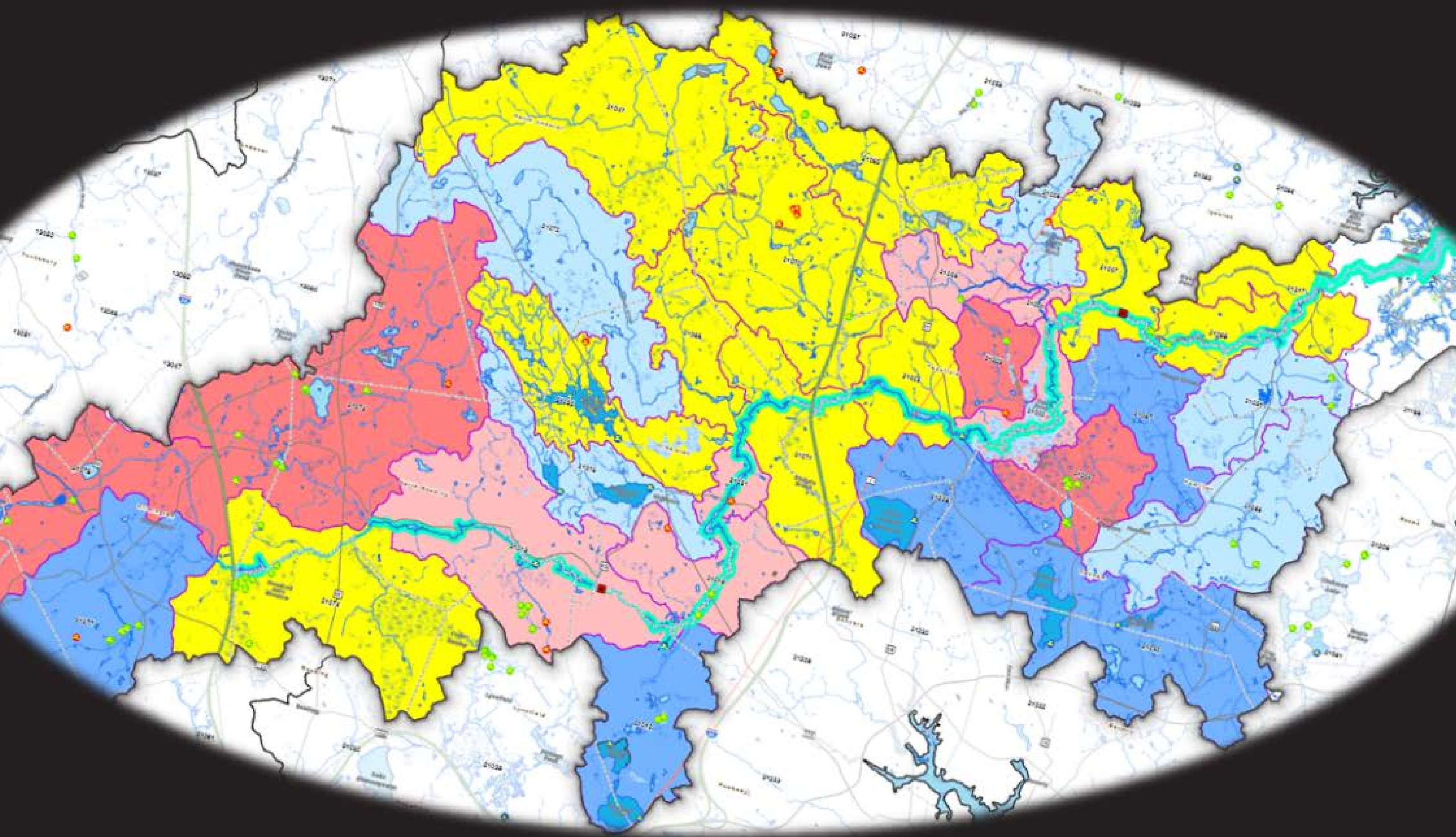
Submitted to: Metropolitan Area Planning Council, acting on behalf of the North Shore Water Resilience Task Force

November 2024

Assessment of Water Supply Alternatives Using the New Ipswich River Streamflow and Watershed Analysis Model (IRSWAM) - APPENDIX A



Horsley Witten Group
Sustainable Environmental Solutions

Weston & Sampson

APPENDIX A

Memorandum: Task 1 Literature Review Summary Memorandum - Ipswich River Watershed Water Supply Alternatives Modeling Project

Horsley Witten Group and Weston & Sampson Engineers, November 30, 2023

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MEMORANDUM

To: Martin Pillsbury, Metropolitan Area Planning Council

From: Neal Price and Mike Demanche, Horsley Witten Group

Kevin MacKinnon, PG, PH and Andrew Walker, PH, CFPM, Weston & Sampson Engineers

Date: November 30, 2023

Re: Task 1 Literature Review Summary Memorandum - Ipswich River Watershed Water Supply Alternatives Modeling Project

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Introduction

The Horsley Witten Group (HW) and Weston and Sampson Engineers (WSE) are pleased to submit this memorandum to the Metropolitan Area Planning Council (MAPC) and the North Shore Water Resilience Task Force (the Task Force) summarizing our review of key background literature for Ipswich River Watershed (IRW) water management issues. The IRW includes 22 cities and towns between the Ipswich River's headwaters in Wilmington and North Andover and its mouth in Ipswich. Public water systems which withdraw water from the IRW serve a population significantly greater than the population who live in the watershed. When a significant proportion of the water withdrawn from a basin is discharged outside of the basin, that creates a situation of net water export that can contribute to strain on the basin's water resources. The IRW also has a relatively low percentage of sand and gravel and relatively high rates of stormwater runoff and evapotranspiration, which together limit the amount of water available for aquifer recharge and storage to supply sustained baseflow during extended periods of low precipitation.

The goal of the current project (the Project) is to evaluate the relative impacts on Ipswich River flow and prioritize the Task Force-identified water supply alternatives developed by others under a separate contract. The primary literature items reviewed and summarized here were specifically listed in the Request for Proposals (RFP) for the Project for review. In addition, several "supplemental" documents were also reviewed and summarized here that we felt added additional context to the background and supported the overall water budget modeling goal of this project. This memorandum serves as the deliverable for Task 1 of the Project and will inform the water budget modeling and analyses conducted in future tasks of the Project. Primary, RFP-requested literature reviewed for this memorandum are:

- Assessment of Habitat, Fish Communities, and Streamflow Requirements for Habitat Protection, Ipswich River, Massachusetts 1998-1999 (Armstrong et al, 2001);

- A Precipitation-Runoff Model for Analysis of the Effects of Water Withdrawals on Streamflow, Ipswich River Basin, Massachusetts (Zariello and Reis, 2000);
- Ipswich River Watershed Management Plan (Horsley & Witten, January 2003);
- Simulated Effects of the 2003 Permitted Withdrawal and Water-Management Alternatives and Reservoir Storage and Firm Yields in Three Surface-Water Supplies, Ipswich River Basin (Zariello, 2004);
- Effects of Low-Impact-Development Practices on Streamflow, Runoff Quality and Runoff Quantity in the Ipswich River Basin (2010);
- Factors Influencing Riverine Fish Assemblages in Massachusetts (Armstrong et al, 2011);
- Ipswich Basin Water Management Act Planning Grant Study for Fiscal Year (FY) 2017;
- Ipswich Basin Water Management Act Planning Grant Study for FY 2018;
- Drought Management Plan Update, Town of Danvers, Massachusetts, July 2019;
- Below WMA-threshold Study for the Ipswich River and Parker River Basins (MassDEP, 2018 and amended in 2019);
- Minimization Plan, Town of Danvers, Massachusetts, 2019; and
- MassDEP Water Management Act (WMA) Program Water Use Data.

Supplemental literature reviewed for this memorandum are:

- IRWA critique of DEP below WMA Threshold Study;
- Massachusetts Sustainable-Yield Estimator: A decision-support tool to assess water availability at ungaged stream locations in Massachusetts (SIR 2009-5227, Archfield et al, 2010);
- Methods Used to Estimate Daily Streamflow and Water Availability in the Massachusetts Sustainable-Yield Estimator Version 2.0 (Levin and Granato, 2018);
- Massachusetts Sustainable Water Management Initiative (SWMI) Framework Study (November 28, 2012);
- STRMDEPL08—An Extended Version of STRMDEPL with Additional Analytical Solutions to Calculate Streamflow Depletion by Nearby Pumping Wells (Reeves, 2008);
- Hydrologic Drought Decisions Support System (HyDroDSS)- (Gregory E. Granato, 2014);
- Simulation of Ground-Water Flow and Evaluation of Water-Management Alternatives in the Upper Charles River Basin, Eastern Massachusetts (Leslie A. Desimone, Donald Walter, John Eggleston and Mark Nimiroski,2002); and
- City of Peabody Integrated Reservoir Model: Coupling Quantity, Conservation; Habitat (Weston & Sampson, 2022);
- MassDEP WMA/SWMI tools and supporting data; and
- 2022 Massachusetts Climate Change Assessment (Executive Office of Energy and Environmental Affairs, December 2022).

Primary, RFP Literature Review Summary

Assessment of Habitat, Fish Communities, and Streamflow Requirements for Habitat Protection, Ipswich River, Massachusetts 1998-1999 (Armstrong et al, 2001)

In this influential paper, researchers from the USGS and MassDEP assessed the consequences of low flow conditions in the Ipswich River on the habitats of fish communities in the system. The study included the delineation of stream macrohabitats by topographic and georeferenced orthophoto maps, visual habitat assessments using USEPA rapid bioassessment protocols, streamflow measurements and calculations, and fish-community sampling via electrofishing with pulsed direct current backpack units. Fish-collection data was used to assess stream macrohabitats in three ways: species richness and composition, trophic composition, and abundance and condition. All information collected in this study was used to establish streamflow requirements for habitat protection at six locations along the Ipswich River. Key findings from the study include:

- Habitat is not a limiting factor for fish communities in years when the Ipswich River maintains flow.
- In dry seasons, such as 1999, channel margin habitats such as exposed roots, undercut banks, woody debris, and overhanging vegetation are unavailable to fish. During this 1999 season entire reaches of the Ipswich River dried completely and in many reaches that did not dry completely flow velocities were so low as to be undetectable.
- 95% of fish species in the Ipswich River mainstem are classified as macrohabitat generalists that do not rely on strong river flow.
- Streamflow requirements for fish passage at four sites are as follows:
    - Mill Street, North Reading/Reading: 7 cubic feet per second;
    - Log Bridge Road, Middleton/Danvers: 22 cubic feet per second;
    - Route 1, Topsfield: 22 cubic feet per second; and
    - Mill Road, Ipswich/Hamilton: 60 cubic feet per second.

A Precipitation-Runoff Model for Analysis of the Effects of Water Withdrawals on Streamflow, Ipswich River Basin, Massachusetts (Zariello and Reis, 2000)

Researchers from the USGS created a hydrologic model of the subbasins of the Ipswich River Watershed using the Hydrologic Simulation Program Fortran (HSPF) to assess the impacts of contemporary and planned water use scenarios. Key findings from the study include:

- HSPF was used to simulate surface and groundwater withdrawals from the Ipswich River basin. HSPF is a physically based mass-balance model based on climate, streamflow, and water use data, land-use derived hydrologic response units (HRU's), and stream hydraulic characteristics. The model was calibrated to data from the South Middletown and Ipswich Gauging Stations. The Ipswich River and main tributaries were divided into stream reaches based on hydrology, water withdrawals, habitat considerations, and wetlands. HRUs simulating unique combinations of land use, surficial geology, and water use practices were developed to characterize the basin.

- Modeling followed a study period from 1989 through 1993 during which time combined water withdrawals exceeded streamflows above the South Middletown gage and nearly exceeded streamflows at the Ipswich gage during the summer. Groundwater withdrawals always exceeded surface water withdrawals at the Middleton gage, but only exceeded surface water withdrawals above the Ipswich gage during seasonal surface water restriction periods.
- Streamflow depletion in HSPF is calculated using the USGS Stream Depletion model (STRMDEPL) to compute the delayed effects of groundwater withdrawals based on well pumping rates, properties of the aquifer and streambed, and distance.
- Multiple water use scenarios were evaluated. Low flow (99.8% exceedance probability) flow-duration curves were approximately an order of magnitude lower in calibration scenarios with only groundwater withdrawals versus simulations with only surface water withdrawals. This difference was larger at the South Middleton station where groundwater withdrawals are a larger portion of streamflow than at the Ipswich station. Surface water withdrawal impacts were minimized during low flow conditions due to restrictions requiring withdrawals only occur only during periods of high flow.

Ipswich River Watershed Management Plan (Horsley & Witten, January 2003)

Horsley & Witten prepared a watershed management plan on behalf of the Ipswich River Watershed Association to build upon research previously conducted in the watershed and work towards balancing the water budget for the basin. Key findings from the plan include:

- Of the water pumped from the Ipswich River watershed by municipalities, 80% is discharged outside of the watershed.
- Over time the assemblage of fish species in the Ipswich River has changed from species that rely on flow to generalist species found in both lake and river environments.
- The Ipswich River experiences severe and chronic low-flow problems in the summer and fall with occasional low flow problems in other seasons.
    - The upper half of the Ipswich River is often not usable for canoeing during the summer and early fall.
    - Canoeing in the lower half of the Ipswich River is impaired at times due to long sections of the riverbed becoming too shallow.
- Communities in the Ipswich River watershed use 25%-160% more water in peak months than in the winter.
- Several measures to improve net water balance in the basin were outlined in the plan, including:

- Improving water conservation, with the goal of reducing demand by 15% basin wide;
- Seeking alternative water supplies and reducing the demand from streamside wells;
- Reducing water exports through the increased treatment and infiltration of wastewater within the basin;
- Enhancing stormwater infiltration to reduce runoff;
- Increasing water storage at various scales, from rainwater cisterns for irrigation to large-scale reservoirs; and
- Improving land use practices through "smart growth" planning measures to reduce the per capita water demand in order to account for increased growth in the region.

Simulated Effects of the 2003 Permitted Withdrawal and Water-Management Alternatives and Reservoir Storage and Firm Yields in Three Surface-Water Supplies, Ipswich River Basin (Zariello, 2004)

Following the original development of the HSPF model, USGS researchers adapted the model to assess the impacts of surface water withdrawal permitting thresholds on the resiliency of public drinking supply reservoir systems that rely on the Ipswich River. Key findings from the study include:

- The HSPF precipitation-runoff model developed by Zariello and Reis (2004) was utilized to assess water budgets and firm yield capacity for the Salem-Beverly, Peabody, and Lynn water supply reservoirs. Multiple reservoirs within each system were modeled as single combined reaches within the HSPF model.
- Firm yield (the maximum demand rate that can be sustained during droughts) calculations for the systems analyzed in this report are complicated by the need to follow minimum streamflow requirements, which vary seasonally, as well as the use by some systems of non-variable pumping rate pumps that are either on at maximum capacity or off.
- Under the 2003 permitted withdrawals, none of the systems analyzed could meet 1998-2000 system demands. Storage in each system failed during multiple years of the study period at each system, and storage was below 25% of capacity during a significant period of the study.

Results Summary Table	Lynn (10.6 MGD demand)	Peabody (5.9 MGD demand)	Salem-Beverly (10.1 MGD)
Average storage as % of capacity	73%	35%	73%
Years during which system failure occurred	4 of 35	34 of 35*	4 of 35 years
Percentage of time storage below 25% of capacity	8%	50%	7%
Firm yield % below 1998-2000 average demand	19%	45%	17%
Calculated Firm Capacity and % below 1998-2000 average demand	8.59 MGD (19%)	3.24 MGD (45%)	8.38 (17%)
Calculated Firm Capacity increase with hypothetical low-flow pumping	+0.31	-0.17	+0.41

*The Peabody system was depleted approximately 25% of the entire simulation time.

- Management alternatives analyzed included adding variable pumping rate pumps with lower pumping rates to each system, creating alternative minimum streamflow thresholds, and allowing withdrawal rates above the firm yield (only limited by streamflow thresholds) during years when that can be attained with the understanding that storage would be depleted leaving the reservoir system more susceptible to failure under conditions of successive droughts where storage is not replenished.
    - The use of lower pumping rate pumps would allow the systems to withdraw water more slowly, enabling withdrawal to continue during lower river flows without withdrawals violating the minimum streamflow threshold.
    - The calculated firm yields for all systems were slightly less sensitive to changes in the spring streamflow threshold value than to the fall/winter threshold.
- The study found that persistent, multi-year droughts pose the greatest risk of system failure, however systems are also vulnerable to short-term droughts during the fall and winter. Low storage in the spring leads to higher risk later in the year.

Effects of Low-Impact-Development Practices on Streamflow, Runoff Quality and Runoff Quantity in the Ipswich River Basin (2010)

USGS, in cooperation with Massachusetts DCR, studied several low impact development (LID) practices in the Ipswich River Watershed between 2005 and 2010. The study included *in situ* experimental installations of LID practices in Wilmington, the results of which were extrapolated to the broader watershed through simulation in the HSPF model described above. Key findings from the study include:

- The following LID practices were evaluated for their impacts on the quality and quantity of surface water runoff and groundwater:

    - Replacing a traditional parking lot with porous pavement: Enhanced infiltration at this installation did not lead to increased nutrient, metals, or petroleum-hydrocarbon concentration in the effluent groundwater.
    - Installing 12 rain gardens and porous pavement throughout a 3-acre neighborhood: No change in water quality parameters were observed. Surface runoff decreased during small storms (<0.25 inches of rain), but no change in runoff ratio was observed during larger rain events.
    - Installing a 3,000ft^2 green roof: More than 50% of precipitation was retained by the roof in storms with an antecedent dry period greater than 70 hours (49 of 70 storms during the study). The total amount of roof-related chemicals decreased, but due to the lower volume of runoff this resulted in higher concentrations.

- New baseline conditions for the HSPF model were established as well as new buildout potential scenarios with LID implementation at multiple scales. LID implementation was reflected in the model via changes in land use parameters. Water conservation pilot-program based withdrawal reductions were also evaluated.
- Modeled impacts of LID implementation on streamflow was limited at the major basin scale by the relatively low prevalence of impervious landcover types throughout the watershed. In most subbasins, the amount of existing impervious area was too low to appreciably increase streamflow even when LID implementation was modeled as reducing the effective impervious area by 50%.
- LID implementation may increase streamflow at a local scale in small subbasins with higher proportions of impervious cover. The impacts are greater when LID practices can capture runoff from relatively large impervious areas and minimize the direct conveyance of runoff to watercourses, thereby increasing aquifer recharge.
- Water conservation pilot projects were included in the study, such as the implementation of "smart" irrigation controllers on municipal athletic fields, soil amendments to improve water retention at athletic fields, use of rainwater collection systems for irrigation water, and offering free residential water-use audits, retrofits, and rebates for low-flow appliances. The effects of widespread implementation of these water-conservation pilot projects yielded a similarly minor impact on streamflows at a basin scale.

Factors Influencing Riverine Fish Assemblages in Massachusetts (Armstrong et al, 2011)

In this so-called "Fish and Flow" study, USGS, in conjunction with MADCR, MADEP, and MA Fish and Game, studied the relationships between fish-assemblage characteristics, anthropogenic factors such as impervious cover and flow alterations, and environmental factors such as physical basin structure and land use in small to medium streams throughout the Commonwealth. Key findings from the study include:

- Data on local habitats (stream width, substrate, stream velocity, water depth, and stream temperature) and data on mesohabitats (number, quality, and sequencing of riffles, runs, and pools) were not available for analysis. Local channel slope, strongly related to velocity, was estimated using GIS for each fish sampling site.
- Percent flow alteration was determined to be a significant variable impacting fish assemblages.
    - As many as 7 fluvial fish species are expected in streams with little flow alteration or impervious cover.
    - No more than 4 fluvial fish species are expected in streams where flow alterations from groundwater withdrawals exceed 50% of the August median or the percent area of impervious cover exceeds 15%.
    - As rates of withdrawal approach 100%, few fluvial fish remain.
- An increase in the estimated percent alteration of August median flow from groundwater withdrawals from 0 to 14% is associated with a loss of roughly 1 fluvial species.
- Keeping all other variables the same, a 1% increase in the percent alteration of August median streamflow from groundwater withdrawals indicator is associated with a 0.9% decrease in relative abundance of fluvial fish, with the 95% confidence interval indicating the decrease is between 0.1 and 1.7%.

Ipswich Basin Water Management Act Planning Grant Study for Fiscal Year (FY) 2017

Six community water suppliers in the Ipswich River Basin (Danvers, Middleton, Hamilton, Lynnfield Center Water District, Topsfield, and Wenham), the Massachusetts Waterworks Association, and Kleinfelder conducted a study to evaluate contemporary and future challenges facing municipal water suppliers in the Basin and identify solutions. Key findings from the study, as reported by Kleinfelder, include:

- The mean annual streamflow at USGS gauging stations is 68 cubic feet per second just below the South Middleton Dam and 194 cubic feet per second just below the Willowdale Dam.
- Evapotranspiration within the Ipswich Basin is seasonal, averaging 24 million gallons per day in December and 352 million gallons per day in July.
- Over 95% of total authorized withdrawals in the Ipswich Basin are from municipal water suppliers.
- On average, water suppliers in the Ipswich Basin meet water conservation standards.
- Due to hydrologic constraints, municipal groundwater suppliers in the Ipswich Basin are unable to implement advanced strategies to minimize environmental impact (e.g. no access to surface supply storage to moderate the use of wells during the summer).

- Modeling by Zarrielo and Ries suggests that benefit gained by enacting restrictions on groundwater withdrawals may be offset by an increase in evapotranspiration caused by climate change.
- Expansion of regional water supplies and surface water supply options should be explored.
- Alternative water sources preliminarily identified, and their feasibility rating, were:
  - New local groundwater sources – Poor feasibility.
  - Constructing a new reservoir – Poor feasibility.
  - Reclaiming water – Poor feasibility.
  - Elevating existing reservoirs – Fair to poor feasibility.
  - Municipal interconnections – Fair to good feasibility.
  - Connection to the Massachusetts Water Resources Authority – Fair to good feasibility.
- Potential stormwater recharge improvement techniques and their limitations are:
  - Permeable paving – Clogging must be prevented.
  - Rain gardens/bioretention cells – Requires careful landscaping.
  - Roof drywells – Best for residential roofs.
  - Leaching catch basins – Best if deep sumps are provided for pre-treatment.
  - Infiltration basins or trenches – Requires frequent maintenance.
  - Subsurface structures – Not suitable for all soils and must be designed to prevent clogging.
  - Artificial recharge/injection well – Pre-treatment required to avoid groundwater contamination.

Ipswich Basin Water Management Act Planning Grant Study for FY 2018

This report builds on the FY 2017 Planning Grant Study by developing an Integrated Operational Model to further examine options for water management within and water importation to the Ipswich Basin. Key findings from the study, as reported by Kleinfelder, include:

- The four types of alternative management scenarios discussed were:
  - Increased storage throughout the basin;
  - Demand reduction;
  - Sharing of water between communities within authorized volumes; and
  - Importing water.
- There is a lack of available suitable aquifers in undeveloped areas away from headwater streams, which has led to very limited success by municipal suppliers in identifying new groundwater sources.
- A year-round demand reduction of 10% would result in a 1-2% improvement in supply reliability.
- The potential for water shortfalls is greatest in communities without storage.

- In general, the Ipswich Basin has enough water to satisfy all authorized needs, but the water is not always in the right place at the right time.
- Augmenting their supplies with imported water from the MWRA system could provide sufficient amount of water for Danvers, Lynnfield Center, and Topsfield. Extensive documentation is required to be admitted to the MWRA system.
- While it would require regulatory consent and additional infrastructure, one potential opportunity would be for two or more communities to form a regional partnership in which the total authorized withdrawals are pooled, and water could be transported from where it is available to where it is needed without exceeding the maximum withdrawal amounts.

Drought Management Plan Update, Town of Danvers, Massachusetts, July 2019

Following the FY 2017 and FY 2018 planning grant studies, Kleinfelder continued their technical support for the Town of Danvers (which also provides water to Middleton), by preparing a drought management plan (DMP) for the Town. This Water Management Act FY 2019 Grant project's purpose was to compile and review the past 18 years of demand (hydrologic and operational), consider climate change and demand projects, and update the Drought Management Plan. Key findings from the study, as reported by Kleinfelder, include:

- The Town of Danvers has a drought management plan, circa 2000, that was developed in response to the need to rely on outside water purchases during drought years. When necessary, during drought conditions, the town has purchased water from Salem Beverly Supply Board.
- The study compared data prior to the DMP (1980-1999) to post-DMP (2000-2018), such as:
    - Demand remained relatively consistent (3 – 3.5 MGD) despite increased population in the towns, likely due to successful conservation efforts and operational efficiency improvements.
    - Rainfall increased by five inches, resulting in increased streamflow of the Ipswich River. The post-DMP period saw a higher overall streamflow rate and less frequent summer low flow conditions.
    - The Middleton Pond reservoir has drawn down further in the winter and maintains more capacity into late summer and fall months.
- The study assessed the applicability of drought stage trigger levels on current and future demand in the Towns. These trigger levels (based on the Middleton Pond Reservoir height) had been established as of the 2000 DMP.
    - A frequency analysis of the drought stage trigger levels indicates that those triggers are relatively stable and are suitable for the supply and demand of the towns.

- The report translated the reservoir elevation triggers into remaining “days of supply” to determine if these triggers allow for sufficient protection of remaining supply in the reservoir.
- Estimated future demand increases of 8% and 15% were assessed. Under these conditions the triggers remained sufficient. Trigger stages may need to be re-evaluated if demand increases exceed 15%.

- The DMP was evaluated for resiliency against climate change.
  - Available climate change predictions suggest that short-term droughts would likely occur more frequently, increasing the frequency of drought triggers. Severe and emergency drought stages were predicted to be in effect 13-14% of the time.
  - Climate predictions suggest that warmer winter and spring temperatures will melt snow earlier, resulting in higher spring flows in the Ipswich River.
  - Existing drought stage triggers are sufficient throughout the year under predicted climatic conditions.

- Additional recommendations included maximizing the current use of existing wells within the limits of the WMA and to explore alternative sources, which may be limited in the future.
- The DMP was updated with the following:
  - Drought responses were updated to reflect outdoor water conservation requirements of the 2006 WMP permit.
  - Roles and responsibilities of staff, public info and outreach, and contact lists were updated to reflect the times.
  - Ipswich flow triggers were updated to reflect the increase in streamflow.

Below WMA-threshold Study for the Ipswich River and Parker River Basins (MassDEP, 2018 and amended in 2019)

MassDEP conducted a study to inventory all water supply sources in the Ipswich and Parker River Basins that withdraw less than 100,000 gpd, and thus are not regulated by the WMA. Key findings from the study include:

- The WMA regulates withdrawals for all entities that withdraw at least 9 million gallons over a 90-day period through registrations and/or permits.
- Sources in the withdrawal inventory included residential wells (drinking water, irrigation, both), wells and surface water sources used for irrigation at large private properties (agriculture, golf courses, housing complexes, retail, industry, non-profit properties), municipal irrigation sources, and water supply sources at commercial and industrial facilities with high water use (concrete batching, car washes, playing fields, etc.).
- WMA withdrawals represent approximately 95% of the total annual withdrawals within Ipswich Basin and approximately 80% of total annual withdrawals within the Parker

Basin. For withdrawals not regulated by the WMA, nonessential outdoor water use is limited.

- Municipal records, municipal Public Water Supply (PWS) boundaries, USGS Data, MassDEP SearchWell database, GIS layers, Annual Statistical Reports (ASRs), and visual observations were utilized in the final calculations and inventory.
    - Estimates were included for both inside and outside municipal PWS boundaries.
    - Independent withdrawals inside municipal PWS boundaries are primarily wells for irrigation.
- The study concluded that a majority of water withdrawals inside of PWS boundaries are for irrigation while those outside of PWS boundaries are for both potable and non-potable uses.

Minimization Plan, Town of Danvers, Massachusetts, 2019

The Town of Danvers was tasked to develop a minimization plan for the impacts of groundwater withdrawal on the Ipswich Basin as a result of the revised 2014 WMA regulations and the renewal of the Towns WMA permit. The goal was to modify well withdrawals to minimize impacts on streamflow while still meeting system demands. Key findings, as reported in the study include:

- The evaluation included a desktop review of existing source optimization, an assessment of potential alternative sources as well as the feasibility, impact, and cost of each, an assessment of surface water releases, and an assessment of additional water conservation measures.
- The SWMI framework was used to balance water supply needs with impacts on streamflow by minimizing groundwater depletion.
    - Danvers' groundwater sources are already constrained by the streamflow maintenance requirement of the existing WMA permit. Therefore, the study opined that further modification of existing well withdrawals to minimize impacts is not considered feasible.
    - Availability of water from the Town of Danvers' wells has varied due to yield and water quality impacts. Wells have needed replacement or improvement to restore yields. One wellsite has been taken offline due to PFAS contamination.
- Operational changes, such as changes in pump capacity or reservoir holding time, and reservoir elevation increases (e.g. increased storage capacity) were modeled under current and predicted future demand scenarios using an updated version of the HSPF model developed for the Ipswich River Watershed.
    - Well pumping rates at Well 1 were below their permitted capacity due to technical constraints such as plugging. Additionally, PFAS was present in Well 1 above the proposed MassDEP health advisory level.

  - Part 1 of this modeling assumed Danvers' existing wells were utilized at the full limit of their existing WMA Permit annual average withdrawal limits. Under this scenario, the existing reservoir system is currently optimized given its physical and hydrologic constraints.
  - Increased reservoir capacity could provide full resiliency to historic drought conditions under current demand by raising the elevation of the Emerson and Middleton Pond Reservoirs by 2 and 5 feet respectively, though a 15% increase in demand would negate this positive impact and water would still need to be purchased during periods of drought.
  - Part 2 of the modeling assumed pumping Danvers' existing wells at current, limited yields. With limited well production, the elevation of Middleton Pond Reservoir would need to be increased by 8 feet in order to provide drought resiliency. The results of this modeling scenario emphasize the inflexibility within the current system, the importance of the wells for meeting demand, and the importance of demand management to the system's resilience.

- Alternatives were considered to minimize withdrawals, including:
  - <u>A new Ipswich basin groundwater source in the North Coastal Basin:</u> Several Ipswich River subbasins in Middleton are under 25% net groundwater depletion, with very low amounts of additional withdrawal available without increasing the groundwater depletion category under the SWMI tier 3 requirements. In subbasins where additional withdrawal would not change the groundwater depletion category, poor hydrogeologic conditions limit the feasibility of an additional groundwater source. A new source may be feasible in a potentially productive aquifer in the North Coastal Basin in Danvers. Development of this source would not trigger the Interbasin Transfer Act, since this well would not increase supply capacity and water would not be delivered across town lines, but any additional groundwater withdrawal (if hydrogeologically feasible) in the subbasin would trigger Tier 3 new source approval of a groundwater source under the WMA.
  - <u>Purchase water from interconnections with other suppliers outside of the Basin:</u> Hydraulic modeling, conceptual design, and cost estimate analyses would be required to fully assess the feasibility of this alternative. In the meantime, the continued purchasing from Salem-Beverly is likely to continue to occur despite high costs.
  - <u>Purchase water from direct connections with MWRA:</u> This alternative may only be affordable as part of a larger regional project with cost-sharing.
  - <u>Increasing the height of the Middleton Pond Reservoir:</u> There may only be an incremental benefit but at a high cost. Therefore, this was deemed unlikely to be feasible.

    - Per WMA Guidance, determine if reservoir releases can improve timing, magnitude, and duration of downstream flows: Modeling in the study determined that the current reservoir and production configuration is currently well optimized and operational changes cannot significantly improve streamflow conditions.
    - Opportunities to return water via infiltration, recharge, or wastewater discharge:
        - Wastewater discharge: Danvers is 95% served by sewer, and Middleton is unsewered. All new development is expected to be served by on-site septic. Existing and future septic returns in Middleton are feasible returns.
        - Infiltration/Inflow improvements: Danvers has an improvement plan which includes infiltration removal in selected sewer subareas.
        - Small scale recharge efforts may yield marginal improvements but are not likely to provide much benefit relative to their costs.
- According to the report, the Town's existing water supplies have little to no flexibility for modification for minimization purposes and current efforts have been effective for minimizing impacts on the Ipswich River.

MassDEP WMA Program Water Use Data

The database comprising the WMA Permitting Tool (release date 11/26/2018) was downloaded and assessed. Data from this tool will be incorporated in the modeling effort in Task 2. Characteristics of the subbasins within the IRW were exported from the database for inclusion in the model. Key characteristics include the area and percent impervious cover of the subbasin, septic system and other groundwater discharges, surface water discharges (NPDES), PWS and commercial well withdrawal volumes, private well withdrawal volumes, and unaffected streamflow.

Data from the WMA tool were extracted and compiled to populate Table 1 (attached) which summarizes the current WMA-regulated, water withdrawal landscape in the watershed by subbasin.

Supplemental Literature Review

Massachusetts Sustainable-Yield Estimator: A decision-support tool to assess water availability at ungaged stream locations in Massachusetts (SIR 2009-5227)

The Massachusetts Sustainable Yield Estimator Tool (MA SYE) was developed by the USGS in conjunction with MassDEP and released in 2009. The MA SYE tool provides screening/planning level estimates of unregulated streamflow in ungaged basins throughout the Commonwealth, adjusted for ground and surface water withdrawals and discharges in those basins. Key findings from the study include:

- Groundwater withdrawals and discharges can be modified using the STRMDEPL analytical program to reflect variations in magnitude and timing caused by aquifer properties at the withdrawal.
- Users of the MA SYE tool can manipulate withdrawal and discharge quantities and timing, the time period of analysis, or flow targets to assess the impacts of different water management scenarios on the sustainable yield of a basin, where the sustainable yield is defined as the difference in volume of water required to meet flow targets and the unregulated flow to the stream.
- The MA SYE tool couples physically based flow duration curve estimates, calculated based on characteristics of the ungaged target basin, with historical streamflow records from a reference locations in order to estimate daily flow. The characteristics needed to parameterize a basin's response can be found using StreamStats.
- Since the SYE flow estimate relies on comparisons to data from reference gaging stations, the MA SYE tool can only be used to estimate historical flows, specifically for the period of October 1, 1960, through September 30, 2004.

The process by which the MA SYE tool estimates unregulated streamflow in an ungaged basin is as follows:

1. Physical and climate characteristics of the basin are used to calculate quantiles of streamflow at six primary exceedance probabilities.
2. Eleven additional exceedance probabilities are calculated by the use of more detailed regression analyses.
3. These exceedance probabilities are interpolated log-linearly to produce a continuous daily flow duration curve for the basin.
4. A reference stream gage is selected based on the estimated Pearson R correlation coefficient between logarithms of streamflows at the ungaged stream and reference stream gages throughout the state. The estimated correlation coefficient is selected based on the location of the ungaged stream, compared to maps of coefficient values determined by correlating the streamflows of all reference stream gages used in the SYE tool. Flows at the reference stream gage are used to estimate flows at the ungaged basin based on their respective FDC curves.

Massachusetts Sustainable Water Management Initiative Framework Study (November 28, 2012)

The Sustainable Water Management Initiative (SWMI) was created under the Massachusetts Executive Office and Environmental Affairs (EEA) with Advisory and Technical subcommittees to advise EEA on sustainable water management practices to balance human and ecological needs. SWMI developed a framework to guide MassDEP's permitting process for new water withdrawals under the WMA. SWMI was partly informed by the SYE, Fish and Flow study, and other studies discussed here in this memorandum. Key findings from the SWMI study include:

- The SWMI framework establishes a Safe Yield for major basins which incorporates environmental protection and hydrologic factors. The Safe Yield is defined as 55% of Drought Basin Yield plus reservoir storage. A 55% factor was determined based on findings from the USGS Fish and Flow study (Armstrong et al, 2011) which found alterations greater than 25% of the August median flow caused significant impacts. A study of August median flows in basins throughout the Commonwealth determined that 25% of the August median flow was approximately equal to 60% of the 90th percentile flows (Drought Basin Yield). Inclusion of a safety factor yields the 55% threshold.
    - Reservoir storage for the calculation of safe yield is only included for those reservoirs of a capacity greater than one year's flow in the river (Chicopee, Nashua, Westfield, Narragansett, Quinebaug, Boston Harbor, Charles, and Housatonic).
- Streamflow criteria were established for biological, groundwater withdrawal, and seasonal criteria.
    - Biological categories were established based on an assumed linear reduction relationship between fish abundance and basin characteristics (flow, impervious cover, drainage area, channel slope, and percent sand and gravel) established by Armstrong et al (2011, Factors Influencing Riverine Fish Assemblages in Massachusetts, summarized above). This model defined alterations to flow that resulted in decreases in fish abundance.
    - Groundwater withdrawal criteria assume a 1:1 relationship between withdrawal and reduction in streamflow. Thresholds were established at the same flow volume alterations which caused the basin to change from one biological category to the next.
    - Seasonal criteria adjust the withdrawal categories (established for August median streamflows) for other times of the year, based on the assumptions that high summer demand and low flow results in the highest streamflow alteration.
- Baseline in the SWMI framework is the condition against which future withdrawal requests are compared. The proposed baseline condition was the higher of 2003-2005 average use, plus 5%. Baseline could not be lower than the registered volume, must comply with permitted volume, and cannot be more than the volume for 20 years of new water needs as forecasted by the agencies.
- The SWMI framework is applied to permitting under the WMA to protect habitat quality by incorporating impacts as changes to the biological and groundwater withdrawal categories. Different permit requirements are applied to utilities withdrawing from waters in different categories.

IRWS critique of DEP below WMA Threshold

Ipswich River Watershed Association issued a critique in response to MassDEP's Below WMA Threshold Water Withdrawal Inventory. Key points from the critique include:

- The assessment focuses solely on the withdrawals in the Ipswich Basin. The IWRA made no conclusions about the Parker River Watershed, which is also a part of the MassDEP study.
- IRWA deemed there were several data gaps and flawed assumptions, such as:
  - Well installations prior to the year 2000 were not (for the most part) included. Prior to 2000, municipalities generally did not require permits for well installation, and therefore, IRWA was concerned that DEP's database likely does not include estimates for the numerous pre-2000 wells.
  - The study assumed that irrigators accounted for rainfall and adjusted accordingly, which may not be accurate.
  - Based on these factors, IRWA determined the study underestimates the total volume of withdrawals.
  - Study did not consider withdrawals from wells inside the PWS service areas and therefore missed some large-scale withdrawals.
  - Water leaks or other unaccounted for water use was not considered.
  - Timing, location, and/or method of withdrawals were not taken into account for the impact on withdrawals.

- IRWA adjusted the DEP inventory to address these data gaps. Based on the IRWA-adjusted data, below threshold withdrawals exceed 4 MGD, are growing, and likely will continue to grow, largely due to their exempt status. These conclusions are in contrast to those found by MassDEP. IRWA requested that the study and DEP amend the report to address the identified concerns.
- IRWA recommendations included:
  - MassDEP should review and lower the 100,000 GPD threshold in stressed basins like Ipswich.
  - MassDEP should de-incentivize below threshold withdrawals in order to reduce impact.
    - Incentives will only increase in the future as Towns try to stay within their permits and registered volumes.
  - MassDEP should apply conservation measures in stressed basins like Ipswich.
  - MassDEP should reconsider below threshold withdrawal volumes for Safe Yield and WMA permit decisions.
  - Total WMA-registered (not WMA-permitted) and below-threshold withdrawals represent approximately 90% of total withdrawals.
  - In order for MassDEP to meet the requirements of the WMA they should condition registrations and bring more of the below threshold withdrawals under the regulatory umbrella in the Ipswich Basin.

STRMDEPL08—An Extended Version of STRMDEPL with Additional Analytical Solutions to Calculate Streamflow Depletion by Nearby Pumping Wells

This USGS report discussed STRMDEPL, a one-dimensional model that uses two analytical solutions to calculate streamflow depletion by a nearby pumping well. The extended program is named STRMDEPL08. The original program incorporated solutions for a stream that fully penetrates the aquifer with and without streambed resistance to groundwater flow. The modified program includes solutions for a partially penetrating stream with streambed resistance and for a stream in an aquitard exposed to pumping from an underlying leaky aquifer. This tool is used in both the HSPF model and SYE.

Methods Used to Estimate Daily Streamflow and Water availability in the Massachusetts Sustainable-Yield Estimator Version 2.0 (SIR 2018-5146)

The Massachusetts Sustainable Yield Estimator Tool (MA SYE) is a decision support tool developed by the USGS in conjunction with MassDEP and originally released in 2009. The MA SYE tool provides screening/planning level estimates of unregulated streamflow in ungaged basins throughout the Commonwealth, adjusted for ground and surface water withdrawals and discharges in those basins. This 2018 report describes an updated Version 2.0 of the SYE that includes refinements made to the previously published methods to estimate unaltered and water-use-adjusted stream flow. Most significant for this current IRW study is the fact that the SYE Version 2.0 now uses streamflow response coefficients (SYE v 1.0 used the USGS STRMDEPL program) to estimate the lag time between groundwater withdrawals and streamflow impacts.

- The report states that "Because of the potential for STRMDEPL to provide unreliable groundwater alteration estimates, the method to estimate the time-lagged streamflow alteration from ground-water withdrawals in the MA SYE v2 has been updated to use algorithms developed for the U.S. Geological Survey Hydrologic Drought Decision Support System (HyDroDSS; Granato, 2014). Monthly groundwater response coefficients range from 0.0 to 1.0 and proportion each monthly water-use volume to the month of pumping and the 11 following months. For example, a response coefficient of 1.0 in the first month of pumping indicates that streamflow depletion in that month is equal to the volume of pumping. A response coefficient of 0.5 in the first month indicates that streamflow depletion in the first month of pumping is only 50 percent of the pumping volume for that month and that the rest of the pumping volume would cause depletions in subsequent months."

- Because the effects of pumping may persist for several months after pumping, the streamflow depletion for a given month is equal to the depletions caused by the current month's pumping plus the continuing effects of the previous 11 months of pumping.

- Response-coefficient values were compiled from the results of calibrated three-dimensional modular finite-difference groundwater-flow models for 108 groundwater sites documented in seven USGS modeling studies in Rhode Island and central and eastern Massachusetts. The 12-month response-coefficient patterns were selected for each groundwater withdrawal or return flow site on the basis of the distance and diffusivity of each site. Groundwater sites that are close to a stream in high-transmissivity aquifers have a rapid altered-flow response. Sites that are distant from the stream or sites in low transmissivity aquifers have a slow altered-flow response. The 108 groundwater sites were classified into groups with similar transmissivities and stream distances, and average response coefficients from many wells were used to identify depletion patterns and select monthly response-coefficient values for each group.

Hydrologic Drought Decisions Support System (HyDroDSS) (Gregory E. Granato, 2014)

The hydrologic drought decision support system was developed by the USGS in cooperation with the Rhode Island Water Resources Board for use in the analysis of hydrologic variables that may indicate the risk for streamflows to be below user defined flow targets and may be adversely affected by pumping. The purpose of HyDroDSS is to provide water managers with some insight on balancing water-supply needs and aquatic-habitat protection goals to mitigate potential effects of hydrologic drought. This document was added to the literature review since it provides a more detailed overview of the response coefficient methodology that was used in the SYE v2. Streamflow-depletion response coefficients are defined as the dimensionless ratio of monthly depletion to unit withdrawals.

This ratio can be applied as an analytical solution to develop response coefficients if a numerical model is unavailable. A case study was discussed in which response coefficients were estimated for seven production wells and one industrial well in the Hunt River Basin in Rhode Island a numerical groundwater model developed for the Annaquatucket and Pettaquamscutt stream-aquifer system area. The well closest to the stream had the quickest response to pumping because of proximity to the stream and local aquifer conditions. The farthest in distance had the slowest response to pumping. The response coefficients for all the other wells are slightly less than 1, with an average of about 0.985. In all cases, the pumping wells were located in relatively close proximity to surface water.

Simulation of Ground-Water Flow and Evaluation of Water-Management Alternatives in the Upper Charles River Basin, Eastern Massachusetts- Leslie A. Desimone, Donald Walter, John Eggleston and Mark Nimiroski,2002

This study was conducted to develop tools for evaluating water-management alternatives in the Upper Charles River basin. Geologic and hydrologic data were compiled and characterized the groundwater and surface water systems. A numerical groundwater model was developed for the basin and applied to evaluate the effects of increased withdrawals and altered recharge on groundwater levels, pond levels, and stream base flow. The management model that was developed was linked to the numerical groundwater model through a matrix of response coefficients. This document was added to the literature review because of the use of response coefficients for a basin within Massachusetts. The response coefficients for streamflow depletion at downstream observation points from pumping wells generally ranged from 0.79 to 0.98.

City of Peabody Integrated Reservoir Model: Coupling Quantity, Conservation, and Habitat (Weston & Sampson, 2023)

In 2022, after each of the City of Peabody's three terminal reservoirs approached or reached their failure level, the City contracted Weston & Sampson to develop an Integrated Reservoir Model to assist in proactively making water supply decisions and to ensure the long-term resilience of their public water supply. The City's water supply system consists predominantly of a series of surface water reservoirs, some of which are filled in part from the Ipswich River. This study not only developed a multi-reservoir model but also evaluated the vulnerability of each of Peabody's terminal reservoirs to climate change, demand increases, and potential future changes to their Ipswich River withdrawal permit with regard to minimum flow requirements. The model was also incorporated into a web-based application that allows the City to simulate the likelihood of failure in any of their three terminal reservoirs under a "Business-as-Usual" approach as well as six alternative reservoir management scenarios, including inter-reservoir transfers, increased regional purchases, and increased water use restrictions. Key findings of the study include:

- Climate change-driven increases in evapotranspiration and seasonal increases and decreases in precipitation were not predicted to significantly alter reservoir vulnerability.
- An evaluation of long-term trends in Ipswich River streamflow since 1970, evaluated on a monthly basis, indicated that climate change-driven changes in streamflow regime were unlikely to significantly impact the City's ability to fill their reservoirs, in part, from the Ipswich River, and as a result the vulnerability of their reservoir system.
- Model simulations indicate that if the minimum flow requirements were adjusted as part of future permitting of the City's Ipswich River withdrawal, those changes would be unlikely to significantly impact their reservoirs' likelihood of failure.
- Peabody's reservoir system is somewhat divided into two sub-systems, one of which is significantly more vulnerable to failure than the other, particularly during multi-drought periods.
- The study identified a number of capital improvement projects and operational changes that could improve the resilience of the City's reservoir system. More detailed analyses and permits may be required to implement those changes.

Current WMA Withdrawals Landscape

In order to better visualize the overall WMA-regulated water withdrawal landscape in the IRW, Table 1 lists all of those WMA-regulated withdrawals by sub-basin, permitted or registered volume, and type. For further reference, Figures 1-3 visually map the various IRW withdrawals by sub-basin with different SWMI-related categorizations shown. Figure 1 depicts the SWMI Groundwater Categories (GWC) for each sub-basin, which are informed by the percent alteration of estimated, unimpacted, August flows (estimated by the USGS SYE) based solely on groundwater withdrawals, referred to in the SWMI context as “August Flow Alteration”. GWC 1 is the least impacted at less than 3% and GWC 5 is the most impacted at 55% or greater. Figure 2 depicts sub-basins not by their GWC but by their underlying percent August Flow Alteration. Figure 3 depicts the “August Net Flow Depletion”, which incorporates wastewater inputs that may partially offset groundwater withdrawals, and then divides that quantity by the estimated, unimpacted August flows.

Comparing the three figures one against the other in sequence provides a bit more of a nuanced look into the data underlying the SWMI GWC categorizations and a fuller picture of the variability of flow impacts amongst the sub-basins. The Figure 1 GWC is the same visual output as can be obtained using the SWMI online viewer where all sub-basins are simply divided into 5 bins of groundwater withdrawal-based flow impacts. Figure 2 uses the same underlying data as Figure 1 but, instead of dividing into 5 bins of relative impact, uses a more nuanced color spectrum of variable impact with the actual percent August flow alteration for each sub-basin shown.

On Figure 2 one can see that there is a broad range of percent August flow alterations amongst GWC-5 sub-basins. Some GWC 5 sub-basins are at or near the 55% threshold for GWC 5, while others (notably sub-basin 21004 at 278% August flow alteration) are far in excess of that threshold. Sub-basin 21004 has a percent August flow alteration approximately double the next closest sub-basin and approximately triple most of the other GWC 5 sub-basins. Similarly, some GWC 4 sub-basins’ percent August flow alteration are not far below the 55% cutoff for GWC-5. This same dynamic of sub-basins with different GWCs having relatively close percent August flow alterations plays out amongst the GWC breakouts between lower GWCs. This is not a criticism of the GWC breakouts. Dividing any dataset that exists along a continuum into bins always requires setting cutoff points somewhere. And, as the SWMI documentation describes, the selection of the percent August flow alterations that serve as GWC breakpoints was based on a scientific assessment of flow impacts relative to biological health categorization. The point of this discussion is simply to point out that some sub-basins within any GWC (and particularly GWC 5) have significantly more impact than others.

Comparing Figure 3 against Figure 2 is also illustrative. Figure 3 includes the offsetting impacts of wastewater discharges in the calculation of percent August flow alteration to arrive at what is termed as August Net Depletion. Figure 3 shows that wastewater discharges have a significant mitigation impact on flow alterations in many sub-basins. And, since the inclusion of wastewater discharges is a physical reality affecting the mass balance of water availability in any sub-basin, this Figure 3 August Net Depletion is, in the opinion of the authors of this memorandum, arguably a more pertinent metric for evaluating flow impacts than is the straight SWMI GWC. Figure 3 still depicts a number of sub-basins with an August Net Depletion well above the 55% GWC 5 threshold (and understanding that this is not a strictly accurate comparison to make between different metrics), but also shows that the overall percent August depletion is less for many sub-basins when comparing Figuring 2 to Figure 3. There are also a number of sub-basins that show up with negative percent alterations meaning that those sub-basins are actually surcharged with wastewater inputs exceeding groundwater withdrawals. This comparison of Figure 2 to Figure 3 highlights the general statements made in the Introduction section of this memorandum about the importance of wastewater exports out of the IRW in general, and sub-basins more specifically, relative to the locations of water withdrawals.

Summary

The Ipswich River was designated as one of the most endangered rivers in the United States by the organization American Rivers in 1997. Segments of the upper river have experienced extended low flow and dry conditions during summers for several decades. These low- or no-flow episodes harm riverine fish species and other native biota, hinder recreational opportunities on the river, and threaten water supplies for communities in the watershed which rely on surface flows to fill their reservoirs. The hydrologic challenges facing the Ipswich River Watershed have been known and studied for decades and include both natural and anthropogenic contributing factors.

Several natural, physical characteristics of the watershed are thought to contribute to its observed low flow regime, including:

- The relatively shallow nature and limited extent of the sand and gravel aquifers limit the overall groundwater recharge potential and groundwater storage capacity within the watershed. Limited groundwater storage in the watershed limits the capacity to supply sustained baseflow to the river during extended periods of low precipitation.
- The low-lying topography, high groundwater table, and significant area of wetlands favor a relatively high loss of water via evapotranspiration, further limiting the amount of water available for aquifer recharge and storage.

At the sub-basin level, the limitations impacting groundwater recharge and storage due to the physical characteristics described above are often magnified. As a result, the baseflow capacity at the sub-basin level can often be significantly less than is the case for the larger watershed.

As discussed in the 2022 Massachusetts Climate Change Assessment (Executive Office of Energy and Environmental Affairs, December 2022), climate change is predicted to cause longer periods of higher temperatures and changing precipitation patterns in the region, exacerbating the recharge limitations described above further impacting baseflow to the river.Wintertime precipitation is expected to increase significantly while summertime precipitation is expected to remain constant or decrease. The number of days of precipitation is expected to decrease overall. Less, frequent, higher intensity precipitation patterns will increase the amount of surface runoff in the region, especially over the winter. Decreased summertime precipitation, coupled with increased evapotranspiration due to increased temperatures, will likely exacerbate low flow conditions during the summer months. Though this project does not specifically assess the impacts of temperature and precipitation changes under climate change, these predications further emphasize the general need for a more sustainable and resilient water management framework for the Ipswich River basin.

The natural watershed characteristics contributing to low flow conditions are compounded by human influences in the watershed associated with the growing population in and around the watershed. The key human factors contributing to low flow include:

- Water withdrawn from the watershed serves a population significantly greater than the population who live in the watershed, creating a situation of significant net water export from the basin. Water delivered to communities with wastewater discharges outside of the watershed represents a significant increase of consumptive water use compared to a scenario without water export. Water used within the basin, when its non-consumptive portion is returned to the aquifer (e.g., septic system effluent), becomes available to contribute baseflow to the river. Water withdrawn from the IRW and discharged out of basin is completely lost.
- This same dynamic of net wastewater export also exists at the sub-basin scale for sub-basins with significant water withdrawals but limited population for wastewater return flow.
- The primary locations for large volume groundwater wells have been historically sited in close proximity to streams and rivers because the Basin's limited sand and gravel aquifers are situated primarily within river and stream valleys. Due to this proximity, flow impacts from well withdrawals happen with relatively short lag times.
- Many of these groundwater wells are located in sub-basins in the upper parts of the watershed with limited natural recharge capacity such that their impacts are proportionally greater. This can cause greater impacts at the sub-basin scale, which propagate and accumulate downstream to negatively impact all connected, downstream sub-basins.
- Reservoirs in the watershed are both "in-line" and "off-line". Off-line reservoirs in which river water is pumped or otherwise transferred to storage through flood skimming are effective tools for storing excess water harvested during high flow periods and minimizing stream impacts during low flow periods. However, in-line reservoirs that are essentially dammed portions of the river or its tributaries, retain back stream flow at all times of the year and, therefore, withdrawals from these in-line reservoirs represent net losses of available flow to the connected downstream river segments. To the extent that such in-line reservoirs can retain excess water during higher flow periods without decreasing outflow during lower flow periods, they can also provide effective water storage capacity while minimizing downstream flow impacts. Effective management of such in-line reservoirs to provide high flow storage while maintaining low flow throughflow can be complicated from an operational water management perspective.
- Impervious cover, while modest at the overall watershed scale, is a potentially significant source for lost aquifer recharge in certain sub-basins with a high percentage of effective impervious cover in close proximity to connected stream corridors.

As a result of the natural and anthropogenic factors cited above, 17 of the 31 sub-basins in the Ipswich Watershed are defined by MassDEP as SWMI GWC 4 or 5 (for significant flow impacts), and 12 are considered to be Net Groundwater Depleted.

As documented in this literature review, a growing body of scientific research has been conducted on the symptoms, causes, and potential solutions to the Ipswich River Watershed water budget problem. These studies have, collectively, contributed to an improved understanding of the natural and anthropogenic factors as they relate to the flow regime of the Ipswich River, even if debate still exists regarding the relative impact of one factor over another. To date, no effective solution or suite of solutions to the problem have progressed to the point where implementation is imminent.

In the opinion of the HW/ WSE technical Project team, conclusively ranking the importance of the various factors affecting flow in the IRW is not a necessary prerequisite to make meaningful progress towards evaluating potential improvements. This is true for several reasons:

- Natural, physical characteristics of the watershed (e.g., available sand and gravel aquifer storage capacity, wetlands area coverage and evapotranspiration, precipitation variability, etc.) are out of societal control (attempting to reduce climate change impacts not withstanding). As such, assessing the relative impact of natural versus anthropogenic factors has minimal bearing on the analysis of water management alternatives since the set of options available to improve flow conditions is limited to those factors which stakeholders have the ability to implement.
- Stormwater runoff from impervious cover is similarly difficult to address on a watershed scale. The amount of directly connected "effective" impervious cover is relatively low for the watershed as a whole, such that retrofitting existing stormwater management measures is unlikely to significantly improve flow conditions overall. And those subbasins with larger percentages of effective impervious area are also the most densely developed, with limited publicly owned land area available with opportunities for implementing effective green infrastructure stormwater management. While there may be potential for significant streamflow improvement to occur in some subbasins from stormwater management, the difficulty of implementing those stormwater management changes at a scale necessary to have significant impact would be high. There is still value in continuing to pursue stormwater management improvements, particularly with regards to water quality and future development. Those improvements, however, are likely less impactful on flow conditions on a basin wide scale compared to other alternatives.
- Flow impacts are already tracked on a subbasin scale using the SWMI framework for groundwater depletion and biological categories and they are an important component of the regulatory basis for decisions regarding WMA permitting. Therefore, the evaluation of how any particular water management strategy, or combination of strategies, may change the SWMI characterizations of specific subbasins is a valuable outcome from a regulatory perspective.

The modeling to be conducted for this Project aims to assess the cumulative impact of various alternative water management practices on the Ipswich River Watershed at a subbasin scale. The intent of this project is to use the existing SWMI framework and related tools (e.g., WMA Tool and the Sustainable Yield Estimator) to relatively assess the ability of selected water supply alternatives (to be determined by the Task Force) to positively improve the SWMI groundwater depletion characterization of various subbasins. Given that the groundwater depletion characterization is one of the more important factors considered for WMA permitting decisions, understanding which potential alternatives have greater relative impacts on groundwater depletion characterization than others will be helpful from both a regulatory perspective and a general physical perspective.

While a watershed-scale, numerical, groundwater model would more accurately estimate aquifer and streamflow dynamics and streamflow responses to water management alternatives than do any of the analytical modeling tools available, such a watershed-scale, numerical groundwater model for the Ipswich River watershed is not currently available. Regardless of the accuracy of the SWMI framework, or the relative significance of any one factor on stream flow, understanding the relative efficacy of the various potential water supply alternatives compared to each other is valuable. Only with this knowledge can other factors associated with each alternative (e.g., cost, difficulty for implementation, regulatory constraints, etc.) be viewed in holistic context to help the Task Force and watershed communities evaluate which alternatives may be more appropriate than others.

This literature review was conducted to support this overall goal for the Project water budget model. The background information and data reviewed here provide suitable material to perform the analytical water budget modeling to be conducted under Task 2 of this project.

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Table 1
Summary of WMA Withdrawals In Ipswich River Watershed

Horsley Witten Group
Sustainable Environmental Solutions

HUC 12 Name	Sub Basin	Water Features	Ground Water Category	Biological Category	Net GW Depletion	August Affected Flow	August Unaffected Flow	GW Withdrawals	WW Discharges	Town	System Name	Average MGY	Withdrawal Point	Registered/ Permitted	PointID	Source Type	Annual Average MGY (2000-2004)	Status
	Subbasin Characteristics									System Characteristics			Water Use Point Characteristics					
Howlett Brook	21009	Lower Pye Brook	4	5	28.301	0.751	1.047	0.497	0.200	TOPSFIELD	TOPSFIELD WATER DEPARTMENT	194.18	NORTH ST. TUB WELL	Reg/Perm	PWS-3298000-01G	GW	93.7006	ACTIVE
	21065	Upper Pye Brook, Ponds	3	4	3.364	0.729	0.755	0.152	0.127	No withdrawal points in these subbasins								
	21001	Lower Howlett Brook	4	5	18.970	1.169	1.443	0.520	0.246									
	21008	Upper Howlett Brook	2	4	-6.132	0.303	0.286	0.021	0.039									
Ipswich River-headwaters to Wills Brook	21013	Ipswich River between Martin and Norris Brooks	5	5	70.198	2.058	6.905	6.986	2.138	LYNNFIELD	LYNN WATER & SEWER COMMISSION	3068.19	IPSWICH RIVER	Reg/Perm	PWS-3163000-05S	SW	702.144	ACTIVE
										LYNNFIELD	LYNNFIELD CENTER WATER DISTRICT	186.15	MAIN STREET G.P. WELL	Reg	PWS-3164000-02G	GW	72.175	ACTIVE
										LYNNFIELD	SAGAMORE SPRING GOLF CLUB INC	35.04	WELL #1	Reg	WMA-81854-G	GW	#N/A	#N/A
													WELL #2	Reg	WMA-81855-G	GW	#N/A	#N/A
													WELL #3	Reg	WMA-81856-G	GW	#N/A	#N/A
													SAGAMORE SPRINGS #1	Reg	WMA-81857-S	SW	#N/A	#N/A
													SAGAMORE SPRING #2	Reg	WMA-81858-S	SW	#N/A	#N/A
										MIDDLETON	BOSTIK INC	3.65	GW 1	Reg	WMA-82386-G	GW	#N/A	#N/A
													GW 2	Reg	WMA-82387-G	GW	#N/A	#N/A
													GW 3	Reg	WMA-82388-G	GW	#N/A	#N/A
													GW 4	Reg	WMA-82389-G	GW	#N/A	#N/A
													SW 1	Reg	WMA-82390-S	SW	#N/A	#N/A
													SW 2	Reg	WMA-82391-S	SW	#N/A	#N/A
													SW 3	Reg	WMA-82392-S	SW	#N/A	#N/A
										NORTH READING	THOMSON COUNTRY CLUB	38.69	MID-IRON DRIVE POND	Reg/Perm	WMA-83334-S	SW	#N/A	#N/A
													INLET POND OFF IPSWICH R.	Reg/Perm	WMA-83335-S	SW	#N/A	#N/A
													SUTLIFF WELL	Reg/Perm	WMA-83336-G	GW	#N/A	#N/A
	21073	Martins Brook	5	5	112.139	-0.222	1.832	2.622	0.568	NORTH READING	NORTH READING WATER DEPARTMENT	477.42	CENTRAL ST. WELLFIELD	Reg/Perm	PWS-3213000-04G	GW	29.2902	ACTIVE
													ROUTE 125 WELL	Reg/Perm	PWS-3213000-05G	GW	39.284	ACTIVE
													RAILROAD BED WELLS	Reg/Perm	PWS-3213000-01G	GW	73.9122	ACTIVE
													LAKESIDE BLVD. WELL # 2	Reg/Perm	PWS-3213000-02G	GW	25.16232	ACTIVE
													LAKESIDE BLVD. WELL # 4	Reg/Perm	PWS-3213000-07G	GW	25.16232	ACTIVE
													LAKESIDE BLVD. WELL # 3	Reg/Perm	PWS-3213000-03G	GW	25.36232	ACTIVE
										WILMINGTON	WILMINGTON WATER & SEWER DEPARTMENT	848.26	SALEM ST. GP WELL	Reg/Perm	PWS-3342000-08G	GW	154.8138	ACTIVE
													BROWNS CROSSING WELLFIELD	Reg/Perm	PWS-3342000-01G	GW	270.7804	ACTIVE
													BARROWS WELLFIELD	Reg/Perm	PWS-3342000-02G	GW	188.604	ACTIVE
	21074	Ipswich River between Lubbers and Martin Brooks	5	5	79.928	0.623	3.106	3.683	1.200	NORTH READING	NORTH READING WATER DEPT.	477.42	STICKNEY WELL	Reg/Perm	PWS-3213000-06G	GW	0	INACT
										READING	MEADOW BROOK GOLF CLUB	61.32	GROVE STREET WELL	Reg	WMA-81810-G	GW	#N/A	#N/A
													MEADOW BROOK POND	Reg	WMA-81811-S	SW	#N/A	#N/A
										READING	READING DPW	529.98	WELL # 82 20	Reg	PWS-3246000-08G	GW	69.20852	ACTIVE
													TOWN FOREST	Reg	PWS-3246000-07G	GW	278.72392	ACTIVE
													WELL # 3	Reg	PWS-3246000-05G	GW	55.38098	ACTIVE
													WELL # 15	Reg	PWS-3246000-11G	GW	52.5459	ACTIVE
													WELL #2	Reg	PWS-3246000-04G	GW	118.63916	ACTIVE
													REVAY WELL # 1	Reg	PWS-3246000-03G	GW	15.89428	ACTIVE
													WELL # 13	Reg	PWS-3246000-10G	GW	37.50682	ACTIVE
													WELL # 66 8	Reg	PWS-3246000-09G	GW	23.38194	ACTIVE
													B LINE WELL	Reg	PWS-3246000-06G	GW	112.1671	ACTIVE
													REVAY WELL # 2	Reg	PWS-3246000-02G	GW	0	ABAND
	21076	Lubbers Brook	5	5	-5.747	0.727	0.688	0.434	0.474	WILMINGTON	WILMINGTON WATER & SEWER DEPARTMENT	848.26	SHAWSHEEN AVE. GP WELL	Reg/Perm	PWS-3342000-05G	GW	128.97738	ACTIVE
													ALDRICH RD. GP WELL	Reg/Perm	PWS-3342000-06G	GW	0	INACT
	21077	Mill , Sawmill, Maple Meadow Brooks (headwaters)	5	5	22.745	1.382	1.788	1.289	0.882	WILMINGTON	WILMINGTON WATER & SEWER DEPARTMENT	848.26	CHESTNUT ST WELL # 1A	Reg/Perm	PWS-3342000-10G	GW	103.67966	ACTIVE
													CHESTNUT ST. GP WELL	Reg/Perm	PWS-3342000-03G	GW	34.97394	ACTIVE
													BUTTERS ROW GP WELL #1	Reg/Perm	PWS-3342000-07G	GW	20.3386	ACTIVE
													BUTTERS ROW GP WELL #2	Reg/Perm	PWS-3342000-09G	GW	76.06716	ACTIVE
													TOWN PARK GP WELL	Reg/Perm	PWS-3342000-04G	GW	25.17272	ACTIVE
Ipswich River-Nichols Brook to mouth (continued on next page)	21002	Ipswich River between Salem-Beverly Canal and Howlett Brook	4	5	29.639	13.488	19.170	9.666	3.984	HAMILTON	HAMILTON WATER DEPARTMENT	194.18	PATTON G.P. WELL	Reg/Perm	PWS-3119000-03G	GW	14.337	ACTIVE
										TOPSFIELD	SALEM BEVERLY WATER SUPPLY BOARD	1060.69	IPSWICH RIVER	Reg/Perm	PWS-3030001-04S	SW	1482.42	ACTIVE
	21003	Mile Brook	5	5	101.747	-0.004	0.213	0.258	0.041	TOPSFIELD	TOPSFIELD WATER DEPARTMENT	194.18	PERKINS ROW TUB WELL	Reg/Perm	PWS-3298000-02G	GW	80.0884	ACTIVE
	21004	Idlewild Brook, Pleasant Pond	5	5	249.982	-0.502	0.335	0.933	0.096	HAMILTON	HAMILTON WATER DEPARTMENT	194.18	CAISSON WELLS	Reg/Perm	PWS-3119000-04G	GW	20.6057	ACTIVE
													IDLEWOOD #2 G.P. WELL	Reg/Perm	PWS-3119000-06G	GW	98.1773	ACTIVE
													IDLEWOOD #1 WELLS	Reg/Perm	PWS-3119000-05G	GW	28.6741	ACTIVE
													PLATEAU G.P. WELL	Reg/Perm	PWS-3119000-07G	GW	24.1029	ACTIVE
										WENHAM	WENHAM WATER DEPARTMENT	108.77	GP WELL # 2	Reg/Perm	PWS-3320000-02G	GW	64.1347	ACTIVE
													GP WELL # 1	Reg/Perm	PWS-3320000-01G	GW	64.1347	ACTIVE
	21006	Putnamville Reservoir, Salem-Beverly Canal	1	3	-14.039	0.586	0.514	0.011	0.084	DANVERS	SALEM BEVERLY WATER SUPPLY BOARD	1060.69	PUTNAMVILLE RES.	Reg/Perm	PWS-3030001-03S	SW	1142.04	ACTIVE
	21007	Gravelly Brook, Ipswich River between Howlett and Black Brooks	4	5	28.966	14.053	19.783	9.745	4.015	IPSWICH	IPSWICH WATER DEPARTMENT	255.5	WINTHROP GD WELL # 2	Reg	PWS-3144000-04G	GW	19.57898	ACTIVE
													WINTHROP GD WELL #3	Reg	PWS-3144000-05G	GW	4.00418	ACTIVE

Table 1
Summary of WMA Withdrawals In Ipswich River Watershed

Horsley Witten Group
Sustainable Environmental Solutions

	Subbasin Characteristics									System Characteristics			Water Use Point Characteristics					
HUC 12 Name	Sub Basin	Water Features	Ground Water Category	Biological Category	Net GW Depletion	August Affected Flow	August Unaffected Flow	GW Withdrawals	WW Discharges	Town	System Name	Average MGY	Withdrawal Point	Registered/ Permitted	PointID	Source Type	Annual Average MGY (2000-2004)	Status
Ipswich River-Nichols Brook to mouth (continued from previous page)	21031	Long Meadow Brook, Lower Miles River below Long Causeway Brook	3	4	-1.468	2.636	2.597	0.342	0.380	IPSWICH	IPSWICH WATER DEPARTMENT	255.5	ESSEX RD GP & GD WELLS	Reg	PWS-3144000-06G	GW	28.56164	ACTIVE
													FELLOWS RD. G.D. WELL	Reg	PWS-3144000-07G	GW	34.4465	ACTIVE
	21032	Upper Miles River, Wenham Lake, Longham Reservoir	1	4	-11.115	1.214	1.092	0.012	0.133	BEVERLY	SALEM BEVERLY WATER SUPPLY BOARD	1060.69	WENHAM LAKE	Reg/Perm	PWS-3030001-01S	SW	3703.019	ACTIVE
										WENHAM			LONGHAM RES.	Reg/Perm	PWS-3030001-02S	SW	840.92	ACTIVE
	21066	Main Ipswich River between Black Brook and Miles River	4	5	27.300	15.076	20.737	9.761	4.100	IPSWICH	IPSWICH WATER DEPARTMENT	255.5	WINTHROP GD #1 & TUBULAR WELLS	Reg	PWS-3144000-03G	GW	0.03508	ACTIVE
	21068	Middle Miles River	2	4	-10.015	2.291	2.082	0.142	0.351	HAMILTON	HAMILTON WATER DEPARTMENT	194.18	SCHOOL G.P. WELL	Reg/Perm	PWS-3119000-02G	GW	35.3432	ACTIVE
													BRIDGE ST. TUB & GP WELLS	Reg/Perm	PWS-3119000-01G	GW	0	INACT
										SOUTH HAMILTON	MYOPIA HUNT CLUB	35.04	MILES RIVER	Reg	WMA-82380-S	SW	#N/A	#N/A
	21217	Ipswich River below Miles River	4	5	22.879	18.908	24.517	10.106	4.497	IPSWICH	CORLISS BROTHERS INC	18.25	CORLISS POND	Reg	WMA-81470-S	SW	#N/A	#N/A
	21005	Ipswich River between Fish Brook and Salem-Beverly Canal	4	5	28.738	10.952	15.369	7.894	3.477	No withdawal points in subbasins								
	21067	Black Brook	1	3	-16.024	0.476	0.410	0.006	0.072									
Ipswich River-Wills Brook to Nichols Brook	21012	Norris Brook	1	5	-16.939	0.717	0.613	0.006	0.110	PEABODY	PEABODY WATER DEPARTMENT	2769.62	IPSWICH RIVER	Reg/Perm	PWS-3229000-03S	SW	1333.92	ACTIVE
													SUNTAUG LAKE	Reg/Perm	PWS-3229000-02S	SW	1019.58	ACTIVE
	21018	Middleton Pond, tributary	2	4	-20.009	0.421	0.351	0.026	0.096	MIDDLETON	DANVERS WATER DEPARTMENT	883.3	MIDDLETON POND RES.	Reg/Perm	PWS-3071000-01S	SW	1128.22	ACTIVE
										NORTH READING			SWAN POND RES.	Reg/Perm	PWS-3071000-02S	SW	25.94	ACTIVE
	21019	Ipswich River between Norris Brook and Middleton Pond tributary	5	5	59.418	3.349	8.251	7.290	2.388	DANVERS	DANVERS WATER DEPARTMENT	883.3	WELL # 2	Reg/Perm	PWS-3071000-02G	GW	44.94	ACTIVE
										MIDDLETON			WELL # 1	Reg/Perm	PWS-3071000-01G	GW	20.752	ACTIVE
													WELL #1NORTH REPLACEMENT	Reg/Perm	PWS-3071000-03G	GW	0	ACTIVE
													WELL #1SOUTH REPLACEMENT	Reg/Perm	PWS-3071000-04G	GW	0	ACTIVE
	21020	Emerson Brook and Ponds	3	4	-12.084	0.478	0.426	0.050	0.101	MIDDLETON	DANVERS WATER DEPARTMENT	883.3	EMERSON BROOK RES.	Reg/Perm	PWS-3071000-03S	SW	852.3	ACTIVE
	21071	Nichols Brook, Ipswich River between Boston Brook and Fish Brook	5	5	38.147	7.471	12.079	7.551	2.944	MIDDLETON	SHERATON FERNCROFT COUNTRY CLUB	24.82	SW 1	Reg	WMA-80653-S	SW	#N/A	#N/A
	21021	Ipswich River between Middleton Pond Tributary and Boston/Emerson Brooks	5	5	54.062	4.096	8.916	7.331	2.511	No withdawal points in subbasins								
	21069	Lower Boston Brook	3	4	-12.449	1.217	1.082	0.112	0.247									
	21072	Upper Boston Brook	2	4	-15.477	0.954	0.826	0.074	0.202									
Fish Brook	21070	Lower Fish Brook	3	4	-4.223	2.356	2.261	0.328	0.424	No withdawal points in subbasins								
	21041	Upper Fish Brook	3	4	-13.248	1.191	1.052	0.117	0.256									


USGS Stream Gauge
Public Water Supplies
Community Groundwater Source
Surface Water Intake
Non-Community Groundwater Source
Emergency Surface Water
MA DFW Coldwater Fisheries Resources
Ipswich River Course
Hydrography Linear
Perennial Stream
Intermittent Stream
Shoreline
Intermittent Shoreline
Manmade Shoreline
Ditch/Canal
Aqueduct
Dam
Channel in Water
Hydrography Polygon
Pond, Lake, Ocean
Reservoir
Wetland
Salt Wetland
Submerged Wetland
Cranberry Bog
Tidal Flat
Inundated Area
SWMI Sub-Basins
Groundwater Withdrawal Category (GWC)
GWC 1 (Least Impacted)
GWC 2
GWC 3
GWC 4
GWC 5 (Most Impacted)
N
0.75 0 0.75
Miles
datasource: Groundwater Withdrawal Category (GWC) August 2013 data
FIGURE 1
IPSWICH RIVER WATERSHED ASSOCIATION
SWMI GROUNDWATER WITHDRAWAL CATEGORY
NOVEMBER 2023
SCALE: NOTED
Weston & Sampson

FIGURE 2

IPSWICH RIVER WATERSHED ASSOCIATION

AUGUST FLOW ALTERATION

NOVEMBER 2023 | SCALE: NOTED

Weston & Sampson

FIGURE 3

IPSWICH RIVER WATERSHED ASSOCIATION

AUGUST NET DEPLETION

NOVEMBER 2023 SCALE: NOTED

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