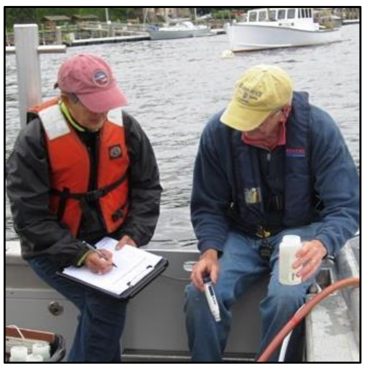
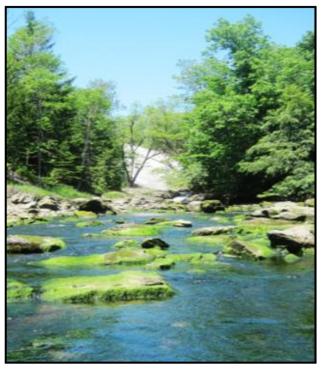
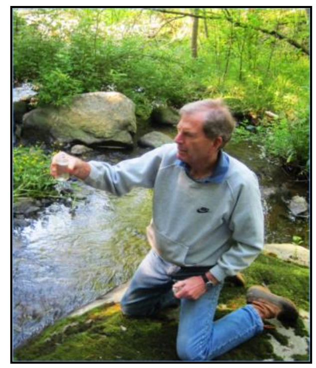
Water Quality Investigations of Rockport Harbor, Goose River and Selected Streams (2012 to 2019)

Conservation Commission
Town of Rockport
Rockport, Maine

November 2020

Water Quality Investigations of Rockport Harbor, Goose River and Selected Streams (2012 to 2019)

By

Robert Kennedy, PhD

Conservation Commission
Town of Rockport
Maine

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Water Quality Investigations of Rockport Harbor, Goose River and Selected Streams (2012 to 2019)

Introduction

Rockport Harbor is the centerpiece of Rockport's water resource heritage offering ample recreational opportunities, postcard vistas and a destination for residents and summer visitors. While historically an important center for shipbuilding and shipping, Rockport Harbor today is predominately recreational with nearly 300 private moorings extending from near the Goose River inflow at the head of the harbor to the outer harbor (Figure 1). With the exception of Walker Park along the western shore, land-based recreation is centered on Goodie's Beach and the Marine Park at the head of the harbor.

Like all coastal waters, the harbor receives material inputs from both marine and terrestrial sources. These include nutrients, sediment and organic matter that play important roles in maintaining a healthy and productive aquatic ecosystem. However, excessive amounts of these materials can have undesirable consequences. Increased availability of nitrogen and phosphorus can have a fertilizing effect leading to excessive growth of phytoplankton (small free-floating algae), which can reduce water clarity and, in some cases, cause harmful algal blooms. Organic matter either produced in coastal waters (e.g., growth of free-floating or attached algae) or contributed by streams and rivers draining coastal watersheds can reduce dissolved oxygen levels when decomposing potentially impacting sensitive aquatic species. Suspended sediments, which often transport contaminants, including heavy metals and pesticides, also reduce water clarity and, when deposited, can adversely impact benthic habitats.

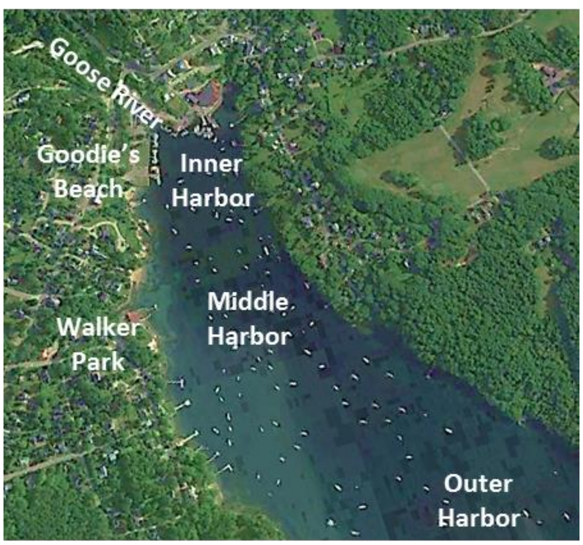


Figure 1. Aerial image of Rockport Harbor and surrounding area (from Google Earth, image dated 2018).

The State of Maine classifies water bodies as a means to guide regulatory efforts. Much of Knox County's estuarine and marine waters, including Rockport Harbor, are classified as Class SB, the second highest of three levels of classification of water quality. The State also classifies the Goose River and the streams draining to the harbor as Class B, the third highest of four classes related to the quality of freshwater streams in Maine. In general, these classifications ensure that the requirements for designated uses are met and that the waters are of sufficient quality to support resident indigenous biological communities. While the classifications are largely narrative, there are quantitative standards for selected water quality variables, such as dissolved oxygen concentration and bacteria levels. There are also water quality variables for which standards have yet to be established or codified but for which the State provides preliminary guidance or recommendations.

Objectives

Given the lack of recent or comprehensive assessments of the quality of Rockport's water resources, the Rockport Conservation Commission (RCC) designed and implemented a monitoring program as a means to gather and assess water quality information for Rockport Harbor, Goose River and four streams draining to the harbor. The effort was guided by the requirements of the State's classification scheme and associated water quality standards, as well as by a desire to provide management-operative information to the Town of Rockport. The study was designed to meet the following objectives.

- Assess current water quality conditions in Rockport Harbor and its tributary streams in the context of applicable standards and criteria
- Identify existing or potential threats to water quality
- Establish a baseline for assessing potential future changes in water quality

Volunteer River Monitoring Program

The RCC, acting on behalf of the Town of Rockport, sought technical support for stream and harbor water quality monitoring through the Maine Department of Environmental Protection's (MDEP) Volunteer River Monitoring Program (VRMP). The VRMP was established in 2009 as a means to support standardized monitoring by local volunteer groups. The program operates under a program-level Quality Assurance Program Plan (QAPP) approved by the US Environmental Protection Agency (USEPA). All participating organizations are required to develop a project-level Sample and Analysis Plan (SAP) that details sampling locations, sample collection methods, and analytical methods. RCC's SAP was initially approved in 2013 and updated in 2020.

MDEP provides water quality instruments on a seasonal-loan basis to assist local volunteers in collecting field data. VRMP staff members provide annual training and certification on the use of these instruments, guidance on data quality objectives, technical support and general assistance (Figure 2). Data are submitted at the end of each sampling season for storage in MDEP's Environmental and

Figure 2. RCC volunteers participate in annual VRMP recertification training conducted by MDEP staff members each spring.

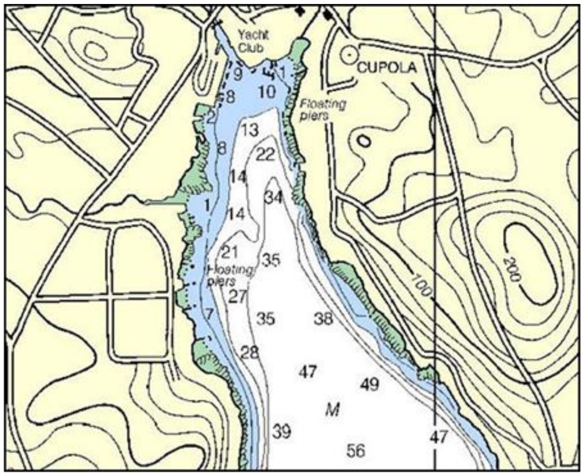


Figure 3. Depth contours (in feet at low tide) for Rockport Harbor. From navigation chart 13307 (NOAA 2012).

Geographic Analysis Database (EGAD). The VMRP staff also develops annual reports summarizing data collected by local volunteers. These are available on the MDEP website[1].

Rockport Harbor

Rockport Harbor, located along the western shore of Penobscot Bay in Maine's mid-coast region, is V-shaped and oriented roughly north to south. Its entrance is approximately 1.12 km (0.7 mi) wide when measured perpendicular from Indian Island along the eastern shore to the western shore. From this point to the head of harbor is approximately 2.41 km (1.5 mi). Maximum depths along the length of the harbor range from less than 6 m (19.7 ft) off the Town floats to approximately 20 m (65 ft) at the mouth of the harbor at mean high tide.

The distribution of depth in the harbor reflects the regional topography. Depth increases rapidly with distance from the eastern shore, while depth development at the head of the harbor and along the western shore is more gradual with areas of shoaling and sediment accumulation (Figure 3).

The Coastal Watersheds

Goose River drains an 8.6-mi^2 (5,504-acre) watershed extending from the hills above Hosmer Pond in Camden to the river's discharge

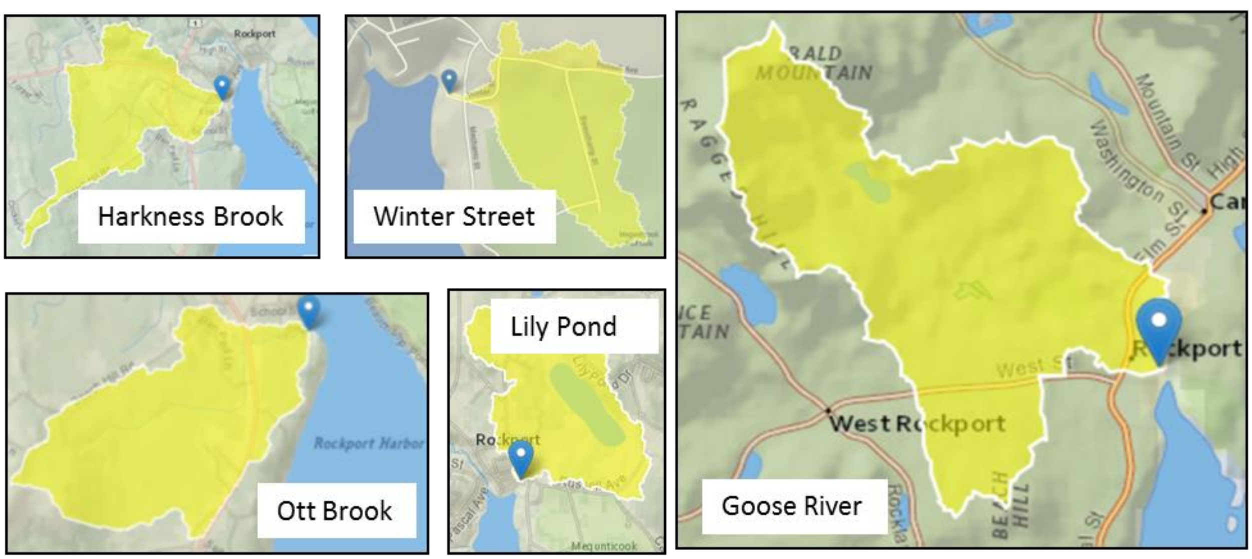


Figure 4. Location and extent of coastal watersheds that discharge freshwater to Rockport Harbor. Watersheds were delineated using US Geological Survey's online utility 'StreamStats' (available at https://streamstats.usgs.gov/ss/). Note that the scales differ for each watershed display and are therefore not comparable.

into Rockport Harbor near Marine Park (Figure 4). Forest is the primary watershed land cover (74%); wetlands/ponds, crop lands, pasture and a golf course account for another 20%[2]. Only 6% of the watershed is developed for residential and commercial purposes. The river, which arises as the outlet from Hosmer Pond, meanders through much of the watershed as a low-gradient stream, is temporarily impounded by an elevated section of Commercial Street near the intersection with Main Street, and continues to the confluence with the harbor as a series of riffles and cascades.

Ott Brook and Harkness Brook (historically referred to as Ells Brook) are associated with smaller watersheds (512 and 448 acres, respectively) draining areas to the south and southwest before discharging to the harbor along its western shore (Figure 4).

A small unnamed stream arises as the discharge from Lily Pond (here referred to as Lily Pond Stream) and is confluent with the harbor just east of the Rockport Marine facilities. The watershed, which includes areas draining to Lily Pond, is 256 acres. A 64-acre area east of the harbor, which includes a natural wetland and portions of the Megunticook Golf Club, drains along Winter Street before discharging to the harbor.

A number of culverts collect storm water runoff from small areas contiguous with the harbor and discharge directly to the harbor. Noteworthy is the 25-acre area bounded by Commercial Street, West Street, Amesbury Hill and Pascal Avenue since storm water flows from this area are discharged immediately adjacent to Goodie's Beach.

Assessing Water Quality

Water quality can be broadly defined to include a wide range of physical, chemical and biological characteristics. The focus here was on those water quality variables related to Maine's water quality standards[3], either numeric or narrative, that serve as the principal basis for protecting the quality of Maine's water resources. These included the following:

Water Temperature – While there are no set numeric standards for water temperature for Class B and SB waters, there are guidelines intended to ensure that discharges to these waterbodies do not increase temperatures to levels that would impair indigenous species.

Dissolved Oxygen – Water in contact with the atmosphere will exhibit 100% oxygen saturation; the actual concentration of oxygen dissolved in water is a function of temperature (i.e., at 100% saturation, concentrations are higher in cold water than in warm water). Processes occurring in water (e.g., algal respiration and photosynthesis, and bacterial decomposition of organic matter) can effect short term deviations in saturation (and concentration) that can have important consequences for aquatic organisms. Dissolved oxygen saturation and concentration are both addressed by Maine's water quality standards.

> Class B Freshwaters – "The dissolved oxygen content of Class B waters may not be less than 7 parts per million (mg/l) or 75% of saturation, whichever is higher, except that for the period from October 1st to May 14th, in order to ensure spawning and egg incubation of indigenous fish species, the 7-day mean dissolved oxygen concentration

may not be less than 9.5 parts per million and the one-day minimum dissolved oxygen concentration may not be less than 8.0 parts per million in identified fish spawning areas."

Class SB Estuarine and Marine Waters – "The dissolved oxygen content of Class SB waters may not be less than 85% of saturation."

Specific Conductance – The ability of water to conduct an electrical current is related to the presence of certain dissolved materials derived from geologic sources or those related to human activity, such as applying road salt. While there is no established numerical standard, measuring changes in conductance can identify potential water quality issues. (Note that 'specific conductance' as reported here refers to conductance adjusted to the standard temperature of 25 C^{o}.)

Water Clarity – In addition to light attenuation by water itself, dissolved substances that impart color to water and suspended materials, including algae, which reduce light penetration, can affect water clarity. Loss of clarity, in addition to the aesthetic impact, progressively reduces the amount of radiation available to algae with increasing depth.

Water clarity is commonly measured by lowering a Secchi disk, a 20-cm (8-in) disk with alternating white and black quarters, into the water and observing the depth at which the disk just disappears from view. There is no numeric standard for water clarity for coastal waters but extremely low clarity could violate narrative criteria established to protect certain designated uses.

Salinity – Salinity is a measure of the amount dissolved salts in water, usually expressed as grams of salt per kilogram of water. Gulf of Maine salinity averages 32-33, while coastal and estuarine values vary widely depending on the amount of freshwater present. In addition to its effect on water density, salinity has a number of important interactions with biological, chemical and physical processes of importance to marine and coastal ecosystems. There is no specific Maine criterion for salinity for coastal waters.

pH – Water having a pH below 7.0 is considered to be acidic while water with a pH greater than 7.0 is considered basic. While there are no numeric criteria, the normal range for surface water is 6.5-8.5. There are a number of environmental, geological, chemical and biological processes that can influence pH making the establishment of a standard difficult. However, acidification of coastal waters is of particular concern since shell-forming organisms are adversely impacted. The impact of acidification on shellfish is the subject of considerable ongoing research.

Nutrients - Nitrogen and phosphorus, which can occur in a variety of forms, are key nutrients essential for algal growth in aquatic ecosystems. However, excesses in the abundance of these nutrients can have a fertilizing effect leading to water quality degradation. Maine has yet to set regulatory standards but recommends that Class B freshwaters not exceed a total phosphorus concentration of 0.03 mgP/l and that total nitrogen concentrations not exceed 0.6 mgN/l. Maine has yet to establish criteria for these nutrients in coastal waters.

Chlorophyll – Chlorophyll is an essential pigment used by plants for capturing solar energy during photosynthesis and is often used as an indication of the abundance of free-floating algae or phytoplankton. While this connection is useful for monitoring purposes, it is imprecise since the chlorophyll content of algal cells can change due to environmental conditions or the health of the cells, and differs from species to species.

There are currently no quantitative standards for chlorophyll in coastal waters, but it is accepted that "excessive" amounts of phytoplankton can lead to water quality degradation, and may pose risks to public health in the form of hazardous algal blooms, such as red tide. While phytoplankton occur in Rockport's streams, much of the photosynthesis there is due to algae attached to the streambed and was not included in this assessment.

Fecal Indicator Bacteria – Bacteria of the genus *Enterococcus* and the bacterium *Escherichia coli* or *E. coli* inhabit the gut of humans and other warm-blooded animals. Their presence in the environment is an indication of contamination by fecal waste. While these organisms pose a limited health risk, their presence serves as an indicator of the potential presence of disease-causing bacteria, viruses and other pathogens. Maine's water quality standards, which apply to levels of enterococcus in estuarine and marine waters, and *E. coli* in freshwaters, are as follows:

> *Class B Freshwaters* – "Between April 15th and October 31st, the number of *Escherichia coli* bacteria in these waters may not exceed a geometric mean of 64 CFU[4] per 100 milliliters over a 90-day interval or 236 CFU per 100 milliliters in more than 10% of the samples in any 90-day interval."

> *Class SB Estuarine and Marine Waters* – "Between April 15th and October 31st, the number of enterococcus bacteria in these waters may not exceed a geometric mean of 8 CFU per 100 milliliters in any 90-day interval or 54 CFU per 100 milliliters in more than 10% of the samples in any 90-day interval."

The Maine Healthy Beaches Program (MHB)[5], a partnership between the MDEP and local/State authorities funded by the U.S. Environmental Protection Agency (USEPA), monitors enterococcus levels at selected beaches (including Goodie's Beach on Rockport Harbor) during the summer recreation season (June-Aug) and applies the following criteria for recommending issuance of public health advisories by local authorities:

> *Coastal and Freshwater Beaches* - In compliance with USEPA standards, the exceedance criteria, or level at which a sample fails, is 104 enterococci bacteria per 100 milliliters of sample water, or enterococci levels exceeding the geometric mean of 35 counts of enterococci per 100 mL of water in at least five samples collected over a 30-day period.

Since Goodie's Beach is located on Rockport Harbor, the RCC has considered both the MHB's and Maine's water quality standards when collecting and assessing enterococcus data.

Data Collection

Four harbor and five stream sampling locations were established as a means to obtain data for describing seasonal (approximately May through September) water quality conditions

(Figure 5). Harbor sites included the inner, middle and outer harbor (designated HR-1, HR-2, and HR-3, respectively), as well as a site near the Rockport Harbor bell buoy (RO) in Penobscot Bay east of Indian Island. Harbor sites were sampled approximately monthly at both low and high tide in 2012 and monthly at midday during high tide in 2013-2019.

Grab samples of water for nitrogen, phosphorus, chlorophyll, and enterococcus bacteria analyses were collected just below the surface at each site in a sealable sample container; temperature, dissolved oxygen (concentration and percent saturation) and salinity were measured at depth intervals from surface to near bottom using a water quality instrument. An instrument capable of also measuring pH and estimating in-situ chlorophyll concentration at depth[6] was used in 2017-2019. Water transparency was measured using a Secchi disk.

Figure 5. Sample sites in Rockport Harbor and Penobscot Bay, and for each of the five streams draining to the harbor.

Sites on Goose River (GR-2), the stream draining from Lily Pond (LPS-1), Ott Brook (OT-1), Harkness Brook (HB-1) and the ephemeral stream located beside Winter Street (WS-1) were each sampled at a point above tidal influence. Samples were collected in early morning on dates when the harbor was sampled. Additional samples were often collected during or following rainfall and runoff events, or on selected dates when the harbor was not sampled, as a means to better describe stream water quality. Dissolved oxygen and specific conductance were measured using an electronic water quality instrument. Water samples for phosphorus, nitrogen and *E. coli* bacteria analyses were collected from mid-depth at each site. A sample was also collected at GR-2 for enterococcus bacteria analysis.

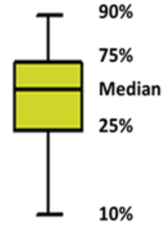
Analyses for phosphorus, nitrogen and chlorophyll were performed by the Nutrient Analytical Services Laboratory at the University of Maryland's Center for Environmental Science. Bacteria analyses were performed by Aqua Maine's, and later Maine Water's Mirror Lake Water Quality Laboratory in West Rockport for the period 2012-2017. Following closure of the Mirror Lake Water Quality Laboratory in late 2017, these analyses were performed by the laboratory operated by the City of Rockland Wastewater Treatment Facility.

Meteorological information, including daily precipitation, was recorded by a National Weather Service's weather station located at the Maine Water facility near Mirror Lake in West Rockport. These data are available online[7].

Resulting data are presented in the following sections as graphical displays with supporting text. Data displays include commonly-used line graphs, scatter graphs or bar graphs as a means to display potential trends and assess compliance to applicable standards. Also included are box and whisker graphs with which

Figure 6. Understanding Box and Whisker Plots

A **Box and Whisker Plot** is a graphical method for visualizing numerical data. When individual data points are arranged in numerical order, the **Median** is the middle value; 50% of the data points are between the upper and lower boundaries of the **Box** (the 75th and 25th percentiles, respectively). **Whiskers** indicate the 90th and 10th percentiles. Thus, the plots display the central tendency and distribution (or spread) of a data set, and can be useful when comparing data sets.



readers may be less familiar (Figure 6). This type of graph has the advantage of displaying both the central tendency (i.e., median value) and spread of the data, both of which can be useful when comparing datasets. A limited number of color contour graphs are included as an additional means to visualize trends over time or distance.

Stream Water Quality

Stream Flow - Goose River flows reflected annual differences in precipitation and were markedly seasonal. While there are no direct measurements, monthly patterns in flow for the Goose River were estimated based on those for the Ducktrap River near Lincolnville, which are recorded daily by the U.S. Geologic Survey[8]. The portion of the Ducktrap River for which flows are recorded has a watershed similar in size and land cover to that of the Goose River affording the opportunity for general comparisons of monthly flow. Flows for the Goose River were estimated by scaling Ducktrap River flows using a watershed area ratio. Similar seasonal flow patterns were obtained using a statistical model developed for ungaged Maine rivers[9].

In general, flows during 2012-2019 were highest in April coincident with snowmelt and thawing conditions and lowest during the summer months. Flows increased again in fall and early winter with increasing amounts of precipitation (Figure 7). Despite high monthly precipitation in June, there was no corresponding increase in flow due, presumably, to drier soil conditions, increased infiltration, and plant uptake.

Similar estimates of flow patterns were not possible for the smaller streams. Flows for these streams, which are markedly affected by individual watershed characteristics and local weather conditions, were observed to range from bank-full flow following heavy rain events,

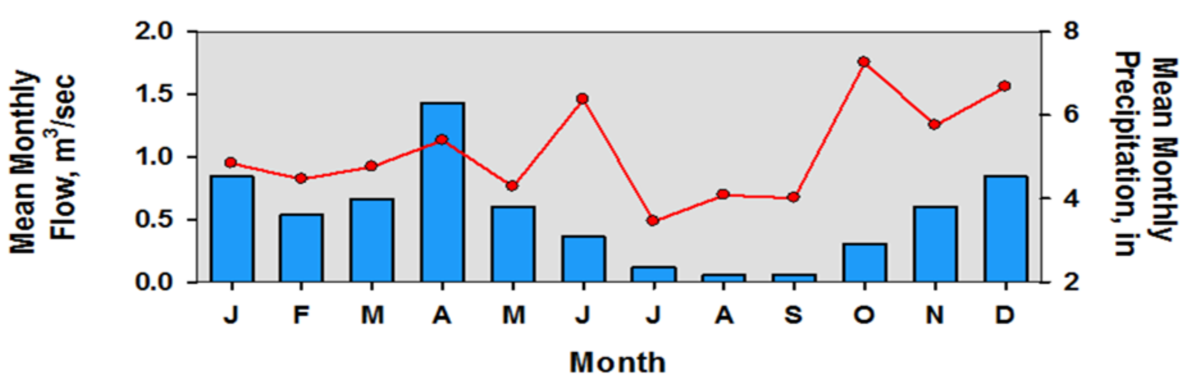


Figure 7. Estimated mean monthly flow rate (m³/sec) for the Goose River for the period 2012-2019 (vertical bar;) and mean monthly precipitation (inches) as recorded at the National Weather Service gage (ID = West Rockport 1 NNW) located at the Maine Water Company facility near Mirror Lake (red line).

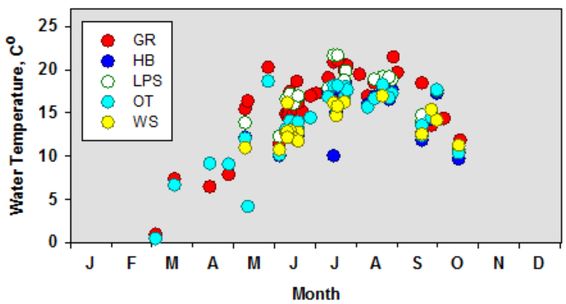


Figure 8. Water temperatures during 2012-2019 for Goose River (GR), Harkness Brook (HB), Lily Pond Stream (LPS) and Winter Street drainage ditch (WS).

especially in spring, to the absence of observable flow during dry, precipitation-free periods in summer.

Temperature - Stream water temperatures exhibited marked seasonal variation with warmest temperatures observed in late July through early September (Figure 8). Temperatures for Goose River and Lily Pond Stream were often higher than those for the other three streams.

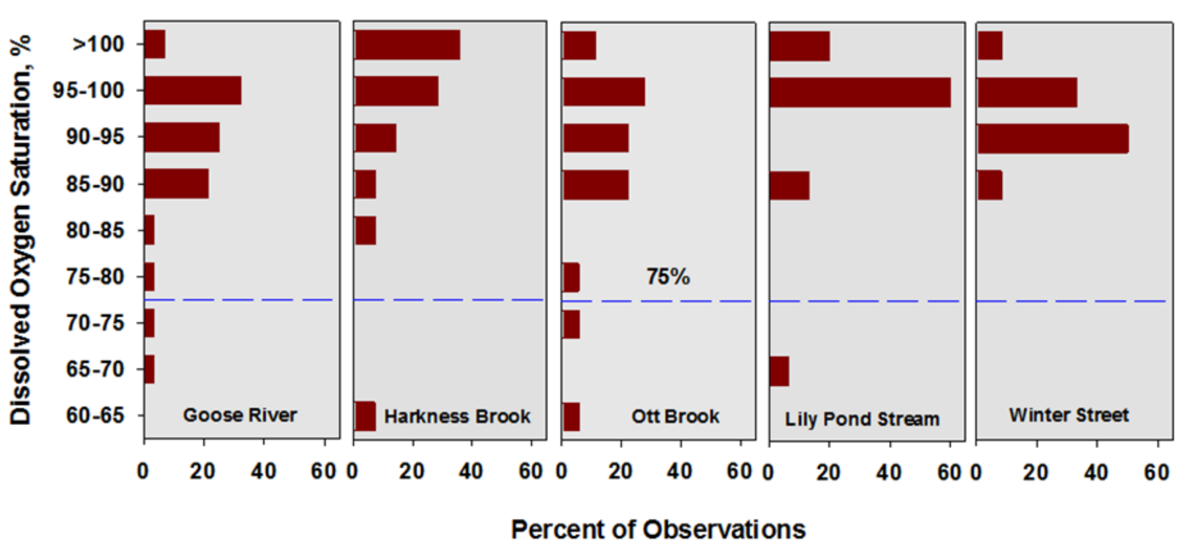
Goose River meanders through large open areas, including the Goose River Golf Course, which offers limited shading by riparian vegetation. The river is also impounded immediately upstream of the culvert under Route 1, which would lead to additional solar warming.

Episodic discharges of warm surface water from Lily Pond, as well as open areas with limited shading by riparian vegetation, could account for the higher temperatures often observed for Lily Pond Stream. This would not be the case during drier periods when much of the flow is derived from cooler ground water.

Dissolved Oxygen - Dissolved oxygen saturation values for all streams were greater than the standard value of 75% on a majority of the sample dates (Figure 9). Dissolved oxygen concentrations associated with saturation values greater than 75% averaged 9.37 mg/l and ranged from 6.80-12.34 mg/l). Concentrations associated with saturation values below 75% ranged from 6.15 to 7.50 mg/l.

The observation of sufficient oxygen saturation

Figure 9. Frequency of occurrence of classes of dissolved oxygen saturation values (%) for the Goose River and streams (bars). Dashed line indicates the 75% minimum value.



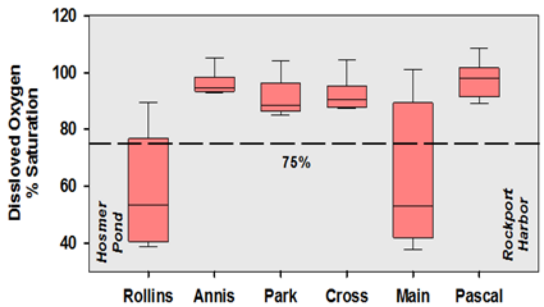


Figure 10. Percent dissolved oxygen saturation values (boxes) during 2015 at six longitudinal sites on Goose River from Hosmer Pond to Rockport Harbor. Locations included Rollins Road, Annis Lane, Park Street at Simonton Corner, intersection of Cross and Main Streets, Main Street near the intersection with Route 1, and upstream of the Pascal Avenue bridge (Site GR-2). Dashed line indicates the Class B standard minimum value (75%).

likely reflects the characteristics of the stream channels. In all cases, the existence of rifles or cascades immediately upstream from each sampling location would increase the potential for reaeration.

However, marked longitudinal differences in dissolved oxygen saturation were apparent from data collected on five dates in 2015[10] at multiple sites along the length of the Goose River from the outlet from Hosmer Pond to the GR-2 sampling site at Rockport Harbor (Figure 10). While percent saturation values of four of the sites were well above the water quality standard value of 75% on all dates, those observed at the site near Rollins Road immediately downstream from the outlet from Hosmer Pond and at the box culvert under Main Street near its intersection with Route 1 were below the standard dissolved oxygen saturation on three of the five sampling dates.

Dissolved oxygen concentrations associated with these low saturation values ranged from 5.33 to 3.44 mg/l at the Rollins Road sampling site and from 5.26 to 3.50 mg/l at the Main Street sampling site. It should be noted that prolonged exposure to dissolved oxygen concentrations below 4.0 mg/l is known to result in physiological stress for some aquatic organisms.

While the data do not allow identification of the cause(s) of the observed reduction in dissolved oxygen levels, it's noteworthy that both sites are immediately downstream from wetlands. The US Fish and Wildlife's National Wetland Inventory[11] identifies 9.9 acres of riparian wetlands along the 0.7-mile reach of the Goose River upstream from the Main Street sampling site (Figure 11). The wetland complex is composed nearly equally of freshwater emergent wetland (defined as herbaceous

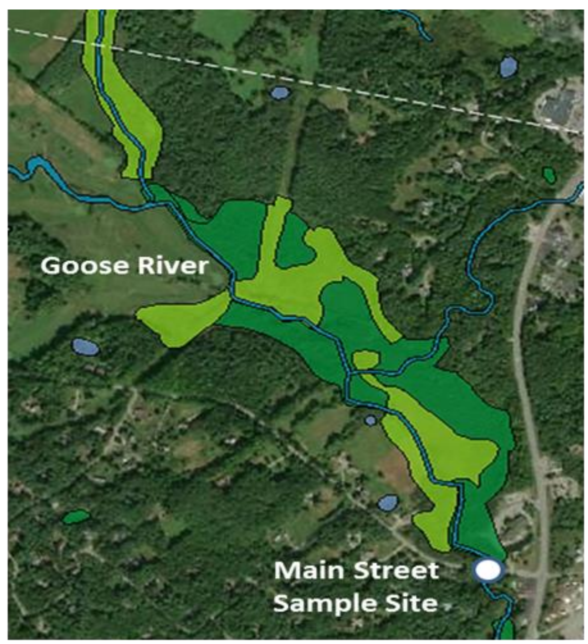


Figure 11. Distribution of freshwater emergent wetlands (light green) and freshwater forested/shrub wetlands (dark green) along the reach of the Goose River immediately upstream from the sampling site at Main Street. (From https://www.fws.gov/wetlands)

marsh, fen, swale or wet meadow) and freshwater forested/shrub wetland (defined as woody wetlands; forested swamp, shrub bog).

A smaller (1.5 acres) freshwater forested/shrub wetland is located along the 0.12-mile reach of the river between Hosmer Pond and the sampling site at Rollins Road. There is also a shallow area at the outlet from the pond that supports the growth of littoral aquatic vegetation.

Restricted flows through these densely vegetated areas could result in the observed low levels of dissolved oxygen downstream due to shading of the streambed, decomposition of organic matter and the limited influx of well-oxygenated water. Flushing of these areas during periods of elevated flow would displace poorly-oxygenated water thereby increasing dissolved oxygen concentrations.

As a general indicator of potential flow rate in the Goose River, total rainfall during the previous 7-day period for each of the dates when low dissolved oxygen were observed were 0.01, 0.40 and 0.69 inches; corresponding totals for the two dates for which higher dissolved oxygen levels were observed were 1.49 and 1.89 inches.

Nutrients - Median total phosphorus and total nitrogen concentrations were, in general, near or below those recommended for Class B freshwaters (Figure 12). Exceptions were Lily Pond Stream for total phosphorus, and Ott Brook and the Winter Street drainage ditch for total nitrogen. These differences likely reflect differences in hydrology and watershed characteristics, including land use.

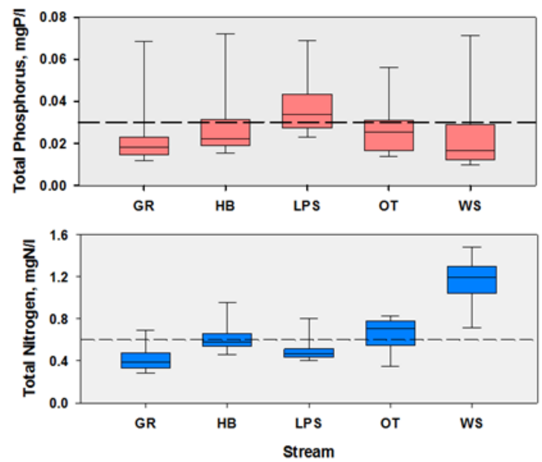


Figure 12. Total phosphorus (upper) and total nitrogen (lower) concentrations for the Goose River (GR), Harkness Brook (HB), Lily Pond Stream (LPS), Ott Brook (OT) and the Winter Street drainage (WS). Dashed lines indicate recommended Class B limits.

While total phosphorus concentrations were mostly below the recommended value of 0.03 mgP/l, the observed positive skew in the distribution for all streams (note length of whiskers in Figure 12) indicates that concentrations can, at times, be substantially higher. The same did not appear to be true for total nitrogen concentrations.

Nutrient concentrations in rivers and streams often exhibit temporal variability related to season or changes in flow. Total phosphorus and total nitrogen concentrations in Goose River varied seasonally with higher concentrations observed in early summer (Figure 13); concentrations were low in spring and during July through September.

As indicated above, since there is no established flow monitoring station on the Goose River, monthly averaged flow rates were estimated based on data for the Ducktrap River, which is monitored. While there was no clear relationship between concentration and

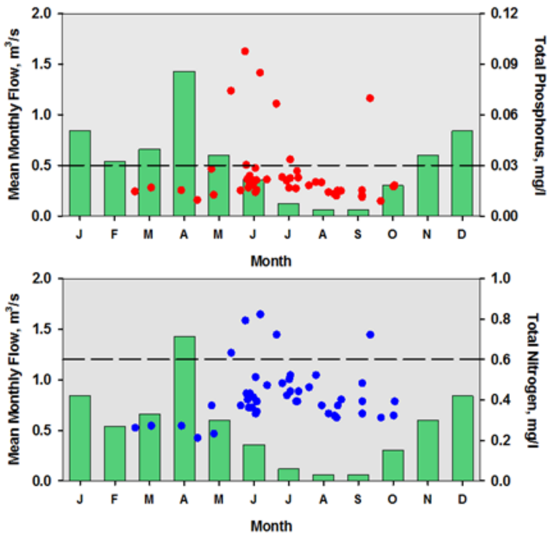


Figure 13. Temporal distribution of total phosphorus (upper) and total nitrogen (lower) concentrations (mg/l), and estimated monthly flow rate (vertical bars) for Goose River during 2012-2019. Dashed lines indicate recommended Class B limits (i.e., 0.03 mgP/l, 0.6 mgN/l).

average estimated flow rate based on current data, highest concentrations were observed on sampling dates when, with one exception, total precipitation during the preceding 7-day period ranged from 0.77 to 3.3 inches and averaged 2.32 inches.

Bacteria – The sample design adopted in this study, while providing information for general monitoring purposes is not completely compatible with the protocol for determining compliance with the bacteria standard for Class B waters. Sample frequency was limited to 3-5 sample events per year over a period of approximately 60-120 days making comparison of a 90-day geometric mean to the standard limit of 64 MPN/100ml problematic. Similar constraints occur when trying to determine if 10% of samples over a 90-day period exceed the standard limit of 236 MPN/100ml. For purposes here, individual sample results were compared to the 236 MPN/100ml limit as a general indication of compliance with the standard.

Stream *E. coli* levels (Figure 14) were generally below 236 MPN/100ml. An exception was the Winter Street drainage ditch, which exhibited levels above the limit nearly 50% of the time. High levels were also detected for Ott Brook and Harkness Brook on a limited number of sample dates. High levels for the Winter Street drainage ditch may be related to the presence of a small (ca. 1 acre) forested wetland upstream from the sample site. While homes in the area are connected to the town sewer, wildlife known to frequent the wetland could

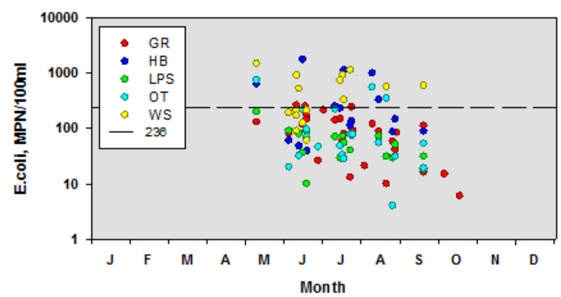


Figure 14. *E. coli* levels in Goose River and streams during 2012-2019. Dashed line indicates the single observation standard of 236 MPN/100ml.

contribute fecal waste and associated bacteria.

Because of potential impacts at Goodie's Beach, levels of both enterococcus and *E. coli* were assessed for the Goose River (Figure 15). As described above, levels of *E. coli* were below the standard on most sample dates. Enterococcus levels, however, exceeded the MHB single-sample standard (104 MPN/100ml) on a limited number of dates with levels ranging from 162 to 344 MPN/100ml.

Levels of enterococcus also exceeded the Maine requirement that Class SB waters not exhibit levels above 54 MPN/100ml in more than 10%

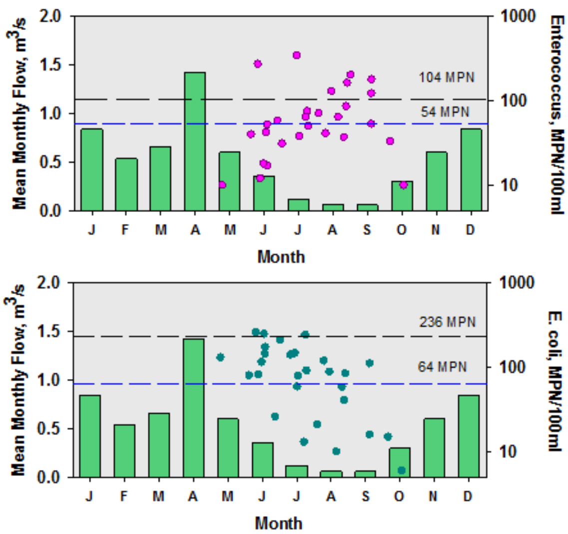


Figure 15. Enterococcus (upper) and *E. coli* (lower) levels in the Goose River during the period 2012-2019, and mean monthly flow (vertical bar) during the same period. Dashed lines indicate associated standard levels.

of samples during a 90-day interval. As was noted above, individual sample results obtained over multiple seasons were compared to the 54 MPN/100ml limit only as a general indication of compliance with the standard.

While there are apparent seasonal trends of increase in enterococcus and decrease in *E. coli* levels, the current data do not support a rigorous determination of seasonal or flow-related trends.

Harbor Water Quality

Water Exchanges - Since freshwater is less dense than salt water, inflows from the Goose River enter the harbor as an overflowing density current the nature of which is determined by the momentum of the inflowing water, mixing due to wind and wave action, and tidal interaction.

While of limited extent during periods of low river flow, density currents can extend well into the harbor and be easily observed as turbid plumes during periods of high runoff or as ice cover during the winter months. The fate of materials transported into the harbor by freshwater flows is determined, in part, by the nature of these currents, settling of particulate materials, biological activity and the extent to which mixing occurs.

While freshwater inflows can have local effects on harbor water quality, particularly during periods of high runoff, it is more strongly influenced by the harbor's connection to Penobscot Bay. A mean tidal range of 10.02 ft (3.12 m) suggests that as much as 40% of the harbor's volume is exchanged daily. A portion of the water entering the harbor with a rising tide is attributable to freshwater inputs to the bay, including from the Penobscot River. Salinity levels for surface waters (1-m depth), as observed by the Penobscot Bay data buoy located southeast of Owls Head, are lower when compared to water at greater depths (Figure 16). These differences indicate that freshwater sources may contribute as much as 10-25% to the volume of surface waters in the bay and harbor during the non-winter months.

Salinity - Salinity levels in the harbor exhibited patterns of change related to season and depth.

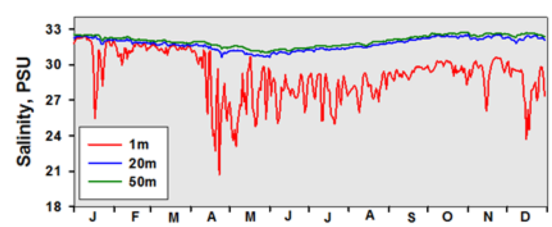


Figure 16. Changes in salinity in Penobscot Bay at depths of 1, 20 and 50 m as observed by the Northeastern Regional Association of Coastal Ocean Observing Systems (NERACOOS) water quality buoy during 2014.

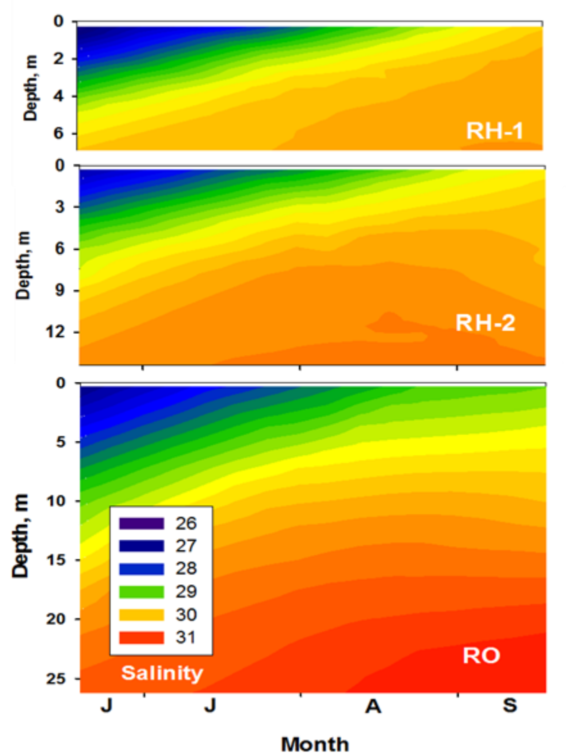


Figure 17. Seasonal and depth-related changes in salinity observed in Rockport Harbor in 2019.

Notable were lower salinity levels in near-surface strata from June through mid to late July, and a broad gradient of increasing salinity with increasing depth (Figure 17).

These patterns would be expected given the runoff of freshwater to the bay and harbor from coastal watersheds during spring and early summer, and, as noted above, the degree to which bay water is exchanged with the harbor.

Vertical gradients of increasing salinity and decreasing temperature result in a gradient in water density which can influence mixing. Resistance to mixing increases as density disparities between adjacent water strata increase. Mixing will occur if energy from wind and wave action or tidal currents is sufficient to overcome these differences. Mixing is important for distributing materials, such as nutrients, as well as oxygen and carbon dioxide. The degree to which observed density gradients in Rockport Harbor affect mixing would require data not gathered during this monitoring effort.

Dissolved Oxygen – Dissolved oxygen concentration and degree of saturation varied widely with depth, location and date. In general, saturation values that exceed 100% reflect the occurrence of oxygen-producing photosynthetic activity by either phytoplankton or attached algae, while values below 100% result from chemical or biological activities that consume dissolved oxygen. Maximum saturation values (120-130%) for 2012-2019 were commonly observed at depths below the surface and associated with maxima in phytoplankton abundance, as inferred from chlorophyll concentrations. (See further discussion of this correspondence in the Chlorophyll and Water Clarity section below.)

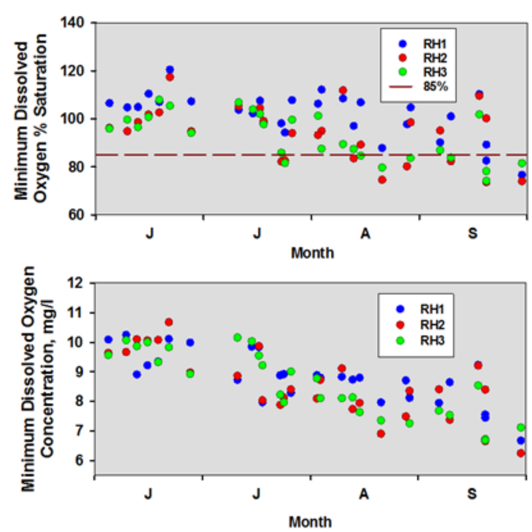


Figure 18. Minimum percent dissolved oxygen saturation (upper) and minimum dissolved oxygen concentration (lower) observed in the water column at harbor stations on each sample date during the period 2012-2019. Dashed line indicates the 85% standard for SB waters.

The minimum oxygen saturation throughout the water column at harbor sites remained above the 85% Maine standard on most sample dates (Figure 18). There was, however, a trend of decreasing oxygen saturation with values below 85% observed from mid-August through September, especially at the inner- and middle-harbor stations (RH-1 and RH-2, respectively). In general, such declines likely resulted from the growth, senescence, settling and subsequent decomposition of phytoplankton, which were more prevalent at these sites during this period.

Dissolved oxygen concentrations exhibited a similar seasonal decline (Figure 18). While minimum values ranged from 9-10.6 mg/l in June, concentrations as low as 6.5-7.0 were observed in September. This decline was, in part, due to increasing water temperature. Such minimum concentrations would have minimal adverse impacts on aquatic species.

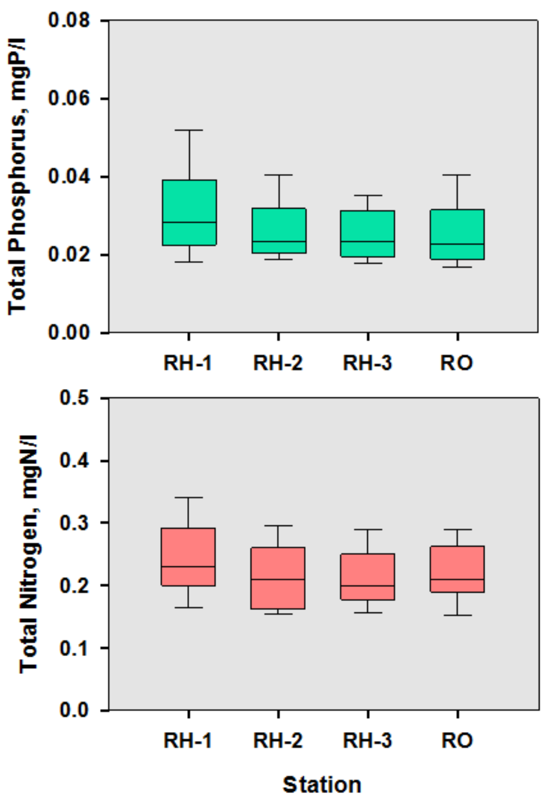


Figure 19. Surface total phosphorus (upper) and total nitrogen (lower) concentrations for Rockport Harbor and Bay stations for 2012-2019.

Nutrients – Nutrient concentrations in coastal waters can vary markedly and are influenced by a number of physical, chemical and biological processes. Important for these waters are the proximity to nutrient sources, such as river and storm water inflows, the degree to which these inflows are mixed, and processes such as sedimentation which can remove nutrients from the water column.

Median total phosphorus and total nitrogen concentrations, which were similar among harbor and bay stations, ranged from 0.023-0.028 mgP/l and 0.20-0.23 mgN/l, respectively (Figure 19). Highest concentrations, especially at station RH-1, tended to be associated with periods were increased runoff. Since all nutrient samples were collected at the surface, concentrations throughout the water column are unknown.

Given that there are currently no nutrient criteria for Maine's coastal waters, data gathered for developing such criteria are useful in assessing nutrient concentrations in Rockport Harbor. Nutrient data compiled by the USEPA[12] for multiple coastal sites during 2003-2008 and those reported by The Cadmus Group in 2009 for several mid-coast estuaries[13] are compared to those obtained by the RCC for Rockport Harbor in Table 1.

The mean and range of total phosphorus concentrations for coastal Maine and Rockport

Table 1. Mean and range of total phosphorus and total nitrogen concentrations for Maine coastal waters compiled by USEPA and the Cadmus Group, and those for Rockport Harbor.

Data Source	Total Phosphorus, mgP/l	Total Nitrogen, mgN/l
EPA All Maine	0.022 (0.006-0.061)	0.363 (0.022-4.416)
Cadmus Mid-coast	NA	0.240 (0.220-0.300)
Rockport Harbor	0.028 (0.012-0.068)	0.231 (0.090-0.790)

Harbor were similar. Total phosphorus data were not included in the Cadmus data for mid-coast sites.

Total nitrogen mean values differed. While the mean total nitrogen concentrations for Rockport Harbor and mid-coast sites included in the Cadmus data were similar (0.231 and 0.240 mgN/l, respectively), that for coastal Maine was decidedly higher (0.363 mgN/l). (The maximum reported value of 4.416 mg/l is the highest of what is likely a limited number of extremely high observations since the 90th percentile value was 0.680 mgN/l). The difference may likely reflect the inclusion of estuaries influenced by more urbanized watersheds in the USEPA compilation.

A comparison of nutrient concentrations in the harbor and those for the Goose River and streams is instructive in assessing the potential impact of inputs from Rockport's coastal watersheds on the harbor (Figure 20). River and stream total phosphorus concentrations were

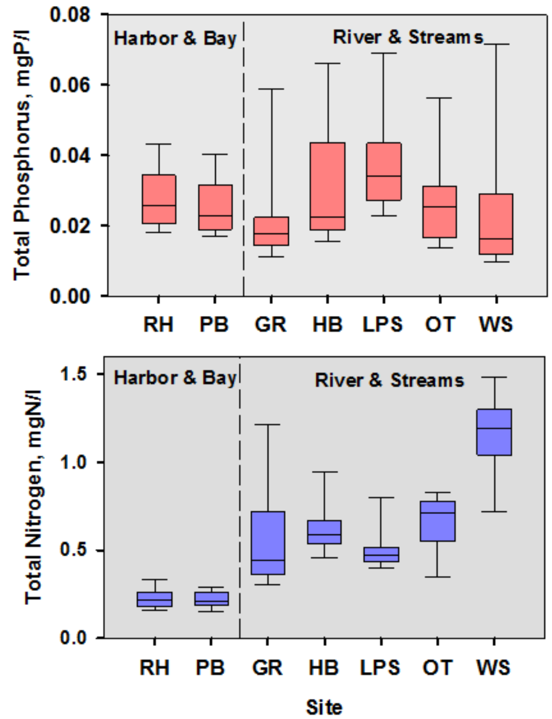


Figure 20. Comparison of total phosphorus (upper) and total nitrogen (lower) concentrations for Rockport Harbor (RH) and Bay (PB) stations with those for Goose River (GR), Harkness Brook (HB), Lily Pond Stream (LPS) Ott Brook and Winter Street drainage ditch (WS) during 2012-2019.

similar to those for harbor and bay surface waters but exhibited greater positive skew suggesting that higher concentrations can occur associated with periods of increased inflow.

Total nitrogen concentrations for the river and all of the streams were significantly higher than those for the harbor and bay, which would indicate that these freshwater sources are net contributors of nitrogen. The proliferation of *Ulva sp*, a macro alga preferring moderate-salinity and high-nitrogen environments, on the rocks along the inter-tidal reach of the Goose River is a visible outcome of the high nitrogen concentrations (Figure 21).

Figure 21. Growths of the macro alga *Ulva* on rocks in the intertidal reach of Goose River as seen from the Pascal Ave bridge.

The relative importance of such contributions, however, cannot be determined based solely on concentration but instead must consider flow and concentration together as the determinants of nutrient load (i.e., the total mass of nutrient contributed). Using average estimated annual flow for the Goose River and mean nutrient concentrations, total phosphorus and total nitrogen annual loads to the harbor during 2012-2019 were 418 kg/yr (921 lb/yr) and 7,223 kg/yr (15,923 lb/yr), respectively[14]. Because of the lack of flow estimates, loads to the harbor from the four smaller streams could not be reasonably determined.

Table 2. Watershed areas (acres) having medium and high nonpoint source (NPS) risk based on soil classification, land use and land cover data.

Watershed	Medium Risk (ac)	High Risk (ac)
Goose River	1359.8	55.4
Harkness Brook	118.5	7.6
Ott Brook	107.4	3.4
Lily Pond Stream	59.6	1.9
Winter Street ditch	20.5	0

Based on methods developed in a previous RCC effort[15], it is possible to identify areas in each of the coastal watersheds draining to the harbor having the potential to export nutrients from nonpoint sources (NPS; Table 2). The Goose River watershed is the largest potential contributor with over 1,400 acres characterized as having medium to high potential for NPS exports. The total acreage with medium and high NPS potential for the four remaining watersheds is 318.9 acres.

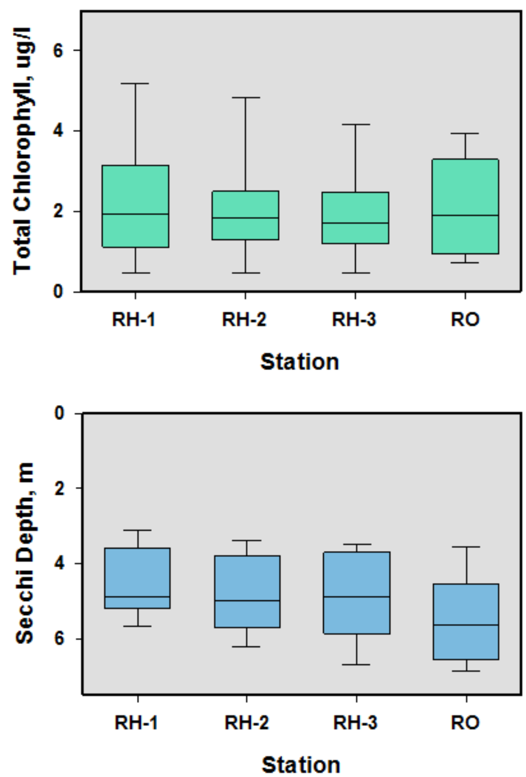


Figure 22. Surface chlorophyll concentration (upper) and Secchi depth (lower) for harbor and bay sites for 2012-2019.

Chlorophyll and Water Clarity – Chlorophyll concentrations and Secchi disk depths were similar among harbor stations and between these stations and the bay station (Figure 22). Near-surface chlorophyll concentrations for the four stations ranged from 0.34 – 9.16 ug/l, and averaged 2.21 ug/l. Secchi disk depths ranged from 2.10 – 10.80 m, and averaged 4.90 m.

Data collected at multiple depths in 2018 and 2019 utilizing a fluorometer installed on the RCC's water quality instrument allow a more detailed assessment of the spatial and temporal distribution of chlorophyll and, by inference, phytoplankton populations. Because phytoplankton require sufficient solar radiation for performing photosynthesis, the attenuation of incident solar radiation in a water column due to color, suspended materials and water itself, results in an upper well-lighted zone, or euphotic zone. Below the euphotic zone, most phytoplankton species are unable to photosynthesize due to insufficient light and instead consume stored energy.

Profiles of chlorophyll concentrations, dissolved oxygen saturation levels and pH observed for the bay station (RO) in September 2019 are illustrative of commonly exhibited patterns in their vertical distribution (Figure 23). Maximum chlorophyll concentration (9.7 ug/l) occurred not at the surface but at a depth of 6 m. Concentrations remained high to the euphotic depth, then declined rapidly with increasing depth below the euphotic zone.

Dissolved oxygen saturation and pH exhibited similar patterns (Figure 23). Since photosynthesis results in the production of oxygen, and since there is limited opportunity

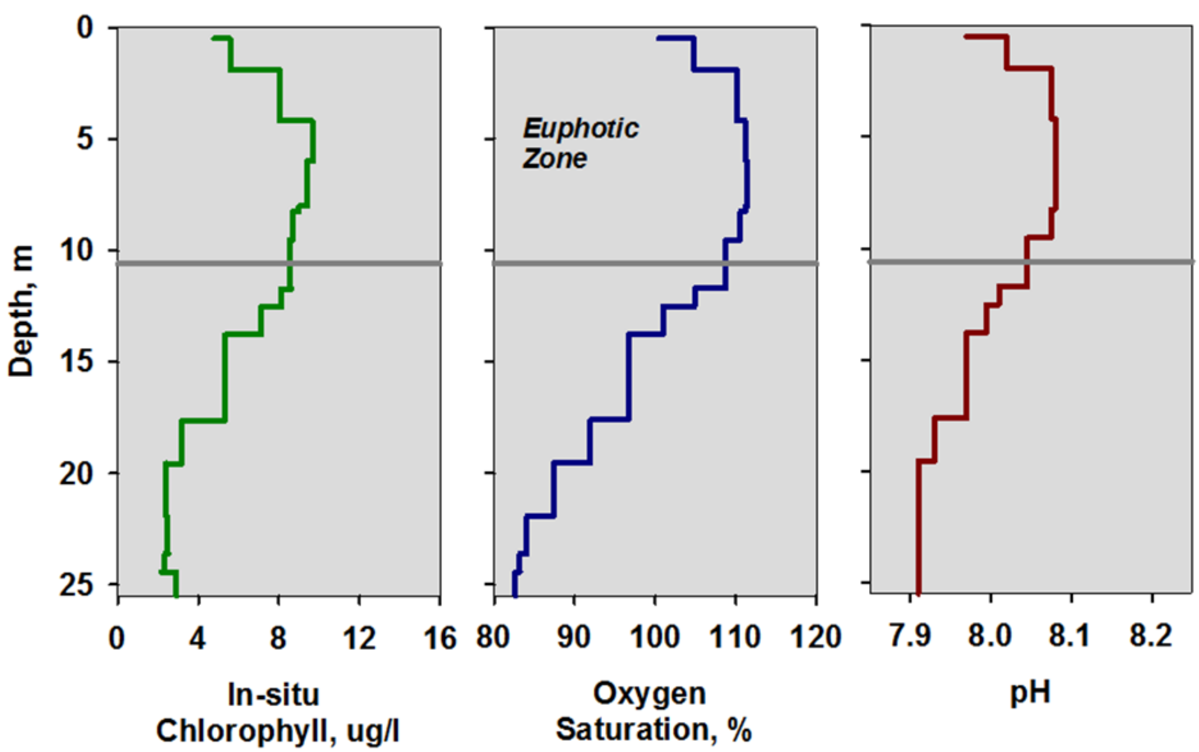


Figure 23. Depth-wise changes in chlorophyll concentration (green), percent dissolved oxygen saturation (blue) and pH (red) at the Bay station (RO) observed on 17 September 2019.

for excesses to be released immediately to the atmosphere, saturation levels above 100% would be expected. Below the euphotic depth, oxygen can be depleted at a rate faster than it can be replaced by mixing and/or production due to algal respiration, decomposition of organic material and a variety of chemical interactions.

The observed depth-wise changes in pH (Figure 23) are also related, in part, to the euphotic depth, algal photosynthesis, and mixing. As a simple description of processes involved, the removal of carbon dioxide from the water column during photosynthesis raises pH, while

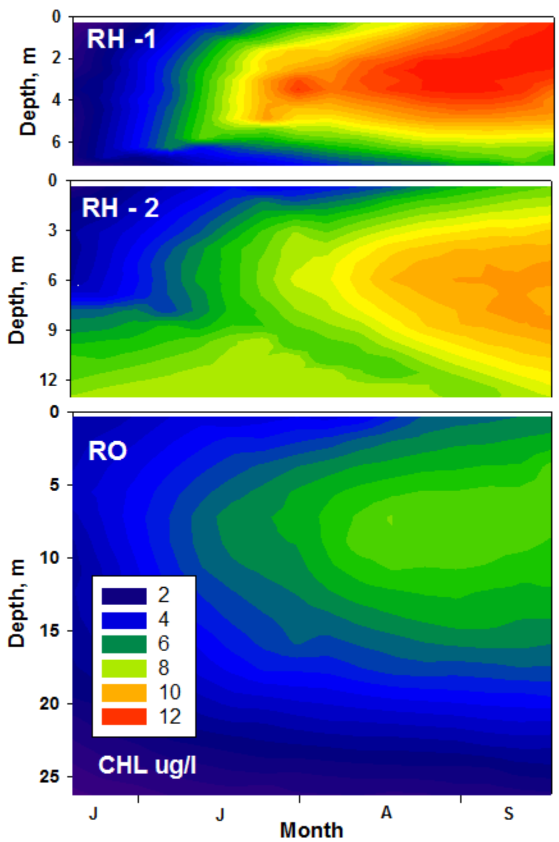


Figure 24. Changes in chlorophyll concentration over depth during summer and early fall 2019 at the inner and middle Rockport Harbor stations (RH-1 and RH-2, respectively) and in the Bay (RO).

Table 3. Comparison of mean and range of chlorophyll concentrations for Maine coastal areas compiled by USEPA and the Cadmus Group, and those for Rockport Harbor/bay stations.

Data Source	Chlorophyll, ug/l
EPA/All Maine Surface only	1.79 (0.15-10.60)
Cadmus/Mid-coast Surface only	3.35 (1.99-5.16)
RCC - Surface only	2.21 (0.34 – 9.16)
RCC - Euphotic zone means	6.94 (2.77-18.06)

respiration and decomposition release carbon dioxide reducing pH.

There were marked differences in the vertical, longitudinal and seasonal distribution of chlorophyll concentration for the harbor and bay stations (Figure 24). In general, concentrations at each station were highest from mid-summer to early fall, highest for the inner harbor (RH-1), and lowest for the bay station (RO). These differences likely reflect differences in water column depth, proximity to nutrient-rich bottom sediments, freshwater and nutrient inflows, degree of mixing, and user-related activities in the harbor.

A comparison of the mean and range in chlorophyll concentrations (Table 3) indicates similarity between surface waters for harbor sites and the bay site, and those compiled by the USEPA and The Cadmus Group for Maine coastal sites. When considering values for the euphotic zone for harbor and bay sites, the mean of euphotic zone means is markedly higher reflecting the range in the vertical distribution of phytoplankton. While a similar increase for Maine coastal sites survey would

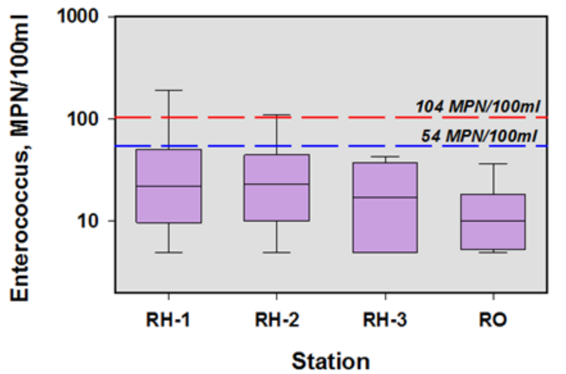


Figure 25. Enterococcus levels at Rockport Harbor and Bay stations during 2012-2019. Dashed lines indicate MHB (red) and MDEP (blue) standards.

be expected, euphotic zone data are unavailable in the USEPA or Cadmus compilations.

Bacteria – Enterococcus bacteria levels on most sampled dates were below the single observation standard for both MHB (104 MPN/100ml) and MDEP (54 MPN/ 100ml; Figure 25). Exceptions occurred at the inner and middle harbor sites (RH-1 and RH-2, respectively). The MDEP standard value was exceeded on 7 and 5 dates during 2012-2019 for the inner and middle harbor, respectively.. The MHB standard was exceeded for these same sites on 5 and 3 of these dates, respectively, with a maximum value of 920 MNP/100ml observed at RH-1.

More problematic from a public health standpoint were elevated enterococcus levels observed during Jun-Aug at Goodie's Beach (Figure 26). Based on samples collected by MBH and the Rockport Harbor Master's staff, MHB recommended that contamination advisories be posted at the beach on 59 dates. There were clear differences between years with higher observed levels and more numerous advisories in 2012-2016 than in 2017-2019.

Such differences in enterococcus levels may be related to precipitation and the fact the storm water runoff from a 25-acre residential area west of Pascal Avenue discharges adjacent to the beach. A comparison of monthly precipitation for June, July and August each year with the seasonal norm based on the period of record for the National Weather Service gage in West Rockport suggests a higher incidence of contamination in wetter years

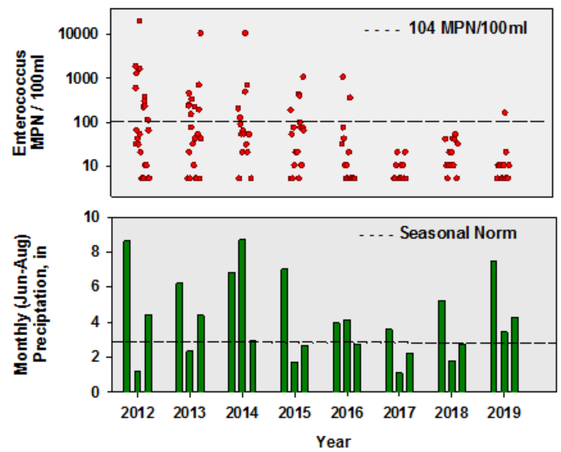


Figure 26. Enterococcus levels at Goodie's Beach during June-August (upper) based on MHB data. Dashed line indicates MHB standard. Total monthly precipitation for Jun-August (lower) as measured at the NWS gage in West Rockport. Dashed line indicates seasonal (Jun-Aug) norm based on the period of record for the gage.

(Figure 26). It's noteworthy that in addition to recommending contamination advisories based on weekly samples, MHB also recommends advisories following precipitation events; MHB did so on 84 dates in 2012-2019.

The RCC continues to support efforts by the Town to identify and manage contaminant sources as a means to effectively protect public health. Efforts to date are described in a forthcoming RCC report[16]

Summary

The Rockport Conservation Commission (RCC) collected water quality information during 2012-2019 for Rockport Harbor, a site in Penobscot Bay near the entrance to the harbor, Goose River and four streams that drain to the harbor as a means to assess current conditions, identify existing or potential issues, and establish a baseline from which to identify trends over time. The State of Maine classifies marine and estuarine waters, and fresh waters based on intended uses for the resource and establishes a set of criteria or regulatory standards, some of which are numeric while others are narrative or in the form of interim recommendations. The RCC assessment was guided by these criteria and standards.

Streams

To a large extent, the river and streams met or exceeded applicable water quality standards. Dissolved oxygen saturation levels were above 75% on a majority of sample dates. However, based on the results of a previous study, there are locations along the length of Goose River that experience extremely low levels of oxygen saturation and concentration due presumably to the existence of wetlands immediately upstream that may reduce flow and increase oxygen loss due to decomposition of organic material.

Total phosphorus and total nitrogen concentrations varied among streams with values exceeding recommended levels (0.03 and 0.6 mg/l, respectively) on several sample dates. Ott Brook and Winter Street drainage exhibited median values in excess of the recommended value for nitrogen while the median phosphorus value for Lily Pond Stream exceeded the corresponding recommended value. Phosphorus values were skewed toward higher values for all streams. Changes in nutrient concentrations for Goose River appeared to be seasonal and/or flow-related.

E. coli levels were generally below the standard single-sample value of 236 MPN/100ml. An exception was Winter Street drainage where numerous excessive values were recorded. Enterococcus levels, for which there is not a freshwater standard, were monitored for the Goose River because of the potential impact on the harbor and Goodie's Beach. Several values did exceed both the MHB and Maine single-sample standard, and appeared to increase seasonally.

Harbor

Tidal exchanges between Penobscot Bay and Rockport Harbor have a significant effect on harbor water quality since such exchanges amount to approximately 40% of the volume of the harbor on a daily basis. While discharges from Goose River and the four smaller streams would contribute modest amounts of freshwater to the bay through these exchanges, potential local influences on harbor water quality were identified.

Nitrogen and phosphorus concentrations in surface waters varied little among harbor and bay sites. The mean and range in total phosphorus concentrations were comparable to values from two published studies involving multiple sites along Maine's coast. Total nitrogen concentrations compared favorably with data for other mid-coast sites, but were decidedly lower than those reported for all coastal Maine sites. ***Higher nutrient concentrations for Goose River and the streams when compared to those for harbor***

and bay indicate the potential for impacts to the harbor from nonpoint source loadings from the coastal watersheds.

Dissolved oxygen saturation at harbor sites remained above the 85% standard on most sample dates. Saturation levels below 85% observed in late August through September were likely related to the growth, senescence, settling and subsequent decomposition of phytoplankton during this period.

Surface chlorophyll concentrations and Secchi depths were comparable to those for other sites in the region. Chlorophyll concentrations at harbor sites exhibited positive skew likely reflecting seasonal increases in phytoplankton abundance. In-situ data allowed a more complete assessment of spatial and temporal distribution of chlorophyll and, by inference, phytoplankton. ***Highest concentrations were observed at intermediate depths in the euphotic zone where there was sufficient solar radiation to support algal photosynthesis.*** Euphotic zone chlorophyll concentrations were progressively higher toward the head of the harbor.

Enterococcus levels were below both the MHB and MDEP standard at the outer harbor and bay sites, but exceeded these levels on several sample dates at middle and inner harbor sites. Of concern for public safety were numerous extremely high numbers at Goodie's Beach, particularly in years with above normal precipitation. Bacteria levels appeared to be primarily related to storm runoff that is discharged adjacent to the beach. Additional investigations as to potential sources of bacteria are ongoing.

Comments and Useful References

[1] Volunteer River Monitoring Program (VRMP) annual reports are available at https://www.maine.gov/dep/water/monitoring/rivers_and_streams/vrmp/reports.html

[2] Based the 2011 National Land Cover Database (NLCD) available from the US Geologic Survey as reported by Homer, C.G., J. A. Dewitz, l. Yang, S. Jin, P. Danielson, G. Xian, J. Coulston, N. D. Herold, J. D. Wickham, and K. Megown. 2015, Completion of the 2011 National Land Cover Database for the conterminous United States - Representing a decade of land cover change information. Photogrammetric Engineering and Remote Sensing, 81(5): 345-354

[3] Maine's Water Quality Standards are available at https://www.maine.gov/dep/water/wqs/index.html

[4] CFU is 'Colony Forming Units'. An equivalent unit, 'Most Probable Number' or MPN, is more appropriate for the analytical method used in the study.

[5] Maine Healthy Beaches Program information and data are available at http://www.mainehealthybeaches.org/index.html

[6] The RCC acquired a Manta 2 Sub 3 water quality instrument (Eureka Water Probes, Austin, TX) through Maine's Coastal Communities Grant Program.

[7] National Weather Service data for West Rockport (ID - 1 NNW ME) available at https://w2.weather.gov/climate/xmacis.php?wfo=gyx

[8] US Geological Survey data for the Ducktrap River are available at https://waterdata.usgs.gov/me/nwis/

[9]Dudley, R.W. 2004. "Estimating Monthly, Annual, and Low 7-Day, 10-Year Streamflows for Ungaged Rivers in Maine." U.S. Geological Survey Scientific Investigations Report 2004-5026, 22p.

[10] Kennedy et al., 2016. "A Watershed Approach to Managing Land Use Impacts to Coastal Waters" is available at https://www.town.rockport.me.us/

[11] The US Fish and Wildlife Service's National Wetland Inventory is available at https://www.fws.gov/wetlands

[12] Battelle . 2008. "Conceptual Plan for Nutrient Criteria Development in Maine Coastal Waters." Report to USEPA Region I & Oceans & Coastal Protection Divisions & State of Maine .February 22, 2008. Work Assignment No. 4-53 Project No. G921353 available at: https://www.maine.gov/dep/water/nutrient-criteria/batelle-nutrient-criteria-report-2008.pdf

[13] The Cadmus Group/Saquish Scientific Nutrient Criteria Report (November 2009) is available at https://www.maine.gov/dep/water/nutrient-criteria/091104_cadmus_saquish_nutrient_criteria_report.pdf

[14] These mass-loading rates correspond to watershed-wide export coefficients of 0.17 lb/ac/yr (0.186 kg/ha/yr) for phosphorus and 2.88 lb/ac/yr (3.224 kg/ha/yr) for nitrogen.

[15] Kennedy et al., 2016. "A Watershed Approach to Managing Land Use Impacts to Coastal Waters" is available at https://www.town.rockport.me.us/

[16] Kennedy, R.H., In Prep. "Goodie's Beach Water Quality Assessment (2009-2019)." Report of the Rockport Conservation Commission.