

Recreational Water Quality Criteria and its Effectiveness at Protecting Human Health: A Review of
State and Federal Standards

By

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ABSTRACT

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In order to protect recreational water quality and human health within the United States, the United States Environmental Protection Agency (EPA) developed and established Recreational Water Quality Criteria to be used as a guidance from which individual states could adopt their own Water Quality Standards. The purpose of this review is to determine the federal criteria and state specific standards' effectiveness at protecting human health. The states of interest that are addressed are California, Colorado, North Carolina, and Virginia. The federal criteria and individual state standards are reviewed individually and then compared to human health data concerning waterborne illnesses resulting from contact with recreational waterbodies. The trends in human health data are then examined and determinations made as to the overall effectiveness of both state and federal standards.

BIOGRAPHY

Lauren Pillow completed her undergraduate degree at Bluefield College where she majored in Chemistry, Biology, and Forensic Science. Upon completion of her degree she began work on her Masters of Environmental Assessment through North Carolina State University.

Lauren worked as a quality control chemist for two years after completing her undergraduate degree and is currently working as a Hazardous Waste Inspector for the State of Virginia.

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ACRONYMS

AGI	Acute Gastrointestinal Illness
ASBS	Area of Special Biological Significance
ASTM	American Society for Testing and Materials
BAV	beach action values
BRI	Benthic Response Index
CDC	Centers for Disease Control and Prevention
CFU	colony forming units
CWA	Clean Water Act
EPA	Environmental Protection Agency
GM	geometric mean
IBI	Index of Biotic Integrity
QMRA	quantitative microbial risk assessment
qPCR	quantitative polymerase chain reaction
MF	membrane filtration
MBAS	Methylene-Blue Active Substances
MPN	most probably number
NEEAR	National Epidemiological and Environmental Assessment of Recreational Water
NGI	NEEAR-GI illness
RBI	Relative Benthic Index
RIVPACS	River Invertebrate Prediction and Classification System
RWQC	Recreational Water Quality Criteria
Stds	standards
STV	statistical threshold value
WQC	water quality criteria
WQS	water quality standards

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1.0 INTRODUCTION

In 1948, the United States Congress passed the Federal Water Pollution Control Act as a means to regulate water quality throughout the United States (US). However, the original organization and scope of this act was lacking, the act was amended in 1972. These resulted in a significant reorganization of the document and an expansion of its original scope. These amendments were titled the Clean Water Act (CWA) of 1972 and are the basis for water quality regulations and guidelines in the US to this day.

While the amendments of 1972 greatly increased the effectiveness of the CWA in terms of pollution control programs and water quality standards for contaminants, additional amendments were made in 1977. These amendments emphasized toxic pollution control and identified the need for basic water quality criteria (WQC), to ensure the latest scientific knowledge is being implemented to protect the health and welfare of individuals who might come into contact with a potentially dangerous water source.

Per §304(a)(1) of the CWA of 1977, the US Environmental Protection Agency (EPA) is required to establish Water Quality Criteria (WQC) for all bodies of water, including groundwater and coastal waters. These criteria are to be based on the latest scientific knowledge and are a non-regulatory, scientific assessment of the effects that various contaminants and pollutants can have on human health and aquatic species. As a result of this regulation, the criteria established by the EPA are general guidelines to protect human and aquatic health, not specific values that must be met. Additionally, §304 of the CWA only requires the EPA to establish WQC, but does not require that water quality testing be performed by the EPA.

In order to develop the required WQC, the EPA reviews a variety of sources and studies to derive numerical limits for criteria in order to protect human health and recreational water quality. However, in some cases the EPA established criteria are not seen as effective enough to various members of the scientific community. For instance, at a conference held in 2013 meant to discuss the EPA recreational water quality criteria (RWQC) of 2012, participants expressed their concerns that the RWQC were lacking (Fujioka et al., 2015). Specifically, opposition to the criteria was made based on the studies reviewed and studies completed as a part of the RWQC development. Conference members expressed concerns that key recommended studies were not completed and risks to individuals exposed to non-point sources of fecal indicator bacteria were not developed (Fujioka et al., 2015). Additionally, it has been suggested that the EPA RWQC do not contain an appropriate number of criteria to assess health risk as the majority of testing emphasis is placed on fecal indicator bacteria (Wuertz, 2010). Due to scientific concern over the effectiveness of the EPA RWQC this review will examine the current EPA WQC, the water quality standards (WQS) for four states of interest, and the associated human health data for those states of interest in order to determine the criteria's effectiveness at protecting human health.

1.1 Parties Responsible for Water Quality Testing

While §304 of the CWA of 1977 does not designate the EPA to perform water quality testing, §303 identifies individual states as the responsible parties for testing and maintaining the waters within their state boundaries. Specifically, §303(c)(2) requires states to develop water quality standards (WQS) that can be based on one of three references. These references include the WQC set by the EPA,

modified WQC to fit site specific conditions, or the use of standards based on scientifically defensible methods. The WQS that are set by each state must be numerical limits that are specific to that state's waters; as water quality and potential contaminants vary widely for each water source based on location, climate, etc.

Based on §303 of the CWA, each individual US state must have WQS for the testing and regulation of their waters on file with the EPA. However, the significant variation among states also allows for significant variation between the structure and testing methods of state WQS. As a result, increased incidences of negative human health impacts as a result of contact with recreational waters are possible depending on the design of the WQS. This paper will assess the overall effectiveness of the WQS for four specific states by examining the current WQC established by the EPA, the specific WQS set by each state of interest, and the general trends in human health data for waterborne illnesses in each state as reported by the Centers for Disease Control and Prevention (CDC). The four states that will be examined are California, Colorado, North Carolina, and Virginia.

1.2 Current Water Quality Legislation

While there are a vast number of current legislations dealing with water quality, both at a federal and state level, only the main legislations listed below will be examined for the purposes of this review. All legislations chosen deal specifically with recreational water quality and RWQC.

1.2.1 Clean Water Act of 1977

The CWA of 1977 established the regulations for the creation of WQC by EPA. It states that all WQC must represent current scientific knowledge in order to protect both human health and aquatic life in coastal and non-coastal recreational waters. The CWA also requires states to establish WQS based on the WQC set by the EPA; as well as, test their waters to ensure compliance with their standards. All additional water quality legislation is based on the requirements established in the CWA of 1977.

1.2.2 Recreational Water Quality Criteria

Recreational Water Quality Criteria (RWQC) is a document published by the EPA in compliance with §304 of the CWA. This document established general WQC recommendations for pathogens and pathogen indicators present in recreational water bodies that are both coastal and non-coastal. In addition to general WQC recommendations, this document also describes the studies from which the WQC were derived; and general tools and methods that states can utilize in developing their WQS.

1.2.3 Elements of a State Water Monitoring and Assessment Program

Elements of a State Water Monitoring and Assessment Program is an additional document published by the EPA that is meant to provide states with guidance and a general framework for establishing their WQS and monitoring methods. States are not required to follow the guidelines set in this document. However, the EPA published this document in the hopes of assisting states with the

establishment of their WQS and as a possible means of establishing continuity amongst the WQS and monitoring programs for each individual state.

1.2.4 Water Quality Control Plan for Enclosed Bays and Estuaries

Water Quality Control Plan for Enclosed Bays and Estuaries – Part 1 Sediment Quality is a water quality control plan that specifically focuses on determining and regulating sediment quality and benthic community conditions in enclosed bays and estuaries. This is not an all-inclusive WQS document for all state waterbody types and does not detail WQC outside of sediment quality and benthic community condition. These WQC are based on the framework provided by the EPA.

1.2.5 Water Quality Control Plan Ocean Waters of California

Water Quality Control Plan Ocean Waters of California is a water quality control plan that specifically focuses on regulating and maintaining the ocean waters for the state of California. This is not an all-inclusive WQS document for all state waterbody types and only details WQC for ocean waters. These WQC are based on the framework provided by the EPA.

1.2.6 The Basic Standards and Methodologies for Surface Water

The Basic Standards and Methodologies for Surface Water is a regulation established by the state of Colorado that establishes the basic classifications, basic standards, antidegradation policy, testing methods, and implementation processes for all waterbodies within the state of Colorado. These WQS are based on the foundations described in the Colorado Water Quality Control Act and apply to the framework provided by the EPA.

1.2.7 Surface Waters and Wetlands Standards

Surface Waters and Wetlands Standards is a monitoring plan document established by the state of North Carolina meant to detail the classification systems, testing methods, and WQC for all surface waters and wetlands within the state of North Carolina. These WQS are based on the framework provided by the EPA.

1.2.8 Virginia Water Quality Standards

The Virginia Water Quality Standards is an all-encompassing monitoring plan document meant to detail the classification system, testing methods and WQC requirements for the state of Virginia and every water body therein. These WQS are based on the framework provided by the EPA.

2.0 Water Quality Criteria

The EPA has established two main categories for providing RWQC guidelines for use by states. These categories include general water quality criteria and general water quality testing. In terms of general WQC, guidelines are provided by listing the qualifications of a recreational water source and listing the general water quality parameters derived from various studies. The most current WQC guidelines for recreational water as established by the EPA are discussed below.

2.1 Qualifications of a Recreational Water Source

There are many distinctions present between water sources as to type and whether they are recreational or non-recreational. In an attempt to clearly define what qualifies as a recreational water source that must be tested regularly and maintain specific WQS, the EPA has provided the following definition as part of the 2012 RWQC. The definition is as follows:

“EPA’s 2012 RWQC are for all waters in the United States including marine, estuarine, Great Lakes, and inland waters that are designated for primary contact recreation. Primary contact recreation typically includes activities where immersion and ingestion are likely and there is a high degree of bodily contact with the water, such as swimming, bathing, surfing, water skiing, tubing, skin diving, water play by children, or similar water-contact activities (USEPA, 2012).”

By using the above definition, the EPA is requiring all states to include all marine, estuarine, Great Lakes, and inland waters as a part of their WQS. As a result, many states have multiple WQS to deal with the specific water types present within their state. This concept will be examined in Section 4.0 State Water Quality Standards.

2.2 General Water Quality Parameters

The general water quality parameters set by the EPA are meant to provide states with recommended levels for pathogens and pathogen indicators that are known to cause adverse health effects to both humans and aquatic life. While there are a wide variety of pathogens, pathogen indicators, and general contaminants that can result in adverse health effects, the RWQC focus on those that generally result from fecal contamination. This is due to the known adverse health effects that can result from contact with feces. Additionally, fecal pathogens and pathogen indicators are present in every water source. However, it is important to note that while other contaminants are not specifically listed in the RWQC, the EPA recommends that states include testing for other contaminants specific to their waters in their WQS to better ensure the safety of human and aquatic health.

The pathogens and pathogen indicators listed in the RWQC were chosen based on their presence in either marine or freshwater and the magnitude values were determined based on the epidemiological and site studies conducted at various locations throughout the US. The recommended values are listed in Table 1 (USEPA, 2012).

Table 1: 2012 Recommended RWQC (USEPA, 2012)

Table 1. Recommended 2012 RWQC.

Criteria Elements	Estimated Illness Rate (NGI): 36 per 1,000 primary contact recreators		OR	Estimated Illness Rate (NGI): 32 per 1,000 primary contact recreators	
	Magnitude			Magnitude	
Indicator	GM (cfu/100 mL) ^a	STV (cfu/100 mL) ^a		GM (cfu/100 mL) ^a	STV (cfu/100 mL) ^a
Enterococci – marine and fresh	35	130		30	110
OR					
<i>E. coli</i> – fresh	126	410		100	320
Duration and Frequency: The waterbody GM should not be greater than the selected GM magnitude in any 30-day interval. There should not be greater than a ten percent excursion frequency of the selected STV magnitude in the same 30-day interval.					

^a EPA recommends using EPA Method 1600 (U.S. EPA, 2002a) to measure culturable enterococci, or another equivalent method that measures culturable enterococci and using EPA Method 1603 (U.S. EPA, 2002b) to measure culturable *E. coli*, or any other equivalent method that measures culturable *E. coli*.

In addition to the general RWQC, the EPA also lists Beach Action Values (BAV) for states to use as a guide for shutting down public beach access based on high pathogen indicator levels. These values are not required by the CWA, but are published by the EPA in order to lower incidences of adverse human health effects. The BAVs are listed below in Table 2 (USEPA, 2012).

Table 2: Beach Action Values (BAVs) (USEPA, 2012)

Table 5. Beach Action Values (BAVs).

Indicator	Estimated Illness Rate (NGI): 36 per 1,000 primary contact recreators	OR	Estimated Illness Rate (NGI): 32 per 1,000 primary contact recreators
	BAV (Units per 100 mL)		BAV (Units per 100 mL)
Enterococci – culturable (fresh and marine) ^a	70 cfu		60 cfu
<i>E. coli</i> – culturable (fresh) ^b	235 cfu		190 cfu
<i>Enterococcus</i> spp. – qPCR (fresh and marine) ^c	1,000 cce		640 cce

^a Enterococci measured using EPA Method 1600 (U.S. EPA, 2002a), or another equivalent method that measures culturable enterococci.

^b *E. coli* measured using EPA Method 1603 (U.S. EPA, 2002b), or any other equivalent method that measures culturable *E. coli*.

^c EPA *Enterococcus* spp. Method 1611 for qPCR (U.S. EPA, 2012b). See section 5.2.

2.3 Methods of Determining Water Quality Parameters

As previously mentioned, the recommended RWQC were established through the use of epidemiological and sites studies conducted at various locations throughout the US for varying periods of time. These studies are collectively known as the National Epidemiological and Environmental Assessment of Recreational Water (NEEAR) study. The time period for each individual study involved in the overall NEEAR study, the water type, and the study location are listed Table 3.

Table 3. Epidemiological Studies Conducted for the NEEAR study (USEPA, 2009)

Year	Water Type	Location
2003-2004	Temperate Fresh Water	Four beach sites on the Great Lakes
2005-2007	Temperate Marine Water	Beach sites Alabama, Rhode Island, and Mississippi
2009	Tropical Water	Puerto Rico
2009	Marine Water with Urban Runoff	South Carolina

For the studies conducted, the values determined correspond with the occurrence of adverse human health effects. The main adverse health effects studied include gastrointestinal (GI) illness, upper respiratory illness, rash, eye ailments, earache, and infected cuts. Each adverse health effect had a specific definition as described by the NEEAR study and had to develop within 10 to 12 days after contact with the water body in question. The study specific definitions are listed below:

- GI illness: “(a) diarrhea (three or more loose stools in a 24 hour period), (b) vomiting, (c) nausea and stomachache, or (d) nausea or stomachache and impact on daily activity”; (USEPA, 2009)
- Upper respiratory illness: “any two of the following: sore throat, cough, runny nose, cold, or fever”;
- Rash: “a rash or itchy skin”;
- Eye ailments: “either an eye infection or a watery eye”;
- Earache: “ear pain, ear infection, or runny ears”;
- Infected cut: “cut or wound that became infected” (USEPA, 2012)

In addition to epidemiological studies, quantitative microbial risk assessments (QMRA), validation studies, modeling, available public health data reviews, and literature reviews were also conducted to establish the recommended RWQC. The NEEAR study ultimately supported the establishment of the 2012 recommended RWQC and concluded:

“that: (1) good indicators of fecal contamination and demonstrated predictors of GI illness in fresh waters are enterococci and E. coli, and enterococci in marine water, but not fecal coliform; and (2) the risk of GI illness is considerably lower in studies where enterococci and E.coli densities were below levels established by the EPA in 1986.”

3.0 Water Quality Testing

Along with RWQC, the EPA has also published various acceptable testing methods that states can use when developing their WQS. It is important to note that the methods provided by the EPA are not the only acceptable methods for use in a state's WQS. A state is free to use any methods they choose provided that the methods are scientifically sound.

3.1 Methods of Testing

The EPA has currently published two categories of testing methods that states can utilize for various purposes. The first set of methods allows states to evaluate their waterbodies based on the RWQC recommendations provided by the EPA, while the second set of methods allows states to develop their own site specific WQC. The individual testing methods provided for each category are discussed below.

3.1.1 EPA RWQC Based Testing

There are three main testing methods that the EPA has listed as part of the category of testing methods that allow states to evaluate waterbodies based on the EPA RWQC recommendations. These testing methods include quantitative polymerase chain reaction (qPCR), sanitary surveys, and predictive modeling.

The process of qPCR is a relatively new testing method recognized by the EPA as a means of rapidly determining the presence and amount of enterococci in ambient waters. This method works by monitoring the amplification of enterococci DNA by polymerase chain reaction, in real time; offering an accurate quantification of the amount of enterococci present in the water being tested. The process of qPCR shows promise as a water quality testing method due to how quickly the test can be performed and the positive relationship shown between GI illness and enterococci levels measured with qPCR. However, the EPA has made it clear that this method may not be appropriate for all sites because there is the potential for qPCR interference. As a result, states must conduct site specific testing in order to determine if qPCR is an appropriate testing method. Along with the reference of qPCR as a possible testing method, the EPA has also provided qPCR values that are listed in Table 4 (USEPA, 2012).

Additionally, sanitary surveys have been identified by the EPA as a possible means of evaluating water quality. Sanitary surveys are conducted at individual sites by collecting information about the surrounding watershed for the site. This includes such information as possible point sources, physical features of the surrounding area, land use of the surrounding area, and any additional information concerning possible influencers of water quality that can be detailed. The collection of this information allows for states to create a reference point for the conditions of specific site at a certain time. Once the survey is complete, it can then be used to help water and public health officials to designate testing locations, identify sources of contamination, and assess contamination levels at specific points in time.

Table 4. Values for PCR in Marine and Fresh Waters (USEPA, 2012)

Table 6. Values for qPCR in marine and fresh waters.

Element	Estimated Illness Rate (NGI): 36/1,000 primary contact recreators		OR	Estimated Illness Rate (NGI): 32/1,000 primary contact recreators	
	Magnitude			Magnitude	
	GM (cce per 100 mL)	STV (cce per 100 mL)		GM (cce per 100 mL)	STV (cce per 100 mL)
qPCR ^a	470	2,000		300	1,280
Duration and Frequency: The waterbody GM should not be greater than the selected GM magnitude in any 30-day interval. There should not be greater than a 10 percent excursion frequency of the selected STV magnitude in the same 30-day interval.					

^a EPA *Enterococcus* spp. Method 1611 for qPCR (U.S. EPA, 2012b).

The final testing method detailed by the EPA for the evaluation of waterbodies based on the EPA RQWC is the use of predictive modeling. Predictive modeling is the use of various modeling tools to estimate the water quality conditions at a site, based on general trends in previously collected data. While predictive modeling is useful in situations where timely pathogen testing is not feasible, it is not meant to serve as the only means for evaluating water quality. Predictive modeling is often helpful for states in making timely water quality management decisions, but should be supplemented with additional monitoring methods. A variety of predictive modeling methods are stated by the EPA as effective tools, but the specific method used should be carefully considered prior to implementation as not all modeling methods are reflective of an individual site. The predictive modeling methods stated by the EPA are:

- Statistical regression modeling
- Rainfall based notifications
- Decisions trees or notification protocols
- Deterministic models
- A combination of models (USEPA, 2012)

3.1.2 Testing for State Specific WQC

There are two main testing methods that the EPA recommends states utilize in the event that they would prefer to use their own WQC for development of their WQS as opposed to those established by the EPA. A state may want to develop their own WQC as a means to ensure that the numerical limits set in place by the WQS are the most accurate for their state and specific sites within their state. The two main testing methods include epidemiological studies and QMRA.

By conducting an epidemiological study and/or QMRA at a specific site within a state, state management is able to provide more accurate limits and values for pathogens and pathogen indicators for that site. Not only this, but it can allow states to determine if there are alternative pathogen indicators present within a waterbody. A variety of pathogen indicators have been suggested by the EPA

to be accurate indicators of contamination in certain waterbodies. However, because these indicators are not applicable to the majority of recommended waterbodies, limits for them are not provided by the EPA. In the event that a state plans on using an additional indicator in their monitoring and testing methods, the EPA will need to determine that the science behind use of the indicator is sound before the state will be approved to so.

3.2 Frequency of Testing

The frequency at which testing is performed is generally set by the state as part of their WQS. However, the EPA recommends that states conduct at least weekly sampling during a duration of 30 days for the calculation of the GM and STV at a specific site. More frequent sampling is also suggested for sites that have higher populations. It is important to note that the recommended frequency of testing described by the EPA is based on the testing of RWQC pathogens and pathogen indicators. Additional and more frequent testing may be required if alternative indicators or contaminant testing are utilized.

4.0 State Water Quality Standards

Per §304 of the CWA, each individual state within the US is required to develop WQS that can be based on the EPA WQC. As a result of the variation in waterbody types, climates, and surrounding areas; the standards established by states can vary widely. In order to exemplify the variation among state standards due to physical difference, the states of California, Colorado, North Carolina, and Virginia will be examined. California and Colorado were chosen for examination based on the extreme drought conditions that each state is currently experiencing. North Carolina and Virginia were chosen based on the presence of coastal and non-coastal waterbodies within their boundaries; as well as the fact that they are not in a state of extreme drought.

4.1 California Standards

4.1.1 Development of Standards

The California WQS were developed by combining site specific testing for waterbodies with WQC and testing methods established by the EPA. The California standards are compliant with all CWA and federal WQS regulations. The current draft of the California WQS is divided into two documents with one document detailing the standards for enclosed bays and estuaries; and the second document detailing the standards for ocean waters. The current draft of the standards for enclosed bays and estuaries available from the EPA became effective as of August 25, 2009. The current draft for the ocean waters standards available from the EPA became effective as of December 3, 2001. For the purposes of this review, the most recently EPA reviewed and approved standards for the state will be utilized as, they have been formally recognized by the EPA.

4.1.2 Classification System

For the state of California, there is no one all-inclusive water quality document. Instead, the state divides how water quality is addressed based on the waterbody types. As a result, the classification system utilized in the California WQS is reflective of the general waterbody types present. These general waterbody classifications include groundwater, ocean water, and enclosed bays and estuaries. For the purposes of this study, groundwater standards will not be addressed.

Within the general waterbody classifications of ocean water and enclosed bays and estuaries, there are additional classifications that can apply. In general, waters within the ocean water classification are defined as, “the territorial marine waters of the State as defined by California law to the extent these waters are outside of enclosed bays, estuaries, and coastal lagoons (CaEPA, 2001).” Ocean waters can also be additionally classified as an Area of Special Biological Significance (ASBS). To be classified as an ASBS, the area of ocean water in question must be demonstrated to have significant value to man or the environment and require protection beyond the general limits.

As for the general classification of enclosed bays and estuaries, the additional classifications apply specifically to the assessment of benthic community conditions and sediment toxicity. Due to their importance within the waterbody, the WQC for enclosed bays and estuaries have criteria specific for

benthic communities. When benthic communities are assessed, they are assigned a classification of one of the four categories listed in Table 5 (CaEPA, 2009). Enclosed bays and estuaries will be additionally classified with the benthic community classification once it has been determined.

Table 5: Benthic Community Categories for California Enclosed Bays and Estuaries (CaEPA, 2009)

Category	Description*
Reference	a community composition equivalent to a least affected or unaffected site
Low Disturbance	a community that shows some indication of stress, but could be within measurement error of unaffected conditions
Moderate Disturbance	confident that the community shows evidence of physical, chemical, natural, or anthropogenic stress
High Disturbance	the magnitude of stress is high

*Descriptions are pulled directly from Chapter V(G)(3) within the water quality control plan for enclosed bays and estuaries

There are also additional classifications for enclosed bays and estuaries based on sediment toxicity. These classifications are listed in Table 6 (CaEPA, 2009).

Table 6: Sediment Toxicity Categories (CaEPA, 2009)

Category	Description*
Non-toxic	response not substantially different from the expected in sediments that are uncontaminated and have optimum characteristics for test species
Low toxicity	a response that is of relatively low magnitude; the response may not be greater than test variability
Moderate toxicity	high confidence that a statistically significant toxic effect is present
High toxicity	high confidence that a toxic effect is present and the magnitude of response included the strongest effects observed for the test

*Descriptions are pulled directly from Chapter V(F)(3) within the water quality control plan for enclosed bays and estuaries. Toxicity tests are performed on test species.

4.1.3 Testing Methods

Similar to the classification system utilized, the testing methods utilized within the California WQS differ based according to the general waterbody classification. For enclosed bays and estuaries, the laboratory testing procedures are described as follows and apply to all testing methods:

“All samples will be tested in accordance with U.S. Environmental Protection Agency (USEPA) or American Society for Testing and Materials (ASTM) methodologies where such methods exist. Where no EPA or ASTM methods exist, the State Water Board or Regional Water Quality Control Boards (Regional Water Boards) (collectively Water Boards) shall approve the use of other methods. Analytical tests shall be conducted by laboratories certified by the California Department of Health Services in accordance with Water Code Section 13176 (CaEPA, 2009).”

For ocean water testing methods, the WQS state that, “detection methods used for coliforms (total and fecal) shall be those presented in Table 1A of 40 CFR PART 136, unless alternate methods have been approved in advance by US EPA pursuant to 40 CFR PART 136 (CaEPA, 2001).” It is also additionally noted for the ocean water testing methods that, “where methods are not available in 40 CFR PART 136, the Regional Boards shall specify suitable analytical methods in waste discharge requirements (CaEPA, 2001).” All testing methods and procedures for ocean waters must comply with these regulations.

4.1.4 Water Quality Criteria

In the state of California the WQC are divided into various documents based on waterbody type, instead of combined into one all-inclusive WQS document. As a result, the main WQC documents detail criteria for groundwater, surface waters, ocean waters, and enclosed bays and estuaries. The documents detailing groundwater and surface water WQC are not addressed in this document. This is because groundwater and surface water criteria in California are specifically geared toward drinking water standards as opposed to recreational water standards.

4.1.4.1 WQC for Enclosed Bays and Estuaries

The WQC for enclosed bays and estuaries is divided into two parts. Part 1 specifically addresses sediment quality based on chemical and biological measures. Part 2 addresses more chemical criteria, such as dissolved oxygen content, pathogens, and nutrients. Part 2 of the sediment quality criteria has not been formally approved and released to the public by the State of California or the EPA. As a result, only Part 1 criteria will be covered here. Within Part 1, there are three main types of criteria that are addressed including sediment toxicity, benthic community condition, and sediment chemistry.

For sediment toxicity, the criteria are based on the reaction of approved test species to the sediment in question. These toxicity tests are performed by exposing the test species to sediment for a certain time period. The reaction of the species during that time period dictates the level of sediment toxicity. The sediment toxicity criteria utilized by the California WQS are depicted in Table 7 (CaEPA, 2009). All sediment toxicity that is performed meets EPA recommended testing procedures.

Table 7: Sediment Toxicity Categorization Values (CaEPA, 2009)

Test Species/ Endpoint	Statistical Significance	Nontoxic (Percent)	Low Toxicity (Percent of Control)	Moderate Toxicity (Percent of Control)	High Toxicity (Percent of Control)
Eohaustorius Survival	Significant	90 to 100	82 to 89	59 to 81	< 59
Eohaustorius Survival	Not Significant	82 to 100	59 to 81		<59
Leptocheirus Survival	Significant	90 to 100	78 to 89	56 to 77	<56
Leptocheirus Survival	Not Significant	78 to 100	56 to 77		<56
Rhepoxynius Survival	Significant	90 to 100	83 to 89	70 to 82	< 70
Rhepoxynius Survival	Not Significant	83 to 100	70 to 82		< 70
Neanthes Growth	Significant	90 to 100*	68 to 90	46 to 67	<46
Neanthes Growth	Not Significant	68 to 100	46 to 67		<46
Mytilus Normal	Significant	80 to 100	77 to 79	42 to 76	< 42
Mytilus Normal	Not Significant	77 to 79	42 to 76		< 42

* Expressed as a percentage of the control.

In terms of benthic community condition, the criteria are based on the various benthic indexes available. These criteria are presented in Table 8 and the full term for the indexes referenced are included in the acronyms section (CaEPA, 2009).

Table 8: Benthic Index Categorization Values (CaEPA, 2009)

Index	Reference	Low Disturbance	Moderate Disturbance	High Disturbance
Southern California Marine Bays				
BRI	< 39.96	39.96 to 49.14	49.15 to 73.26	> 73.26
IBI	0	1	2	3 or 4
RBI	> 0.27	0.17 to 0.27	0.09 to 0.16	< 0.09
RIVPACS	> 0.90 to < 1.10	0.75 to 0.90 or 1.10 to 1.25	0.33 to 0.74 or > 1.25	< 0.33
Polyhaline Central San Francisco Bay				
BRI	< 22.28	22.28 to 33.37	33.38 to 82.08	> 82.08
IBI	0 or 1	2	3	4
RBI	> 0.43	0.30 to 0.43	0.20 to 0.29	< 0.20
RIVPACS	> 0.68 to < 1.32	0.33 to 0.68 or 1.32 to 1.67	0.16 to 0.32 or > 1.67	< 0.16

The criteria for sediment chemistry requires that a minimum list of chemical analytes be characterized to determine the chemistry of the soil. This lists includes 25 specific analytes and is included in Attachment A of the Part 1 document. However, the numerical criteria for these analytes are based on mathematical formulas instead of numerical limitation values and are not listed in this review as a result.

4.1.4.2 WQC for Ocean Waters

Similar to the criteria for enclosed bays and estuaries, the criteria for ocean waters is divided into different characteristics. For ocean waters, the criteria are based on general provisions, bacterial characteristics, physical characteristics, and chemical characteristics. All ocean waters must meet the criteria for each characteristics as well as the general provision that all limits or levels of water quality listed in the standards must be met for the reasonable protection of ocean waters.

In terms of bacterial characteristics, all ocean waters must meet the criteria established in Chapter II(B)(1)(a). These criteria are listed below (CaEPA, 2001):

“(1) Samples of water from each sampling station shall have a density of total coliform organisms less than 1,000 per 100 ml (10 per ml); provided that not more than 20 percent of the samples at any sampling station, in any 30-day period, may exceed 1,000 per 100 ml (10 per ml), and provided further that no single sample when verified by a repeat sample taken within 48 hours shall exceed 10,000 per 100 ml (100 per ml).

(2) The fecal coliform density based on a minimum of not less than five samples for any 30-day period, shall not exceed a geometric mean of 200 per 100 ml nor shall more than 10 percent of the total samples during any 60-day period exceed 400 per 100 ml.”

The physical characteristics for California ocean waters do not involve specific numerical criteria as the bacterial characteristics do. Instead, the ocean water criteria outlines that there should be no floating particulars or grease, discoloration, or reduction of natural light as a result of the discharge of waste.

For chemical characteristics, the WQC list both general characteristics and specific numerical limits that cannot be surpassed. Both types of characteristics are listed in Chapter (II)(D) of the ocean water criteria. The general characteristics state that,

- “1. The dissolved oxygen concentration shall not at any time be depressed more than 10 percent from that which occurs naturally, as the result of the discharge of oxygen demanding waste materials.
2. The pH shall not be changed at any time more than 0.2 units from that which occurs naturally.
3. The dissolved sulfide concentration of waters in and near sediments shall not be significantly increased above that present under natural conditions.
4. The concentration of substances set forth in Chapter II, Table B, in marine sediments shall not be increased to levels which would degrade indigenous biota.
5. The concentration of organic materials in marine sediments shall not be increased to levels that would degrade marine life.
6. Nutrient materials shall not cause objectionable aquatic growths or degrade indigenous biota (CaEPA, 2001).”

In addition to these general characteristics, the specific criteria are presented as a table to provide a more objective view of the water quality criteria. The referenced table contains 83 objectives that must be met by all ocean waters and can be found in Appendix C of this review.

4.1.4.3 Antidegradation Policy

While it is not specifically referenced in either of the WQC documents discussed above, the state of California does have an antidegradation policy in place. This policy is a separate document and is identified as Resolution No. 68-16. Pursuant to this policy, all waters in the state of California with a water quality level higher than the established criteria shall be maintained at the existing high quality level. As a result, additional practices involving the waterbody in question may be implemented to protect its water quality.

4.2 Colorado Standards

4.2.1 Development of Standards

The Colorado WQS were developed by utilizing a variety of criteria, including EPA established criteria, table value standards, ambient quality-based standards, site-specific criteria based standards, standards for surface waters in wetlands, and site-specific narrative standards. The Colorado standards are compliant with all CWQ and federal WQS regulations. The current draft of the Colorado WQS available from the EPA became effective as of December 31, 2007 and is set to be reviewed every three

years. For the purposes of this review, the state standards referenced by the EPA will be utilized as they have been formally recognized by the EPA.

4.2.2 Classification System

The WQS applied to a specific waterbody are based upon the way that waterbody is classified by the state. For the state of Colorado, all waterbodies are classified into one of five main classifications that may have associated subclasses. These five main classifications include recreation, agriculture, aquatic life, domestic water supply, and wetlands. The associated subclasses for each classification are represented in the table below (CoDPHE, 2007).

Table 9: Classifications of Colorado Waters (CoDPHE, 2007)

Classification	Subclass	Description
Recreation	Class E	existing primary contact use
	Class P	potential primary contact use
	Class N	not primary contact use
	Class U	undetermined use
Agriculture		intended or suitable for irrigation of crops and non-hazardous as livestock drinking water
Aquatic Life	Class 1 Cold Water	capable of sustaining a wide variety of cold water aquatic life
	Class 1 Warm Water	capable of sustaining a wide variety of warm water aquatic life
	Class 2	capable of sustaining a wide variety of cold or warm water aquatic life
Domestic Water Supply		intended or suitable for potable water supplies
Wetlands		meet the characteristics of a wetland as described in the WQS

In addition to the main classifications and subclasses, the Colorado WQS also provide additional signifiers to classify a waterbody. There are two main types of signifiers including qualifiers and areas requiring special protection. In terms of qualifiers, there are three types of qualifiers listed in the WQS that can be added to any classification as a means of indicating special consideration. These qualifiers are described in Table 10. If a waterbody is given a designation of an area requiring special protection, this indicates that the standards provided by the initial classification are not protective enough and may require specialized standards. All classifications, including specialized standards, are assigned by the State Water Quality Control Commission.

Table 10: Qualifiers for Colorado Waterbodies (CoDPHE, 2007)

Qualifiers	Description
Goal	indicates the waterbody is not presently suitable for the intended purpose and a modification of one or more numerical standards has been granted
Seasonal	indicates that a waterbody may only be suitable for a classified use during certain periods of the year
Interrupted Flow	indicates that the continuity of flow for a waterbody is broken due to natural or human induced conditions

4.2.3 Testing Methods

Within the Colorado WQS, there are specific testing procedures and methods referenced. These testing procedures are divided into three main categories, including standard testing procedures, toxicity testing and criteria development procedures and other procedures. The majority of the testing procedures utilized by the state are those recommended by the EPA. Table 11 depicts the regulations and documents where all approved testing procedures are derived (CoDPHE, 2007). All testing procedures utilized for the classification or monitoring of a waterbody within the state of Colorado must comply with the testing procedures established by the WQS.

Table 11: Regulations Utilized to Establish Colorado Water Quality Testing Procedures (CoDPHE, 2007)

Testing Procedures	Regulations
Standard Testing Procedures	Code of Federal Regulations, Title 40, Part 136
	The latest approved EPA Methods for Chemical Analysis of Water and Wastes
	Standard Methods for the Examination of Water and Wastewater (current edition) American Public Health Association
	ASTM Standards, Part 31, Water
	EPA Biological Field and Laboratory Methods
Toxicity Testing and Criteria Development Procedures	The latest EPA Methods for Chemical Analysis of Water and Wastewater, ASTM, Standard Methods for Examination of Water, Wastewater
	Interim Guidance on Determination and Use of Water Effect Ratio for Metals, EPA-823-B-94-001, U.S. Environmental Protection Agency, February, 1994
	Other approved EPA methods
Other Procedures	Other procedures as deemed appropriate by the Water Quality Control Commission and/or the Water Quality Control Division

4.2.4 Water Quality Criteria

For the state of Colorado, the WQC are divided into both basic and specific surface water standards. The basic standards apply to all surface waters within the state and are listed in section 31.11. This section depicts overall general standards, standards for radioactive materials, and standards

for basic organic chemicals. In terms of the overall general standards, there are six standards listed in section 31.11(1)(a) that all surface waters must meet unless otherwise approved by the Water Quality Control Division. These six standards read as follows (CoDPHE, 2007):

“(1) Except where authorized by permits, BMPs, 401 certifications, or plans of operation approved by the Division or other applicable agencies, state surface waters shall be free from substances attributable to human-caused point source or nonpoint source discharge in amounts, concentrations or combinations which:

- (a) for all surface waters except wetlands;
 - (i) can settle to form bottom deposits detrimental to the beneficial uses. Depositions are stream bottom buildup of materials which include but are not limited to anaerobic sludges, mine slurry or tailings, silt, or mud; or
 - (ii) form floating debris, scum, or other surface materials sufficient to harm existing beneficial uses; or
 - (iii) produce color, odor, or other conditions in such a degree as to create a nuisance or harm existing beneficial uses or impart any undesirable taste to significant edible aquatic species or to the water; or
 - (iv) are harmful to the beneficial uses or toxic to humans, animals, plants, or aquatic life; or
 - (v) produce a predominance of undesirable aquatic life; or
 - (vi) cause a film on the surface or produce a deposit on shorelines”

In addition to the overall general standards, there are also standards for radioactive materials mentioned in the basic standards. These materials and their associated limits are depicted in Table 12 below.

Table 12: Basic Standards for Radioactive Materials (CoDPHE, 2007)

<u>Radionuclide Standards</u>	
<u>Parameter</u>	<u>Picocuries per Liter</u>
Americium 241*	0.15
Cesium 134	80
Plutonium 239, and 240*	0.15
Radium 226 and 228*	5
Strontium 90*	8
Thorium 230 and 232*	60
Tritium	20,000

As for the standards for organic chemicals listed as a part of the basic WQC, they are divided based on human health and aquatic life values. All chemicals with regulatory values are listed in a table

within section 31.11. There are a total of 156 organic chemicals listed with associated regulatory values that must be met by all surface waterbodies within the state of Colorado.

Along with the basic standards that must be met by all surface waterbodies, there are also additional specific parameters that must be met by each waterbody based on its classification. These specific parameters are divided into three descriptive tables that depict physical and biological parameters, inorganic parameters, and metal parameters. These three tables are referenced within the WQS as Table I, II, and III; and are provided in Appendix D of this review.

Pursuant to section 40 CFR 131.12 of the Code of Federal Regulations, the Colorado WQS also contain an antidegradation policy. This policy requires that all waterbodies within the state of Colorado be maintained to one of three levels of water quality. These three levels include highest quality, intermediate quality, and minimum quality. The higher the level of quality assigned to a waterbody, the more stringent the regulations present to maintain and protect that waterbody. The antidegradation policy in place for Colorado is often considered when determining the classification of a waterbody. See Appendix B for listing of federal regulation 40 CFR 131.12.

In addition to the WQC described above, the Colorado WQS also incorporate low flow exceptions into their standards in order to compensate for periods of low flow. The standards state that,

“Water quality standards shall apply at all times; provided, that in developing effluent limitations or other requirements for discharge permits, the Division shall normally define critical flow conditions using the following low-flow values: the empirically based 30-day average low flow with an average 1-in-3 year recurrence interval (30E3) for chronic standards and the empirically based 1-day low flow with an average 1-in-3 year recurrence interval (1E3) for acute standards, or the equivalent statistically-based flow (CoDPHE, 2007).”

Applicable WQC for a waterbody may be temporarily suspended in the event of extreme low flow periods as determined on a case-by-case basis.

4.3 North Carolina Standards

4.3.1 Development of Standards

The North Carolina WQS were developed by utilizing the WQC and testing methods established by the EPA. In addition to this, some site specific testing was used to develop standards for certain waterbodies and waterbody types. The North Carolina standards are compliant with all CWA and federal WQS regulations. The draft of the North Carolina WQS available from the EPA became effective as of April 1, 2003 and is set to be reviewed every four years. At the time of review, all changes must be approved by the State Water Control Board and subsequently provided to the EPA. For the purposes of this review, the state standards referenced by the EPA will be utilized as they have been formally recognized by the EPA.

4.3.2 Classification System

In order for the WQC of a waterbody to be determined, the waterbody must first be classified based on its characteristics. For the North Carolina WQS, waterbodies are divided into three main categories that each have a variety of classes. These three main categories include freshwater, tidal salt waters and supplemental classifications. It is possible for waterbodies to fit into more than one category as the supplemental classifications can apply to both freshwater and tidal salt waters. The categories and classifications for North Carolina waterbodies are as follows (NCDENR, 2003):

Table 13: Classifications of North Carolina Waters (NCDENR, 2003)

Category	Class	Description
Freshwater	Class C	freshwaters protected for secondary recreation, fishing, and aquatic life
	Class B	freshwaters protected for primary recreation, including swimming, and all Class C uses
	Class WS-I	waters that are essentially in natural, undeveloped watersheds and are protected as water supplies
	Class WS-II	waters that are in predominantly undeveloped watersheds and are protected as water supplies
	Class WS-III	waters that are in low to moderately developed watersheds and are protected as water supplies
	Class WS-IV	waters that are in moderately to highly developed watersheds and are protected as water supplies
	Class WS-V	waters that are generally upstream of and draining to Class WS-IV waters and are protected as water supplies
	Class WL	waters that meet the definition of wetlands - excluding those classified as Class SWL
Tidal Salt Waters	Class SC	salt waters protected for secondary recreation, fishing, and aquatic life
	Class SB	salt waters protected for primary recreation, including swimming, and all Class C uses
	Class SA	salt waters suitable for commercial shellfishing and all other tidal saltwater uses
	Class SWL	waters that meet the definition of coastal wetlands and wetlands contiguous to estuarine waters
Supplemental Classifications	Trout Waters (Tr)	freshwaters protected for propagation and survival of stocked trout
	Swamp Waters (Sw)	waters that have low velocities and other natural characteristics differing from adjacent streams
	Nutrient Sensitive Waters (NSW)	waters subject to growths of microscopic or macroscopic vegetation - require nutrient input limitations
	Outstanding Resource Waters (ORW)	waters of exceptional recreational or ecological significance that require special protection to maintain uses
	High Quality Waters (HQW)	waters which are rated excellent based on biological and physical/chemical characteristics
	Future Water Supply (FWS)	waters that have been adopted as a future source for drinking, culinary, or food-processing purposes
	Unique Wetland (UWL)	wetlands of exceptional ecological significance that require special protection to maintain uses

4.3.3 Testing Methods

As part of the North Carolina WQS, specific reference is given to the testing methods utilized. According to Section 15A NCAC 02B .0103 within the WQS “tests or analytical procedures to determine conformity or non-conformity with standards shall, insofar as practicable and applicable, conform to the guidelines by the Environmental Protection Agency codified as 40 CFR, Part 136, which are hereby incorporated by reference including any subsequent amendments and editions (NCDENR, 2003).”

In addition to analytical procedures, biological and wetland evaluation procedures are also specifically mentioned within the standards. It is stated that these procedures are to comply with suggested EPA testing methods as well. Per the standards, In the event that a required testing method is not listed in 40 CFR, Part 136, the testing method utilized must comply with scientifically accepted methods as listed by federal agencies such as the American Public Health Association.

4.3.4 Water Quality Criteria

The WQC established in the North Carolina WQS address both general and specific criteria that each waterbody must meet based on its classification. As a result of this, the criteria is represented based on the three main categories and classes listed in Table 13.

In terms of general criteria, there are standards listed for each main category of waterbody classification. These criteria are listed in 15A NCAC 02B .0211, 15A NCAC 02B .0220, and 15 NCAC 02B .0225. While each general criteria is specific to either the fresh surface water, tidal salt water, or outstanding resource water classification; they are all similar in the fact that they note minimal acceptable standards. For both fresh surface water and tidal salt water, the minimal acceptable standard are the most basic classifications of Class C and Class SC respectively. For outstanding resource water, the minimal acceptable standard refers back to those for fresh surface water or tidal salt water based on the classification of the waterbody in question. Additionally, each general criteria listing notes that more stringent standards are applicable to the remaining classes for each main category.

While the general criteria apply to all classes within a category of waterbodies, the specific criteria are individualized for each class within a category. The same standard types are applicable to all specific criteria for all classifications. However, the numerical values associated with the standard type differ, allowing for more stringent standards. The standards types that must be addressed by each basic classification (Class C and Class SC) are as follows (NCDENR, 2003):

- Chlorophyll a
- Dissolved oxygen
- Floating solids; settleable solids; sludge deposits
- Gases, total dissolved
- Organisms of the coliform group
- Oils; deleterious substance; colored or other wastes
- pH
- Phenolic compounds

- Radioactive substances
- Temperature
- Turbidity
- Toxic substances; and
- Action levels for toxic substances

For more stringent water quality classifications, the above standard types must be addressed as well as some additional standards. These include the following (NCDENR, 2003):

- Sewage, industrial wastes, non-process industrial wastes, or other wastes
- Nonpoint source and stormwater pollution
- MBAS (Methylene-Blue Active Substances)
- Odor producing substances contained in sewage, industrial wastes, or other wastes
- Total hardness; and
- Total dissolved solids

The numerical values associated with each standard type within a classification were developed based on values established by the EPA; as well as, state specific testing of waterbodies.

In addition to the specific numerical standards provided for each classification, all waterbodies within the state of North Carolina must adhere to the antidegradation policy detailed in 15A NCAC 02B .0201. This section states that (NCDENR, 2003):

“It is the policy of the Environmental Management Commission to maintain, protect, and enhance water quality within the State of North Carolina. Pursuant to this policy, the requirements of 40 CFR 131.12 are hereby incorporated by reference including and subsequent amendments and editions.”

The antidegradation policy in place for North Carolina is often considered when determining the classification of a waterbody. See Appendix B for listing of federal regulation 40 CFR 131.12.

4.4 Virginia Standards

4.4.1 Development of Standards

The Virginia WQS were developed by combining the WQC established by the EPA with additional site-specific testing performed throughout the state of Virginia. The Virginia standards are compliant with all CWA and federal WQS regulations. The current draft of the Virginia WQS became effective as of January 6, 2011 and is set to be reviewed every three years. At the time of review, all changes must be approved by the State Water Control Board and subsequently provided to the EPA. For the purposes of this review, the state standards referenced by the EPA will be utilized as they have been formally recognized by the EPA.

4.4.2 Classification System

As a part of the Virginia WQS, all waters are classified into one of seven categories. These categories determine the numerical criteria that apply for the water source in question. Several classifications may be applied to one water source at varying locations depending on the contributing tributaries. The classification of Virginia waters is depicted below:

Table 14: Classification of Virginia Waters (VADEQ, 2011)

CLASS OF WATERS	NUMERICAL CRITERIA
I and II (Estuarine Waters)	Saltwater criteria apply
II (Transition Zone)	More stringent of either the freshwater or saltwater criteria apply
II (Tidal Freshwater), III, IV, V, VI and VII	Freshwater criteria apply

In addition to general water classifications, Virginia waters also have additional classifications for waters containing trout. These waters have a classification value of 1 through 8 and signify a water source as a natural or stockable location for trout to inhabit. Waters with a trout classification have stricter criteria than those without. The general classifications are listed below (VADEQ, 2011):

Table 15: Classifications for Trout Waters (VADEQ, 2011)

Classification	Trout Stream Type	Description
Class I	Wild, Natural	A stream that is considered an exceptional representation of a wild trout stream with outstanding natural characteristics
Class II	Wild, Natural	A stream that is considered a good representation of a wild trout stream but is lacking in aesthetics, productivity or some other structural characteristic
Class III	Wild, Natural	A stream that is considered to contain a fair wild trout population with a depressed carrying capacity due to natural or human factors
Class IV	Wild, Natural	A stream that is considered to contain an adequately reproducing wild trout population but has severely reduced natural characteristics; especially in the summer
Class V	Stockable	A stream that is not considered to contain an adequately reproducing wild trout stream but has good to excellent natural characteristics. Stream has potential for stocking trout and fingerling
Class VI	Stockable	A stream that is not considered to contain an adequately reproducing wild trout stream but has adequate to good natural characteristics. Stream has potential for stocking trout
Class VII	Stockable	A stream that is not considered to contain an adequately reproducing wild trout stream and has marginal structural characteristics. Stream would not be generally recommended for stocking
Class VIII	Stockable	A stream that is not considered to contain an adequately reproducing wild trout stream and has poor summer flow. Stream would not be recommended for summer or fall stocking

4.4.3 Testing Methods

In terms of the testing methods utilized by the Virginia WQS to determine if aquatic monitoring values are in accordance with the stated WQC, there are no specific tests mentioned. Instead, the Virginia WQS state that, “analytical testing should be done in accordance with accepted procedures in 40 CFR 136, as amended or other board/EPA recognized and approved methods (VADEQ, 2011).” As a result, all testing methods utilized by the state of Virginia for aquatic monitoring comply with the analytical testing recommended by the EPA.

4.4.4 Water Quality Criteria

The WQC listed in the Virginia WQS provide both general and specific criteria to which waterbodies within the state of Virginia must comply. According to 9VAC25-260-20A General Criteria:

“State waters, including wetlands, shall be free from substances attributable to sewage, industrial waste, or other wastes in concentrations, amounts, or combinations which contravene established standards or interfere directly or indirectly with designated uses of water or which are inimical or harmful to human, animal, plant, or aquatic life.

Specific substances to be controlled include, but are not limited to: floating debris, oil, scum, and other floating materials; toxic substances (including those which bioaccumulate); substances that produce color, tastes, turbidity, odors, or settle to form sludge deposits; and substances which nourish undesirable or nuisance aquatic plant life. Effluents which tend to raise the temperature of the receiving water will also be controlled (VADEQ, 2011).”

While the general criteria outline a broad range of water quality attributes that will be upheld, the WQS also list specific criteria that must be followed. This specific criteria falls into six main categories. These categories include dissolved oxygen, pH, temperature, ammonia nitrogen, bacteria and specific parameters.

The attributes of dissolved oxygen, pH and temperature are based on the classification of waterbody. As a result, the specific criteria a waterbody must adhere to depends on the classification the state of Virginia applies to a waterbody. The specific criteria for each classification are listed in Table 16 below (VADEQ, 2011):

Table 16: Numerical Criteria for Dissolved Oxygen, pH, and Maximum Temperature (VADEQ, 2011)

CLASS	DESCRIPTION OF WATERS	DISSOLVED OXYGEN (mg/l)****		pH	Max. Temp. (°C)
		Min.	Daily Avg.		
I	Open Ocean	5.0	--	6.0-9.0	--
II	Estuarine Waters (Tidal Water-Coastal Zone to Fall Line)	4.0	5.0	6.0-9.0	--
III	Nontidal Waters (Coastal and Piedmont Zones)	4.0	5.0	6.0-9.0	32
IV	Mountainous Zones Waters	4.0	5.0	6.0-9.0	31
V	Stockable Trout Waters	5.0	6.0	6.0-9.0	21
VI	Natural Trout Waters	6.0	7.0	6.0-9.0	20
VII	Swamp Waters	*	*	3.7-8.0*	**

While the attributes of dissolved oxygen, pH, and temperature may generally apply to all classifications of waterbodies within Virginia without dependence on other criteria, certain attributes such as ammonia nitrogen concentrations apply to waterbodies based on a variety of criteria. In order for the ammonia nitrogen concentration for a specific waterbody to be determined, the waterbody classification, pH, temperature, and the presence or absence of trout (in freshwater bodies) must be accounted for. Not only this, but ammonia nitrogen concentrations are also dependent on time. The allowable ammonia nitrogen concentration depends on whether the criteria is classified as an acute or chronic timeframe. The detailed numerical criteria associated with ammonia nitrogen concentrations are listed in 9VAC25-260-155 of the Virginia WQS.

Similarly to ammonia nitrogen concentrations, the water quality attributes dealing with bacteria have a variety of classifications. In general, the bacteria criteria are divided into three main categories based on waterbody type. These include shellfish waters, primary contact recreational waters and other recreational waters. Each waterbody type has specific bacteria criteria that apply in order to protect the waterbody and those utilizing it. The criteria for each waterbody are depicted in the table below:

Table 17: Bacterial Criteria Based on Waterbody Type* (VADEQ, 2011)

Waterbody Type	Fecal coliform bacteria GM (MPN or MF)	E. Coli bacteria GM (CFU/100 mL)	Enterococci bacteria GM (CFU/100 mL)
Shellfish Waters	14 per 100 mL	—————	—————
Primary Contact Recreational Waters	—————	126 CFU per 100 mL	35 CFU per 100 mL
Other Recreational Waters	—————	630 CFU per 100 mL (freshwater)	175 CFU per 100 mL (transition or saltwater)

*the values listed are those that cannot be exceeded per the Virginia WQS

There are some additional criteria and exceptions that apply to the bacterial criteria listed above. These additional criteria and exceptions are listed in 9VAC25-260-160 and 9VAC25-260-170 of the Virginia WQS.

In addition to the specific attributes listed above, there are also specific parameters listed in the Virginia WQS for a wide variety of contaminants. The allowable values depend on a variety of factors including aquatic life versus human health, freshwater versus saltwater, public water supply versus other surface waters and acute versus chronic limits. There are 134 specific criteria listed with values that must be adhered to in order to protect a waterbody and the organisms that come into contact with that waterbody. These criteria are listed in 9VAC25-260-140 of the Virginia WQS.

As part of the WQC for Virginia, there is also an antidegradation policy in place. This policy applies to all waterbodies in Virginia and classifies them into one of three categories. These categories depict the amount of antidegradation protection required and are as follows (VADEQ, 2011):

- Tier 1: At a minimum, existing water uses and the water quality necessary to continue those uses must be maintained.
- Tier 2: Where water quality exceeds water quality standards, that quality shall be maintained and protected unless the Virginia water board allows a lowering of water quality for important economic or social reasons. Minimum water quality standards must still be maintained in the event that the lowering of water quality is allowed.
- Tier 3: Those surface waters that provide exceptional environmental settings, aquatic communities, or recreational opportunities may be designated or protected through a specified procedure.

A waterbody's antidegradation classification is often considered when determining the stringency of the water quality criteria applied to a waterbody and the frequency of testing required. See Appendix B for listing of federal regulation 40 CFR 131.12.

5.0 Human Health Data

In order to determine the effectiveness of the WQS and criteria in place for each state, the data trends for incidents of human illness related to recreational water exposure must be considered. These data are tracked by year and compiled by the U.S Centers for Disease Control and Prevention (CDC). For this review, the human health data for the years 1978 to 2012 will be examined. This is because the human health data related to recreational water illnesses are electronically available for this time period and more recent data has not yet been made available. Only illnesses specifically related to untreated (natural) recreational waters will be addressed. There have been additional outbreaks of waterborne illnesses within each state, however they have either been related to drinking waters or treated recreational waters such as pools or hot tubs.

5.1 California Data

Within the state of California, there have been six outbreaks of waterborne diseases that are specifically related to contact with untreated recreational waters. The etiology and general information concerning these outbreaks is listed in Table 18. Overall there were a total of 6 outbreaks in the state of California between 1978 and 2012 with 116 recorded cases associated with those outbreaks.

Table 18: Outbreaks of Waterborne Illnesses within California Related to Untreated Recreational Waters

Venue	Setting	Year	Etiology	Predominant Illness	No. Cases
Lake/Reservoir	Beach	2012*	Avian schistosomes	Skin	2
Stream	Stream	2005^	<i>Leptospira</i> spp.	Bacterial Infection	3
Hot Spring	Recreational Area	1991+	Naegleria	Meningoencephalitis	1
Lake	Recreational Area	1986&	Norwalk-like	Gastroenteritis	41
Lake	Recreational Area	1985\$	<i>Shigella sonnei</i> & <i>boydii</i>	Skin	68
Hot Spring		1978!	Amoeba	Meningoencephalitis	1

Sources: *(Hlavsa et al., 2015), ^(Yoder et al., 2008), +(Moore et al., 1993), &(Levine et al., 1990), \$(St. Louis, 1988), !(CDC, 1978)

5.2 Colorado Data

The state of Colorado has had four instances of outbreaks of waterborne illnesses due to contact with untreated recreational waters. The etiology and general information concerning these outbreaks is listed in Table 19. Overall there were a total of 4 outbreaks in the state of Colorado between 1980 and 2012 with 69 recorded cases associated with those outbreaks.

Table 19: Outbreaks of Waterborne Illnesses within Colorado Related to Untreated Recreational Waters

Venue	Setting	Year	Etiology	Predominant Illness	No. Cases
Lake/Reservoir	Public Beach	2012*	<i>Shigella sonnei</i> subgroup D	Skin	31
Pond	Public Outdoor Area	2010^	Unidentified	Skin	9
Stream	Wilderness	1981&	Giardia	Parasite	7
Creek	Recreational Area	1980#	AGI	AGI	22+

Sources: *(Hlavsa et al., 2015), ^(Hlavsa et al., 2014), &(amp;CDC, 1981), #(CDC, 1980)

5.3 North Carolina Data

Within the state of North Carolina, there have been six outbreaks of waterborne diseases that are specifically related to contact with untreated recreational waters. The etiology and general information concerning these outbreaks is listed in Table 20. Overall there were a total of 6 outbreaks in the state of North Carolina between 1990 and 2003 with 667 recorded cases associated with those outbreaks.

Table 20: Outbreaks of Waterborne Illnesses within North Carolina Related to Untreated Recreational Waters

Venue	Setting	Year	Etiology	Predominant Illness	No. Cases
Lake	Lake	2003*	<i>Naegleria fowleri</i>	Parasite	1
Ocean	Beach	2004*	<i>V. alginolyticus</i> and <i>V. parahaemolyticus</i>	Bacterial Infection	1
Pond	Camp	1991^	adenovirus	Pharyngitis	595
Pond	Swimming Area	1991^	Naegleria	Meningoencephalitis	1
Lake	Swimming Area	1991^	Naegleria	Meningoencephalitis	1
Lake	Recreation Area	1990&	<i>Shigella sonnei</i>	Gastroenteritis	68

Sources: *(Dziuban et al., 2006), ^(Moore et al., 1993), &(amp;Herwaldt et al., 1992)

5.4 Virginia Data

The state of Virginia has had two instances of outbreaks of waterborne illnesses due to contact with untreated recreational waters. The etiology and general information concerning these outbreaks is listed in Table 21. Overall there were a total of 2 outbreaks in the state of Virginia between 1982 and 2004 with 17 recorded cases associated with those outbreaks.

Table 21: Outbreaks of Waterborne Illnesses within Virginia Related to Untreated Recreational Waters

Venue	Setting	Year	Etiology	Predominant Illness	No. Cases
Ocean	Beach	2004*	<i>V. parahaemolyticus</i>	Bacterial Infection	1
River	Power Plant	1982^	AGI	AGI	16

Sources: *(Dziuban et al., 2006), ^(CDC, 1982)

5.5 General Trends

In general, the number of waterborne illness outbreaks due to contact with untreated water are relatively low for the states in question compared to the total number of outbreaks reported by the CDC. For the states of interest, California and North Carolina reported the highest number of outbreaks with six outbreaks each between 1978 and 2012. Following California and North Carolina, Colorado has the third highest number of outbreaks with four and Virginia has the lowest number of outbreaks with two (Table 22). Based on data and figures generated by the CDC, there were a total of 170 outbreaks of acute gastrointestinal illness between the years of 1978 to 2012 (Figure 1). It is important to note that this number only represents gastrointestinal illness and no additional waterborne illnesses. As a result, the total number of waterborne illness outbreaks during the time period represented is higher. The total number of illness outbreaks and associated cases for each state are provided in Table 22 along with their relation to the number of outbreaks documented by the CDC (CDC, 2015). Based on the data available, only one outbreak of AGI was associated with each state signifying that each state only contributed 0.59% to the total number of AGI outbreaks recorded by the CDC.

Table 22: Total Number of Outbreaks and Associated Cases of Waterborne Illness for California, Colorado, North Carolina, and Virginia from 1978 to 2012 (CDC, 2015)

State	Number of Outbreaks	Number of Cases	Number of Bacterial/Parasitic Outbreaks	Number of AGI Outbreaks	Percentage of AGI Outbreaks*
California	6	116	5	1	0.59
Colorado	4	69	3	1	0.59
North Carolina	6	667	5	1	0.59
Virginia	2	17	1	1	0.59

*Only instances of AGI were considered in the calculation of this percentage. The percentage was calculated using the formula: $(n/170) \times 100$

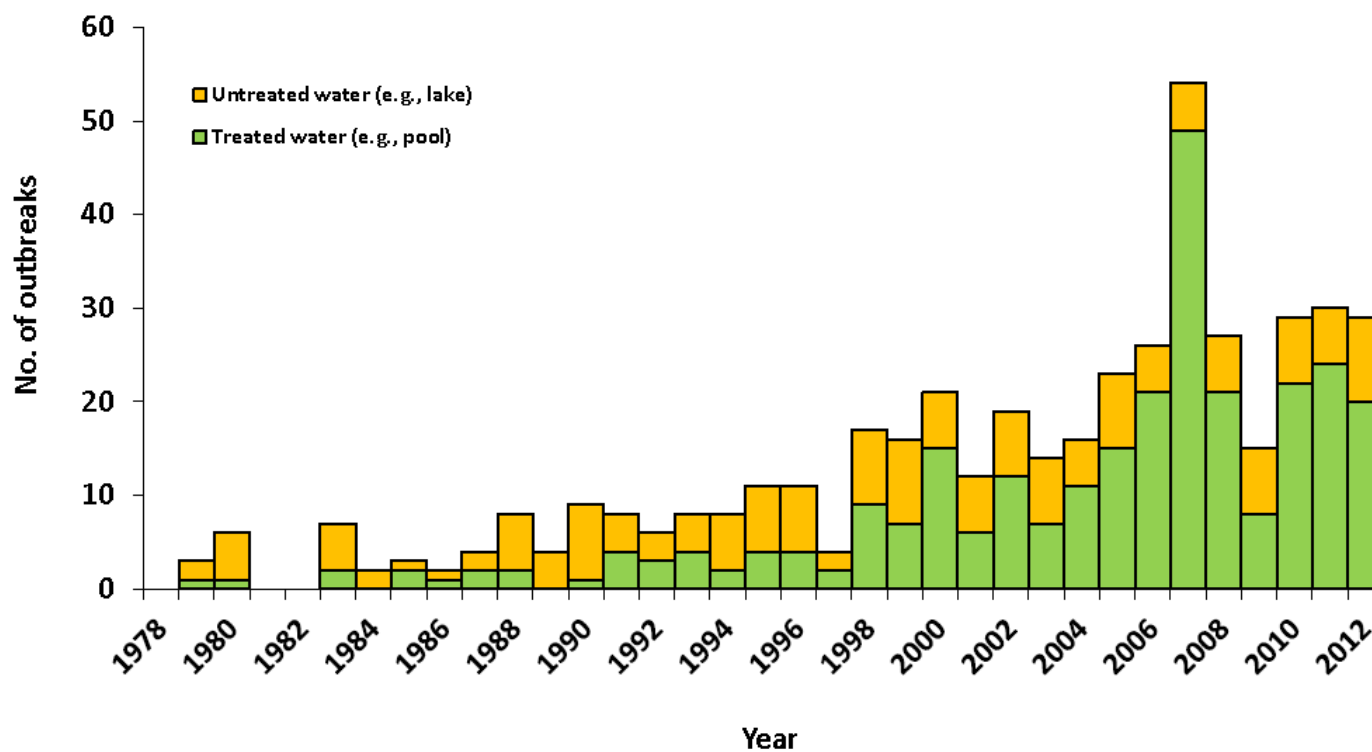
There are several factors to consider when examining the data related to waterborne illnesses. The first factor is that the number of outbreak incidents compiled and presented by the CDC is not all inclusive. This is due to the fact that some individuals who contract illnesses from contact with recreational water will not seek medical attention as a result. When individuals do not seek medical attention, there is no way to document the incident and so it will not be included when data is compiled. A second factor to consider is the location of the states examined. California and Colorado are both located in areas of the United States that are prone to drought. Because of this, these states may be more likely to develop cases of waterborne illness outbreaks as water levels decrease and individuals

come into contact with more of the potentially harmful bacteria that may settle at the bottom of a waterbody (Yoder et al., 2004).

By taking into account the general trends in illness outbreaks and the structure of each states' WQS, it is evident that improvements to each states' standards can be made. While the number of outbreaks indicate that the standards for California and North Carolina need the most improvement, it is important to consider the characteristics of the states examined. Each of the states represented have a large variety in characteristics including type of soil, waterbody type, and climate. As a result different bacteria, parasites, and other contributors to illness may flourish in each state. The different contributors to illness that are present can result in drastically diverse outbreak rates and etiology from state to state. Because of this, the main method to reduce the number of illness outbreaks for a state is to increase the states reliance on site-specific testing for its individual water bodies. The use of criteria developed from site-specific testing would increase the effectiveness of each states WQS at protecting human health as the criteria would more accurately reflect the waterbodies in question. Additional recommendations to the EPA WQC and state WQS are discussed in Section 6.0.

Figure 1: Recreational Water-associated Outbreaks of Acute Gastrointestinal Illness, by Type of Exposure and Year — United States, 1978–2012 (CDC, 2015)

FIGURE 6. Recreational Water-associated Outbreaks of Acute Gastrointestinal Illness, by Type of Exposure* and Year — United States, 1978–2012



*n=452; treated water, n=282; untreated water, n=170.



6.0 Conclusion

As a whole, the WQC guidelines established and published by the EPA serve the purpose of providing states with the general and numerical criteria necessary to protect recreational water quality and human health. However, because these EPA established WQC are only guidelines there is a large amount of variance that can result between individual state WQS. Depending on the degree of variance between a states' WQS and the WQC guidelines, a states' established WQS may be lacking in some areas and result in an increased likelihood of human health illness due to contact with recreational water sources.

6.1 Relationship Between Human Health Data and WQC/WQS

For the four states of California, Colorado, North Carolina, and Virginia in this review, the human health data available indicate that the WQS are all generally effective at protecting human health from illnesses associated with recreational water. This effectiveness is derived from the fact that the majority of the waterborne illness outbreaks reported in each state are associated with bacteria and parasites present in the water (Table 22). Neither the EPA WQC guidelines nor the individual state WQS address testing methods or regulations for the presence of various bacteria or parasites other than fecal coliform bacteria (Table 23). By excluding bacterial and parasitic outbreaks from the human health data, there are limited outbreaks of waterborne illnesses associated with human contact to the recreational water in question. These limited illness outbreaks indicate that the established WQS for each state are generally effective for the criteria for which they test.

While the WQS for each state is effective in terms of limiting human health illnesses due to poor recreational water quality, the more prevalent presence of bacterial and parasitic waterborne illness outbreaks does indicate lacking criteria within the WQS and criteria as a whole. The main reasoning behind the larger number of bacterial and parasitic waterborne illness outbreaks stems from a lack of testing for these organisms. While select bacteria such as *Enterococci* and *E.coli* are generally tested for to determine overall water quality, routine testing methods do not tend to test for the presence of other bacteria or parasitic organisms. As a result, harmful bacteria and parasites may be present within a recreational waterbody unbeknownst to the individuals testing the water quality or the individuals coming into contact with that waterbody.

Although the WQS and criteria may be lacking in terms of testing for additional bacterial and parasitic organisms to protect human health, the reasoning for this stems from the nature of the organisms in question. While contaminants and some types of bacteria are present throughout a waterbody at various concentrations, other bacteria and parasitic organisms may only be present in select locations of a waterbody in limited amount. As a result, it can be very difficult to isolate the presence of harmful organisms within a waterbody. In addition, there are a vast array of bacterial and parasitic organisms that can be present within a waterbody making it nearly impossible to test for the presence of all possible organisms.

Table 23: Basic Information Concerning Federal WQC and State WQS

Standards (Stds)	Method of Std Development	Classification System		Testing Methods	Water Quality Criteria		Organization of Stds
		Number of Classes	Basis of system		Bacterial Criteria	Chemical Criteria	
Federal*	NEEAR study, epidemiological studies, QMRA, validation studies, modeling, public health data reviews and literature reviews		Must include all marine, estuarine, Great Lakes, and inland waters	qPCR, sanitary surveys, and predictive modeling	Enterococci and E.coli indicators used. Bacterial numerical criteria provided for general criteria and beach action values	Testing for chemical contaminants is recommended, but specific contaminants are not listed as part of the RWQC	One all-inclusive document detailing RWQC and a supporting document detailing possible implementation techniques for states
California^{%%}	Site specific testing and EPA established testing/criteria	3 main classes and 2 sets of subclasses	Main classes based on waterbody type; subclasses based on benthic communities and sediment toxicity	Those established by the EPA, ASTM, and the state water board	Fecal coliform density tested for ocean waters only with numerical limits mimicking those established by the EPA	Criteria differ based on waterbody type but testing generally focuses on dissolved oxygen, pH, dissolved sulfide, organic materials, nutrient materials, and substances that indicate toxicity	Separate stds document for each waterbody type. Estuaries and enclosed bays stds divided into 2 parts
Colorado^{&}	EPA established criteria, table value stds, ambient quality-based stds, site-specific criteria based stds, stds for surface waters in wetlands, and site-specific narrative standards	5 main classes, 7 subclasses, 3 additional qualifiers	Main classes based on waterbody use, subclasses define the extent of waterbody use, and qualifiers indicate special consideration	Those established by the Federal Code, the EPA, ASTM, American Public Health Association, and the state water commission	E. coli is tested for with numerical limits mimicking those established by the EPA	There are 156 organic chemicals listed in the state WQS with associated regulatory values. Additionally there are radionuclide stds, inorganic parameters, and metal parameters as part of the chemical criteria	One all-inclusive document detailing the WQS and criteria for the state
North Carolina[§]	EPA established criteria and testing methods, along with some site-specific testing	3 main classes and 19 subclasses	Main classes based on waterbody type; subclasses based on waterbody health and use	Those established by the EPA and scientifically accepted methods listed by additional federal agencies	Organisms of the coliform group are tested based on the numerical values established by the EPA	There are general criteria for each waterbody classification with differing numerical criteria based on classification. Chemical criteria include dissolved oxygen, dissolved gases, pH, radioactive substances, phenolic compounds, temperature, turbidity and toxic substances	One all-inclusive document detailing the WQS and criteria for the state
Virginia[!]	EPA established criteria and site-specific testing	7 main classes and 8 subclasses	Main classes based on waterbody type; subclasses based on trout stream type	Those established by the EPA, additional federal agencies, and the state water board	Fecal coliform bacteria, E. coli, and Enterococci are tested based on numerical values established by the EPA	Dissolved oxygen, pH, maximum temperature, ammonia nitrogen and 134 specific criteria with numerical values are listed as part of the state WQS	One all-inclusive document detailing the WQS and criteria for the state

Sources: *(USEPA, 2012), ^(CaEPA, 2009), %(CaEPA, 2001), &(CoDPHE, 2007), §(NCDENR, 2003), !(VADEQ, 2011)

6.2 Recommendations

By taking the above factors into consideration, improvements to the WQS and criteria can be made. This can be done by taking into consideration historical human health data for a waterbody, the characteristics of a waterbody, and the characteristics of the organisms in questions. For instance, by looking at the historical human health data for a particular lake and nearby waterbodies, the main bacterial and parasitic contributors to past illness outbreaks can be established. From here, the characteristics of the known illness contributors and the characteristics of the lake can be analyzed to determine locations within the lake that would have the most favorable conditions for the organisms in question to flourish. Once these locations have been determined, water samples from the locations can then be collected and tested for the organisms of interest to determine if they are present in the lake and to what extent. While this method of testing would still not allow for the testing of all possible harmful organisms, it would allow for an increased likelihood of detecting harmful organisms that have been present in the area of a waterbody historically. By more effectively detecting harmful organisms present in a waterbody, human health is able to be more effectively protected. It is important to note that this method of testing would be very time consuming. As a result, to make this testing method feasible, states could require this method of testing once every several years and possibly only for waterbodies with higher levels of recreation associated with them.

Additionally, human health may be further protected by increasing the speed at which water quality testing is performed. By using methods such as qPCR, the bacterial content of a waterbody can be assessed more quickly than using traditional testing methods (Wade et al., 2010). The faster the water quality of a waterbody can be tested; the faster that steps can be taken to prevent illness outbreaks if bacterial content is above numerical limits.

In terms of the individual state standards and federal criteria, there are also additional improvements that can be made. For the federal criteria, the established criteria generally protects human health from poor recreational water quality related to fecal coliforms. However, more consideration should be given to chemical criteria and bacteria/parasites aside from fecal coliform bacteria. To accomplish this, the EPA WQC could incorporate an index system similar to the one developed in the study by Almeida et al (2012). As a part of this study, the researchers developed a recreational water quality index that focused on using a combination of chemical, physical and microbiological parameters. Through the use of this indexing system they were able to increase the overall water quality of a river in Argentina (Almeida et al., 2012). By incorporating more diverse criteria into the established RWQC, the EPA could increase its overall effectiveness.

Similar to the federal criteria, the state standards are effective in some regards but could be improved upon in terms of organization and focus. For instance, the WQS for the State of California are effective in that they address the specific waterbody types that are present within the state. However, other than waterbody type there is no further classification to depict the health of a waterbody. By further classifying the waterbodies present, the state could gain a better understanding of which waterbodies suffer from poorer water quality and in turn address the issue in order to further protect human health.

Conversely to California, the State of Colorado has a significant number of classifications and subclassifications that apply to its waterbodies. While this is very effective at specifically addressing the water quality within the state, improvements could be made to the bacterial criteria of the waterbodies in question. The WQS for Colorado only list *E. coli* as a bacterial indicator. Although *E. coli* is an effective fecal coliform indicator, only testing for this bacteria means that other bacteria that has negative effects on human health could be present in a waterbody without individuals' knowledge. By testing for more bacterial indicators, the state would gain a more realistic understanding of the bacterial levels present in a waterbody and could further protect human health from adverse effects.

Along with Colorado, the State of North Carolina also has a significant number of classifications and subclassifications that apply to its waterbodies. In addition to this, the North Carolina WQS also test for a wide variety of chemical criteria in order to assess the water quality of its waterbodies. While the wide variety of chemical criteria tested allows for a more effective assessment of a waterbody, the WQS are lacking in bacterial testing based on the types of outbreaks that occurred from 1978 – 2012 (Table 20). These outbreaks are the result of contact with specific bacteria or parasites and as a result, the North Carolina WQS could be improved by implementing testing methods for the bacteria or parasites in question. This could be done using the previously mentioned recommendation. By testing for specific bacteria and parasites, the State of North Carolina could improve its WQS effectiveness at protecting human health.

While the State of Virginia has the fewest number of outbreaks associated with contact with recreational water, there are improvements that can be made to the WQS. Overall, the WQS cover a wide range of bacterial and chemical criteria for testing. This wide range of testing lends to a more effective and realistic record of water quality. However, the classification system utilized may place too much focus on the presence of trout. While many of the recreational waterbodies of the state do contain trout, basing a waterbodies WQC on the presence of trout may not fully represent the uses of that waterbody. As a result, a waterbody that may not contain trout but does have high recreational use may be incorrectly classified and therefore held to the incorrect standards. By expanding the classification system past trout waters, the state WQS could more accurately reflect the water quality of a waterbody and more effectively protect human health.

Overall, the EPA WQC guidelines and state specific WQS of the states listed in this review are effective at protecting human health and recreational water quality based on the limited number of recreational water illness outbreaks, for the listed states, between the years 1978 – 2012. While there are enhancements that can be made to increase the effectiveness of both the WQC and WQS, these enhancements would likely protect against outbreaks resulting from less common etiologies. In terms of outbreaks resulting from more common etiologies associated with poor recreational water quality, human health is generally protected. However, in order to continue to protect recreational water quality and human health, WQC and WQS must be consistently reviewed and updated to reflect continuing changes in recreational waterbody characteristics and conditions.

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APPENDIX A: Terms of submission of non-thesis masters papers to the NCSU Digital Repository

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APPENDIX B: Federal Regulation 40 CFR 131.12 Antidegradation Policy

§ 131.12 Antidegradation policy.

(a) The State shall develop and adopt a statewide antidegradation policy and identify the methods for implementing such policy pursuant to this subpart. The antidegradation policy and implementation methods shall, at a minimum, be consistent with the following:

(1) Existing instream water uses and the level of water quality necessary to protect the existing uses shall be maintained and protected.

(2) Where the quality of the waters exceed levels necessary to support propagation of fish, shellfish, and wildlife and recreation in and on the water, that quality shall be maintained and protected unless the State finds, after full satisfaction of the intergovernmental coordination and public participation provisions of the State's continuing planning process, that allowing lower water quality is necessary to accommodate important economic or social development in the area in which the waters are located. In allowing such degradation or lower water quality, the State shall assure water quality adequate to protect existing uses fully. Further, the State shall assure that there shall be achieved the highest statutory and regulatory requirements for all new and existing point sources and all cost-effective and reasonable best management practices for nonpoint source control.

(3) Where high quality waters constitute an outstanding National resource, such as waters of National and State parks and wildlife refuges and waters of exceptional recreational or ecological significance, that water quality shall be maintained and protected.

(4) In those cases where potential water quality impairment associated with a thermal discharge is involved, the antidegradation policy and implementing method shall be consistent with section 316 of the Act.

APPENDIX C: California Water Quality Objectives Table (CaEPA, 2001)

**TABLE B
WATER QUALITY OBJECTIVES**

	Units of Measurement	Limiting Concentrations		
		6-Month Median	Daily Maximum	Instantaneous Maximum
OBJECTIVES FOR PROTECTION OF MARINE AQUATIC LIFE				
Arsenic	ug/l	8.	32.	80.
Cadmium	ug/l	1.	4.	10.
Chromium (Hexavalent) (see below, a)	ug/l	2.	8.	20.
Copper	ug/l	3.	12.	30.
Lead	ug/l	2.	8.	20.
Mercury	ug/l	0.04	0.16	0.4
Nickel	ug/l	5.	20.	50.
Selenium	ug/l	15.	60.	150.
Silver	ug/l	0.7	2.8	7.
Zinc	ug/l	20.	80.	200.
Cyanide (see below, b)	ug/l	1.	4.	10.
Total Chlorine Residual (For intermittent chlorine sources see below, c)	ug/l	2.	8.	60.
Ammonia (expressed as nitrogen)	ug/l	600.	2400.	6000.
Acute* Toxicity	TUa	N/A	0.3	N/A
Chronic* Toxicity	TUc	N/A	1.	N/A
Phenolic Compounds (non-chlorinated)	ug/l	30.	120.	300.
Chlorinated Phenolics	ug/l	1.	4.	10.
Endosulfan	ug/l	0.009	0.018	0.027
Endrin	ug/l	0.002	0.004	0.006
HCH*	ug/l	0.004	0.008	0.012
Radioactivity	Not to exceed limits specified in Title 17, Division 1, Chapter 5, Subchapter 4, Group 3, Article 3, Section 30253 of the California Code of Regulations. Reference to Section 30253 is prospective, including future changes to any incorporated provisions of federal law, as the changes take effect.			

Table B Continued

Chemical	30-day Average (ug/l)	
	Decimal Notation	Scientific Notation
OBJECTIVES FOR PROTECTION OF HUMAN HEALTH – NONCARCINOGENS		
acrolein	220.	2.2×10^2
antimony	1,200.	1.2×10^3
bis(2-chloroethoxy) methane	4.4	4.4×10^0
bis(2-chloroisopropyl) ether	1,200.	1.2×10^3
chlorobenzene	570.	5.7×10^2
chromium (III)	190,000.	1.9×10^5
di-n-butyl phthalate	3,500.	3.5×10^3
dichlorobenzenes*	5,100.	5.1×10^3
diethyl phthalate	33,000.	3.3×10^4
dimethyl phthalate	820,000.	8.2×10^5
4,6-dinitro-2-methylphenol	220.	2.2×10^2
2,4-dinitrophenol	4.0	4.0×10^0
ethylbenzene	4,100.	4.1×10^3
fluoranthene	15.	1.5×10^1
hexachlorocyclopentadiene	58.	5.8×10^1
nitrobenzene	4.9	4.9×10^0
thallium	2.	$2. \times 10^0$
toluene	85,000.	8.5×10^4
tributyltin	0.0014	1.4×10^{-3}
1,1,1-trichloroethane	540,000.	5.4×10^5
OBJECTIVES FOR PROTECTION OF HUMAN HEALTH – CARCINOGENS		
acrylonitrile	0.10	1.0×10^{-1}
aldrin	0.000022	2.2×10^{-5}
benzene	5.9	5.9×10^0
benzidine	0.000069	6.9×10^{-5}
beryllium	0.033	3.3×10^{-2}
bis(2-chloroethyl) ether	0.045	4.5×10^{-2}
bis(2-ethylhexyl) phthalate	3.5	3.5×10^0
carbon tetrachloride	0.90	9.0×10^{-1}
chlordane*	0.000023	2.3×10^{-5}
chlorodibromomethane	8.6	8.6×10^0

Table B Continued

Chemical	30-day Average (ug/l)	
	Decimal Notation	Scientific Notation
OBJECTIVES FOR PROTECTION OF HUMAN HEALTH – CARCINOGENS		
chloroform	130.	1.3×10^2
DDT*	0.00017	1.7×10^{-4}
1,4-dichlorobenzene	18.	1.8×10^1
3,3'-dichlorobenzidine	0.0081	8.1×10^{-3}
1,2-dichloroethane	28.	2.8×10^1
1,1-dichloroethylene	0.9	9×10^{-1}
dichlorobromomethane	6.2	6.2×10^0
dichloromethane	450.	4.5×10^2
1,3-dichloropropene	8.9	8.9×10^0
dieldrin	0.00004	4.0×10^{-5}
2,4-dinitrotoluene	2.6	2.6×10^0
1,2-diphenylhydrazine	0.16	1.6×10^{-1}
halomethanes*	130.	1.3×10^2
heptachlor	0.00005	5×10^{-5}
heptachlor epoxide	0.00002	2×10^{-5}
hexachlorobenzene	0.00021	2.1×10^{-4}
hexachlorobutadiene	14.	1.4×10^1
hexachloroethane	2.5	2.5×10^0
isophorone	730.	7.3×10^2
N-nitrosodimethylamine	7.3	7.3×10^0
N-nitrosodi-N-propylamine	0.38	3.8×10^{-1}
N-nitrosodiphenylamine	2.5	2.5×10^0
PAHs*	0.0088	8.8×10^{-3}
PCBs*	0.000019	1.9×10^{-5}
TCDD equivalents*	0.0000000039	3.9×10^{-9}
1,1,2,2-tetrachloroethane	2.3	2.3×10^0
tetrachloroethylene	2.0	2.0×10^0
toxaphene	0.00021	2.1×10^{-4}
trichloroethylene	27.	2.7×10^1
1,1,2-trichloroethane	9.4	9.4×10^0
2,4,6-trichlorophenol	0.29	2.9×10^{-1}
vinyl chloride	36.	3.6×10^1

APPENDIX D: Table I, II and III from Colorado WQS Depicting Specific Water Quality Parameters Based on Classification (CoDPHE, 2007)

TABLE I PHYSICAL AND BIOLOGICAL PARAMETERS								
Parameter	Recreational			Aquatic Life			Agriculture	Domestic Water Supply
	CLASS E (Existing Primary Contact) and CLASS U (Undetermined Use)	CLASS P (Potential Primary Contact Use)	CLASS N (Not Primary Contact Use)	CLASS 1 COLD WATER BIOTA	CLASS 1 WARM WATER BIOTA	CLASS 2		
PHYSICAL								
D.O. (mg/l) ⁽¹⁾⁽⁹⁾	3.0(A)	3.0(A)	3.0(A)	6.0 ⁽²⁾ (G) 7.0(spawning)	6.0 ⁽²⁾ (G) 7.0(spawning)	5.0(A)	3.0(A)	3.0(A)
pH (Std. Units) ⁽³⁾	6.5–9.0 (Bm)	6.5–9.0 (Bm)	6.5–9.0 (Bm)	6.5–9.0(A)	6.5–9.0(A)	6.5–9.0(A)		5.0–9.0(A)
Suspended Solids ⁽⁴⁾								
Temperature (°C) ⁽⁶⁾ effective through 12/30/07				Max 20 °C, with 3 °C Increase ⁽⁹⁾ (G)	Max 30 °C, with 3 °C Increase ⁽⁹⁾ (G)			
Temperature (°C) ⁽⁶⁾ effective 12/31/07				19.3 °C (MWAT) ^a ; 23.8 °C (DM) ^b ; 12.6 (sp ^c)(MWAT); 17.8 °C (ct ^d) (MWAT) 25.6 °C (ct) (DM); 16.3 (ct/sp) (MWAT); 24.2 °C (cw ^e) (MWAT); 29.4 °C (cw)(DM) ;	29.2 °C (MWAT); 32.5 °C (DM)	Cold: 19.3 °C (MWAT) ^a ; 23.8 °C (DM) ^b ; 12.6 (sp ^c)(MWAT); Warm: 29.2 °C (MWAT); 32.5 °C (DM)		
BIOLOGICAL:								
<i>E. coli</i> per 100 ml	126 ⁽⁷⁾	205 ⁽⁷⁾	630 ⁽⁷⁾					630
Note: Capital letters in parentheses refer to references listed in section 31.16(3); Numbers in parentheses refer to Table 1 footnotes.								
Temperature Definitions								
^a MWAT = Maximum weekly average maximum temperature								
^b DM = Daily maximum								
^c sp = Spawning, season is dependent on the species expected to be present in the segment; implemented as a MWAT.								
^d ct = cutthroat								
^e cw = cool water								

TABLE II INORGANIC PARAMETERS							
PARAMETER	AQUATIC LIFE				AGRICULTURE	DOMESTIC WATER SUPPLY	
	CLASS 1 Cold Water Biota		CLASS 1 Warm Water Biota				
INORGANICS:							
Ammonia (mg/l as N) Total	chronic = elsp or elsa ⁽¹⁾ acute = sp ⁽¹⁾ (N)		chronic = Apr 1-Aug 31=elsp ⁽¹⁾ Sept 1-Mar 29=elsa ⁽¹⁾ acute = sa ⁽¹⁾ (N)		Class 2 Cold/Warm have the same standards as Class 1 Cold/Warm (N)		
Total residual Chlorine (mg/l)	0.019 (L) (1-day)	0.011 (L) (30-day)	0.019 (L) (1-day)	0.011 (L) (30-day)	0.011 (L) (30-day)		
Cyanide - Free (mg/l)	0.005(H) (1-day)		0.005(H) (1-day)		0.005(H) (1-day)	0.2(G) (1-day)	0.2(B,D ^m) (1-day)
Fluoride (mg/l)						2.0 ⁽³⁾ (E) (1-day)	
Nitrate (mg/l as N)						100 ⁽²⁾ (B)	10 ⁽⁴⁾ (K) (1-day)
Nitrite (mg/l as N)	TO BE ESTABLISHED ON A CASE BY CASE BASIS ⁽³⁾				A CASE BY CASE BASIS ⁽³⁾	10 ⁽²⁾ (B) (1-day)	1.0(2) ⁽⁴⁾ (K) (1-day)
Sulfide as H ₂ S (mg/l)	0.002 undissociated(A) (30-day)		0.002 undissociated(A) (30-day)		0.002 undissociated(A) (30-day)	0.05(F) (30-day)	
Boron (mg/l)						0.75(A,B) (30-day)	
Chloride (mg/l)						250(F) (30-day)	
Sulfate (mg/l)						250(F) (30-day)	
Asbestos						7,000,000 fibers/L ⁽⁵⁾	

NOTE: Capital letters in parentheses refer to references listed 31.16(3); numbers in parentheses refer to table II footnotes.

TABLE III METAL PARAMETERS (Concentration in ug/l)						
METAL ⁽¹⁾	AQUATIC LIFE ⁽¹⁾⁽³⁾⁽⁴⁾⁽⁵⁾		AGRICULTURE ⁽²⁾	DRINKING WATER-SUPPLY ⁽²⁾	WATER + FISH ⁽⁷⁾	FISH INGESTION ⁽¹⁰⁾
	ACUTE	CHRONIC				
Aluminum	750 (tot.rec.)	87 (tot.rec.) ⁽¹¹⁾			---	---
Antimony				6.0 (30-day)	5.6	640
Arsenic	340	150	100 ^(A) (30-day)	0.02 – 10 ⁽¹³⁾ (30-day) ⁽¹⁴⁾	0.02	7.6
Barium				1,000 ^(E) (1-day) 490 (30-day)	---	---
Beryllium			100 ^(A,B) (30-day)	4.0 (30-day)	---	---
Cadmium	$(1.136672 - [\ln(\text{hardness}) \times 0.9151 \ln(0.041838)] - 3.1485) \times e$ (Trout) = $(1.136672 - [\ln(\text{hardness}) \times 0.9151 \ln(0.041838)] - 3.6236) \times e$	$(1.101672 - [\ln(\text{hardness}) \times 0.7990 \ln(0.041838)] - 4.4451) \times e$	10 ^(B) (30-day)	5.0 ^(E) (1-day)	---	---
Chromium III ⁽⁵⁾	$e^{(0.819[\ln(\text{hardness})] + 2.5736)}$	$e^{(0.819[\ln(\text{hardness})] + 0.5340)}$	100 ^(B) (30-day)	50 ^(E) (1-day)	---	---
Chromium VI ⁽⁵⁾	16	11	100 ^(B) (30-day)	50 ^(E) (1-day)	100(30-day)	---
Copper	$e^{(0.9422[\ln(\text{hardness})] - 1.7408)}$	$e^{(0.8545[\ln(\text{hardness})] - 1.7428)}$	200 ^(B)	1,000 ^(F) (30-day)	1,300	---
Iron		1,000(tot.rec.) ^(A,C)		300(dis) ^(F) (30-day)	---	---
Lead	$(1.46203 - [(\ln(\text{hardness})^* (0.145712))]^* e^{(1.273[\ln(\text{hardness})] - 1.46)})$	$(1.46203 - [(\ln(\text{hardness})^* (0.145712))]^* e^{(1.273[\ln(\text{hardness})] - 4.705)})$	100 ^(B) (30-day)	50 ^(E) (1-day)	---	---
Manganese	$e^{(0.3331[\ln(\text{hardness})] + 6.4676)}$	$e^{(0.3331[\ln(\text{hardness})] + 5.8743)}$	200 ^(B) (30-day) ⁽¹²⁾	50(dis) ^(F) (30-day)	---	---
Mercury	1.4	0.77 FRV(fish) ^(B) = 0.01 (Total)		2.0 ^(E) (1-day)	---	---
Nickel	$e^{(0.846[\ln(\text{hardness})] + 2.253)}$	$e^{(0.846[\ln(\text{hardness})] + 0.0554)}$	200 ^(B) (30-day)	100 ^(E) (30-day)	610	4,600

TABLE III METAL PARAMETERS (Concentration in ug/l)						
METAL ⁽¹⁾	AQUATIC LIFE ⁽¹⁾⁽³⁾⁽⁴⁾⁽⁵⁾		AGRICULTURE ⁽²⁾	DRINKING WATER-SUPPLY ⁽²⁾	WATER + FISH ⁽⁷⁾	FISH INGESTION ⁽¹⁰⁾
	ACUTE	CHRONIC				
Selenium ⁹	18.4	4.6	20 ^(B,D) (30-day)	50 ^(E) (30-day)	170	4,200
Silver	$\frac{1}{2}e^{(1.72[\ln(\text{hardness})]-6.52)}$	$e^{(1.72[\ln(\text{hardness})]-9.06)}$ (Trout) = $e^{(1.72[\ln(\text{hardness})]-10.51)}$		100 ^(F) (1-day)	—	---
Thallium		15 ^(C)		0.5 (30-day)	0.24	0.47
Uranium	$e^{(1.1021[\ln(\text{hardness})]+2.7088)}$	$e^{(1.1021[\ln(\text{hardness})]+2.2382)}$		30	---	---
Zinc	$0.978 e^{(0.8525[\ln(\text{hardness})]+1.0617)}$	$0.986 e^{(0.8525[\ln(\text{hardness})]+0.9109)}$	2000 ^(B) (30-day)	5,000 ^(F) (30-day)	7,400	26,000
NOTE: Capital letters in parentheses refer to references listed in section 31.16(3); Numbers in parentheses refer to Table III footnote						