Contents

Foreword vii
Executive Summary ix
Notices xix
Acknowledgments xxi

I. Introduction 1
National Criteria 2
Regional Nutrient Criteria 2
Chesapeake Bay Criteria 3

II. Chesapeake Bay Nutrient and Sediment Enrichment Criteria . . . 5

III. Dissolved Oxygen Criteria 7

Background 7
Chesapeake Bay science 7
Natural dissolved oxygen processes 8
Chesapeake Bay oxygen dynamics 8
Low dissolved oxygen: historical and recent past 10

Approach to Deriving Dissolved Oxygen Criteria 12
Chesapeake Bay dissolved oxygen restoration goal framework 14
Regionalizing the EPA Virginian Province saltwater dissolved oxygen criteria 15
Applying the EPA freshwater dissolved oxygen criteria 25
Species listed as threatened or endangered 27
Scientific literature findings 33
Instantaneous minimum versus daily mean 33
Strengths and limitations of the criteria derivation procedures 34

Chesapeake Bay Dissolved Oxygen Criteria Derivation 40
Migratory fish spawning and nursery designated use criteria 42
Open-water fish and shellfish designated use criteria 46
Deep-water seasonal fish and shellfish designated use criteria 52
Deep-channel seasonal refuge designated use criteria 60

Chesapeake Bay Dissolved Oxygen Criteria 65

Literature Cited 67

IV. Water Clarity Criteria 81

Background 81

Approach 82

The relationships between water quality, light and underwater bay grasses 82

Determining light requirements 84

Strengths and limitations of the criteria derivation procedures 85

Water Clarity Criteria Derivation 90

Minimum light requirements 90

Light-through-water requirements 95

Chesapeake Bay Water Clarity Criteria 96

Literature Cited 97

V. Chlorophyll *a* Criteria 101

Background 101

Scope and magnitude of nutrient enrichment in Chesapeake Bay . . 101

Chlorophyll *a*: key indicator of phytoplankton biomass 102

Chesapeake Bay Chlorophyll *a* Criteria 104

Supporting Technical Information and Methodologies 105

Context for the narrative Chesapeake Bay chlorophyll *a* criteria . . . 105

Chlorophyll *a* concentrations characteristic of various ecological conditions 107

Chlorophyll *a* concentrations characteristic of trophic-based conditions 129

Chlorophyll *a* concentrations protective against water quality impairments 132

Methodologies for deriving waterbody-specific chlorophyll *a* criteria 134

Literature Cited 137

VI. Recommended Implementation Procedures 143

Defining Criteria Attainment 144

Dissolved oxygen criteria 144

Water clarity criteria 144

Chlorophyll *a* criteria 147

Addressing Magnitude, Duration, Frequency, Space and Time 148

Developing the Cumulative Frequency Distribution 152

Step 1. Interpolation of water quality monitoring data 152

Step 2. Comparison of interpolated water quality monitoring data to the appropriate criterion value 155

Step 3. Identification of interpolator cells that exceed the criterion value` 156

Step 4. Calculation of the cumulative probability of each spatial extent of exceedance 156

Step 5. Plot of spatial exceedance vs. the cumulative frequency . . . 159

Diagnosing the Magnitude of Criteria Exceedance 164

Defining the Reference Curve 166

Strengths and limitations 166

Approaches to defining reference curves 167

Reference curves for dissolved oxygen criteria 168

Reference curves for water clarity criteria 171

Reference curves for chlorophyll *a* criteria 174

Reference curve implementation 174

Monitoring to Support the Assessment of Criteria Attainment 176

Shallow-water monitoring 176

Dissolved oxygen criteria assessment 177

Water clarity criteria assessment 185

Chlorophyll *a* criteria assessment 191

Evaluation of Chesapeake Bay Water Quality Model Output 194

Chesapeake Bay Watershed Model 195

Chesapeake Bay Water Quality Model 196

Integration of Monitoring and Modeling for Criteria Assessment . . 196

Literature Cited 197

VII. Diagnostic Procedures for Natural Processes and Criteria Nonattainment 201

Addressing Natural Exceedance of the Chesapeake Bay Criteria . . . 201

Natural excursions of low dissolved oxygen conditions 202

Natural reductions in water clarity levels 206

Natural elevated chlorophyll *a* concentrations 209

Diagnosing Causes of Criteria Nonattainment 210
Dissolved oxygen criteria 210
Water clarity criteria 211
Chlorophyll *a* criteria 218
Literature Cited 218

Glossary 221

Acronyms 229

Appendices

A. Refined Designated Uses for the Chesapeake Bay and Tidal Tributaries A-1

B. Sensitivity to Low Dissolved Oxygen Concentrations for Northern and Southern Atlantic Coast Populations of Selected Test Species B-1

C. Summary of Literature on the Tolerance of Chesapeake Bay Macrobenthic Species to Low Dissolved Oxygen Conditions C-1

D. Narrative, Numerical and Method-based Chlorophyll *a* Criteria Adopted as Water Quality Standards by States Across the U.S. D-1

E. 1950s–1990s Chesapeake Bay and Tidal Tributary Chlorophyll *a* Concentrations by Chesapeake Bay Program Segment E-1

F. Phytoplankton Reference Community Data Analyses F-1

G. Data Supporting Determination of Adverse Affect Thresholds for Potentially Harmful Algal Bloom Species G-1

H. Derivation of Cumulative Frequency Distribution Criteria Attainment Reference Curves H-1

I. Analytical Approaches for Assessing Short-Duration Dissolved Oxygen Criteria I-1

J. Development of Chesapeake Bay Percent Light-at-the-Leaf Diagnostic Requirements J-1