suitability criteria developed for macroinvertebrates, landlocked salmon parr, adult rainbow and brown trout as used in IFIM applications (as per recommendation in Bovee, 1982) to calculate and interpolate habitat availability. In applying the SI criteria, it appeared that observed substrates reported at study sites were generally uniform, and were generally rated as suitable to optimal, and thus substrates (as opposed to flow rate) are not a limiting habitat factor. The emphasis on this analysis was therefore on water depth and average cross-sectional velocity, as yielded from hydraulic modeling. Based on the observed repeating patterns of habitat use, habitat guilds were established for riffle and run/pool uses. Macroinvertebrate, darter and spawning (sucker and brown trout) SI criteria were used for riffle evaluation. Brown trout (juvenile and adult), and white sucker (juvenile) were used to evaluate runs and pools.

Once the locations of the stream transects were established by the fisheries biologists, GZA used standard survey techniques to develop cross-sectional profiles at each transect. Using observed flow data and hydraulic parameters established by the FEMA flood study for the Town of Hingham,[86] the hydraulics of each transect were modeled using the software package FlowMaster (Haestad Methods, Waterbury, Connecticut, 1995). The hydraulic model allowed relationships to be established at each location which correlate potential flow regimes through the channel with depth, flow velocity, and wetted perimeter (shown in **Appendix E**). The modeled relations for flow versus depth and velocity were calibrated against the observed data from the field measurement program.

All transect data (e.g. bed elevation, substrate data, water depth, wetted perimeter, and velocity) for each discharge was entered into a spreadsheet (Excel) and quality checked. The width between vertical stations along each transect provides a "cell" dimension. Cell area was calculated by cell width by an assumed 100-ft cell length. Habitat area was then calculated for all wetted stream cells for each transect at each modeled flow by adjusting wetted area based on depth and velocity SI criteria (as developed in Section 5.32 and shown in **Appendix I**) for each applicable species and lifestage. For each wetted microhabitat cell, the spreadsheet rated each species/lifestage-specific depth, velocity and wetted substrate criterion on a scale of 0.0 to 1.0,

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[86] Federal Emergency Management Agency, "Flood Insurance Study: Town of Hingham, Massachusetts," June 3, 1986.

multiplied these values together with the area of the cell, and then summed all resulting areas together to estimate total habitat area at each flow. Habitat output was expressed in units of Usable Area (UA). One UA unit corresponds to 1 square foot of optimal habitat. For multi-transect study sites, all transects within each study site were equally weighted, and results combined to provide a composite estimate of habitat area in terms of Weighted Usable Area (WUA) for the study site. Habitat availability at various times of the year was evaluated by inputting average monthly baseflow and/or streamflow values predicted by the water budget model into the habitat curves.

5.43 Stream-specific Aquatic Habitat Evaluation

Appendix J contains detailed microhabitat calculation summaries for applicable species, lifestages evaluated at each specific study site and transect.

At each of the study transects discussed below, the monthly average flow rates predicted in the water balance model were input into the habitat curves. The habitat available for each species and/or lifestage was then evaluated at each transect for the predicted monthly flows. Each table contained in Appendix J contains a Weighted Usable Area (WUA) value for each transect within the specific study site for a single organism or lifestage. A summary table is also presented for each study site.

The Weir River watershed study has utilized recommendations and methodologies developed as part of the USFWS ABF Policy. The primary focus of the USFWS ABF Policy was to evaluate the Aquatic Base Flow established by the low flow conditions in the summer dry months. Vernon Lang, in his commentary on the USFWS New England Policy states, “Low flow conditions in August typically represent a natural limiting period because of high stream temperatures and diminished living space, dissolved oxygen and food supply. Over the long term, stream flora and fauna have evolved to survive these adversities without major population changes. The median flow for August was therefore designated as the Aquatic Base Flow.” “Natural” or “virgin” low flow conditions before human influence on the watershed represent the situation to which indigenous species would have adapted. The “virgin” low flow condition produces what Lang refers to as “critical chemical and physical parameters that could function as limiting factors on aquatic life.” The indigenous aquatic life would therefore be expected to have evolved to produce populations which would maximize but not over-utilize the amount of habitat available under the “virgin” low flow conditions. The habitat available under these low flow conditions is not necessarily optimal. Lang states, “The term optimal flow is a relative term depending on the life cycle requirements and preferences of the species involved.”

Seasonal flow recommendations for the Weir River have been evaluated on the basis of maintaining spawning and incubating habitats for those species present in the streams which are reproducing during a particular season. This is consistent with USFWS Interim Regional Flow Recommendation Policy which states, “[T]he USFWS shall recommend that the ABF release for all times of the year be equivalent to the median August flow for the period of record unless superceded by spawning and incubation flow recommendations."[87] The indicator species used in the October to March period is spawning brown trout. These fish build redds on gravel bars for their eggs. Such habitat was not noted in the sample reaches. But if available elsewhere on the streams, then the habitat value for brown trout spawning and egg incubation would be established by the minimum flow in virgin conditions during the period, since fish would not be likely to lay eggs in areas which would be exposed under typical normal conditions. Likewise, white sucker spawning habitat was used to establish the flow recommendations for the May to June period. This evaluation of seasonal flow requirements is based on the USFWS Policy which states, "The USFWS shall recommend flow releases equivalent to the historical median stream flow throughout the applicable spawning and incubations period."[88] Flow recommendations from March to April were evaluated on the basis of "bankfull" flow, i.e. the amount of flow which is required to fill the stream channel to the top of the banks. This criterion is generally thought to be useful for channel-forming purposes. The Tennant Method criteria state that periodic high flows should be provided to remove silt, sediment, and other bed material.[89] No overbank spawning species are present in the watershed. In general, it appears that the non-summer seasonal flows under developed and future conditions are not limiting for the species studied. Monthly average flows estimated by the water balance model suggest that under average hydrologic conditions, the non-summer flow recommendations will be met when flows are averaged over the period in question. The summer low-flows are the limiting factor to habitat availability and population development for the indicator species.

The water balance model produced by GZA estimates monthly average flows for both the baseflow component of streamflow and for total streamflow. Monthly averages are not the same as monthly median values, and at times may be quite different. This is particularly true in a relatively small watershed where surface water flows pass quickly through the system during periods when base flow is low. An example of this is found in the Old Swamp River, which is similar to the Weir River. The <u>median</u> August flow rate in the Old Swamp River is 1.30 cfs (0.29 cfsm) while the <u>mean</u> August flow rate is 3.03 cfs (0.67 cfsm). A second example is provided by another similar river, the Indian Head River. The <u>median</u> August flow rate in the Indian Head River is 11.0 cfs (0.36 cfsm) while the <u>mean</u> August flow rate is 22.2 cfs (0.73 cfsm). In both of the similar rivers, the median August streamflow is approximately half of the mean August streamflow. It was not possible to directly calculate the monthly medians of either baseflow or total streamflow within the Weir River watershed since a long term data set is not available.

Monitoring of flows within a stream may either concentrate on statistical analysis of a data set compiled over a certain time period (e.g. monthly) composed of numerous, more frequent flow measurements (e.g. daily or continuous), or on individual instantaneous flow rates. Both

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[87] U.S. Fish and Wildlife Service. "Questions and Answers on the New England Flow Policy – Appendix A: Interim Regional Policy for New England Stream Flow Recommendations." Vernon Lang, May 11, 1999.

[88] U.S. Fish and Wildlife Service. "Questions and Answers on the New England Flow Policy – Appendix A: Interim Regional Policy for New England Stream Flow Recommendations." Vernon Lang, May 11, 1999.

[89] Stalnaker, Clair, et. al. "The Instream Flow Incremental Methodology – A Primer for IFIM", National Biological Service Biological Report 29, March 1995.

approaches have advantages and disadvantages. The primary constraint on using a statistical approach is that a significant amount of data must be collected and reduced. The lack of an automated flow gage in the Weir River watershed may make such data collection difficult. As such, GZA has chosen to consider both monthly average streamflows and instantaneous streamflows in our analysis of habitat availability during the low-flow period of the year.

The water budget model created by GZA for this study estimates two flow values: 1) Average Monthly Baseflow, and 2) Average Monthly Streamflow (of which baseflow is a component). The later value, average monthly streamflow, may be directly compared to flow data from the streams and rivers of the Weir River, provided that enough measurements are collected to form a statistically significant data set. Average monthly streamflow is not, in GZA's opinion, a good indicator of what the typical instantaneous streamflows are likely to be. This is because the average or mean monthly streamflow takes into account both periods of high and low flow. And, as shown above, the average monthly streamflow is not, in GZA's opinion, a good indicator of median monthly streamflow, particularly in the summer.

It is GZA's opinion that that average monthly baseflow value predicted by the water budget model is more representative of the median monthly streamflow in the Weir River watershed. This is because during summer months when effective precipitation is at its lowest, streamflow will be comprised primarily of groundwater outflow (i.e. baseflow) for the majority of the time; however, rain events such as thunderstorms can produce high intensity, short duration runoff which will account for the majority of streamflow quantity when averaged over the month (as evidenced by baseflow accounting for only 37 percent of total streamflow in August on a cfsm basis).

For the purposes of evaluating aquatic habitat, total amount of flow in the channel is the important parameter – regardless of whether the flow originates from groundwater outflow or surface runoff. The important issue is to establish the appropriate and representative quantity of total streamflow. In GZA's opinion, the flow rate associated with baseflow is more representative of typical (i.e. median) flow rates during summer low-flow periods than the average monthly total streamflow rate estimated by the water budget model.

Therefore, for the summer low-flow periods, GZA recommends evaluating habitats using streamflow rate equivalent to the baseflow value predicted by the water balance discussed above. The USFWS New England Flow Policy states that "Aquatic Base Flow as used here should not be confused with the hydrologic base flow, which usually refers to the minimum discharge over a specified period." However, it is also very specific that the flow recommendations apply to instantaneous flow releases. It is GZA's opinion that the water balance-derived baseflow value is a better indicator of typical instantaneous flow (i.e. median streamflow) in the streams and rivers of the Weir River watershed during the summer months. In other words, aquatic habitat will be evaluated based on typical total streamflow, but in summer low-flow months, the typical streamflow is assumed to be more closely modeled by the water balance average monthly baseflow value than the water balance average monthly streamflow value. For seasons other than summer, the water balance average monthly streamflow has been used to analyze habitat availability and make flow recommendations since precipitation and runoff are more frequent and regular.

5.43.1 Accord Brook

According to the water balance model for this subbasin (Section 4.54.3), a typical virgin streamflow of approximately 1.0 cfs (based on the water balance baseflow estimate) could be expected to prevail in this habitat during summer low flow conditions (July and August) in an average year. Under developed conditions, a typical flow of essentially zero cfs prevails for this same period. These flows will be applied to the habitat area-to-flow relationship curves developed for the sample stream reaches to evaluate stream-specific minimum instantaneous flows. The stream-specific flows in each sample reach are discussed below and the recommended minimum instantaneous flows and seasonal flow recommendations are discussed in section 5.44

As a comparison, the minimum instantaneous flow recommendation for Accord Brook (including total basin upstream of the diversion dam) based on MADEM / Mass. Water Resources Commission recommendations for the Weymouth and Weir River is 0.56 cfs. For most of the selected indicator species, this flow rate is still in the linear part of the curves, and produces on average less habitat than the virgin typical streamflow but more than the developed typical streamflow. The minimum instantaneous flow recommendation for Accord Brook based on the USFWS New England Flow Policy is 1.89 cfs. The USFWS ABF is also still generally in the initial linear part of the habitat curves, but produces more habitat value than even the virgin typical streamflow and certainly more than the developed typical streamflows.

A. Run-riffle

Habitat of this type was represented by three transects designated as Accord Brook study site 1 (A-1), and was modeled between a discharge of zero to 8 cfs. Relatively little gain in habitat occurs between 0 and 2 cfs; usable area then increases at a high rate between 2 and 4 cfs (**Figure 5-1**) for all lifestages other than macroinvertebrates and spawning Brown trout. The greatest suitability in this section appears to be for juvenile white sucker; the least suitability appears to be for macroinvertebrates. Brown trout adult suitability reaches a plateau between 4 and 5 cfs, then decreases rapidly at higher discharges primarily due to increases in excessive velocities. Habitat suitability for juvenile brown trout and white sucker peaks at 5 cfs, but reaches an inflection point at 4 cfs. Brown trout spawning habitat is minimal but achieves a plateau between 2 to 5 cfs, then decreases. The typical virgin summertime streamflow of approximately 1.0 cfs is in the linear (constant rate of increase) portion of the curves rising from zero. This indicates that a flow of 1.0 cfs would provide approximately twice the habitat as a flow of 0.5 cfs and would provide and four times that of a flow of 0.25 cfs. No habitat exists for any of the species during the predicted developed minimum baseflow of zero cfs.

B. Run

Habitat of this type was represented by one transect designated as Accord Brook study site 2 (A-2). It was modeled between discharges of zero to 5 cfs (**Figure 5-2**). No habitat suitability existed for macroinvertebrates at any discharge, primarily due to depths falling outside of the optimal/suitable range at all flows. Brown trout (both adult and juvenile) habitat suitability increased gradually across the entire flow range as depth increased, but without excessive velocities occurring. White sucker (juvenile and spawning) habitat suitability increased more rapidly to a peak at 2 cfs. Flow increases to 5 cfs were equally suitable for this lifestage. A typical virgin summertime streamflow of approximately 1.0 cfs appears to generally be in a linear portion of the curves rising from zero.

C. Run-riffle

This run-riffle, Accord Brook site 3 (A-3) differed somewhat from site 1 in that it represents a wider channel area. Habitat of this type was represented by three transects, and was modeled between a discharge of zero to 9 cfs (**Figure 5-3**). Habitat suitability increases gradually for both lifestages of brown trout throughout the entire flow range modeled. The greatest suitability in this section appears to be for juvenile white sucker and macroinvertebrates. Habitat suitability for these life stages inflects to a plateau at 4 cfs. The typical virgin summertime streamflow of approximately 1.0 cfs is within a linear (from zero) portion of the macroinvertebrates, white sucker, and both lifestages of brown trout curves. No habitat exists for typical summer streamflow conditions under developed conditions, but measurable habitat increases exist even at low flow under virgin conditions, with the most pronounced increases occurring for the juvenile white sucker lifestage.

5.43.2 Weir River

According to the water balance model for this subbasin (Section 4.54.6), a typical virgin streamflow of approximately 3.5 cfs could be expected to prevail in this habitat during summer low flow conditions (July and August) in an average year. Under developed conditions, typical summertime streamflow is reduced to 2.6 cfs in August in an averaged year. By comparison, the minimum instantaneous flow recommendation for the Weir River based on MADEM / Mass. Water Resources Commission recommendations for the Weymouth and Weir River is 2.22 cfs. For most of the selected indicator species, WRC-recommended flow rate is still in the linear part of the habitat curves, and produces, on average, less habitat than the virgin typical summer streamflow but more than the developed typical summer streamflow. The minimum instantaneous flow recommendation for Accord Brook based on the USFWS New England Flow Policy is 7.40 cfs. In the Weir river study transect, the USFWS ABF is beyond the inflection point of most of the habitat curves; therefore more habitat is produced than under the virgin or developed typical summer streamflow conditions, but the marginal returns are greatly diminished.

Study sites in the Weir River main stem were located below the confluence of a number of tributaries, such as Accord Brook, Fulling Mill Brook, and Crooked Meadow River. As such the drainage area of this section has increased accordingly, resulting in a receiving channel much larger than that found in the Accord Brook subbasin.

A. Riffle/shallow pool

Habitat of this type was located in Weir River site 1 (W-1), and was represented by three transects. The site was modeled between discharges of zero to 30 cfs (Figure 5-4). The diversity of cover, substrate and richness of riffles suggested that species represented by all the study guild life stages could utilize this reach type. Habitat was depth-limited for macroinvertebrates at all flows, and therefore no flow provided suitable habitat. The greatest habitat suitability at any given flow was provided for juvenile white sucker. However, results for all lifestages other than macroinvertebrates show a consistent trend for rapid increases in suitability between 0 and 5 cfs, after which suitability did not increase or decrease significantly across the range of higher flows, other than juvenile and spawning white sucker. These lifestages experienced a secondary, gradual increase in suitability at flows greater than 20 cfs. Typical virgin and developed summertime streamflows are approximately 3.5 and 2.6 cfs, respectively. These flows are within the portions of the relation curves which are linear from the origin. This is when habitat suitability is most sensitive to and directly proportional to changes in flow for all lifestages other than macroinvertebrates. The virgin flow therefore may be seen to provide approximately a third more habitat than is available under developed conditions.

B. Run

Habitat of this type was represented by one transect designated as Weir River study site 2 (W-2). It was modeled between a discharge of zero to 30 cfs (Figure 5-5). No habitat suitability existed for macroinvertebrates at any discharge, primarily due to depths falling outside of the optimal/suitable range at all flows. Brown trout (both adult and juvenile) habitat suitability increased gradually across the entire flow range as depth increased, but without excessive velocities occurring. A rough inflection point occurs for both lifestages of brown trout at 20 cfs, and juvenile habitat begins to decline slightly at flows greater than 25 cfs. Adult habitat resumes increasing above 25 cfs, albeit slightly. White sucker habitat suitability essentially reaches a plateau at 10 cfs. Both virgin and developed typical summertime streamflows are within the range where habitat suitability is most sensitive to changes in flow for all lifestages other than macroinvertebrates. The virgin flow again therefore may be seen to provide approximately one third more habitat than is available under developed conditions.

C. Riffle

The lower reaches of the Weir River contain observable riffles uninterrupted by run or pools. Weir River Study site 3 (W-3) was used to represent this habitat type, was represented by three transects, and was modeled between a discharge of zero to 40 cfs (Figure 5-6). This study site had perhaps the most complex channel profile, including a thalweg, but also a shoal area that becomes submerged at flows greater than 25 cfs. The diversity of cover, substrate and richness of riffles suggested that species represented by all study guild life stages could utilize this reach type. This appeared to be the only study site offering any potential habitat suitability for brown trout spawning.

Habitat was depth-limited for macroinvertebrates at flows less than 20 cfs, then increased up to 25 cfs. A plateau existed between 25 to 30 cfs, followed by a slight decline as depth and velocity suitability declined slightly. A newly wetted channel area becomes submerged above 30 cfs and increases in suitability as flow increases to 40 cfs. Therefore, no flow provided suitable habitat. Results for all lifestages other than macroinvertebrates and brown trout (adults and spawning) show a consistent trend for rapid increases in suitability between 0 and 5 cfs, after which suitability did not increase or decrease significantly until a discharge of 30 cfs provides sufficient depth and velocity across the shoal area to generate additional usable area. This results in slight increases in habitat for most lifestages, with white sucker juvenile habitat being the most significant. Brown trout (adult and spawning lifestages) increased at a relatively linear rate across the entire flow range. Again virgin and developed typical summertime flows are in the linear portions of the curves which start at the origin, when habitat suitability is most sensitive and directly proportional to changes in flow for all lifestages other than macroinvertebrates.

5.44 Stream-specific Minimum Streamflow Threshold Recommendations

The stream-specific habitat evaluations discussed in the previous sections allow the relationship between habitat and flow to be studied for the chosen evaluation species. The habitat evaluation curves were developed using specific stream morphology data gathered during surveys of sections of Accord Brook and Weir River. The average monthly flow data used in the habitat evaluation was developed specifically for each subbasin of the Weir River watershed using the water balance model previously discussed.

The general trend is for habitat to achieve optimal or at least stable conditions at study sites for most lifestages at flows of approximately 2 to 5 cfs in Accord Brook and 5 to 10 cfs in the Weir River (subbasin 6), with some variation among sites and lifestages. If water availability was unlimited and no competing demands were present, flows in this range would be ideal from a habitat standpoint. However, it is evident from GZA's hydrologic analyses that flows of that magnitude would not naturally be sustained during summer months. Under virgin conditions, in an average year, typical streamflows (as modeled by baseflow) are predicted to drop below the level which would produce optimum habitat in the months of July, August, and into September. In other words, optimum habitat conditions are not expected to occur during average summer months – even under natural, virgin, undeveloped conditions. Therefore it has been judged that "maintenance" of optimum habitat in the summer under developed conditions is unrealistic, since such habitat is not expected to occur naturally. At least for lifestages existing year round, the naturally-occurring low flow cycle occurring in July and August sets a natural habitat attainment level. This is consistent with the USFWS ABF New England Policy which states that "Low flow conditions occurring in August typically result in the most metabolic stress to aquatic organisms, due to high water temperatures and diminished living space, dissolved oxygen, and food supply. Over the long term, stream flora and fauna have evolved to survive these periodic adversities without major population changes. The USFWS has therefore designated the median flow for August as the Aquatic Base Flow (ABF). The USFWS has assumed that the ABF will be adequate throughout the year, unless additional flow releases are necessary for fish spawning and incubation."[90]

Unregulated August median flow has long been used as a regulatory seasonal minimum flow target for instream habitat protection in New England, particularly when site-specific data is lacking. August median flow is an annual naturally-occurring low flow that year-round aquatic life stages can presumably adjust to without stress.[91] Unregulated August median flow has been estimated by the USFWS to be 0.5 cfs per square mile in New England. This flow has been used by USFWS to establish their recommended ABF. However, August median flows can vary somewhat, depending on individual basin characteristics[92], and have been estimated to be 0.20 cfs per square mile (cfsm) in eastern Massachusetts.[93] USGS gage records for similar watersheds in the region are useful for comparison. The August median flow in the Indian Head River basin is 0.36 cfsm, and the August median flow in the Old Swamp River watershed is 0.29 cfsm. A previous study by DEM presented to the Water Resources Commission set the minimum instantaneous streamflow threshold in the Weymouth and Weir River Basin as 0.15 cfsm. The previous DEM and USFWS recommendations would result in recommended summer minimum flow thresholds ranging from approximately 0.56 cfs to 1.89 cfs in the Accord Brook basin (subbasin 3), and approximately 2.2 cfs to 7.40 cfs in the vicinity of the lower section of the Weir River (subbasin 6). In general, the amount of available aquatic habitat increases as the flows

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[90] U.S. Fish and Wildlife Service. Interim Regional Policy for New England Stream Flow Recommendations. Newton Corner, MA. 1981.

[91] USFWS, 1981, V. Lang, USFWS, personal communication.

[92] Kulik, Brandon H. A Method to Refine the New England Aquatic Base Flow Policy. "Rivers" Vol.1 No. 1. pp 8-22. 1990.

[93] U.S. Geological Survey. August Median Streamflows in Massachusetts. Water-Resources Investigations Report 97-4190. Kernell G. Ries III. 1997.

increase; however, it is fair to consider whether the level of habitat would be elevated beyond that which would naturally be expected, even under pre-development conditions.

The water balance model for the watershed indicates that undeveloped (or "virgin") average summer typical streamflows are approximately 0.28 cfsm for Accord Brook and 0.26 cfsm for the Weir River. The resulting typical total streamflows (in an average summer) at the downstream edge of the subbasins are 1.06 cfs for Accord Brook and 3.80 cfs for the Weir River. The habitat produced by these flows is not necessarily optimal, but represents the limiting factor for indigenous aquatic life. These typical streamflows were derived from the water balance model estimation of baseflow during the summer. It is GZA's opinion that the water balance model-derived baseflows are an appropriate predictor of median (typical instantaneous) streamflow during the summer in the Weir River watershed.

The need to provide a specific degree of aquatic habitat conservation in a given reach of river is often driven by specific management objectives established by agencies responsible for management of fishery resources, and balanced against the need for competing uses of the stream flow.[94] Current typical August streamflows in the Weir River watershed range from zero cfsm in Accord Brook to 0.18 cfsm in the Weir River. Clearly, existing levels of water withdrawals and development result in a significant reduction of habitat in the study area. Therefore, any increases of in-stream flow above current levels would be beneficial. Active management for species of high ecological and/or social/economic importance may require a greater degree of habitat protection than a passively managed fishery resource.

In the case of the subbasins in the Weir River watershed, our understanding is that management objectives are generally passive. A minimum flow achieving an intermediate degree of habitat conservation would be an improvement over current conditions and enable water supply withdrawals to continue to occur. The specific level of habitat conservation/restoration is dependent on balancing habitat management objectives with human consumption objectives. For purposes of this analysis, we selected a flow for each reach that produces 50 percent of the habitat area produced under the typical virgin summertime streamflow conditions for each reach as a starting point. This was based on the assumption that a compromise would have to be made between aquatic habitat needs and water supply needs, and that an "adequate", not "optimal" habitat conservation strategy would be attainable in each subbasin. Such an approach is similar to the Tennant Method, which recommends stream management goals through the maintenance of certain percentages of mean annual flow.[95]

The Massachusetts Division of Fisheries and Wildlife (DFW) states, however, that active fisheries management is occurring in certain portions of the watershed. A letter from Todd Allan Richards of Mass. DFW states the following: "The Weir River and the lower Plymouth River are managed as seasonal coldwater streams. The Plymouth River also has holdover brook trout and

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[94] Bovee, et al., U.S. Fish and Wildlife Service. 1998

[95] ibid.

the Weir River has holdover brown trout. The unnamed tributary of the Plymouth River (also known as Leary's Brook) and the Eel River are managed as a wild brook trout fisheries. Leary's Brook was historically managed by MDFG as a "feeder stream" to the Plymouth River and was closed to fishing to protect the wild fish. Due to their sensitive ecological nature wild brook trout streams receive special attention from the MDFW during environmental reviews such as water withdrawal permitting." It may therefore be preferable to maintain a habitat percentage greater than 50 percent of virgin in this brook. It is worthwhile to note that the Plymouth River subbasin (subbasin 2) is currently the subbasin least affected by development, but there are now plans for housing and golf course development in the area.

The suggested minimum acceptable instantaneous streamflows are presented in **Table 5-4**. These flows represent the amount of streamflow needed to maintain 50 percent of the habitat provided by the water balanced-derived typical virgin streamflows in an average summer. In summary, the minimum streamflows which maintain 50 percent of the average virgin August aquatic habitat are <u>0.53 cfs in Accord Brook</u> and <u>2.07 cfs in the Weir River</u>. It is important to understand that the choice of the minimum acceptable amount of habitat for a stream is a somewhat arbitrary decision which is dependant on a variety of factors and values. It should be noted that the proposed values are very close to the Massachusetts Water Resources Commission Minimum Instantaneous Streamflow Threshold recommendations but less than the USFWS ABF recommendations. The stakeholders within the watershed must decide on the relative values they place on all potential uses of a basin's water resources and then accordingly allocate the finite resources to meet those functions. The 50 percent aquatic habitat threshold is presented as a departure point to spur discussion and identify potential areas of resource allocation conflict. Nothing in this report should be taken to imply that the DEM or the authors advocate a loss of water withdrawal rights for the public water supply sources presently utilized. Rather, it is hoped that this study will provide data by which the impacts of withdrawals can be understood, and which will lead to water management alternatives to minimize negative impacts where options are available.

The USFWS ABF New England Policy states that the ABF based on August median flow will be adequate throughout the year, unless additional flow releases are necessary for fish spawning and incubation. The New England Policy states, "We have determined that flow releases equivalent to historic median flows during the spawning and incubation periods will protect critical reproductive functions." GZA has evaluated seasonal flow requirements based on DEM and MDFW requests to examine the flow needs of fall-spawning salmonids and spring-spawning fish such as white sucker. Seasonal flow recommendations for spawning and incubation purposes are based on the lowest monthly average virgin streamflow in the period of interest. These conditions serve to define the limit of usable habitat under undeveloped conditions. October streamflows are limiting to Fall / Winter (Oct. 1 through Feb. 28) spawning. Streamflows equal to or greater than the October average (1.07 cfsm) will be at or above the habitat inflection point for spawning Brown trout, shown for Weir River site 3 on Figure 5-6. June streamflows are limiting to Late Spring (May 1 through June 30) spawning. Streamflows equal to or greater than the June average (1.36 cfsm) will be at or above habitat inflection points for spawning White sucker in both Accord Brook and Weir River, as shown on Figures 5-2 and 5-4.

A fourth season, which might be referred to as the Early Spring (March 1 through April 30) high flow period, is also important to the overall health of the stream system. While there are no aquatic species present in the water courses which require high flows for overbank spawning, etc., the stream channels themselves benefit from periodic flushing by high flows. In order to insure that this flushing action (which removes silt and debris and helps keep the channel defined) occurs, GZA has recommended that minimum average high flow period streamflow be set equal to "bankfull" flow. Bankfull flow occurs when the entire main channel is filled and the water surface in the stream is at the top of the bank slope.

It should be noted that the water balance-derived total streamflow parameter (groundwater outflow plus surface water runoff) has been used in the non-summer flow recommendations. It is GZA's opinion that the estimated total streamflow is an acceptable criteria for the wetter periods of the year due to a more uniform distribution of precipitation. For the summer seasonal streamflow recommendation, the minimum flow was developed based on average August runoff (0.44 cfsm) plus a quantity of baseflow equal to the minimum recommended instantaneous flow (0.14 cfsm).

All instantaneous and average seasonal streamflow recommendations were developed based on the assumption of average annual precipitation totals and distributions. Actual streamflows may be expected to fall below these levels during drought conditions. The water balance model predicts that, even under pre-development conditions, streamflows are reduced in response to below-average rainfall. An exemption or waiver from meeting the recommended seasonal minimum streamflows may therefore be justified during periods of State-declared drought emergency.

Using these procedures, seasonal flow recommendations have been developed. A minimum instantaneous flow recommendation has been presented first. This is the recommended minimum streamflow which should be maintained in the stream channels at all times. The minimum instantaneous streamflow recommendation was developed based of summertime habitat and flows, but it is applicable to all seasons. At no time during the year should flow in any stream be diverted or depleted below this threshold. The seasonal average flow recommendations account for the average streamflow over an extended time period. Evaluation of the attainment of these goals will require a data set of flow measurements over the entire season so that actual average streamflow may be computed. These seasonal average streamflow recommendations are presented for each subbasin in **Table 5-5** and may be summarized (as generalized for the watershed as a whole) as shown below:

Period	Minimum Instantaneous Streamflow per Unit Watershed Area

Summer: July 1 to September 30 (Also applies during other seasons)	0.14 cfsm

Period	Minimum Seasonal Average Steamflow per Unit Watershed Area
Summer: July 1 to September 30	0.58 cfsm
Fall/Winter: October 1 to February 28	1.07 cfsm
Early Spring: March 1 to April 30	3.11 cfsm
Late Spring: May 1 to June 30	1.36 cfsm

Examination of the streamflow rates estimated by the water balance model indicates that flows in Accord Brook are currently unlikely to meet either the minimum instantaneous or seasonal average streamflow recommendations, under average conditions. Recommended instantaneous flows within the Weir River itself appear to be maintained in August under current average summer conditions (primarily due to flows out of the Crooked River subbasin), but the recommended summer seasonal average streamflow does not appear to be attained under current average conditions. These conditions are predicted to be exacerbated by increased future demand.

5.50 AQUATIC HABITAT SAFE YIELD ESTIMATES

Safe Yield is a hydrologic term with several different meanings. When used in discussions of reservoirs and water supply systems, *Safe Yield* is defined as, "The maximum quantity of water which can be guaranteed during a critical dry period."[96] When referring to groundwater, *Safe Yield* is said to "Express the quantity of water which can be withdrawn without impairing the aquifer as a water source [i.e. irreversible depletion], causing contamination, or creating economic problems from a severely increased pumping lift."[97] Safe Yield may be expressed in terms of million gallons per day (MGD), which is a convenient term, particularly because DEP Water Management Act registrations and permits refer to average daily demand (ADD) in terms of MGD.

For the purposes of this study, a new term, *Aquatic Habitat Safe Yield,* has been coined. Aquatic Habitat Safe Yield will be defined as the maximum quantity of water which may be withdrawn under given hydrologic conditions which will allow streamflows to remain at or above specified seasonal minimums in order to conserve, restore, and manage sustainable fish and wildlife populations. In other words, Aquatic Habitat Safe Yield will be used as an estimate of how much demand may be supported by a watershed without serious impact to the associated aquatic habitat.

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[96] Linsley, R.K. and Franzini, J.B. Water-Resources Engineering. McGraw-Hill. 1964.

[97] ibid

Aquatic Habitat Safe Yield in the Weir River watershed, as defined by and for the purposes of this study, has been evaluated using the water balance model discussed in Section 4.52 and the Recommended Minimum Flow Thresholds established in Section 5.44. As per the requirements of the Department of Environmental Management, Aquatic Habitat Safe Yield has been assessed on both an annual and a seasonal basis.

The potential Aquatic Habitat Safe Yield of each subbasin was evaluated individually. It was assumed that minimum flows must be maintained in each subbasin. Therefore, each subbasin could be and was evaluated separately, without regard to upstream or downstream subbasins. All subbasins were assessed for maximum amount of water withdrawal possible while maintaining minimum seasonal streamflows. Since remaining streamflows after water withdrawals were adequate on a per square mile basis, flows from one subbasin to the next did not create either a surplus or deficit in streamflow. It is important to note that the estimates of Aquatic Habitat Safe Yield did not account for the specific locations of wells or diversions within the Weir River watershed. Diversions and groundwater withdrawals were assumed to take place in each subbasin. In actuality, some subbasins in the watershed are heavily subscribed while others are barely impacted. Currently, the infrastructure needed to utilize the maximum groundwater and/or surface water available from all sub-basins does not exist; therefore the Aquatic Habitat Safe Yield estimated in this report may be somewhat higher than is currently feasible. The Aquatic Habitat Safe Yield represents a ceiling of water withdrawal assuming withdrawals could be made at maximum efficiencies.

The Aquatic Habitat Safe Yield for each subbasin was estimated in each month by determining the amount of streamflow available in excess of the recommended average minimum flow. The quantity of water to remain in the stream was subtracted from the average monthly streamflow under virgin conditions to estimate the volume of water available for withdrawal:

$$\mathbf{Q_{vir} - Q_{rec} = Q_{avail}}$$

Where:

$\mathbf{Q_{vir}}$ = Virgin total streamflow (baseflow + runoff)
$\mathbf{Q_{rec}}$ = Recommended Average Streamflow
$\mathbf{Q_{avail}}$ = Flow available for withdrawal

Thus all streamflow in excess of the seasonal recommended minimum for that month is assumed to be available for withdrawal. Withdrawals may be either from surface water diversion or via groundwater pumping, which would affect streamflow through baseflow reduction. The Aquatic Habitat Safe Yield calculations have been made on the basis of a year with average precipitation and evaporation rates. **Table 5-6a through Table 5-6f** show the monthly Aquatic Habitat Safe

Yield calculations for each subbasin. The annual and seasonal results are summarized in **Table 5-7**. Note that Subbasin 7, the tidal subbasin has been excluded from the calculations.

The results of the analysis indicate that the average annual Aquatic Habitat Safe Yield of the entire Weir River watershed is 5.99 MGD. This is the average quantity of water available for withdrawal in a year from the watershed while maintaining sufficient water within the streams and rivers of the basin to meet the minimum streamflow thresholds recommended by this study. The Aquatic Habitat Safe Yield varies from season-to-season, however, due to natural variation in precipitation and changing streamflow requirements. When viewed seasonally, the Aquatic Habitat Safe Yield Estimates are as follows:

Period	Seasonal Aquatic Habitat Safe Yield
Summer: July 1 to September 30	0.72 MGD
Fall/Winter: October 1 to February 28	11.48 MGD
Early Spring: March 1 to April 30	2.94 MGD
Late Spring: May 1 to June 30	3.31 MGD

For dry conditions, virgin baseflow approaches zero in each subbasin. The Aquatic Habitat Safe Yield under such conditions is estimated as zero, since any withdrawals would exacerbate the dry conditions and extreme low flows in the watershed.

It must be noted that the Aquatic Habitat Safe Yield estimated by this study is does not refer to physical capability of supply systems to actually withdraw water from the watershed. No long-term operations study or simulation was undertaken to estimate reliability of the systems to meet demand; nor were the capacities of individual wells, pumps, treatment plants, or storage tanks taken into account. And as previously noted, the analysis performed in this study assumes the ability to make (and desirability of making) withdrawals from all sub-basins. The current configuration of wells and diversions does not allow for the full utilization of all excess water from all subbasins.

The Aquatic Habitat Safe Yield estimates are dependent on the minimum acceptable in-stream flow recommendations. The preliminary recommendations developed in this report are in turn dependent on the choice of level of acceptable habitat. In this study, 50 percent of the virgin, summertime habitat was used to develop the minimum flow recommendation. The amount of water which should be allocated to habitat is actually dependent on the values and needs of the various stakeholders within the watershed. The Aquatic Habitat Safe Yield estimates provided in this report are intended to provide an indication of the availability of water resources in the watershed and to identify where conflicts between uses may occur.

Current levels of withdrawals from the watershed (4.12 MGD), based on data presented in Section 4.30, do not exceed the estimated Aquatic Habitat Safe Yield of the watershed (5.99 MGD) on an annual basis. However, because withdrawals are concentrated in certain sub-basins (such as Accord Brook) rather than spread evenly across the whole watershed, impacts may be disproportionate on some streams. In addition, while the average annual withdrawals appear acceptable, comparison of seasonal withdrawals to seasonal Aquatic Habitat Safe Yield (AHSY) indicates that excess withdrawals (and thus excessive impacts on aquatic habitat) may be occurring. Seasonal average withdrawals from all suppliers / users are compared to seasonal average safe yields below:

Period	Seasonal AHSY		Ave. Seasonal Withdrawal
July 1 to September 30	0.72 MGD	<	4.94 MGD
October 1 to February 28	11.48 MGD	>	3.61 MGD
March 1 to April 30	2.94 MGD	<	3.55 MGD
May 1 to June 30	3.31 MGD	<	4.71 MGD

In three of the four seasons, average daily withdrawals from the watershed exceed the Aquatic Habitat Safe Yield estimate. The problem is the worst in the summer months. This is logical since precipitation is lowest in the summer, at the very time that demand for water is greatest. Thus while it appears that on average, there is sufficient water within the Weir River watershed to meet the needs of both water users and aquatic habitat, the seasonal distribution of supply and demand may be causing stress on both the water supply system and the aquatic ecosystem.

Several potential courses of action might be considered in order to restore the aquatic habitat to desirable levels while at the same time meeting the water supply needs of the community. One alternative is to reduce demand via consumer education, improvements in efficiency, changes to water cost structure, etc. A second alternative is to find new sources of water either in locations within the watershed where impacts are not yet critical, or more likely, from outside the watershed altogether. It is also possible that modifications to the operational strategies of the water utilities/suppliers might help mitigate the problems, some wells may have more impact than others. Changes in the timing of withdrawals from surface water sources such as Accord Pond might help to keep groundwater levels, and consequently baseflows, higher during the critical summer months. The Town of Norwell might also be able make adjustments to its pump utilization schedule. Another potential option is to make releases from Accord Pond (via a pump, siphon, or new low-level outlet) directly into Accord Brook when flows fall below minimum thresholds. Finally, if it were possible to store excess water available in the winter months for use in the water-deficit summer, then better advantage could be taken of the total amount of water available in the watershed throughout the year.

6.00 SUMMARY & CONCLUSIONS

6.10 SUMMARY OF FINDINGS

This study of the Weir River watershed offers two important resources to watershed planners, municipalities, water supply operators, fisheries managers, and all other interested stakeholders including the public. First, the report brings together under one cover much of the basic facts and information needed to understand the character, configuration, and resources of the watershed. In addition to the baseline data compiled within this report, the study goes on to examine the interaction between the intersecting needs of both humans and the environment for an adequate supply of water. An interdisciplinary approach involving both hydrology and biology was used to study the overall availability of water in the watershed and the role of water in maintaining a suitable habitat for the living aquatic resources of the area. Recommended minimum seasonal streamflow thresholds have been suggested for the streams and rivers of the watershed, and the estimated amount of water supply withdrawal compatible with maintaining these in-stream flows has been computed. Summaries of some of the pertinent findings and results of this study are presented below for ease of reference.

6.11 Summary of Watershed Characteristics

General Watershed Data

Major Rivers and Streams:	Weir River, Accord Brook, Plymouth / Crooked Meadow River
Major Lakes and Ponds:	Accord Pond, Triphammer Pond, Fulling Mill Pond, Foundry Pond, Straits Pond
Stream Gages	No Permanent Gages
Watershed Area:	23.4 sq. mi. Total Study Area 14.8 sq. mi. Non-Tidal (to Foundry Pond Dam)
Delineated Subbasins:	7
Towns within watershed (fully or partially):	Hingham, Hull, Cohasset, Norwell, Rockland, Weymouth
Population (2000):	30,319 within Total Study Area
Population Supplied from Watershed :	38,014 (adjusted service population)
Ave. Annual Precipitation:	48.1 in.
Ave. Annual Evapotranspiration:	26.5 in.

Registered and Permitted Withdrawals

	Aquarion Water Company (MGD)	Norwell Water Department (MGD)	Watershed Total (MGD)
Registered	3.51	0.32	3.83
Permitted	0.00	0.35 (2000) 0.40 (2010)	4.07 (1998) 4.23 (2010)
Totals	3.51	0.67 (2000) 0.72 (2010)	4.18 (2000) 4.23 (2010)

Actual and Predicted Withdrawals

	Aquarion Water Company (MGD)	Norwell Water Department (MGD)	Other (Assumed) Withdrawals (MGD)	Total (MGD)
Actual (ave. 1996-2000)	3.57	0.46	0.08	4.12
Projected 2020 [Method 2 baseline]	4.04	0.49	0.09	4.63
Projected 2020 [Method 2 with major development]	4.28*	0.49	0.34	5.13*

* Additional 0.35 MGD proposed to be purchased from Taunton Desalination Project

6.12 Summary of Flow Characteristics & Water Balance Results

Water Balance-Derived Annual Average Streamflow Rates

	Average, Virgin	Dry, Virgin	Average, Developed	Dry, Developed	Average, Future	Dry, Future
Subbasin 3 (Accord Brook at Diversion Dam)	7.4 cfs	5.1 cfs	6.2 cfs	4.4 cfs	6.2 cfs	4.4 cfs
Subbasin 6 (Weir River at Rt 3A)	28.6 cfs	19.7 cfs	25.0 cfs	17.4 cfs	24.6 cfs	17.1 cfs

Water Balance-Derived Typical August Streamflow Rates

	Average, Virgin	Dry, Virgin	Average, Developed	Dry, Developed	Average, Future	Dry, Future
Subbasin 3 (Accord Brook at Diversion Dam)	0.9 cfs	0.2 cfs	0.0 cfs	0.0 cfs	0.0 cfs	0.0 cfs
Subbasin 6 (Weir River at Rt 3A)	3.5 cfs	0.8 cfs	2.6 cfs	0.2 cfs	2.6 cfs	0.2 cfs

6.13 Summary Of In-Stream Aquatic Habitat Flow Needs

Aquatic Evaluation Species: Brown trout, White sucker, Tessellated darter, Cadisfly / Mayfly

Flow Rate for Optimum Habitat Suitability Index

	Brown Trout	White Sucker	Tessellated Darter	Cadisfly / Mayfly
Accord Brook (and Plymouth / Crooked Meadow River)	7.0 cfs	5.0 cfs	7.0 cfs	4.0 cfs
Weir River	20.0 cfs	10.0 cfs	20.0 cfs	25.0 cfs

Note: Optimum flow rates may not be sustained during low flow conditions, even under pre-development conditions.

Recommended Minimum Instantaneous Streamflow

Watershed-wide per Unit Area Flow Recommendations	0.14 cfsm
Accord Brook (total contributing area = 3.77 sq. mi.)	0.5 cfs
Weir River (total contributing area = 14.8 sq. mi)	2.1 cfs

Recommendation based on preservation of
50 percent of summertime, pre-development aquatic habitat.

Recommended Minimum Seasonal Average Streamflows

	Summer July 1 – Sept 30	Fall/ Winter Oct 1 – Feb 28	Early Spring Mar 1 – Apr 30	Late Spring May 1 – June 30
Watershed-wide per Unit Area Flow Recommendations	0.58 cfsm	1.07 cfsm	3.11 cfsm	1.36 cfsm
Accord Brook (3.77 sq. mi.)	2.2 cfs	4.0 cfs	11.7 cfs	5.1 cfs
Weir River (14.8 sq. mi)	8.6 cfs	15.8 cfs	46.0 cfs	20.1 cfs

6.14 Summary of Safe Yield Estimates

Reported Public Supply System Safe Yields

	Reported Safe Yield (MGD)
Aquarion Water Company System (with emergency sources)	4.29 (4.95)
Norwell Weir River Watershed Wells	1.00

Estimated Seasonal Aquatic Habitat Safe Yields Compared to Current Seasonal Withdrawals

Season	Aquatic Habitat Safe Yield (MGD)	Current Average Seasonal Withdrawal (1996-2000) (MGD)
Summer: (July 1 – Sept 30)	0.72	4.94
Fall/Winter: (Oct 1 – Feb 28)	11.48	3.61

Early Spring: (Mar 1 – Apr 30)	2.94	3.55
Late Spring: (May 1 – June 30)	3.31	4.71
Annual: (Jan 1 – Dec 31)	5.99	4.12

6.20 CONCLUSIONS

The water resources of the Weir River watershed are taxed in terms of both their capacity to provide a stable public water supply and their ability to maintain adequate habitat for aquatic wildlife. In the summer of 1999, outdoor water use restrictions were implemented in Hingham and Hull. At the same time, pond levels were also low and Accord Brook was dry in some reaches. Many of the same conditions were repeated in 2002. In the five years between 1996 through 2000, total withdrawals from the watershed by the Massachusetts American Water Company (now the Aquarian Water Company) exceeded the registered limit during 3 separate years. In addition, average daily demand in Hingham and Hull consistently approached or exceeded the reported system safe yield (excluding emergency sources) in June, July, and August.

The watershed provides water for approximately 38,014 persons living in the suburban communities of Hingham, Hull, Cohasset, and Norwell. The small portions of Rockland and Weymouth are within the watershed, but these two towns withdraw virtually no water from the watershed. The Aquarion Water Company of Massachusetts (AWC), which supplies virtually all of Hingham and Hull and a portion of Cohasset, withdraws water exclusively from the Weir River watershed. AWC pumps water from six (6) wells in Hingham and withdraws surface water from Accord Pond and Accord Brook. AWC is currently registered for withdrawals of up to 3.51 MGD annually. The Norwell Water Department was registered and permitted in 2000 for up to 0.67 MGD of withdrawals annually from the Boston Harbor (Weir River) watershed via its four wells. Average withdrawal rates in the five years between 1996 through 2000, as reported by the public water suppliers, indicated that AWC (then MAWC) withdrew an average of 3.57 MGD, which is slightly (0.06 MGD) in excess of its registration level. In the same period, Norwell pumped 0.46 MGD, which did not exceed its total registered and permitted limit. Water supplied by these suppliers is provided to residential, commercial, and industrial consumers in and around the watershed.

When taken together, withdrawals from the Weir River Watershed that are currently regulated by the Water Management Act totaled 4.04 MGD on average during the five years from 1996 through 2000. In addition to registered and permitted withdrawals, there are private wells and golf courses in the watershed which are assumed to have withdrawn another 0.08 MGD on average, making total average daily demand in the watershed 4.12 MGD

Based on the population and demand projections, water withdrawals are anticipated to increase in the future. Total average daily withdrawals from the watershed may be expected to increase to up to 4.63 MGD by the year 2020. Increased in demand above this level may occur as a result of major developments currently proposed for construction within the watershed. Development projects which have recently filed notices with the Massachusetts Environmental Protection Act Office could increase futures demands to as high as 5.13 MGD. An additional 0.35 MGD of water is expected to be purchased from a desalination plant outside the watershed. If this water is unavailable, then even more withdrawals from the Weir River watershed may be requested.

To quantify the effects of water withdrawals on aquatic wildlife in the streams of the watershed, a simplified water balance model was employed. The model accounts for both natural and human-caused inputs and outputs of water to and from the watershed and its various subbasins. The water budget model was used to examine the watershed under both average and dry conditions, for virgin ("natural"), developed, and future scenarios. The water budget model produced estimates of monthly average baseflow and total streamflow in the various streams and rivers of the watershed under each combination of flow and development conditions. To evaluate the adequacy of the estimated in-stream flows, stream-specific habitat suitability-to-discharge curves were developed for a number of indicator aquatic species. The curves, which were developed based on stream morphology for specific stream sites, show the relationship between streamflow and aquatic habitat in a manner similar to the IFIM-type of approach. The curves indicate the amount of flow that optimizes aquatic habitat, and they also show inflection points where additional flow produces only small marginal habitat gains.

Flow rates estimated by the water balance model were compared against the habitat curves to evaluate the effects of current and potential future development on aquatic habitat. Results of the water balance model for virgin (pre-development) conditions indicate that summer low-flow conditions produce the minimum aquatic habitat. Even under undeveloped conditions and during years with average precipitation habitat is sub-optimum during the summer and early fall. Therefore, the low-flow period was likely the limiting condition to the indigenous fish populations of the Weir River even before development and water withdrawals by humans. This is consistent with the conclusions and methodology of the U.S. Fish and Wildlife Service New England Aquatic Base Flow Policy.

When current and predicted future levels of water withdrawals are incorporated into the water balance model, streamflows are reduced in every subbasin where withdrawals occur. Accord Brook and the Weir River are particularly affected. The model indicates that existing demand causes sections of Accord Brook to run dry over significant portions of the year, even during average years. The drying up of portions of Accord Brook was observed by GZA during field work in August and October of 1999. The model suggests that water supply withdrawals have a significant impact on typical summertime streamflows and therefore also impact aquatic habitat. During dry year scenario (modeled as an event with a 5 percent annual chance of occurrence) low-flow effects quite pronounced throughout the watershed. Aquatic habitat is severely impaired even in the virgin (pre-development) condition, as well as under the current and future conditions.

The naturally-occurring, pre-development aquatic habitat levels during the summer months were taken as baseline reference habitats. Based on GZA's understanding of stream management objectives and in order to account for various water resources priorities, the minimum acceptable instantaneous streamflow was recommended to be that level of flow which provides 50 percent of the aquatic habitat produced by the summer, pre-development typical streamflows. The average monthly baseflows developed using the water balance model were used as a proxy for typical streamflows since these flow rates were assumed to more closely represent summertime median streamflows. Given the physical and hydrologic characteristics of the watershed, it is GZA's opinion that in the summer low-flow season average, the model derived baseflow value is a reasonable approximation of median streamflow, which is the parameter used by the USFWS. The minimum recommended instantaneous streamflow threshold developed for the Weir River watershed using these criteria is 0.14 cubic feet per second per square mile. Minimum average seasonal streamflow rates have also been developed which reflect flow variability within each season and over the course of the year. Seasonal streamflow recommendations are based on the seasonal requirements of spawning fish and incubating eggs. It is also important that high flows in the spring are sufficient to provide natural channel forming and scour action. Current and future development in the watershed does not appear to significantly impact the adequacy of flows in seasons other than summer.

These recommended in-stream flow rates should be adequate to meet the needs of most of the aquatic species present in the watershed, including anadromous fish such as alewife. It should be recognized, however, that the restoration of anadromous fish populations in the watershed is dependant on a number of factors. In particular, the proper functioning of the fish ladders at Foundry Pond Dam and Triphammer Pond Dam is critical to allow upstream passage for spawning anadromous fish.

Maintenance of recommended minimum instantaneous and average streamflow within the streams of the watershed requires that water withdrawals be limited to a rate that does not cause depletion of the rivers and streams. The average daily demand which may be sustained without causing average streamflow in any month to fall below the minimum acceptable seasonal threshold has been termed the *Aquatic Habitat Safe Yield*. The average year Aquatic Habitat Safe Yield for the entire Weir River Basin has been estimated to be 5.99 MGD. Current levels of demand do not exceed the Aquatic Habitat Safe Yield when averaged over a full year; however, Aquatic Habitat Safe Yield values have also been developed seasonally to account for the changing needs of aquatic habitat and the seasonal aspect of water availability within the watershed. When viewed seasonally, withdrawals from the Weir River Watershed exceed seasonal Aquatic Habitat Safe Yield values in three of the four seasons, with the largest deficit occurring in the summer. During the five fall/winter months (October through February), the seasonal Aquatic Habitat Safe Yield of 11.48 MGD far exceeds the average seasonal withdrawal of 3.61 MGD. The methodology used to develop the Aquatic Habitat Safe Yield estimates presented in this report accounts for general withdrawals from each subbasin. The specific configurations of the water supply systems (i.e. well location, reservoir storage, etc.) in the Weir River watershed was not modeled.

The Aquatic Habitat Safe Yield estimates are directly dependent on the minimum seasonal streamflow recommendations, which are in turn dependent on judgements regarding appropriate relative levels of aquatic habitat. The amount of water allocated to the maintenance of aquatic habitat is ultimately a function of the value placed upon fisheries and the aquatic environment by the various stakeholders with interests in the watershed. These values must be weighed against the utility of water used by residents and other consumers who use withdrawn water to drink, bathe, water lawns, and run businesses. A balance must be struck between the needs of the aquatic environment and the water users who are dependant on the watershed. The results of this study should be used as a basis for discussions and additional study. Ultimately, policy decisions relating to the allocation of limited water resources must be in the public arena through a consensus of all stakeholders.

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8.00 GLOSSARY

Aquifer: A geologic formation, group of formations, or part of a formation that contains sufficient saturated permeable materials to yield significant quantities of water to wells or springs

Baseflow: The portion of streamflow derived from groundwater discharge.

Bedrock: Solid rock, commonly called “ledge,” that forms the earth’s crust.

Casing: Any construction material that keeps unconsolidated earth materials and water from entering a well.

Coagulation: The process by which material clumps together or becomes viscous or thickened.

Coefficient of Permeability: The rate of flow of water (in gallons per day) through a cross sectional area (of one square foot) of a saturated material under a hydraulic gradient (of one foot per foot) at a Temperature of 16^o C.

Coliform Bacteria: Any of a group of bacteria, some of which, inhabit the intestinal tracts of vertebrates. Their occurrence in water is regarded as evidence of possible contamination.

Color Unit: A standard of color in water measured by the platinum-cobalt method. The color produced by 1 mg/L of platinum in water equals 1 color unit.

Cone of depression: A depression produced in a water table by the withdrawal of water in an aquifer.

Cubic feet per second, cfs: A unit expressing discharge. One cubic foot per second is equal to the discharge of a stream 1 foot wide and 1 foot deep flowing at an average velocity of 1 foot per second.

Direct Runoff: Water that moves over the land surface directly into a water body shortly after a precipitation event.

Dissolved Solids: The residue from a clear sample of water after evaporation and drying for one hour at 180^o C.

Draft Rate: A rate of regulated flow at which water is withdrawn from storage in a reservoir.

Drawdown: The lowering of the water table or potentiometric surface caused by the withdrawal of water from an aquifer by pumping; equal to the difference between the static water level and the pumping water level.

Eutrophic lake: A lake rich in dissolved nutrients, commonly shallow and having season oxygen deficiency.

Evapotranspiration: Loss of water to the atmosphere by direct evaporation from water surfaces and moist soil combined with transpiration from living plants.

Flocculation: The process by which clumps of material in a liquid aggregate or increase in size.

Flood: Any high streamflow overtopping the natural or artificial banks in any reach of a stream.

Flow duration: In a stream, the percentage of time during which specified daily discharges have been equaled in magnitude within a given time period.

Fracture: A break or opening in bedrock along which water may move.

Frequency: The average number of extreme events over a period of many years.

Gaging station: A site on a flowing body of water for systematic observations of water height or discharge.

Gravel: Unconsolidated rock debris comprised principally of particles larger than 2 mm in diameter.

Groundwater: Water in the saturated zone (subsurface).

Groundwater discharge: The discharge of water from the saturated zone by natural processes such as groundwater runoff and evapotranspiration and/or discharge through wells and other human-made structures.

Groundwater divide: A hypothetical line on a water table on each side of which the water table slopes downward in a direction away from the line.

Groundwater outflow: The sum of groundwater runoff and underflow; it includes all natural groundwater discharge from a drainage area exclusive of groundwater evapotranspiration.

Groundwater recharge: Amount of water added to the saturated zone through infiltration.

Groundwater runoff: Water that has discharged into stream channels by seepage from saturated earth materials.

Head, static: The height of the surface of a water column above a standard datum that can be supported by the static pressure at a given point.

Hydraulic boundary: A physical feature that limits the areal extent of an aquifer. The two types of boundaries are termed impermeable barrier boundaries and line-source boundaries.

Hydraulic conductivity: A measure of the ability of a porous medium to transmit a fluid. The ratio of velocity to hydraulic gradient, indicating permeability of a material. The material has a hydraulic conductivity of unit length per unit time if it will transmit in unit time a unit volume of water at the prevailing kinematic viscosity through a cross section of unit area, measured at right angles to the direction of flow, under a hydraulic gradient, of unit change in head over unit length of flow path.

Hydraulic gradient: The change in static head per unit of distance in a given direction.

Hydrograph: A graph showing stage (height) versus discharge with respect to time.

Impermeable barrier boundary: The contact between an aquifer and adjacent impermeable material that limits the areal extent of the aquifer.

Induced infiltration: The process by which water infiltrates an aquifer from an adjacent surface water body in response to groundwater pumping.

Induced recharge: The amount of water entering an aquifer from an adjacent surface water body by the process of induced infiltration.

Line-source boundary: A boundary formed by a surface water body that is hydraulically connected to an adjacent aquifer.

Partial record gaging station: A site at which random measurements of stream elevation or flow are made at irregular intervals.

Perennial stream: A stream that flows during all seasons of the year.

pH: The negative logarithm of the hydrogen-ion concentration. pH of 7.0 indicates neutrality; pH below 7.0 denotes acidity, above 7.0 denotes alkalinity (base).

Porosity: The property of rock or unconsolidated material to contain voids or open spaces; it may be expressed quantitatively as the ratio of the volume of its open spaces to its total volume.

Precipitation: The discharge of water from the atmosphere, either in a liquid or solid state.

Recurrence interval: The average interval of time between extremes of streamflow, such as floods or droughts, that will at least equal in severity a particular extreme value over a period of many years.

Runoff: That part of precipitation that appears in streams. It is the same as streamflow unaffected by artificial diversions, storage, or other artificial works in stream channels.

Saturated thickness: Thickness or depth of an aquifer below the water table.

Saturated zone: Subsurface zone in which all open spaces are filled with water. The water table is the upper limit of this zone.

Sediment: Fragmental material that originates from weathering of rocks.

Specific capacity of a well: The rate of discharge of water divided by the corresponding drawdown of the water level in the well.

Specific yield: The ratio of the volume of water which, after being saturated, a rock or soil will yield by gravity, to its own volume.

Storage coefficient: The volume of water an aquifer releases from or takes into storage per unit surface area of the aquifer per unit change in head. In an unconfined aquifer, the storage coefficient is virtually equal to the specific yield.

Stratified drift: A predominantly sorted sediment laid down by or in meltwater from a glacier; includes sand and gravel and minor amounts of silt and clay arranged in layers.

Subbasins: Hydrologic divisions of a watershed.

Transmissivity: Measure of how easily water in an aquifer can travel through its porous material. Equal to the hydraulic conductivity times the saturated thickness.

Transpiration: The process whereby plants release water vapor to the atmosphere.

Turbidity: The extent to which penetration of light is restricted by suspended sediments, microorganisms, or other insoluble material.

Unconfined aquifer: (water table aquifer) An aquifer whose upper surface of the saturated zone is at atmospheric pressure and free to rise and fall.

Unconsolidated: Loose, not firmly cemented or interlocked.

Underflow: The downstreamflow of water through the permeable deposits that underlie a stream.

Unsaturated zone: The zone between the water table and the land surface in with the open spaces are not entirely filled with water on a permanent basis.

Water divide: Point where the water table is at a maximum and flow does not cross.

Water table: The upper surface of the saturated zone.

Watershed: Area of land that drains to a single outlet and is separated from other watersheds by a divide.

Well: Vertical hole dug into the soil that penetrates an aquifer and is usually cased and screened.

Well screen: Slotted casing that allows water to enter a well from the aquifer.