Nitrogen Mass Balance for Quonochontaug Pond-A Preliminary Estimate

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Beginning in 2008, Salt Pond Coalition (SPC) volunteers have been collecting data on nitrogen in Rhode Island's salt ponds. The data set for Quonochontaug Pond is particularly rich. Each of the sources and sinks for dissolved inorganic nitrogen (DIN) in the pond has been systematically investigated and calculations of each are now available. These calculations show the following:

- Independent measurements and calculations of the various sources and sinks of DIN in the pond are not quite in balance. More nitrogen enters the pond from its watershed and benthic recycling than leaves the system via flow to the ocean and sequestration in bottom sediments.
- About the same amount of DIN enters the pond each year from the three primary sources—surface water, ground water, and the atmosphere.
- Current measurements of tidal exchange with the ocean represent only 5% of the loss of DIN from the pond. This term needs more study.
- A significant amount of nitrogen is released to Quonochontaug Pond water from degradation of organic matter in the bottom sediments. However, the bottom sediment also acts as a sink for nitrogen. On an annual basis more nitrogen is sequestered in the sediments than is released into the water from the sediment.
- The annual increase in DIN that has been measured in pond water is relatively small when compared to the nitrogen in each of the sources and sinks. For example, the annual increase in DIN in pond water is only about 2% of the DIN that enters the pond from ground water.

Background:

Nitrogen is a key factor in the aquatic health of Quonochontaug Pond (QP). In the simplest terms, nitrogen is a nutrient required for growth of phytoplankton and other algae. Excessive amounts of nitrogen could lead to excessive growth of phytoplankton and other algae. When these organisms die, bacterial decomposition of their organic matter consumes oxygen in the pond waters. If oxygen levels fall too low, fish and shellfish will die. Thus, if levels of nitrogen in pond waters are high or if they are increasing, the pond's ecosystem can become unbalanced and the pond will be less suitable for fish and wildlife and for human recreation.

Understanding the inputs and outputs of nitrogen (the mass balance) allows aquatic scientists, resource managers, the interested public, and other decision makers to prioritize actions that might help to reduce ecological degradation. For example, regulatory agencies in Rhode Island have focused on groundwater inputs of nitrate as the major cause of nutrient enrichment in the State's salt ponds. Regulation of cesspools and individual sewage disposal systems near the salt ponds is one of the management actions that have been taken to prevent increased levels of nitrogen in pond waters. What other sources of nitrogen could be important? What mechanisms remove nitrogen from pond waters? Are there other management actions that could be taken to reduce the levels of nitrogen in the pond? Understanding the mass balance for nitrogen can help to answer these questions and set priorities for further research and new management actions.

This article will focus on dissolved inorganic nitrogen (DIN) in the water of QP because this is the form of nitrogen that is most available to support phytoplankton growth. There are two major forms of DIN, dissolved nitrate and dissolved ammonium. Both can support algal growth and the individual values are combined in this article and expressed as DIN. There are four major sources (inputs) of DIN to the pond: the atmosphere, groundwater, surface water, and DIN (primarily ammonium) released from bottom sediments. One other input, the direct deposit of fecal material containing nitrogen from waterfowl, is relatively minor based on calculations of this source from the existing literature and described in more detail in the technical notes that accompany this article (see SPC website: www.saltpondscoalition.org).

There is one primary output of DIN from the pond: tidal flow to Block Island Sound through the Quonnochontaug breachway. A second mechanism that reduces biologically available nitrogen is sequestration of DIN (contained within particulate organic matter) in pond sediments. Technically, the nitrogen is still in the system but because it is not available to support algal growth, it is considered to be an output or sink in this article. Additional outputs of nitrogen include the removal of fish and shellfish from the pond watershed by humans or wildlife. There are no good data on this term but it is thought to be minor compared to the daily tidal export of DIN to the ocean and the sequestration of nitrogen in bottom sediments.

Mass Balance Terms:

The overall mass balance of dissolved inorganic nitrogen (DIN) and the terms that contribute to this mass balance are shown in Table 1. All values are all given as kilograms of nitrogen per year (KgN/year) and are thus directly comparable. Where possible these values are calculated based on data from QP, taken at several locations over several years. Sources of basic data and calculations from that data are fully documented in the technical note that accompanies this article (www.saltpondscoalition.org). It is important to realize that inferences are made for some terms based on data taken from locations near QP rather than directly in or on the pond. Further, data from samples taken at selected representative points are extrapolated to give the mass of DIN for the entire pond on a yearly basis. These extrapolations are typical of scientific studies done for large water bodies where it is clearly impossible to monitor every location all of the time.

Surface Water: Surface water represents the mass input of DIN that comes into the pond's waters from brooks or direct runoff from land adjacent to the pond. The largest surface water input to QP is Harmonic Brook which was monitored by SPC for water quality and nutrients from 2009 to 2013. The average nitrate and ammonium concentrations from SPC measurements were combined with the modeled flow for Harmonic Brook (Masterson et al, 2007) to generate the mass of 2,540 KgN/year of DIN entering QP from this source. Another brook entering the pond (Ninigret Cove Brook) was also monitored but it does not flow year round and its flow is minor compared to Harmonic Brook. There is some direct runoff from land adjacent to the pond; however, there is not very much impervious surface adjacent to the pond and most of this runoff infiltrates through the soil.

Atmosphere: The atmospheric component of the mass balance is the wet (rain or snow) and dry (aerosol) input of DIN that falls directly on the water surface of the pond. The atmospheric component of the annual mass input of DIN is 2,370 KgN/year. This value was computed using the surface area of the pond and the measured areal deposition of DIN at Avery Point in nearby New London, Connecticut (Nadim et al, 2001).

Groundwater: Groundwater enters the through the gravel, sand, and silt along the shoreline and through bottom sediments in the pond. Shallow ground water is likely to come from sources near the pond. In deeper ground water flow systems, water may travel underground from some distance away. Ground water contributes 2,100 KgN/year to the pond. This value is derived from recent work conducted on the pond by scientists at the University of Rhode Island (Moran et al, 2014).

Outflow to the ocean: During every tidal cycle, water is exchanged between the pond and the ocean. SPC data show that the average concentration of DIN in pond water of the eastern basin of QP is higher than the DIN in the water of Block Island Sound and adjacent waters (see references in technical note that accompanies this article; www.saltpondscoalition.org). Combining the difference in DIN concentration with data on the volume of water exchanged between the two water bodies (Guarinello, 2009) gives a net output of 686 KgN/year from QP to the ocean. This is a substantially smaller amount of DIN flowing out of QP than that of any of the three input terms mentioned above. For the ebb tide, the DIN concentration that was used was the sampling year average (2008-2014) of surface and bottom water from two stations in the eastern basin of QP (see supporting information that accompanies this article in the saltpond-scoalition website). For the flood tide of water entering the pond, the DIN concentration that was used was a combination of tidal waters in the Quonochontaug breachway and the mean DIN concentration of Block Island and Rhode Island Sound waters (see supporting information that accompanies this article in the saltpondscoalition website).

Recycling of DIN within the pond: When algae and other organisms living in the pond die, they settle to the bottom where some of their organic matter is degraded by microorganisms, releasing DIN to the pore water of the surface sediments. Eventually this DIN reenters pond waters where it could be reused by algae to support growth of new organisms. Not all of the organic matter is degraded, however. A significant fraction of the nitrogen that reaches the bottom accumulates in the benthic sediment and becomes part of the sedimentary record of the history of the pond. On an annual basis more nitrogen is sequestered in the sediment than is released back into pond waters. The flux of DIN from the bottom sediment was experimentally determined using sediment cores from QP (Callender, 2014) and calculated using seven years of ammonium data in the pond's surface and bottom water (see technical note that accompanies this article; www.saltpondscoalition.org). Using these data from the cores and pond water, the calculated flux of DIN from the bottom sediment into pond water is 8,760 KgN/year. From data on sediment composition and sedimentation rates in the pond (Ford, 2003) the accumulation of nitrogen from pond water into the sediment is calculated to be 11,930 KgN/year. Subtracting the amount of nitrogen mobilized into the water from the amount of nitrogen accumulated in the sediment gives a value of 3,170 KgN/year of DIN that is sequestered in the sediment.

Pond water: Beginning in 2008, SPC volunteers have collected water samples at the top and bottom of the water column at 5 locations in QP (Figure 1). These samples were analyzed for DIN by an analytical laboratory at the University of Rhode Island. The monitoring data for the period 2008-2014 shows both increases and decreases in DIN with an overall upward trend (Figure 2). Combining the DIN concentrations in pond water with the total water volume in the pond results in an average accumulation of about 40 KgN/year in the water of QP.

Discussion of the mass balance and management implications:

On an annual basis, the mass of nitrogen entering the pond (15,770 KgN/year) is somewhat larger than the amount removed from pond water (12,616 KgN/year). Because all of the mass balance components were measured and calculated independently, it is not surprising that the inputs and outputs do not exactly equal each other. Each of these components will have some degree of uncertainty which might account for some of the difference. This is especially true of the flux of DIN to the ocean. It was not possible to measure an accurate ebb tidal flux as the only time that this was sampled was in September 2016 immediately after a substantial rain event and the resultant DIN concentrations approximated that of fresh water. Further research and additional monitoring would likely improve the values for each of the components, especially that of the outflow to the ocean term. Mass balance calculations for large natural systems are often made using data for some of the components and calculating one or more other components by difference. This method will result in an exact balance between the mass of the inputs and outputs but any error in calculating one component would then lead to an error in the calculation of the components derived by difference.

The amount of nitrogen that enters the pond each year from surface water, the atmosphere, and ground water are all about equal. In regard to any management action that might be taken to reduce the total amount of DIN entering the pond annually from the watershed and airshed, it seems that the ground water component is the most likely to yield results. Nothing can really be done about the nitrogen deposited on the pond from the atmosphere. Harmonic Brook, the most significant source of surface water nitrogen drains a relatively undeveloped area which is already protected by conservation easements. Direct runoff from the land surface of water containing nitrogen has not been measured or included in this mass balance but is thought to be relatively minor. However, efforts to prevent increases in impervious surface near the pond and to reduce residential application of fertilizer could be useful in reducing this input. Rhode Island management agencies have already undertaken significant efforts to reduce the amount of nitrogen entering the pond through ground water. Eliminating cess pools and requirements to install denitrifying individual sewage disposal systems could very well change the amount of nitrogen entering the system in the future.

Only 4% of the total amount of nitrogen that enters the pond each year is exported from the pond through tidal exchange with Block Island Sound. Any action that can be taken to improve the tidal exchange through dredging the breachway or dredging sediment within the pond that impedes tidal circulation would likely be important in improving the flux of DIN from the pond to the ocean. Also, better data on the quantity of the ebb flux of DIN would be helpful (see data explanation in the section on Outflow to the Ocean). However, the pond sediments contain a lot of stored nitrogen that is not currently available. Therefore, any disturbance of these sediments that might make the stored nitrogen more bioavailable to the water column should be carefully considered.

Recycling of DIN within the pond is very significant. The amount of nitrogen that is mobilized from the sediments into the water and the amount of nitrogen that is sequestered within the sediments are both very large numbers compared with the other sources and sinks of nitrogen in the pond. The difference between these two shows that there is a net deposition of 3,170 KgN/year. This is larger than any one of the three primary sources of nitrogen entering the pond from its watershed   The flux of nitrogen from the sediment and the sequestration of nitrogen within the sediment both need further study. Because both of these terms are very large, any refinement in their values would improve the overall understanding of the mass balance for the pond.

Sampling year (May to October) annual average measurements of DIN concentration in pond water have some variability from year to year. Over the period 2008 to 2014, DIN has increased in pond water by 40 KgN/year. This is a relatively small number compared with the various sources and sinks. For example, it is only about 2% of the DIN that enters the pond from ground water and about 1.5% of the amount that enters from surface water. Therefore, small changes in the DIN in either of these sources could have a significant effect on the rate of accumulation of DIN in pond water. As discussed above, some of these efforts are already underway. And, further monitoring of the ebb and flow of DIN between the pond and the ocean might improve the reliability of the mass balance.

In conclusion, it is apparent that the hard work and dedication of SPC's monitoring volunteers and the establishment of a nutrient and water-quality database have substantially improved the public's understanding of the ecology of southern Rhode Island's Salt Ponds. For without this, the decisive nature of the nitrogen mass balance presented in this article would not be possible.

Table 1

Nitrogen in Quonochontaug Pond water: The inputs (sources) include surface water, the atmosphere, and ground water plus nitrogen that is released from benthic sediments. Nitrogen is removed from the pond via flow to the ocean and sequestration in the bottom sediments. All values are given in kilograms of nitrogen per year (KgN/year)

Mass balance component	Input to QP	Output to ocean or accumulation within pond sediment
Surface water	2,540	
Atmosphere	2,370	
Groundwater	2,100	
Flux from bottom sediment	8,760	
Flow to Block Island Sound		686
Deposition and sequestration in bottom sediment		11,930
Total	15,770	12,616

Acknowledgement

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EBYC
NBI
HC Ch
HC Buoy
JR
Sampling Sites
JR: Judge's Rock
HCBuoy: Harmonic Cove Buoy
HCCh: Harmonic Cove Channel
NBI: North Bill's Island
EBYC: East Basin Yacht Club
N
W
E
S
0
0.25
0.5
1
Miles
Salt Ponds Coalition
RIGIS

Figure 1

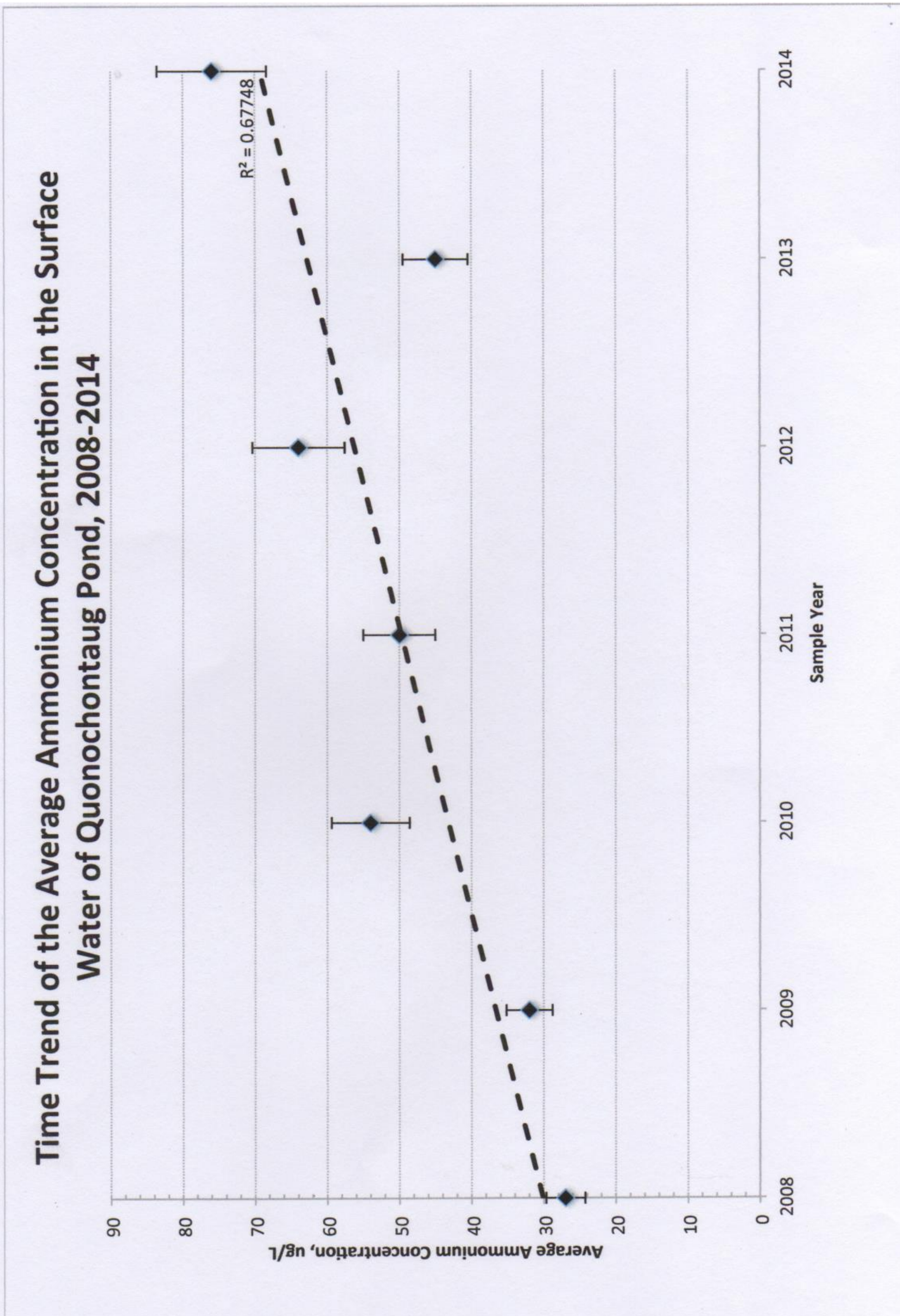
Time Trend of the Average Ammonium Concentration in the Surface Water of Quonochontaug Pond, 2008-2014
R² = 0.67748
Average Ammonium Concentration, ug/L
0
10
20
30
40
50
60
70
80
90
2008
2009
2010
2011
2012
2013
2014
Sample Year

Figure 2