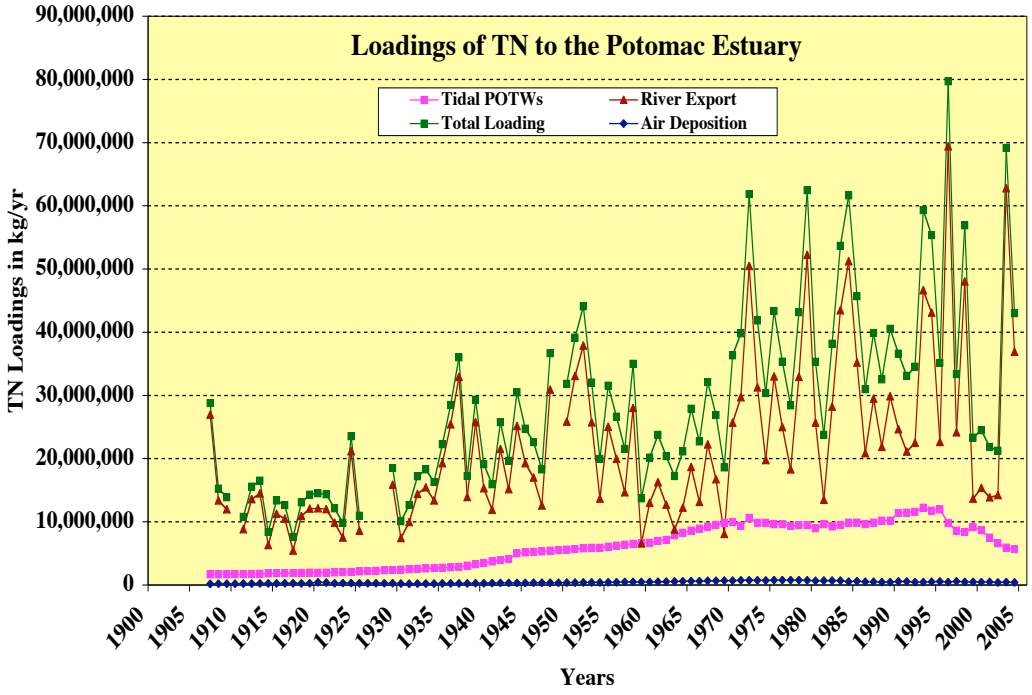
A Treatise

# The Potomac River Basin and its Estuary: Landscape Loadings and Water Quality Trends 1895-2005





**Norbert A. Jaworski, Retired, U.S. Environmental Protection Agency**
**Bill Romano, Maryland Department of Natural Resources**
**Claire Buchanan, Interstate Commission on the Potomac River Basin**
**Edited by Carole L. Jaworski**



**Edition 1.0**
**March 1, 2007**

## Preface

**The principal goal of this treatise is to provide a broad historical analysis of the landscape loading changes and resulting water quality trends of both the Potomac River Basin and its Estuary for the past century.**

**Data for this treatise came from numerous sources including federal and state government reports, electronic databases, and scientific publications. One of our major challenges was how to reduce the very large quantity of data into a systematic exposition of information that could be readily understood and utilized by readers of this treatise.**

**Where appropriate, we used summary tables and graphs to display the information. Detailed data tables and graphs are stored in Excel formats and can be made available upon request to the senior author.**

**To provide a systematic flow of concepts and data, we embedded the summary tables and graphs within the text of this treatise. Where appropriate, we normalized item information into units per square kilometer (for example, numbers of cattle per square kilometer or kilograms of fertilizer per square kilometer per year). This normalization facilitated the comparison of landscape loadings and water quality trends.**

**In developing this treatise, we are very fortunate to have some of the longest water quality monitoring databases that exist for the Potomac River Basin and its Estuary.**

**This is Edition 1.0 of the treatise. We hope to update about every five years.**

## Table of Contents


| Chapter and Topic | Page |
|---|---|
| **Preface** | **iii** |
| **Chapter One: Introduction** | **1** |
| The Setting | 1 |
| Previous Scientific and Technical Assessment | 2 |
| The Principal Goal and Objectives of the Potomac Treatise | 3 |
| The Potomac River Basin | 4 |
| The Potomac Estuary | 6 |
| Data Sources and Analysis Methods | 7 |
| Description of the Potomac River Basin | 11 |
| Land Use | 11 |
| Population | 12 |
| Climate | 14 |
| References for Chapter One | 18 |
| **Chapter Two: Water Quality Trends of the Upper Basin** | **21** |
| Drinking Water Supply | 21 |
| Drinking Water Quality | |
| Water Quality Trends | 22 |
| Temperature | 25 |
| Nutrients and Major Ions | 27 |
| Upper Basin Water Quality | 31 |
| Coal Mine Drainage | 34 |
| Annual Variability | 36 |
| Total Residue, Suspended Solids, Dissolved Solids, and Major Ions | 39 |
| Heavy Metal Concentrations in the Major Middle Atlantic Rivers | 40 |
| Water Quality Assessment of the Upper Basin in 1969 | 41 |
| USGS National Water Quality Assessment Program (NAWQA) Studies, 1979-1990 and 1992-1996 | 42 |
| Maryland's Middle Potomac River Basin Environmental Assessment | 43 |
| USGS Trend Study, 1985-2003 | 43 |
| Water Quality Studies in the Headwaters of the Potomac Basin in West Virginia | 44 |
| References for Chapter Two | 47 |
| **Chapter Three: Sources of Landscape Inputs to the Upper Basin** | **49** |
| Population and Wastewater Trends | 50 |
| Land Use Trends | 53 |
| Animal Production Trends | 55 |
| Crop Production Trends | 60 |

Fertilizer Use Trends 63
Air Deposition Trends 64
Upper Basin Nutrient Landscape Loading Input Trends Predicting Riverine Export Fluxes: Mass Balances Versus Landscape Loading Inputs 67
References for Chapter Three 70

**Chapter Four: Nutrients (including $SO_4$ and Cl), Riverine Export Fluxes, and River Concentration Relationships with Landscape Loading Inputs 71**

Upper Basin Landscape Inputs and Riverine Export Fluxes 71
Middle Atlantic and Northeast USA Watersheds and Export 73
Major Sub-basins of the Upper Potomac River Basin 85
Annual Upper Basin Landscape Loading and Riverine Export Trends 88
Riverine $NO_3$ Concentration/Landscape Input Loading Relationships 91
Application of Methodology to Mississippi River Sub-basins 94
Mass Balance of the Sum of the Water Quality Constituents of the Individual Sub-basins of the Upper Basin 97
Changes in Inorganic/Total Ratios for Nitrogen and Phosphorus 100
References for Chapter Four 102

**Chapter Five: Estuary Loadings from Wastewater Discharges Directly into the Tidal Waters, Direct Air Deposition onto the Tidal Waters, and Riverine Export 103**

Average Annual Loading Trends from Wastewater Discharges Directly into the Tidal Waters 103
Upper Potomac Basin Average Annual Loading Trends 104
Monthly Variability of TN and TP Loadings for the 1965-2000 Period 108
Nitrate Export Flux Trends from Upper Basin 110
Total Estuary Nutrient Input Fluxes from the Upper Basin and Direct POTW Discharges 111
Point-of-Entry Concentrations of TN and TP in the Upper Potomac Estuary 112
Total Loadings of TN and TP to the Entire Potomac Estuary 113
References for Chapter Five 116

**Chapter Six: Estuary Water and Sediment Quality Trends 117**

Bacterial and Dissolved Oxygen (DO) Concentrations of Upper Estuary 117
Upper Estuary at the Piscataway, Indian Head, and Maryland Point Stations 119
Nutrient Concentration and Impact of Nutrient Enrichment Trends 124
Total Phosphorus 124
Total Nitrogen 126
Dissolved Inorganic Nitrogen 128

Chlorophyll 129
Light Penetration (Secchi Disk) in Inches 130
Bottom Dissolved Oxygen 131
The 1912-13 Dissolved Oxygen Surveys of the Potomac Estuary 132
Point-of-Entry TN Concentrations and Bottom DO in Lower Estuary 134
Sediment Quality 135
Maryland Department of Natural Resources Trend Analyses: 1985-2005 Time Frame 138
References for Chapter Six 140

**Chapter Seven: Factors Affecting the Impact of Nutrient Enrichment on the Lower Estuary 141**

TN, TP, and Molar TN/TP Ratios of the Entire Potomac Waterway and its Estuary 141
Factors Affecting Bottom DO in the Lower Estuary 145
How Riverine Flow Impacts Nutrient Transport from the Upper to the Lower Estuary 149
Impact of Phosphorous Reduction by the POTW Wastewater Treatment Plants on the Nutrient Enrichment of the Lower Estuary 151
References for Chapter Seven 154

**Chapter Eight: Nutrient Dynamics, Depletion, and Replenishment 155**

Upper Estuary at the Indian Head Station 155
Monthly Nutrient Concentrations at the 301 Bridge, Ragged Point, and Point Lookout Stations 157
Nitrogen and Dissolved Oxygen Depletion and Replenishment at the Ragged Point Station 159
Phosphorus and Dissolved Oxygen Depletion and Replenishment at the Ragged Point Station 161
Silica and Dissolved Oxygen Depletion and Replenishment at the Ragged Point Station 162
Nutrient Dynamics at the 301 Bridge Station 163
DIN, Organic Nitrogen, Inorganic Phosphorus, Organic Phosphorus (OP), and Silica Concentrations at the Ragged Point Station 166
References for Chapter Eight 168

**Chapter Nine: A Summary of How and Why the Water Quality of the Potomac River and its Estuary Have Changed Over the Past 100 Years 169**

Bacteriological Conditions in the Potomac River and Upper Estuary (in Chapters Two and Six) 169
Chemical Quality of the Drinking Water at Great Falls (in Chapter Two) 170
Land Use and Nutrient Loading Trends for the Upper Basin (in Chapters Three and Four) 171

Relationships Between Landscape Loading Inputs Versus Riverine Export Fluxes and Nutrient Landscape Loading Inputs Versus Riverine Nitrate Concentrations (in Chapter Four) 173
Allocations of Landscape TN Loading Inputs to Riverine Export (in Chapter Four) 175
Upper Basin Riverine Nutrient Export and Water Quality Trends (in Chapters Two, Four, and Five) 175
POTWs Discharging into Tidal Waters (in Chapter Five) 179
Total Loadings of TN and TP to the Entire Potomac Estuary (in Chapter Five) 179
Upper Potomac Estuary Wastewater Treatment and Summer Surface DO Concentrations (in Chapters Five and Six) 181
Nutrient and Chlorophyll Trends for the Potomac Estuary (in Chapters Six and Seven) 182
Maryland Department of Natural Resource Trend Analyses: 1985-2005 Time Frame (in Chapter Six) 184
Nitrogen and Dissolved Oxygen Depletion and Replenishment (in Chapter Eight) 185
Low DO Concentrations in the Bottom Waters of the Lower Estuary (in Chapter Six) 189
Plankton Production Limitations (in Chapters Seven and Eight) 187
Ecological Successions of the Upper Estuary in Response to Changes in Point-of-Entry Concentrations of TN and TP (in all chapters) 191
Will a Greater than 50% Reduction of TN Inputs into the Potomac Estuary Improve Conditions at Ragged Point? (in Chapter Eight) 192
Effect of Increasing Nitrogen Removal at the Tidal POTWs Resulting in Effluents of 8.0 and 3.0 mg/l (in Chapter Five and Appendix A) 194
Meeting the Chesapeake Bay Program Goals for Nitrogen and Phosphorus (in Appendix A) 196
Fish Advisories and Overall Health of the Potomac River and its Estuary (in Recent Newsletters, Web Sites, Articles, and News Media) 197

**Appendix A: Possible Nutrient Management Strategies 199**

The Chesapeake Bay Program Base Loads and Nutrient Goals 199
Allocation of Potomac Nutrient Goals to Sub-basins Based on Balances 201
Equal Percent Reductions of Landscape Loading Inputs To Meet CBPO Nutrient Goals 204
Landscape Loading Input Reductions 205
Making the Case for Nitrogen Reduction Based on Improving Bottom DO Levels at 301 Bridge Station 208
Reducing to 1950 TN Inputs 211

TN Point-of-Entry Concentrations When Tidal POTW Effluents Are at 8.0 and 3.0 mg/l 211
Exponential $NO_3$ River Concentration/Landscape Loading Relationship Used to Obtain Maximum Nitrogen Reduction for Least Amount of Landscape Loading Reduction 213
Targeting Sub-basins with High Nitrate River Export Concentrations and High Watershed Runoff Rates 214
Changes in Agriculture Practices 215
Cover Crops, Buffers, and Wetland Restoration 216
Efficient Use of Commercial and Animal Fertilizers 218
References for Appendix A 220

**Acknowledgements** **221**

**Epilogue** **223**