

# Municipal Wastewater Treatment

Evaluating Improvements  
in National Water Quality

Andrew Stoddard   Jon Harcum   Jonathan Simpson

James R. Pagenkopf   Robert K. Bastian

## CONTENTS

---

<b>Preface</b>	<b>xv</b>
<b>Acknowledgments</b>	<b>xix</b>
<b>Acronyms</b>	<b>xxiii</b>
<b>1. Introduction</b>	<b>1</b>
Background	2
Study Approach	4
The First Leg: An Examination of BOD Loadings Before and After the CWA	5
The Second Leg: An Examination of "Worst-Case" DO in Waterways Below Point Sources Before and After the CWA	6
The Third Leg: Case Study Assessments of Water Quality	12
The Target Audience for this Book	13
References	13
<b>2. An Examination of BOD Loadings Before and After the CWA</b>	<b>17</b>
A. History of Water Supply and Its Effects on Public Health	17
Impacts on Water Supply Users and "The Great Sanitary Awakening"	19
Impacts on Water Resources Users	21
B. Evolution of Wastewater Treatment	23
Primary Treatment	23
Dissolved Oxygen as an Indicator of Water Quality	23
Secondary Treatment	25
Biochemical Oxygen Demand (BOD) as a Measure of Organic Wasteload Strength	26
C. The Federal Role in Implementing Secondary Treatment in the Nation's POTWs	27
The Federal Role in Secondary Treatment Before the Clean Water Act	27

The Federal Role in Secondary Treatment After the Clean Water Act	33
D. Nationwide Trends in BOD Loading from POTWs	42
Types of BOD Reported in this Trends Analysis	43
Trends in POTW Inventory	48
Trends in Population and Influent Wastewater Flow to POTWs	50
Trends in Influent BOD Loading to POTWs	52
Trends in Effluent BOD Loading from POTWs	57
Trends in BOD Removal Efficiency	63
Future Trends in BOD Effluent Loading	64
E. BOD <sub>5</sub> Loadings from Point and Nonpoint Sources	70
Pollutant Loading from Sources Other than POTWs	71
BOD <sub>5</sub> Loads from the National Water Pollution Control Assessment Model (NWPCAM)	76
Comparison of Point and Nonpoint Sources of BOD <sub>5</sub> at the National Level	85
F. Investment Costs for Water Pollution Control Infrastructure	85
The Construction Grants Program	85
Other Investment Costs for Water Pollution Control Infrastructure	90
Future Infrastructure Needs	93
G. Summary, Conclusions, and Future Trends	95
Key Points of the Background Sections	95
Key Points of the BOD Loading Analysis Sections	96
Key Points of the Investment Costs Section	98
Conclusions and Future Trends	98
References	100
<b>3. An Examination of "Worst-Case" DO in Waterways Below Point Sources Before and After the CWA</b>	<b>105</b>
A. Background	106
Sources of DO Data	107
"Worst Case" Conditions as a Screening Tool	107
The Role of Spatial Scale in this Analysis	119
B. Data Mining	119
Step 1—Data Selection Rules	119
Step 2—Data Aggregation Rules from a Temporal Perspective	120
Step 3—Calculation of the Worst-Case DO Summary	
Statistic Rules	121
Step 4—Spatial Assessment Rules	122
Step 5—Data Aggregation Rules from a Spatial Perspective	125

Step 6—Development of the Paired Data Sets (at Each Spatial Scale)	126
C. Comparison of Worst-Case DO in Waterways Below Point Source Discharges Before and After the CWA at Three Spatial Scales	126
Before and After DO at Reach Scale	127
Before and After DO at Catalog Unit Scale	130
Comparison of the Change in Signal Between the Reach and Catalog Unit Scales Using the Upper White River Basin (Indiana) as an Example	154
Before and After DO at Major River Basin Scale	162
D. Summary and Conclusions	171
Key Points of the Background Section	172
Key Points of the Data Mining Section	173
Key Points of the Comparison Analysis Section	174
Conclusions	176
References	179
<b>4. Case Study Assessments of Water Quality</b>	<b>181</b>
A. Background	181
B. Selection of Case Study Waterways	183
C. Before and After CWA	184
D. Policy Scenarios for Municipal Effluent Discharges	189
E. Discussion and Conclusions	194
References	195
<b>5. Connecticut River Case Study</b>	<b>199</b>
Background	199
Physical Setting and Hydrology	200
Population, Water, and Land Use Trends	203
Historical Water Quality Issues	204
Legislative and Regulatory History	205
Impacts of Wastewater Treatment	206
Pollutant Loading and Water Quality Trends	206
Recreational and Living Resources Trends	207
Summary and Conclusions	210
References	211

<b>6. Hudson-Raritan Estuary Case Study</b>	<b>213</b>
Background	213
Physical Setting and Hydrology	215
Population, Water, and Land Use Trends	215
Historical Water Quality Issues	220
Legislative and Regulatory History	223
Impacts of Wastewater Treatment	225
Pollutant Loading and Water Quality Trends	225
Recreational and Living Resources Trends	242
Summary and Conclusions	248
References	249
<b>7. Delaware Estuary Case Study</b>	<b>255</b>
Physical Setting and Hydrology	256
Population, Water, and Land Use Trends	259
Historical Water Quality Issues	261
Legislative and Regulatory History	262
Impacts of Wastewater Treatment	263
Pollutant Loading and Water Quality Trends	263
Evaluation of Water Quality Benefits Following Treatment Plant Upgrade	270
Recreational and Living Resources Trends	273
Summary and Conclusions	279
References	281
<b>8. Potomac Estuary Case Study</b>	<b>285</b>
Physical Setting and Hydrology	286
Population, Water, and Land Use Trends	288
Historical Water Quality Issues	290
Legislative and Regulatory History	290
Impacts of Wastewater Treatment	291
Pollutant Loading and Water Quality Trends	291
Evaluation of Water Quality Benefits Following Treatment Plant Upgrades	294
Recreational and Living Resources Trends	298

Summary and Conclusions	308
References	309
<b>9. James River Estuary Case Study</b>	<b>311</b>
Physical Setting and Hydrology	311
Population Trends	314
Historical Water Quality Issues	315
Legislative and Regulatory History	316
Impacts of Wastewater Treatment	317
Pollutant Loading and Water Quality Trends	317
Evaluation of Water Quality Benefits Following Treatment Plant Upgrades	321
Recreational and Living Resources Trends	324
Summary and Conclusions	325
References	325
<b>10. Upper Chattahoochee River Case Study</b>	<b>327</b>
Physical Setting and Hydrology	328
Population, Water, and Land Use Trends	331
Historical Water Quality Issues	333
Legislative and Regulatory History	335
Impacts of Wastewater Treatment	336
Pollutant Loading and Water Quality Trends	336
Recreational and Living Resources Trends	340
Summary and Conclusions	342
References	342
<b>11. Ohio River Case Study</b>	<b>345</b>
Physical Setting and Hydrology	346
Population, Water, and Land Use Trends	347
Historical Water Quality Issues	350
Legislative and Regulatory History	350
Impacts of Wastewater Treatment	352
Pollutant Loading and Water Quality Trends	352

Recreational and Living Resources Trends	356
Summary and Conclusions	358
References	358
<b>12. Upper Mississippi River Case Study</b>	<b>361</b>
Physical Setting and Hydrology	362
Population, Water, and Land Use Trends	366
Historical Water Quality Issues	367
Legislative and Regulatory History	372
Impacts of Wastewater Treatment	373
Pollutant Loading and Water Quality Trends	373
Evaluation of Water Quality Benefits Following Treatment Plant Upgrades	383
Recreational and Living Resources Trends	386
Summary and Conclusions	390
References	393
<b>13. Willamette River Case Study</b>	<b>399</b>
Physical Setting and Hydrology	400
Population, Water, and Land Use Trends	403
Historical Water Quality Issues	404
Legislative and Regulatory History	405
Impacts of Wastewater Treatment	406
Pollutant Loading and Water Quality Trends	406
Recreational and Living Resources Trends	408
Summary and Conclusions	410
References	412
<b>Appendix A. United States Waterways Identified with Water Pollution Problems Before the 1972 Clean Water Act</b>	<b>415</b>
<b>Appendix B. National Municipal Wastewater Inventory and Infrastructure, 1940–2016</b>	<b>449</b>
<b>Appendix C. National Public and Private Sector Investment in Water Pollution Control</b>	<b>501</b>

<b>Appendix D. Before and After CWA Changes in Tenth Percentile Dissolved Oxygen and Ninetieth Percentile BOD<sub>5</sub> at the Catalog Unit Level</b>	<b>507</b>
<b>Appendix E. Before and After CWA Changes in Tenth Percentile Dissolved Oxygen at the RF1 Reach Level</b>	<b>523</b>
<b>Appendix F. Hydrologic Conditions of the 48 Contiguous States, Summer (July–September) from 1961 through 1995</b>	<b>537</b>
<b>Appendix G. Municipal and Industrial Wastewater Loads by Major River Basin Before and After the Clean Water Act: 1950, 1973, and <i>ca.</i> 1995</b>	<b>583</b>
<b>Appendix H. Municipal and Industrial Water Withdrawals by Major River Basin: 1940–1995</b>	<b>593</b>
<b>Glossary</b>	<b>601</b>
<b>Index</b>	<b>615</b>