

Contents

1 Introduction.....	21
1.1 Greenhouse Gases and Reservoirs	21
1.2 Reservoir Dynamics.....	27
1.2.1 Water Quality	27
1.2.2 Plankton	30
1.2.3 Benthos	31
1.2.4 Fish	32
1.3 Contents and Rationales	32

Gross Emissions

2 Analytical Techniques for Measuring Fluxes of CO₂ and CH₄ from Hydroelectric Reservoirs and Natural Water Bodies.....	37
Abstract.....	37
2.1 Introduction	38
2.2 History of the Methods Used by Hydro-Québec	38
2.3 Description of the Methods	39
2.3.1 Floating Chambers with <i>in situ</i> Laboratory Analysis	39
2.3.2 Floating Chambers with <i>ex situ</i> Laboratory Analysis.....	42
2.3.3 Floating Chambers Coupled to an NDIR or FTIR Instrument	43
2.3.4 Thin Boundary Layer.....	45
2.4 Comparison of the Different Methods	47
2.4.1 Stability of Air and Water Samples in Syringes and Bottles ...	47
2.4.2 Effect on the Mode of Transportation of the Samples.....	47
2.4.3 Effect of the Mode of Transportation Between Sites	48
2.4.4 Quality Control for all Methods	48
2.4.5 Comparison of the two Methods with Syringe	52
2.4.6 Comparison of Syringe and Thin Boundary Layer Methods...	53
2.4.7 Comparison of Syringe and Automated Instrument Methods .	54

2.4.8 Comparison of NDIR and FTIR Instruments	55
2.4.9 Advantages and Disadvantages for Each Method	57
2.5 Conclusion	60

3 Development and Use of an Experimental near Infrared Open Path Diode Laser Prototype for Continuous Measurement of CO₂ and CH₄ Fluxes from Boreal Hydro Reservoirs and Lakes..... 61

Abstract.....	61
3.1 Introduction	62
3.2 Methodology.....	63
3.2.1 Choice of the Gradient Technique for Flux Estimates	63
3.2.2 Assessing Average CO ₂ and CH ₄ Concentration Gradients	64
3.2.3 Assessing Average GHG fluxes	65
3.3 Experimental Set-Up and Technique.....	66
3.3.1 Description of the Optical Paths	66
3.3.2 Spectral Resolution of the Laser Device	68
3.3.3 Description of the Signal Detection.....	69
3.4 Major Results and Discussion	71
3.4.1 Technical Developments and Optimizations	71
3.4.2 CO ₂ and CH ₄ Fluxes at FLUDEX - ELA Experimental Reservoir.....	72
3.4.3 CO ₂ and CH ₄ Fluxes at Robert-Bourassa Hydroelectric Reservoir.....	79
3.4.4 Major Benefits of Flux Measurements by Tunable Diode Lasers.....	83
3.5 Conclusion and Directions for Future Work.....	84

4 Greenhouse Gas Fluxes (CO₂, CH₄ and N₂O) in Forests and Wetlands of Boreal, Temperate and Tropical Regions 87

Abstract.....	87
4.1 Introduction	88
4.2 Net Ecosystem Exchange of CO ₂ (NEE) in Forests	89
4.3 Net Ecosystem Exchange of CO ₂ in Wetlands	97
4.4 CH ₄ Fluxes in Wetlands.....	101
4.5 CH ₄ Fluxes in Forests	113
4.6 N ₂ O Fluxes in Forest and Wetland Soils	116
4.7 N ₂ O in Wetlands	120
4.8 GHG Budgets in Forests and Wetlands	120
4.9 General Evaluation of Gas Flux Data	125

5 Diffuse Flux of Greenhouse Gases – Methane and Carbon Dioxide – at the Sediment-Water Interface of Some Lakes and Reservoirs of the World	129
Abstract.....	129
5.1 Introduction	130
5.2 Lakes and Reservoirs Sampled in this Study	133
5.2.1 Sediment Sampling for Gases.....	135
5.2.2 Diffuse Flux Calculations.....	138
5.3 Results and Discussion	142
5.3.1 Sediment Gas Diffuse Flux.....	142
5.3.2 Relationships Between Sediment Gas Fluxes and Lake and Reservoir Trophic Conditions	146
5.4 Conclusions	152
Acknowledgements	152
 6 Organic Carbon Densities of Soils and Vegetation of Tropical, Temperate and Boreal Forests.....	155
Abstract.....	155
6.1 Introduction	156
6.2 Soil Organic Carbon Density.....	157
6.3 Physical and Biological Factors Affecting SOC Density	165
6.4 Uncertainties of SOC Estimates	169
6.5 Organic Carbon in Vegetation	170
6.6 High Spatial Heterogeneity of Biomass.....	173
6.7 Uncertainties in Evaluating the Organic Carbon in Vegetation....	178
6.8 Total Carbon Densities and Stocks of Forest Biomes	181
6.9 Export of Organic Carbon to Aquatic Ecosystems	183
6.10 Conclusion	185
 7 Carbon Dioxide and Methane Emissions from Estuaries	187
Abstract.....	187
7.1 Introduction	188
7.2 Estuaries: Some Useful Definitions for Describing Carbon Cycling and Gas Emissions.....	188
7.3 Organic Carbon Sources and Mineralization in Estuaries	190
7.4 Estuarine Specificity for Gas Transfer.....	191
7.5 Carbon Dioxide Emissions	194
7.6 Methane Emissions.....	200
7.7 Significance at the Global Scale	206
Acknowledgments	207

8 GHG Emissions from Boreal Reservoirs and Natural Aquatic Ecosystems.....	209
Abstract.....	209
8.1 Introduction	209
8.2 Material and Methods	210
8.2.1 Study Areas	210
8.2.2 Measurement of GHG Fluxes and Other Variables.....	212
8.2.3 Statistical Analyses.....	218
8.3 Results and Discussion	218
8.3.1 Spatial Variation of GHG Emissions.....	218
8.3.2 Temporal Variation of GHG Emission from Reservoirs	229
8.3.3 Fluxes in CO ₂ Equivalent Carbon.....	231
8.4 Conclusion	231
 9 CO₂ Emissions from Semi-Arid Reservoirs and Natural Aquatic Ecosystems.....	 233
Abstract.....	233
9.1 Introduction	233
9.2 Material and Methods	234
9.2.1 Study Areas	234
9.2.2 Measurement of CO ₂ Flux and Other Variables	239
9.2.3 General Chemical Characteristics of the Water Bodies	239
9.2.4 Statistical Analyses.....	243
9.3 Results and Discussion	243
9.4 Conclusion	250
 10 A Comparison of Carbon Dioxide Net Production in Three Flooded Uplands (FLUDEX, 1999-2002) and a Flooded Wetland (ELARP, 1991-2002) Using a Dynamic Model.....	 251
Abstract.....	251
10.1 Introduction	251
10.2 Methods	253
10.2.1 The model.....	253
10.2.1 Running the Model and Calibrating to the Measured Data ..	257
10.3 Results	257
10.3.1 ELARP	257
10.3.2 FLUDEX	259
10.4 Discussion.....	261
10.5 Conclusions	265

11 Gross Greenhouse Gas Emissions from Brazilian Hydro Reservoirs	267
Abstract.....	267
11.1 Introduction	267
11.2 Material and Methods.....	268
11.2.1 Site Description	268
11.3 Methodology.....	269
11.4 Results and Discussion: Gross Emissions of CO ₂ and CH ₄ from Brazilian Power Dams	271
11.5 Concluding Remarks and Future Orientations.....	279
11.6 Annex.....	281
11.6.1 Procedures for Capturing Bubbles.....	281
11.6.2 Calculation of Averages of Greenhouse Gases Emissions by Bubbles	282
11.6.3 Measurement Procedures for Diffusion Rates.....	284
11.6.4 Principle of Exchange Rates Measurement	284
Acknowledgements	291
 12 Long Term Greenhouse Gas Emissions from the Hydroelectric Reservoir of Petit Saut (French Guiana) and Potential Impacts.....	293
Abstract.....	293
12.1 Introduction	293
12.2 Experimental Site and Campaigns.....	295
12.2.1 The Petit Saut Reservoir	295
12.2.2 Measurements	295
12.3 Results	297
12.3.1 Observed and Predicted Emissions Over 20 Years	297
12.3.3 Long Term Data and Recent Flux Measurements	305
12.4 Conclusion and Perspective.....	309
12.4.1 Future Initiatives.....	310
Acknowledgments	312

Processes Leading to GHG Production

13 Production of GHG from the Decomposition of <i>in vitro</i> Inundated Phytomass and Soil	315
Abstract.....	315
13.1 Introduction	316
13.2 Methodology.....	318
13.2.1 Field Site and Sample Collection	318
13.2.2 Experimental Setup.....	319
13.2.3 Experimental Conditions	319
13.2.4 Measurements of Carbon Dioxide and Methane	322
13.2.5 Production of Gases.....	323
13.3 Results and Discussion	324
13.3.1 Soil Samples	324
13.3.2 Vegetation Samples	328
13.4 Conclusion	336
Acknowledgements	338
14 Diffusive CO₂ Flux at the Air-Water Interface of the Robert-Bourassa Hydroelectric Reservoir in Northern Québec : Isotopic Approach (¹³C)	339
Abstract.....	339
14.1 Introduction	339
14.2 Materials and Methods	341
14.2.1 Study Site.....	341
14.2.2 Sampling Scheme	343
14.2.3 In situ Sampling Measurements	343
14.3 Model Construction	345
14.4 Estimation of the FCO ₂ prod./FCO ₂ atm. eq. for the Robert-Bourassa Reservoir.....	346
14.5 Estimating FCO ₂ atm. eq and Mean CO ₂ Flux at the Air-Water Interface	348
14.6 Estimate of the Mean Annual Diffusive CO ₂ Flux from the Robert-Bourassa Reservoir	352
14.7 Comments and Conclusions	353

15 The Use of Carbon Mass Budgets and Stable Carbon Isotopes to Examine Processes Affecting CO₂ and CH₄ Production in the Experimental FLUDEX Reservoirs.....	355
Abstract.....	355
15.1 Introduction	356
15.2 Methods and Rationale	357
15.2.1 Study Site and Reservoir Construction.....	357
15.2.2 Theoretical Approach to Quantification of Net Reservoir CO ₂ and CH ₄ Production, Gross DIC Production and NPP, and CH ₄ Production and CH ₄ Oxidation	360
15.2.3 Inorganic C and CH ₄ Mass Budgets and Stable Carbon Isotopic Ratio Mass Budgets	362
15.2.4 $\delta^{13}\text{C}$ Values of Gross DIC Production, NPP, CH ₄ Production and Oxidation	364
15.2.5 Analytical Methods.....	366
15.3 Results and Discussion	367
15.3.1 Inorganic C and CH ₄ Budgets and Net Reservoir CO ₂ and CH ₄ Production.....	367
15.3.2 Gross Reservoir DIC Production and Consumption Via NPP	369
15.3.3 CH ₄ Production and Oxidation	376
15.3.4 Reservoir GHG Production, OC Storage, and Timescale.....	377
15.3.5 Extrapolation of FLUDEX Results to Other Studies.....	379
15.4 Conclusions	382
 16 Mass Balance of Organic Carbon in the Soils of Forested Watersheds from Northeastern North America	383
Abstract.....	383
16.1 Introduction	383
16.1.1 Emission of Greenhouse C Gases.....	383
16.1.2 Contribution of Soils from Forest Ecosystems	385
16.2 Organic Carbon in Forest Soils.....	386
16.2.1 Biogeochemical Cycle of Organic Carbon in Forested Ecosystems	387
16.2.2 Key Role of Forest Soils in the Organic Carbon Cycle.....	390
16.2.3 Nature and Properties of Organic Substances in Soils	392
16.2.4 Functions of Organic Carbon in Soils	396
16.2.5 Links between Carbon and Other Elemental Cycles in Forest Soils	398
16.3 Organic C Pools and Fluxes in Forest Watersheds.....	405
16.3.1 Forest Ecosystems from Northeastern North America	405

16.3.2 Forest Ecosystems from Southeastern North America	413
16.3.3 Forest Ecosystems from Northwestern Europe	413
16.3.4. Carbon Pools and Fluxes in Northern Wetlands.....	414
16.4 Implications for the Emission of Greenhouse Gases	417
16.4.1 Net Role of Soils on the Cycling of Organic Carbon in Terrestrial Ecosystems.....	417
16.4.2 Changes in the Transport of DOC from Terrestrial to Aquatic Ecosystems	419

**17 Planktonic Community Dynamics over Time in a Large Reservoir
and their Influence on Carbon Budgets..... 421**

Abstract.....	421
17.1 Introduction	421
17.2 Materials and Methods	423
17.2.1 Long-term Data Set (1978-1984)	423
17.2.2 Recent Data Set	427
17.3 Results	428
17.3.1 Long-term Variation in Zooplankton Community (1978-1984)	428
17.3.2 Relation with Water Quality and Trophic Status.....	430
17.3.3 Recent Data Set: A Comparison between Reservoirs.....	432
17.4 Discussion.....	436
17.5 Conclusions	440

**18 Production and Consumption of Methane in Soil, Peat, and
Sediments from a Hydro-Electric Reservoir (Robert-Bourassa) and
Lakes in the Canadian Taiga 441**

Abstract.....	441
18.1 Introduction	442
18.2 Material and Methods.....	443
18.2.1 Site Description and Sample Collection.....	443
18.2.2 Physico-Chemical Variables.....	444
18.2.3 Bacterial Methane Metabolism.....	445
18.2.4 Statistics.....	448
18.3 Results	448
18.3.1 Methanogenesis	448
18.3.2 Methanotrophy	454
18.4 Discussion.....	457
18.4.1 Methanogenesis	457
18.4.2 Methanotrophy	460

18.5 Methane Biogeochemistry and Concluding Remarks.....	463
Acknowledgments	465
19 Bacterial Activity in the Water Column and its Impact on the CO₂	
Efflux.....	467
Abstract.....	467
19.1 Introduction	468
19.2 Study Sites and Methods	469
19.3 Results	471
19.3.1 Temperature and DOC.....	471
19.3.2 Bacterial Abundance and Production in the Study Sites	473
19.4 Discussion.....	475
19.4.1 Factors Affecting Bacterioplankton Activities (i.e. Production, Specific Production and % HNA)	475
19.4.2 Bacterioplankton Activities and Variations in CO ₂ Fluxes to the Atmosphere.....	478
19.4.3 Contribution of Bacterioplankton Activities to CO ₂ Fluxes from Freshwaters to the Atmosphere.....	479
19.5 Conclusion	482
20 Production-Consumption of CO₂ in Reservoirs and Lakes in Relation to Plankton Metabolism	483
Abstract.....	483
20.1 Introduction	484
20.2 Study Site.....	485
20.3 Methods	487
20.4 Results and Discussion	490
20.4.1 Phytoplankton Biomass	490
20.4.2 Areal Gross Production	492
20.4.3 Areal Planktonic Respiration.....	493
20.4.4 Spatial Variation of the Production: Respiration Ratio	494
20.4.5 Gross Primary Production and Total Respiration Mass Balance and their Relationship to CO ₂ Flux at the Water-Air Interface	503

21 Impacts of Ultraviolet Radiation on Aquatic Ecosystems: Greenhouse Gas Emissions and Implications for Hydroelectric Reservoirs	509
Abstract.....	509
21.1 Introduction	510
21.2 Ultraviolet Radiation and Dissolved Organic Matter	510
21.2.1 Types of Dissolved Organic Matter.....	511
21.2.2 Dissolved Organic Matter Quality.....	512
21.2.3 Photoreactions and DOM	514
21.2.4 Ionic Conditions	518
21.3 Ultraviolet Radiation and Microorganisms	519
21.3.1 Plankton.....	519
21.3.2 Harmful Effects of UV on Microorganisms	521
21.4 Photooxidation in Reservoirs.....	522
21.4.1 Vegetation.....	522
21.4.2 Residence Time	523
21.4.3 Temperature and Ice	523
21.4.4 Estimate of the Rate of Photooxidation in Reservoirs.....	523
21.5 Conclusion	526
 22 Impact of Methane Oxidation in Tropical Reservoirs on Greenhouse Gases Fluxes and Water Quality.....	 529
Abstract.....	529
22.1 Introduction	529
22.2 Site and Measurement Descriptions	531
22.2.1 The Example of the Petit Saut Reservoir and the Downstream River	531
22.2.2 Measurements.....	533
22.3 Water Quality and Methane Oxidation in the Reservoir	534
22.3.1 Stratification and General Water Quality	534
22.3.2 Methane Production and Oxidation in the Reservoir.....	538
22.3.3 Principal Factors Influencing Water Quality.....	541
22.4 Methane Emission and Oxidation Downstream of the Reservoir.....	544
22.4.1 Evidence of a Consumption of Dissolved Oxygen in the Downstream Sinnamary River Due to an Oxidation of Dissolved Methane	544
22.4.2 Building of an Aerating Weir in the Plant Outlet Canal in Order to Guarantee 2 mg L ⁻¹ of DO in the Downstream Sinnamary River	547

22.4.3 Historical Reconstruction (1994-2002) of the DM Concentrations and Fluxes in the Water Crossing the Dam	548
22.4.4 Efficiency of DM Elimination in the Near Downstream of the Dam (1994-2002)	550
22.4.5 DM Emissions to the Atmosphere in the Sinnamary River Downstream of the Aerating Weir.....	553
22.4.6 A New Assessment of the Methane Emissions to the Atmosphere in the Downstream Sinnamary River (1994-2002 Period)	556
22.4.7 Extrapolation of CH ₄ Findings to Other Morphological Conditions.....	557
22.4.8 The Role of DM Oxidation in the DO Budget of the Downstream Sinnamary	557
22.5 General Conclusion	558
Acknowledgements	560

Modelling

23 Using Gas Exchange Estimates to Determine Net Production of CO₂ in Reservoirs and Lakes	563
Abstract.....	563
23.1 Introduction	563
23.2 Methods Used to Estimate Gas Exchange	564
23.3 Discussion of the Methods.....	566
23.4 Using a Model to Assist Interpretation.....	568
23.5 Other Sources of Variability	571
23.6 Conclusion	574
 24 A One-Dimensional Model for Simulating the Vertical Transport of Dissolved CO₂ and CH₄ in Hydroelectric Reservoirs	575
Abstract.....	575
24.1 Introduction	575
24.2 Thermodynamic Lake Models.....	577
24.3 Description of the Hostetler Lake Model	578
24.3.1 Energy Balance Equations.....	578
24.3.2 Turbulent Diffusion	579
24.3.3 Convective Adjustment	583

24.3.4 Ice Model.....	583
24.4 Calculation of CO ₂ and CH ₄ Fluxes at the Air-Water Interface .	584
24.4.1 Bulk Aerodynamic Technique (BAT)	585
24.4.2 Thin Boundary Layer (TBL)	585
24.5 Results	587
24.5.1 Model Definition of Atmospheric GHG Concentrations and GHG Sources and Sinks	587
24.5.2 Sensitivity Test and Validation.....	589
24.5.3 Application: Comparison of the Annual CO ₂ Emissions for Two Reservoirs in Central Northern Québec	592
24.6 Conclusion	593
 25 Modelling the GHG emission from hydroelectric reservoirs.....	597
Abstract.....	597
25.1 Introduction	598
25.2 Model formulation.....	601
25.2.1 Basic configuration of the reservoir	601
25.2.2 Constitutive equations of the model	604
25.3 Mass transfer of CO ₂ and CH ₄ at the water-air interface	605
25.3.1 Wind effect	606
25.3.2 Water temperature effect	607
25.3.3 Mass transfer coefficient for carbon dioxide and methane	607
25.3.4 Effect of ice formation.....	609
25.3.5 Effect of oxic conditions.....	612
25.3.6 Effect of water temperature	612
25.3.7 Effect of pH	612
25.3.8 Kinetic parameters.....	613
25.3.9 Numerical solution of the constitutive equations	616
25.4 Results and discussion	618
25.4.1 Input data to the model	618
25.4.2 Simulation with the model.....	625
25.4.3 Limitations of the Model	633
25.5 Conclusion	633
25.5.1 Model characteristics	633
25.5.2 Performance of the model.....	634
Acknowledgements	635

26 Synthesis	637
Abstract.....	637
26.1 Greenhouse Gases in Natural Environments	638
26.1.1 Terrestrial Ecosystems.....	638
26.1.2 Aquatic Ecosystems.....	640
26.1.3 Estuaries	642
26.2 The Issue of Greenhouse Gases in Hydroelectric Reservoirs	644
26.2.1 Flooded Soils and Sediments.....	645
26.2.2 Water Column.....	650
26.2.3 Exchange at the Water-Air Interface	651
26.2.4 Reservoir Characteristics	655
26.2.5 Assessment of Net GHG Emissions from Reservoirs	656
26.2.6 Comparison of GHG Emissions from Various Energy Sources	657
26.2.6 Conclusion and Unresolved Issues	659
 References.....	 661

Greenhouse Gas Emissions - Fluxes and Processes
Hydroelectric Reservoirs and Natural Environments
Tremblay, A.; Varfalvy, L.; Roehm, C.; Garneau, M. (Eds.)
2005, XXIX, 732 p., Hardcover
ISBN: 978-3-540-23455-5