Table of Contents

EXECUTIVE SUMMARY 1
1 INTRODUCTION 9
1.1 Study Rationale 9
1.2 Project Objectives 11
1.3 Study Area and Seasons 12
2 LITERATURE REVIEW 14
2.1 Synoptic Weather Typing 14
2.1.1 Weather System-based Techniques 15
2.1.2 Air Mass-based Techniques 17
2.2 Prediction of Air Pollution Concentrations using Statistical Models 21
2.3 Health Impacts of Weather and Air Pollution 23
2.4 Statistical Downscaling of Climate Change Scenarios 25
2.5 Climate Change and Human Health 26
3 COLLECTION AND TREATMENT OF DATA 28
3.1 Meteorological Data 28
3.2 Mortality Data 29
3.3 Air Pollution Data 35
3.4 Climate Change Scenarios 42
3.5 Pollen Data 44
4 RESEARCH DESIGN AND METHODOLOGY 45
4.1 Development and Validation of the Models for Measuring Differential and Combined Impacts of Extreme Temperatures and Air Pollution on Elevated Mortality 47
4.1.1 Automated Synoptic Weather Typing Approach 47
4.1.2 Identification of the Weather Types Associated with Elevated Mortality and High Air Pollution Concentrations 48
4.1.3 Determination of Differential and Combined Health Impacts of Extreme Temperatures and Air Pollution 49
4.1.4 Development of the Elevated Mortality Prediction Models Using Within-weather-type Regression Analyses 50

4.1.5 Development of Air Pollution Prediction Models Using Within-weather-type Regression Analyses *51*
4.1.6 Validation of Models *51*
4.2 Impacts of Snowfall and Freezing Rain on Mortality Caused by Ischemic Heart Disease and Traffic Accidents 52
4.3 Impacts of Pollen on Mortality Caused by Respiratory Diseases 52
4.4 Impacts of Climate Change on Human Health 52
4.4.1 Statistical Downscaling Methods *53*
4.4.2 Projection of Future Weather Types *57*
4.4.3 Estimation of Future Air Pollution Concentrations *57*
4.4.4 Assessment of Climate Change Impacts on Elevated Human Mortality *58*
4.4.5 Estimation of Human Acclimatization to Increased Heat *59*
5 RESULTS AND DISCUSSIONS 61
5.1 Synoptic Weather Typing 61
5.1.1 Principal Component Analysis (PCA) *61*
5.1.2 Hierarchical Clustering *63*
5.1.3 Nonhierarchical Cluster Modification *63*
5.1.4 Weather-type Verification *64*
5.2 The Link between Weather Types and Air Pollution 65
5.3 Meteorological Characteristics of Hot, Cold, and Air Pollution-related Weather Types 71
5.4 Differential and Combined Impacts of Extreme Temperatures and Air Pollution on Elevated Mortality 77
5.5 Within-weather-type Potential Years of Life Lost 85
5.6 Air Quality Regression Model Development and Validation 87
5.7 Regression Analyses on Elevated Mortality associated with Extreme Temperatures and Air Pollution Concentrations 100
5.7.1 Elevated Mortality Prediction Models from Logistic Regression Analysis *100*
5.7.2 Elevated Mortality Prediction Models from Multiple Regression Analysis *110*
5.8 Results from Snowfall and Freezing Rain Impacts on Elevated Mortality 114
5.9 Results from Pollen Impacts on Respiratory Mortality 117

5.10 Possible Impacts of Climate Change on Elevated Mortality 118
5.10.1 Future Weather Characteristics from GCM Downscaling 118
5.10.2 Future Synoptic Weather Types 126
5.10.3 Future Air Pollution Concentrations 127
5.10.4 Changes in the Number of Days with Heat-related Health Risk under the Future Projected Climate 134
5.10.5 Changes in Future Elevated Mortality Based on Changes in Weather Type Frequency 135
5.10.6 Changes in Future Elevated Mortality Based on Future Weather and Air Pollution Scenarios 137
5.10.7 Changes in Future Elevated Mortality Based on Air Pollution 139
5.10.8 Assessments of the Population's Acclimatization to Global Warming 141
6 DEVELOPMENT OF A POTENTIAL EFFECTIVE ADAPTATION PLAN 144
7 ASSUMPTIONS AND UNCERTAINTIES OF THE STUDY 146
7.1 Assumption Regarding Human Acclimatization to Increased Heat 146
7.2 Assumptions Regarding Pollutant Emission Control Policies in the 21st Century 146
7.3 Assumption Regarding Determining Weather Types Associated with One Particular Pollutant 147
7.4 Uncertainty of GCM Scenarios 147
7.5 Uncertainty of the Potential Health Impacts of Climate Change 148
7.6 Limitation of Mortality Data 148
7.7 Limitation of Air Pollution Data 149
8 CONCLUSIONS 150
8.1 Major Findings of Historical Analysis 151
8.1.1 Synoptic Weather Typing 151
8.1.2 Weather Types Link with Air Pollution 151
8.1.3 Impacts of Weather Characteristics on Air Pollution Concentrations 152
8.1.4 Mortality Baseline 152
8.1.5 Elevated Mortality Associated with Extreme Temperatures and Air Pollution 153
8.1.6 Within-weather-type Potential Years of Life Lost 154
8.1.7 Air Pollution "Day-to-day" Prediction 154

8.1.8 Regression Analysis on Elevated Mortality *155*
8.1.9 Snowfall Impacts on Ischemic Heart Diseases *156*
8.1.10 Freezing Rain Impacts on Traffic Accident Mortality and Pollen Impacts on Respiratory Mortality *156*
8.2 Major Findings on Future Climate Change Impact Assessments 156
8.2.1 Daily and Hourly GCM Statistical Downscaling *156*
8.2.2 Assessment of Future Air Pollution Levels *157*
8.2.3 Future Number of Days with Heat-related Health Risk under the Future Projected Climate *157*
8.2.4 Future Heat/Cold-related Elevated Mortality *158*
8.2.5 Assessment of Population's Acclimatization to Increased Heat *158*
8.2.6 Assessment of Future Air Pollution-related Elevated Mortality *158*
GLOSSARY OF TECHNICAL TERMS 159
ABBREVIATIONS 164
REFERENCES 167
APPENDICES 181
Appendix A Economic Losses and Health Care Costs due to Premature Mortality A-1
Appendix B Figures and Tables for Montreal B-1
Appendix C Figures and Tables for Ottawa C-1
Appendix D Figures and Tables for Windsor D-1