Development of Numeric Phosphorus and Chlorophyll-a

Targets for the Newport Water Supply Reservoirs

Rhode Island Department of Environmental Management

Office of Water Resources

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Executive Summary

As the state agency delegated to fulfill the duties of the federal Clean Water Act, the Rhode Island Department of Environmental Management (RIDEM), initiated a Total Maximum Daily Load (TMDL) study to address drinking water and aquatic life use impairments on all nine Newport Water Supply Reservoirs. All nine water supply source reservoirs exhibit degraded water quality, showing moderate to severe nutrient enriched conditions that include elevated levels of total phosphorus and total nitrogen, total organic carbon (TOC), and chlorophyll-*a*; low water clarity; frequent algal and cyanobacteria blooms; and low levels of dissolved oxygen.

The intended outcome of this evaluation is to establish target phosphorus and chlorophyll-*a* concentrations for the reservoirs that ensure that algal growth and total organic carbon concentrations are reduced to a level that supports drinking water and aquatic life uses. Using data collected in 2015, RIDEM evaluated empirical relationships between nutrients, algal growth, total organic carbon, and the potential for total trihalomethane production. The findings from this study indicate that seasonal mean epilimnetic total phosphorus and chlorophyll-*a* targets of 18 ug/l and 11 ug/l, respectively, would be protective of Newport's drinking water reservoirs. Reductions in algal/cyanobacterial-derived organic carbon will result in reduced risk of disinfection by-product formation, reduced treatment costs, and reductions in cyanobacterial dominance of the phytoplankton communities in the reservoirs-with concomitant reductions in the potential for cyanobacterial toxin formation.

The focus of the TMDL is on control of algal abundance via reductions in nutrients (as opposed to control with copper sulfate) and it affects only the contribution that phytoplankton make to the pool of DOC in the reservoirs. In addition, 1) The chlorophyll and phosphorus targets for the Newport reservoirs are a means to achieve the TMDL goals that source waters are of sufficient quality to allow the TTHM MCLs to be achieved with conventional treatment, 2) The focus of this TMDL is on control of algal abundance via reductions in nutrients (as opposed to control with copper sulfate) thus reducing the contribution that phytoplankton make to the pool of DOC in the reservoirs, 3) The targets are not intended as a means of *guaranteeing* compliance with DBP MCLs.

Introduction

Water Supply System

The Newport Water System (Newport Water) is owned by the City of Newport and operated and maintained by the City's Department of Utilities, Water Division. Newport Water's retail service area includes Newport, Middletown, and a small section of Portsmouth. In addition, Newport Water provides water wholesale to the Portsmouth Water & Fire District and Naval Station Newport. Newport Water operates and maintains two water treatment facilities (Station 1 and Lawton Valley Treatment Plant) with a combined capacity of 16 MGD, 170 miles of water main and approximately 14,700 service connections. Newport Water draws its raw water supply from a system of nine surface reservoirs, which includes North and South Easton Ponds, Gardiner Pond, Paradise Pond, St Mary's Pond, Sisson Pond, Lawton Valley Reservoir, Nonquit Pond and Watson Reservoir. The reservoirs and their associated watersheds are located in Newport, Middletown, Portsmouth, Tiverton, and Little Compton. The reservoirs and ponds were all artificially built and are interconnected through a complex network of piping and pump stations.

The quality of the raw water delivered to the treatment plants is of particular concern during summer and fall when environmental conditions favor peak phytoplankton growth. Based on data collected in 2011, 2012, and 2015, the ponds exhibit elevated levels of both phosphorus and nitrogen and experience frequent and long lasting cyanobacteria blooms.   Newport Water relies heavily on the use of copper sulfate to control nuisance algal and cyanobacteria blooms.

The challenges of producing drinking water that consistently meet Safe Drinking Water Act (SDWA) standards despite the poor quality of source water brought into the plants led Newport Water to undertake studies and eventually make significant improvements at Station 1 and construct a new Lawton Valley Treatment Plant – both of which are equipped with Advanced Water Treatment Processes. Upgrades to the Station 1 Treatment Plant went online at the end of July 2014 and the new Lawton Valley Treatment Plant came online September 17, 2014. With these improvements, the Newport Water System is the first water treatment system in New England to incorporate Advanced Treatment Processes. The improvements to the water treatment plants are funded by an $85 million subsidized loan from the Drinking Water State Revolving Fund administered by the Rhode Island Clean Water Finance Agency and the Rhode Island Department of Health (RIDOH). Water rates for all customers of the Newport Water System have increased significantly - an investment essential to ensure safe drinking water for Aquidneck Island.

The quality of the drinking water distributed to homes and businesses on Aquidneck Island has substantially improved as a result of the new and improved treatment plants. This is evident from the sampling results of water collected from the distribution system since the new treatment facilities have gone on-line which find that concentrations of total trihalomethanes (TTHMs) are lower. However, given the intense algal/cyanobacteria blooms that continue to occur in most of the reservoirs as well as the continued reliance on copper sulfate to treat these blooms, improvement to the water treatment facilities alone is not considered a sufficient response to the degraded condition of these source waters. Protection of a water supply's source waters is considered by the RIDOH as the frontline in protecting public health and is essential to the long term viability of Aquidneck Island's water supply.

Regulatory Structure

Under the federal Clean Water Act, all states, territories, and tribes are required to comprehensively assess and report on the condition of their waters. Rhode Island's Water Quality Regulations classify all nine reservoirs as Class AA waters designated for use as a public drinking water supply source, primary and secondary contact recreational activities and fish and wildlife habitat. As part of the 2014 Integrated Reporting assessment cycle, the RIDOH assessed the Newport Water System and determined that all nine source reservoirs failed criteria determining whether the quality of the water supply sources support their use for drinking water purposes.[1] This assessment of drinking water use impairment is

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[1] RIDEM's Consolidated Assessment and Listing Methodology (RIDEM 2014) states that *"Surface source waters are considered fully supporting drinking water use when there are no violations of MCLs and no restrictions or advisories, and no requirement of more than conventional treatment (standard filtration and chlorination). Surface source waters are considered impaired for drinking water use when there are violations of the MCLs, and/or requirements of more than conventional treatment (standard filtration and chlorination), and/or, frequent taste and odor problems, and/or contamination-based closures of the source water".*

based upon the fact that the Newport Water System had experienced violations of Safe Drinking Water Act (SDWA) Maximum Contaminant Level (MCLs) for total trihalomethanes (TTHMs), frequent taste and odor problems, and that conventional treatment alone is not sufficient to consistently meet Safe Drinking Water Act requirements. Furthermore, the data collected in 2011 and 2012 indicated the nine source reservoirs violated the State's criteria for nutrient criteria for aquatic life use. All nine reservoirs violated the State's criterion for total phosphorus (0.025mg/L)[2].

All nine reservoirs are listed as impaired for drinking water and aquatic life uses on the 2014 303(d) List.   The specific parameters causing these impairments are:

- **Total Phosphorus**: impairs aquatic life use (contributes to frequent and excessive algal growth and cyanobacteria blooms).
- **Total Organic Carbon (TOC)**: impairs drinking water use (contributes to elevated levels of trihalomethanes in finished water).

As mandated by the federal Clean Water Act, RIDEM has begun steps to develop water quality restoration plans (called Total Maximum Daily Loads or TMDLs) to establish acceptable pollutant loads for the nine source reservoirs. The primary objective of the Newport Water Supply Reservoirs TMDL is to restore the source waters to a condition that supports their primary designated use, which is drinking water supply, and protects them from future degradation. The TMDL will establish nutrient reduction targets to control algal abundance, which will benefit the reservoirs' use as public drinking water sources and their aquatic life. Improving the quality of the source waters will enhance protection of public health, and is expected to lessen Newport Water's use of the Advanced Treatment Processes and thus associated operational costs.

TMDL Development

Development of the TMDLs for the Newport water supply reservoirs will require the establishment of numeric phosphorus and chlorophyll-*a* targets that are protective of the more stringent use classification of drinking water supply sources. The TOC drinking water impairment will be addressed via the total phosphorus TMDL. The goal is that the quality of the reservoirs is such that the Safe Drinking Water Act (SDWA) requirements (for trihalomethanes specifically) can be met with conventional treatment alone.

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[2] RI Water Quality Regulations Rule 8D(2) Class Specific Criteria, 10. Nutrients (as amended December 2010):

(a) Average Total Phosphorus shall not exceed 0.025 mg/l in any lake, pond, kettlehole, or reservoir, and average Total P in tributaries at the point where they enter such bodies of water shall not cause exceedance of this phosphorus criteria, except as naturally occurs, unless the Director determines, on a site-specific basis, that a different value for phosphorus is necessary to prevent cultural eutrophication.

(b) None in such concentration that would impair any usages specifically assigned to said Class, or cause undesirable or nuisance aquatic species associated with cultural eutrophication, nor cause exceedance of the criterion of 10(a) above in a downstream lake, pond, or reservoir. New discharges of wastes containing phosphates will not be permitted into or immediately upstream of lakes or ponds. Phosphates shall be removed from existing discharges to the extent that such removal is or may become technically and reasonably feasible.

The derivation and adoption of numeric nutrient and chlorophyll-*a* targets that are protective of drinking water supply sources has been slow to develop at both the state and federal levels.   Rhode Island is currently re-evaluating its numeric nutrient criteria for lakes but has specifically targeted non-drinking water lakes, due to the complex nature of management at drinking water source supplies. To date, the States of Colorado, Oklahoma, and Kansas have developed chlorophyll-*a* targets for drinking water supply reservoirs, and New York State has developed chlorophyll-*a* and phosphorus targets that would apply to all potable water supplies in the state. Although the chlorophyll-a targets derived in NY state have yet to be formally adopted they have been used as TMDL endpoints for several Class A waterbodies which, in NY, are waterbodies suitable for use as drinking water sources following conventional treatment.

RIDEM's technical approach for deriving nutrient and chlorophyll-*a* targets for the Newport Reservoirs TMDL is largely patterned after a study conducted by the New York State Department of Environmental Conservation (NYSDEC). Additionally, some aspects of RIDEM's study have incorporated elements of the study/analysis performed by the state of Colorado Water Quality Control Division (WQCD 2011). NYDEC has proposed phosphorus and chlorophyll-*a* thresholds for the protection of water supply lakes and reservoirs by establishing relationships between nutrients, algal abundance, dissolved organic carbon, and trihalomethanes to set appropriate numeric nutrient thresholds (Callinan et al. 2013). In 2015, RIDEM initiated a water quality study of the Newport reservoirs similar in scope and purpose to the one conducted by NYSDEC (Callinan 2009). A summary of major findings from this study, as well as the technical approach to defining the phosphorus and chlorophyll targets for the nine reservoirs is detailed below.

Water Quality and Trophic Status of the Newport Reservoirs

Data collected in 2011 and 2012 by consultants to the City of Newport revealed that all nine reservoirs experience moderate to severe nutrient enriched conditions, including elevated levels of phosphorus, nitrogen, and chlorophyll-*a*, low water clarity, frequent algal and cyanobacteria blooms, and low levels of dissolved oxygen.   Additional data collected in 2015 by RIDEM confirmed the eutrophic conditions in the reservoirs. Table 1 provides a summary of trophic state related parameters, as well as the Trophic State Index (TSI) calculations in the Newport reservoirs from the 2015 dataset.   The trophic status of each reservoir is calculated according to Carlson (1977).   The TSI, developed by Carlson (1977) utilizes three variables-total phosphorus, chlorophyll-a pigments, and secchi depth to estimate algal biomass. Phosphorus, chlorophyll-a (algae concentration) and secchi depth are related. When phosphorus increases, that means there is more food available for algae, so algal concentrations increase. When algal concentrations increase, the water becomes less transparent and the Secchi depth decreases.   In Table 1, total phosphorus and nitrogen, and chlorophyll-*a* epilimnetic mean concentrations are expressed in ppb. Secchi disc depth is reported in meters. Epilimnetic means for each parameter are generally based on 12 samples.

Table 1 Epilimnetic Mean Trophic Indices from 2015 sampling of Newport Reservoirs.

Reservoir	TP	TN	Chl-a	Secchi	Carlson TSI (TP)	Carlson TSI (Chl-a)	Carlson TSI (Secchi)	Trophic State
Nonquit	41.3	594.9	16.2	1.0	57.8	57.9	60.0	Eutrophic
Watson	17.2	597.9	14.4	1.47	45.2	56.8	54.5	Eutrophic
Lawton Valley	41.7	1027.8	35.1	1.08	57.9	65.5	58.9	Eutrophic
Sisson	87.7	1261.4	55.9	0.81	68.7	70.1	63.0	Eutrophic
St. Mary's	71.1	1246.9	38.2	1.16	65.6	66.3	57.9	Eutrophic
North Easton	57.2	858.3	44.7	0.77	62.5	67.9	63.8	Eutrophic
South Easton	37.1	984.2	31.0	0.78	56.3	64.3	63.5	Eutrophic
Gardiner	43.1	1209.7	36.7	1.15	58.4	65.9	58.0	Eutrophic
Paradise	79.6	1191.5	37.3	0.86	67.3	66.1	62.2	Eutrophic

Nutrient Enrichment and Drinking Water Supply Reservoirs

While phytoplankton plays a key role in aquatic systems, its excessive proliferation can become a significant problem for waterbodies utilized as a source of drinking water.   Elevated nutrient concentrations are the primary cause of increased algal growth although temperature, solar radiation, predation, and other factors also play a role.   Excessive algal growth can lead to impairments in surface waters used for drinking water by: 1) contributing to total organic carbon (TOC) and turbidity (e.g., algae cells), 2) producing taste and odor compounds, and, 3) contributing precursors which form disinfection by-products (DBP) upon chlorination, such as trihalomethanes (THMs) and haloacetic acids (HAAs) (Nguyen et al 2005).

Callinan et al. (2013) provide an excellent conceptual model showing the theoretical linkages between nutrient enrichment and drinking water human health concerns.   This conceptual model (excerpted from Callinan et al. (2013) is presented below in Figure 1 and provides additional insight for examining the relationships between nutrients, algal abundance, natural organic matter, and disinfection by-product formation (specifically, total trihalomethanes (TTHM)) in the Newport reservoirs.   Below is a description of the linkages in Figure 1, as they are described by Callinan et al. (2013) and as applied in the context of the Newport Reservoirs.
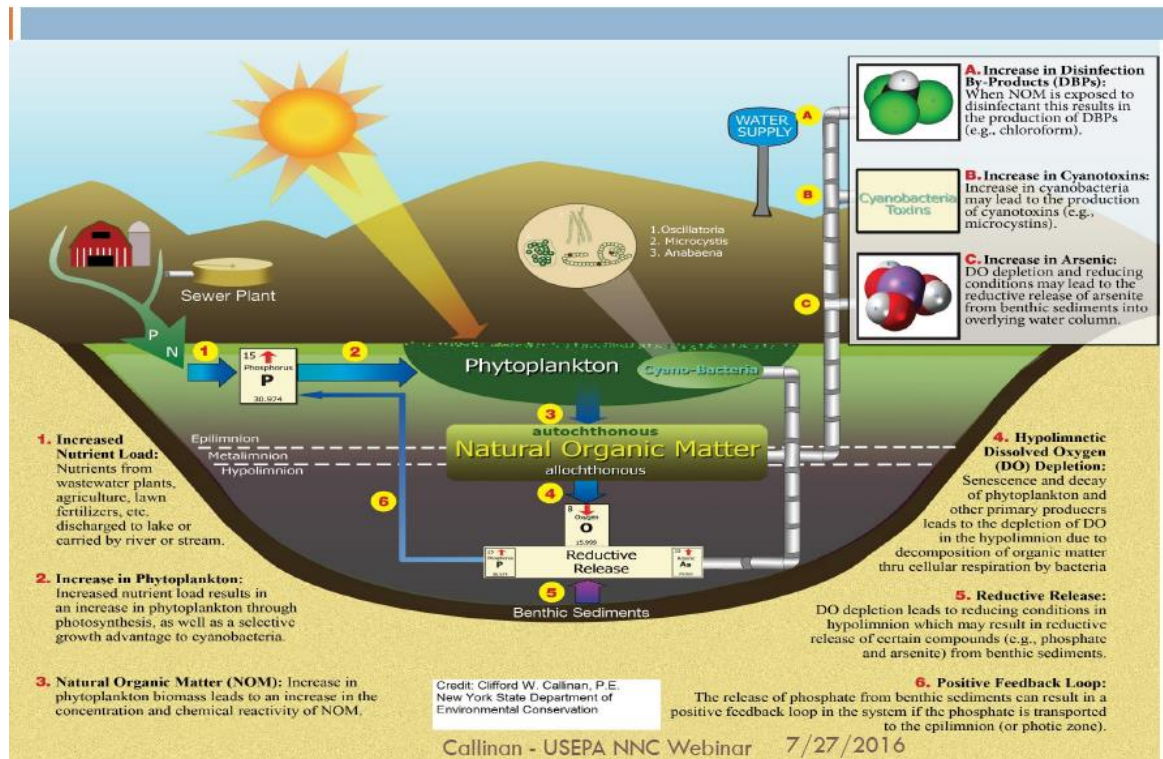
Figure 1. Conceptual Model of Theoretical Linkages between nutrient enrichment and drinking water health concerns (taken from Figure 1. Callinan et al. 2013).

Linkage 1- **Increased nutrient loads:** Elevated nutrient (phosphorus and nitrogen) loads to the reservoirs comes from agricultural, commercial, and urban-residential land uses in the watersheds and are transported via tributaries, most significantly from Baileys Brook, Paradise Brook, and the Maidford River. This has been documented via investigation by RIDEM, URI, and the City of Newport. Nutrient loads (namely phosphorus) also come from internal cycling from reservoir sediments (see Linkages 5-6). A substantial portion of the internal load may also come from anthropogenic legacy phosphorus loads. Increased nutrient loads results in elevated levels of nutrients in the reservoirs (documented in Table 1).

Linkage 2- **Increase in phytoplankton:** Increases or elevated levels of nutrients results in increases in phytoplankton as well as selective growth advantage to cyanobacteria. Results from 2011-2012 and 2015 sampling efforts document elevated levels of chlorophyll-*a* during the growing season as well as dominance (and early dominance) of the phytoplankton community by cyanobacteria in a majority of the reservoirs. Newport Water has been applying copper sulfate to control algal and cyanobacteria growth in the reservoirs for over 60 years (Julia Forgue-City of Newport Department of Utilities public meeting Oct 13th, 2016). Cyanobacteria blooms have necessitated the issuance of recreational/non-contact advisories with untreated water by the Rhode Island Department of Health in 2011, 2012, 2015, and 2016.

Linkage 3- **Natural Organic Matter (NOM):** Increases in phytoplankton biomass can lead to increases in both the concentration and reactivity of NOM, which then form disinfection byproducts when the raw water is treated with chlorine.   Figure 2 displays the mean TTHM (Summers et al. 1996), and chlorophyll-a concentrations for all nine Newport reservoirs from early May through mid-October. Figure 2 shows the tendency of TTHM formation potential to increase as primary productivity (as measured by chlorophyll-a) increases within the reservoirs.
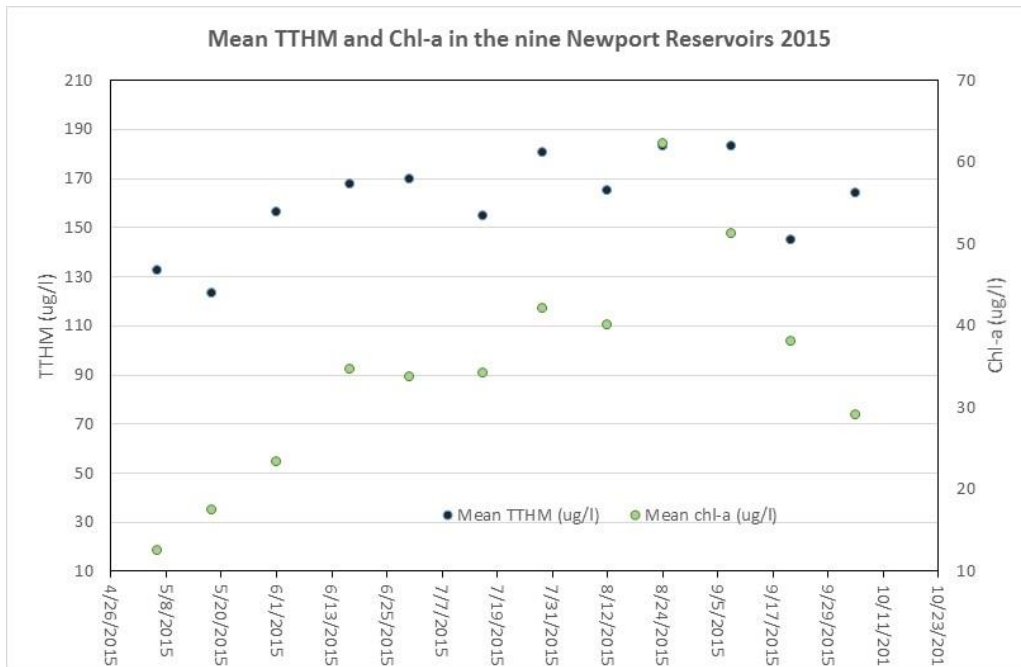

Figure 2. Plot of seasonal changes in reservoir-mean TTHM and chlorophyll-a concentrations in the Newport Reservoirs-2015.

Linkage 4- **Bottom Water DO Depletion:** Decay of organic matter (primarily phytoplankton) through cellular respiration by bacteria causes depletion of oxygen in the hypolimnion of stratified reservoirs. The same mechanism causes oxygen depletion in the bottom waters of the shallow, non-stratified reservoirs. Low oxygen levels were observed in a majority of the reservoirs in 2011, 2012, and 2015.

Linkage 5 and 6- **Reductive Release and Internal Loading of Nutrients:** Oxygen depletion in the hypolimnion or bottom waters of the reservoirs leads to reducing conditions and reductive release of nutrients (nitrogen and phosphorus) from the benthic sediments, which is available to further increase phytoplankton abundance. Results from the 2011-2012 and 2015 sampling efforts confirm elevated levels of both nitrogen and phosphorus in the anoxic portions of reservoirs during periods of the growing season.

Linkage A- **Increase in DBPs:** While disinfectants are effective in controlling many harmful microorganisms, they react with organic and inorganic matter in the water to form disinfection by-products (DBP), some of which pose health risks at certain levels. Prior to the advanced treatment processes becoming operational in the fall of 2014, Newport Water had a history of violations of the TTHM MCL of 80 ug/l.

Linkage B- **Increase in cyanotoxins**: Increases in cyanobacteria abundance increase chances of cyanotoxins in raw water. Both microcystins, a hepotoxin, and anatoxin-A, a neurotoxin, have been detected in several of the raw water samples from Newport's reservoirs. A water sample from Sisson Pond collected on August 12, 2015 had a measured anatoxin level of 80 ug/l.

Natural Organic Matter-Sources, Properties, and Significance

As stated earlier, control and reduction of the algal-derived component of organic matter in the reservoirs via reduction of nutrients is one of the major goals of the TMDL and thus it is useful to evaluate the likely source of DOC in each reservoir. The focus on algae is important because algal-derived precursors are difficult to remove during conventional water treatment (Saunders et. al 2015). Natural Organic Matter (NOM) is widely accepted as the primary precursor of disinfection by-product compounds (EPA 2001). NOM is usually measured and reported in terms of either dissolved organic carbon (DOC) or total organic carbon (TOC).

The primary source of DOC in a waterbody can either be (or a combination of) external (allochthonous) or internal (autochthonous), depending on the waterbody and watershed characteristics as well as season or year. External inputs tend to consist of humic substances originating from terrestrial and wetland/littoral higher plant tissues (Wetzel 2001) while internal sources are derived from internal primary productivity and include algal/cyanobacteria biomass, extra-cellular products, and products of cell lysis (Veum 2006). Differences in the properties of external and internal-derived DOC are often used to interpret the composition of DOC in a waterbody. The type of DOC, external versus internal-derived, can influence the production of disinfection by-product compounds.

Optical properties are used to infer the source of DOC. Organic matter tends to absorb light strongly in the ultraviolet (UV) range and UV absorbance is sometimes used as a surrogate for DOC concentration (Edzwald et al. 1985). DOC source can be determined by what is called 'specific UV absorbance' or SUVA. SUVA is calculated as the ratio of UV absorbance (UV 254) to the DOC concentration and is expressed in units of L/mg-m. SUVA is useful for generalizing about sources because internal and external DOC are at opposite ends of the SUVA spectrum (CO WQCD 2011). DOC composed of larger and more complex molecules (external) absorb UV light more strongly than DOC composed of simpler molecules (internal) (Weishaar et al. 2003). DOC of external origin tends to have a high degree of aromacity because it consists mainly of larger molecules like humic and fulvic acids. The SUVA for external DOC is likely to be in excess of 3.0 or 3.5 (Mash et al. 2004) while algal-derived, or internal DOC is composed of small molecules such as carbohydrates and amino acids with a SUVA value less than 2 L/mg-m (Mash et al. 2004, Nguyen et al. 2005). The carbon to nitrogen ratio (C/N ratio) can also be used to discern internal versus external sources of organic carbon. Internal, algal-derived sources of carbon, are indicated by C/N ratios less than 8 while external organic matter has C/N ratios greater than 20 (Hein et al. 2003).

Table 2 provides a summary of chlorophyll-*a*, dissolved organic carbon, UV-254, SUVA, C-N ratio, Specific Yield, and TTHM levels from the 2015 sampling of the Newport Reservoirs. In addition to DBP concentrations (as represented by TTHM levels), specific yields are useful for further evaluating the reactivity of the DOC pool and better understanding of the TTHM precursor material. Specific yields represent the concentration of TTHM normalized to the DOC for a water sample (μg DBP/mg C). This allows for determining a particular water samples yield of a particular DBP per unit carbon, or essentially its reactivity to chlorine.

The final column in Table 2, the likely predominant source of DOC for each reservoir, was determined based on the above information as well as ancillary information such as watershed size and knowledge of tributary inputs.

Table 2. Natural Organic Matter characteristics of Newport Reservoirs based on 2015 Sampling Results

Reservoir	Direct Watershed Size acres	Chl-a ppb*	DOC mg/l*	UV 254 nm(cm-1)*	SUVA L/mg-m*	C:N ratio*	TTHM ug/l*	Specific Yield ug TTHM/mg DOC*	Likely Predominant DOC source
Nonquit	4436	16.2	11.3	0.5	4.2	19.0	434.2	38.4	Watershed - Derived
Watson	2295	14.4	5.17	0.10	2.01	8.7	119.63	23.1	Phytoplankton-based
Lawton Valley	742	35.1	4.68	0.08	1.84	4.5	96.85	20.7	Phytoplankton-based
Sisson	225	55.9	8.52	0.16	1.98	6.8	137.08	16.1	Phytoplankton-based
St. Mary's	546	38.2	5.64	0.11	2.01	4.5	103.93	18.4	Phytoplankton-based
North Easton	2812	44.7	5.09	0.12	2.48	5.9	133.67	26.3	Combination
South Easton	2850	31.0	5.36	0.11	2.13	5.4	136.92	25.5	Combination
Gardiner	146	36.7	6.23	0.09	1.51	5.2	91.89	14.7	Phytoplankton-based
Paradise	2049	37.3	7.97	0.20	2.58	6.7	186.92	23.4	Combination

*Expressed as seasonal mean epilimnetic value

Direct watershed size is the contributing watershed to each reservoir in the 'conventional sense', however water from each reservoir can and is transferred

Development of Chlorophyll and Phosphorus Targets

The data used to support this analysis was collected in 2015 and involved sampling of the nine reservoirs on a bi-weekly basis from May through October. Sampling was conducted at a location corresponding to the deepest location in each reservoir and included in-situ vertical profiling of temperature, conductivity, pH, and dissolved oxygen. Water samples were obtained from the surface, and, if present, from within the thermocline and hypolimnion of each reservoir. Samples were analyzed for total and dissolved phosphorus, total nitrogen, nitrate and nitrite nitrogen, total Kjeldahl nitrogen (TKN), ammonia nitrogen, dissolved organic carbon, chlorophyll-*a*, ultraviolet absorbance (UV 254), and total trihalomethanes (utilizing the UFC method developed by Summers et al. 1996). Surface samples were also analyzed for phytoplankton identification and enumeration as well as algal toxins (on a monthly basis).

All data were collected according to a US EPA approved quality assurance project plan developed by RIDEM in 2007 (RIDEM, 2007) and available on-line at: http://www.dem.ri.gov/pubs/data.htm#quapps. A final data report, which includes an evaluation of data quality and final results is also available on-line at:http://www.dem.ri.gov/programs/water/quality/restoration-studies/.
The methodology utilized by RIDEM to derive chlorophyll-*a* and phosphorus targets for the nine reservoirs are described below and, as stated earlier, are somewhat patterned after the New York studies (Callinan 2009 and Callinan et al. 2013). RIDEM's study examined the relationships between 1) dissolved organic carbon (DOC) and the formation potential of total trihalomethanes (TTHMs), 2) chlorophyll-a and dissolved organic carbon, and 3) total phosphorus and chlorophyll-a.

The waterbodies investigated in the NY study span a wider trophic state range (oligitrophic through eutrophic) while the trophic state of the nine Newport reservoirs ranges from eutrophic to hypereutrophic. Due to the highly eutrophic nature of the Newport reservoirs, as well as the similarities of the studies themselves, it was believed that expanding the Newport reservoir dataset to include the waterbodies examined in the NY study may improve the predictive capability of the relationships between chlorophyll-*a* and DOC, and total phosphorus and chlorophyll-*a* in the Newport reservoirs. This is easily observed in Figures 4 and 5 and further justification is provided in Steps 2 and 3.   Table 3 provides a comparison of key trophic variables from the New York and Rhode Island study waterbodies.

Table 3. Trophic Summaries of NY Study and RI Study waterbodies.

System	TP (ug/l)	Chl a (ug/l)	Secchi Disk (m)	DOC (mg/l)	Average TSI*
NEW YORK STATE STUDY WATERBODIES					
Skaneateles Lake	4.14	0.71	8	1.4	27
Alcove Reservoir	5.69	2.43	6.3	3	34
Keuka Lake	5.7	2.62	6	2.7	34
Canandaigua Lake	7.69	2.32	6.9	2.8	35
Chenango Lake	8.65	5.59	-	2.9	41
Seneca Lake	9.01	2.36	6.3	2.4	36
Hemlock Lake	10.22	5.16	4.3	2.6	41
Canadice Lake	11.37	2.53	3.9	2.5	40
Kiamesha Lake	12.71	3.84	2.5	4.1	44
Owaska Lake	13.04	4.55	4.5	2.5	42
Tomhannock Reservoir	14.3	6.9	4.1	2.9	44
Cayuga Lake	15.82	4.07	3.9	2.5	43
Otisco Lake	16.21	6.34	3.5	2.2	45
Stoney Creek Reservoir	18.6	9	3.3	4.6	47
Lake Louise Marie	19.51	8.5	2.4	4.1	49
Sleepy Hollow Lake	20.97	6.74	1.5	5.2	51
Honeoye Lake	26.9	11.36	3.7	3.7	49
Chadwick Lake	27.6	20.96	1.3	4.8	56
Conesus Lake	28.31	7.37	3	3.1	49
Basic Creek Reservoir	35.34	22.75	1.5	4.5	57
De Forest Reservoir	47.14	28.49	-	4.5	62
RHODE ISLAND STUDY WATERBODIES					
Nonquit Pond	41.3	16.2	1.0	11.3	59
Watson Reservoir	17.21	14.41	1.47	5.2	52
Lawton Valley Reservoir	41.66	35.06	1.08	4.7	61
Sisson Pond	87.74	55.92	0.81	8.5	67
St. Marys Pond	71.10	38.17	1.16	5.6	63
North Easton Pond	57.20	44.73	0.77	5.1	65
South Easton Pond	37.13	30.96	0.78	5.4	61
Gardiner Pond	43.08	36.69	1.15	6.2	61
Paradise Pond	79.55	37.27	0.86	8.0	65

*Carlson (1977). All values represent seasonal mean epilimnetic values.

Step 1: Evaluate the relationship between mean epilimnetic total trihalomethane (TTHM) and mean dissolved organic carbon (DOC) in the Newport reservoir waterbodies.   The relationship between mean epilimnetic DOC and mean TTHM for the nine reservoirs is presented in Figure 3.   TTHM values reported in the New York study (APHA Standard Method 6232) were derived using a different methodology than those in the Rhode Island study (Summers et al. 1996), were not comparable, and therefore were not included in the analysis. As expected, there is a fairly strong relationship between epilimnetic DOC and TTHM concentrations which show increasing levels of TTHM production with increasing levels of DOC. Nonquit Pond exhibited the highest levels of DOC of any of the nine ponds and much of this appears, as evidenced by elevated SUVA values, to be of external origin (i.e. watershed-derived natural humic and tannic acids). The trend in increasing TTHM with increasing DOC is best represented by an exponential function, which shows that approximately 74% of the variability in TTHM concentration is accounted for by differences in DOC concentration.
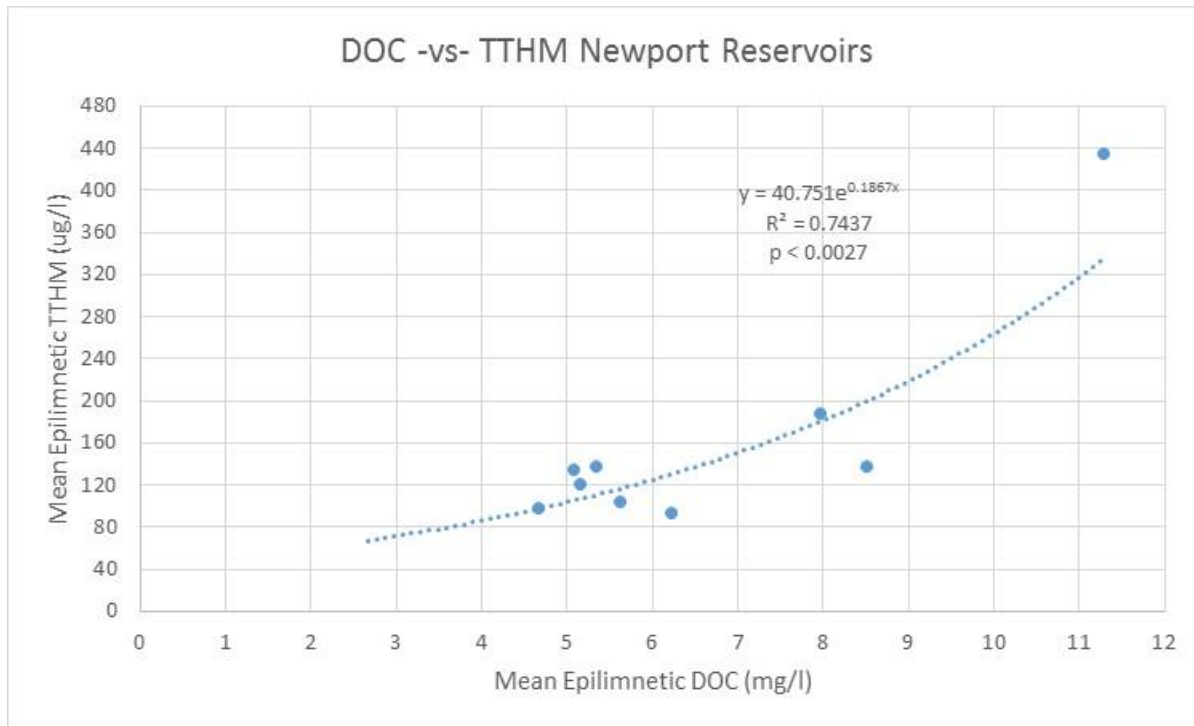
Figure 3. Mean epilimnetic DOC versus TTHM- Newport Reservoirs 2015.

Utilizing the equation derived solely from the RI study dataset and substituting the current TTHM MCL of 80 ug/l results in a mean epilimnetic DOC value of 3.6 mg/l. The Newport reservoirs raw water DOC target of 3.6 mg/l derived from the above equation is within the range of various other technically derived source water DOC thresholds for drinking water supplies. Callinan (2009) and Callinan et al. (2014) proposed a raw water DOC threshold of 3.0 mg/l and the Colorado Water Quality Control Division, utilizing a different methodology, proposed a raw water threshold of 4.0 mg/l (COWQCD 2011).

Solving for TOC from a TTHM value of 80 ug/l, which is the current SDWA MCL, is conservative in that it does not account for any reduction of TOC within the treatment process. There are two reasons why this was deemed reasonable and defensible within the context of both the SDWA and CWA. First, the properties of organic carbon affect the effectiveness with which it can be removed by either conventional treatment or by enhanced coagulation (WQCD 2011)[3]. EPA guidance (US EPA 1999a) and multiple other authors (White et al. (1997), Archer and Singer (2006a & 2006b), and Cheng and Chi (2003) find that in general, the performance of enhanced coagulation is poor when organic carbon has a low SUVA value. Furthermore for SUVA values less than 2 L/mg-m, DOC removal is generally less than 25% (summarized in Eikebrokk et al. 2007). As documented in Table 2 above, with the exception of Nonquit Pond, Newport's water supply reservoirs exhibit seasonal average SUVA values less than 2.5 L/mg-m with five reservoirs having seasonal averages of 2.0 L/mg-m or less.

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[3] Enhanced coagulation refers to optimizing coagulation, flocculation, clarification and filtration to remove organic matter from water that may contribute to formation of disinfection byproducts.

Second, Section 7.5 (b)(1)(ii) of the state of Rhode Island 'Rules and Regulations Pertaining to Public Drinking Water' [R46-13-DWQ] specify conditions that §5.0 systems (Public Water Supply systems supplied by a surface water source, or a ground water source under the direct influence of surface water) must meet in order to qualify for <u>reduced monitoring of TTHM and HAA5</u>. One common requirement is that the source water annual average TOC value, before any treatment, be **≤ 4.0 mg/l**. If this 4.0 mg/l TOC requirement is met, then systems may reduce TTHM and HAA5 monitoring <u>if the annual average TTHM concentration is ≤ 0.040 mg/l and the annual average HAA5 concentration is ≤ 0.030 mg/l</u>. These concentrations are half of the current Stage 2 MCL values of 0.080 mg/l for TTHM and 0.060 mg/l for HAA5, respectively.

In conclusion establishing a TOC target of 3.6 mg/l is consistent with and provides a margin of safety in achieving the TMDL's goal that the quality of the reservoirs is such that the Safe Drinking Water Act (SDWA) requirements (for trihalomethanes specifically) can be met with conventional treatment alone.

Step 2: Step 2 involves examining the relationship between epilimnetic levels of chlorophyll-*a* and dissolved organic carbon. Figure 4 displays the relationship between chlorophyll-*a* and dissolved organic carbon in the combined NY and RI waterbodies dataset which indicates a trend of increasing DOC concentrations with increasing levels of chlorophyll. Nonquit Pond is clearly an outlier. Relative to the other 8 reservoirs, the Nonquit Pond watershed is much larger in size and drains a large cedar swamp. In addition, one of the two major tributaries-Quacket Brook drains the Tiverton Landfill- which is likely a significant source of organic carbon. The calculated mean epilimnetic SUVA value for Nonquit Pond is 4.2 L/mg-M indicating a primary DOC source that is external to the waterbody.

With Nonquit Pond removed, there is a strong and significant (p<0.0001) association between DOC and chlorophyll-*a*, suggesting that DOC levels are largely governed by phytoplankton abundance. The trend of increasing DOC with increasing chlorophyll is best represented by a linear function. It can be seen that the RI waterbodies make up the upper end of the relationship albeit with slightly more scatter then the NY waterbodies. To provide additional credibility for combining the NY and RI datasets, a comparison of slopes test was applied to the linear regression of each individual dataset.   Application of the significance of the difference between two slopes test (Sokal et al. 1981) (T value= 0.01678, Df= 25, and P= 0.9867) showed that the slopes of the two linear regressions are not statistically significantly different.

Approximately 73 percent of the variability in mean epilimnetic DOC concentrations is explained by variations in mean epilimnetic phytoplankton biomass (as measured by chlorophyll-*a*).   Thus, inclusion of the NY dataset provides valuable insight as to what levels of DOC could be expected with reductions in chlorophyll levels in the Newport Reservoirs. Solving the regression curve for chlorophyll using a threshold DOC value of 3.6 mg/l results in a mean value of 10.8 ug/l (For practicable purposes-rounded to 11.0 ug/l). This value is meant to be interpreted as a seasonal average.
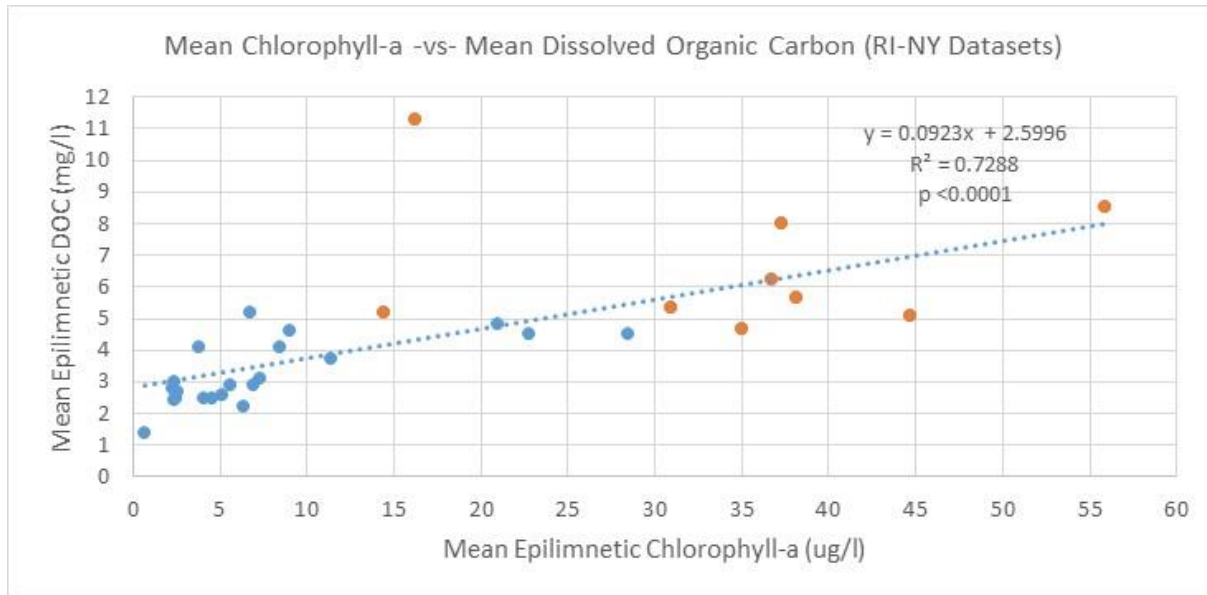
Figure 4 Mean epilimnetic chlorophyll-*a* versus DOC- NY and RI waterbodies.

Step 3: Step 3 involves evaluating the relationship between epilimnetic levels of total phosphorus and chlorophyll-*a* in the RI and NY waterbodies. The relationship between mean epilimnetic total phosphorus and mean chlorophyll-*a* from the NY and RI waterbodies is presented in Figure and indicates that approximately 88 percent of the variability in phytoplankton biomass, as measured by chlorophyll-*a*, is accounted for by differences in total phosphorus concentrations (p<, 0.0001). Again, inclusion of the NY dataset allows for evaluation of the phytoplankton response in the Newport Reservoirs as phosphorus levels are reduced to a more meso-oligotrophic state. As in Step 2, a comparison of slopes test was applied to the linear regression of each individual dataset. Application of the significance of the difference between two slopes test (Sokal et al. 1981) (T value= 0.0182, Df= 26, P= 0.985) showed that the slopes of the two linear regressions are not statistically significantly different. Substituting the chlorophyll-*a* target of 10.8 ug/l derived in Step 2 and solving for TP results in a mean epilimnetic total phosphorus target of 20 ug/l. Adding an explicit MOS of 10% results in a final total phosphorus target of 18 ug/l-expressed as a seasonal mean value.
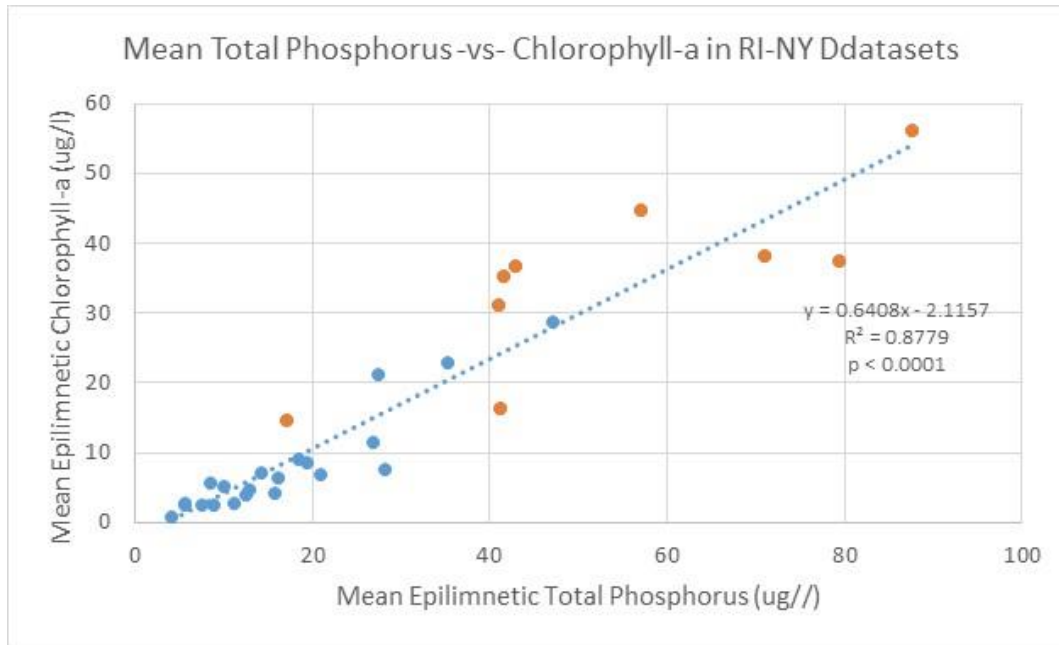
15

Figure 5. Mean epilimnetic total phosphorus versus chlorophyll- NY and RI waterbodies.

Summary

In summary, RIDEM is proposing a chlorophyll target of 11 ug/l and a total phosphorus target of 18 ug/l for Newport reservoirs. These targets should be assessed as a mean of values obtained during the growing season- May through October. The threshold values proposed for chlorophyll-*a* and total phosphorus derived for the Newport reservoirs are consistent with findings from previous investigations. As mentioned earlier, other states have considered development of chlorophyll-*a* criteria (and in the case of NY, total phosphorus criteria) that would provide protection to drinking water supplies. The total phosphorus target of 18 ug/l will be used to develop allowable phosphorus loads to the reservoirs. Since the target is lower than the existing Rhode Island numeric criterion of total phosphorus 25 ug/l it will also be protective of the reservoirs' less sensitive designated use of aquatic life.

Corroborative Studies and Research

As stated earlier, the study conducted by RIDEM largely patterns the work done by the NYSDEC. NYSDEC proposed chlorophyll-*a* and total phosphorus criteria to restrict DBP formation potential by controlling algal abundance in water supply lakes and reservoirs (Callinan 2009 and Callinan et al. 2013). Findings from this study indicated that a mean chlorophyll-*a* threshold of 4-6 ug/l would be protective of potable water supply lakes and reservoirs. A mean total phosphorus threshold of 12 ug/l corresponded to these chlorophyll values. To date, these proposed thresholds have not become adopted in state regulation.

The state of Colorado conducted a study similar to the New York study and determined that a chlorophyll-*a* concentration of 5 ug/l would be protective of Colorado's direct-use public water supply source reservoirs (CDPHE 2011). This criterion is assessed as the average of values measured in the water supply from March through November and may be exceeded once every 5 years. The criterion was calculated from the chlorophyll-*a* level associated with an in-lake dissolved organic carbon threshold of 4 ug/l. Setting a limit on algal abundance by regulating chlorophyll-a in direct-use water supply reservoirs was meant as a preventative measure aimed at controlling or reducing algal-derived precursors of DBPs (Saunders et al. 2015).

The state of Oklahoma Water Resources Board developed a chlorophyll-*a* criterion, expressed as a long-term average, of 10 ug/l for selected public water supplies (OWRB 2005). The criterion is intended to limit the occurrence of carcinogenic disinfection byproducts and offensive taste and odor problems in drinking water that are caused by excessive algae and blue-green algae. This criterion became effective as state law July 1, 2006 and was approved by EPA Region 6 in November 2006.

In 2011, the Kansas Department of Health and the Environment-Bureau of Water published a white paper (KDHE 2011) outlining the rationale for protecting water quality in drinking water lakes and reservoirs by adopting a chlorophyll-*a* criterion for public water supply lakes.   The white paper develops options for numeric chlorophyll-*a* standards that range between 8 and 10 ug/l. The 2010 Kansas 303(d) list used 10 µg/L of chlorophyll-*a* as the listing criterion for domestic water supply lakes. The 2008 Kansas 305(b) list used the following thresholds of chlorophyll-*a* for domestic water supply uses: < 10 µg/L fully supportive; 10-12 µg/L fully supportive but threatened; 12-20 µg/L partially supportive; and >20 µg/L non-supportive.

In peer-reviewed studies, Downing et al (2001) attempted to predict the risk of waterbodies with phytoplankton populations dominated by cyanobacteria. Their study concluded that chlorophyll-*a* levels above 10 µg/l exponentially increased the likelihood of cyanobacteria dominance, causing more occurrences of taste and odor problems for drinking water supply reservoirs.

Rhode Island has also been in the process of evaluating its current numeric nutrient criterion for TP and other numeric indicators of nutrient enrichment. As part of this effort, RIDEM evaluated historical water quality data collected between 2000 and 2009 from 72 freshwater lakes, ponds, and reservoirs in Rhode Island. RIDEM used multiple lines of evidence and analyses including change point analysis and conditional probability to evaluate and select numeric criteria and thresholds.   A **change point analysis** searches along a gradient of TP (low to high concentrations) to find the greatest change in chlorophyll-*a*

response. The results of the chlorophyll-*a* change point analysis suggest that an ecological change is occurring in Rhode Island lakes at TP equal to 24µg/L and at 16µg/L.

A **conditional probability** analyzes the probability that a chlorophyll-*a* response will happen given a concentration of TP or greater has occurred. The conditional probability analysis confirmed the suggested TP change points discussed above. For a worst-case scenario, lakes at TP equal to or greater than 24µg/L have an 80% risk of a growing season mean chlorophyll-*a* greater than 10µg/L, and lakes at TP equal to 16µg/L have a 45% risk of a growing season mean chlorophyll-*a* greater than 10µg/L. As noted earlier the concentration of 10µg/L of chlorophyll-*a* can be linked to increased risk of cyanobacteria populations (Downing et al. 2001)

In 2011 and 2012, a separate RIDEM/OWR project focused on understanding cyanobacteria in Rhode Island lakes sampled several of the lakes being used to develop NNC. Lakes exceeding recreational health advisory levels for cyanobacteria also tended to exceed 10µg/L of chlorophyll-*a* in more than 50% of samples in a single growing season. This suggests exceeding 10µg/L of chlorophyll-*a* in more than 50% of five or more samples is indicative of cyanobacteria dominance in Rhode Island lakes.

While the analysis of Rhode Island's numeric nutrient criteria focused on non-drinking water lakes greater than 2m in maximum depth it can be informative to the analysis of the Newport Water System TMDL. The lower TP value of 16ug/L suggested by the evaluation of Rhode Island's numeric nutrient criteria is in line with the 18ug/L derived in the Newport analysis. The numeric nutrient criteria TP value was derived using a chlorophyll-*a* target of 10ug/L, which is similar to that derived in the Newport analysis. The values from Rhode Island's numeric nutrient criteria evaluation confirm that the Newport analysis values are in line with the general conditions in Rhode Island lakes and should be protective of the designated uses.

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