Eutrophication and Wastewater Management: An Interdisciplinary Analysis of Falmouth and Cape Cod, Massachusetts

by
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Introduction

Eutrophication is defined as an increase in the rate of organic matter supply in an ecosystem (Nixon 1995). While this may sound innocuous, eutrophication of coastal marine environments is an incredibly widespread form of environmental degradation. By jeopardizing the ability for coastal water bodies to perform their primary ecological functions, eutrophication threatens ecosystems and the coastal communities that rely on them (Yang and He 2008). Marine eutrophication has been found to threaten ecosystems by reducing species diversity and abundance through changes in water quality that eliminate species critical for ecological processes (Villnäs et al. 2012, Fox et al. 2009, D’avanzo and Kremer 1994). In many cases, eutrophication has caused the depletion of fauna from local ecosystems, creating ‘dead zones’. Figure 1.1 shows a global distribution of dead zones around the world, caused by hypoxia linked to eutrophication (Diaz and Rosenberg 2008).

The degradation of ecosystems has often translated to economic and social losses for coastal communities. In Long Island, New York, eutrophication led to the decline of local shellfisheries (Nixon 1995). Off the coast of Sweden, eutrophication is responsible for periodically reducing fish catches (Rosenberg 1985). In the Gulf of Mexico, eutrophication has lowered the size of shrimp caught by fishermen (Smith et al. 2017). In the Caribbean, eutrophication has made the international news by threatening the economies of countries with water quality undesirable for tourists (Associated Press 2015, Pastore 2014). Through each of these cases, eutrophication threatens the
economic viability of ocean-dependent industries, ultimately impacting the residents of these areas and eroding many communities’ connections to the sea.

![Map showing global distribution of 'dead zone' hypoxic coastal systems linked to eutrophication](image)

**Figure 1.** Global distribution of over 400 ‘dead zone’ hypoxic coastal systems linked to eutrophication with map human influence of terrestrial systems. *Source:* Diaz and Rosenberg (2008).

**Cape Cod and Eutrophication**

One of the regions threatened by eutrophication is Cape Cod, Massachusetts. Also known as Barnstable County, Cape Cod is a peninsula on the eastern coast of Massachusetts famous for its cultural and economic coastal identity. Over 4 million tourists flock to Cape Cod every year, overwhelmingly in the summer months, to take advantage of swimming, boating, fishing, sightseeing, and other activities that rely on the pristine water conditions (Cape Cod Chamber of Commerce 2018). These tourists are critical, accounting for 40% of the region’s economy (*CLF and CBB v US EPA 2011*). In many cases, those enamored with the beauty of the Cape decide to purchase summer homes in the area. Cape Cod ranks seventh for the number of seasonal homes in the
nation, and summer homes make up over a third of all homes in the area (Ramachandran 2017). Aside from tourism, Cape Cod also serves as a hub for seafood harvest. The Cape Cod Commercial Fishermen’s Alliance produced about 9 million pounds of fresh seafood in the 2015 season (CCCFA 2015). A survey of shellfish aquaculture leaseholders across Massachusetts showed that 64% of shellfish farmers had growing locations in Cape Cod towns (Augusto and Holmes 2015). Over half of all the 19 million oysters sold by respondents were farmed in Cape Cod towns and nearly all hard-shell clam sales originated in Cape Cod (Augusto and Holmes 2015).

Despite the region's dependency on coastal ecosystem health, Cape Cod suffers from eutrophic water conditions in many of its estuaries, threatening the livelihoods of the locals and the regional economy. Home septic systems are the primary cause of eutrophication, due to nitrogen loading from human waste. Though the local government and communities have responded to the problem, substantive progress has been slow due to an inefficient political framework and uncertainties regarding which solutions should be pursued.

There are a wide range of factors that have led to the increase in eutrophication and failure to curtail it on Cape Cod. To best understand the contributions of these factors required analysis from multiple disciplinary perspectives. My thesis will address the biological, geological, historical, and political factors that contribute to the problem and how they interact with one another. I focus on the town of Falmouth, one of Cape Cod’s largest towns. I will also consider solutions for eutrophication on the Cape using those explored by the town of Falmouth. I will utilize an academic literature review, use
of primary government documents, and interviews with local government officials, scientists, and advocacy groups intimately involved in the situation. While comprehensive regional analyses have been conducted on the Cape before (Cape Cod Commission 2015, Cape Cod Commission 2013), no study has been able to provide a comprehensive yet detailed analysis at the town level. In doing so, my analysis yields insight on (1) the impacts of eutrophication, (2) its emergence as a problem, (3) the efficiency of government response, and (4) the effectiveness of proposed and implemented solutions. While grounded in the particular conditions of Falmouth, the lessons learned from this analysis can be used to guide multidimensional analysis and create points of comparison to other towns across the Cape Cod, as well as other municipalities where eutrophication poses a problem due to waste management.

Outline and Organization

To cover the wide range of topics, this thesis is organized by disciplinary analysis. Chapter 1 discusses the biological processes by which nitrogen from septic tank effluent facilitates eutrophication. The chapter then transitions to the impacts of eutrophication through a literature analysis of the impacts faced on Cape Cod and Falmouth. By identifying the main ecological and social impacts on Cape Cod, this chapter grounds the consequences of eutrophication on the Cape within a larger body of accepted research and situates Cape Cod in a wider body of sites that suffer from eutrophication.

Chapter 2 moves beyond the impacts of eutrophication to discuss the factors that precipitate its occurrence throughout the Cape. Beginning with a brief overview on
the area’s geologic history, this chapter studies how the hydrology of the area dictates groundwater flow into the embayments and impaired estuaries, facilitating the transmission of nitrogen from septic tanks in the community to these bodies of water.

Chapter 3 examines the historical context of the issue by studying how increasing population around Cape Cod in the 1960s and 1970s led to increased use of septic tanks, which led to contemporary eutrophic conditions. This chapter also shows how the lack of scientific understanding and presence of other pressing water quality issues caused towns to neglect preventative action. However, the historical issues of water quality also formed the basis for policy on eutrophication and, as Falmouth demonstrates, the infrastructure solutions being considered today.

Analysis in Chapter 4 examines policy solutions to eutrophication. Much of the policy is dictated by the federal government through the framework of the Clean Water Act (CWA), and the state of Massachusetts and localities in Cape Cod have acted to address eutrophication caused by septic tanks. This section evaluates the efficiency of these policies in implementing solutions to eutrophication, identifies their shortcomings, and discusses policy changes recently implemented.

Chapter 5 of this thesis provides an analysis of several solutions proposed and implemented in Falmouth to mitigate eutrophication. The solutions do so through the reduction of nitrogen in wastewater flow or reduction of nitrogen once within embayments. While no solution is outright superior, analyses of common factors such as cost and ease of implementation provide insight on the best conditions for each method.
Chapter 1. Biology

Before the ecological and social consequences of eutrophication on Cape Cod can be discussed, we must first understand the natural ecological process of nitrogen cycling and how humans have disrupted it. Nitrogen is a critical component in biochemical processes of all living things, yet nitrogen undergoes a series of chemical changes before it becomes usable for most organisms.

1.1. The Nitrogen Cycle

A large majority of nitrogen on Earth exists in the air as atmospheric nitrogen (N₂) (Ricklefs and Miller 2000). Before most organisms can use nitrogen, it must first be ‘fixed’ into usable forms by microorganisms such as bacteria (Ricklefs and Miller 2000). This begins with nitrogen fixation of the atmospheric nitrogen (N₂) to ammonia (NH₃) (Ricklefs and Miller 2000). Ammonia is then converted by specialized aerobic bacteria to nitrite (NO₂⁻) and then to nitrate (NO₃⁻) (Ricklefs and Miller 2000). In some cases, anaerobic environments break down nitrate and nitrite via denitrification, converting the nitrogen back to molecular forms (Ricklefs and Miller 2000). Nitrogen, in its ammonium and nitrate forms, is absorbed by plants and converted into organic molecules such as DNA, RNA, proteins, and enzymes (Ricklefs and Miller 2000). Animals receive nitrogen by consuming the plant or by consuming herbivores (Ricklefs and Miller 2000). Nitrogen absorbed by organisms is eventually converted back to ammonia through ammonification when the organisms release waste or die (Ricklefs and Miller...
A diagram of the transformations involved in the nitrogen cycle is shown in Figure 1.1.

![Diagram of transformations of the nitrogen cycle. Source: Ricklefs and Miller (2000).](image)

**Figure 1.1.** Diagram of transformations of the nitrogen cycle. *Source:* Ricklefs and Miller (2000).

### 1.1.1. Human Alteration of the Nitrogen Cycle

While the natural nitrogen cycle allows for stable transformations and reallocations of nitrogen throughout the environment, anthropogenic influences have upset this balance on a global scale. The natural rate of nitrogen fixation on land is about 140 million metric tons (Tg) per year (Vitousek *et al.* 1997). However, reactive nitrogen created for fertilizers, the burning of fossil fuels, and the planting of legume crops have led to a rapid increase in the reactive nitrogen produced per year by
converting forms of stored nitrogen such as nitric oxide (Galloway et al. 2008, Vitousek et al. 1997). Since 1860, reactive nitrogen production has increased from 15 Tg to 156 Tg in 1995 and 187 Tg in 2005 (Galloway et al. 2008). This has effectively doubled the annual transfer of nitrogen from atmospheric to biological forms, while the destruction of long-term nitrogen sinks such as forests and grasslands has also increased the rate of which nitrogen is converted through the cycle (Vitousek et al. 1997).

The largest anthropogenic contribution to the nitrogen cycle is the industrialized fixation of nitrogen for artificial fertilizers. Artificial fertilizers are responsible for about 80 Tg of nitrogen per year (Vitousek et al. 1997). Since the 1940s, fertilizer production has grown exponentially as both industrially developed and developing countries have relied on artificial fertilizer for intensive crop production (Vitousek et al. 1997, Smil 1997). Because access to fixed nitrogen often serves as limiting factor for productivity, farmers have used artificial fertilizers to raise the maximum productivity of their farms beyond normal levels (Galloway et al. 2008, Vitousek et al. 1997). As human population growth continues to increase, the reliance on artificial fertilizers is expected to increase with food demand (Vitousek et al. 1997).

1.1.2. *Macroalgae Overpopulation*

Eutrophication on Cape Cod is due primarily to nitrogen loading from septic tanks. There are several steps of the nitrogen cycle that occur before the nitrogen inputs cause eutrophication. Wastewater nitrogen takes the form of mostly organic nitrogen (40%) and ammonia (60%) (Lusk et al. 2017). When the raw wastewater is left to settle
in the septic tank and then released into the drainage field, they are converted into other forms. Bacteria converts the organic nitrogen into ammonia (NH$_3$) and ammonium (NH$_4^+$) through ammonification (Lusk et al. 2017). Through nitrification, the ammonia load is converted into nitrate, NO$_3^-$ (Lusk et al. 2017). While in some cases nitrate can undergo denitrification and be converted into molecular nitrogen (N$_2$) and nitrous oxide (N$_2$O), large amounts of nitrate are more commonly discharged into estuaries and absorbed by macroalgae. Figure 1.2 illustrates the process.

![Diagram of nitrogen transformations from house septic systems to outside environment. Source: Lusk et al. (2017).](image)

The presence of abundant nitrates in aquatic ecosystems functions as fertilizer for macroalgae, removing nitrogen as a limiting factor and allowing macroalgae to rapidly increase. For this reason, the amount of macroalgae biomass observed is closely
related to the size of nitrogen loads in the local area, with areas of high nitrogen loading having the greatest macroalgae biomass (Valiela et al. 2016). The increase in the rate of supply of organic matter, such as through rampant overpopulation of macroalgae, is called eutrophication (Primack and Sher 2016, Nixon 1995). Because areas with high concentrations of houses release high amounts of septic effluent, nitrogen loading is high and eutrophication tends to impact these areas the most (Valiela et al. 2016).

1.2. Impacts of Eutrophication

Eutrophication’s primary threat stems from the degradation of ecological conditions, resulting in both natural habitat loss for organisms and reduced quality of life for humans. The most the direct consequence of eutrophication is macroalgae overpopulation due to the overabundance of nutrients, but eutrophication can also threaten estuarine ecological conditions through three main consequences—algal blooms, deoxygenation, and eelgrass loss. Around the world, many examples illustrate the severity of any one of these consequences. On Cape Cod, excessive nitrogen loading into its estuaries precipitates them all. Given the area’s rich history of maritime commerce and tourism, the ecological damage to the area results in natural and anthropogenic losses that are particularly poignant.

1.2.1. Algal Blooms

Overpopulation of macroalgae due to the abundance of nutrients often occurs through macroalgae blooms, where thick mats of filamentous, unattached,
predominantly green algae form canopies both on the surface and within the benthos of a waterbody (Primack and Sher 2016, Valiela et al. 1997b). Macroalgae blooms are ubiquitous in areas with high amounts of nutrients, such as Hawaii, Italy, Portugal, Argentina, the Baltic Sea, and the Great Lakes (Valiela et al. 1997b, Teichberg et al. 2010). These macroalgae growths can persist for years. In southwestern Australia, excess phosphorous from farm runoff was linked to a macroalgae bloom that persisted over about 12 years (Gordon and McComb 1989). In Waquoit Bay, Falmouth, high amounts of nitrogen facilitated macroalgae blooms that have been present for over 20 years (Valiela et al. 1992). Macroalgae blooms are widespread throughout Cape Cod and Falmouth, such as on the Cape Cod National Seashore, Waquoit Bay, Little Pond, Green Pond, and West Falmouth Harbor, to name a few (Lyons et al. 2009, MassDEP 2007, Valiela et al. 1997b, Howes and Goehringer 1994).

Macroalgae blooms are notorious for the unpleasant sight they bring to local coastal communities. In June 2008, an immense macroalgae bloom event occurred along the coast of Qingdao, China four weeks before the city was planned to host the Olympic sailing regatta (Liu et al. 2013). The bloom covered about 400 km², making international headlines with photographs of the vast mat of bright green algae while underlining concerns regarding health standards for visitors and athletes before the Olympic Games (Liu et al. 2013, Branigan 2008, Reuters 2008, Yardley 2008). To avoid international disaster, the Chinese government mobilized over 20,000 people per day for the cleanup operation (Wang et al. 2009). The event cost an estimated 200 million
RMB ($30.8 million U.S. dollars) to clean up, and an untold loss in environmental damages and tourism losses (Liu et al. 2013, Wang et al. 2009).

Smaller mats of macroalgae blooms on Cape Cod still make the local, regional, and national news (Moran 2016, Spillane 2016, Ketchum and Burnett 2015, Abel 2011, Zezima 2010). Macroalgae mats can reach 50cm thick and can “look like huge lily pads… it’s really gross” (Abel 2011, Peckol and Rivers 1996, D’avanzo and Kremer 1994). These mats can form overgrowth that makes it difficult for shellfish growers to keep their platforms clean (Milton 1998). In large densities, the macroalgae give off foul odors that can be carried by the wind and “smells like rotten eggs” (Abel et al. 2011, Lyons et al. 2009). Algae that washes onshore can resemble “black mayonnaise” and rots in the summertime (Abel et al. 2011, Zezima 2010). Ultimately, these factors are but annoyances, as macroalgae blooms tend to consist of only a few dominant taxa and green macroalgae species are unlikely to contain toxins (Valiela et al. 1997). However, these nuisances are problem enough for Cape Cod communities given the region’s economic dependence on tourism, which makes up approximately 40% of the regional economy (CLF and CBB v US EPA 2011). In some ways, the effect of declining water quality has already taken a toll on residents. A study on the economic effects of poor water quality in the town of Barnstable found that declining water quality is associated with decreasing home values, resulting in revenue declines brought in by property taxes for the town of Barnstable (Ramachandran 2015). This suggests losses of hundreds of millions of dollars Cape-wide should nitrogen levels continue to rise (Ramachandran 2015). Focus groups have shown that residents also enjoy water-based recreational
activities, like boating and swimming, but interest in these recreational activities have declined to the point that some residents have considered the possibility of moving away from impaired embayments or the Cape altogether (Ramachandran 2015).

1.2.2. Anoxic Events

Accomplice to the unseemly sight of macroalgae blooms are anoxic events. When macroalgae biomass is high, the respiration and photosynthetic processes of the macroalgae can cause daily fluctuations in dissolved oxygen levels in the water, where oxygen levels are extremely low in the early morning but increase through midday (Costa et al. 1992, Valiela et al. 1992). On cloudy days, photosynthesis is hindered, and oxygen taken from the water through respiration may not be restored, leading to short periods where oxygen is totally removed from the water (Costa et al. 1992). These events require a combination of warm temperature, low light, and stratification of the water column, and so are fairly rare (D’avanzo and Kremer 1994, Costa et al. 1992, Valiela et al. 1992).

The Peconic River in Long Island has had a frustratingly consistent history of experiences with anoxic events in recent years. In 2015, three anoxic events on the river led to mass die-offs of Atlantic Menhaden, Brevoortia tyrannus, which are frequently used as bait fish (Gallagher 2015, Squire2015). These anoxic events are known as ‘fish kills’, due to the massive number of fish deaths from asphyxiation (D’avanzo and Kremer 1994). During each fish kill, Atlantic Menhaden causalities ranged from 10,000 to 100,000 (Suffolk County Department of Health Services 2016). The local news quickly
reported the events, describing instances of thousands of dead fish “piling on top of each other” on both town and private beaches (Pinciaro 2015, Squire 2015, np). Like on Cape Cod, the algal blooms responsible for these events have been largely attributed to high amounts of nitrogen from septic tank wastewater effluent entering the estuary, and government organizations have mobilized to tackle the issue (Gallagher 2015, Lloyd 2014). Attitude towards the problem has been pessimistic, with “word of thousands of dead fish washing up on local shores seeming like old news at this point” (Pinciaro 2015, np). Fish kills are expected to continue as long as nitrogen remains overabundant (Lisinki 2016).

Because of high freshwater inputs and tidal outflows, the water conditions necessary for anoxic events are rare on Cape Cod (Valiela pers. com.). However, these conditions still occur, and fish kills have been observed around Falmouth and throughout Cape Cod, such as in Waquoit Bay, Buzzards Bay, Three Bays estuary, Little Pond, and elsewhere (Jakuba pers. com., Saunders 2016, Teehan 2012, D’avanzo and Kremer 1994, Valiela et al. 1992, Portnoy 1991). Little Pond experienced one of the most severe fish kills in Falmouth’s recent history in 2012 and experienced another in the summer of 2014 (Buesseler pers. com., Teehan 2012). After witnessing the fish kill of 2014, residents of Little Pond were more acutely aware of the consequences of eutrophication, sparking momentum for greater efforts to reduce nitrogen inputs and ultimately contributing to the approval of sewage expansion for the community (Buesseler pers. com., Rafferty pers. com.).
1.2.3. *Hypoxia*

When oxygen levels are low but not anoxic, water conditions are said to be hypoxic (D’avanzo and Kremer 1994). Hypoxic conditions can still pose a danger to organisms and cause ecological degradation. Unlike anoxic events, hypoxia is a chronic condition, and consistently impacts the health of estuaries around the Cape (D’avanzo and Kremer 1994). Because hypoxic conditions are chronic, they are less evident to local residents than anoxic events, however hypoxia can bring about severe harm to organisms that lead to overall ecological degradation. Hypoxic conditions harm resident organisms by interfering with endocrine systems and functioning as a teratogen, reducing the ability of fish to reproduce and leading to malformed embryos (Weinke and Biddanda 2017). Low oxygen levels can lower consumption and growth in organisms (Weinke and Biddanda 2017, Costa *et al.* 1992). In natural settings, the hypoxic conditions force mobile organisms, such as fish, to move out of their habitats, leading to a decline in abundance and diversity in the particular area (Breitburg 2002). Hypoxic conditions are dangerous to benthic organisms, as these organisms reside too far below the surface to receive sufficient oxygen from the atmosphere and sediments in hypoxic areas tend to be depleted of oxygen (Vaquer-Sunyer and Duarte 2008). The loss of benthic organisms such as gastropods and bivalves in a community can be a critical loss for local ecosystem health. Benthic organisms perform critically important tasks such as sediment nutrient cycling, performing changes in nutrients and transporting particles through digestion and other processes (Villnäs *et al.* 2012).
On Cape Cod, hypoxic conditions are prevalent, and local habitats have suffered as a result. About 89% of the deepest ponds and 45% of all ponds on the Cape are impaired by hypoxia caused by human development (Cape Cod Commission 2013c). In Waquoit Bay, a comparison between a eutrophic and non-eutrophic estuary showed that the eutrophic estuary suffered from hypoxia, resulting in significant changes in ecological health through changes in benthic area community structure and food webs (Fox et al. 2009). The benthic community within the eutrophic estuary contained one-third fewer taxa and seven times lower species abundance than the non-eutrophic estuary (Fox et al. 2009). Amphipods, isopods, and other crustaceans were among the most affected, as studies have shown them to be particularly vulnerable to hypoxia (Fox et al. 2009, Vaquer-Sunyer and Duarte 2008). Grazers also suffered significantly, with an almost 25-fold decrease in abundance (Fox et al. 2009). Because many of these grazers are small crustaceans, their scarcity caused omnivores, mostly shrimp, to modify their diets to consume more macroalgae and predators such as fish to consume more omnivores (Fox et al. 2009). In this way, eutrophication forced ecological changes that marginalized the grazers as participants of benthic food webs and placed greater responsibility on omnivorous species.

1.2.4. Eelgrass Loss

The most significant consequence of macroalgae overgrowth in Cape Cod estuaries is the loss of native eelgrass, *Zostera marina*. Eelgrass loss due to eutrophication has been observed in several sites around the world, such as the North

Across various sites, research has shown that eelgrass is critically important in habitats by providing organisms with habitat for development, feeding, and refuge from predation. *Homarus americanus* lobsters off the coast of Massachusetts use eelgrass patches to dig shelters, which can be modified to a greater extent than rock shelters in order to function as a permanent residence (Karnofsky et al. 1989). Sogard and Able (1991) found that epibenthic fishes and decapods specifically preferred *Zostera marina* eelgrass as habitat over other potential habitats. Atlantic cod (*Gadus morhua*) density is positively linked to eelgrass cover and negatively linked to its removal (Lilley and Unsworth 2014). Juvenile Atlantic Cod, which rely on Crustacea for a large portion of their diet, take advantage of high macroinvertebrate densities in eelgrass to feed
(Tupper and Boutilier 1995, Bowman 1981). Eelgrass also provides habitat for fish. Fish abundance and diversity are positively linked to seagrass meadows and seagrass canopy complexity (Jackson et al. 2001). A study in Nauset Marsh, Cape Cod compared eelgrass meadows to other areas and found that eelgrass habitats held the greatest species richness and abundance, as well as macroinvertebrate biomass and production (Heck et al. 1995). Eelgrass habitats in Nauset Marsh also had macrofaunal production rates 5-15 times greater than other areas, predominantly from taxa like polychaetes, gastropods, bivalves, amphipods, and commercially important species such as bay scallops (Argopecten irradians) and blue mussels (Mytilus edulis) (Heck et al. 1995).

Bay scallops have historically been an important delicacy on Cape Cod. Bay scallops rely on eelgrass as a substrate for growth and are popularly harvested around Cape Cod (Costa et al. 1992). However, as macroalgae population issues have spread around the Cape, the subsequent loss of eelgrass has led to severe bay scallop populations declines (Costa et al. 1992). Waquoit Bay was home to a large population of bay scallops in the 1970s that rapidly declined due to eelgrass loss from increased algal growth (Costa et al.1992). Since 1992, bay scallops have been nearly entirely absent from the bay (Costa et al. 1992). Similarly, the bay scallop harvest in Buzzards Bay began as “what oysters were to Long Island and Chesapeake Bay” (Buzzards Bay Coalition 2015b, p.10). As the Chesapeake Bay lost its oyster population to overexploitation and disease, the bay scallop population of Buzzards Bay was devastated by macroalgae population (Buzzards Bay Coalition 2015b, Newell 1988). Bay scallop catches by fishermen in Buzzards Bay suffered as a result. In 1985, fishermen harvested almost
70,000 bushels of bay scallops in Buzzards Bay; by 2015 that catch declined to only 1,500 bushels annually (Buzzards Bay Coalition 2015).

1.3. Conclusion

Analyses of eutrophication around Cape Cod has shown that macroalgae growths affect both local ecosystems and the local residents. By reducing species richness, abundance, and diversity through hypoxia and the loss of eelgrass, overabundant macroalgae threaten the ecological health of the estuaries through fundamental changes in energy dynamics. Likewise, overabundant macroalgae growths precipitate blooms and anoxic events that threaten the reputation of the region as a hub for tourism and as a place for locals to enjoy the area around their coastal homes. Overabundant macroalgae and its consequences are closely tied to excessive nitrogen loading in the area, which research has demonstrated is largely due to contributions from septic tank wastewater. As the next section shows, nitrogen loading from septic tanks is controlled by groundwater dynamics that are the result of geological processes during the formation of Cape Cod. These processes dictate where and how wastewater flows to these estuaries and ultimately affect how policy towards eutrophication on Cape Cod is designed.
Chapter 2. Geology Background

The geological processes that created Cape Cod have had a significant impact on the problem of eutrophication. This is due to the hydrologic properties of the Cape Cod area, which produce high rates of groundwater flow throughout Cape Cod’s subsurface. In turn, the high rate of groundwater flow facilitates the rapid lateral transport of nitrogen-rich effluent and the creation of local environments for eutrophication to occur.

2.1. Geologic History

Cape Cod was created approximately 15,500 years ago when glaciers began to progressively melt and recede during the last continental glaciation (Odale 1981). As the glacier ice melted, it deposited large volumes of rock material at its terminus, known as drift, creating the basis of Cape Cod and the islands of Martha’s Vineyard, Nantucket, and Long Island (Koteff and Pessl 1981).

Figure 2.1 shows the diversity of glacial drift deposits on Cape Cod. The Cape Cod landscape is largely made up of outwash deposits, local ice-contact deposits, and till. Outwash and local ice-contact deposits are primarily made up of gravel and coarse sand, making them extremely permeable (Guswa and LeBlanc 1985). Due to repeated glacial advances and retreats, the deposits are thick and form laterally extensive layers (Olcott 1995). Till is made up of moraines, deposits of rock fragment that range from silt and...
clay to boulders (Odale 1981). While moraines deposits typically have low permeability, they are limited in their distribution (Odale 1981).

**Figure 2.1.** Geological map of the glacial deposits in Cape Cod. Modified from USGS Water Atlas (1995).
2. 2. Hydrology

The hydrology of Cape Cod is defined by the movement of water from the land surface to the Cape Cod Aquifer and eventually into the embayments that surround the Cape [Figure 2.2]. The aquifer is solely supplied by precipitation, at a rate of about 53.3 cm per year (LeBlanc 1984). The precipitation, usually either rain or snow, infiltrates the land surface and percolates downward to recharge the aquifer, while groundwater is also lost via coastal embayments and human consumption. Because it is the only aquifer on the peninsula, the presence and quality of water of the Cape Cod Aquifer is extremely important to both residents and local ecosystems (Cambareri and Eichner 1998).

![Figure 2.2. Groundwater flow dynamics table on Cape Cod. Source: Cape Cod Commission (2013c).](image)

2.2.1. Groundwater Characteristics

The Cape Cod Aquifer is constrained both vertically and horizontally. The water table of Cape Cod, which extends across the region, forms the upper boundary of
groundwater levels in the area [Figure 2.3]. In western and central Cape Cod, the lower boundary of the aquifer is defined by bedrock that lies at low elevation, making the groundwater column thick in these areas [Figure 2.2] (Olcott 1995). On the eastern Cape, near Truro, the groundwater column is about 200 feet thick (LeBlanc et al. 1986). In some coastal areas, the lower boundary of the groundwater column is defined by

![Figure 2.3. Water table on Cape Cod and elevation contours. Source: Olcott (1995).](image)
glacial outwash deposits that differ from those previously mentioned. These outwash deposits are composed of tightly packed fine-grain silt and clay sediments that, unlike previously mentioned glacial outwash deposits, are impermeable (LeBlanc et al. 1986). Horizontally, the boundaries of the aquifer are defined by locations where the groundwater mixes with ocean saltwater (LeBlanc et al. 1986). In most cases, these areas are coastal embayments, but in some cases groundwater is discharged directly to open coastal water, such as Nantucket Sound or Cape Cod Bay (Cape Cod Commission 2013c).

2.2.2. Groundwater Flow

The Cape Cod Aquifer itself is defined mostly by the outwash deposits that comprise much of the Cape. The high permeability of the outwash deposits allows groundwater to flow rapidly and horizontally, with hydraulic conductivity for sand and gravel outwash at 200 to 300 feet per day (LeBlanc 1984). Figure 2.4 shows the flow rate of groundwater across Cape Cod. While these flows are geologically fast, the figure shows the time of travel can take many years, even near the coast. Vertical flow is confined only to recharge areas where the water table is high and to coastal regions where discharge takes place (Le Blanc et al. 1986). About 270 million gallons of water moves through the Cape Cod Aquifer per day (Olcott 1995).
2.2.3. Watersheds

The direction and destination of groundwater flow from the Cape Cod Aquifer to discharge sites around the Cape is dictated by watersheds. Cape Cod contains 105 watersheds that regulate the groundwater flow [Figure 2.5] (Cape Cod Commission 2013c, p. 10).
2013c). Fifty-seven watersheds drain directly into coastal embayment systems at the margins of the aquifer (Cape Cod Commission 2013c).

While these 57 watersheds are not the majority of all watersheds, they span 79% of the land surface of Cape Cod, making up "the spine of the peninsula" (Cape Cod Commission 2013c). The extensive watershed area that discharges into coastal embayments highlights the importance of groundwater quality, since the health of estuary ecosystems on these embayments depend on unpolluted groundwater flowing from these watersheds.

Figure 2.5. Hydrological map of watersheds around Cape Cod. Source: Cape Cod Commission (2013c).
2.2.4. Transition Zone

The transition zone is a narrow, dynamic mixing zone where freshwater moving seaward and salt water moving landward meet [Figure 2.6]. Because salt water is denser than freshwater, the differences in density allow the waters to remain mostly separated in the transition zone during non-turbulent flow (Guswa and LeBlanc 1985). This steady state condition keeps the transition zone in a fixed area. However, the transition zone may drift landward or seaward depending on changes in groundwater pressure to the area (LeBlanc 1986). During droughts, the reduced groundwater flow forces the transition zone to drift towards land due to consistent landward motion of the salt water tides.

Figure 2.6. Location of the transition zone relative and recharging areas of groundwater for each coast. Sources: Le Blanc et al. (1986) as cited by Olcott (1995, p. M17).

Wells in the Cape Code Aquifer draw significant amounts of water to keep up with anthropogenic water consumption, over 9 billion gallons per year [Figure 2.7]. Wells can vary in performance, commonly ranging between 100 to 1,000 gallons per
minute and reaching as high as 2,000 gallons per minute (Olcott 1995). Because the wells decrease the flow of freshwater moving seaward, groundwater pressure decreases, leading to a shift in the location of the transition zone towards land. In doing so, the transition zone moves upwards towards the overlaying pumping wells, increases the salinity of groundwater at the well locations. This process is known as upconing (Reilly et al. 1987).

![Figure 2.7. Total Yearly Pumping from Cape Cod Public Supply Wells. Source: Cape Cod Commission (2013c)](image)

2.3. Geology and Eutrophication on Cape Cod

The existence and quality of groundwater from the Cape Cod Aquifer is critical to local ecosystems and human communities. Today, the Cape Cod Aquifer sustains an estimated population of about 215,000 permanent residents, which triples during summer months (Cape Cod Commission 2013b). The volume of wastewater discharged by these populations, coupled with the rapid flow rate and horizontal travel time of the
groundwater allows for the quick transport of nitrogen-rich effluent from septic systems to the watersheds and into coastal embayments. Because so much of the Cape Cod Aquifer discharges into these coastal embayments, estuarine ecosystems throughout the Cape are affected by the eutrophication. The same is also true for local freshwater ponds and wetlands, which rely on the aquifer to re-supply them with fresh water.
Chapter 3. Social Background

Eutrophication on Cape Cod emerged as an issue in the public consciousness in the late 20th century and continues to this day. While the geological factors that have facilitated the flow of nitrogen from septic tanks to embayments occurred over thousands of years, the anthropogenic conditions that precipitated eutrophication as a regional issue required only decades to form. The driving force behind eutrophication is the rapid population growth and associated development that occurred on Cape Cod in the 1960s and 1970s, which led to an unchecked increase in wastewater effluent.

When wastewater effluent increased substantially in the 1960s and 1970s, it traveled through local watersheds into coastal embayments and the local environment. Wastewater inputs led to an overabundance of nitrogen and widespread concerns over drinking water quality that emerged in the 1970s. Nitrogen overabundance occurred both suddenly and without regulatory correction at a time when the scientific study of eutrophication was in its infancy. Concerns over drinking water quality eclipsed concerns regarding nitrogen discharge, but it also prompted towns to consider their wastewater infrastructure in ways that later became useful when addressing nitrogen concerns, particularly in Falmouth. By the time eutrophication became a widespread concern for Cape Cod residents in the 1990s, towns around the Cape were forced to grapple with the legacy of their rapid development. In the case of Falmouth, this meant taking advantage of whatever wastewater infrastructure they had in order to address the issue.
3. 1. Population Growth on Cape Cod

The latter half of the 20th century was an extremely active time for Cape Cod in terms of settlement, as visitors and new residents alike flocked to the area’s pristine beaches and pleasant summertime weather. Figure 3.1 shows how the population of Cape Cod skyrocketed from 1900 to 2016, climbing nearly 700% (US Census Bureau 2010). Development rapidly rose to keep in step with the growing population; by 1972 only 100,000 acres (40%) of developable land were left available, of 252,000 total acres of the Cape (Bauer Engineering Inc. 1972). This rapid development lacked careful planning, resulting in uncontrolled sprawl that varied housing densities across the Cape (Perry pers. com.). Like the rest of Cape Cod, Falmouth also experienced rapid growth, climbing 800% within the same time period [Figure 3.1] (US Census 2010). Seasonal tourists raise the number of inhabitants even further. In Falmouth, the population climbs to over 100,000 due to summer-going tourists (Lowell pers. com.).

With the influx of new residents and tourists came the need to provide for them through shelter, and consequently, wastewater management. From 1938 to 1990, the number of houses in Waquoit Bay rose from 250 to over 4000, increasing wastewater discharge 12-fold in Waquoit Bay and leading to 2-fold increase in the total nitrogen inputs into the bay (Bowen and Valiela 2001). Since 1990, wastewater nitrogen loads into Waquoit Bay estuaries increased by about 80% (Valiela et al. 2016). Today, septic systems are commonly accepted as the primary contributor of nitrogen to impaired estuaries on the Cape (Bowen and Valiela 2001, Valiela et al. 2000, Nowicki et al. 1999, Valiela et al. 1997a, Valiela et al. 1992, Giblin and Gaines 1990, Valiela and Costa 1988).
3.2. Wastewater Management on Cape Cod

Wastewater management systems before 1995 were primarily of two types: cesspools or two-stage septic systems (Perry pers. com.). Cesspools are structures where solid and liquid wastes are released from the home to a buried cylindrical receptacle filled with gravel, where microorganisms digest the waste material, but the wastewater is otherwise untreated (Cape Cod Commission 2013a). Pre-1995 septic tanks function in a similar manner, though solid waste is stored in a septic tank while wastewater is released into a leach field where microorganisms can break down the liquid waste (Cape Cod Commission 2013a). In both systems, there is no mitigation of nitrogen discharge and no methods to remove pathogens from the waste effluent (Perry pers. com.).
The rapid rise in development and untreated wastewater management systems spurred concern over water quality in the 1960s and 1970s, both in Cape Cod and around the country. In Falmouth, wastewater pollution plagued areas with high concentrations of septic systems in tightly packed areas such as town center (Heufelder *pers. com.*, Rafferty *pers. com.*; Williams *pers. com.*, Turkington 1986). In 1973, raw waste bubbled up onto streets, and the stench of raw waste emanated from several ponds around the town (Williams *pers. com.*, Turkington 1986). Around the same time period, areas around the country were grappling with similar problems. From 1971 to 1979, 63% of reported illnesses caused by consumption of contaminated or untreated groundwater were the result of septic system or cesspool waste, making up 43% of all reported disease outbreaks in the United States (Pedley and Howard 1997). Outbreaks of gastrointestinal illness caused by consumption of septic system-contaminated drinking water occurred in Florida in 1974 (Weissman *et al.* 1976). In 1972, cases of typhoid occurred in Washington as the result of contamination by septic systems (Yates 1985). Throughout the 1970s, drinking water contamination due to septic system pollution of groundwater was also observed in Delaware, New Mexico, New York, and North Carolina (Yates 1985).

Under Section 208 of the Clean Water Act (CWA), local governments with water polluted due to nonpoint sources, such as septic systems, are required to release a plan to respond to the issue (Clean Water Act of 1972). The policy framework of this plan and how it applies to eutrophication will be discussed in Chapter 4. In 1978, the Cape Cod Planning and Economic Development Commission (CCPEDC) released its 1978 Section
208 Plan, which identified water quality and wastewater management problems in the region and traced them to increasing residential densities around the Cape and tourism during the summertime (CCPEDC 1978). By this point, septic systems were ubiquitous around the Cape; about 90% of the year-round population relied on septic systems for waste disposal (Cape Cod Commission 2015). While the 1978 Plan acknowledged eutrophication as a problem, polluted drinking water concerns largely took up the focus of the plan (Cape Cod Commission 2015, CCPEDC 1978).

Though 1978 Plan’s focus on drinking water pollution is indicative of the weight this issue carried, the lack of emphasis on eutrophication exemplifies how little the issue was scientifically understood during the time period. The history of marine eutrophication as a scientific issue and its rise to popular attention is detailed in Scott W. Nixon’s “Coastal Marine Eutrophication: A Definition, Social Causes, and Future Concerns” (1995).

Until the 1970s, marine eutrophication was poorly understood. While some scientific concern towards marine eutrophication had been expressed as early as the 1950s, the topic failed to enter the mainstream. Significant documents such as Treatise on Marine Ecology and Paleoecology (1957) made no mention of marine eutrophication. Eutrophication was difficult for scientists to define given dynamic variables such as nutrient concentrations and oxygen levels, and many used taxonomic or chemical concentration data that made standardization difficult and lead to confusion within the scientific community. The First International Symposium on Eutrophication was hosted in 1967, and at the symposium scientists posed overarching questions regarding how to
define eutrophication and measure its levels of severity. Of the 32 chapters of a report produced by the symposium, only 2 were focused on marine eutrophication.

It wouldn’t be until 1979 that eutrophication began garnering attention as an environmental issue, the product of an increasing number of scientific studies and growing concern over eutrophication in the Chesapeake Bay, the U.S.’s largest estuary. In that year, the U.S. Environmental Protection Agency hosted the first International Symposium on the Effects of nutrient Enrichment in Estuaries, marking the start of steadily increasing scientific and popular international attention in the form of publications, conferences, and government publications that went on through the 1990s and has continued today.

3.3. Sewage Service in Falmouth

The 1978 Plan’s emphasis on drinking water quality was expressed through recommendations it made to towns regarding how to resolve these water quality issues. The overhaul of septic systems was not a widespread concern; the 1978 Plan suggested that most of the population could rely on septic systems for the next 20-year planning period (Cape Cod Commission 2015, CCPEDC 1978). However, the plan did recommend the implementation of sewer systems for several towns to treat wastewater for contaminants and to manage wastewater outflow. Among these towns was Falmouth.

By the time the 1978 Plan was released, the town of Falmouth already had long been debating the implementation of a sewer system. At the time, Falmouth’s sewer system was limited to Woods Hole, built in response to the Massachusetts State Board
of Health’s concerns over the possibility of epidemic disease brought on by Woods Hole’s polluted waters (Turkington 1986). Beginning in 1927, it took two decades of studies, committees, and failed votes to approve the sewage system in Woods Hole, as citizens often opposed the high cost and feared the potential influx of new residents that might follow (Heufelder pers. com., Perry pers. com., Williams pers. com.). Despite this, approval was finally granted in 1947 (Turkington 1986). Construction began in 1948 and was finished in 1954 (Rafferty pers. com., Turkington 1986).

The sewage system was crude at best. Sewage passing through the system was treated only with chlorine before being pumped 1,000 feet off the coast and into Great Harbor, off the coast of Woods Hole (Turkington 1986, Camp, Dresser & McKee 1981). Again, the poor quality of waste management caught the attention of the state, when the State Division of Water Pollution Control threatened the town with legal action in 1971 and again in 1979 (Turkington 1986). In 1979, the town approved plans for a sewage system covering what would become the backbone of Falmouth’s present-day sewage infrastructure [Figure 3.2] (Rafferty pers. com., Turkington 1986). Construction began in 1984 with financial assistance from state and federal governments, which agreed to pay for 90% of the estimated $21.6 million construction cost (Turkington 1986).
Figure 3.2. Arial image of Falmouth’s wastewater treatment facility. Source: GHD Engineering Inc. (2013).

While Falmouth’s wastewater treatment facility helped to remedy health concerns regarding septic effluent, the lack of awareness towards eutrophication was evident in the facility’s original planning and design. A study conducted by consulting firm Bauer Engineering Inc. in 1972 to investigate the implementation of sewage considered the motivations for building a wastewater treatment facility and different approaches. While saltwater intrusion and drinking water safety were listed as motivations for sewage treatment implementation, eutrophication was not (Bauer Engineering Inc. 1972). In 1978, a report for sewage implementation of Falmouth Village created by consulting firm Camp, Dresser & McKee, Inc. acknowledged concerns of
excessive nutrient enrichment in several ponds around town center, but not
eutrophication of estuaries (Camp, Dresser & McKee 1978).

Upon completion, the sewage system in Falmouth had several limitations. Because of its focus on areas suffering from refuse pollution, sewage service was limited to densely populated areas such as town center, for a total of only 3% of the town, while the rest of the town remained using septic systems [Figure 3.3] (Buesseler pers. com., Williams pers. com.). Though sewage in the areas that were covered meant fewer homes would be releasing nitrogen effluent via septic tanks, it did not decrease the amount of nitrogen entering estuaries around Falmouth. Instead, wastewater was directed to the wastewater treatment facility and released into several aeration ponds, which converted the ammonia-rich wastewater (NH$_3$) into nitrate (NO$_3$) using nitrification (Pires pers. com.). Once converted into mostly nitrate, the wastewater was then released into infiltration beds and allowed to enter the groundwater, where it eventually reached West Falmouth Harbor. Through these means, nitrogen effluent was not mitigated through sewage, so much as it was redirected from several areas around Falmouth to West Falmouth Harbor. The consolidation of wastewater from so many homes to West Falmouth Harbor has since degraded the area greatly. Since its construction, the Falmouth Wastewater Treatment Facility has undergone several upgrades to its treatment process and has expanded its area of service. However, the issue of redirecting high amounts of nitrogen effluent to West Falmouth Harbor has remained to this day. These topics will be discussed in Chapter 5.
Figure 3.3. Map of Falmouth wastewater service coverage with dates. Sources: Rafferty pers. com., Cape Cod Commission GIS Portal (2017), Falmouth, Massachusetts Wastewater System Overview Map (2017), and Reckford (2008).
Chapter 4. Policy

As the issue of eutrophication has become more pressing through the 20th century, government bodies at all levels have acknowledged it on Cape Cod. Federal, state, regional, and town government all participate in a large system of regulation and policy that targets eutrophication around Cape Cod through the reduction of nitrogen entering local estuaries via watersheds. This approach is a form of cooperative federalism as part of a larger body of clean water regulation set forth by the federal government, in which the federal government requires water quality standards to be met by charging local governments with investigating the issue and creating plans to alleviate the problem. On Cape Cod, water quality standards for nitrogen are set by the federal government, the regional government provides a framework for towns to approach the issue, and towns must each create plans to meet standards for nitrogen concentrations of water bodies within their jurisdiction.

Though the reasoning behind cooperative federalism is practical, the implementation of this inter-governmental system has had mixed success on Cape Cod due to a weak system of top-down federal legislation. Regional-level frameworks mandated by the federal government lack enforcement and accountability, and so oversight of towns within the region is limited. Towns often don’t produce action plans, and those that have struggle to pass the final level of approval by residents. To facilitate the implementation of town plans, the regional government has promoted a bottom-up approach by focusing on increasing town stakeholder participation and reframing the
focus of plans away from entire town jurisdictions and towards watersheds within and between towns.

4.1. Cooperative Federalism for Water Quality

The principle driver of government plans to treat eutrophication is the federal Clean Water Act, which provides a structure of cooperative federalism through which the federal, state, and local governments work together on water quality issues (Copeland 2016). Originally enacted as the Federal Water Pollution Control Act of 1948, the law provided technical assistance and funds to state and local governments for addressing water pollution without imposing any federally required goals, objectives, limits, or guidelines (Copeland 2016). From 1965 to 1987, the law was amended several times to drastically expanded its reach. In 1972, the law formally shifted authority for water pollution control from the states to the federal government (Copeland 2016). This was dubbed the Clean Water Act of 1972 and changed the priority of the Clean Water Act to restoring and maintaining the integrity of the nation’s water (Copeland 2016).

While water bodies within states are under their jurisdictions, the Clean Water Act imposes a system for which states work towards accomplishing the Clean Water Act’s goals. This is done by requiring states to produce water quality standards, which both maintain the beneficial uses of a water body as well as create pollution concentration limits necessary to preserve the water body’s designated uses (Copeland 2016). When water bodies fail to meet these quality standards, the Clean Water Act requires states to develop Total Maximum Daily Loads (TMDLs), which establish
pollutant loading capacities needed so that the quality standards there can be met (Copeland 2016). Once the TMDL is developed, it is approved by the federal Environmental Protection Agency after a period of public comment (Mattson and Isaac 1999). If the state fails to develop their own TMDL, the EPA is authorized under the CWA to develop the TMDL instead (Copeland 2014).

4.1.1. EPA Regulation for Water Quality Standards

Once a TMDL is approved, it is the obligation states have to meet their requirements. However, TMDLs are ultimately self-enforced, as the federal government has no ability to force the states to meet them (Copeland 2014). However, depending on the source of the pollutant, the EPA has several tools to mitigate waterway pollution and bring water quality levels closer to TMDL compliance. The Clean Water Act designates two approaches that can be taken by the EPA to mitigate the source of the pollutant. These approaches depend on whether or not the pollution can be identified as discharged from a discernible or discrete source, such as pipes, channels, tunnels, and wells (Section 502 Clean Water Act).

4.1.2. Point Source Regulation Under the Clean Water Act

If pollution can be traced back to a discrete source, it is defined as “point source pollution”, and the EPA has in its arsenal a powerful tool to curb its emission. The National Pollutant Discharge Elimination System (NPDES) program requires point-source dischargers to apply for an EPA permit to release effluent into the environment. The
program places limits on pollution loading, a deadline for compliance, and requires dischargers to carry out effluent monitoring programs (Copeland 2016). Should dischargers violate the requirements of the permit, the EPA may order the discharger to correct their practices or sue the discharger in U.S. district court (Copeland 2016). The penalty for violating a NPDES permit can be $25,000 per day, though the penalty is much higher for criminal violations and violations that knowingly endanger the health of others (Copeland 2016).

4.1.3. Non-Point Source Regulation under the Clean Water Act

If pollution cannot be traced back to a discrete source, it is identified as a non-point source (Section 502 CWA). Unlike point source pollution, the EPA does not regulate nonpoint sources according to the Clean Water Act (Copeland 2014). The absence of regulation for nonpoint sources in the Clean Water Act has drawn criticism from many sides. Nicknamed “the non-point source loophole”, scholars have accused Congress of intentionally limiting the EPA’s authority over nonpoint sources to spare the agriculture industry from regulation of storm water and irrigation runoff (Milz 2015, Angelo and Morris 2013, Laitos and Ruckriegle 2012). Municipalities and industries have objected to perceived disproportionate regulation of their activities, while nonpoint sources are essentially unrestricted (Copeland 2014). This is particularly true in circumstances where both point and nonpoint sources pollute a single water body, but only the former is pressured into reforming their practices (Copeland 2014).
The Clean Water Act does impose some requirements in an attempt to curb nonpoint source pollution of water bodies, however these requirements are lax and unrestrictive. Among these requirements are those of Section 208 of the Clean Water Act, which requires the creation of an area-wide waste treatment management plan aimed at solving water quality issues that is updated annually (CCPEDC 1978, Section 208 Clean Water Act). The plan must identify the sources of pollution, possible solutions, and possible programs for funding, but does not carry out any actions, leaving the implementation of solutions to local governments (Section 208 CWA). The local governments assigned to make and carry out solutions are designated as waste treatment management agencies by the governor of the state (Section 208 CWA). States are not obligated to follow through on 208 Plans (Laitos and Ruckriegle 2012). Instead, Section 208 of the CWA incentivizes action by requiring “the federal government to share the costs of developing and implementing the plans through EPA grants” (Laitos and Ruckriegle 2012). However federal funding for these plans ended in 1981 (Laitos and Ruckriegle 2012).

4.2. Cooperative Federalism and Cape Cod

On Cape Cod, the program charged with monitoring nitrogen pollution for the creation of TMDLs is the Massachusetts Estuaries Project (MEP), created in 2001 through a partnership with the University of Massachusetts School of Marine Science and Technology (SMAST), and the state Department of Environmental Protection (MassDEP) (Howes et al. 2006, Cape Cod Commission 2015). By determining nitrogen
loads, water quality, and hydrodynamic information, the MEP provides the data necessary for the state Department of Environmental Protection to create TMDLs for affected estuaries (MassDEP and SMAST n.d., Howes et al. 2006). Though the MEP has conducted research in many estuaries around Cape Cod, analysis of all impaired water bodies has yet to be completed. Of the 15 study sites around Falmouth, 6 have been completed, 4 are currently ongoing, and 5 are planned (MassDEP and SMAST n.d., Howes et al. 2006).

Despite the strong regulatory power the EPA holds under the NPDES program, the NPDES program cannot widely be implemented to resolve nitrogen pollution on Cape Cod in its current state because septic tank effluent does not qualify as a point source of pollution. The EPA lists septic tank effluent, fertilizers, herbicides, pesticides, and others as “nonpoint sources” (Cape Cod Commission 2015). Nonpoint sources are considered the responsibility of the state and local governments (Goldfarb 1994). As a result, the EPA has no power to regulate these sources, and its influence is limited to addressing nonpoint sources though grants and funding for state-run programs (Copeland 2014).

Cape Cod was plagued by water quality issues due to inadequate waste management systems. Because these systems are classified as non-point source pollution, the region was mandated to create a plan that adheres to the requirements of Section 208 of the Clean Water Act. This plan was called the 1978 Section 208 Plan and was created by the Cape Cod Planning and Economic Development Commission (CCPEDC) as directed by the state (CCPEDC 1978). The 1978 Section 208 Plan sought to
“provide a comprehensive view of a region’s water quality problems, develop alternative means of solving these problems, and involve the public in selecting an appropriate management program to protect the region’s water resources” (CCPEDC 1978).

While the 1978 Section 208 Plan attempted to provide a comprehensive analysis of the Cape’s water quality problems, the document itself did little to respond to nitrogen pollution. The 1978 Section 208 Plan was focused on drinking water quality, not nitrogen pollution (CCPEDC 1978). Because of weak legislation on non-point sources of the Clean Water Act, the 1978 Section 208 Plan was not an enforceable plan, but rather a collection of analyses, recommendations, and alternatives respond to water contamination. It did, however, propose a framework that designated townships the responsibility of responding to waste quality concerns by naming them as waste management agencies (CCPEDC 1978). This proposal was accepted by the state governor, and while current water pollution concerns have shifted away from the concerns of the 1970s, this designation has remained with the towns and charged them with responding to nitrogen pollution that impairs Cape Cod today (Spalding 2015).

4.3. State and Local Action under the 1978 Section 208 Plan

In order to respond to estuaries impaired by nitrogen pollution, towns must meet the estuaries’ nitrogen TMDL requirements within their jurisdictions (Perry pers. com., Spalding 2015). The towns’ plans for meeting these goals are described through Comprehensive Wastewater Management Plans (CWMPs), where towns plan the
implementation of technologies and approaches to meet the nitrogen TMDL requirements of the estuaries (Perry pers. com., GHD Engineering Inc. 2013). These TMDL requirements are met through reduction targets, monitored through the distribution of nitrogen reduction permits granted through the state DEP (Cape Cod Commission 2015). In many cases, the lack of adequate expertise and manpower for creating CWMPs exceed the ability of the small Cape Cod towns, and so towns hire engineering firms to create the CWMPs instead (Perry pers. com.). These firms often rely on traditional frameworks that most easily fit the requirements necessary for nitrogen reduction permits. Usually, this is sewage implementation, despite oppositions from local residents (Perry pers. com., Gentile 2015, Gentile 2014). The subsequent backlash on sewage proposals by residents is a serious problem for the implementation of effective solutions and will be discussed in the Chapter 5.

Once the town creates a CWMP, it is submitted for approval by both the county and the state. Both the Cape Cod Commission (CCC), the county’s planning agency, and the state Department of Environmental Protection review the CWMP projects for environmental impacts according to their own policy regulations. At this level, the state also considers requests for financing for CWMP projects (Cape Cod Commission 2015, Perry pers. com.).

Towns are mandated by the state to produce CWMPs. However, few towns have actually done so. Over the past 10 years, all of Cape Cod’s 15 towns are somewhere along the CWMP creation process, but only 6 towns have submitted CWMPs for
approval (Perry pers. com.). Despite the responsibilities of the towns, there have been no repercussions for failing to submit CWMPs (Perry pers. com.).

Upon authorization by the county and the state, the CWMP returns to the town for final approval. Because most towns require loans to implement their CWMPs, a two-thirds vote is required for the CWMP to be approved and funded (Perry pers. com., Cape Cod Commission 2015). In most towns, this is done through a popular vote held at a town meeting (Perry pers. com.). It is here where many CWMPs are rejected, ending the multi-level design and approval process.

Town locals have voted to reject proposed CWMPs primarily due to high costs they fear would have to be made up through higher taxes (Perry pers. com.). The fear of high costs stem from several aspects of CWMPs. Because CWMPs are created by towns, the proposal considers all areas under town’s jurisdiction and all the town’s estuaries, leading to extensive construction proposals and high overall cost. This is especially true for CWMP proposals hinged on sewage system implementation, which is a common strategy for the engineering firms behind the CWMPs because nitrogen reduction permits are designed with traditional infrastructure, like sewage, in mind (Cape Cod Commission 2015, Perry pers. com.). Locals often object that sewage implementation is unnecessary when alternative solutions are less costly and less invasive and have complained that the process for determining TMDLs lacks transparency (Kazarian 2009).
4.4. Attempts at Improving the Top-Down Regulation

The failure of towns on Cape Cod to create and pass CWMPs is a symptom of several problems of cooperative federalism in the region. Without effective regulation from federal, state, and regional governments that hold towns more accountable, top-down pressure is too weak to push towns towards developing CWMPs designed to alleviate eutrophication.

The most direct response to increasing top-down regulation would be to close the “non-point source loophole” of the Clean Water Act by granting the EPA greater regulatory power of non-point sources (Milz 2015). However, given today’s political climate and the need for Congressional legislation, Presidential approval, and implementation by the EPA, such legislative action would be unlikely.

Some organizations have attempted to circumvent the legislative process through judicial action by arguing for a reinterpretation of the Clean Water Act to bring about stronger federal regulation. In August 2010, the Conservation Law Foundation (CLF) and the Coalition for Buzzards Bay (CBB) sued the EPA through the U.S. District Court, claiming the EPA “inappropriately categorized septic systems as nonpoint sources of pollution in the load allocation sections of the Cape Cod TMDLs”, and so “arbitrarily and capriciously” approved the TMDLs created by the state DEP (CLF and CBB v. EPA 2010, p.15). By arguing that wastewater is received by septic systems through a pipe, which functions as a discernable source, and nitrogen pollution can be traced back to septic systems, the CLF and CBB demanded that septic systems be classified as point sources (CLF and CBB v. EPA 2010). In doing so, septic systems would be obliged to
follow the much stricter regulations of the Clean Water Act applied NPDES permitting, rather than those applied to nonpoint sources. However, this case was dismissed by the court for lack of jurisdiction (Cape Cod Commission 2014).

While there exists great difficulty in creating new legislation through Congress and reinterpreting legislation through the judiciary, there has been some success in promoting solutions to eutrophication by taking advantage of existing legislation. In September 2011, the Conservation Law Foundation and the Buzzards Bay Coalition again sued the Environmental Protection Agency, this time due to its failure to approve an updated 208 Plan for Cape Cod and for how the EPA handled grants to the Massachusetts State Revolving Fund, a fund for waste management projects implemented in an amendment to the Clean Water Act (CLF and CBB v US EPA 2011). According to the Clean Water Act, the Section 208 Plan released in 1978 is required to be updated annually and then approved by the EPA (Section 208 CWA). For this reason, the EPA chose to settle the case in November 2014 (Cape Cod Commission 2014). As part of the settlement agreement, the state agreed to update the 1978 Section 208 Plan, which would then be submitted to the EPA for review (Cape Cod Commission 2014).

In January 2013, the state handed the responsibility of updating the Section 208 Plan to the Cape Cod Commission, which had succeeded the Cape Cod Planning and Economic Development Commission in terms of duties (Cape Cod Commission 2015). With a project budget of $3.35 million, the Cape Cod Commission was obligated to complete the 208 Update within one year (Cape Cod Commission 2015, Perry pers.)
com.). Through the 208 Plan Update, the Cape Cod Commission expanded the target of the 1978 Plan from drinking water quality and concerns analyzed in Chapter 3 to addressing eutrophication due to nitrogen loading.

4.5. The 208 Plan Update and the Case for Bottoms Up Planning

The Cape Cod Commission successfully completed the Plan 208 Update in June 2014, and while it shares many similarities with the 1978 Plan, differences in style show how it functions to empower local residents towards combating eutrophication as an alternative to top-down regulation (Cape Cod Commission 2015). Like the 1978 Plan before it, the 208 Plan Update lacked the authority to regulate pollution, but the Cape Cod Commission took the opportunity to expand on the precedent set by the 1978 Plan in several ways. By taking an approach oriented around identifying points of concern, the underlying causes behind them, and proposing solutions, the 208 Plan Update presents a comprehensive analysis of eutrophication on Cape Cod as the 1978 Plan had done for drinking water concerns prior. The analyses in the 208 Plan Update range in scope and size from the geological background of Cape Cod to methods of funding CWMP programs to technological solutions to curbing nitrogen pollution, and every angle of the eutrophication problem is acknowledged at least briefly in the document. At the same, the 208 Update separates itself from its 1978 counterpart visibly, through the inclusion of many tables, diagrams, and maps regarding natural processes, kinds of permitting, and implementable solutions so as to easily and quickly introduce the reader to each topic without extensive text and technical explanations.
The wide breadth of subjects covered in the 208 Plan Update and its reliance on readily discernable data through figures and tables allows residents to better understand eutrophication in their area and solutions to combating it. The document is careful to suggest possible solutions for towns to consider, but never to claim an optimal solution that towns should implement, leaving judgement of the information supplied to the discretion of the residents (Cape Cod Commission 2015). In this way, the Cape Cod Commission was able to use the opportunity of updating the 208 Plan as a means to introduce eutrophication mitigation strategies to towns designing CWMPs as well as to educate locals on the gravity of the situation, its causes, and the possible implementation of solutions that they will eventually vote on. By educating residents, the 208 Plan Update can empower them as stakeholders by granting them the information needed to participate in public discussion on the issue, give input on the development process, and make a more educated decision on whether or not to approve their town’s CWMP proposal and the solutions described within during the final vote.

While the 208 Plan Update is both comprehensive in subject and accessible in style, these traits also reveal its drawbacks. The 208 Plan Update itself is immense, 254 pages—over half the size of the original 1978 Plan it was meant to update. At the same time, though each topic is neatly organized and discussed, the document rarely spends longer than one or two pages on any particular topic, leading the reader through a whirlwind course meant to introduce the reader to conditions all around the Cape. With some exceptions, the document rarely analyzes conditions in detail for any particular
area, and analyses are usually restricted to across the Cape. Overall, the 208 Plan Update loses the accessibility it had gained from its wide frame of analysis through its overwhelming size and comprehensiveness, pushing the reader to pick out certain sections rather than read the comprehensive introduction of various subjects and to make up for its wide geographic range with independent research on the reader’s locality. Like the 1978 Section 208 Plan before it, the usefulness of the educative material presented in the 208 Plan Update rests on the reader’s engagement and willingness to follow up topics with research centered on their particular town.

4.5.1. The Section 208 Update and Funding

Since federal funding for Section 208 of the Clean Water Act was exhausted in 1981, the Cape Cod Commission has proposed state and federal sources of funding through the 208 Plan Update. The 208 Plan Update recommended that the state allow Targeted Watershed Management Plans to apply for funding from the State Revolving Fund, a program organized by the state to provide zero percent loans for wastewater infrastructure projects towards nutrient management. Regulators made these changes in 2016, which allowed Falmouth to use the program for the Little Pond sewer expansion project in 2017 (Cape Cod Commission 2015, Gentile 2015). The 208 Plan Update also recommended that the EPA expand the Southeast New England Coastal Watershed Restoration Program, which has provided over $2 million in funding since 2014 (Cape Cod Commission 2015). In 2014, the state Environmental Bond Bill allocated $4 million for monitoring programs and $4.5 million for pilot projects related to water
quality (Cape Cod Commission 2015). The 208 Plan Update recommended that the state make these funds from the Environmental Bond Bill available to Cape Cod projects consistent with the 208 Plan Update, and in 2006 the state agreed, providing the county with $250,000 each year for four years to support a region-wide water monitoring program (Cape Cod Commission 2015).

4.5.2. The Section 208 Update and Watershed-Based Solutions

Aside from the breadth of educational material presented in the 208 Plan Update, the document also recommends streamlining the planning and eventual implementation of programs meant to mitigate eutrophication. The 208 Plan Update argues for reframing eutrophication solutions away from the town-wide focus of CWMPs and towards a system organized around watersheds, dubbed Targeted Watershed Management Plans (TWMPs).

Because eutrophication is caused by nitrogen-polluted groundwater traveling through these watersheds, focusing on watershed-based solutions as organizational spaces rather than an entire townscape is a better-suited approach than town-wide CWMPs, due to the mismatch between watershed and town boundaries. Figure 4.1 shows a map of the watersheds in Falmouth.

As Figure 4.1 shows, the areas of watersheds are often not well captured by town boundaries, and so Falmouth shares several watersheds with Mashpee, Sandwich, and Bourne. Until recently, towns have mostly kept to themselves with regard to the
Figure 4.1. Map of Falmouth watersheds and coastal embayments. Sources: MassDEP and SMAST (n.d.), Cape Cod Commission GIS (2017), and GHD Engineering Inc. (2013).
implementation of solutions to eutrophication, a consequence of a 300-year tradition of individualism and small-town rivalries (Williams *pers. com.*).

By organizing eutrophication-mitigation strategies according to towns, Falmouth, Mashpee, Sandwich, and Bourne must each plan CWMPs for the estuaries under their municipal boundaries while also bearing pollution output from the other towns’ whenever watersheds are shared across boundaries. In doing so, local stakeholders to a single watershed remain divided by town-specific plans, regulations, and solutions despite contributing to eutrophication of their local estuaries through the same watershed.

Under TWMPs, eutrophication mitigation programs are still implemented by a town, require approval by the same voting processes held under CWMPs, and undergo the same regulatory approval process by the DEP and EPA as CWMPs. However, TWMPs are limited in scale only to a particular watershed (Cape Cod Commission 2015). When a watershed is shared by multiple towns, the towns share an intermunicipal agreement (IMA) that commits towns to providing agreed upon resources, facilities, and payment so that each town contributes to the implementation of the watershed-specific programs as part of each towns’ TWMPs.

Perhaps the most critical aspect of watershed-based management is the lower financial burden of watershed management plans, alleviating the common sticking point for voters that have rejected CWMPs in the past. Because CWMPs must present solutions for eutrophication across multiple estuaries within the jurisdiction of a town, the ultimate cost of the proposal is exceptionally high and can be intimidating to voters.
Furthermore, the implementation of solutions for any one estuary is dependent on a passing vote for the entire management plan. By taking a more piecemeal approach to eutrophication management, watersheds that lie completely within the boundary of a town would still benefit from a TWMP approach, as proposals for the particular watershed would both be independent from that of other watersheds and would carry a smaller price tag than a CWMP proposal, increasing the likelihood of voters approving the passage of the plan.

While TWMPs are designed to circumvent issues surrounding CWMPs, they may also create complications. The successful approval of TWMPs shared by multiple towns rely on cooperation between towns, which traditionally celebrate their individuality, participate in rivalries, and function independently. Should towns be willing to cooperate, negotiations between towns concerning how to distribute both costs and responsibilities are likely be a tedious process. Finally, the Section 208 Plan Update make no mention of ways towns should negotiate disagreements, and such a process would need to be agreed on by towns themselves (Cape Cod Commission 2015).

Evaluations of both the effectiveness and hurdles of the TWMP approach are limited by the few number of TWMPs currently in place and how recent they are. In 2013 Falmouth implemented its CWMP, containing within it a TWMP for the Little Pond Watershed that called for sewage implementation in the Little Pond area (GHD Engineering Inc. 2013). In this situation, Falmouth’s approach to the Little Pond Watershed was decided independently of other towns, because its borders lie within Falmouth’s boundaries. Instead, the TWMP was used as a way to divide Little Pond’s
sewage implementation proposal from the rest of the CWMP during approval (GHD Engineering Inc. 2013). This implementation and the effectiveness of sewage as a eutrophication-mitigation solution will be discussed in the following chapter.

In late 2017, the towns of Barnstable, Mashpee, and Sandwich approved an IMA for the Popponesset Bay Watershed, serving as a model for the 208 Plan Update’s proposed implementation of targeted watershed management (Houghton 2017). Since Mashpee is responsible for over half the nitrogen inputs to Popponesset bay, the towns coordinated intermunicipal funding responsibilities by naming Mashpee as the fiscal agent to “receive, hold, and expend any funds appropriated by the parties for joint actions required in the implementation of this agreement” (Towns of Barnstable, Mashpee, and Barnstable 2017, p. 3). For projects taken independently by each town, financing is determined as part of their TWMPs or CWMPs (Towns of Barnstable, Mashpee, and Barnstable 2017). The IMA agreement carries no authoritative power in terms of implementing solutions to eutrophication. However, it does implement the creation of a “Work Group”, a collection of representatives of each town to research solutions and propose recommendations for each of the towns (Towns of Barnstable, Mashpee, and Barnstable 2017). Similar to the 208 Plan Update, the power of the IMA is felt in its administrative decisions and implementation of particular programs will rest on town governments themselves. Ultimately town representatives are confident that a watershed-based approach is the best way to frame the problems and solutions to eutrophication. As Mashpee Selectman Andrew Gottlieb stated, “We all share in causing the problem; therefore, we all share in the solution” (Houghton 2017, n. p.).
4.6. Conclusion

The lack of regulation on non-point sources under the Clean Water Act has seriously hampered regulatory authority on septic tanks that would have facilitated top-down reform concerning eutrophication, leaving the state and local governments with a relatively vague and weak framework for which to handle the issue. However, the precedent set in place in the 1978 Plan have organized the regional and town governments into a system that can evaluate and implement solutions through nitrogen mitigation. Though this system lacks strong enforcement and has had mixed success, the Cape Cod Commission’s 208 Plan Update helps to motivate local residents through education and simplifies the implementation of solutions through watershed-based approaches, making up for deficiencies in top-down regulation with bottoms-up mobilization of local residents.

The combination of expansive research on eutrophication and the initiatives featured in the 208 Plan Update demonstrate the Cape Cod Commission’s unique qualifications for approaching eutrophication. By educating locals on the urgency of the situation and facilitating their involvement as stakeholders, the Cape Cod Commission has motivated the implementation of solutions to eutrophication on a town scale while still respecting their independence. At the same time, the Cape Cod Commission has shown its ability to improve the framework begun in the 1879 Plan by facilitating work between towns through shared watershed management and providing federal and state sources of funding for towns to use. The CCC’s unique position as a facilitator between federal, state, and town levels of government is an opportunity for federal and state
governments to motivate eutrophication mitigation on Cape Cod by providing resources to the CCC to expand its influence. In this way, both the state and the federal government would be able to facilitate the bottoms-up approach to solution implementation without needing the political consensus needed for a top-down approach through revision of the Clean Water Act.
Chapter 5. Solutions of Falmouth’s CWMP

Chapter 4 evaluates the policy framework towns use to implement solutions for mitigating eutrophication and determines why this framework has led to mixed results. As the previous chapter explains, the use of CWMPs has been unreliable, as voters have criticized the solutions proposed for being too costly and called for workable alternatives. There are many methods to reducing the influx of nitrogen into the estuaries around the Cape, but these solutions vary in effectiveness, cost, ease of implementation, and other criteria, creating uncertainty in locals who ultimately decide whether to reject or accept their town’s CWMP.

In 2013, the Falmouth CWMP proposed several solutions for different water bodies on the town’s east coast, with the goal of meeting TMDL requirements and designing a system of “cost-effective wastewater and nutrient management for a 20-year period” (GHD Engineering Inc. 2013, p. ES–3). Falmouth’s CWMP was successfully finalized by popular vote to approve its funding in 2014, and research, demonstration projects, and steps towards implementation have been underway since then (Gentile 2014). By using the knowledge gained from the proposal and approval of the solutions listed within the Falmouth CWMP, this chapter compares different nitrogen mitigation solutions to draw general conclusions on their suitability that the Falmouth town leadership and policymakers elsewhere can use when deciding how to proceed with further initiatives. This chapter begins with analyses of how the Falmouth CWMP establishes goals for mitigating eutrophication and its steps toward implementing
several solutions. This chapter then compares several solutions listed within the Falmouth CWMP using data from government projects and outside literature to determine the advantages, disadvantages, and suitability of each.

5. 1. Solutions of the Falmouth CWMP

In order to determine the extent to which nitrogen mitigation strategies would be needed within the town’s embayments, the Falmouth CWMP identifies the percentage of wastewater removal per watershed necessary to meet TMDL requirements for its embayments [Figure 5.1]. In many cases, the extent of eutrophication caused by wastewater nitrogen is warranted enough to demand a complete removal of wastewater nitrogen from the system, a monumental task. To reach the TMDL requirements for each waterbody, the CWMP identifies several solutions and sets forth plans for future implementation.

The CWMP organizes these solutions as either “traditional” or “non-traditional”, according to their stature as commonly accepted wastewater and nutrient management strategies (GHD Engineering Inc. 2013). The sole traditional wastewater management strategy is the expansion of sewage service to the Little Pond area, which was approved through a Little Pond-specific TWMP within the larger CWMP and completed in 2017 (Lowell pers. com., GHD Engineering Inc. 2013). Non-traditional solutions include alternative treatment units (ATUs), inlet widening, and shellfish aquaculture. Though other solutions are included in the Falmouth CWMP, the evaluations and comparisons made in this chapter will center on these four methods.
Figure 5.1. Map showing embayments and watersheds for the southern coast of Falmouth. Numbers indicate the percent of wastewater removal necessary to meet TMDL requirements. Sources: Rafferty (pers. com.), Cape Cod Commission GIS (2017). Falmouth (2017), GHD Engineering Inc. (2013), Reckford (2008).
Overall, the steps to implementing solutions listed in the Falmouth CWMP are gradual and indicate a conservative approach. Though the CWMP lists these solutions as part of the town’s plan, the CWMP does not describe how to implement them. Instead, these solutions undergo evaluation through demonstration projects, programs begun independently from the CWMP to test their ability to adequately reduce nitrogen in impaired waterbodies around Falmouth. The demonstration projects also give insight on the social aspects to their solutions, such as imposed costs and local opinion. Because the demonstration projects are still underway, their results will determine to what extent Falmouth uses these solutions in the future and how they will be implemented. The Falmouth CWMP describes this approach as ‘adaptive management’ (GHD Engineering Inc. 2013). Scientific literature regarding these solutions also describes the underlying mechanisms behind these methods. By using scientific literature to explain these solutions and demonstration projects to evaluate their suitability, the comparisons made here can give insight to Falmouth town leaders when considering these solutions for implementation and to other towns when considering whether to follow the initiatives Falmouth has adopted.

5.2. Sewage

Falmouth has grappled with its history of sewage treatment implementation for decades. Falmouth’s current sewage treatment infrastructure is fairly recent. As previously stated, Falmouth’s sewage treatment plant was first approved in 1979 and completed in the 1980s, replacing septic systems for several communities and curtailing
wastewater from continuing to enter their local watersheds (Smith 1988, Town of Falmouth n.d.). Instead, the wastewaters from these communities were consolidated through the sewage system, treated, discharged as groundwater into West Falmouth Harbor via the local watershed. At the time of the facility’s completion, wastewater was treated via aeration ponds that did little to mitigate the flow of nitrogen that entered West Falmouth Harbor (Pires pers. com.).

The large quantities of wastewater discharged by the facility to West Falmouth Harbor has been a primary concern for many years. In 2006, the wastewater treatment facility contributed 43% of the total measured land-derived nitrogen loads to West Falmouth Harbor (Kroeger et al. 2006b). The 2007 TMDL for West Falmouth Harbor estimates that the treatment facility contributed 60% of all nitrogen loading in West Falmouth Harbor (MassDEP 2007). Total nitrogen loads to West Falmouth Harbor ranged from 1.24-40.77 kg/day, varying between sites within West Falmouth Harbor. This resulted in nitrogen concentrations around West Falmouth Harbor ranging from 0.34-0.74 mg/L by site (MassDEP 2007). To reach adequate water quality standards necessary for curbing eutrophication, the TMDL mandated that the West Falmouth Harbor embayment system be restricted to nitrogen loads between 1-7 kg per day, depending on location, for an overall nitrogen concentration of 0.35 mg/L (MassDEP 2007). The most impacted site within West Falmouth Harbor was Mashapaquit Creek, which receives 62% of the nitrogen load to West Falmouth Harbor (Howes et al. 2006b). As a result, it receives the highest quantity of nitrogen and holds the highest nitrogen concentration in the harbor. The excessive nitrogen loads entering West Falmouth
Harbor has resulted in eelgrass loss, algal blooms, deoxygenation events, and reduction of species diversity, with some of the worst habitat degradation effects found in Mashapaquit Creek (Jakuba pers. com., Buzzards Bay Coalition 2015a, MassDEP 2007).

To mitigate nitrogen loading from the treatment facility into West Falmouth Harbor, the town of Falmouth upgraded its wastewater treatment facility in 2005 and 2016 with technology meant to remove nitrogen from the treated effluent (Town of Falmouth n.d.). This technology relies on a pair of Sequencing Batch Reactors, an illustration of which is provided in Figure 5.2.

![Sequencing Batch Reactors Phase Cycle](image)

**Figure 5.2.** Model of the Sequencing Batch Reactors in the Falmouth WWTF. Each reactor goes through a cycle of filling, mixing, settling, and decanting of waste, however the reactors are not synchronized in their cycles. Modified from CDR Maguire Corporation (n.d.).

The Sequencing Batch Reactors of the Falmouth Wastewater Treatment Facility function by creating conditions for which the nitrogen cycle can convert organic
nitrogen and ammonia (NH$_3$) found in waste into nitrogen gas (N$_2$). These conditions are formed through a series of settling and mixing phases within each reactor. During mixing, aeration allows nitrifying bacteria to fix the nitrogen into nitrate, NO$_3$. During the settling period, the loss of oxygen in the waste allows denitrifying bacteria to convert the NO$_3$ to molecular nitrogen, N$_2$, releasing the nitrogen as nitrogen gas. Once the nitrogen is removed from the waste, the liquid component is decanted and treated for pathogens before being released into the filtration beds (Dutta and Sarkar 2015, New England Interstate Water Pollution Control Commission 2005, Pires, pers. com.).

Through the use of Sequencing Batch Reactors, the Falmouth Wastewater Treatment Facility was able to reduce the nitrogen concentration of the facility’s treated discharge from 27mg/L to 3 mg/L, removing over 90% of nitrogen from the wastewater (Reckford 2007). This performance makes nitrogen-mitigating sewage treatment one of the most effective means of removing nitrogen from discharge (MassDEP 2014, Reckford 2007). Before the facility’s upgrades, between 5,000-10,730 kg of nitrogen was released into West Falmouth Harbor between 1991 and 1998 (Howes et al. 2006b). After these upgrades, this has been reduced to 1,863 kg per year (MassDEP 2014). The low concentration of nitrogen discharge is required by the facility’s groundwater discharge permit, and though these requirements are not always met due to cold weather or mechanical issues, violations are rare and contingencies exist to avoid consistent problems (Pires, pers. com.).

Despite the improvements made to the treatment facility, nitrogen discharge remains a concern for West Falmouth Harbor water quality. These improvements are
insufficient for West Falmouth Harbor to reach its prescribed adequate water quality standards, and their beneficial effect on the local environment will take several years to observe due to groundwater flow time between the treatment facility and the local embayment (Reckford 2007). Moreover, the discharge from the treatment facility will continue to disproportionately flow into Mashapaquit Creek and contribute to habitat degradation there.

As West Falmouth Harbor’s condition indicates, centralized waste management via sewage system service can harm areas receiving the facility’s discharge. Should further expansion of sewage service continue, as has been considered for areas of East Falmouth such as Great Pond, Green Pond, and Bournes Pond, the habitat degradation at the discharge site will continue as the quantity of nitrogen discharged rises with service expansion (GHD Engineering Inc. 2013). As approved under its TMDL, sewage service arrived at the Little Pond area in 2017, adding about 1,400 homes to the town’s sewage service (GHD Engineering Inc. 2013). To mitigate the amount of nitrogen discharge reaching West Falmouth Harbor, the Falmouth CWMP considers creating new discharge sites in several areas, however doing so would threaten environmental conditions in those sites as well and has sparked opposition from residents of these proposed sites (The Falmouth Enterprise 2018, GHD Engineering Inc. 2013). The CWMP proposes the creation of an ocean outfall pipe to release the discharge away from coastal embayments, a strategy already employed in Boston and other areas on the Cape. The implementation of new outfall pipes is banned in Massachusetts under the state Ocean Sanctuaries Act with the intention of preserving ocean water quality,
however recent changes by the state legislature has provided the means for an exception under the condition that the discharge be thoroughly treated (Rafferty pers. com., Feldott 2018b). Town selectmen are expected to receive formal recommendations regarding future discharge sites by 2021 (Feldott 2018b).

The extent to which the wastewater treatment facility today will contribute to eutrophic conditions in Mashapaquit Creek and West Falmouth Harbor is difficult to predict. Due to the hydrology of Cape Cod, it takes 6 years for effluent from the treatment facility to travel via the local watershed and reach the harbor, creating a time lag between discharge via groundwater and arrival to the harbor and a subsequent gap between the reduced nitrogen discharge loads from the facility and measurable differences in water quality within the harbor (Howes et al. 2006b). Research by the MEP predicted that nitrogen loads in the Mashapaquit Creek should decline after 2010 to coincide with the lower concentration of nitrogen produced by the facility’s upgrades established in 2005 (Howes et al. 2006b). However, these upgrades have not yet been reflected in overall conditions of Mashapaquit Creek as researched by the Buzzards Bay Coalition (Buzzards Bay Coalition 2015a).

Aside from the burdens placed on discharge sites, sewage service is also significantly hampered by cost. Falmouth’s sewage system, approved in 1979, cost $30 million dollars and relied on state and federal funding (Smith 1986, Town of Falmouth n.d.). It cost $14.8 million to upgrade the treatment plant for nitrogen mitigation in 2005 (Reckford 2003). Recent controversy concerning the high cost of sewage implementation emerged with the construction of sewage service for Little Pond, which
was completed in 2017. Just under $30 million, the Little Pond extension was funded for by the town through the State Revolving Fund, a program organized by the state to provide 0% loans for wastewater infrastructure projects for nutrient management and a popular resource for towns around the Cape (Gentile 2015, Cape Cod Commission 2015). To finance the loan, the town established a system where 70% of the amount would be paid for by Little Pond residents through a betterment charge and 30% would be paid through taxes levied on the whole town (Gentile 2014). The average betterment was estimated at about $13,000 and can be paid in full, part, or across 30 years at 0% interest (Cole 2017). Additionally, homeowners are also charged a hook up fee usually between $3,000-5,000 (Gentile 2015). These charges have been a serious concern for Little Pond residents, who attended informational meetings and town halls by the hundreds to express their opinions, sometimes with agitation at the high cost or suspicion that alternative solutions would be cheaper to implement (Gentile 2014a, Gentile 2015).

As Falmouth considers further expanding its sewage service, more residents have objected to potential high costs imposed on them and have casted doubt on the service’s effectiveness. In 2009, two town selectmen feuded over whether sewage service was the only viable option for nitrogen mitigation in East Falmouth, in reference to a proposal to provide sewer services to East Falmouth that would cost $350 million-390 million dollars to build and $2.9 million-5.9 million to maintain per year (Kazarian 2009). While sewage implementation remains adaptable, reliable, and a commonly used waste management system, its high cost and effect on habitats downstream of
discharge sites demand that sewage implementation be reserved as a nitrogen reduction technology for only the most severely eutrophic areas (Neill pers. com., Hugus 2009).

5.3. Alternative Treatment Unit (ATU) Systems

The limitations of sewage system implementation restrict sewage to dense communities where the infrastructure necessary would be most efficient. For areas with wider distributions of houses, other methods of nitrogen effluent mitigation will have to be explored. Most prominent of these methods are innovative/alternative systems (ATUs), self-contained waste management systems that function in a similar manner as septic tanks. Like septic tanks, ATUs are buried in the property of the homeowner, collect solid waste that is periodically pumped out by contractors, and discharge liquid wastewater to the watershed (Heufelder pers. com.). Unlike septic tanks, ATUs contain technology that is able to capture nitrogen from waste before releasing the liquid discharge to the watershed, preventing the nitrogen from flowing to the estuaries. Alternative treatment units rely on several different designs to remove nitrogen from wastewater effluent. Like the sequencing batch reactors in the Falmouth WWTF, all ATU designs rely on the use of nitrifying bacteria and denitrifying bacteria by subjecting the waste to both aerobic and anaerobic conditions through fans, pumps, gravity, and other methods (Heufelder pers. com., Heufelder et al. 2007, Washington State Department of Health 2005).
Standardized testing of these designs takes place in only a few locations around the country (Heufelder *pers. com.*). One such location is the Massachusetts Alternative Septic System Test Center (MASSTC), created in 1999 by Barnstable County and the Massachusetts Office of Coastal Zone Management through an EPA program (Heufelder *pers. com.*, MASSTC n.d.). The facility is directed by George Heufelder, who helped found MASSTC and has served as Barnstable County’s Health Director and on the Falmouth Board of Health for 25 years (Heufelder *pers. com.*). Typically, corporations or universities pay to have their systems evaluated through third-party standards or to conduct research and development in the MASSTC (Heufelder *pers. com.*).

Evaluations of ATUs by MASSTC and other testing sites show that nitrogen removal effectiveness is largest shortcoming of the technology when compared to sewage. While the nitrogen mitigation technology of the Falmouth WWTF is able to accomplish concentrations of 3mg/L of nitrogen, over 90% removal, current on-market solutions tend to range between 50%-60% removal (Heufelder *pers. com.*). A nitrogen removal rate of 50% is assumed to be approximately 19 mg/L, the regulatory requirement per state regulations (Heufelder *et al.* 2007). Reaching rates of 50% nitrogen removal is also inconsistent, with most systems doing so only about 77% of the time (Heufelder *pers. com.*). There are many operating condition factors that complicate nitrogen removal efficiency by interfering with the success of the nitrifying and denitrifying bacteria, such as fluctuating flow rates, temperature, and alkalinity (Washington State Department of Health 2005). The accuracy of data accumulated in the field versus actual performance can also vary, as taking representative
measurements of beginning nitrogen concentrations of fresh wastewater is made difficult in systems that mix denitrified and fresh wastewater in the ATU system (Heufelder et al. 2007). Taking representative samples of influent before entering an ATU system is also difficult due to the wide range of wastewater sources, such as from toilets, sinks, and laundry machines that each have different initial concentrations of nitrogen (Heufelder et al. 2007).

Analysis of cost to homeowners indicates that cost remains a concern for the implementation of ATUs. Research conducted by the Barnstable County Wastewater Cost Task Force shows that traditional Title 5 septic systems cost between $8,000-15,000 to implement, depending on soil and groundwater properties (Barnstable County Wastewater Cost Task Force 2010). Implementation of nitrogen mitigation technology has been estimated from $17,000-30,000 and from $15,000-25,000, making it slightly more expensive than the betterment costs for sewage implementation in Little Pond (Barnstable County Wastewater Cost Task Force 2010, Cole 2017, Gentile 2015, Houghton 2014). Additionally, operation and maintenance costs are estimated to be around $1,000 per year, since ATUs constantly require electricity for moving parts such as fans and pumps (Heufelder pers. com., Houghton 2014, Barnstable County Wastewater Cost Task Force 2010). Given the high maintenance cost, the town would likely need to devote resources and personnel to implement a program of regular monitoring and enforcement to ensure homeowners across the community leave their ATUs running as necessary and are functioning properly (Heufelder pers. com.).
While the cost of ATU implementation and maintenance is somewhat higher than costs incurred through the Little Pond betterment program, this comparison is likely to differ when considering the expansion of either solution across the town. Future areas considering sewage implementation may face higher costs depending on local housing density and feasibility of construction. Furthermore, taxes incurred by the entire town to pay for sewage implementation, as those intended to pay for sewage in Little Pond, are likely to continue to increase as sewage service is expanded. While town residents would have to devote more taxes to sewage service expansion for other residents, costs incurred through ATU installation are on a homeowner basis, keeping the cost of ATU installation constant even with growing popularity. A study conducted by Wood et al. (2014) indicated that, when considering a one-solution answer, alternative treatment unit implementation across the town would be significantly cheaper than sewage service over time.

Overall, comparisons between sewage service and ATU implementation show that ATUs are a reasonable method for curtailing nitrogen discharge to local watersheds. Though ATU implementation exceeds recent costs imposed through betterment fees for sewage service, overall costs are likely to be cheaper than sewage service implementation on a town-wide basis and a refrain from increased taxes. However, on-the-market ATUs suffer from their inability to compete with sewage treatment in terms of nitrogen effluent concentrations, with current ATUs producing nitrogen concentrations six times higher than effluent discharged by the Falmouth WWTF (Heufelder pers. com., Reckford 2007). Their performance leaves them best
implemented in areas with housing densities too low for justify sewage implementation or as a strategy for reducing tax burdens at the cost of lower nitrogen mitigation effectiveness.

The low effectiveness of ATUs in terms of nitrogen mitigation may soon change. Researchers from the MASSTC, University of Rhode Island, Stony Brook University in New York, and from Florida have developed a new method for nitrogen mitigation meant to work using septic systems, dubbed “layer cake systems” (Heufelder pers. com., Feldott 2016). These layer cake systems function by layering soil beneath the leach field of a septic system with wood byproduct like sawdust or woodchips, to facilitate the growth of denitrifying bacteria (Heufelder pers. com., Feldott 2016). While testing began in 2014 at the MASSTC and is still ongoing, results have been promising, with a nitrogen removal rate of over 90% and nitrogen concentrations of 3.8 mg/L, rivaling the performance of the Falmouth WWTF (Heufelder pers. com., Feldott 2016). The installation of these systems is also dramatically cheaper than ATU systems, at about $10,000 (Feldott 2016). It is not known when layer cake systems will be readily available to homeowners, but further investigation is required to determine their effectiveness over time (Heufelder pers. com.). Because the wood byproduct in these systems provides on a finite supply of carbon beneath the leach field, a method for maintenance will have to be devised to replenish the carbon supply and preserve the system’s effectiveness (Heufelder pers. com.). However, these systems have already been implemented in limited numbers to homes in Falmouth under a pilot program coordinated by the Buzzards Bay Coalition in 2016 (Buzzards Bay Coalition 2016).
5.4. Oyster Aquaculture

While sewage service and ATUs are solutions to eutrophication defined by their ability to mitigate nitrogen effluent from entering estuaries, the Falmouth CWMP has also considered the implementation of solutions meant to reduce the level of nitrogen already in estuaries (GHD Engineering Inc. 2013). Oyster and shellfish aquaculture businesses already dot Falmouth, and their impact on water quality has been noted as a method for curbing eutrophication by reducing nitrogen quantities already present in estuaries. By consuming algae that overpopulate due to excess nitrogen, oysters are able to remove nitrogen from the system or convert it to other forms (Reitsma et al. 2017, Caffrey et al. 2016, Kellog et al. 2014, Carmichael et al. 2012). At the same time, the removal of algae improves water quality by improving water clarity and lowering concentrations of organic nitrogen (Caffrey et al. 2016, Kellog et al. 2014). While many shellfish perform these benefits, the Falmouth CWMP chose the oyster *Crassotrea virginica* for its effectiveness in storing nitrogen and its potential marketable value (GHD Engineering Inc. 2013).

After oysters consume algae, the nitrogen is stored through several methods. In a review paper analyzing oyster use to mitigate eutrophication, Kellogg et al. (2014) determines that these storage methods vary widely in their permanence and are determined through many complex environmental variables. Digested nitrogen can be assimilated into the shell or soft tissue, both of which can store the nitrogen for years. It can be deposited on sediment as feces, where it may be consumed by organisms, buried
in sediments, or converted into other forms of nitrogen NO$_3$ and N$_2$. Oysters can also return the nitrogen quickly back into the water column through ammonium, urea, and other waste products. Of these results, assimilation, long-term burial, and conversion to molecular nitrogen provide the most substantial long-term storage (Kellogg et al. 2014). The distribution of how the oysters store the nitrogen consumed among these three methods varies widely with environmental conditions. Assimilation relies heavily on biological behaviors influenced by water temperature, salinity, tidal regime, and other variables. Storage time of feces depends on local hydrodynamic properties, while conversion to molecular nitrogen depends on factors such as dissolved oxygen concentrations, sediment geochemistry, and water column nutrient concentrations.

Scientific analysis of oyster aquaculture effectiveness has been difficult given the many variables that determine how nitrogen is stored. As Kellogg et al. (2014) note, no study has been able to collect sufficient data from a single site to estimate the combined nitrogen mitigation of all three storage methods of $C.~virginica$, and most rely on only a single method of nitrogen mitigation. Furthermore, there have no published studies on long-term nitrogen storage through sediment burial. Analysis by these same authors on papers concerning denitrification showed mixed results, with both positive and negative denitrification rates and few values significantly different from zero. Analysis on studies of nitrogen assimilation in soft tissue showed a range between 7.4 to 11.8% of mean values. Overall, oysters from sites in the mid-Atlantic and New England averaged nitrogen contents of about 8.5% N g$^{-1}$ DW for soft tissue and 0.2% N g$^{-1}$ DW for shells. In a separate review study, Carmichael et al. (2012) found that nitrogen mitigation through
assimilation of the sites studied ranged from less than 1% to 15% of total annual nitrogen load for their water bodies, with a daily maximum of 25% daily load. Kellogg et al. (2014) refer that the wide variation in results per study indicate that reliable estimates for nitrogen assimilation require that testing be done through site-specific analysis.

To test the feasibility of oyster aquaculture as an effective nitrogen mitigation strategy in Falmouth, the town began testing in 2012, beginning with a viability test in Little Pond and Green Pond to determine if oysters could be cultivated at all in the eutrophic waters, given the effect of eutrophic conditions on bay scallop decline in the past (GHD Engineering Inc. 2013). The results were surprisingly favorable, defying expectations of a 50% survival rate with a mortality rate of 1 out of 1,247 individuals, likely due to good husbandry, resilient genes, lack of predation, and low stocking densities (GHD Engineering Inc. 2013). Analysis of low oxygen toleration of 206 marine species by Vaquer-Sunyer and Duarte (2008) also found that C. virginica oysters were extremely resistant to hypoxic conditions. In 2013, the town continued its investigation through the Little Pond Oyster Aquaculture Demonstration Project, which called for 2.5 million oysters to be grown across a two-acre area in two 1.25 million batches (GHD Engineering Inc. 2013). This project has the potential to be invaluable to the restoration of Little Pond, as current data indicates that even the full diversion of wastewater through sewage service would be insufficient for eelgrass to regrow in the area (Howes et al. 2006a). Predictions suggested that the oysters would be able to assimilate 26% of Little Ponds spring-to-fall nitrogen load, approximately 1,250 kg (GHD Engineering Inc.
Results from the 2013 deployment of oysters showed noticeable changes in nitrogen concentrations, as well as reductions in chlorophyll and other measurements attributed to poor water quality due to eutrophication. However, further deployments will need to be used to determine whether oysters are capable of assimilating substantial quantities of nitrogen (Howes et al. 2014). While 2014 marked the new deployment of oysters for monitoring in Little Pond, the town has also been able to expand its efforts to other sites (Howes et al. 2014). In 2014, the town of Falmouth also installed an oyster project in West Falmouth Harbor (Karplus 2017). In 2017, the Falmouth Marine and Environmental Services Department received a grant from the Waquoit Bay National Estuarine Research Reserve to investigate different approaches to oyster aquaculture systems and develop a best practice guide for other groups interested in using aquaculture as a nitrogen mitigation strategy (Feldott 2017a).

Analyses of research articles from many locations show that the performance of oysters in mitigating nitrogen in estuaries is highly variable, and more research is necessary to develop a greater understanding of its effectiveness. While demonstration projects for Little Pond and Waquoit Bay are underway and will supply data needed for their respective locations, the uncertainty regarding the effectiveness of oyster aquaculture indicates that other potential sites in Falmouth and beyond likely require that their own site-specific testing be completed rather than relying on data from other locations. The Falmouth CWMP cites the opportunity to mitigate costs by selling harvested oysters, however more testing must be required to ensure their safety, especially given the recent occurrences of PSP-causing *Alexandrium Fundyense*.
outbreaks in Falmouth estuaries (Crespo et al. 2011). The Little Pond Oyster Demonstration Project cost $200,000 to fund, and while demonstration projects in other areas will likely vary in cost, the potential to reduce the presence of nitrogen in eutrophic estuaries while also providing benefits through algae consumption makes oyster strategies especially notable for dramatically impaired estuaries and estuaries that require large percentages of their current nitrogen load be removed (GHD Engineering Inc. 2013).

5.5. Inlet Widening

Like oyster farming, the Falmouth CWMP also considers inlet widening as a means for mitigating eutrophication by minimizing nitrogen once it has traveled through the watershed and arrived at estuaries. Ordinarily, nitrogen levels in estuaries are gradually reduced by tidal flushing, carrying the excess nitrogen to open ocean. In some embayments, such as Bournes Pond, narrow inlets limit the tidal outflow of the estuaries, resulting in higher tidal attenuation and longer residence times of the tidal water (Howes et al. 2005). To greater facilitate tidal outflow of nitrogen from the estuaries into open ocean, the Falmouth CWMP has considered construction projects to widen the inlets of Bournes Pond and Little Pond, with the expectation that inlet widening be a quick and cost-effective means of improving water quality in the estuary (GHD Engineering Inc. 2013).

Like many of the estuaries around Falmouth, Bournes Pond is overladen with nitrogen loads from the local watershed, as 100% of wastewater nitrogen will need to
be removed from the estuary (GHD Engineering Inc. 2013). A MEP report from 2005 describes the current nitrogen loading situation in Bournes Pond and the potential benefits of inlet widening there. The report shows that estimated average daily nitrogen load to Bournes Pond is 9.61 kg/day, largely due to anthropogenic loading; a scenario with no anthropogenic nitrogen loading would provide only 0.95 kg/day (Howes et al. 2005). Figure 5.3 shows a model simulation supposing the hydrodynamics of Bournes Pond after increasing the inlet width from 50 feet to 100 feet. While the elevation of the tides is not expected to change, the period of the tide is shifted, reducing residence time of the tide from 1.09 days to 0.82 days (Howes et al. 2005). The simulated enhanced tidal outflow produced nitrogen concentrations reductions of 11.4% in the mid-section of the pond, though lower in other areas (Howes et al. 2005). Though inlet widening would be cheaper than the implementation of sewage service on the Bournes Pond watershed, inlet widening would be unable to meet the nitrogen concentrations required for the restoration of Bournes Pond. However, the implementation of both sewage service and inlet widening would be sufficient in improving nitrogen concentrations to restoration levels.

Since the release of the MEP report in 2005, the town of Falmouth has moved past simulated models of Bournes Pond and towards direct action. In 2012, the town initiated the Bournes Pond Inlet Opening Demonstration Project as a way to investigate the feasibility of inlet widening by using Bournes Pond as a model (GHD Engineering Inc. 2013).
Figure 5.3. Modeled tide behavior for existing conditions (top) and for conditions after the implementation inlet widening to 100ft (bottom). Source: Howes et al. (2005).

The Falmouth CWMP summarizes the key expectations for the demonstration project. The demonstration project calls for a 90ft wide inlet through the removal of 12,600 square feet of coastal bank and barrier beach and the dredging of 5,800 cubic yards to the north and south of the inlet, as well as the construction of a longer bridge to replace one currently in use (Feldott 2017c, GHD Engineering Inc. 2013). This would result in the removal of an estimated 1,995 kg of nitrogen per year (GHD Engineering Inc. 2013). The estimated total cost is $5,520,000, making it substantially cheaper than
the traditional alternative (GHD Engineering Inc. 2013). The total cost of sewage service for the equivalent amount of nitrogen reduction would be between $12,830,000 to $19,130,000 (GHD Engineering Inc. 2013). Funding for the project was approved in April 2014 (Bray 2016).

Despite the move to widen Bournes Pond under the Bournes Pond Inlet Opening Demonstration Project, there are several significant drawbacks to its implementation. Applicability of the demonstration project to other areas is limited to embayments with similarly narrow inlets. The narrow inlet of Bournes Pond produces great tidal attenuation, resulting in average tide range in Bournes Pond is substantially less than the range of offshore tides, but this is not the case for neighboring Great Pond and Green Pond due to their wider inlets (Howes et al. 2005). The widening of the Bournes Pond inlet carries with it concerns regarding erosion. In 2017, property owners on Bournes Pond filed an appeal with the Massachusetts Department of Environmental Protection to halt the project based on fears that the increased tidal flow would erode the shores of Bournes Pond.

Fears of erosion around Bournes Pond are part of a larger conversation concerning erosion around Falmouth and Cape Cod in general. The Massachusetts Office of Coastal Zone Management and the Cape Cod Commission have cited coastal erosion, flooding, and shoreline change as the greatest risk for residents on Cape Cod (Roberts et al. 2015). These fears are rooted in the threat of sea-level rise, which have been made significant due to concerns regarding sea level rise as a result of climate change. In some areas of Cape Cod, sea level rise is expected to rise as high as 6ft by 2100, and areas
around Cape Cod such as the Cape Cod National Seashore are at extremely susceptible to weathering from sea level fluctuations, storms, tides, and other mechanisms (Walter et al. 2016, Hammar–Klose et al. 2003).

While erosion and sea-level rise are serious concerns for Cape Cod, inlet widening for Bournes Pond has little effect due to the geological and anthropological conditions of Falmouth and the Bourne Pond area. Due to the presence of Nantucket and Vineyard Sounds and the position of Falmouth’s southern coast in relation to the Atlantic Ocean, the wave environment around Bournes Pond and neighboring Great and Green Ponds is comparatively calmer than other areas around the Cape, resulting in low observed longshore transport rates of sediment (Howes et al. 2005). Because of the quiescent wave environment and small tide range around Great, Green, and Bourne Ponds, inlet migration of these embayments is not a serious concern, and the construction of jetties around the ponds have further caused their inlets to remain fairly stable over time (Howes et al. 2005). Similarly, the quiescent wave environment inhibits erosion within Great and Green Ponds despite having inlets about 100ft wide, suggesting that widening the inlet of Bourne Pond will have little impact on the shores of the pond (Ramsey et al. 2015). Analysis of future projections of sea-level rise around Bourne’s Pond indicate likely sea-level rise between 0.8 and 1.3 feet by 2090, and a more liberal estimate of 2.8 feet by 2090 [Figure 5.4] (Ramsey et al. 2015). These projections place sea-level rise under 4.5 feet by 2090, the estimated lowest elevation of the road that passes through the Bournes Pond inlet and the expected end of the proposed bridge’s designed lifespan (Ramsey et al. 2015).
Figure 5.4. Analyses of predictions for sea-level rise given models by the Intergovernmental Panel on Climate Change [IPCC] (2007) and IPCC and Rignot (2011). Source: Ramsey et al. (2015).

Sudden flooding from storm surges brought on by hurricanes and severe storms are severe concerns to Falmouth and are likely to increase in frequency due to climate change. However, flooding conditions of 100-year storms are predicted to reach 10.1ft, overtopping the elevation of the road and allowing floodwaters to enter regardless of inlet widening (Ramsey et al. 2015). In the event of flooding, models determined no significant difference in storm surge height between the current inlet width and proposed inlet width (Ramsey et al. 2015).

Several engineering projects have been undertaken to ‘armor’ the beachside and prevent sediment loss. Around the late 1800s and early 1900s, shoreline armoring projects consisting of stone and wooden groin fields and bulkheads have helped keep
sediment in place around the southern coast of Falmouth such as around Bournes Pond (Howes et al. 2005). Additionally, the glacial deposit geology of Falmouth has formed bluffs and drumlins that provide a natural barrier to erosion by allowing waves to erode fine-grained material while leaving larger material in place (Ramsey et al. 2015).

In light of these analyses, the Massachusetts Department of Environmental Protection affirmed the approval for widening the Bournes Pond inlet in February 2018 and dismissed the objections raised by the property owners (Feldott 2018a). As a result, the town plans to begin construction in 2018 or 2019, concluding an unexpectedly long permit approval process that began in 2016 and had been expected to take 12 to 18 months (Bray 2016).

Like using oyster farming, inlet widening provides a means to reduce nitrogen content in estuaries after they have already arrived from watersheds, making it a powerful tool for restoring water quality in cases where either sewage implementation or alternative treatment units alone are insufficient for restoring water quality. Like oyster cultivation, the effectiveness of inlet widening is dependent on the local conditions of the embayment, particularly only to embayments where inlet widening would be able to decrease tidal attenuation. Unlike oyster farming, demonstration projects for inlet widening are considerably riskier. Failed oyster demonstration projects would mainly return a loss on investment. Meanwhile, inlet widening demonstration projects may cause unintended damage to embayments by promoting erosion, and so their use is dependent on extensive modeling before undertaking the demonstration project, as was done for Bournes Pond. While direct comparisons between the nitrogen
mitigation abilities of oyster farming and inlet widening are difficult due to differing conditions between Little Pond and Bournes Pond, the oyster demonstration project in Little Pond is an order of magnitude cheaper and is projected to reduce half the amount of nitrogen. Ultimately, the effectiveness of both strategies are location-specific and require extensive planning. However, given the higher cost compared to oyster farming and the potential risk of erosion, it may be prudent to consider inlet widening projects only in particularly impaired areas in tandem with sewage service or ATUs and only after excluding the possibility of oyster farming as an alternative.
Conclusion

This thesis brings biology, geology, history, and policy analysis to bear on the problem of eutrophication on Cape Cod and Falmouth to study the development of eutrophication and the challenges that come in remedying it. By examining the relationships between each of these fields, this thesis constructs a comprehensive understanding of the issue’s impacts, causes, government response, and solutions.

Chapter 1 used biology to study the underlying processes of septic tank use that lead to eutrophication. By examining the eutrophication in terms of macroalgae blooms, deoxygenation, and eelgrass loss, the social and ecological consequences of eutrophication on Cape Cod become clear. Hypoxia and the loss of eelgrass beds lead to conditions inhospitable for benthic organisms, threatening the estuaries through losses in species richness, abundance, and fundamental ecological changes. At the same time, macroalgae blooms and anoxic events are unsightly and indicative of deteriorating ecosystem health, threatening the region’s tourism industry and distressing local residents.

The geological factors described in Chapter 2 explain how septic tank effluent is carried to embayments and contributes to eutrophication. My analysis highlights two features of eutrophication: first, due to the hydrology of Cape Cod, groundwater flows of wastewater can take years to reach the embayments, and, second, which embayments wastewater flows towards depends on the watershed the septic tank is located in.
The lag time groundwater flow creates between wastewater emission and eutrophic conditions helps explain why eutrophication emerged as a problem only after the Cape’s population boom during the 1960s and 1970s and complicates the use of solutions such as sewage service and ATUs by creating a delay between nitrogen emission reduction and observed consequences in impaired estuaries. Likewise, wastewater flow direction through watersheds dictates to what extent different embayments are eutrophic, as watersheds with high densities of houses tend to produce the most severely eutrophic waterbodies. For this reason, policy should be oriented towards watersheds rather than town boundaries.

Chapter 3 examined the history of eutrophication as a scientific phenomenon. Because marine eutrophication was not a heavily researched area, the topic was not well understood and lacked the attention necessary for the town to take preventative measures. Furthermore, concerns over declining water quality and failing wastewater management systems overshadowed the threat of eutrophication. While these factors led to the delayed government response on eutrophication, the concerns raised over water quality in the 1970s set the precedent for towns to manage water quality concerns as designated waste treatment management agencies under the Clean Water Act. In Falmouth, water quality concerns led the construction of the town’s wastewater treatment facility, which forms the backbone of the town’s sewage expansion strategy to combat eutrophication.

Chapter 4 investigated the role of the Clean Water Act in providing the foundation for policy responses to eutrophication on Cape Cod. Though the Clean Water
Act provides little federal oversight of eutrophication because of the “non-point source loophole” and fails to grant power to regulate septic tank effluent, it has provided the opportunity for the Cape Cod Commission to encourage reform at the town level by educating locals through the 208 Plan Update and invoking a transition away from a town-based approach and towards watersheds. Town-based policy organized through CWMPs are wide-reaching, slow to develop, expensive, and are frequently rejected by residents. By promoting TWMPs and IMAs, the Cape Cod Commission allows towns to focus on a narrower scope, leading to a lower proposed cost for residents to approve and targeting specific eutrophic estuaries for reform based on watershed management that takes advantage of local hydrology rather than artificial town boundaries.

Chapter 5 compared several of the strategies outlined in the Falmouth CWMP to evaluate the suitability of each. There is no single, superior solution, as each has advantages and disadvantages that suit them for particular situations. For this reason, no single solution can be universally applied, but multiple strategies are needed for marked improvement. Sewage system expansion can remove wastewater effluent from entering watersheds at the site of serviced homes and can treat wastewater to nitrogen concentrations far lower than current ATU systems. However, the sheer quantity of treated wastewater entering West Falmouth Harbor remains a concern that will need to be addressed, likely through an outfall pipe. Sewage expansion is also extremely expensive and likely to impose both town-wide taxes and betterment fees for serviced communities. For this reason, sewage implementation is best reserved for areas in most serious need of nitrogen removal and in areas where housing is particularly
concentrated. While the nitrogen concentrations of ATUs are higher than those of sewage from a wastewater treatment facility, they are likely the cheaper solution, and can be implemented on an individual basis. For these reasons, ATU implementation is best suited to areas where houses are too far apart to justify sewage service and on watersheds where impaired estuaries do not require especially large reductions in nitrogen loads. While future ATU technology may be able to compete with sewage service in terms of nitrogen reduction, when these ATUs will be available for implementation is difficult to say. In addition, because both strategies impact pollution entering groundwater, it will take years before the reduction in nitrogen loading is observed in impaired estuaries.

Both oyster aquaculture and inlet widening provide means for eutrophication mitigation at the impaired estuary. Both strategies are immensely dependent on the local conditions, thus it is difficult to say without site-specific testing which method would be preferred. Between both demonstration sites, it can be noted that oyster aquaculture is significantly cheaper than inlet widening and is estimated to provide a comparable level of nitrogen reduction. Ultimately, deciding which strategy to implement will require a site-specific evaluation for each impaired estuary. The demonstration project for oyster aquaculture does not require permanent changes to estuary conditions, while an inlet widening demonstration project will require careful modeling and analysis before implementation to prevent potential damage. Because of the lower cost and risk, the implementation of oyster aquaculture is generally preferred
over inlet widening, though results are likely to vary widely and necessitate research through trial runs and demonstration projects.

While the analyses completed in this thesis elucidate several aspects of eutrophication on Cape Cod, more research could be done to develop our understanding of the issue. Few economic analyses of the effects of eutrophication have been completed on Cape Cod, despite the threat it poses on the regional economy. Future research on the impact of eutrophication on tourism would serve to justify the high cost of solutions and add urgency to the issue. Likewise, while some research has been conducted regarding water quality declines and property values, analyses of whether eutrophic water conditions influence the market value of vacation homes on Cape Cod would also be useful in determining the severity of the issue.

Another potential avenue for further research would be an analysis on the role of scientific institutions and advocacy groups in Cape Cod communities. Falmouth is fortunate to host several prestigious environmental science organizations in Woods Hole, such as the U.S. Geological Survey, National Oceanic and Atmospheric Administration, Woods Hole Research Center, Marine Biological Laboratory, Woods Hole Oceanographic Institute, and others. Many environmental advocacy groups such as the Falmouth Water Stewards, Oyster Pond Environmental Trust, and Buzzards Bay Coalition, are also based or hold offices in the area. While my thesis does not examine the role these organizations play directly within the community, it does use research and interviews provided by their members. In many cases, scientists from these institutions are members of advocacy groups. Analyses of how these organizations
interact with the local government and with the public would expand on the natural science and political aspects of this work.

While this thesis focused on a particular case of eutrophication, the insights gleaned about the causes of eutrophication and the policy solutions to address the problem are applicable to other locations. Long Island, for example, shares many similar traits with Cape Cod. Both areas suffer from eutrophication due to septic tank effluent and share similar geologies that allow for fast groundwater travel (Gallagher 2015, Olcott 1995). The impacts of eutrophication on Long Island are also similar, such as eelgrass loss, deoxygenation, and decline in sea scallops (Gallagher 2015, Squire 2015). Also similar is Long Island’s 208 Plan, which was developed in the 1970s and focuses on the quality of the area’s drinking water supply (Nassau-Suffolk Regional Planning Board 1977). Unlike Cape Cod, Long Island has yet to update its 208 Plan, and though research and demonstration projects are underway, further studies will need to be completed before advancing with the implementation of solutions. With this in mind, Cape Cod and Falmouth demonstrate the importance of interdisciplinary analyses to understand the impacts of eutrophication, its causes, political response, and suitability of solutions for eutrophication mitigation.
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Appendix 1. Interviewees Bios

Wendi Buesseler. Personal interview. 10 Jan. 2018
Scientist, Director | Oyster Pond Environmental Trust

Wendi Buesseler is a scientist and Executive Director of the Oyster Pond Environmental Thrust (OPET), a Director the Falmouth Water Stewards, a Falmouth Town Meeting Member, and a member of the Coonamessett River Trust. She monitors the water quality of the pond in order to preserve it for resident herring populations. She also works on the eradication of exotic invasive plants species affecting the Oyster Pond watershed.

George Heufelder. Personal interview. 9 Jan. 2018
Director | Mass Alternate Septic System Test Center

George Heufelder is a founder of the Massachusetts Alternative Septic Test Center, a division of the Barnstable County Department of Health and Environment and served as its Director until recently. He has also served on Falmouth’s Board of Health for 25 cumulative years and is the former Health Director of Barnstable County. He holds a Master of Science degree on Aquatic Biology, and a Bachelor degree on Fisheries and Wildlife Biology. He has conducted and supervised research on septic system treatment for nutrients, pathogens, and contaminants.

Dr. Rachel Jakuba. Personal interview. 12 Jan. 2018
Scientist, Director | Buzzards Bay Coalition

Rachel Jakuba is a marine scientist with experience in environmental policy, and project management interested in applying technical expertise to tackling environmental issues facing businesses and communities. She oversees and coordinates the Buzzards Bay Coalition’s research and monitoring efforts and advises on environmental management.
plans and policy, coastal nutrient pollution, and harmful algal blooms. Rachel holds a doctorate in Oceanography from the MIT/WHOI Joint Program.

Amy Lowell. Personal interview. 10 Jan. 2018
Wastewater Superintendent, Town of Falmouth

Amy Lowell is the Wastewater Superintendent of the Town of Falmouth, and the immediate Supervisor of the Little Pond Sewer Project. Previously, she acted as the Assistant to the Wastewater Superintendent. Ms. Lowell supervises the planning of new road traffic configurations associated to new DPW infrastructure, the main wastewater system composed of the Falmouth Main Wastewater Facility, and the New Silver Beach Wastewater Project located at North Falmouth.

Dr. Christopher Neill. 8 Jan. 2018
Senior Scientist | Woods Hole Research Center

Christopher Neill is a Marine Biology Laboratory Fellow and a Senior Scientist at the Woods Hole Research Center. He also holds an appointment in the Department of Ecology and Evolutionary Biology at Brown University. He is an active collaborator with the MBL Ecosystems Center and a Director of the Falmouth Water Stewards. He researches the quantification and impact of nitrogen runoff in Cape Cod and Southeastern Massachusetts coastal areas, the effect of ecological restoration and resources management of coastal grasslands, and other related topics.

Erin Perry. Personal interview. 16 Jan. 2018
Projects Coordinator | Cape Cod Commission

Erin Perry is the Special Projects Manager of the Cape Cod Commission. She served as Special Projects Coordinator for the Commission’s Regional Wastewater Management
Plan and the Commission’s 208 Plan Update. She has worked on water quality work for the Cape Cod Commission for over 6 years and regularly coordinates the Commission’s efforts with both the Massachusetts DEP and U.S. EPA.

**Charlie Pires. Personal interview. 10 Jan. 2018**
Chief Operator | Falmouth Wastewater Treatment Facility

Charlie Pires is Chief Operator of the Falmouth Wastewater Treatment Facility. He has served as the facility’s Chief Operator since 2005 years and has experience working in other treatment facility for years prior. He is a graduate of Cape Cod Community College and Northeastern University and serves as an educator for Cape Cod Community College regularly. He is assisted by Cory Melemed, who kindly oriented me to the workings of the Falmouth WWTF.

**Steve Rafferty. Personal interview. 09 Jan. 2018**
Water Superintendent at Falmouth DPW

Steve Rafferty is the current Water Superintendent of the Town of Falmouth. He has also been a member of the Board of Health since 2012. Previously, he was part of the Water Quality and the Comprehensive Wastewater Plan Review committees. His previous experience includes 37 years as an engineer for the environmental engineering firm CDM Smith, where he worked on water treatment for the Boston Metropolitan Area. He also has experience with municipal government, alternative and variances for septic systems, and planning of municipal wastewater plans such as the Little Pond sewer service expansion and eco–toilet projects.
Dr. Ivan Valiela. Personal interview 10 Jan. 2018
Distinguish Scientist | Marine Biological Laboratory, The University of Chicago

Dr. Ivan Valiela is a marine scientist and a recipient of the Odum Lifetime Achievement Award. His career achievements and contributions to understand coastal marine ecosystems, estuaries, and coastal environments are extensive and span over 45 years. His research at the Waquoit Bay system have enabled the understanding of the causes and consequences eutrophication in coastal environments, and its role on eelgrass decline and macroalgal blooms. He has written more than 300 technical papers in biochemistry, coastal marine environments, marine ecology, and related fields.

Dr. Jeffress Williams. Personal interview. 08 Jan. 2018.
Coastal Scientist

S. Jeffress Williams is a Director of the Falmouth Water Stewards and senior scientist emeritus and a research coastal marine geologist with the USGS Woods Hole Science Center in Woods Hole. He holds over 40 years of research experience on the understanding of geologic history and processes of coastal, estuarine, wetland, and inner continental shelf regions such as the Great Lakes coastal systems. He is recipient of the Coastal Zone Foundation Award and the U. S. Geological Survey Award from his achievements in coastal science and years of service. He is the author of over 350 scientific publications and has been a member of national and state science committees including the National Academy of Sciences, National Ocean Partnership Program, 1998 National Oceans Conference, U.S Coral Reef Task Force, Louisiana Wetlands Restoration Task Force, and the Louisiana Sand Task Force.
Appendix 2. Interview Guide

1. History of Cape Cod settlement:
   - How and when did the problem of eutrophication begin?
   - What is the current wastewater/municipal water design on Cape Cod?
   - How has the problem of eutrophication changed over time?

2. Consequences of Eutrophication on Cape Cod:
   - Nitrogen Cycle:
     - Could you describe how septic tanks affect the local nitrogen cycle?
     - About how long does it take for nitrogen effluent to travel to an embayment after leaving the estuary?
   - What are the main consequences of marine eutrophication on Cape Cod?
     - Deoxygenation
     - Toxic algal blooms
     - Eelgrass loss
   - Are there other effects besides these three that are widely observable around the Cape?
   - How have these effects interfered with human life in Falmouth/Orleans/around the Cape? Have these effects worsened, lessened, stayed constant in severity?

3. Political and social response to eutrophication crises:
   - What solutions are currently underway to prevent or mitigate eutrophication?
     - What actors are implementing these programs? Towns? County? State?
   - Are there solutions that were proposed, but struck down?
     - What are the obstacles preventing solutions from being accepted?
   - What are volunteer and NGO groups doing to address eutrophication?
   - Have home prices changed according to eutrophication?

4. Closing Comments