Analysis of Ambient Air Quality Trends at Residential Air Monitoring Stations in Edmonton, Alberta

by

Salina Kathleen Fairbank

A thesis submitted in partial fulfillment of the requirements for the degree of

Master of Science

in

Environmental Health Sciences

School of Public Health
University of Alberta

ABSTRACT

Trends in ambient air quality concentrations were analyzed for three air pollutants (NO_2, $PM_{2.5}$, CO) in Edmonton, AB for the years 2003-2013. Hourly concentration data was obtained from three residential ambient air monitoring stations: Edmonton South, Woodcroft, and Gold Bar. Annual concentration-based benchmarks were determined between the 50th and 98th percentiles for the three pollutants over the study period. Trend analysis of the concentration percentile data, as well as population, traffic volume, and industrial emissions data for the study area, was completed using Mann-Kendall and Theil-Sen trend tests. An exploratory multiple linear regression analysis was completed to determine if population, traffic volume, and industrial NO_2 emissions are predictors of 50th percentile NO_2 concentrations at the Woodcroft station.

Ambient NO_2 concentrations showed a statistically significant (α=0.05) decreasing trend at all air monitoring stations over the study period. A statistically significant (α=0.05) increasing trend was detected for $PM_{2.5}$ at the Edmonton South station, however it is attributed to changes in monitoring instrumentation over the study period. No statistically significant (α=0.05) trends were detected for $PM_{2.5}$ at the Woodcroft monitoring station, or for CO at the Edmonton South station. Trend analysis of population and traffic volume detected statistically significant (α=0.05) increasing trends for the population and number of registered vehicles in the City of Edmonton over the study period. Analysis of industrial emissions data detected a statistically significant decreasing trend in reported NO_2 emissions for the study period; no statistically significant trends were observed for reported $PM_{2.5}$ and CO industrial emissions (α=0.05). The exploratory multiple linear regression analysis did not detect a relationship between population, traffic volume, industrial NO_2 emissions, and 50th percentile NO_2 concentrations at the Woodcroft station; the relatively small data set was deemed insufficient for this type of analysis.

ACKNOWLEDGEMENTS

I would like to thank Dr. Warren Kindzierski for his knowledge, guidance, and support throughout the thesis process. It was a pleasure working with him.

I would also like to thank my colleague, Dr. James Jeng, for his assistance with Microsoft Excel and revisions.

I would like to acknowledge Amec Foster Wheeler for providing me with the opportunity to pursue my Master of Science.

TABLE OF CONTENTS

Abstract .... **ii**
Acknowledgements .... **iii**
Table of Contents .... **iv**
List of Tables .... **vii**
List of Figures .... **viii**
List of Symbols .... **ix**
List of Abbreviations .... **xi**

CHAPTER 1: INTRODUCTION **1**

1.1 Ambient Air Quality **1**
1.2 Monitoring Ambient Air Quality **1**
1.3 Regulating Ambient Air Quality in Alberta **3**
1.4 Objectives **5**
1.5 Study Area **5**

CHAPTER 2: LITERATURE REVIEW **8**

2.1 Nitrogen Dioxide (NO_2) **8**
2.1.1 Characteristics and Sources 8
2.1.2 Human Health Effects 10
2.1.3 Environmental Effects 11
2.1.4 AAAQO’s 12

2.2 Fine Particulate Matter ($PM_{2.5}$) **13**
2.2.1 Characteristics and Sources 13
2.2.2 Human Health Effects 14
2.2.3 Environmental Effects 15
2.2.4 AAAQO’s 16

2.3 Carbon Monoxide (CO) **17**
2.3.1 Characteristics and Sources 17
2.3.2 Human Health Effects 18
2.3.3 Environmental Effects 19
2.3.4 AAAQO’s 20

2.4 Sources of Urban Ambient Air Quality **20**
2.4.1 Source concepts 21
2.4.1.1 Near-field sources versus Far-field sources 21
2.4.1.2 Point Sources versus Nonpoint Sources 21
2.4.1.3 Primary versus Secondary Pollutants 21
2.4.2 Emissions Sources 22

2.4.2.1 Industrial Emissions ... 22
2.4.2.1.1 Bias within the NPRI data set ... 23
2.4.2.2 Mobile Emissions ... 24
2.4.2.3 Human Activity ... 25
2.4.2.4 Natural Sources and Exceptional Events ... 26

2.5 Meteorological factors affecting air quality ... 26
2.5.1 Wind ... 26
2.5.2 Atmospheric Turbulence and Stability ... 27
2.5.3 Temperature ... 28
2.5.4 Precipitation and Humidity ... 28
2.5.5 Topography ... 29

2.6 Pollutant Transport ... 29
2.6.1 Distance-Decay of Traffic Emissions ... 30
2.6.2 Modelling Industrial Emissions ... 30
2.6.3 Long-range Transport ... 31

2.7 Air quality trends ... 32
2.7.1 Analyzing Air Quality Trends ... 32
2.7.1.1 Mann-Kendall Test ... 33
2.7.1.2 Theil-Sen Test ... 34

CHAPTER 3: METHODOLOGIES ... 36

3.1 Population Data ... 36
3.1.1 Population Trend Analysis ... 38

3.2 Traffic Volume Data ... 38
3.2.1 Selection of Traffic Count Sites ... 39
3.2.1.1 Edmonton South ... 40
3.2.1.2 Woodcroft ... 42
3.2.1.3 Gold Bar ... 42
3.2.2 Traffic Volume Trend Analysis ... 43

3.3 Industrial Emissions Data ... 44
3.3.1 Industrial Emissions Trend Analysis ... 45

3.4 Air Quality Monitoring Data ... 46
3.4.1 Air Quality Trend Analysis ... 47
3.4.2 Trend Analysis Methodology ... 48
3.4.2.1 Mann-Kendall Test ... 48
3.4.2.2 Theil-Sen Test ... 50
3.4.3 Multiple Linear Regression Analysis ... 51

3.4.3.1 Required Data 52

CHAPTER 4: RESULTS AND DISCUSSION 54

4.1 Population Trend Analysis 54

4.2 Traffic Volume Trend Analysis 56
4.2.1 Number of Registered Vehicles 58

4.3 Industrial Emissions Trend Analysis 59

4.4 Air Quality Data Set Characteristics 61
4.4.1 NO_2 61
4.4.2 $PM_{2.5}$ 62
4.4.3 CO 62

4.5 Air Quality Trend Analysis 63
4.5.1 NO_2 63
4.5.2 $PM_{2.5}$ 67
4.5.3 CO 71
4.5.4 Multiple Linear Regression Analysis 73

CHAPTER 5: CONCLUSIONS AND RECOMMENDATIONS 77

REFERENCES 80

Appendix A: Census Population Data and ProUCL Mann-Kendall/Theil-Sen Outputs 88
Appendix B: Traffic Count Data and ProUCL Mann-Kendall/Theil-Sen Outputs 94
Appendix C: NPRI Emissions and Emitters Data, and ProUCL Mann-Kendall/Theil-Sen Outputs 97
Appendix D: Air Quality Data Set Characteristics 118
Appendix E: Air Quality Concentration Percentile Data 120
Appendix F: Sample Cumulative Frequency Distributions for Edmonton South, 2008.... 127
Appendix G: Air Quality Trend Analysis Summary for NO_2: ProUCL Mann-Kendall/ Theil-Sen Outputs 129
Appendix H: Air Quality Trend Analysis Summary for $PM_{2.5}$: ProUCL Mann-Kendall/ Theil-Sen Outputs 148
Appendix I: Air Quality Trend Analysis Summary for CO: ProUCL Mann-Kendall/Theil-Sen Outputs 161

LIST OF TABLES

Table 1: Alberta Ambient Air Quality Objectives for NO_2, $PM_{2.5}$, and CO 4
Table 2: Alberta Ambient Air Quality Objectives for NO_2 13
Table 3: Alberta Ambient Air Quality Objectives for $PM_{2.5}$ 16
Table 4: Alberta Ambient Air Quality Objectives for CO 20
Table 5: Traffic count site locations 40
Table 6: Pollutant parameters measured and time period 47
Table 7: Study area population trend analysis: Mann-Kendall and Theil-Sen Slope summary ... 55
Table 8: Registered vehicles trend analysis: Mann-Kendall and Theil-Sen Slope summary 58
Table 9: NPRI emissions trend analysis: Mann-Kendall and Theil-Sen Slope summary 60
Table 10: NO_2 trend analysis: Mann-Kendall and Theil-Sen Slope summary 65
Table 11: $PM_{2.5}$ trend analysis: Mann-Kendall and Theil-Sen Slope summary 69
Table 12: CO trend analysis: Mann-Kendall and Theil-Sen Slope summary 72
Table 13: Woodcroft NO_2 50^{th} percentile Analysis of Variance table 75

LIST OF FIGURES

Figure 1: Residential ambient air monitoring station locations 6
Figure 2: Woodcroft and Planetarium station locations 7
Figure 3: Anthropogenic sources of NOx in Canada, 2010 10
Figure 4: Anthropogenic sources of $PM_{2.5}$ in Canada, 2006 14
Figure 5: Anthropogenic sources of CO in Canada, 2010 17
Figure 6: Map of the Edmonton South station and surrounding neighborhoods 37
Figure 7: Map of the Woodcroft station and surrounding neighborhoods 37
Figure 8: Map of the Gold Bar station and surrounding neighborhoods 38
Figure 9: Edmonton South study area traffic count sites available 41
Figure 10: Edmonton South study area combined traffic count sites 41
Figure 11: Woodcroft study area traffic count sites 42
Figure 12: Gold Bar study area traffic count sites 43
Figure 13: Boundary for analysis of industrial emissions data and facilities located within the boundary, 2003-2013 45
Figure 14: Population in the Edmonton South, Woodcroft, and Gold Bar study areas for census years between 2001 and 2014 54
Figure 15: City of Edmonton population for census years between 2001 and 2014 54
Figure 16: Edmonton South study area traffic volume counts, 2002-2013 56
Figure 17: Woodcroft study area traffic volume counts, 2002-2013 57
Figure 18: Gold Bar study area traffic volume counts, 2002-2013 57
Figure 19: Number of registered vehicles in Edmonton, 2004-2013 58
Figure 20: Annual industrial emissions, 2003-2013 (tonnes/year) 60
Figure 21: Edmonton South NO_2 concentration percentiles, 2006-2013 (ppb) 63
Figure 22: Woodcroft NO_2 concentration percentiles, 2003-2013 (ppb) 64
Figure 23: Gold Bar NO_2 concentration percentiles, 2007-2013 (ppb) 64
Figure 24a: Edmonton South $PM_{2.5}$ concentration percentiles, 2006-2013 ($\mu g/m^3$) 67
Figure 24b: Edmonton South $PM_{2.5}$ concentration percentiles, 2006-2013 excluding 2010 ($\mu g/m^3$) 68
Figure 25a: Woodcroft $PM_{2.5}$ concentration percentiles, 2003-2013 ($\mu g/m^3$) 68
Figure 25b: Woodcoft $PM_{2.5}$ concentration percentiles, 2003-2013 excluding 2010 ($\mu g/m^3$) 69
Figure 26: Edmonton South CO concentration percentiles, 2006-2013 (ppm) 71
Figure 27: Woodcroft station 50th percentile NO_2 concentrations, 2003-2013 (ppb) 73
Figure 28: Woodcroft study area interpolated population, 2003-2013 74
Figure 29: Woodcroft study area interpolated traffic volume, 2003-2013 74
Figure 30: NPRI reported NO_2 emissions, 2003-2013 (tonnes/year) 75

LIST OF SYMBOLS

b_0	intercept or constant
b_i	i^{th} coefficient corresponding to x_i (i=1,2,…,p)
deg or °	degrees
F	ANOVA test statistic
H_0	null hypothesis
H_A	alternative hypothesis
m	pairwise slope estimate
N	number of pairwise slope estimates
n	number of observations
p	number of independent variables/coefficients
ppb	parts per billion
ppbv	parts per billion by volume
ppm	parts per million
ppmv	parts per million by volume
Pr	probability
Q	Theil-Sen estimate of slope
S	Mann-Kendall test statistic
t	sampling times
$\tilde{t}$	median sampling time
t/yr	metric tonnes per year
x_i	i^{th} independent variable from total set of p variables
y	measurement response variable

y^1	dependent variable
$\tilde{y}$	median measurement variable
z_t	time series data set
α	significance level
α_{cp}	tabulated p-value
$\mu g/m^3$	micrograms per cubic meter

LIST OF ABBREVIATIONS

AAAQO	Alberta Ambient Air Quality Objectives
AAWDT	Average Annual Weekday Traffic
CASA	Clean Air Strategic Alliance
CEMS	Continuous Emissions Monitoring Systems
CO	Carbon monoxide
CO_2	Carbon dioxide
COPD	Chronic obstructive pulmonary disease
COHb	Carboxyhemoglobin
CWS	Canada Wide Standard
ESRD	Alberta Environment and Sustainable Resource Development
FDMS	Filter Dynamics Measurement System
HNO_3	Nitric acid
LCL	Lower confidence limit of slope
LRT	Light Rail Transit
MSAT	Mobile-source air toxics
NAPS	National Air Pollution Survey
NO	Nitric oxide
NO_2	Nitrogen dioxide
NO_X	Oxides of nitrogen
NPRI	National Pollutant Release Inventory
O_3	Ozone
PEM	Predictive Emissions Monitoring

PM	Particulate matter
$PM_{2.5}$	Particulate matter with mean aerodynamic diameter ≤2.5 µm
SIA	Strathcona Industrial Association
SO_2	Sulfur dioxide
TEOM	Tapered Element Oscillating Microbalance
UCL	Upper confidence limit of slope
US EPA	United States Environmental Protection Agency
VOC	Volatile organic compounds

CHAPTER 1: INTRODUCTION

1.1 AMBIENT AIR QUALITY

Ambient air quality is defined as the state of the air in the outdoor environment (ESRD, 2008; Vallero, 2014). Good air quality is important to human and environmental health. Poor air quality occurs when pollutant concentrations reach levels that may affect quality of life or have detrimental effects on the environment (ESRD, 2008). Air quality can be influenced by natural and anthropogenic sources. For example, fine ash particles and sulphur dioxide from an erupting volcano (a natural source), and anthropogenic sources such as vehicular emissions or industrial pollutants can all have a significant influence on air quality (Colls, 2002a). Maintaining good air quality, through controlling and monitoring anthropogenic air emissions, is crucial to protecting humans and the environment.

1.2 MONITORING AMBIENT AIR QUALITY

As air quality can influence our day to day health and have long-term impacts on both humans and the environment, it is necessary to monitor pollutants. There are several different monitoring methods utilized in the Edmonton region to monitor ambient air (CASA, 2006). Continuous, intermittent, and passive monitoring are most commonly used.

Continuous monitoring is able to provide real-time, 24/7 ambient air quality data for multiple pollutants and meteorological parameters. Ambient air is continuously drawn through an analyzer, and the output provides a measure of pollutant concentration. Measurements are taken every minute, and averaged to calculate 1-hour averages for reporting. Continuous monitoring is able to capture minute variations in pollutant concentrations, providing a more accurate representation of ambient air quality. While continuous monitoring is highly advantageous in this regard, it comes with high operating costs (CASA, 2006). Requirements to operate a continuous monitoring station include commercial analyzers, support equipment, a sufficient location with electricity and internet services, as well as trained technicians. In Alberta, there are over 150 continuous ambient air monitoring stations, operated by various stakeholders such as Alberta Environment and Sustainable Resource Development, Environment Canada, industry, and Airsheds (ESRD, 2014a). Continuous air monitoring data from three residential stations located in Edmonton, AB is utilized for trend analysis in this study.

Intermittent sampling refers to instantaneous air samples collected for a pre-defined time period. Canisters or filters are commonly used to collect samples. For example, fine particulate matter ($PM_{2.5}$) samples are routinely collected for 24-hours every 6 days, according to the National Air Pollution Survey (NAPS) monitoring schedule. These samples are collected using a gravimetric filtration method, and filters are weighed for analysis. A 24-hour average concentration is obtained, and it is used to compare to standards or objectives, such as the Canada Wide Standard (CWS) for $PM_{2.5}$ (CASA, 2006).

Passive monitoring is routinely used in locations where continuous monitoring is not possible. Passive monitoring requires no electricity to operate, allowing samplers to be set up in remote locations. As well, minimal knowledge and training is required to deploy and collect samples, and minimal equipment is required to operate the system. Passive samplers are made up of a sampling matrix with a reactive surface that interacts with pollutants in the air. These filters are deployed for a period of time (e.g. 30 days), and filters are analyzed by a laboratory to determine average concentrations. Passive monitoring is most appropriately used to examine long-term trends and spatial variability (CASA, 2006).

1.3 REGULATING AMBIENT AIR QUALITY IN ALBERTA

The Alberta Ambient Air Quality Objectives (AAAQO) are a set of guidelines and objectives for 50 different pollutants, used to report on the state of Alberta's atmospheric environment (ESRD, 2013). These objectives are in place to provide protection for human health and the environment, in addition to helping reduce emissions from human activity. The AAAQO's were developed based on several factors: scientific factors (e.g. how a substance behaves in the atmosphere and environment); social factors (e.g. who are the sensitive receptors); technical factors (e.g. what technology is available to monitor a substance or reduce emissions); and economic factors (e.g. what costs are associated with monitoring or reducing emissions) (ESRD, 2013).

The AAAQO's have multiple purposes. In industry, they are used to assess compliance, evaluate a facility's performance, assess facility design, as well as establish stack heights and release protocols. They may also be used to evaluate proposals for new facilities (ESRD, 2013). Other stakeholders, such as Airsheds, may utilize the AAAQO's as a guide for planning and management, to examine local air quality concerns, or as a general indicator of air quality in a region (ESRD, 2013).

AAAQO's may be available for a number of different averaging times. Frequently used is a 1-hour, 24-hour, or annual average. AAAQO averaging times may vary between pollutants, as they are derived based on different factors deemed to be most significant. For example, a 1-hour average AAAQO value may be used for a certain pollutant because it is an important trigger level for human health, while a 24-hour average based on environmental effects may be used for another pollutant (ESRD, 2013). For the pollutants examined in this study, the AAAQO's are presented in Table 1, and discussed in greater detail in Chapter 2.

Table 1: Alberta Ambient Air Quality Objectives for NO_2, $PM_{2.5}$, and CO (adapted from ESRD, 2013)

Alberta Ambient Air Quality Objectives				
Pollutant	**1-hour**	**8-hour**	**24-hour**	**Annual**
NO_2	159 ppbv (300 µg/m^3)	-	-	24 ppbv (45 µg/m^3)
$PM_{2.5}$	*80 µg/m^3	-	30 µg/m^3	-
CO	13,000 ppbv (13 ppmv) (15,000 µg/m^3)	5,000 ppbv (5 ppmv) (6,000 µg/m^3)	-	-

*For $PM_{2.5}$, the one-hour value is a Guideline used for planning and management purposes only.
**Standard conditions of 25°C and 101.325 kPa are used as the basis for conversion from µg/m^3 to ppbv (ESRD, 2013).

While monitoring, reporting and regulating air quality is necessary, analyzing and interpreting the data obtained is even more important. To understand air quality within our region, data must be examined for trends. Detecting long-term trends in air quality concentrations is crucial to understanding changes in ambient air quality over a period of time. Human development and activities may cause changes in ambient air quality; it is necessary to monitor and investigate trends to determine the impact these activities may have on human health. This study focuses on an analysis of ambient air quality trends in Edmonton, AB to determine how air quality has changed in the region between 2003 and 2013. Three common air quality pollutants were examined for trends: nitrogen dioxide (NO_2), fine particulate matter ($PM_{2.5}$), and carbon monoxide (CO). An exploratory analysis was also completed using a multiple linear regression model, to determine if changes in population, traffic volume, and industrial NO_2 emissions were related to changes in ambient NO_2 concentrations.

1.4 OBJECTIVES

The objectives of this study are as follows:

- To investigate long-term trends in ambient air quality at residential air monitoring stations in Edmonton, AB between 2003 and 2013.
- To establish whether changes in population, traffic volume, industrial emissions, and ambient air quality have occurred over the past decade, and if changes have occurred, to what extent.
- To explore whether any detected air quality trends in Edmonton are related to changes in population, traffic volume, and industrial emissions.

1.5 STUDY AREA

Historical air quality data from three residential air quality monitoring stations in Edmonton, AB was examined for air quality trends in the urban environment. Together these stations provide adequate information on the ambient air quality in the City of Edmonton, and are the best available residential stations for the air quality parameters examined. Residential stations were chosen to provide an accurate depiction of the air quality where people live and spend much of their time. Figure 1 shows the locations of the air monitoring stations utilized in this study.

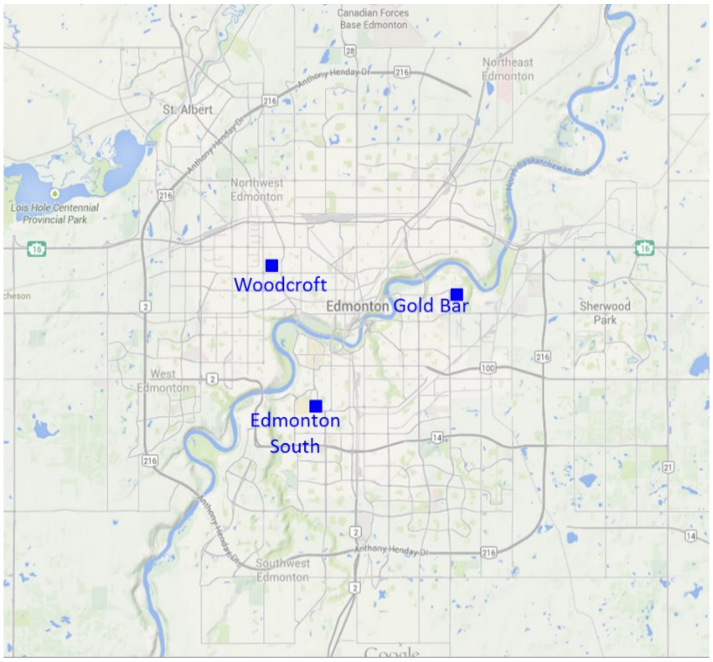

Figure 1: Residential ambient air monitoring station locations
*Map obtained from Google Maps

The Edmonton South station is located at 6240-113 Street (Latitude 53°30’0.47”N, Longitude 113°31’33.83”W), and is operated by Alberta Environment and Sustainable Resource Development. It is located in the University of Alberta Farm neighborhood, near the Alberta School for the Deaf. NO_2, $PM_{2.5}$ and CO concentrations have been measured at this station since September 2005.

The Woodcroft station is located at 13915-115 Avenue within the Woodcroft Community League building, in the Woodcroft Neighborhood (Latitude 53°33’53.59”N, Longitude 113°33’45.56”W). This station is operated by Lehigh Cement. The station has been operating at this location since November 4, 2010. Previously, the station was located within the Queen Elizabeth II Planetarium, in Coronation Park. The previous station was located 310 m to the SSE (150°) from the current location, at an elevation of 672 m. The Woodcroft station elevation is 673 m; it is assumed that the impacts on air quality is similar at both station sites due to the relatively short distance between the stations and only a minor change in elevation. Figure 2 shows the locations of the two stations. NO_2 and $PM_{2.5}$ concentrations are measured at this station.

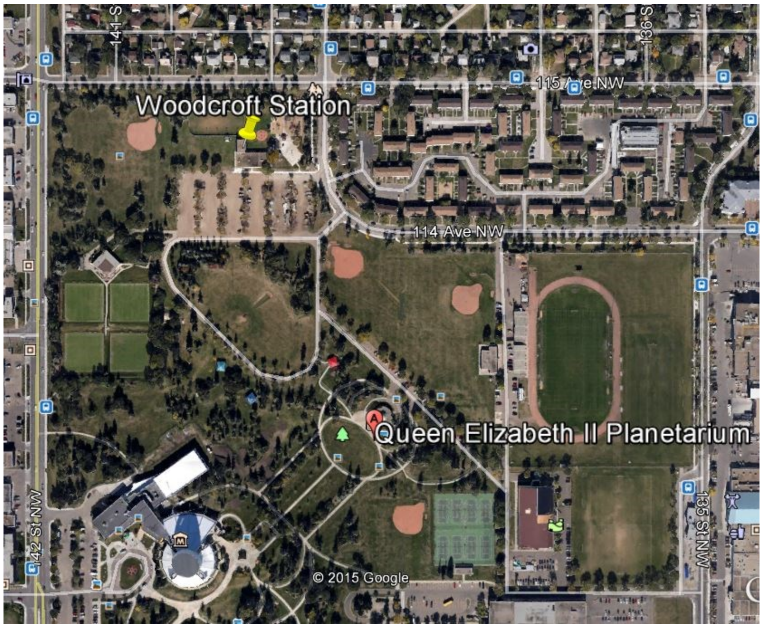

Figure 2: Woodcroft and Planetarium station locations
*Map obtained from Google Earth

The Gold Bar station is located at 10524-46 Street, next to Gold Bar Elementary School in the Gold Bar neighborhood (Latitude 53°32'57.16"N, Longitude 113°24'53.11"W). This station is operated by the Strathcona Industrial Association. NO_2 concentrations have been measured at this station since May 2006.

A study area of approximately a 1 km radius surrounding each station was arbitrarily set. This area was used to provide a sufficient measure of the population and traffic that may be interacting in the neighborhood.

CHAPTER 2: LITERATURE REVIEW

Three ambient air pollutants are examined and discussed in this study: nitrogen dioxide (NO_2), fine particulate matter ($PM_{2.5}$), and carbon monoxide (CO). NO_2 is typically formed in combustion processes and is a good urban pollutant indicator (Alberta Environment, 2007a). NO_2 concentrations are highly associated with human activities, vehicle emissions, and industrial processes (Environment Canada, 2013a). $PM_{2.5}$ can be emitted directly from a source, or formed as a secondary pollutant through atmospheric reactions (World Health Organization, 2013). There are many human health concerns linked to high concentrations of ambient $PM_{2.5}$ (Wallace & Smith, 2007). CO is one of the most common atmospheric pollutants, and is also formed during combustion processes (ATSDR, 2012; Flaschsbart, 2007; World Health Organization, 2000). Vehicle emissions are the primary source of CO in the urban environment, and therefore CO is an excellent indicator of traffic-related pollution (Environment Canada, 2013d). These three pollutants are discussed in greater detail in the following sections.

2.1 NITROGEN DIOXIDE (NO_2)

2.1.1 *Characteristics and Sources*

Oxides of Nitrogen (Nitrogen oxides, NOx) is a term that refers to the sum of nitrogen dioxide (NO_2) and nitric oxide (NO). NO is formed during combustion processes when nitrogen in the atmosphere combines with molecular oxygen. NO typically oxidizes to form NO_2. NO_2 in the gaseous state is a non-flammable, reddish-brown gas, with a strong, pungent odour (Alberta Environment, 2007a). NO_2 takes on a liquid state below 21.15°C, and is corrosive, non-flammable, and highly oxidizing (Alberta Environment, 2007a).

Spatial and temporal variations in NO_2 concentrations around sources are key to understanding exposure to this pollutant, and are related to the short life-span NO_2 has in the atmosphere (Boersma et al., 2009). NO_2 concentrations are typically highest in the fall and winter, due to the relatively low mixing layer heights during the colder months (Alberta Environment, 2002; US EPA, 2008). In larger cities such as Edmonton, daily concentration peaks associated with high volumes of traffic are observed, such as during morning and evening rush hour (Alberta Environment, 2002). Spatial variations also exist for NO_2 concentrations, with higher concentrations recorded in urban environments, particularly near industry, power generation plants, and major highways (Alberta Environment, 2007a; Boersma et al., 2009). The annual mean ambient NO_2 concentration across Canada has been declining over the past decade, and in 2012 was measured at 9.4 ppb (Environment Canada, 2014a).

Emissions of NO_2 can be a direct result of certain industrial processes. However, NO_2 is typically formed from the conversion of NO during combustion processes, through the combustion of fossil fuels such as natural gas, oil, coal, and gasoline (ATSDR, 2002; Alberta Environment, 2011). Major anthropogenic sources include transportation (accounting for over 50% of anthropogenic emissions in Canada), oil and gas industries, and power plants (Environment Canada, 2013a). NO_2 is also found naturally in the atmosphere, forming from lightning strikes, forest fires, or emitted from soil (Alberta Environment, 2011). Figure 3 shows the contribution of anthropogenic sources to NO_2 emissions in Canada in 2010 (presented as NOx) (Environment Canada, 2013a).

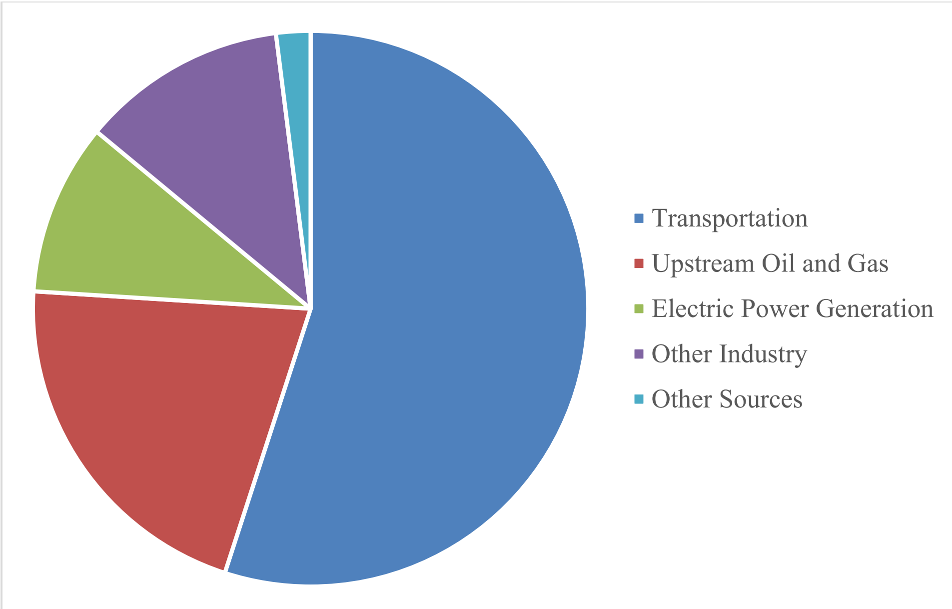

Figure 3: Anthropogenic sources of NOx in Canada, 2010 (adapted from Environment Canada, 2013a)

2.1.2 *Human Health Effects*

Nitrogen dioxide is a respiratory irritant, affecting the lower respiratory tract when inhaled (ATSDR, 2002). Low concentration exposures can cause irritation in the eyes, nose, and throat, as well as shortness of breath and coughing (ATSDR, 2002). Acute, short-term exposures (<2 ppm) can cause respiratory responses in healthy individuals (Alberta Environment, 2011). For individuals with existing respiratory conditions such as asthma, chronic bronchitis, or chronic obstructive pulmonary disease (COPD), respiratory responses can occur at much lower concentrations (<0.3 ppm) (Alberta Environment, 2007a). Respiratory responses can include lung and airway inflammation and sensitivity, coughing and wheezing, decreased lung function, and immune responses (Alberta Environment, 2007a; Alberta Environment 2011; Peel et al., 2012). Studies have also detected positive associations between high ambient NO_2 concentrations and emergency department visits or hospitalizations among sensitive individuals, such as those with pre-existing conditions like COPD and asthma (To et al., 2013; US EPA, 2008). The evidence supports a causal relationship between acute, short-term NO_2 exposure and respiratory effects (US EPA, 2008).

The health impacts of chronic, long-term NO_2 exposures has also been examined. The evidence suggests that long-term exposure can have an impact on lung growth and life-long lung function (Gauderman et al., 2004); however, it is difficult to assess the long-term impact of a single pollutant in an ambient environment. As NO_2 is a combustion-related pollutant, it is highly associated with other combustion pollutants such as $PM_{2.5}$, and epidemiological studies are unable to distinguish the individual long-term effects of a specific pollutant (Gauderman et al., 2004; US EPA, 2008). Further evidence is needed before conclusions can be made about the relationship between chronic NO_2 exposure and long-term health effects.

2.1.3 *Environmental Effects*

In the environment, NO_2 exposure can influence vegetation growth and development. Impairment is observed only in high concentration exposures; no impacts are observed in vegetation exposed to typical ambient concentrations (Alberta Environment, 2007a). NO_2 uptake occurs through stomatal openings in the leaf surface, and common effects include the development of lesions, changes in growth rates, decreased crop yields, and changes in photosynthesis (Alberta Environment, 2007a). The observed effects are dependent on exposure concentration and duration, sensitivity of the vegetation species, and the growth stage during which exposure occurs (Alberta Environment, 2011).

Nitrogen dioxide has a substantial role in the formation of smog, which is defined as poor air quality and reduced visibility. Atmospheric reactions between NO_2, volatile organic compounds (VOCs), and ultraviolet radiation form the gaseous pollutant ground-level ozone (O_3), which makes up one of two primary smog pollutants (along with $PM_{2.5}$) (Environment Canada, 2013c).

Nitrogen oxides are also a significant contributor to acid deposition. NO_2 is rapidly oxidized in the atmosphere, forming secondary pollutants such as nitric acid (HNO_3) (Alberta Environment, 2007a). Secondary nitrogen oxides react with sulphur dioxide, oxygen, particulate matter, and water in the atmosphere, forming acidic compounds (US EPA, 2014). These acidic compounds may deposit on surfaces through wet or dry deposition. Wet deposition includes rain, snow, or fog. Particles may also fall to the earth's surface on dust and smokes particles through the process of dry deposition (US EPA, 2014). Acid deposition can have detrimental effects on vegetation and surface water systems, damaging trees and plants, and causing acidification of soils and waterways (US EPA, 2014). Acid deposition can also affect materials and surfaces, such as building exteriors, bridge surfaces, metals, and painted surfaces, causing both structural and aesthetic damage (US EPA, 2014).

2.1.4 *AAAQO's*

There are two AAAQO's used for NO_2 in Alberta, presented below in Table 2. The 1-hour average AAAQO is 159 ppbv (300 $\mu g/m^3$) and it is derived based on human respiratory health effects (ESRD, 2013). As discussed, respiratory symptoms can develop in sensitive individuals at concentrations below 0.3 ppm (300 ppb) (Alberta Environment, 2007a). An AAAQO of 159 ppb was set to provide adequate protection for humans. An annual average is also utilized, with a reporting concentration of 24 ppbv (45 $\mu g/m^3$). The annual average is derived based on the effects of NO_2 on vegetation (ESRD, 2013).

Table 2: Alberta Ambient Air Quality Objectives for NO_2

Alberta Ambient Air Quality Objectives				
Pollutant	**1-hour**	**8-hour**	**24-hour**	**Annual**
NO_2	159 ppbv (300 µg/m^3)	-	-	24 ppbv (45 µg/m^3)

**Standard conditions of 25°C and 101.325 kPa are used as the basis for conversion from µg/m^3 to ppbv (ESRD, 2013).

2.2 FINE PARTICULATE MATTER ($PM_{2.5}$)

2.2.1 *Characteristics and Sources*

Particulate matter (PM) is a mixture of airborne solid and liquid particles (Environment Canada, 2013b). PM is categorized by size: fine or respirable particulate matter with a mean particle diameter of less than 2.5 µm is classified as $PM_{2.5}$; particles less than 10 µm in diameter are classified as PM_{10} (Environment Canada, 2013b). Sources of PM can include both natural and anthropogenic sources, such as road dust, forest fires, wood burning stoves, volcanoes, cigarette smoke, vehicle emissions from combustion engines, industrial processes, power plants, and agricultural processes (US EPA, 2013; ESRD, 2013c). The most significant sources of human exposure to particle pollution are vehicular sources, smoking, cooking, and residential heating (Wallace & Smith, 2007). Figure 4 shows the primary ambient anthropogenic sources of $PM_{2.5}$ in Canada in 2006 (Environment Canada, 2013c). The source will also determine the composition of the particles. Substances commonly found in $PM_{2.5}$ include smoke and dust particles, biological agents, such as mould or spores, toxic organic compounds (e.g. polycyclic aromatic hydrocarbons), and heavy metals (e.g. nickel) (Kelly & Fussell, 2012).

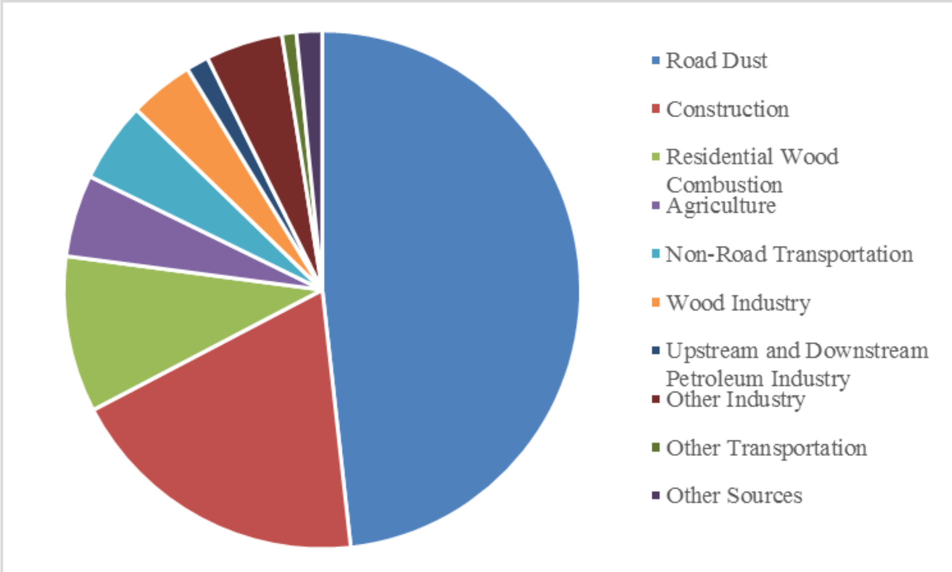

Figure 4: Anthropogenic sources of $PM_{2.5}$ in Canada, 2006 (adapted from Environment Canada, 2013c)

Particles emitted directly from a source are classified as primary PM. The largest source of primary $PM_{2.5}$ in Canada is road dust (transportation) and construction activities (Environment Canada, 2013c). Secondary PM forms in the atmosphere through chemical and physical reactions with atmospheric gases. Secondary particles formed through chemical reactions comprise the majority of $PM_{2.5}$ (World Health Organization, 2013). Both primary and secondary $PM_{2.5}$ can remain in the atmosphere for long periods of time, and be transported over long-ranges (World Health Organization, 2013). The Canadian national ambient average concentration of $PM_{2.5}$ in 2012 was 6.3 $\mu g/m^3$ (Environment Canada, 2014b).

2.2.2 *Human Health Effects*

Particulate pollution is a major health concern in urban environments around the world, particularly in developing countries (Wallace & Smith, 2007). Urban vehicular $PM_{2.5}$ pollution, as well as the contribution of indoor pollution from poor ventilation while cooking and heating, are linked to health concerns and premature deaths (Wallace & Smith, 2007). Exposure occurs when

$PM_{2.5}$ enters the body through inhalation, either through the mouth or nasal passage. Small, fine particles can easily penetrate deep into the lungs and alveolar gas exchange region. Because of this, $PM_{2.5}$ is referred to as respirable particulate matter (Kelly & Fussell, 2012).

Exposure to $PM_{2.5}$ is associated with morbidity and mortality in the human population (Kelly & Fussell, 2012). Children, the elderly, and those with existing heart or lung conditions are particularly at risk for adverse effects when exposed to $PM_{2.5}$ (World Health Organization, 2013). $PM_{2.5}$ is known to cause and aggravate respiratory and cardiovascular conditions through inflammatory responses to particles in the body. Exposure can impair lung function and normal breathing, irritate the airways, aggravate asthma and respiratory infections, and impair normal lung development in children. $PM_{2.5}$ exposure is also associated with cardiovascular effects such as heart disease and stroke, and linked to premature death (Kelly & Fussell, 2012; World Health Organization, 2013; US EPA, 2013). It is estimated that approximately 800,000 premature deaths globally can be attributed to ambient particle pollution each year (Wallace & Smith, 2007).

2.2.3 *Environmental Effects*

Fine particulate matter can damage vegetation and crops, change the acidity or nutrient balance in water bodies, affect soil chemistry, and influence ecosystem diversity (Grantz, Garner, & Johnson, 2003; US EPA, 2013). Particles can also cause aesthetic damage by depositing on materials such as stone and metal, and corroding the surface (US EPA, 2013).

Fine particulate matter can have detrimental effects on vegetation and soil. Particles of varying size and composition can deposit on a plant's surface and cause a variety of physical and chemical effects, dependent on the particle properties. Particles can physically reduce a plant's ability to photosynthesize by blocking sunlight. Particles may also enter through the stomata and cause damage to the plant structure. Chemical effects are strongly dependent on the particle composition, and can include changes in pH (e.g. acidification), or nitrogen saturation. Acidification and metal deposition in the soil can also have negative effects on plant growth, and may impact the entire ecosystem if exposure to particle pollution is high (Grantz et al., 2003; US EPA, 2009).

Haze and reduced visibility is primarily caused by $PM_{2.5}$, when sunlight interacts with $PM_{2.5}$ in the atmosphere. Particles will absorb some of the light while the rest is scattered, reducing visibility. Haze is exacerbated during humid conditions, as some particles show enhanced scattering abilities in high humidity (US EPA, 2012). $PM_{2.5}$ and ground-level O_3 comprise the primary components of smog (Environment Canada, 2013c).

2.2.4 *AAAQO's*

Alberta has adopted the Canada Wide Standard (CWS) for $PM_{2.5}$ as the AAAQO (refer to Table 3). This objective is 30 μg/m^3 as a 24-hour average concentration. The CWS for $PM_{2.5}$ is derived to provide the best health and environmental outcomes achievable by minimizing risk and providing feasible emissions reductions (Alberta Environment, 2007b). Alberta also has a 1-hour average guideline in place for $PM_{2.5}$. The 1-hour average of 80 μg/m^3 is utilized for planning and assessment purposes (ESRD, 2013).

Table 3: Alberta Ambient Air Quality Objectives for $PM_{2.5}$

Alberta Ambient Air Quality Objectives				
Pollutant	**1-hour**	**8-hour**	**24-hour**	**Annual**
$PM_{2.5}$	*80 μg/m^3	-	30 μg/m^3	-

*The one-hour value reported is a Guideline used for planning and management purposes.

2.3 CARBON MONOXIDE (CO)

2.3.1 *Characteristics and Sources*

Carbon monoxide (CO) is a colourless, odourless, tasteless gas emitted to the atmosphere during incomplete combustion of fuel or materials containing carbon atoms (ATSDR, 2012; Flaschsbart, 2007). Vehicle and mobile emissions are the primary source of CO in the urban ambient environment, accounting for over 3/4 of anthropogenic emissions (Environment Canada, 2013d). Emissions controls on new vehicles have been extremely successful in reducing CO emissions and ambient concentrations in developed countries, however CO continues to be a significant pollutant in developing countries where emission controls are less stringent (Flaschsbart, 2007). Other anthropogenic sources include wood burning fireplaces, industrial manufacturing processes, natural gas combustion, and cigarette smoke (ATSDR, 2012). Figure 5 shows the primary anthropogenic sources of CO emissions in Canada in 2010. Natural sources of CO include volcanic eruptions and forest fires (ATSDR, 2012).

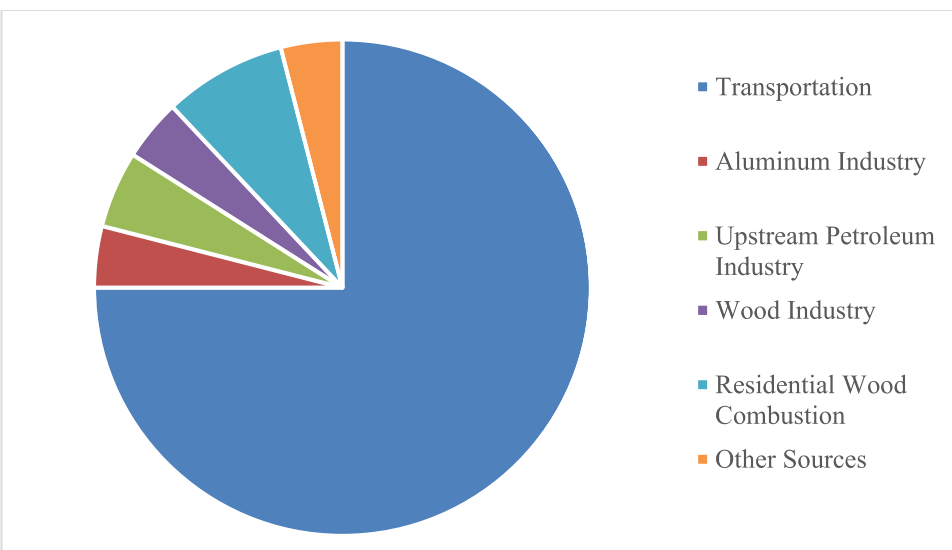

Figure 5: Anthropogenic sources of CO in Canada, 2010 (adapted from Environment Canada, 2013d)

Carbon monoxide is one of the most common pollutants in the environment, residing in the atmosphere for an average of 2 months (ATSDR, 2012; World Health Organization, 2000). Ambient concentrations are on average 0.12 ppm in the northern hemisphere, ranging from 0.05 to 0.2 ppm (Alberta Environment, 2002; ATSDR, 2012). CO concentrations are typically highest in the winter months during temperature inversions, and lowest in the summer months (ATSDR, 2012). Diurnal patterns are observed in urban environments, with peak concentrations observed during periods of high traffic volumes, such as morning and evening rush hour (ATSDR, 2012; Flaschsbart, 2007). Spatial variations in concentration are also common in urban environments, with highest exposures occurring along major traffic routes and at intersections with high traffic volumes (Flaschsbart, 2007).

2.3.2 *Human Health Effects*

Exposure to CO can have a detrimental effect on human health, and cause death at high exposures. High exposures to CO are less likely to occur in the ambient outdoor environment; over 85% of CO exposures resulting in the need for medical treatment occur in residential or occupational settings (ATSDR, 2012). As a result, certain population groups are at a higher risk for exposure to high concentrations. Individuals who work in industries with high exposure to vehicle exhaust, such as mechanics, taxi drivers, and traffic police, will have higher exposure to CO. Firefighters are also at risk. Individuals who smoke tobacco and those who are frequently exposed to second-hand smoke will also experience high exposures to CO (ATSDR, 2012).

Carbon monoxide enters the body through inhalation, entering the lungs and passing into the bloodstream (Flaschsbart, 2007). In the bloodstream, CO will compete with oxygen to bind with hemoglobin (Flaschsbart, 2007). The affinity for CO to bind with hemoglobin is approximately

200 times stronger than oxygen. Binding with hemoglobin forms carboxyhemoglobin (COHb), which decreases the oxygen carrying capacity of blood and reduces oxygen distribution to organs and tissue, causing hypoxia (ATSDR, 2012; Flaschsbart, 2007). It is a slow, difficult process to eliminate COHb from the blood, meaning even continuous exposure to low CO concentrations will begin to cause hypoxia (Flaschsbart, 2007). The heart and brain are particularly vulnerable organs to CO induced hypoxia (ATSDR, 2012; Flaschsbart, 2007). Individuals with underlying health conditions, such as heart or lung disease, as well as pregnant women, children, the elderly, and smokers, are at a greater risk for harmful effects when exposed to CO (Flaschsbart, 2007). Pregnant women and the developing fetus are highly susceptible to suffer harmful health effects from exposure, as CO is able to easily diffuse across the placental membranes (World Health Organization, 2000).

Acute CO poisoning will result in tissue hypoxia (ATSDR, 2012). Physical symptoms of CO toxicity include headache, nausea, dizziness, and vomiting, followed by chest pain, arrhythmias, confusion, loss of consciousness, seizures, and comas. High exposure levels of greater than 300 ppm for more than 500 minutes, or greater than 1000 ppm for 90 minutes, can result in death (ATSDR, 2012). High concentration exposures are rare in the ambient environment. Epidemiological research has examined exposure to typical ambient CO conditions (<2 ppm to <10 ppm), and the results of long-term studies have shown relatively no risk associated with long-term exposure to ambient CO levels (ATSDR, 2012).

2.3.3 *Environmental Effects*

There is little evidence that ambient concentrations of CO have direct detrimental effects on the environment. However, in the atmosphere, CO can influence the abundance of other greenhouse gases through hydroxyl radical chemistry (Flemming & Inness, 2014). CO also acts as a precursor to the formation of tropospheric O_3, along with NO_2 and non-methane VOCs (Flemming & Inness, 2014; Hartmann et al., 2013). In addition, CO is eventually converted into CO_2 through interactions with other atmospheric compounds or through conversion by microorganisms, consequently contributing to the formation of greenhouse gases in the atmosphere (ATSDR, 2012). Thus, CO may indirectly impact climate change (Flemming & Inness, 2014; Hartmann et al., 2013).

2.3.4 *AAAQO's*

The AAAQO's for carbon monoxide (refer to Table 4) are based on the prevention of human health effects. They were derived based on the oxygen carrying capacity of blood, and the affinity of CO to bind with hemoglobin over oxygen (ESRD, 2013; World Health Organization, 2000). The 1-hour average AAAQO utilized is 13 ppmv (15,000 μg/m^3; 13,000 ppbv). An 8-hour time-weighted average of 5 ppmv (6,000 μg/m^3; 5,000 ppbv) is also used (ESRD, 2013).

Table 4: Alberta Ambient Air Quality Objectives for CO

Alberta Ambient Air Quality Objectives				
Pollutant	**1-hour**	**8-hour**	**24-hour**	**Annual**
CO	13,000 ppbv (13 ppmv) (15,000 μg/m^3)	5,000 ppbv (5 ppmv) (6,000 μg/m^3)	-	-

**Standard conditions of 25°C and 101.325 kPa are used as the basis for conversion from μg/m^3 to ppbv (ESRD, 2013).

2.4 SOURCES OF URBAN AMBIENT AIR QUALITY

There are multiple factors that can influence urban ambient air quality and our exposure to air pollution. Important source concepts, as well as major sources impacting air quality are discussed in this section.

2.4.1 *Source concepts*

2.4.1.1 Near-field sources versus Far-field sources

Near-field sources are defined as sources that are within close proximity to the receptor (i.e. humans). This means sources within several meters of where humans spend time and carry out daily activities. Examples of near-field sources include motor vehicle exhaust inside our vehicles, cooking, and the use of personal or cleaning products (Kindzierski, 2013).

Far-field sources are sources which are further away from the receptor and their personal microenvironment. Typically these sources are greater than 30-100 m away. Industrial facility emissions are an example of a far-field source. While these sources are further away from the receptor, they may still contribute to human exposure, dependent on how the pollutant is dispersed in the environment (Kindzierski, 2013).

2.4.1.2 Point Sources versus Nonpoint Sources

Point sources are stationary sources that are easily identified, such as a stack at an industrial facility (ESRD, 2014b). Nonpoint sources of air pollution include both mobile and stationary sources that do not have a single point of origin. It can be difficult to monitor and control these relatively small emitters, but collectively nonpoint sources have a large influence on air quality. Examples include vehicle emissions, agricultural activities, construction, and residential heating (ESRD, 2014b).

2.4.1.3 Primary versus Secondary Pollutants

Sources of air quality can contribute to pollution through two different pathways. A source can directly emit a pollutant, which is classified as a "primary pollutant" (Vallero, 2014). For example, vehicles can directly emit CO during fuel combustion (Flaschsbart, 2007). The second pathway by which a pollutant can enter the environment is through the formation of "secondary pollutants". This occurs through chemical reactions of primary pollutants in the atmosphere (Vallero, 2014). $PM_{2.5}$ and O_3 are common pollutants that form through secondary reactions in the atmosphere (World Health Organization, 2013).

2.4.2 *Emissions Sources*

2.4.2.1 Industrial Emissions

Industrial emissions are classified as a far-field point source, as they can be traced back to a single point of origin. Examples of industrial sources of emissions can include: oil and gas processing, plastics and chemical production, manufacturing, pulp and paper, mining, logging, construction, and electricity production. The pollutant emitted will vary depending on the process, product, facility operations, and emissions controls in place (Environment Canada, 2014c).

Direct emissions from a facility are highly regulated and monitored in Alberta. Facilities must have pollution prevention controls in place, and are required to monitor and report their emissions (e.g. monitor stack emissions, fence-line monitoring) (Alberta Environment, 2009). Facilities must report industrial emissions as stipulated by regulatory approvals to operate, as well as report any exceedances above monitoring criteria (ESRD, 2013). Federal-level reporting to the National Pollutant Release Inventory (NPRI) is also required for many facilities (Environment Canada, 2014c). The NPRI collects information on over 300 pollutants, including Criteria Air Contaminants that contribute to acid rain, smog, and poor air quality, as well as certain heavy metals and persistent organic pollutants (Environment Canada, 2014c).

2.4.2.1.1 Bias within the NPRI data set

The NPRI database is an important tool used to identify and monitor pollutant sources, however it fails to capture all emissions or sources and is subject to significant bias. There are multiple factors that create bias within the database:

1) *Variations in reporting:* The NPRI only collects data from facilities that meet certain reporting requirements, based on the number of employees at the facility, quantity of the substance manufactured, processed, used or released, as well as the types of activities performed at the facility. There are certain facilities that may not be required to report, such as small facilities or facilities in certain sectors (e.g. auto repair shops). In addition, reporting requirements have changed over time: new substances have been added, reporting thresholds have been reduced, and exemptions to certain industrial sectors have been removed (Environment Canada, 2014d).
2) *Variations within and between facilities:* The amount of pollutants reported annually can vary significantly for a single facility or across facilities. Changes to reporting requirements, changes in production or processes, changes in how emissions are estimated, or facility expansion/decline could cause an increase or decrease in reported emissions (Environment Canada, 2014d).
3) *Variations in methods of estimation:* The methods used to determine the quantity of emissions will differ between facilities, or within a facility from year to year. These methods are dependent on the substance being reported, facility processes, and available technology. There are multiple methods used to determine emissions: continuous emission monitoring systems (CEMS), predictive emission monitoring (PEM), source testing, mass balance, site-specific and published emission factors, and engineering estimates. For

example, CEMS continuously records emissions from a stack, and annual emissions are calculated by multiplying the measured concentration by the annual flow rate of the gases in the stack. As a contrasting example, emission factors relate the quantity of emissions from a source to a common activity associated with the emissions; specific emission factors for certain equipment may be known, and emissions are estimated this way. Typically, larger facilities are more likely to report based on monitored data, while smaller facilities rely on emissions factors to derive reported emissions. The differences in how emissions are estimated could lead to substantial bias between facilities reporting to the NPRI (Environment Canada, 2014d).

2.4.2.2 Mobile Emissions

Traffic is considered to be a near-field, nonpoint source of air pollution, and it has a significant impact on urban air quality. Traffic can be divided into on-road and non-road mobile sources (Health Effects Institute, 2010). On-road traffic includes passenger or freight vehicles (e.g. cars, buses, transport trucks), while non-road sources include aircraft, rail, construction, recreational, or agricultural vehicles (Health Effects Institute, 2010). Both on-road and non-road sources contribute air pollutants including PM, CO, CO_2, SO_2, NOx, VOC, hydrocarbons, as well as other substances known as “mobile-source air toxics” (MSAT) (Gilbert et al., 2003; Health Effects Institute, 2010; Small & Kazimi, 1995). MSAT include substances such as lead, benzene, and formaldehyde (Health Effects Institute, 2010). These pollutants can affect human and environmental health.

Pollutants are released through vehicle emissions in the process of burning fossil fuels such as gasoline and diesel. Emissions occur in the combustion process as a result of the interactions between air, hydrocarbons, and additives and impurities in the fuel. Emissions are related to the type, age, and condition of the vehicle, fuel type used, and emissions controls utilized in the vehicle (Health Effects Institute, 2010). The Canadian government has strict regulations in place for vehicle emissions controls, as do many other developed countries (Environment Canada, 2014e; Health Effects Institute, 2010). Vehicle inspections, the use of clean fuels, and improving engine designs and emissions controls are used to reduce vehicle emissions (Environment Canada, 2014e). Increasing urban populations and expanding metropolitan areas result in an increase in the number of vehicles on the roads, potentially leading to an increase in traffic emissions despite the implementation of vehicle emissions controls.

2.4.2.3 Human Activity

Human activity is classified as a near-field, nonpoint source. These sources are typically found in our personal environments, and it can be challenging to quantify the impact of a single source. At an individual level, many activities can contribute to air pollution throughout our daily lives. Heating our homes, driving, smoking tobacco, and cooking are examples of activities that act as sources that can impact air quality and personal exposure to pollutants (Colls, 2002a; Wallace & Smith, 2007).

At a global level, population rates are rapidly increasing, resulting in increasing rates of energy consumption. While sustainable energy is utilized throughout the world, a heavy reliance is still placed on energy derived from the burning of fossil fuels, such as coal, oil, or natural gas (Colls, 2002a). In less developed countries individuals must often rely on poor fuel sources, such as wood burning stoves, for heating and cooking. Poor fuel sources will have a greater impact on both indoor and outdoor air quality than clean fuel sources (Colls, 2002a).

It is crucial to understand the impact human activities and population growth can have on air pollution. This study will use population counts as a surrogate of human activity in Edmonton.

2.4.2.4 Natural Sources and Exceptional Events

Acts of nature or "exceptional events" are air quality events that are considered to be caused by nature or due to an event out of the ordinary (CASA, n.d.). For example, wildfires are an exceptional event that can impact the air quality across a large region. The Edmonton region is often affected by wildfire smoke from fires burning during the summer months across British Columbia, Alberta, Northern regions of Canada, and even the U.S. The effects of natural events can often be observed hundreds or thousands of kilometers from the source (Schäfer et al., 2011). While these events do not typically impact our air on a daily basis, they can be important contributors to short-term air quality. Pollutants such as PM, NO_2, CO. and SO_2 can be released to the atmosphere in high concentrations following large scale regional events, increasing respiratory health risks, particularly for sensitive individuals (Moore et al., 2006; Schäfer et al., 2011).

2.5 METEOROLOGICAL FACTORS AFFECTING AIR QUALITY

Meteorological conditions will impact the transport and dispersion of pollutants in the atmosphere. Sudden increases in pollutant concentrations are generally not caused by an extreme release of pollutants, but rather unfavourable meteorological conditions preventing the dispersion of pollutants (Ocak & Turalioğlu, 2011). Wind, atmospheric stability, temperature, precipitation and humidity, and topography are the key factors influencing air quality in a region.

2.5.1 *Wind*

Wind speed and direction are crucial factors to the dispersion and transport of pollutants. Wind is the natural movement of air in the environment. Wind occurs due to differences in a pressure gradient that cause air to flow from areas of high pressure to areas of lower pressure

(Vallero, 2014). Wind direction is defined as the direction from which the wind is flowing; the direction will determine whether a pollutant will influence a receptor as it is released from the source (Colls, 2002b). Wind speed and distance from a source will determine how long it takes for pollutants to travel from the source to the receptor (CASA, 2006). Wind speed affects the rate of dispersion of air pollutants: high wind speeds will create greater turbulence, causing pollutants near ground-level to disperse quickly, while low wind speeds will disperse pollutants at a slower rate (CASA, 2006).

2.5.2 *Atmospheric Turbulence and Stability*

Atmospheric turbulence is defined as the random motion of a parcel of air in the atmosphere. Movement of an air parcel is affected by the mechanical processes of wind and topography, as well as thermal forces such as solar heating (CASA, 2006). Vertical and horizontal air movements will affect pollutant transport and dispersion, as well as meteorology.

Atmospheric stability occurs when little vertical motion or mixing is happening, causing pollutants to remain near the earth's surface. Conversely, in an unstable atmosphere, high rates of vertical motion will occur, causing pollutants to disperse (Vallero, 2014). Vertical motion is dependent on the temperature profile and humidity of the atmosphere, as well as pollutant concentration profiles (e.g. the concentration profile of a plume released from an industrial stack) (Colls, 2002b). Vertical motion is also dependent on the mixing height of the atmosphere. Mixing height refers to the top of the unstable layer where pollutants are well mixed; the thickness of the unstable layer will determine the ability of pollutants to mix and disperse (Vallero, 2014). If the top of the mixing height is low, there is less volume in the unstable layer to disperse pollutants. A low mixing height will lead to high concentrations of pollutants being trapped near the surface of the earth (CASA, 2006). The mixing layer height will vary substantially with season and diurnal temperature patterns (Colls, 2002b). Atmospheric stability and turbulence in the atmosphere are one of the primary factors affecting dispersion of pollutants.

2.5.3 *Temperature*

Seasonal and diurnal temperature patterns will also affect dispersion. Temperature patterns, such as inversions, can create stable atmospheric conditions that trap pollutants near the earth's surface. Inversions occur when the air near the earth's surface is cooler than the air above. During the day, air near the surface is heated by the sun making it warmer than the air aloft. During the night, the air near the earth's surface cools rapidly, eventually resulting in cooler air near the surface (inverse of daytime). The cooler air is heavier than the warmer air aloft, creating stable atmospheric conditions. Combined with low wind speeds, a temperature inversion will allow emitted pollutants to be trapped in the stable layer of air, leading to increased concentrations near the surface (Alberta Environment, 2002). In Alberta, temperature inversions are more common and last longer during the winter months. Strong temperature inversions can last several days, causing poor air quality in the Edmonton region as pollutants linger (Alberta Environment, 2002).

2.5.4 *Precipitation and Humidity*

Precipitation is water that forms in the atmosphere and falls to the ground, in the form of snow, rain, freezing rain, sleet, hail, or drizzle (Environment Canada, 2015a). Humidity is the amount of water vapour/moisture in the air. Precipitation can act as a mechanism of removal from the atmosphere, by "washing out" pollutants. However, precipitation can also react with pollutants in the atmosphere to form secondary pollutants and acid rain, contributing to acid deposition at the earth's surface (US EPA, 2014). Humid conditions also contribute to haze and reduced visibility by increasing the scattering ability of particle pollution in the atmosphere (US EPA, 2012).

2.5.5 *Topography*

Topographical features such as mountains, valleys, hills, flat landscapes, or bodies of water can influence the dispersion of pollutants. Mountain and valley terrain will create distinct upslope and downslope diurnal wind patterns, as well as a channeling of wind through valleys. Terrain will affect wind flow, turbulence of the atmosphere, and mixing of pollutants (Vallero, 2014).

In addition to natural topographic features, man-made environments can greatly affect dispersion. Urban environments vary substantially from rural environments, as they are characterized by a high density of buildings and roadways. Urban areas have a high capability to retain heat because of the asphalt, steel, and concrete surfaces, leading to generally warmer temperatures compared to surrounding rural areas (Vallero, 2014). The high density of buildings in an urban setting will also cause variations in pollutant dispersion as air flow can vary greatly around a structure, causing areas of stagnation, recirculation, or enhanced downstream turbulence (Colls, 2002b).

2.6 POLLUTANT TRANSPORT

Health and environmental effects are known to be influenced by proximity to a pollutant source (Blanchard et al., 2014). It is necessary to understand the spatial distribution of pollutants from a source, and at what distance the impact of a source will become negligible.

2.6.1 *Distance-Decay of Traffic Emissions*

Roadway traffic is a major source of air pollutants, including NO_2, $PM_{2.5}$, and CO (Gilbert et al., 2003). Several studies have looked at the distance-decay relationship of traffic-related pollutants near major roadways (Beckerman et al., 2008; Gilbert et al., 2003; Zhu et al., 2009). Beckerman et al. (2008) examined NO_2 concentration gradients, and found that concentrations rapidly decline within 200 m downwind of a major roadway, and return to ambient background levels by 400 m. Zhu et al. (2009) has identified an exponential decay relationship for $PM_{2.5}$. Concentrations exhibit sharp decay gradients within a distance of 100-150 m downwind from a major roadway, with concentrations returning to typical ambient levels at a distance of approximately 300 m (Zhu et al., 2009). This concentration gradient is not detected upwind of major roadways, indicating that wind conditions play an important role in distance-decay and the dispersion of air pollutants from a source (Zhu et al., 2009). CO follows a similar pattern to both $PM_{2.5}$ and NO_2, with concentrations decreasing exponentially with distance from a major roadway, returning to upwind ambient concentrations within several hundred meters from the roadway (Clements et al., 2009).

The residential air monitoring stations selected for this study have major roadways in close proximity. The closest major roadway for each station is located within 250 m, indicating that traffic could potentially have an effect on measured ambient air quality.

2.6.2 *Modelling Industrial Emissions*

The transport of industrial emissions is typically examined through dispersion modelling. Dispersion models are used to determine compliance by estimating ambient air concentrations of a pollutant emitted from industrial sources. Modelling is used to estimate how a pollutant is transported in the atmosphere, how meteorological factors will effect dispersion, and to provide spatial information on where a pollutant will have the greatest impact (Idriss & Spurrel, 2009). Source emissions data, meteorological data, surface characteristics and terrain, as well as nearby building heights are all considered when modelling pollutant transport from industrial sources (Idriss & Spurrel, 2009). The distance at which an industrial source no longer influences air quality will depend greatly on these factors. Grids are used to represent receptor locations; ground-level ambient concentrations are calculated at varying distances along a grid to determine the area of maximum impact. In areas with a high density of industrial operations, it may be necessary to examine the impact up to 20 km from a source (Idriss & Spurrel, 2009). Most regulatory models utilized in Alberta are capable of reliably predicting short-range air quality within 25 km of a source (Idriss & Spurrel, 2009).

The ambient air monitoring stations selected for this study are located within several kilometers of major industrial activities, particularly the Woodcroft and Gold Bar stations. Industrial emission sources could potentially have an effect on measured ambient air quality at these stations.

2.6.3 *Long-range Transport*

While the majority of the effects of air pollution will be observed within a relatively close distance to the source, evidence has shown that long-range transport of air pollutants is also a significant concern (National Research Council of the National Academies, 2010). It is possible for pollutants to travel far from the initial source, including across continents and oceans. Long-range transport is dependent on the properties and life span of a pollutant in the atmosphere, as well as atmospheric conditions. For example, PM transported from Asian sources has been documented in the Western United States, and PM from Canadian forest fires has been observed as far as Washington, DC (National Research Council of the National Academies, 2010). The adverse effects of emissions may not necessarily be limited to local and regional areas near the source; we must also consider the possible impact thousands of kilometers from a source (National Research Council of the National Academies, 2010).

2.7 AIR QUALITY TRENDS

Ambient air quality is dependent on multiple factors, such as proximity to both natural and anthropogenic sources, meteorological factors, and local topographical features. The transport of pollutants in the atmosphere will create variations in ambient air quality. Continuously monitoring and evaluating ambient air is crucial to understanding the air quality of a region. However, to truly comprehend the long-term impact of air quality, one must examine whether there have been changes in air quality over a period of time (Bari & Kindzierski, 2015a). Identifying long-term temporal trends in air quality will allow us to recognize the impacts of anthropogenic sources and development, as well as characterize the possible impacts on public health.

2.7.1 *Analyzing Air Quality Trends*

Statistical trend analysis of air quality data sets is carried out using either parametric or non-parametric methods. Parametric methods (e.g. linear regression) make the assumption that data follows a normal distribution. Sample sizes should be adequately large (e.g. >30 samples) in order for approximate normal distribution to apply. Non-parametric methods (e.g. Mann-Kendall) do not require data to be normally distributed, and these methods are utilized when the assumptions of parametric methods cannot be met (Bari & Kindzierski, 2015b).

Parametric and non-parametric methods are both suitable for detecting small temporal trends, providing the data set shows adequate variation for a trend to be detected. Any statistical method utilized for environmental trend analysis will be subject to bias and uncertainty, especially when the trend is weak (Bari & Kindzierski, 2015b). This study utilized non-parametric methods for statistical analysis, including the Mann-Kendall and Theil-Sen trend tests.

2.7.1.1 Mann-Kendall Test

The Mann-Kendall test is a non-parametric test used to identify trends in time series data, with distinct values for the time variable (i.e. a single measurement is reported for each sampling time), however the actual variable of time is not required (Singh & Singh, 2010). Given n consecutive observations of a time series z_t; t=1; …, n, Mann (1945) suggested using the Kendall rank correlation of z_t with t; t=1; …, n to test for a monotonic trend. A monotonic trend is a gradual increasing or decreasing trend that does not reverse direction (Kindzierski, Chelme-Ayala, & Gamal El-Din, 2009). The Mann-Kendall test is useful as the data set does not have to follow a normal distribution. The Mann-Kendall test statistic "S" is calculated to determine whether a trend exists and the direction of the trend (Singh & Singh, 2010).

The Mann-Kendall test is limited to testing the null hypothesis, H_0: the data set does not exhibit significant evidence of any trend; the data are equally distributed and independent data points. Time series data (e.g. data sets containing hourly pollutant concentration measurements) may deviate from this assumption in two ways: autocorrelation (the tendency for similar characteristics or mutual bias of neighboring observations in time or space), and seasonality (patterns in data that are caused by seasons of the year) (Bari & Kindzierski, 2015b).

Air quality data sets follow temporal and/or spatial sequences; hourly concentrations over a year are time series data that have a sequential correlated relationship. Autocorrelation of data sets leads to a non-normal distribution: data is typically skewed to the right with most values in the low concentration range, and few in the high concentration range (Bari & Kindzierski, 2015b). One can use annual data (such as an annual average) to limit autocorrelation, although this tends to reduce the efficacy of the test. However, data acquired from a frequency distribution and/or cumulative frequency distribution of raw data is considered to be more representative than general annual average values (Colls, 1997). The use of hourly concentration percentiles as a response variable for each year will reduce the effects of autocorrelation in trend analysis (Bari & Kindzierski, 2015b). Hourly concentration percentiles for the 50^{th}, 65^{th}, 80^{th}, 90^{th}, 95^{th}, and 98^{th} percentiles are utilized in this study.

Air quality data sets are cyclical in nature, caused by seasonal effects throughout a calendar year. Using hourly concentration percentiles as the response variable for trend analysis eliminates the need to adjust for seasonality. Hourly concentration percentiles are drawn from cumulative frequency distributions for each year; the cyclical effects of season is the same for each annual cumulative frequency distribution (Bari & Kindzierski, 2015b).

2.7.1.2 Theil-Sen Test

The Theil-Sen test is a non-parametric test used to determine the magnitude of a trend in time series data. Unlike the Mann-Kendall test, the time variable at which measurements are taken is required for analysis (Singh & Singh, 2010). A key feature of the Theil-Sen test is that it is free from statistical hypotheses that typically affect the traditional regression methods used in analytical sciences (i.e. data sets are not required to be normally distributed) (Lavagnini, Badocco, Pastore, & Magno, 2011; Singh & Singh, 2010). Actual concentrations are used to calculate the pairwise slope estimate; the median slope value is used as an estimate of the unknown population slope. The median pairwise slope, combined with the median concentration value and the median time value is used to determine the final Theil-Sen trend line, thus estimating the change in median concentration over time (Singh & Singh, 2010).

CHAPTER 3: METHODOLOGIES

3.1 POPULATION DATA

Census data was used to examine trends in the population of the study area neighborhoods and City of Edmonton. Human activities will impact air quality (as discussed in section 2.4.2.3), and this study uses population counts as a surrogate to characterize the impact of human activity over the study period. Census data was obtained from the City of Edmonton for the following census years: 2005, 2008, 2009, 2012, and 2014 (City of Edmonton, 2014a; City of Edmonton, 2015a). Federal census data for Edmonton was also obtained for 2001 (City of Edmonton, 2001). Population data for neighborhoods surrounding a station within a 1 km radius was used, as this provides a sufficient estimate of the population interacting within the station area. Maps showing the neighborhoods used in population analysis are presented in Figures 6 through 8; the neighborhoods shown intersect the 1 km radius from the station. There are four exceptions to the 1 km radius: the Sherbrooke, Westmount, Ottewell and Terrace Heights neighborhoods are located between 1 km and 1.1 km from the Woodcroft or Gold Bar stations. It was assumed that residents in these neighborhoods would also interact within these study areas, based on the locations of major roadways and shopping districts within the neighborhoods. The populations of these neighborhoods were utilized in analysis. The populations for the selected neighborhoods were summed for each census year, to derive one number representing population count in each of the three study areas. Population data for the selected neighborhoods is presented in Appendix A. Population data for the entire City of Edmonton was also obtained for the census years 2001, 2005, 2006, 2008, 2009, 2011, 2012, and 2014 (City of Edmonton, 2015b); this data is presented in Appendix A.

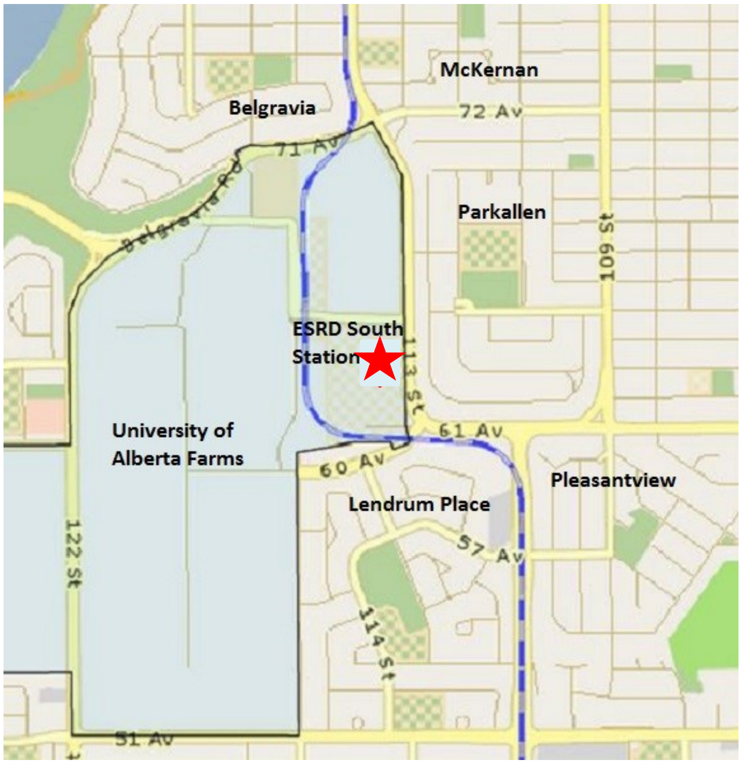

Figure 6: Map of the Edmonton South station and surrounding neighborhoods
*Map obtained from City of Edmonton: Neighborhood Interactive Maps (maps.edmonton.ca)

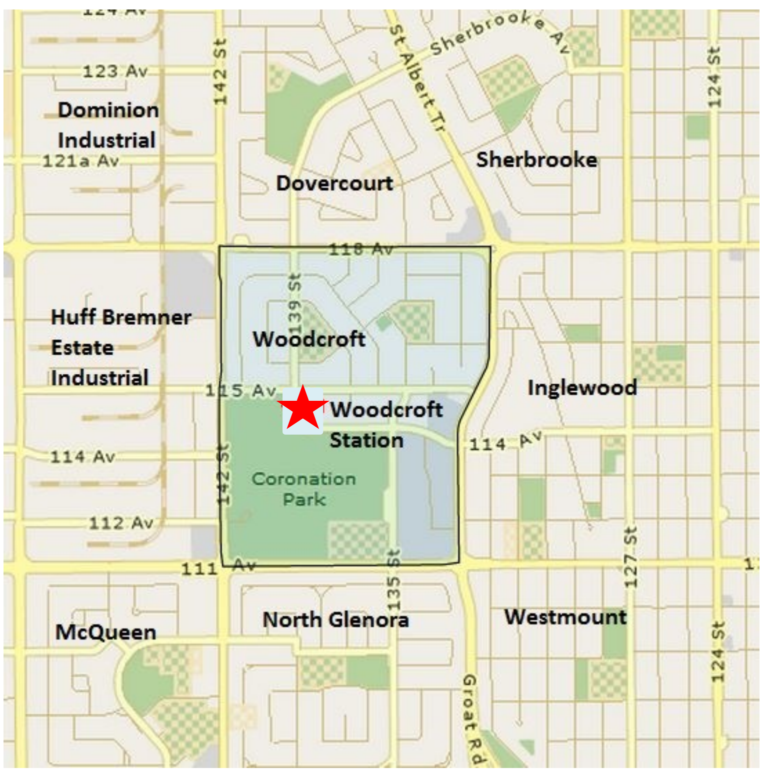

Figure 7: Map of the Woodcroft station and surrounding neighborhoods
*Map obtained from City of Edmonton: Neighborhood Interactive Maps (maps.edmonton.ca)

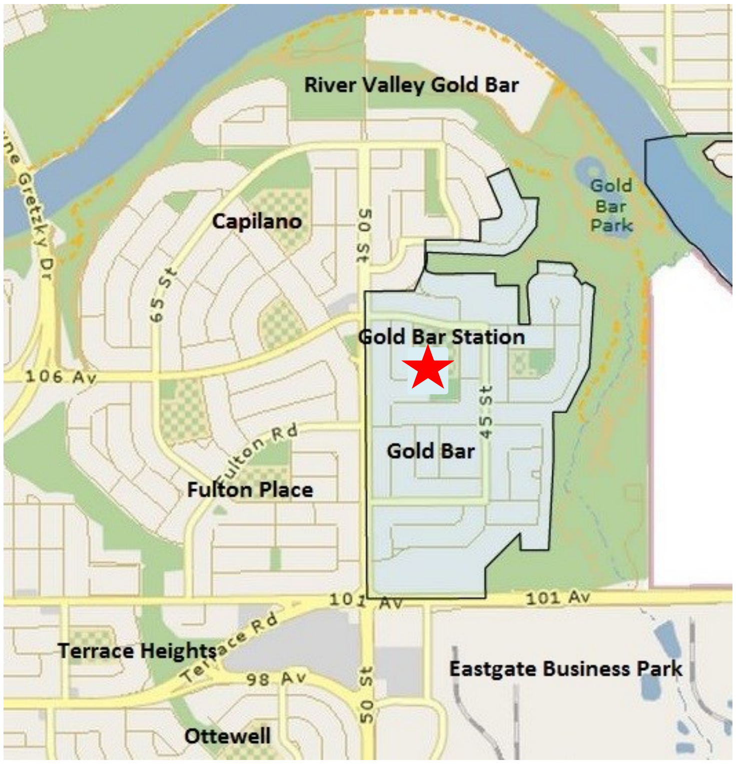

Figure 8: Map of the Gold Bar station and surrounding neighborhoods
*Map obtained from City of Edmonton: Neighborhood Interactive Maps (maps.edmonton.ca)

3.1.1 *Population Trend Analysis*

Population trend analysis was completed using the summed populations for each study area, and for the total population of the City of Edmonton. Trends analysis was completed using Mann-Kendall and Theil-Sen trend tests, using ProUCL 5.0 Statistical software. Analysis was completed as outlined in Singh and Singh (2010).

3.2 TRAFFIC VOLUME DATA

Traffic volume data was used as an indicator of the number of vehicles travelling in the study areas. As discussed in section 2.4.2.2, mobile emissions are an important source of urban air pollutants. It is necessary to characterize the changes in traffic volume in the study areas and City of Edmonton to determine the potential impact on ambient air quality.

Average Annual Weekday Traffic (AAWDT) volume data collected by the City of Edmonton from 2002 through 2013 was utilized. This data represents the total number of vehicles travelling in both directions along a roadway over a 24 hour period of a typical Monday, Tuesday, Wednesday, or Thursday (City of Edmonton, 2008; City of Edmonton, 2014b). This data represents the best available data for traffic volume for the study period. The number of registered vehicles in the City of Edmonton for 2004-2013 was also collected. The number of registered vehicles includes all motorized vehicles that can be driven on the highway, and excludes trailers, off-highway vehicles, and dealer-plated vehicles. The location of the vehicle is determined by the registered owners mailing address at the end of the fiscal year (Alberta Transportation, 2008).

3.2.1 *Selection of Traffic Count Sites*

Traffic volume count sites were chosen based on proximity, within a 1 km radius of each station. The location of the count sites utilized is presented in Table 5; proximity and direction is relative to the air monitoring station and was determined using Google Earth. Proximity is the distance from the station to the traffic count site in meters, while the direction is where the traffic count site is located relative to the station in degrees from north. Volume data is collected on a rotational basis throughout the City. As a result, all traffic count site data sets were incomplete for 2002-2013. Traffic count data for the sites selected is presented in Appendix B.

Table 5: Traffic count site locations

Station	Site name	Count Site description/location	Proximity and Direction*
Edmonton South 6240-113 Street	ES-1	113 Street S of Belgravia Rd (2002-2007)	840 m 10deg
		113 Street N of 67 Ave (2008-2013)	500 m 20deg
	ES-2	111 Street S of 61 Ave (2002-2007)	640 m 110deg
		111 Street N of 57 Ave (2008-2013)	910 m 140deg
	ES-3	Belgravia Rd E of Fox Drive (2002-2007)	890 m 300deg
		Belgravia Rd W of 116 Street (2008-2013)	850 m 330deg
Woodcroft 13915-115 Avenue	W-1	142 Street N of 118 Ave	690 m 340deg
	W-2	118 Avenue W of 133 Street	910 m 50deg
	W-3	Groat Road N of 111 Ave	950 m 130deg
	W-4	111 Avenue W of 142 Street	730 m 200deg
Gold Bar 105A Ave & 47 Street	GB-1	50 Street N of 101A Avenue	870 m 200deg
	GB-2	101 Avenue E of 50 Street	900 m 190deg

*Proximity: distance from the station to the traffic count site in meters. Direction: location of the traffic count site relative to the station in degrees from north.

3.2.1.1 Edmonton South

Data for nine traffic count sites was available for the study area surrounding the Edmonton South station. Unfortunately, the sites monitored in 2002-2007 were different sites than those monitored for 2008-2013 (City of Edmonton, 2008; City of Edmonton, 2014b). Traffic sites were combined along the same roadways to provide a more complete data set. The assumption was made that there would be only minor changes in traffic volume along the selected roadways. Figure 9 shows all the traffic count sites within the Edmonton South study area, and Figure 10 shows the combined sites utilized in analysis.

Figure 9: Edmonton South study area traffic count sites available
*Map obtained from City of Edmonton: Neighborhood Interactive Maps (maps.edmonton.ca)

Figure 10: Edmonton South study area combined traffic count sites
*Map obtained from City of Edmonton: Neighborhood Interactive Maps (maps.edmonton.ca)

3.2.1.2 Woodcroft

There were 8 monitoring sites located within a 1 km radius of the Woodcroft station. Four sites were selected. Only one site along each major roadway was selected to avoid duplication of traffic counts. Selection was based on location of the site relative to other sites along the same roadway and the completion of the data set. Figure 11 displays the traffic count sites in the Woodcroft study area.

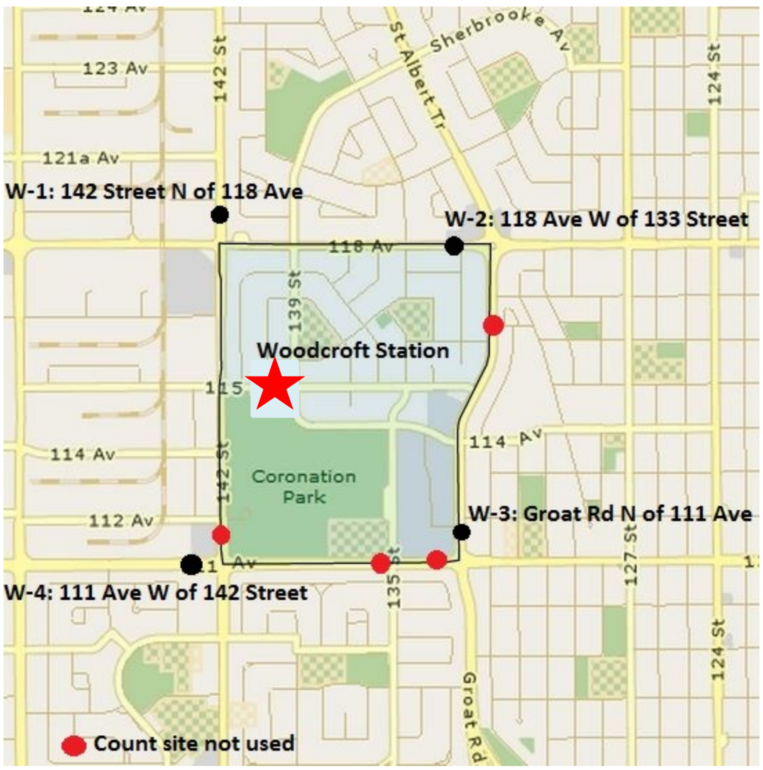

Figure 11: Woodcroft study area traffic count sites
*Map obtained from City of Edmonton: Neighborhood Interactive Maps (maps.edmonton.ca)

3.2.1.3 Gold Bar

For the Gold Bar station, only two traffic count sites collected data within a 1 km radius; both sites were used in analysis. Figure 12 shows the location of the traffic count sites.

Figure 12: Gold Bar study area traffic count sites
*Map obtained from City of Edmonton: Neighborhood Interactive Maps (maps.edmonton.ca)

3.2.2 *Traffic Volume Trend Analysis*

Characterizing the changes in traffic in the City of Edmonton provides an understanding of the potential impacts on air quality, as vehicle emissions are a major source of ambient air pollutants. Trend analysis was completed for the number of registered motorized vehicles in the City of Edmonton for 2004-2013. Analysis was completed using Mann-Kendall and Theil-Sen trend tests in ProUCL 5.0 statistical software, following the methods outlined in Singh and Singh (2010).

Traffic volume count data for the sites within the study areas could not be analyzed for trends due to the incompleteness of the data sets. The data was deemed insufficient for formal trend analysis due to the rotational schedule of the monitoring; only a visual inspection for trends was completed.

3.3 INDUSTRIAL EMISSIONS DATA

Industrial emissions are a significant contributor to ambient air quality in an urban environment. Identifying trends in reported industrial emissions can provide an understanding of how emissions have influenced air quality over time. National Pollutant Release Inventory (NPRI) data was collected from Environment Canada (Environment Canada, 2015b). As discussed in section 2.6.2, the impact of industrial emissions is modelled over a large spatial area, typically up to 25 km from an industrial source (Idriss & Spurrel, 2009). NPRI data was analyzed for a larger region than traffic and population data to account for the transport of industrial pollutants and the impact of industrial sources that are further away. The city limits of Edmonton were used to determine the north, west, and south boundaries. The city limits and the boundary of the Strathcona Industrial Association was used to determine the eastern boundary. Capturing the industrial operations east of Edmonton was assumed to be essential, as the impact of emissions may be observed at the air monitoring stations operating within the City of Edmonton (Idriss & Spurrel, 2009). Total annual reported emissions data (tonnes per year) within these boundaries was collected for NO_2, $PM_{2.5}$, and CO; this data is presented in Appendix C. The total number of emitters reporting annually for each pollutant is also presented in Appendix C. Figure 13 shows the boundary utilized for examining the NPRI emissions data and the NPRI facilities operating within this boundary in 2003 through 2013.

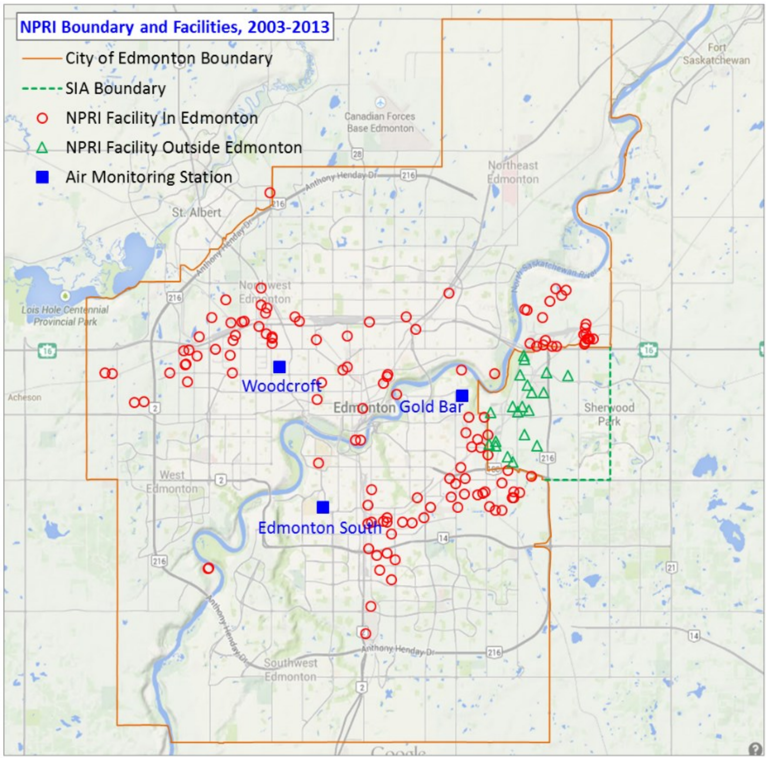

Figure 13: Boundary for analysis of industrial emissions data and facilities located within the boundary, 2003-2013 (adapted from Environment Canada, 2014c)
*Map obtained from Google Maps

3.3.1 *Industrial Emissions Trend Analysis*

Characterizing industrial emissions trends provides an estimate of the change in reported industrial emissions over the study period. Trend analysis was completed for the total annual reported emissions (tonnes per year) within the boundaries for NO_2, $PM_{2.5}$, and CO. Analysis was completed using Mann-Kendall and Theil-Sen trend tests available in the ProUCL 5.0 statistical software package. Methodologies for these tests are described in Singh and Singh (2010).

3.4 AIR QUALITY MONITORING DATA

Air quality data was collected for NO_2, $PM_{2.5}$, and CO. One hour average concentration data was downloaded from the Clean Air Strategic Alliance (CASA) Data Warehouse for the Edmonton South station (CASA, 2006). Woodcroft station data was provided by Lehigh Cement and Amec Foster Wheeler. Gold Bar station data was provided by the Strathcona Industrial Association and Amec Foster Wheeler. Data was processed as follows:

1) All hourly flagged data was removed from the data sets as invalid. A minimum of 80% valid data after processing was required to utilize an annual data set for trend analysis. This represents approximately 7000 hours of valid hourly concentration data per year, which is sufficient for the purposes of this study and similar to the criteria used in comparable studies (Bari & Kindzierski, 2015a). A total of 8768 hours of data is recorded per year (valid and invalid data; does not include intercalary (leap) years).
2) Air quality data was processed to adjust negative $PM_{2.5}$ and NO_2 concentrations to zero. It is standard industry practice to adjust valid negative hourly concentrations for NO_2 to zero, and concentrations between 0 and -3 to zero for $PM_{2.5}$ (ESRD, 2014c). No negative concentrations were recorded for CO.
3) Edmonton South NO_2 data was converted from parts per million (ppm) to parts per billion (ppb) for analysis. Edmonton South NO_2 hourly concentrations are reported in ppm in the CASA Data Warehouse, while the Woodcroft and Gold Bar station report in ppb (CASA, 2006). Due to this conversion, Edmonton South NO_2 concentrations are reported to a different precision.
4) The hourly maximum, minimum, and median for each parameter and year monitored was calculated. The maximum value represents the 1-hour maximum concentration for

each year of data, while the minimum value represents the 1-hour minimum concentration for each data set. The median value is the measure of the central tendency of a distribution of data (Montgomery, Runger & Hubele, 2001). Data set characteristics are presented in Appendix D.

The stations, parameters, and time period of available data is displayed in Table 6. The target time period for this study was 2003-2013. Only the Woodcroft station had a complete data set; eight complete years of data was available for the Edmonton South station, and seven complete years was available for the Gold Bar station. Partial data sets were available for 2005 for Edmonton South (~25% valid data), and 2006 for Gold Bar (~60% valid data), however these data sets did not meet the 80% data completeness criteria. In addition, Edmonton South $PM_{2.5}$ did not meet the 80% criteria in 2009 (73%) and 2012 (71%), however this data was included for analysis. If these years are removed, the data set becomes too small for trend analysis.

Table 6: Pollutant parameters measured and time period

	Pollutant Parameter		
Station	**NO_2**	**$PM_{2.5}$**	**CO**
Edmonton South	2006-2013	2006-2013	2006-2013
Woodcroft	2003-2013	2003-2013	x
Gold Bar	2007-2013	x	x

x: Parameter not monitored

3.4.1 *Air Quality Trend Analysis*

The PERCENTILE function in Microsoft Excel was used to determine concentration-based benchmarks for all pollutant parameters. The 50^{th}, 65^{th}, 80^{th}, 90^{th}, 95^{th}, and 98^{th} percentiles were determined for each parameter annually. The data represented by these percentiles is well above the detection limit of the analyzers (e.g. $\geq 50^{th}$ percentile), and captures high concentration events while excluding extreme values (e.g. $\leq 98^{th}$ percentile) (Bari & Kindzierski, 2015b). Percentile data for each parameter is presented in Appendix E. Sample cumulative frequency distributions are also presented for NO_2, $PM_{2.5}$, and CO for 2008 at the Edmonton South station in Appendix F. Cumulative frequency distributions demonstrate the typical distribution of the hourly concentration data sets. The 2008 data set was chosen to demonstrate the cumulative frequency distributions as the percent of valid data was greater than 97% for all parameters.

The 2010 $PM_{2.5}$ percentile data from the Edmonton South and Woodcroft stations was removed from the data sets for trend analysis, as the 2010 data was deemed an outlier. In 2010, there were a large number of forest fires in Alberta and British Columbia. Smoke from these fires caused an increase in $PM_{2.5}$ concentrations in Edmonton (ESRD, 2015a). As well, several wintertime smog events also contributed to high $PM_{2.5}$ concentrations in January and February (ESRD, 2015a). No other data was removed from trend analysis. Trend analysis was completed for each concentration percentile for each parameter.

3.4.2 *Trend Analysis Methodology*

Trend analysis was completed using the ProUCL 5.0 Statistical Software. This software is recommended by the US EPA for the analysis of environmental data sets. It is a comprehensive statistical software that provides statistical methods and graphical tools required for analysis of environmental samples (Singh & Singh, 2010). Trend analysis was completed using Mann-Kendall and Theil-Sen tests. These non-parametric tests are commonly used to determine trends in data sets over a specific time period (Singh & Singh, 2010).

3.4.2.1 Mann-Kendall Test

The Mann-Kendall test is a non-parametric test used to identify trends in time series data, with distinct values for the time variable (i.e. a single measurement is reported for each sampling time) (Singh & Singh, 2010). The Mann-Kendall test determines the "S" statistic, by examining all possible distinctive pairs (y_j, y_i) (e.g. pairs of percentile values from consecutive years) in the data set and scoring them as either 0 (paired numbers are equal), 1 (earlier measurement is smaller in magnitude than the later measurement), or -1 (earlier measurement is larger in magnitude than the later measurement) (Singh & Singh, 2010). S is the sum of the assigned scores. S is calculated as follows (Singh & Singh, 2010):

(1) Compute all possible differences between pairs of measurements:

$$(y_j - y_i) \text{ for } j > i$$

(2) Compute the sign of the difference:

$$sgn\left(y_j - y_i\right) = \begin{cases} 1 \; if \left(y_j - y_i\right) > 0 \\ 0 \; if \left(y_j - y_i\right) = 0 \\ -1 \; if \left(y_j - y_i\right) < 0 \end{cases}$$

(3) Compute S:

$$S = \sum_{i=1}^{n} \sum_{j=i+1}^{n} sgn\,(y_j - y_i)$$

A positive S value suggests an increasing trend; a negative S value suggests a decreasing trend; and an S value close to zero suggests no evidence of an increasing or decreasing trend (Singh & Singh, 2010).

Tabulated p-values (α_{cp}) are calculated in the Mann-Kendall test based on the S statistic when $n<23$, and used to conclude if there is statistically significant evidence to determine a trend. If $S > 0$ and $\alpha > \alpha_{cp}$, ($\alpha = 0.05$) we can conclude there is statistically significant evidence of an increasing trend at the α significance level. If $S < 0$ and $\alpha > \alpha_{cp}$, we can conclude there is statistically significant evidence of a decreasing trend at the α significance level. If $\alpha \leq \alpha_{cp}$, we can conclude that the data does not exhibit sufficient evidence of any significant trend at the α significance level (Singh & Singh, 2010). The hypotheses tested for the Mann-Kendall test are:

H_0: Data set does not exhibit significant evidence of any trend.

H_A: Data set exhibits an upward trend; or

H_A: Data set exhibits a downward trend; or

H_A: Data set exhibits a trend, two-sided alternative (Singh & Singh, 2010, pg.231).

3.4.2.2 Theil-Sen Test

The Theil-Sen test is a non-parametric test used to determine the magnitude of a trend in time series data. Actual concentrations are used to calculate the pairwise slope estimate; the median slope value is used as an estimate of the unknown population slope. The median pairwise slope, combined with the median concentration value and the median time value is used to determine the final Theil-Sen trend line, thus estimating the change in median concentration over time (Singh & Singh, 2010). The Theil-Sen slope is determined as follows (Singh & Singh, 2010):

(1) Compute the simple pairwise slope estimate for all possible distinct pairs of measurements (y_i, y_j) for $j > i$:

$$m_{ij} = \frac{(y_j - y_i)}{j - i}$$

(2) For a data set of size n, there are $N=n(n-1)/2$ pairwise slope estimates, m_{ij}. Order m_{ij} from smallest to largest and re-label as $m(1), m(2), \ldots, m(N)$.

(3) Determine the Theil-Sen estimate of slope, Q, as the median value of this set of N ordered slopes:

$$Q = \begin{cases} m_{(N+1)/2} \; if \; N = odd \\ \dfrac{\left(m_{(N/2)} + m_{\left(\frac{(N+2)}{2}\right)}\right)}{2} if \; N = even \end{cases}$$

(4) Arrange the *n* measurements in ascending order from smallest to largest as *y(1), y(2),…, y(n)* and determine the median measurement:

$$\tilde{y} = \begin{cases} y_{(n+1)/2} \ if \ n = odd \\ \dfrac{\left(y_{\left(\frac{n}{2}\right)} + y_{\left(\frac{n+2}{2}\right)}\right)}{2} if \ n = even \end{cases}$$

(5) Compute the median time, $\check{t}$ of the *n* ordered sampling times ($t_1, t_2, \ldots, t_n$) using the same algorithm as above in Steps 3 and 4.

(6) Compute the Theil-Sen trend line:

$$y = \tilde{y} + Q(t - \tilde{t}) = (\check{y} - Q\tilde{t}) + Qt$$

The Theil-Sen trend line estimates the change in median concentration over time, providing the magnitude of the trend (Singh & Singh, 2010).

3.4.3 *Multiple Linear Regression Analysis*

A simple multiple linear regression analysis was undertaken as an exploratory exercise using the 50th percentile concentration data for NO_2 at the Woodcroft station. Analysis was completed using the statistical software SAS v.9.2. The purpose was to explore whether three independent variables (population, traffic volume, and industrial NO_2 emissions data) acted together to affect the dependent variable (50th percentile NO_2 concentration), and to what extent. The hypotheses tested in the analysis are:

H_0: $b_0 = b_1 = b_2 = \ldots = b_i = 0$

H_A: at least one parameter $b_i \neq 0$ (Montgomery et al., 2001)

In multiple linear regression, the effects of multiple independent variables often overlap in their association with the dependent variable. This means a variable's coefficient shows the 'net strength' of the relationship of that particular independent variable to the dependent variable, above and beyond the relationships of the other independent variables. Each coefficient is then interpreted as the predicted change in the value of the dependent variable for a one-unit change in the independent variable, after accounting for the effects of the other variables in the model (Montgomery et al., 2001). The general form of the model used is:

$$y^1 = b_0 + b_1x_1 + b_2x_2 + \ldots b_px_p$$

y^1: dependent variable (predicted by a regression model)

b_0: intercept (or constant)

b_i (i=1, 2, …p): ith coefficient corresponding to x_i

x_i (i=1, 2, …p): ith independent variable from total set of p variables

p: number of independent variables (number of coefficients)

3.4.3.1 Required Data

Complete data sets were required for multiple linear regression analysis. The air quality and NPRI emissions data sets were complete for 2003-2013; population and traffic count data sets were incomplete. The census is not completed annually; neighborhood level population data for the Woodcroft study area was interpolated to estimate population changes for years where no census was taken (2003-2013). The populations for the selected neighborhoods were summed to derive a single number each year, representing population in the Woodcroft study area. Interpolated population data for the Woodcroft study area is provided in Appendix A.

Traffic volume data is collected on a rotational basis throughout the City of Edmonton. As a result, all traffic count data sets were incomplete for 2003-2013. Volumes were interpolated from count data for the years where no traffic count was taken. Estimated traffic volume data from the 2013 AAWDT Report was used when available for 2008-2013. Estimated volume was "derived from growth factors at permanent counting sites, applied to the most recent actual count volume at a given location" (City of Edmonton, 2014b, p.3). Traffic counts for the selected sites were summed to derive a single number each year, representing traffic volume in the Woodcroft study area. Interpolated traffic count data for the Woodcroft study area is presented in Appendix B.

CHAPTER 4: RESULTS AND DISCUSSION

4.1 POPULATION TREND ANALYSIS

The population of the three study areas for the census years between 2001 and 2014, as well as the overall population for the City of Edmonton is presented below in Figures 14 and 15. Collected population data for the selected neighborhoods is available in Appendix A.

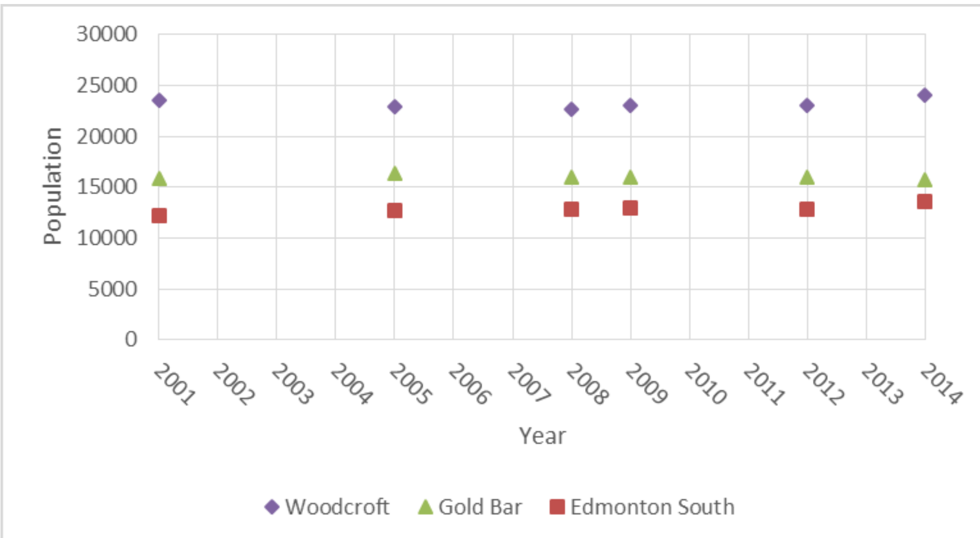

Figure 14: Population in the Edmonton South, Woodcroft, and Gold Bar study areas for census years between 2001 and 2014

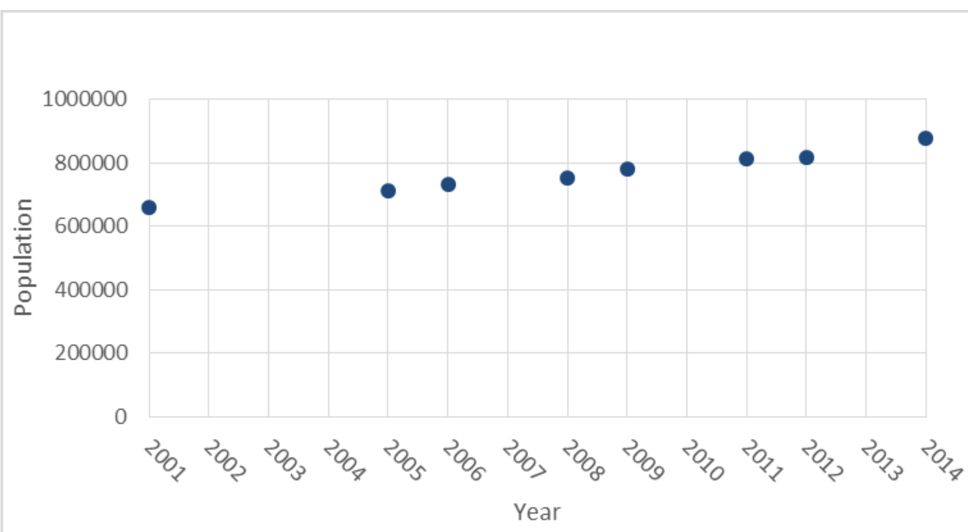

Figure 15: City of Edmonton population for census years between 2001 and 2014

Table 7 presents the results of the Mann-Kendall and Theil-Sen trend analysis. Trend analysis outputs from the ProUCL software are available in Appendix A.

Table 7: Study area population trend analysis: Mann-Kendall and Theil-Sen Slope summary (α=0.05)

Study Area	Mann-Kendall Trend Analysis	Theil-Sen Slope: People per decade	LCL, UCL per decade
Edmonton South	↑	855	(30, 1287)
Woodcroft	No Trend	-	(-1019, 2201)
Gold Bar	No Trend	-	(-940, 150)
City of Edmonton	↑	163,000	(138203, 184402)

*LCL/UCL: lower and upper confidence limits of Theil-Sen slope.

A statistically significant increasing trend was observed for the population of the Edmonton South study area, with an increase of 855 people per decade (α=0.05). No significant trends were observed for the population of the Woodcroft and Gold Bar study areas. Trend analysis determined a statistically significant increasing trend for the total population of the City of Edmonton, with a magnitude of 163,000 people per decade (α=0.05). The population increased from 657,350 in 2001, to 877,926 in 2014, equivalent to a 34% growth in population over 13 years (City of Edmonton, 2015b).

The growth observed in the overall population is not evenly distributed throughout the City of Edmonton. The neighborhoods comprising the study area are mature neighborhoods where little population growth is occurring. Much of the population growth and development occurs in new neighborhoods in Edmonton (City of Edmonton, n.d.). The small growth observed in the Edmonton South study area could be attributed to the location of these neighborhoods. These neighborhoods are in close proximity to the University of Alberta and the LRT (Light Rail Transit) line. Many students and working professionals may choose to move to these neighborhoods as they are convenient for accessing the University and downtown.

4.2 TRAFFIC VOLUME TREND ANALYSIS

It is challenging to interpret traffic counts and conclusively show a trend in traffic volume. The 2013 AAWDT Report notes that an increase or decrease in traffic volume does not necessarily indicate an actual trend for a roadway (City of Edmonton, 2014b). Recorded temporary or long-term volume changes could be attributed to roadway construction and major traffic diversions (e.g. 102 Avenue bridge closure over Groat Road) (City of Edmonton, 2014b). In addition, new traffic counting equipment was introduced in 2009. The new technology utilizes Vehicle Magnetic Imaging to count traffic, whereas the older equipment used hoses to detect vehicle axles. The most notable decline in traffic counts due to the change in technology would be observed along designated truck routes (City of Edmonton, 2014b).

Traffic volume counts for the monitored sites are presented in Figures 16 through 18. Traffic count data is available in Appendix B. The traffic volume data obtained from the count sites is not suitable for Mann-Kendall and Theil-Sen trend analysis due to the rotational monitoring schedule; only a visual inspection for trends was completed.

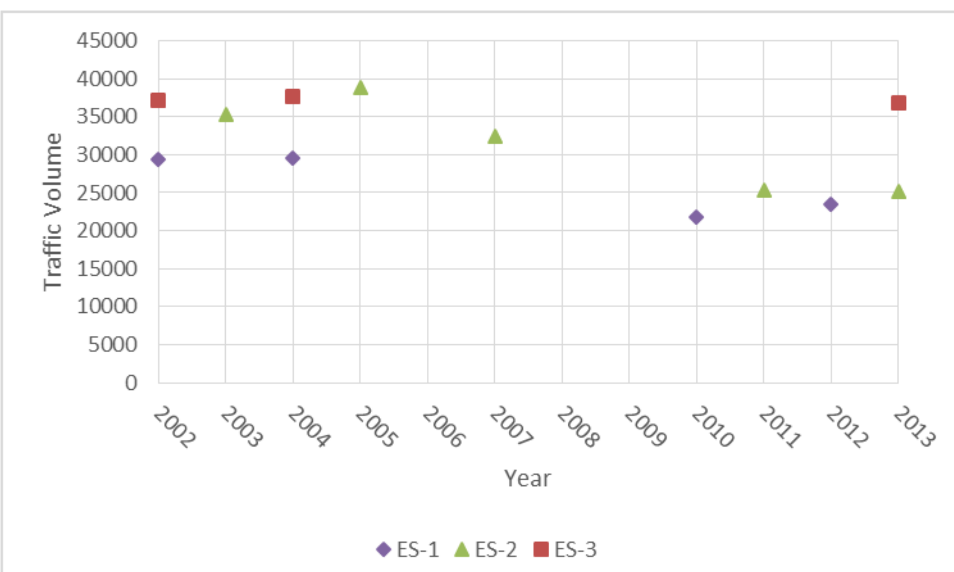

Figure 16: Edmonton South study area traffic volume counts, 2002-2013

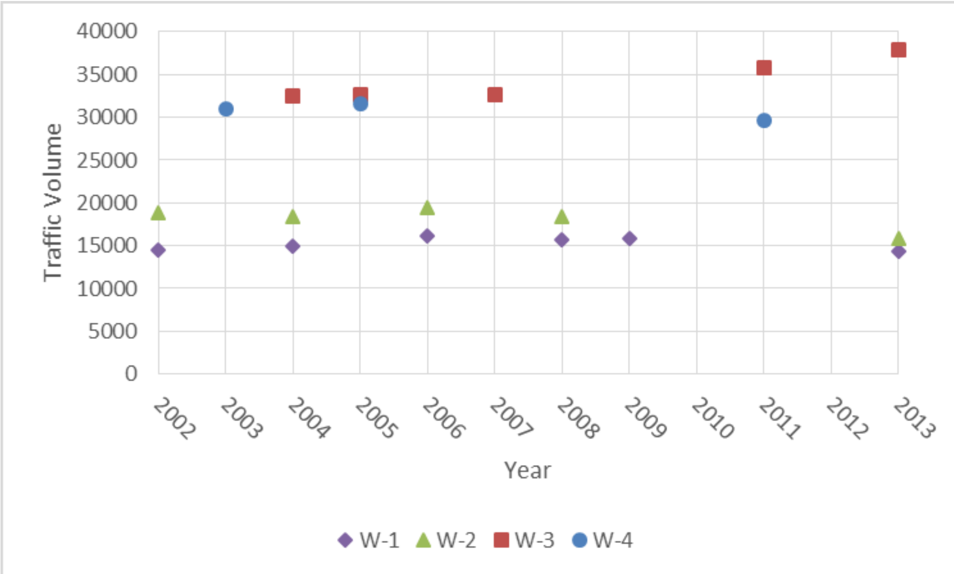

Figure 17: Woodcroft study area traffic volume counts, 2002-2013

Figure 18: Gold Bar study area traffic volume counts, 2002-2013

For the count sites within the Edmonton South study area, a decrease in traffic volume is observed for sites ES-1 and ES-2. While this could be attributed to the change in traffic count technology, this decrease could also potentially be caused by the opening of the LRT line from the Health Sciences station to the South Campus station in April 2009, and the extension to Century Park in April 2010 (City of Edmonton, 2015c). The LRT line travels along 111 and 113 Street, providing access to the University and downtown for commuters on the south side of Edmonton. Any changes in commuter patterns along these roadways due to the implementation of the LRT services would be reflected in traffic counts at sites ES-1 and ES-2. In contrast, no observable trend was detected at the Woodcroft or Gold Bar study area count sites for 2002-2013.

4.2.1 *Number of Registered Vehicles*

The number of registered motor vehicles in Edmonton for 2004-2013 is presented in Figure 19. Mann-Kendall and Theil-Sen trend analysis results are shown in Table 8, and trend analysis outputs from the ProUCL software can be found in Appendix B.

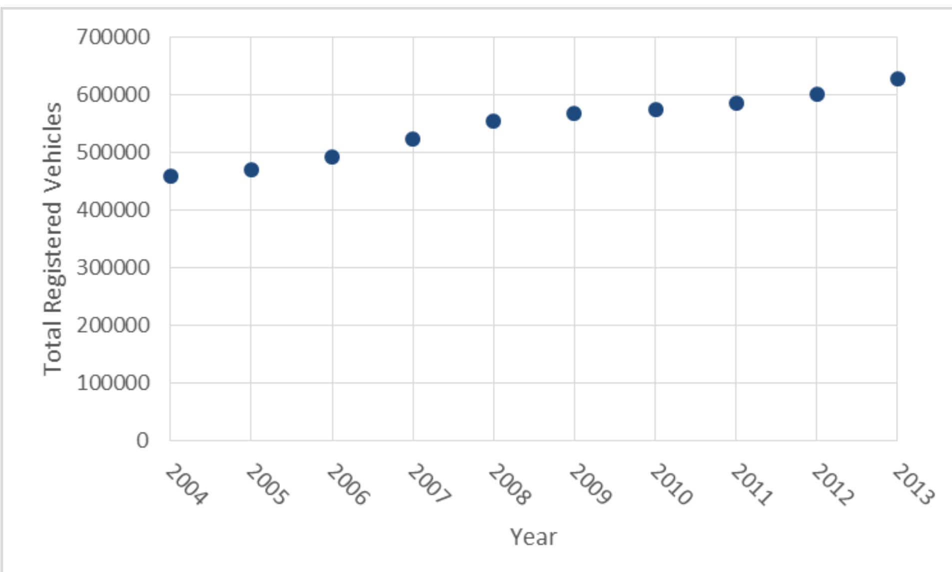

Figure 19: Number of registered vehicles in Edmonton, 2004-2013

Table 8: Registered vehicles trend analysis: Mann-Kendall and Theil-Sen Slope summary (α=0.05)

Registered Vehicles	**Mann-Kendall Trend Analysis**	**Theil-Sen Slope: Vehicles per decade**	**LCL, UCL per decade**
City of Edmonton	↑	186,000	(150917, 216316)

A statistically significant increasing trend of 186,000 vehicles per decade is observed for the number of registered vehicles in the City of Edmonton (α=0.05). The number of registered vehicles on the roads in Edmonton increased by 27% from 2004 to 2013 (Alberta Transportation, 2008, 2012, 2014). With the significant growth observed in the population of the City of Edmonton, one can assume the increase in the number of registered vehicles is directly related to the population growth. The increase in the number of registered vehicles (27%) is comparable to the growth observed in the total population (34%). A significant increase in population will be reflected in the number of registered vehicles, particularly in a city such as Edmonton where much of the growth is outwards and people heavily rely on their vehicles for transportation.

4.3 INDUSTRIAL EMISSIONS TREND ANALYSIS

Annual reported industrial emissions data for NO_2, $PM_{2.5}$, and CO within the study region (obtained from the NPRI data base) is presented in Figure 20. Bubble plots presenting the spatial distribution of the annual emissions for 2003 through 2013 for the pollutants NO_2, $PM_{2.5}$, and CO are presented in Appendix C. Bubble plots show the spatial distribution of industrial emitters and the annual value of the reported emissions for each pollutant. The scaling factor for each bubble is representative of the emissions relative to other industrial emitters; large emitters have a larger bubble representing emissions while small emitters have smaller bubbles.

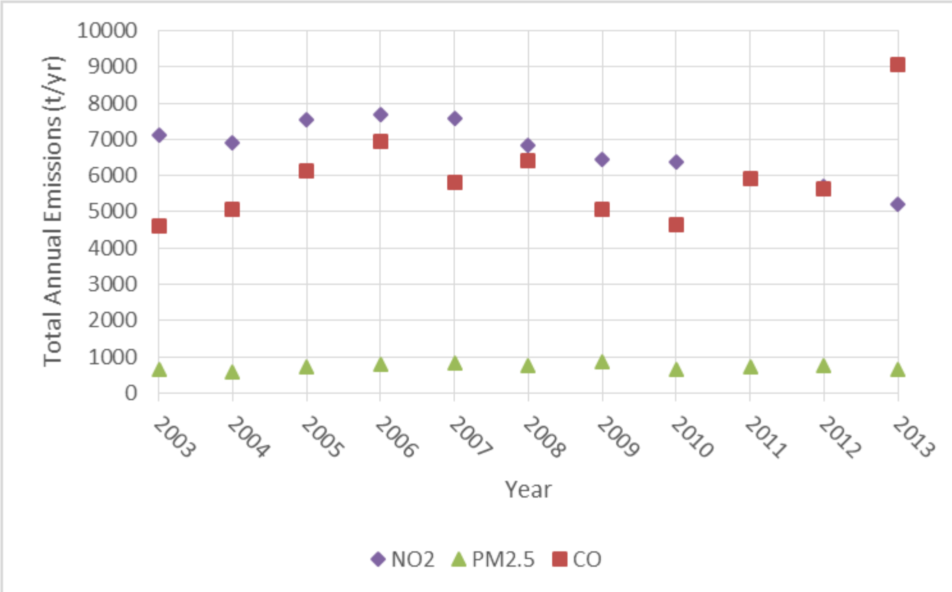

Figure 20: Annual industrial emissions, 2003-2013 (tonnes/year) (Environment Canada, 2014c)

Table 9 presents the results of the Mann-Kendall and Theil-Sen trend analysis for the 2003-2013 data set. Mann-Kendall and Theil-Sen output results from the ProUCL software are presented in Appendix C.

Table 9: NPRI emissions trend analysis: Mann-Kendall and Theil-Sen Slope summary (α=0.05)

Pollutant	Mann-Kendall Trend Analysis	Theil-Sen Slope: Tonnes per decade	LCL, UCL per decade
NO_2	↓	-2,490	(-3486, -1092)
$PM_{2.5}$	No Trend	-	(-181, 260)
CO	No Trend	-	(-191, 450)

A decreasing trend was detected for industrial NO_2 emissions, at a rate of 2,490 tonnes per decade (α=0.05). This decreasing trend in NO_2 emissions is attributed to improvements in industrial emissions controls. This trend is expected to continue as technology improves and alternate fuel sources become available (ESRD, 2015b). No significant trends were detected for industrial $PM_{2.5}$ or CO emissions.

4.4 AIR QUALITY DATA SET CHARACTERISTICS

Air quality data set characteristics for each station are presented in Appendix D. Section 4.4 presents a summary of the highlights of each data set. The maximum value represents the 1-hour maximum concentration for each year of data, while the minimum value represents the 1-hour minimum concentration for each year of data. The median value is the measure of the central tendency of a distribution of data (Montgomery et al., 2001).

4.4.1 *NO_2*

Nitrogen dioxide was monitored at the Edmonton South, Woodcroft, and Gold Bar stations. All data sets for the years analyzed were greater than 80% valid; no annual data sets were excluded from analysis. The NO_2 data sets were fairly similar when comparing the three stations. At the Edmonton South station, the median range was 7 ppb (2013) to 10 ppb (2006), and the maximum 1-hour concentration of 83 ppb was recorded in 2010. The median range recorded at the Gold Bar station was 9.5 ppb (2012, 2013) to 11.2 ppb (2010), with a maximum 1-hour concentration of 75.9 ppb recorded in 2010. The Woodcroft station tended to record a higher median concentration when compared to Edmonton South and Gold Bar. The median ranged from 10.9 ppb (2012) to 19.5 ppb (2011), with a maximum 1-hour average concentration of 190 ppb recorded in 2003. This value would exceed the current hourly AAAQO of 159 ppb.

The Woodcroft station likely has different factors influencing NO_2 concentration, as the median concentrations recorded are considerably higher when compared to the Edmonton South and Woodcroft stations. The impact of the surrounding major roadways could be a contributing factor, as there are multiple major roadways within close proximity to the station, while the Edmonton South and Gold Bar stations only have 1-2 major roadways nearby.

4.4.2 *$PM_{2.5}$*

Fine particulate matter was monitored at the Edmonton South and Woodcroft stations. All annual data sets were greater than 80% valid, with the exception of 2009 and 2012 at the Edmonton South station. The median range for the Edmonton South station was 3.4 $\mu g/m^3$ (2006) to 9.8 $\mu g/m^3$ (2010). The median range for the Woodcroft station was 3.1 $\mu g/m^3$ (2005) to 5.4 $\mu g/m^3$ (2013). The maximum 1-hour concentration recorded at the Edmonton South station was 396 $\mu g/m^3$ in 2010. This value is significantly higher than the second highest maximum 1-hour concentration of 154 $\mu g/m^3$ in 2011. A similar pattern was observed at the Woodcroft station; the maximum 1-hour average concentration of 403 $\mu g/m^3$ was recorded in 2010, while the second highest 1-hour maximum of 177 $\mu g/m^3$ was recorded in 2008. The high concentration of $PM_{2.5}$ in 2010 is attributed to the impact of wildfire smoke in the region and several wintertime smog events. In August 2010, the Edmonton region was greatly impacted by wildfire smoke from fires in Alberta and British Columbia (ESRD, 2015a). In addition, several temperature inversions occurring in January and February led to winter smog events with high concentrations of $PM_{2.5}$ as pollutants were trapped near the earth's surface (ESRD, 2015a). The 2010 data set was removed from trend analysis due to these abnormal events.

4.4.3 *CO*

Carbon monoxide was monitored at the Edmonton South station. All annual data sets were greater than 80% valid. The median concentration recorded for all studied years is 0.2 ppm. The maximum 1-hour concentration was highest in 2006, at 2.8 ppm, and the lowest 1-hour maximum concentration was recorded in 2012, at 1.3 ppm. The hourly maximums showed an overall decline over the study period from 2006 to 2013.

4.5 AIR QUALITY TREND ANALYSIS

Trend analysis was completed using the benchmark concentration percentiles for NO_2, $PM_{2.5}$, and CO. Sample cumulative frequency distributions for NO_2, $PM_{2.5}$, and CO at the Edmonton South station in 2008 are presented in Appendix F. The Mann-Kendall and Theil-Sen trend tests were used in the ProUCL software. Outputs from the ProUCL software for the trend analysis are presented in Appendix G, H, and I.

4.5.1 *NO_2*

Figures 21 through 23 present the benchmark concentration percentiles for NO_2 at the Edmonton South station (2006-2013), Woodcroft station (2003-2013), and Gold Bar station (2007-2013).

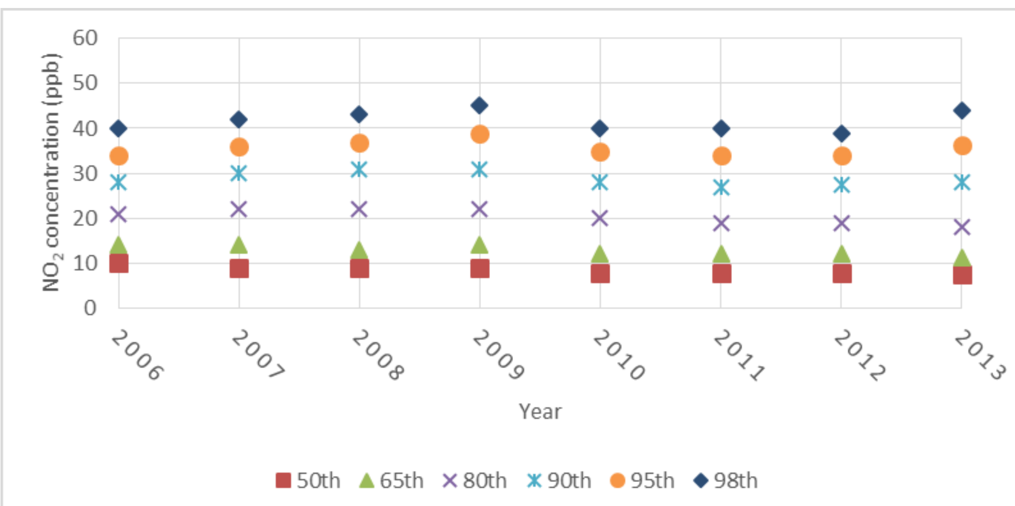

Figure 21: Edmonton South NO_2 concentration percentiles, 2006-2013 (ppb)

Figure 22: Woodcroft NO_2 concentration percentiles, 2003-2013 (ppb)

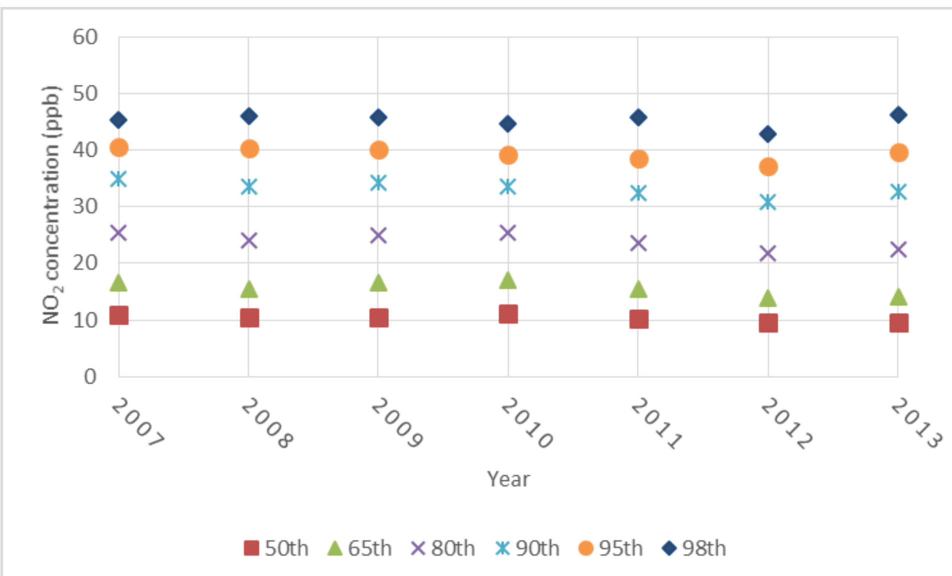

Figure 23: Gold Bar NO_2 concentration percentiles, 2007-2013 (ppb)

Table 10 presents the summary of the Mann-Kendall and Theil-Sen trend analysis for NO_2. Trend analysis detected decreasing trends in NO_2 concentrations for several of the benchmark concentration percentiles at each station. Outputs for the Mann-Kendall and Theil-Sen tests for NO_2 from the ProUCL software are presented in Appendix G.

Table 10: NO_2 trend analysis: Mann-Kendall and Theil-Sen Slope summary (α=0.05)

Station	Concentration	Mann-Kendall Trend Analysis	Theil-Sen Slope: Magnitude per decade (ppb)	LCL, UCL per decade
Edmonton South 2006-2013	50th Percentile	↓	-3.3	(-4.5, -1.7)
	65th Percentile	↓	-3.9	(-6.2, -1.1)
	80th Percentile	↓	-6.3	(-10.0, -0.9)
	90th Percentile	No Trend	-	(-9.5, 5.0)
	95th Percentile	No Trend	-	(-9.2, 11.0)
	98th Percentile	No Trend	-	(-10.0, 14.5)
Woodcroft 2003-2013	50th Percentile	↓	-3.3	(-4.4, -1.7)
	65th Percentile	↓	-3.4	(-6.3, -1.9)
	80th Percentile	↓	-3.2	(-8.0, -0.5)
	90th Percentile	No Trend	-	(-9.4, 3.1)
	95th Percentile	No Trend	-	(-9.1, 3.2)
	98th Percentile	No Trend	-	(-12.2, 2.4)
Gold Bar 2007-2013	50th Percentile	No Trend	-	(-5.6, 0.4)
	65th Percentile	No Trend	-	(-10.5, 0.7)
	80th Percentile	No Trend	-	(-14.4, 0.1)
	90th Percentile	↓	-4.8	(-11.6, -1.8)
	95th Percentile	↓	-4.9	(-8.9, -1.3)
	98th Percentile	No Trend	-	(-9.3, 2.7)

At the Edmonton South station, trend analysis detected a statistically significant decreasing trend at the 50th, 65th, and 80th percentiles. The most significant trend was observed at the 80th concentration percentile, with a decrease in magnitude of -6.3 ppb per decade (α=0.05). The 50th and 65th concentration percentiles averaged a decrease of -3.6 ppb per decade (α=0.05). At the Woodcroft station, trend analysis also detected a decreasing trend at the 50th, 65th, and 80th percentiles. The magnitude of the trend was similar across the three concentration percentiles, averaging a decrease of -3.3 ppb per decade (α=0.05).

Nitrogen dioxide concentrations at the Gold Bar station exhibit a different trend when compared to the Edmonton South and Woodcroft stations. Trend analysis detected a decreasing trend at the higher concentration percentiles (90th and 95th), rather than at the 50th, 65th, and 80th

concentration percentiles observed at the other two stations. The decrease in magnitude at the 90th percentile was -4.8 ppb per decade, and -4.9 ppb per decade at the 95th percentile (α=0.05). The changes in NO_2 concentration over the study period are observed in the high concentration data rather than in the median and mid-range concentration data, as observed at the other two stations.

Near-field (local) and far-field (regional) sources can both impact the air quality measured at a station (Kindzierski, 2013). While regional effects should be similar for all three stations, local effects may vary significantly, potentially causing the distinctive trend observed at the Gold Bar station. The main sources of NO_2 in urban environments include vehicular emissions, industrial emissions, and power generation plants (Alberta Environment, 2007a; Boersma et al., 2009; Environment Canada, 2013a). The Gold Bar station is located in close proximity to major industrial operations in East Edmonton and Strathcona County (refer to Figure 13); the Eastgate Business Park and Northeast Edmonton Industrial Area are located just over 1 km to the south and east (refer to Figure 8). Industry in this area includes manufacturing, oil and gas refineries, and wastewater treatment services. While this analysis cannot identify the true cause of the trend, it is possible that industrial emissions sources may exhibit a greater impact at this station. Further investigation would be required to confirm the cause of the trends observed at the Gold Bar station.

A recent study carried out by ESRD has also detected decreasing trends in NO_2 concentrations in most urban centers in Alberta over the past two decades (ESRD, 2015b). Recorded NO_2 concentrations are higher in large urban centers such as Edmonton and Calgary; however, ESRD reports a decline of 38% in the annual average NO_2 concentration at the Edmonton Central station between 1990 and 2012 (ESRD, 2015b). This decrease is attributed to improvements in industrial and vehicle emissions controls, and the decline in ambient NO_2

concentrations is expected to continue with the introduction and use of new emissions control technologies and alternative fuel sources (ESRD, 2015b).

4.5.2 *$PM_{2.5}$*

Figures 24a and 25a present the benchmark concentration profiles for $PM_{2.5}$ at the Edmonton South station (2006-2013) and Woodcroft station (2003-2013). Figures 24b and 25b presents the benchmark concentration profiles, excluding the 2010 data. The 2010 data sets were influenced by a high number of wildfires and winter smog events, and were determined to be an outlier (ESRD, 2015a). The 2010 $PM_{2.5}$ data was removed from the data sets for trend analysis. 2003 data from the Woodcroft station also shows higher concentrations for the benchmark concentration percentiles, however there is a lack of information available to determine if 2003 was also influenced by a high number of wildfires or smog events. The 2003 data set was retained for analysis.

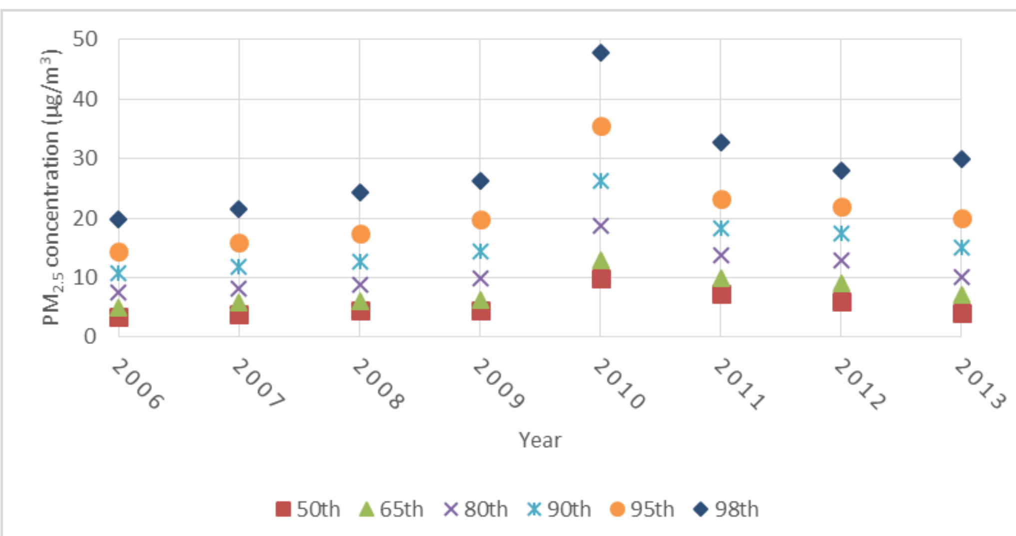

Figure 24a: Edmonton South $PM_{2.5}$ concentration percentiles, 2006-2013 (µg/m^3)

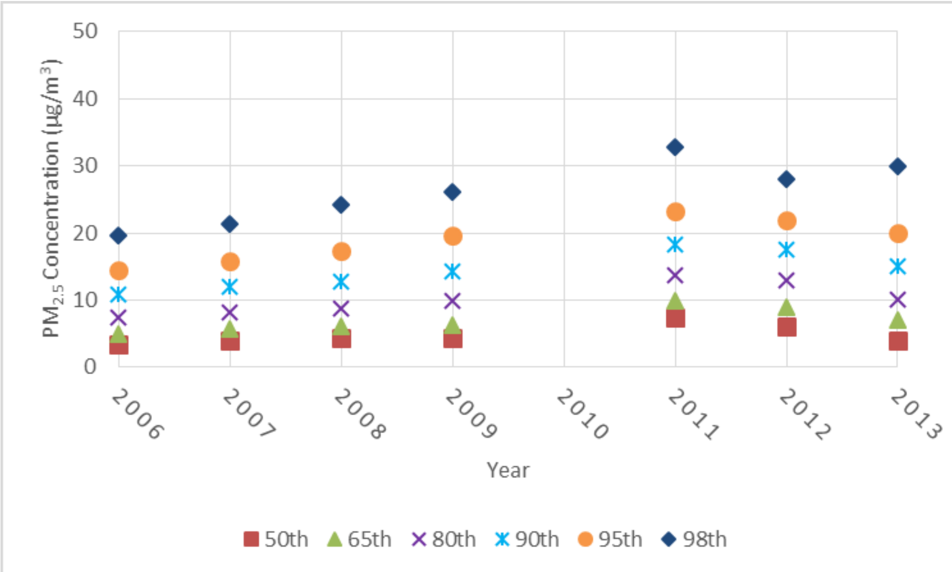

Figure 24b: Edmonton South $PM_{2.5}$ concentration percentiles, 2006-2013 excluding 2010 (µg/m^3)

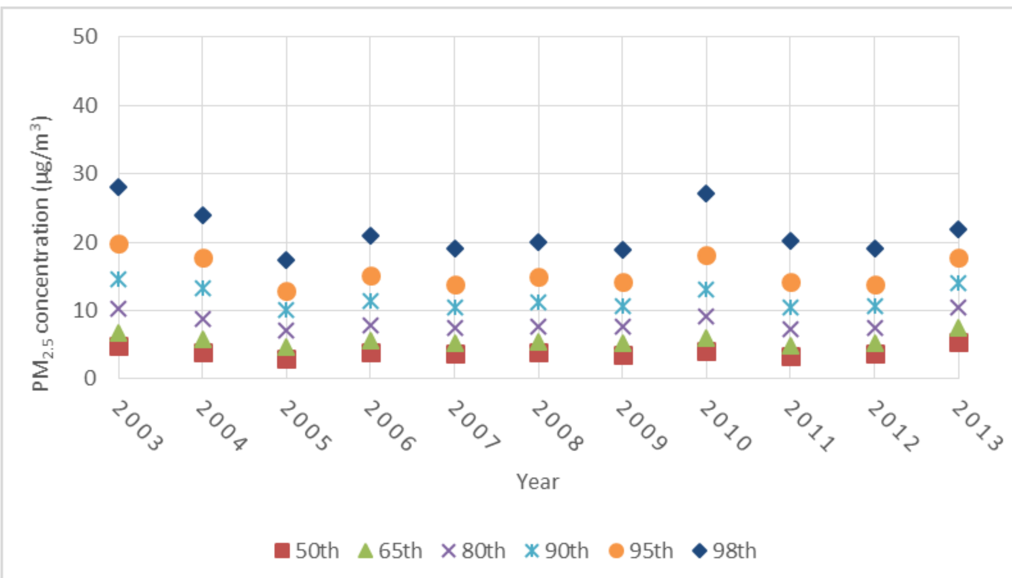

Figure 25a: Woodcroft $PM_{2.5}$ concentration percentiles, 2003-2013 (µg/m^3)

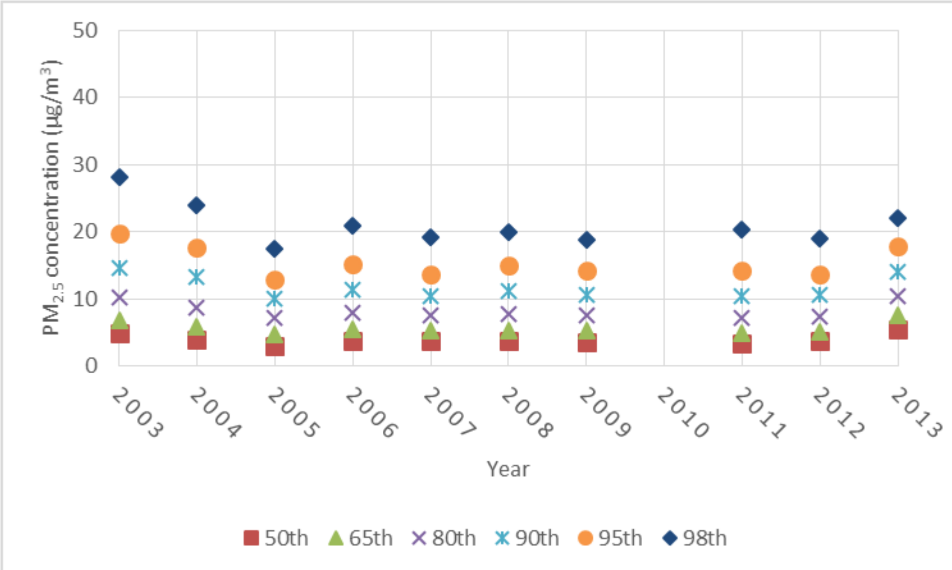

Figure 25b: Woodcroft $PM_{2.5}$ concentration percentiles, 2003-2013 excluding 2010 (µg/m^3)

Table 11 presents the summary of the Mann-Kendall and Theil-Sen trend analysis for $PM_{2.5}$. Trend analysis detected statistically significant increasing trends for $PM_{2.5}$ concentration for almost all of the benchmark concentration percentiles at the Edmonton South station. No significant trends were observed at the Woodcroft station. Outputs for the Mann-Kendall and Theil-Sen test for $PM_{2.5}$ from the ProUCL software is presented in Appendix H.

Table 11: $PM_{2.5}$ trend analysis: Mann-Kendall and Theil-Sen Slope summary (α=0.05)

Station	Concentration	Mann-Kendall Trend Analysis	Theil-Sen Slope: Magnitude per decade (µg/m^3)	LCL, UCL per decade
Edmonton South 2006-2013	50th Percentile	No trend	-	(-0.9, 5.3)
	65th Percentile	↑	4.3	(1.5, 9)
	80th Percentile	↑	7.7	(0.2, 11)
	90th Percentile	↑	11	(1.5, 15)
	95th Percentile	↑	13	(0.4, 18)
	98th Percentile	↑	17	(9.4, 26.2)
Woodcroft 2003-2013	50th Percentile	No trend	-	(-1.4, 1.5)
	65th Percentile	No trend	-	(-1.6, 1.7)
	80th Percentile	No trend	-	(-3.4, 1.9)
	90th Percentile	No trend	-	(-5.8, 1.8)
	95th Percentile	No trend	-	(-7.5, 2.7)
	98th Percentile	No trend	-	(-11.4, 3.8)

Trend analysis for the Edmonton South station detected a statistically significant increasing trend in $PM_{2.5}$ concentrations for almost all concentration percentiles, with the exception of the 50th percentile. The increasing trend is strongest at the 98th percentile, with an increase in magnitude of 17 $\mu g/m^3$ per decade (α=0.05).

Trend analysis results for this station should be interpreted with caution. Several changes in monitoring instrumentation methods occurred over the analyzed time period (CASA, 2006; ESRD, 2015a). A Tapered Element Oscillating Microbalance (TEOM) analyzer is in use at the Edmonton South station to monitor $PM_{2.5}$. The analyzer was upgraded in October 2009, with the addition of a Filter Dynamics Measurement System (FDMS). The FDMS is designed to preserve volatile particulate matter and reduce the impact of atmospheric conditions. This instrumentation change would typically increase the recorded measurement values of $PM_{2.5}$, as the volatile portion of PM is preserved (Thermo Electron Corporation, 2006). In addition to this instrumentation change, operation modes and reporting conditions were also altered in 2008, 2009, and 2011 (CASA, 2006). The increasing trend observed at this station may be attributed to the changes in instrumentation throughout the study period, therefore trend analysis may not be suitable for the Edmonton South $PM_{2.5}$ data set. The Woodcroft station was not affected by instrumentation changes, as it was only upgraded with an FDMS in August 2013. No trends were detected for $PM_{2.5}$ at the Woodcroft station.

The trend analysis of the NPRI $PM_{2.5}$ emissions data further supports the inference that the observed increasing trend in $PM_{2.5}$ concentrations at the Edmonton South station can be attributed to instrumentation changes. Mann-Kendall and Theil-Sen trend analysis did not detect any statistically significant trends in industrial $PM_{2.5}$ emissions within the study area for 2003-2013.

4.5.3 *CO*

Figure 25 presents the benchmark concentration percentiles for CO at the Edmonton South station (2006-2013). Little to no change was observed in the studied percentiles; only a minor decrease in CO concentration was detected at the 95th and 98th percentiles, while almost no change was observed at the remaining percentiles.

Figure 25: Edmonton South CO concentration percentiles, 2006-2013 (ppm)

Table 12 presents the summary of the Mann-Kendall and Theil-Sen trend analysis for CO. Mann-Kendall trend analysis detected a statistically significant decreasing trend in CO concentration only at the 98th concentration percentile, however Theil-Sen analysis determined the magnitude of change to be insignificant (α=0.05). No significant magnitude of change in CO concentrations was observed at the Edmonton South station from 2006-2013. Outputs for the Mann-Kendall and Theil-Sen tests for CO from the ProUCL software are available in Appendix I.

Table 12: CO trend analysis: Mann-Kendall and Theil-Sen Slope summary (α=0.05)

Station	Concentration	Mann-Kendall Trend Analysis	Theil-Sen Slope: Magnitude per decade (ppm)	LCL, UCL per decade
Edmonton South 2006-2013	50th Percentile	No Trend	-	(0.0, 0.0)
	65th Percentile	No Trend	-	(-0.2, 0.0)
	80th Percentile	No Trend	-	(0.0, 0.0)
	90th Percentile	No Trend	-	(0.0, 0.0)
	95th Percentile	No Trend	-	(-0.5, 0.0)
	98th Percentile	↓	Insignificant	(-0.5, 0.0)

In an urban environment, vehicles are the greatest contributor to CO emissions (Environment Canada, 2013d). Despite a significant increase in the number of registered vehicles in Edmonton, no increase is observed in CO concentrations. This is largely due to the improvement of vehicle emissions control technology since the 1970's, as well as stringent vehicle emissions regulations (ESRD, 2015c). The development of catalytic converters, improvements to fuel quality, and the introduction of hybrid cars are effectively working to reduce vehicular CO emissions (ESRD, 2015c).

An additional factor that could be limiting the power of the trend analysis is the small data set available for the Edmonton South station. The study period is only 2006-2013; perhaps examining a station with a larger data set would yield different results in trend analysis. ESRD completed a trend analysis for CO across the province from 1990 through 2012 (ESRD, 2015c). A significant decrease in CO emissions was reported, with annual average CO concentrations decreasing by 33% to 83% at monitoring stations throughout Alberta (ESRD, 2015c). An even greater decrease was observed in peak CO concentrations (99^{th} percentile), with 44% to 99% reduction in CO concentrations for the same time period across the province (ESRD, 2015c).

4.5.4 *Multiple Linear Regression Analysis*

An exploratory multiple linear regression analysis was attempted using the 50th percentile concentration data for NO_2 at the Woodcroft station. This data set was determined to be the strongest of the calculated concentration profiles, as it demonstrates a robust statistically significant decreasing trend (α=0.05). The lower and upper confidence limits of the Theil-Sen slope indicate the associated confidence interval is relatively small (-4.4, -1.7) and does not include the value 0, thus indicating the decreasing trend is significant at α=0.05.

Figure 27 presents the 50th percentile NO_2 concentrations at the Woodcroft station for 2003-2013; Figure 28 presents the interpolated population data for the Woodcroft study area for 2003-2013; Figure 28 presents the interpolated traffic volume data for the selected count sites in the Woodcroft study area for 2003-2013; and Figure 29 presents the NPRI reported NO_2 emissions for 2003-2013.

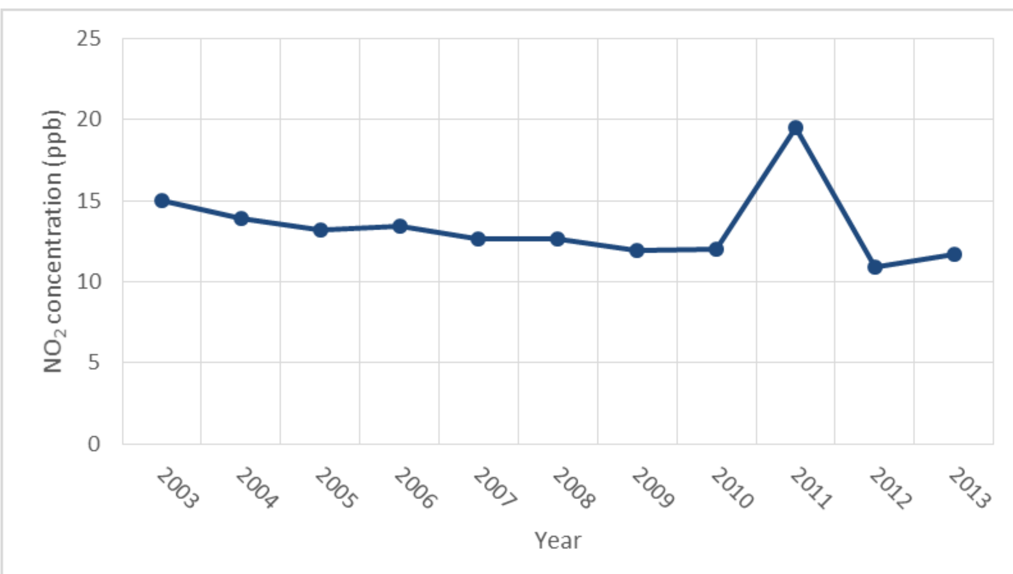

Figure 26: Woodcroft station 50th percentile NO_2 concentrations, 2003-2013 (ppb)

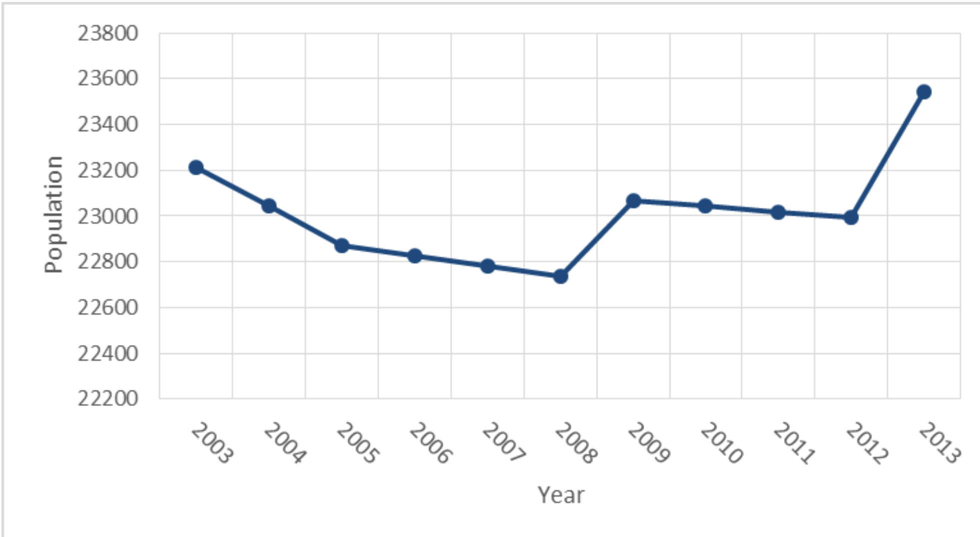

Figure 27: Woodcroft study area interpolated population, 2003-2013

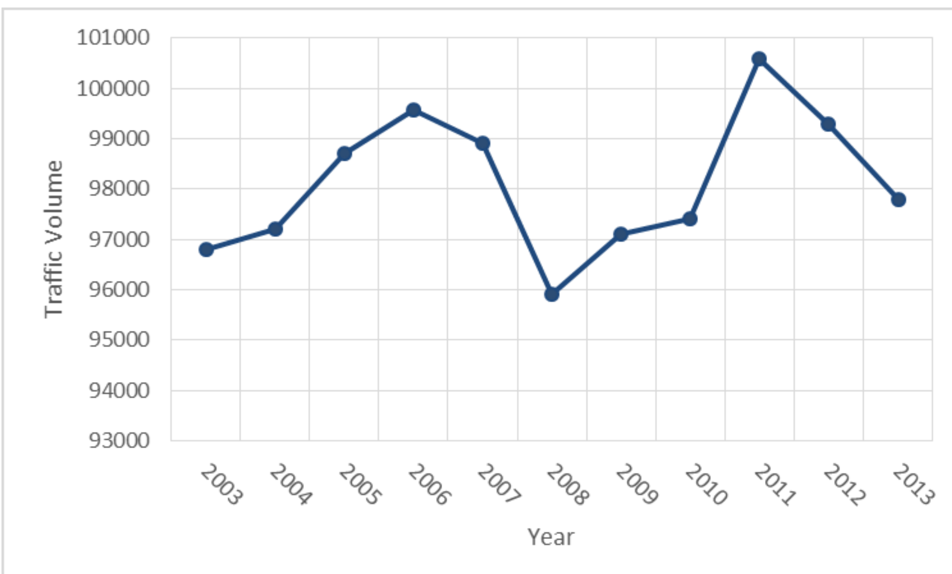

Figure 28: Woodcroft study area interpolated traffic volume, 2003-2013

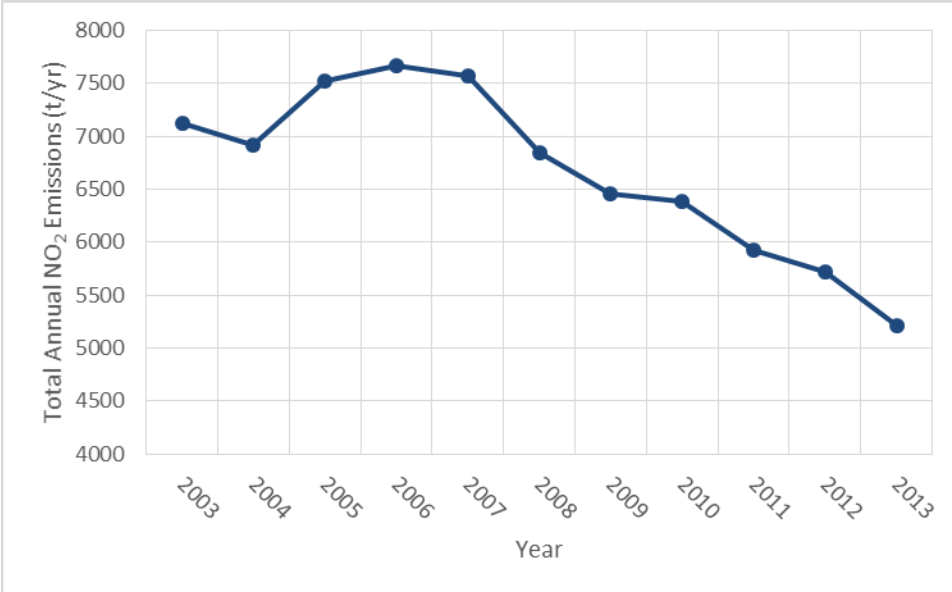

Figure 29: NPRI reported NO_2 emissions, 2003-2013 (tonnes/year)

The outcome of the multiple linear regression analysis is presented in the Analysis of Variance table (ANOVA), Table 13. Analysis was completed as per the methods outlined in Montgomery et al., 2001 using SAS v.9.2.

Table 13: Woodcroft NO_2 50th percentile Analysis of Variance table (α=0.05)

Predictor	Degrees of freedom	Sum of Squares	Mean of the Squares	F value	Pr (>F)
Population	1	0.035	0.0353	0.0055	0.9429
Traffic	1	9.225	9.2248	1.4406	0.2691
Industry	1	0.777	0.7773	0.1214	0.7378
Residuals	7	44.824	6.4035	-	-

The probability (Pr) that the calculated statistic is greater than the F-statistic represents the p-value. If $p < \alpha$ (α=0.05), then the independent variables x (population, traffic volume, industrial NO_2 emissions) would be significant predictors for the dependent variable y^1 (50th percentile NO_2 concentrations at the Woodcroft station). P-values for the three independent variables were all significantly larger than the significance level, α=0.05, meaning we cannot reject the null hypothesis (H_0: $b_0 = b_1 = b_2 = \ldots = b_i = 0$). It is concluded that these predictors (population, traffic volume, industrial NO_2 emissions) are unsuitable for reconstructing ambient NO_2 concentrations at the Woodcroft station. The relatively small data set could be the cause of this outcome; a small data set is limited in its statistical power. No additional data sets were examined, as they would all yield similar outcomes due to the small sample size. Analysis with a larger data set would be recommended to accurately determine if any relationship exists between the independent and dependent variables.

CHAPTER 5: CONCLUSIONS AND RECOMMENDATIONS

The purpose of this study was to investigate long-term trends in ambient air quality at residential air monitoring stations in Edmonton, AB between 2003 and 2013. Three common ambient pollutants (NO_2, $PM_{2.5}$, and CO) were examined for trends. In addition, trends in population, traffic volume, and industrial emissions were also investigated. Mann-Kendall and Theil-Sen tests were used for trend analysis. A simple multiple linear regression analysis was attempted to determine if the three independent variables (population, traffic volume, and industrial emissions) were able to predict changes in ambient air quality.

Census data and traffic volume counts were used to analyze population and traffic trends. Increasing trends were observed for the overall population of the City of Edmonton, and for the number of vehicles registered in Edmonton (α=0.05). No significant changes were observed for population or traffic volume in the Woodcroft or Gold Bar study areas. An increase in population was detected in the Edmonton South study area (α=0.05), while a decreasing trend was visually detected for traffic volume at two count sites in this area. The increase in population in the Edmonton South study area is attributed to the proximity of these neighbourhoods to the University of Alberta and LRT line. Traffic volumes in this area are likely influenced by the development of the LRT line, which provides easy access to the University and downtown for residents in South Edmonton, thus potentially reducing the number of vehicles travelling along the roadways near the LRT.

NPRI emissions data was utilized to analyze trends in reported industrial emissions for NO_2, $PM_{2.5}$, and CO. A decreasing trend was observed for NO_2 concentrations (α=0.05). This is attributed to improvements in industrial emissions controls. No significant trends were detected for reported industrial emissions of $PM_{2.5}$ or CO.

Concentration-based percentile benchmarks for NO_2, $PM_{2.5}$, and CO were used to analyze long-term trends at the Edmonton South, Woodcroft, and Gold Bar residential ambient air monitoring stations in Edmonton, AB. Statistically significant decreasing trends were observed at all stations for NO_2 concentrations ($\alpha=0.05$). At the Edmonton South and Woodcroft stations, these trends were detected in the median and mid-range percentiles (50^{th}, 65^{th}, 80^{th}), while the Gold Bar station detected decreasing trends in the higher concentration percentiles (90^{th} and 95^{th}). This decrease in NO_2 concentrations is attributed to improvements in emissions controls for industrial facilities and vehicles. At the Edmonton South station, trend analysis detected a statistically significant increasing trend for $PM_{2.5}$ at almost all concentration-based percentiles ($\alpha=0.05$). This trend should be interpreted with caution, as it may be caused by changes in instrumentation during the study period. Analysis of the Woodcroft station and NPRI data did not detect any trends in $PM_{2.5}$ concentrations over the study period, further indicating instrumentation changes are the likely cause of the trend observed at the Edmonton South station. No statistically significant trends were observed for CO concentrations at the Edmonton South station over the study period.

A simple multiple linear regression analysis attempted to relate the trends observed in the 50^{th} concentration percentile for NO_2 at the Woodcroft station with changes in population, traffic volume, and industrial NO_2 emissions. Analysis determined that these predictors were unsuitable for reconstructing ambient NO_2 concentrations at the Woodcroft station. Unfortunately, the relatively small data set was determined to be insufficient for this type of analysis; a larger data set may yield different outcomes.

The target study period was 2003-2013, however only the Woodcroft station met this criteria. To fully understand long-term trends, and provide greater confidence in the trends detected, a longer study period would be recommended for the Edmonton South and Gold Bar stations; greater than 10 years of data would provide a better indication of ambient air quality trends and influences. Further investigation into the trends observed in $PM_{2.5}$ concentrations at the Edmonton South station would be beneficial, to confirm that the detected trend is attributable to instrumentation changes. A larger data set (e.g. 15+ years) may also be beneficial for analyzing correlations using multiple linear regression; the data set used was limited and unable to provide convincing evidence of any relationships between population, traffic volume, industrial emissions, and pollutant concentration.

Three residential ambient air monitoring stations and three pollutants were examined in this study. There are additional residential and industrial ambient air quality monitoring stations operating in the Edmonton region. Further studies could include all monitoring stations and all monitored pollutant parameters to better understand the spatial and temporal changes in air quality in Edmonton.

REFERENCES

Alberta Environment. 2002. Alberta State of the Environment: Air Quality 1998. Government of Alberta, Alberta Environment. Edmonton, AB.

Alberta Environment. 2007a. Assessment report on Nitrogen dioxide for developing ambient air quality objectives. Prepared by Toxico-Logic Consulting Inc. Edmonton, AB.

Alberta Environment. 2007b. Alberta Ambient Air Quality Objectives: Fine Particulate Matter ($PM_{2.5}$). Government of Alberta, Alberta Environment. Edmonton, AB. Available at: http://esrd.alberta.ca/focus/state-of-the-environment/air/condition-indicators/documents/AirQualityObjectivesFinePM-Feb1-2007.pdf (accessed January, 2015).

Alberta Environment. 2009. Air management in Alberta. Government of Alberta, Alberta Environment. Edmonton, AB. Available at: http://environment.gov.ab.ca/info/library/8137.pdf (accessed January, 2015).

Alberta Environment. 2011. Alberta Ambient Air Quality Objectives: Nitrogen Dioxide. Government of Alberta, Alberta Environment. Available at: http://environment.gov.ab.ca/info/library/8303.pdf (accessed January, 2015).

Alberta Environment and Sustainable Resource Development (ESRD). 2008. Focus on: Air Quality. Government of Alberta, ESRD. Edmonton, AB. Available at: http://esrd.alberta.ca/about-esrd/documents/FocusOn-AirQuality-2014.pdf (accessed January, 2015).

Alberta Environment and Sustainable Resource Development (ESRD). 2013. Alberta Ambient Air Quality Objectives and Guidelines Summary. Government of Alberta, ESRD. Available at: http://environment.gov.ab.ca/info/library/5726.pdf (accessed January, 2015).

Alberta Environment and Sustainable Resource Development (ESRD). 2014a. Ambient Air Monitoring. Government of Alberta, ESRD. Available at: http://esrd.alberta.ca/air/monitoring-and-reporting/ambient-air-monitoring/default.aspx (accessed January, 2015).

Alberta Environment and Sustainable Resource Development (ESRD). 2014b. South Saskatchewan Region Air Quality Management Framework for Nitrogen Dioxide, Ozone and Fine Particulate Matter. Government of Alberta, ESRD. Available at: http://esrd.alberta.ca/focus/cumulative-effects/cumulative-effects-management/management-frameworks/documents/SSRD-AirQualityFramework-Jul21-2014.pdf (accessed February, 2015).

Alberta Environment and Sustainable Resource Development (ESRD). 2014c. Air Monitoring Directive, Chapter 6: Ambient Data Quality. Government of Alberta, ESRD, Air Policy. Edmonton, AB. Available at: http://esrd.alberta.ca/air/objectives-directives-policies-and-standards/air-monitoring-directive/default.aspx (accessed March, 2015).

Alberta Environment and Sustainable Resource Development (ESRD). 2015a. State of the Environment-Air: Fine Particulate Levels ($PM_{2.5}$). Government of Alberta, ESRD. Available at: http://esrd.alberta.ca/focus/state-of-the-environment/air/condition-indicators/fine-particulate-levels.aspx (accessed March, 2015).

Alberta Environment and Sustainable Resource Development (ESRD). 2015b. State of the Environment-Air: Nitrogen Dioxide (NO_2) Levels. Government of Alberta, ESRD. Available at: http://esrd.alberta.ca/focus/state-of-the-environment/air/condition-indicators/nitrogen-dioxide.aspx (accessed March, 2015).

Alberta Environment and Sustainable Resource Development (ESRD). 2015c. State of the Environment-Air: Carbon Monoxide Levels. Government of Alberta, ESRD. Available at: http://esrd.alberta.ca/focus/state-of-the-environment/air/condition-indicators/carbon-monoxide-levels.aspx (accessed March, 2015).

Alberta Transportation. 2008. Number of Motorized Vehicles Registered in Alberta as of March 31 2004-2008. Government of Alberta, Alberta Transportation, Office of Traffic Safety. Available at: http://www.transportation.alberta.ca/Content/docType47/Production/VehReg2008.pdf (accessed April, 2015).

Alberta Transportation. 2012. Number of Motorized Vehicles Registered in Alberta as of March 31 2008-2012. Government of Alberta, Alberta Transportation, Office of Traffic Safety. Available at: http://www.transportation.alberta.ca/Content/docType47/Production/vehreg2012.pdf (accessed April, 2015).

Alberta Transportation. 2014. Number of Motorized Vehicles Registered in Alberta as of March 31 2010-2014. Government of Alberta, Alberta Transportation, Office of Traffic Safety. Available at: http://www.transportation.alberta.ca/Content/docType47/Production/VehReg2014.pdf (accessed April, 2015).

Agency for Toxic Substances and Disease Registry (ATSDR). 2002. ToxFAQs: Nitrogen Oxides (nitric oxide, nitrogen dioxide, etc.). ATSDR, Division of Toxicology. Atlanta, GA. Available at: http://www.atsdr.cdc.gov/toxfaqs/tfacts175.pdf (accessed January, 2015).

Agency for Toxic Substances and Disease Registry (ATSDR). 2012. Toxicological Profile for Carbon Monoxide. U.S. Department of Human Services, Public Health, ATSDR. Atlanta, GA. Available at: http://www.atsdr.cdc.gov/toxprofiles/tp201.pdf (accessed January, 2015).

Bari, M.A. and Kindzierski, W.B. 2015a. Fifteen-year trends in criteria air pollutants in oil sands communities of Alberta, Canada. *Environment International*, 74: 200–208. doi:10.1016/j.envint.2014.10.009

Bari, M.A. and Kindzierski, W.B. 2015b. Supplemental Information: Fifteen-year trends in criteria air pollutants in oil sands communities of Alberta, Canada. *Environment International*, 74: Supplemental Information.

Beckerman, B., Jerrett, M., Brook, J.R., Verma, D.K., Arain, M.A., and Finkelstein, M.M. 2008. Correlation of nitrogen dioxide with other traffic pollutants near a major expressway. *Atmospheric Environment*, 42(2): 275–290. doi:10.1016/j.atmosenv.2007.09.042

Blanchard, C.L., Tanenbaum, S., and Hidy, G.M. 2014. Spatial and temporal variability of air pollution in Birmingham, Alabama. *Atmospheric Environment*, 89: 382–391. doi:10.1016/j.atmosenv.2014.01.006

Boersma, K.F., Jacob, D.J., Trainic, M., Rudich, Y., DeSmedt, I., Dirksen, R., and Eskes, H.J. 2009. Validation of urban NO_2 concentrations and their diurnal and seasonal variations observed from the SCIAMACHY and OMI sensors using in situ surface measurements in Israeli cities. *Atmospheric Chemistry and Physics*, 9(12): 3867–3879. doi:10.5194/acp-9-3867-2009

Clean Air Strategic Alliance (CASA). n.d. CASA - Static Codes. Available at: http://www.casadata.org/Reports/CASA_FQ.asp?type=3 (accessed January, 2015).

Clean Air Strategic Alliance (CASA). 2006. CASA Data Warehouse. Available at: http://www.casadata.org/ (accessed January, 2015).

City of Edmonton. n.d. Population Change Map, 1971-2011. City of Edmonton, Sustainable Development. Available at: http://www.edmonton.ca/city_government/documents/Neighbourhood_Population_Change_1971_2011_Map.pdf (accessed April, 2015).

City of Edmonton. 2001. 2001 Edmonton Demographic Profile. City of Edmonton, Planning and Development Department. Available at: http://www.edmonton.ca/business_economy/documents/InfraPlan/AgeHholds.pdf (accessed February, 2015).

City of Edmonton. 2008. Traffic Volumes Average Annual Weekday Monitoring 2002-2007. City of Edmonton, Transportation Planning. Edmonton, AB.

City of Edmonton. 2014a. Municipal Census Results: City of Edmonton. Available at: http://www.edmonton.ca/city_government/facts_figures/municipal-census-results.aspx (accessed February, 2015).

City of Edmonton. 2014b. 2013 AAWDT Report: Average Annual Weekday Traffic Volumes. City of Edmonton, Planning Implementation and Evaluation, Strategic Monitoring and Analysis. Edmonton, AB.

City of Edmonton. 2015a. A Community Profile: Area Profiles (2005 Census). Available at: http://coewebapps3.edmonton.ca/DataDemographics/SearchProfiles.aspx (accessed February, 2015).

City of Edmonton. 2015b. Population History: City of Edmonton. City of Edmonton, Election and Census Services. Edmonton, AB. Available at: http://www.edmonton.ca/city_government/facts_figures/population-history.aspx (accessed February, 2015).

City of Edmonton. 2015c. Century Park LRT Station. City of Edmonton, Edmonton Transit System. Edmonton, AB. Available at: http://www.edmonton.ca/transportation/ets/alerts_routes_schedules_maps/century-park-lrt-station.aspx (accessed April, 2015).

Clements, A.L., Jia, Y., Denbleyker, A., McDonald-Buller, E., Fraser, M.P., Allen, D.T. Collins, D.R., Michel, E., Pudota, J., Sullivan, D., and Zhu, Y. 2009. Air pollutant concentrations near three Texas roadways, part II: Chemical characterization and transformation of pollutants. *Atmospheric Environment*, 43(30): 4523–4534. doi:10.1016/j.atmosenv.2009.06.044

Colls, J. 1997. *Air Pollution: An Introduction*. E & FN Spon, London, UK and New York, NY, USA. 1st edition.

Colls, J. 2002a. Gaseous air pollutants: sources and control. In *Air Pollution: Measurement, Modelling and Mitigation*. Spon Press, London, UK and New York, NY, USA. 2nd edition.

Colls, J. 2002b. Meteorology and modelling. In *Air Pollution: Measurement, Modelling and Mitigation*. Spon Press, London, UK and New York, NY, USA. 2nd edition.

Environment Canada. 2013a. Nitrogen Oxides: Main Emission Sources. Government of Canada, Environment Canada. Available at: https://ec.gc.ca/air/default.asp?lang=En&n=125BB36D-1 (accessed February, 2015).

Environment Canada. 2013b. Particulate Matter. Government of Canada, Environment Canada. Available at: http://www.ec.gc.ca/air/default.asp?lang=En&n=2C68B45C-1 (accessed January, 2015).

Environment Canada. 2013c. Canadian Smog Science Assessment Highlights and Key Messages. Government of Canada, Environment Canada. Available at: https://www.ec.gc.ca/Air/default.asp?lang=En&n=72F82C27-1&offset=7&toc=show (accessed February, 2015).

Environment Canada. 2013d. Carbon Monoxide: Main Emission Sources. Government of Canada, Environment Canada. Available at: https://ec.gc.ca/air/default.asp?lang=En&n=959FDFB1-1 (accessed February, 2015).

Environment Canada. 2014a. Ambient Levels of Nitrogen Dioxide Government of Canada, Environment Canada. Available at: https://www.ec.gc.ca/indicateurs-indicators/default.asp?lang=en&n=C8BFC3F2-1 (accessed February, 2015).

Environment Canada. 2014b. Ambient Levels of Fine Particulate Matter. Government of Canada, Environment Canada. Available at: https://www.ec.gc.ca/indicateurs-indicators/default.asp?lang=en&n=029BB000- (accessed February, 2015).

Environment Canada. 2014c. National Pollutant Release Inventory. Government of Canada, Environment Canada. Available at: https://www.ec.gc.ca/inrp-npri/default.asp?lang=En&n=4A577BB9-1 (accessed February, 2015).

Environment Canada. 2014d. Guide for Reporting to the National Pollutant Release Inventory (NPRI) 2014 and 2015. Government of Canada, Environment Canada. Available at: https://www.ec.gc.ca/inrp-npri/default.asp?lang=En&n=28C24172-1 (accessed February, 2015).

Environment Canada. 2014e. Environmental Regulations for the Energy and Transportation sectors. Government of Canada, Environment Canada. Available at: https://www.ec.gc.ca/Air/default.asp?Lang=En&n=DDBB166E-1 (accessed January, 2015).

Environment Canada. 2015a. Climate Glossary. Government of Canada, Environment Canada, Climate. Available at: http://climate.weather.gc.ca/glossary_e.html#p (accessed February, 2015).

Environment Canada. 2015b. Pollution Data and Reports - National Pollutant Release Inventory. Government of Canada, Environment Canada. Available at: http://www.ec.gc.ca/inrp-npri/default.asp?lang=En&n=B85A1846-1 (accessed February, 2015).

Flaschsbart, P.G. 2007. Exposure to Carbon Monoxide. In Ott, W.R., Steinemann, A.C., and Wallace, L.A. (editors). *Exposure Analysis* (p. 113-146). Taylor & Francis Group, Boca Raton, FL.

Flemming, J. and Inness, A. 2014. [Global Climate] Carbon Monoxide [in "State of the Climate in 2013"]. *Bulletin of the American Meteorology Society,* 95(7): S43. doi: 10.1111/j.1467-2979.2010.00380.x

Gauderman, J., Avol, E., Gilliland, F., Hita Vora, M.S., Thomas, D., Berhane, K. McConnell, R., Kuenzli, N., Lurmann, F., Rappaport, E., Margolis, H., Bates, D., and Peters, J. 2004. The effect of air pollution on lung development from 10 to 18 years of age. *New England Journal of Medicine*, 351(11): 1057–1067.

Gilbert, N.L., Woodhouse, S., Stieb, D.M., and Brook, J.R. 2003. Ambient nitrogen dioxide and distance from a major highway. *The Science of the Total Environment*, 312: 43–46. doi:10.1016/S0048-9697(03)00228-6

Grantz, D.A, Garner, J.H.B., and Johnson, D.W. 2003. Ecological effects of particulate matter. *Environment International*, 29: 213–239. doi:10.1016/S0160-4120(02)00181-2

Hartmann, D.J., Klein Tank, A.M.G., Rusticucci, M., Alexander, L.V, Brönnimann, S., Charabi, Y. Dentener, F.J., Dlugokencky, E.J., Easterling, D.R., Kaplan, A., Soden, B.J., Thorne, P.W., Wild, M., and Zhai, P.M. 2013. Observations: Atmosphere and Surface. In Stocker, T.F., Qin, D., Plattner, G-K., Tignor, M., Allen, S.K., Boschung, J., Nauels, A., Xia, Y., Bex, V. and Midgley, P.M. (editors). *Climate Change 2013: The Physical Science Basis. Contribution of Working Group I to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change* (pp. 159-254). Cambridge, UK and New York, NY, USA: Cambridge University Press. doi:10.1017/CBO9781107415324.008

Health Effects Institute. 2010. Traffic-related air pollution: A critical review of the literature on emissions, exposure, and health effects. Health Effects Institute, HEI Panel on the Health Effects of Traffic-Related Air Pollution. Boston, MA.

Idriss, A. and Spurrel, F. 2009. Air Quality Model Guideline. Government of Alberta, Alberta Environment, Climate Change, Air and Land Policy Branch. Edmonton, AB. Available at: http://www.assembly.ab.ca/lao/library/egovdocs/2009/alen/173465.pdf (accessed February, 2015).

Kelly, F.J. and Fussell, J.C. 2012. Size, source and chemical composition as determinants of toxicity attributable to ambient particulate matter. *Atmospheric Environment*, 60: 504–526. doi:10.1016/j.atmosenv.2012.06.039

Kindzierski, W. B., Chelme-Ayala, P., & Gamal El-Din, M. 2009. Wood Buffalo Environmental Association: Ambient Air Quality Data Summary and Trend Analysis Part 1 Main Report. University of Alberta. School of Public Health. Department of Public Health Sciences.

Kindzierski, W.B. 2013. Lecture on Exposure Concepts, PHS 511 Exposure Assessment. University of Alberta, Edmonton, AB.

Lavagnini, I., Badocco, D., Pastore, P., and Magno, F. 2011. Theil-Sen nonparametric regression technique on univariate calibration, inverse regression and detection limits. *Talanta,* 87: 180–188. doi:10.1016/j.talanta.2011.09.059

Montgomery, D.C., Runger, G.C., and Hubele, N.F. 2001. *Engineering Statistics*. John Wiley & Sons, Inc. New York, NY, USA. 2nd edition.

Moore, D., Copes, R., Fisk, R., Joy, R., Chan, K., and Brauer, M. 2006. Population health effects of air quality changes due to forest fires in British Columbia in 2003. *Canadian Journal of Public Health*, 97(2): 105-108.

National Research Council of the National Academies. 2010. Global Sources of Local Pollution: An Assessment of Long-Range Transport of Key Air Pollutants to and from the United States. National Research Council of the National Academies, Committee on the Significance of International Transport of Air Pollutants, Board on Atmospheric Sciences and Climate, Division of Earth and Life Studies. National Academies Press. Washington, DC.

Ocak, S. and Turalioğlu, F.S. 2011. The criteria air pollutants levels during calm atmospheric conditions : A case study. *International Journal of Ecosystems and Ecology Sciences (IJEES),* 1(I): 1–9.

Peel, J.L., Haeuber, R., Garcia, V., Russell, A.G., and Neas, L. 2012. Impact of nitrogen and climate change interactions on ambient air pollution and human health. *Biogeochemistry*, 114: 121–134. doi:10.1007/s10533-012-9782-4

Schäfer, K., Thomas, W., Peters, A., Ries, L., Obleitner, F., Schnelle-Kreis, J., Birmill, W., Diemer, J., Fricke, W., Junkermann, W., Pitz, M., Emeis, S., Forkel, R., Suppan, P., Flentje, H., Gilge, S., Wichmann, H.E., Meinhardt, F., Zimmermann, R., Weinhold, K., Soentgen, J., Munkel, C., Freuer, C. and Cyrys, J. 2011. Influences of the 2010 Eyjafjallajökull volcanic plume on air quality in the northern Alpine region. *Atmospheric Chemistry and Physics*, 11: 8555–8575. doi:10.5194/acp-11-8555-2011

Singh, A. and Singh, A.K. 2010. ProUCL Version 5.0.00 Technical Guide: Statistical Software for Environmental Applications for Data sets with and without Nondetect Observations. US EPA, Office of Research and Development. Washington, DC.

Small, K.A. and Kazimi, C. 1995. On the Costs of Air Pollution from Motor Vehicles. *Journal of Transport Economics and Policy*, 29(1): 7–32.

Thermo Electron Corporation. 2006. Operating Manual: Series 8500 FDMS Filter Dynamics Measurement System. Thermo Electron Corporation, Environmental Instruments Division, Air Quality Instruments. East Greenbush, NY, USA.

To, T., Shen, S., and Atenafu, E. 2013. The air quality health index and asthma morbidity: a population-based study. *Environmental Health Perspectives*, 121(1): 46–52.

United States Environmental Protection Agency (US EPA). 2008. Integrated Science Assessment for Oxides of Nitrogen - Health Criteria. US EPA, National Assessment for Environmental Assessment-RTP Division, Office of Research and Development. Research Triangle Park, NC.

United States Environmental Protection Agency (US EPA). 2009. Integrated Science Assessment for Particulate Matter. US EPA, National Assessment for Environmental Assessment-RTP Division, Office of Research and Development. Research Triangle Park, NC.

United States Environmental Protection Agency (US EPA). 2012. Visibility. US EPA. Available at: http://www.epa.gov/visibility/ (accessed January, 2015).

United States Environmental Protection Agency (US EPA). 2013. Six Common Pollutants: Particulate Matter (PM). US EPA. Available at: http://www.epa.gov/pm/ (accessed January, 2015).

United States Environmental Protection Agency (US EPA). 2014. Acid Rain. US EPA. Available at: http://www.epa.gov/acidrain/index.html (accessed January, 2015).

Vallero, D.A. 2014. *Fundamentals of Air Pollution*. Academic Press. Amsterdam, Netherlands. 5th edition.

Wallace, L.A. and Smith, K.R. 2007. Exposure to Particles. In Ott, W.R., Steinemann, A.C., and Wallace, L.A. (editors.). *Exposure Analysis* (pp.171-199). Taylor & Francis Group. Boca Raton, FL.

World Health Organization. 2000. Air quality guidelines for Europe: Carbon Monoxide. World Health Organization, Regional Office for Europe. Copenhagen, Denmark.

World Health Organization. 2013. Health effects of particulate matter: Policy implications for countries in eastern Europe, Caucasus, and central Asia. World Health Organization, Regional Office for Europe. Copenhagen, Denmark.

Zhu, Y., Pudota, J., Collins, D., Allen, D., Clements, A., DenBleyker, A., Fraser, M., Jia, Y., McDonald-Buller, E., and Michel, E. (2009). Air pollutant concentrations near three Texas roadways, Part I: Ultrafine particles. *Atmospheric Environment*, 43: 4513–4522. doi:10.1016/j.atmosenv.2009.04.018

APPENDIX A: CENSUS POPULATION DATA AND PROUCL MANN-KENDALL/ THEIL-SEN OUTPUTS

Table A-1: Edmonton South station study area population, 2001-2014

Neighborhood	University of Alberta Farms	Parkallen	Lendrum Place	Mckernan	Belgravia	Pleasantview	TOTAL
Proximity	0 m	220 m 90 deg	380 m 180 deg	980 m 10 deg	910 m 340 deg	720 m 110 deg	
*2001	NA	2215	1745	2415	2165	3715	12255
2002	-	-	-	-	-	-	-
2003	-	-	-	-	-	-	-
2004	-	-	-	-	-	-	-
*2005	NA	2142	1889	2860	2153	3734	12778
2006	-	-	-	-	-	-	-
2007	-	-	-	-	-	-	-
*2008	NA	2253	1902	2667	2200	3786	12808
*2009	0	2265	1930	2711	2180	3853	12939
2010	-	-	-	-	-	-	-
2011	-	-	-	-	-	-	-
*2012	0	2215	1888	2817	2141	3755	12816
2013	-	-	-	-	-	-	-
*2014	0	2303	1883	2785	2350	4229	13550

*Census Year
Blank cell (-): no census taken

Table A-2: Woodcroft station study area population, 2001-2014

Neighborhood	Woodcroft	Huff Bremner Estate Industrial	Dominion Industrial	Dovercourt	Sherbrooke	Inglewood	Westmount	North Glenora	McQueen	TOTAL	Interpolated Total, used for Linear Model
Proximity	0 m	290 m 270 deg	730 m 330 deg	630 m 0 deg	1,100 m 50 deg	810 m 90 deg	1,030 m 130 deg	700 m 180 deg	800 m 200 deg		
*2001	2710	NA	NA	2170	2610	6530	5870	1945	1725	23560	23560
2002	-	-	-	-	-	-	-	-	-	-	23388
2003	-	-	-	-	-	-	-	-	-	-	23215
2004	-	-	-	-	-	-	-	-	-	-	23043
*2005	2551	NA	NA	2048	2522	6353	5814	1883	1699	22870	22870
2006	-	-	-	-	-	-	-	-	-	-	22825
2007	-	-	-	-	-	-	-	-	-	-	22780
*2008	2586	0	0	2090	2431	6925	5421	1656	1626	22735	22735
*2009	2617	NA	0	2063	2471	6394	5946	1919	1658	23068	23068
2010	-	-	-	-	-	-	-	-	-	-	23043
2011	-	-	-	-	-	-	-	-	-	-	23019
*2012	2598	0	0	2048	2438	6310	5900	2012	1688	22994	22994
2013	-	-	-	-	-	-	-	-	-	-	23543
*2014	2692	0	0	2118	2489	6771	6111	2095	1816	24092	24092

*Census Year
Blank cell (-): no census taken

Table A-3: Gold Bar station study area population, 2001-2014

Neighborhood	Gold Bar	Capilano	River Valley Gold Bar	Eastgate Business Park	Ottewell	Terrace Heights	Fulton Place	TOTAL
Proximity	0 m	390 m 310 deg	670 m 90 deg, 440m 40 deg	960 m 180 deg	1,000 m 200 deg	1,080 m 210 deg	300 m 270 deg	
*2001	2865	2800	NA	NA	5950	2150	2120	15885
2002	-	-	-	-	-	-	-	-
2003	-	-	-	-	-	-	-	-
2004	-	-	-	-	-	-	-	-
*2005	2859	2830	NA	NA	6010	2378	2264	16341
2006	-	-	-	-	-	-	-	-
2007	-	-	-	-	-	-	-	-
*2008	2784	2770	0	0	5902	2370	2215	16041
*2009	2717	2764	0	0	6019	2279	2247	16026
2010	-	-	-	-	-	-	-	-
2011	-	-	-	-	-	-	-	-
*2012	2840	2692	0	0	5869	2332	2244	15977
2013	-	-	-	-	-	-	-	-
*2014	2712	2615	0	0	5985	2272	2161	15745

*Census Year
Blank cell (-): no census taken

Table A-4: City of Edmonton total population, 2001-2014

Year	Population
*2001	657350
2002	-
2003	-
2004	-
*2005	712391
*2006	730372
2007	-
*2008	752412
*2009	782439
2010	-
*2011	812201
*2012	817498
2013	-
*2014	877926

*Census Year

Table A-5: Population trend analysis: Mann-Kendall and Theil-Sen Slope summary (α=0.05)

Study Area	Mann-Kendall Trend Analysis	Theil-Sen Slope: People per decade	LCL, UCL per decade
Edmonton South	↑	855	(30, 1287)
Woodcroft	No Trend	-	(-1019, 2201)
Gold Bar	No Trend	-	(-940, 150)
City of Edmonton	↑	163,000	(138203, 184402)

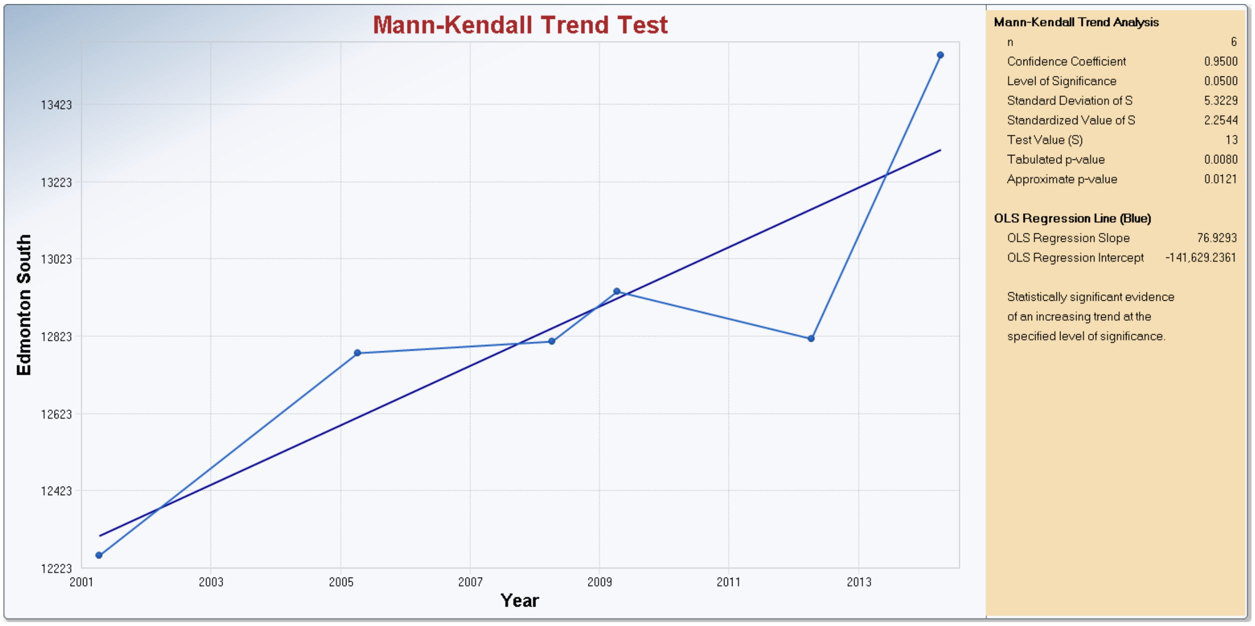

Figure A-1: Edmonton South Population: Mann-Kendall Trend Test Output

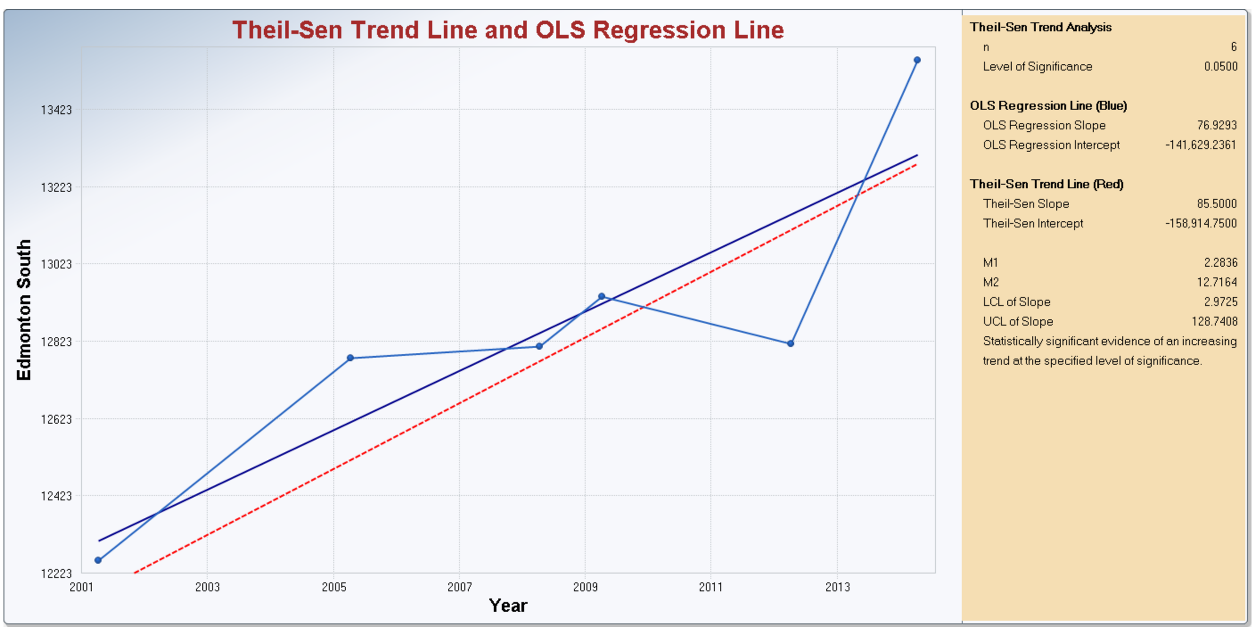

Figure A-2: Edmonton South Population: Theil-Sen Trend Line Output

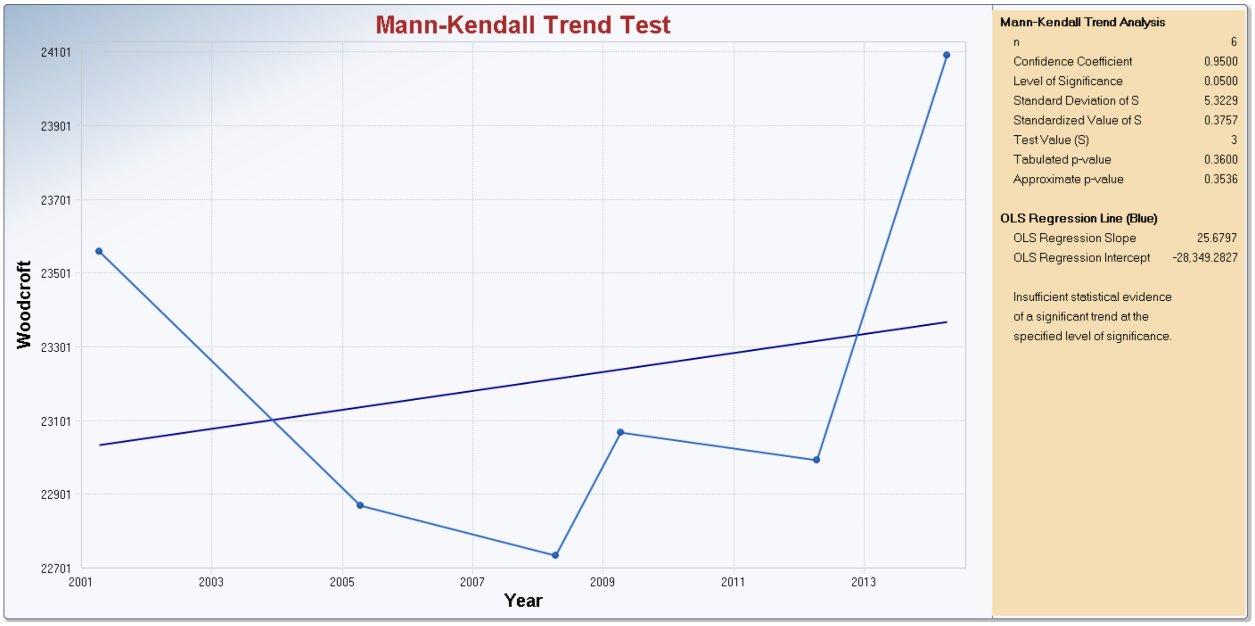

Figure A-3: Woodcroft Population: Mann-Kendall Trend Test Output

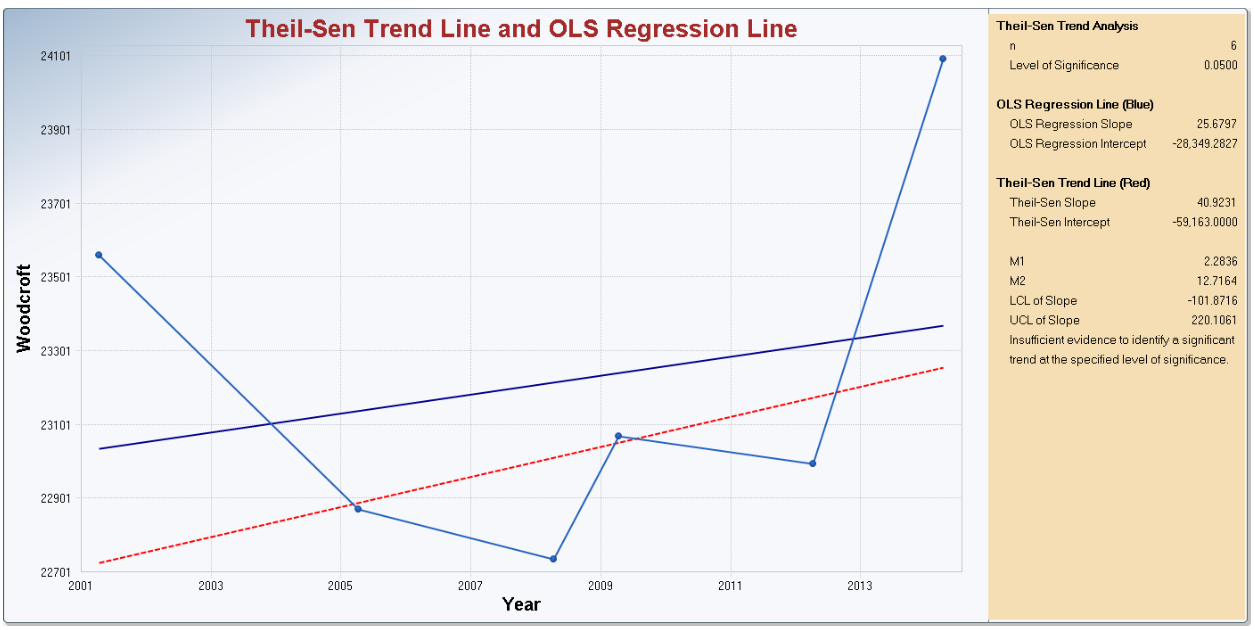

Figure A-4: Woodcroft Population: Theil-Sen Trend Line Output

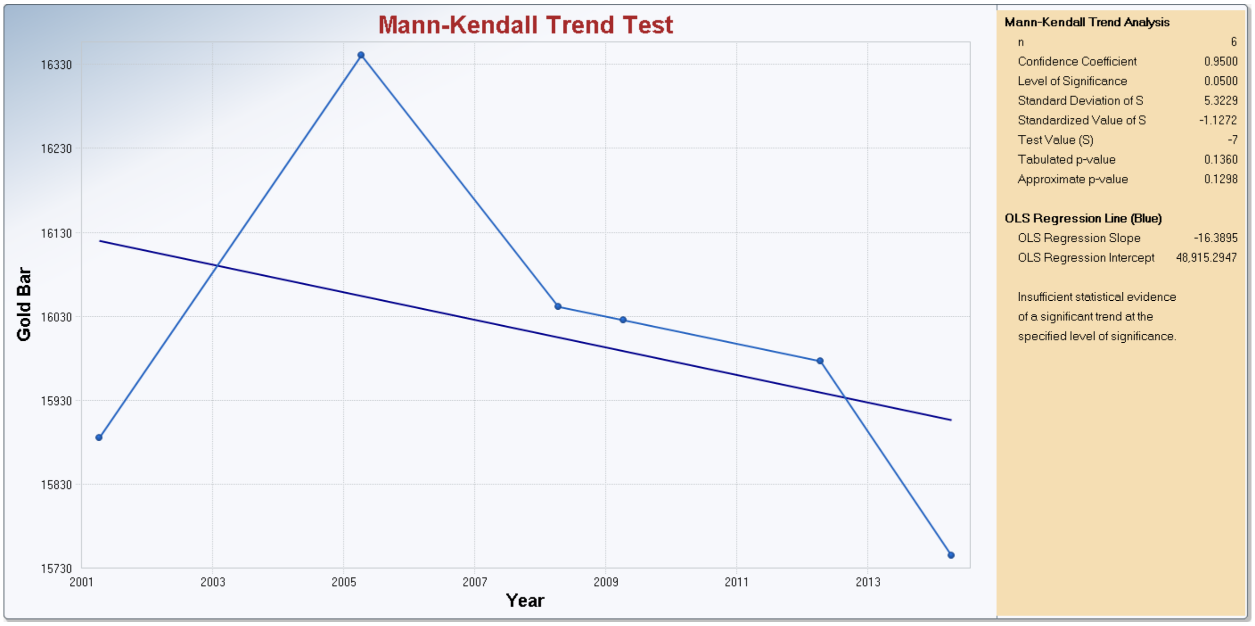

Figure A-5: Gold Bar Population: Mann-Kendall Trend Test Output

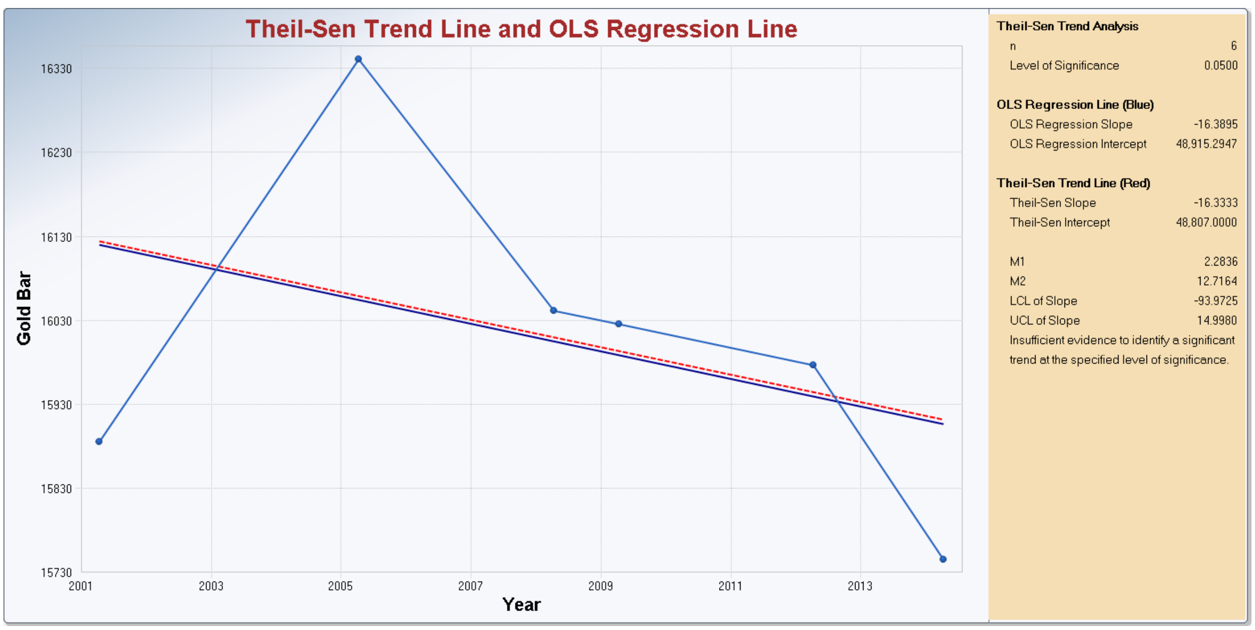

Figure A-6: Gold Bar Population: Theil-Sen Trend Line Output

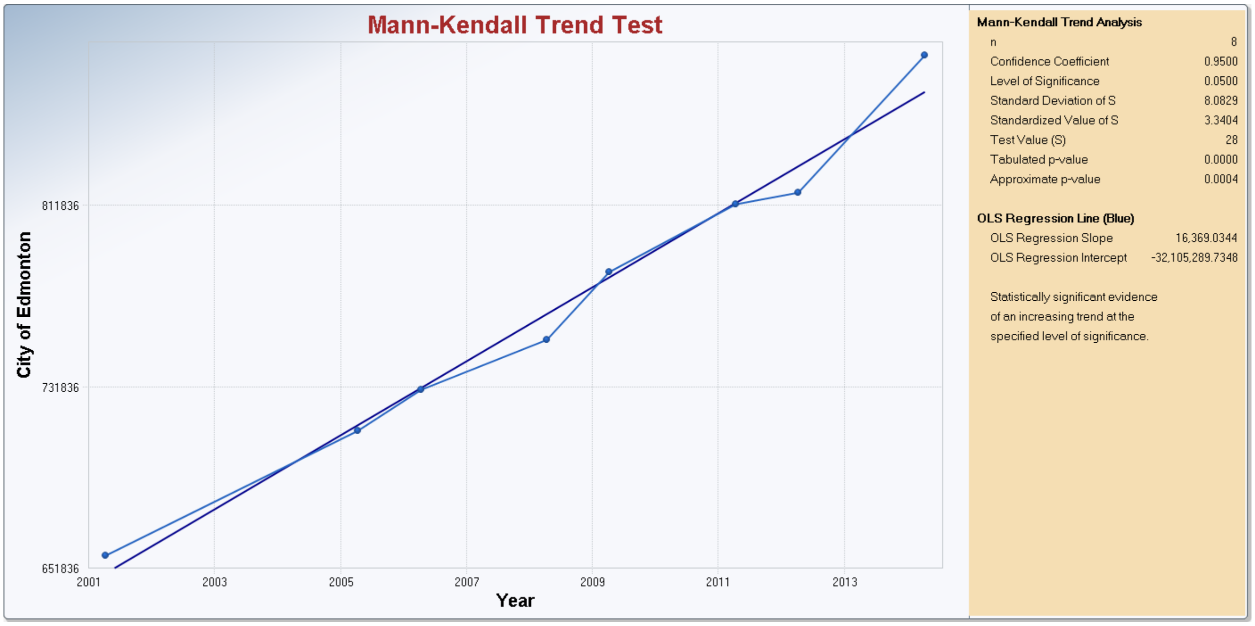

Figure A-7: City of Edmonton Population: Mann-Kendall Trend Test Output

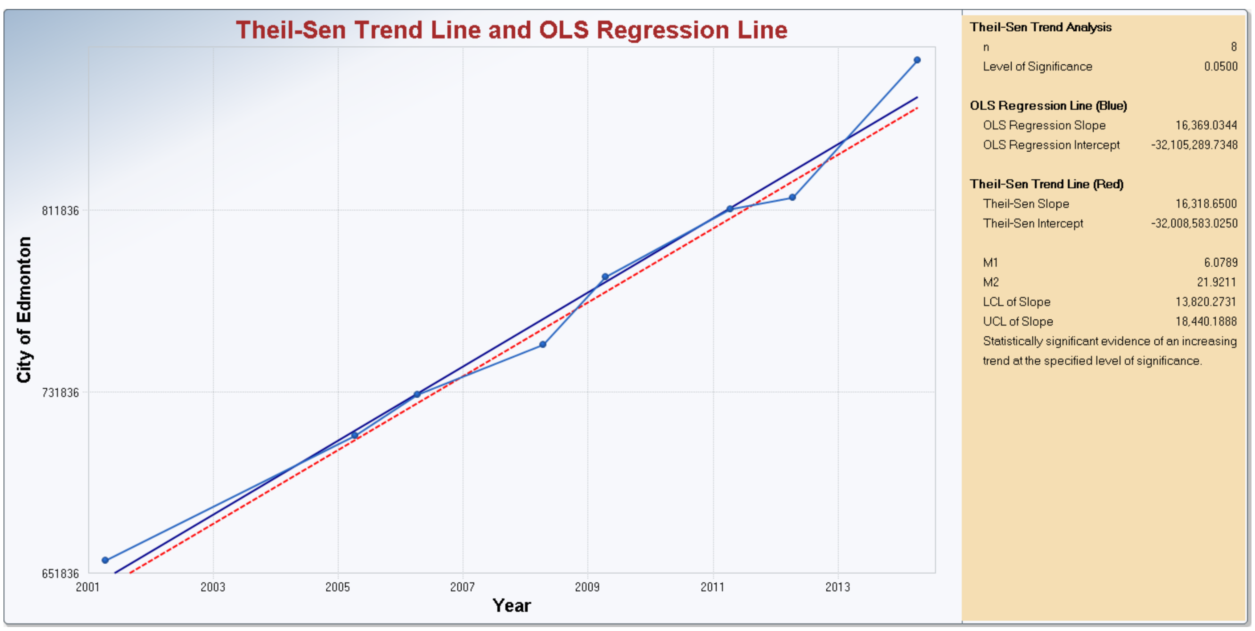

Figure A-8: City of Edmonton Population: Theil-Sen Trend Line Output

APPENDIX B: TRAFFIC COUNT DATA AND PROUCL MANN-KENDALL/THEIL-SEN OUTPUTS

Table B-1: Traffic count data for the sites utilized, 2002-2013

Station	Count Site description/location	Proximity and Direction*	Site name	Average Annual Weekday Traffic Counts											
				2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013
Edmonton South 6240-113 Street	113 Street S of Belgravia Rd (2002-2007), N of 67 Ave (2008-2013)	840 m 10 deg, 500 m 20deg	ES-1	**29400**	-	**29500**	-	-	-	-	-	**21800**	-	**23400**	-
	111 Street S of 61 Ave (2002-2007), N of 57 Ave (2008-2013)	640 m 110deg, 910 m 140 deg	ES-2	-	**35300**	-	**38900**	-	**32500**	-	-	-	**25300**	-	**25100**
	Belgravia Rd E of Fox Drive (2002-2007), W of 116 Street (2008-2013)	890 m 300deg, 850 m 330deg	ES-3	**37200**	-	**37600**	-	-	-	-	-	-	-	-	**36800**
Woodcroft 13915-115 Avenue	142 Street N of 118 Ave	690 m 340deg	W-1	**14500**	-	**15000**	-	**16200**	-	**15700**	**15900**	-	-	-	***14300***
	118 Avenue W of 133 Street	910 m 50deg	W-2	**18900**	-	**18400**	-	**19400**	-	**18400**	-	-	-	-	**15900**
	Groat Road N of 111 Ave	950 m 130deg	W-3	-	-	**32500**	**32600**	-	**32700**	-	-	-	**35800**	-	**37900**
	111 Avenue W of 142 Street	730 m 200deg	W-4	-	**31000**	-	**31600**	-	-	-	-	-	**29600**	-	-
Gold Bar 105A Ave & 47 Street	50 Street N of 101A Avenue	870 m 200deg	GB-1	-	-	**21500**	**21800**	**23600**	-	**22700**	-	-	-	**19700**	-
	101 Avenue E of 50 Street	900 m 190 deg	GB-2	**26500**	-	**27700**	-	**26200**	-	**33800**	-	-	-	**25200**	-

Table B-2: Interpolated traffic count data for the Woodcroft study area, 2002-2013

Station	Count Site description/location	Proximity and Direction	Site name	Average Annual Weekday Traffic Counts											
				2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013
Woodcroft 13915-115 Avenue	142 Street N of 118 Ave	690 m 340deg	W-1	**14500**	14750	**15000**	15600	**16200**	15950	**15700**	**15900**	15900	16200	16000	***14300***
	118 Avenue W of 133 Street	910 m 50deg	W-2	**18900**	18650	**18400**	18900	**19400**	19200	**18400**	18600	18700	19000	18700	**15900**
	Groat Road N of 111 Ave	950 m 130deg	W-3	-	32400	**32500**	**32600**	32650	**32700**	31000	31400	31500	**35800**	35400	**37900**
	111 Avenue W of 142 Street	730 m 200deg	W-4	-	**31000**	31300	**31600**	31333	31067	30800	31200	31300	**29600**	29200	29700
				Total	*96800*	*97200*	*98700*	*99583*	*98917*	*95900*	*97100*	*97400*	*100600*	*99300*	*97800*

Bold: Volume obtained for traffic count taken that year (City of Edmonton, 2014b)
Bold Italic: Volume estimated from 24 hour Turning Movement counts conducted that year (City of Edmonton, 2014b)
Blank (-): No count for that year
Blue: Interpolated data
Red: City modelled data- Estimated from previous counts; derived from growth factors at permanent counting sites, applied to most recent count at the actual location (City of Edmonton, 2014b)
Italic: Total Average Annual Weekday Traffic Count for study area

Table B-3: Number of registered vehicles in Edmonton, 2004-2013

*Counts include all motorized vehicles that can be driven on the highway. Counts exclude trailers, off-highway vehicles, and dealer-plated vehicles. Location of the vehicle is determined by the registered owners mailing address at the end of the fiscal year (Alberta Transportation, 2008, 2012, 2014).

Year	Total Motorized Registered Vehicles in Edmonton
2004	459,799
2005	470,839
2006	492,886
2007	524,845
2008	554,714
2009	567,745
2010	574,802
2011	585,765
2012	602,783
2013	629,349

Table B-4: Registered vehicles trend analysis: Mann-Kendall and Theil-Sen Slope summary (α=0.05)

Registered Vehicles	Mann-Kendall Trend Analysis	Theil-Sen Slope: Vehicles per decade	LCL, UCL per decade
City of Edmonton	↑	185,758	(150917, 216316)

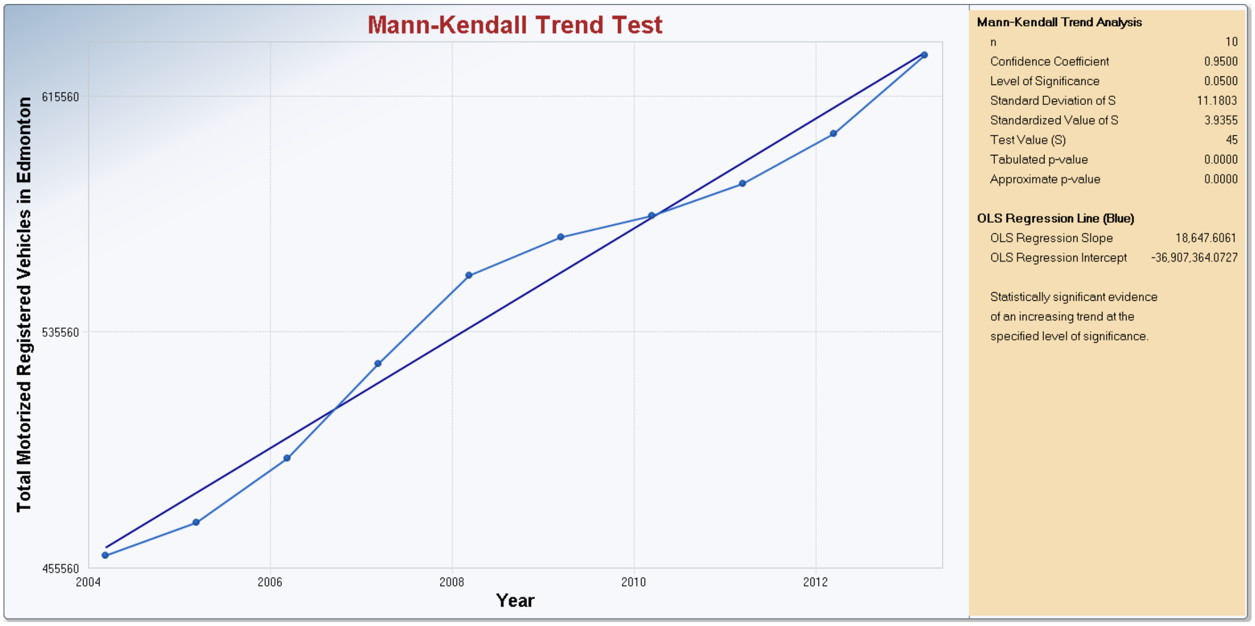

Figure B-1: Registered Vehicles in Edmonton: Mann-Kendall Trend Test Output

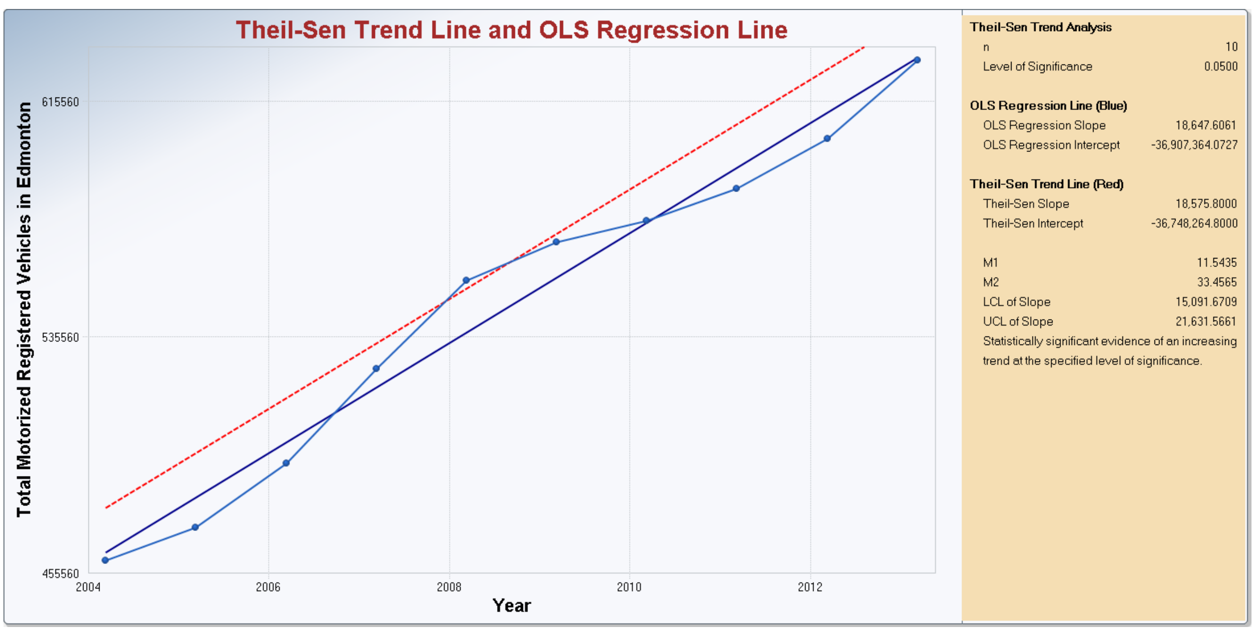

Figure B-2: Registered Vehicles in Edmonton: Theil-Sen Trend Line Output

APPENDIX C: NPRI EMISSIONS AND EMITTERS DATA, AND PROUCL MANN-KENDALL/THEIL-SEN OUTPUTS

Table C-1: Annual NPRI emissions for NO_2, $PM_{2.5}$, and CO, 2003-2013 (tonnes/year)

	Total Annual Emissions (t/yr)		
Year	**NO_2**	**$PM_{2.5}$**	**CO**
2003	7118	660	4599
2004	6919	573	5075
2005	7526	713	6112
2006	7670	785	6957
2007	7567	811	5827
2008	6843	746	6396
2009	6460	860	5083
2010	6389	656	4660
2011	5928	726	5901
2012	5713	741	5636
2013	5212	659	9071

Table C-2: Number of NPRI reporting emitters for NO_2, $PM_{2.5}$, and CO, 2003-2013

	Number of Reporting Emitters		
Year	**NO_2**	**$PM_{2.5}$**	**CO**
2003	17	32	14
2004	17	32	15
2005	18	32	16
2006	15	31	15
2007	17	35	19
2008	17	36	18
2009	17	35	16
2010	17	35	19
2011	16	36	19
2012	15	34	19
2013	15	36	19

Bubble plots show the spatial distribution of industrial emitters and the annual value of the reported emissions for each pollutant. The scaling factor for each bubble is representative of the emissions relative to other industrial emitters; large emitters have a larger bubble representing emissions while small emitters have smaller bubbles.

*All maps in this section were obtained from Google Maps.

Emissions Map Legend:

City of Edmonton Boundary

SIA Boundary

NPRI Facility In Edmonton

NPRI Facility Outside Edmonton

Air Monitoring Station

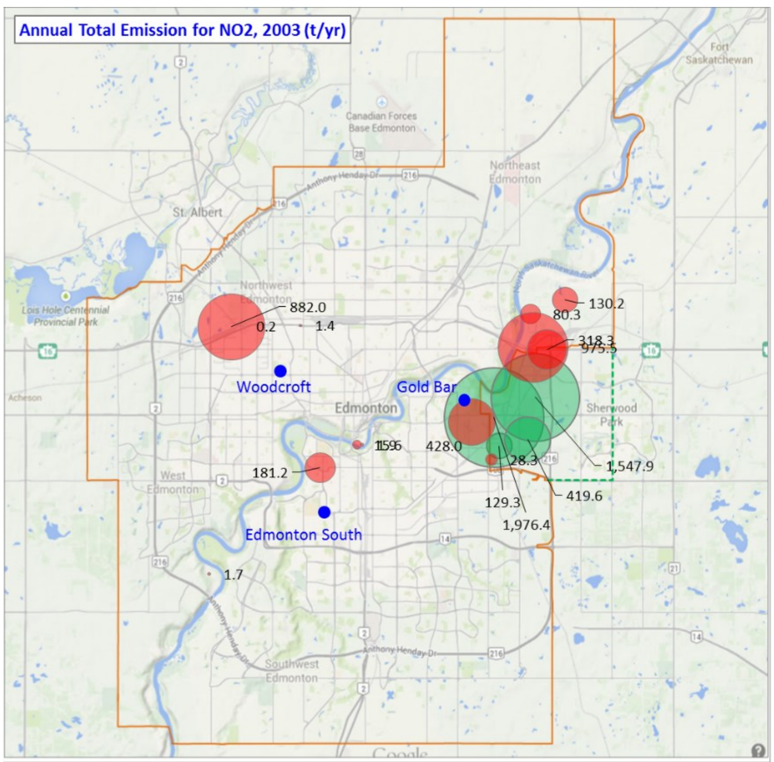

Figure C-1: Annual NO_2 Emissions by Facility, 2003

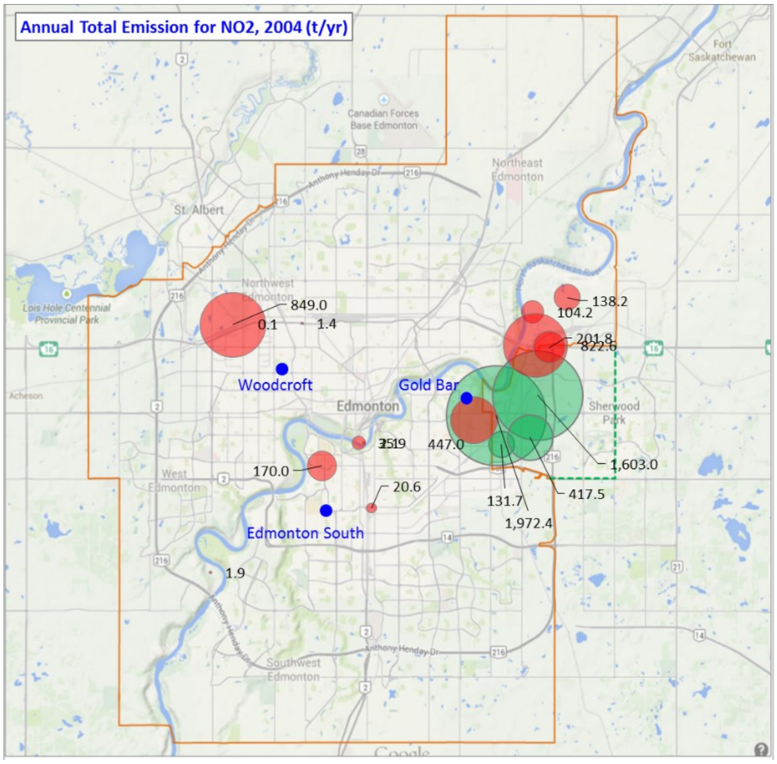

Figure C-2: Annual NO_2 Emissions by Facility, 2004

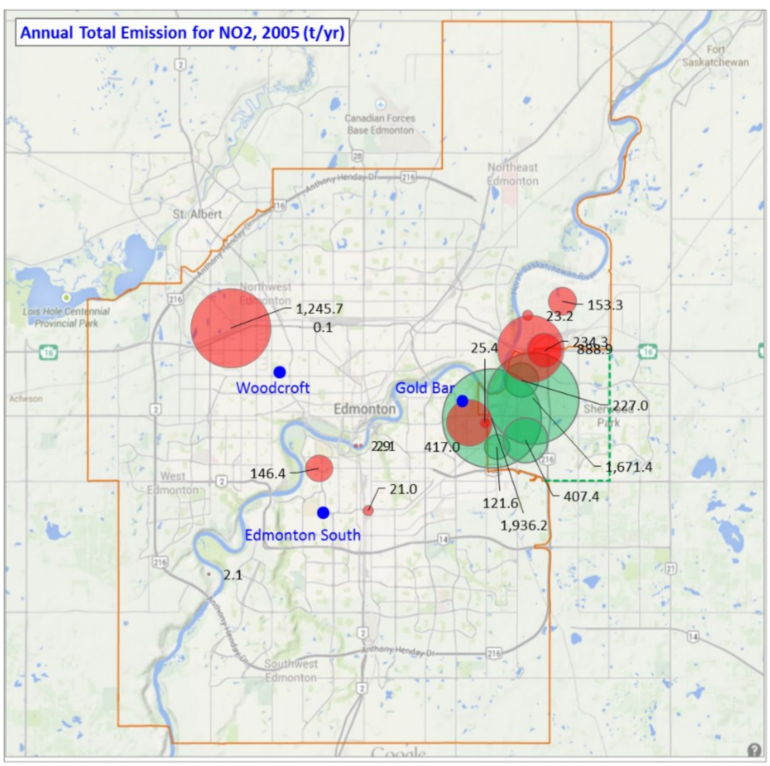

Figure C-3: Annual NO_2 Emissions by Facility, 2005

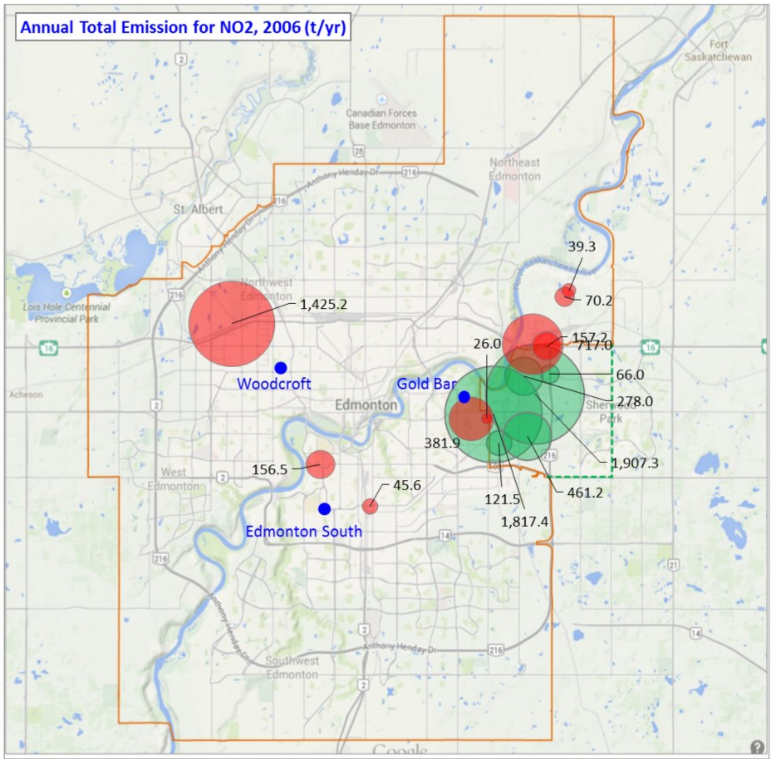

Figure C-4: Annual NO2 Emissions by Facility, 2006

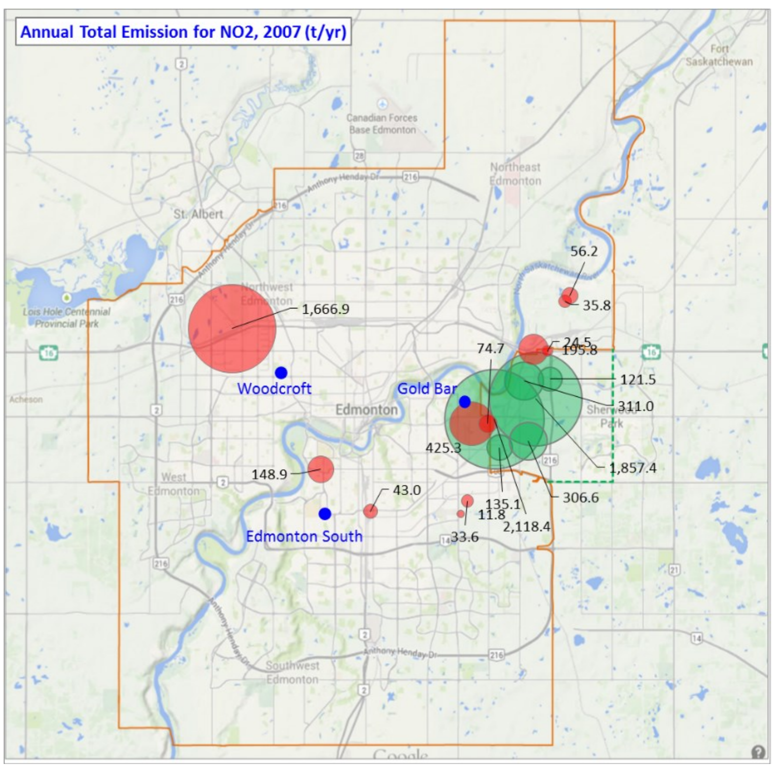

Figure C-5: Annual NO2 Emissions by Facility, 2007

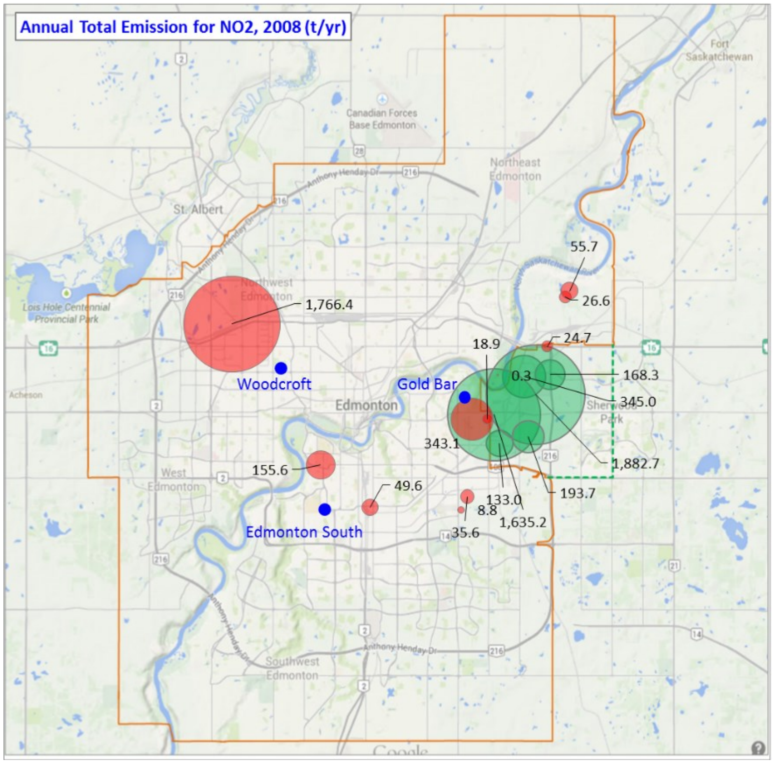

Figure C-6: Annual NO_2 Emissions by Facility, 2008

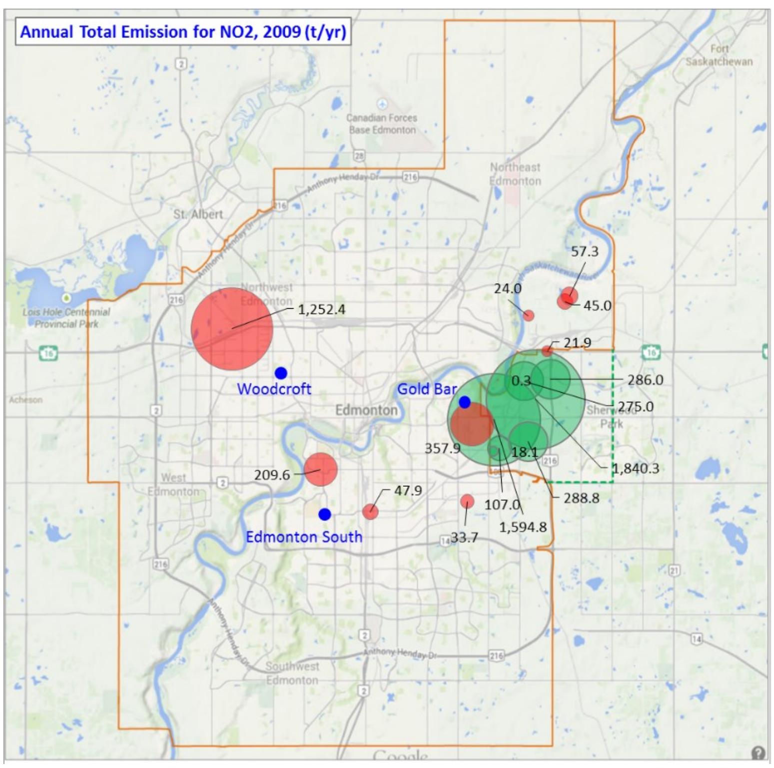

Figure C-7: Annual NO_2 Emissions by Facility, 2009

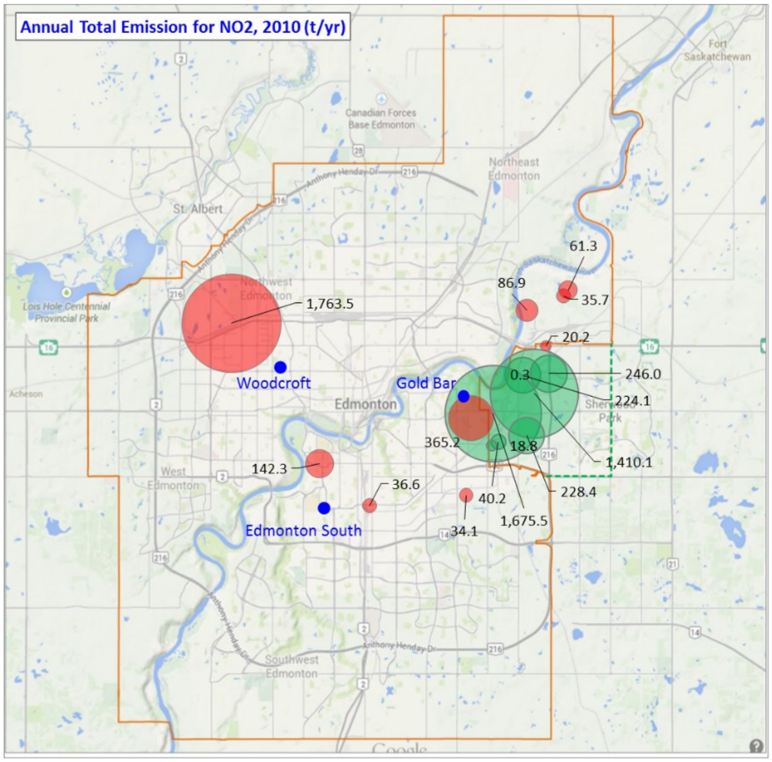

Figure C-8: Annual NO2 Emissions by Facility, 2010

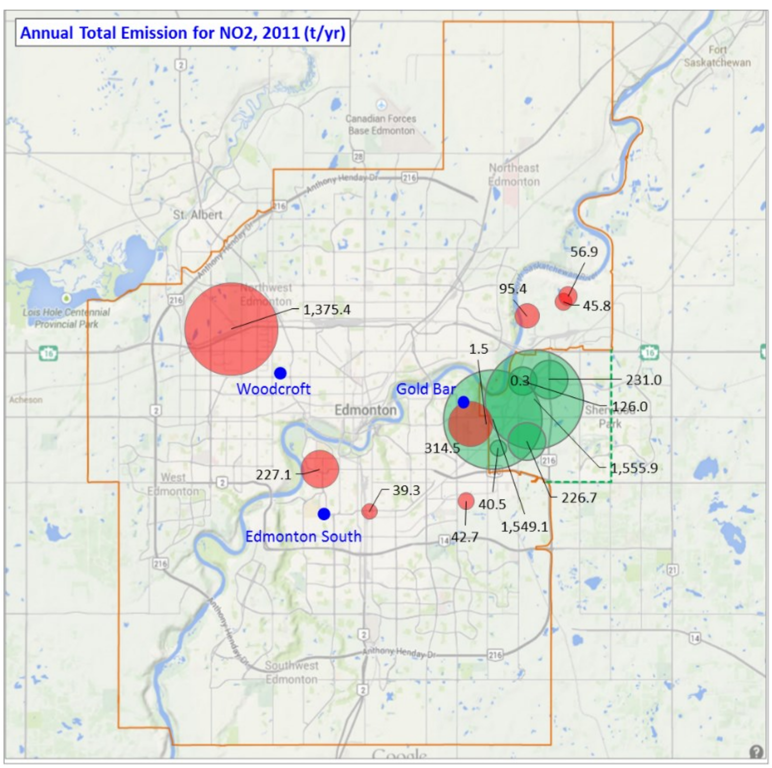

Figure C-9: Annual NO2 Emissions by Facility, 2011

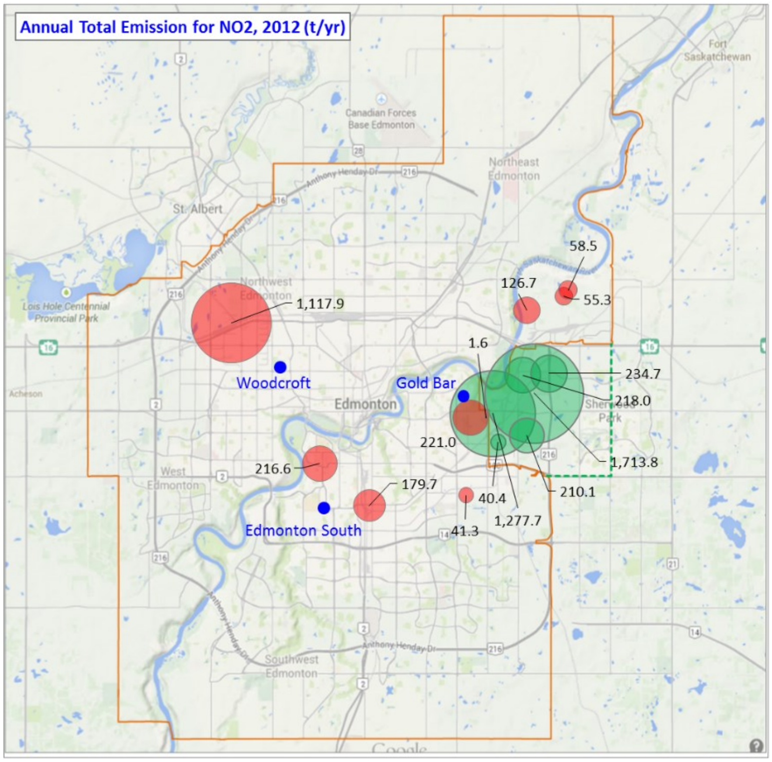

Figure C-10: Annual NO_2 Emissions by Facility, 2012

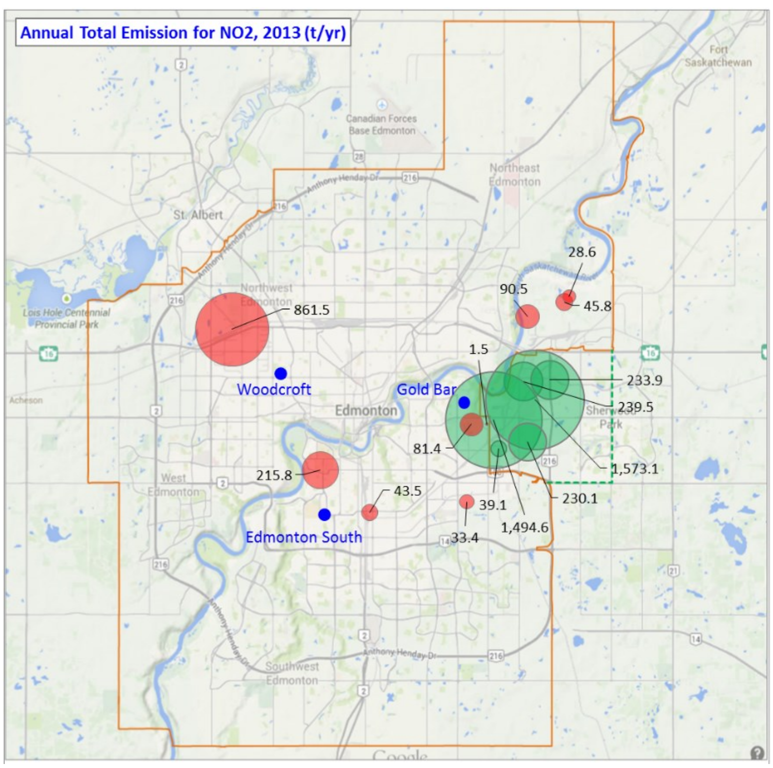

Figure C-11: Annual NO_2 Emissions by Facility, 2013

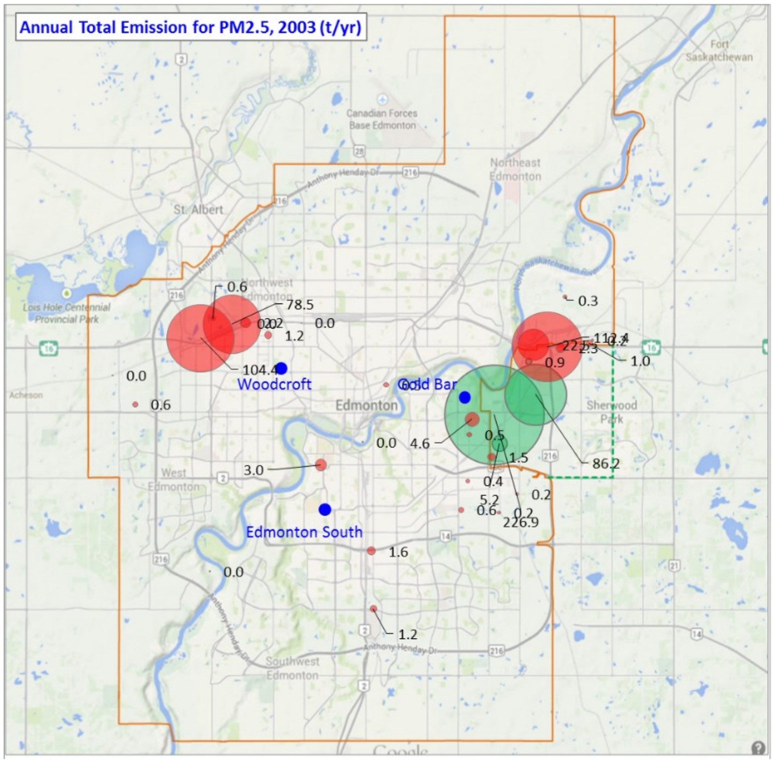

Figure C-12: Annual $PM_{2.5}$ Emissions by Facility, 2003

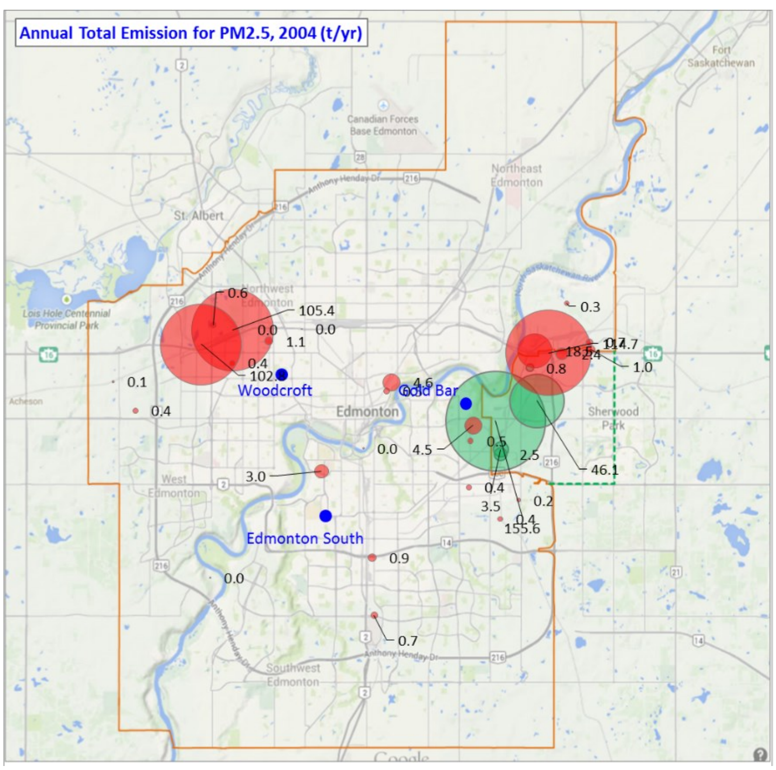

Figure C-13: Annual $PM_{2.5}$ Emissions by Facility, 2004

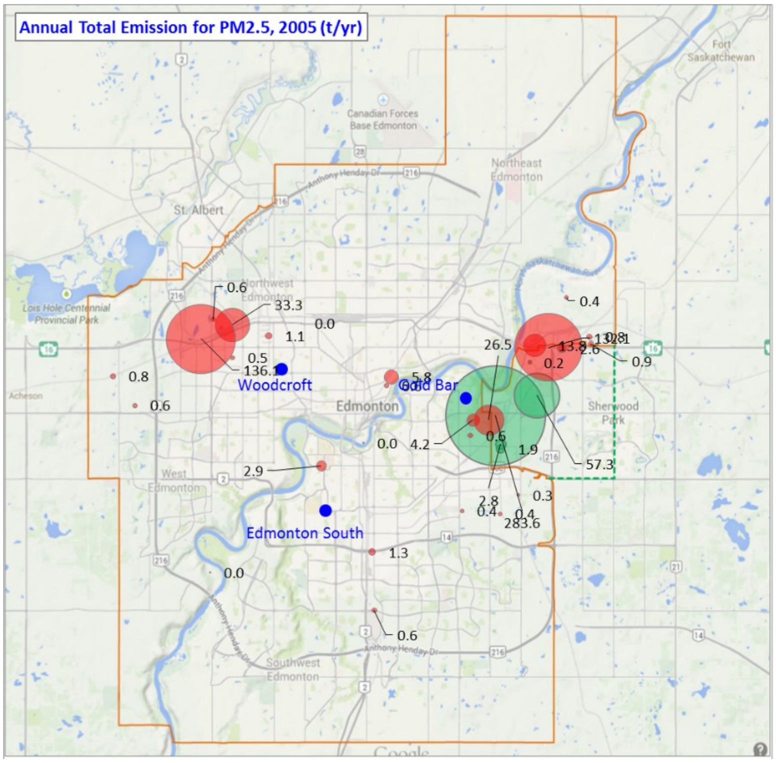

Figure C-14: Annual $PM_{2.5}$ Emissions by Facility, 2005

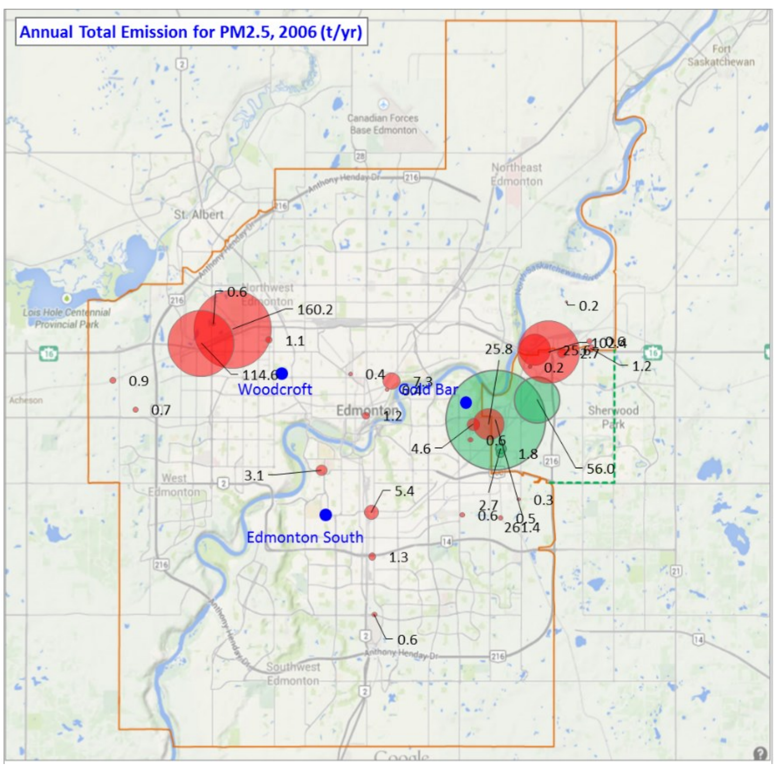

Figure C-15: Annual $PM_{2.5}$ Emissions by Facility, 2006

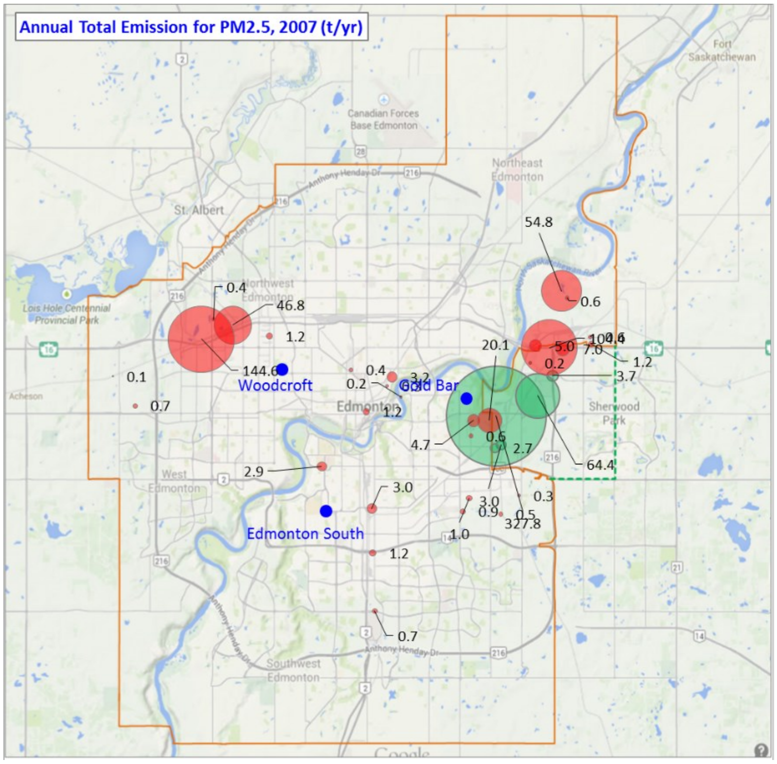

Figure C-16: Annual $PM_{2.5}$ Emissions by Facility, 2007

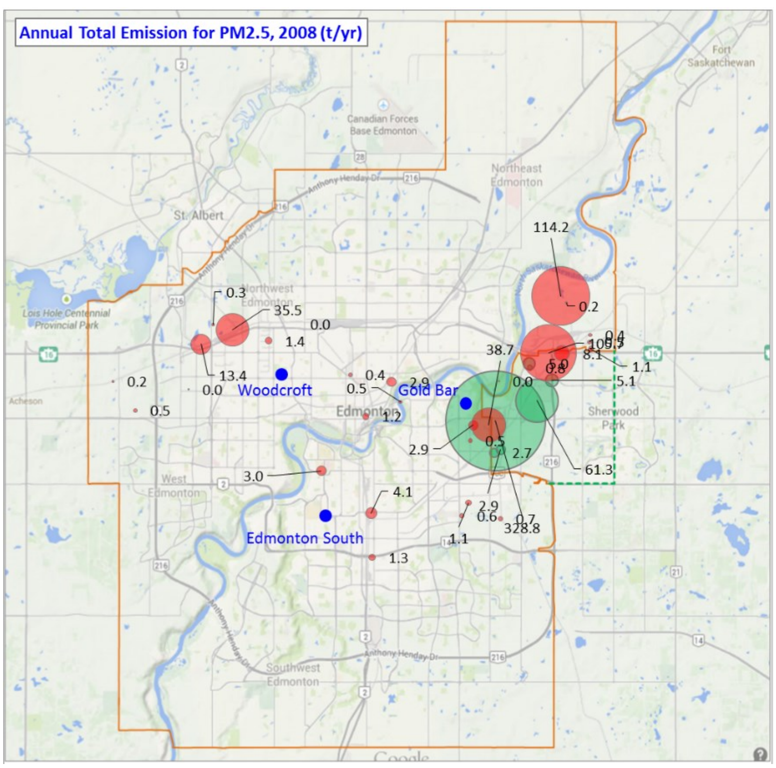

Figure C-17: Annual $PM_{2.5}$ Emissions by Facility, 2008

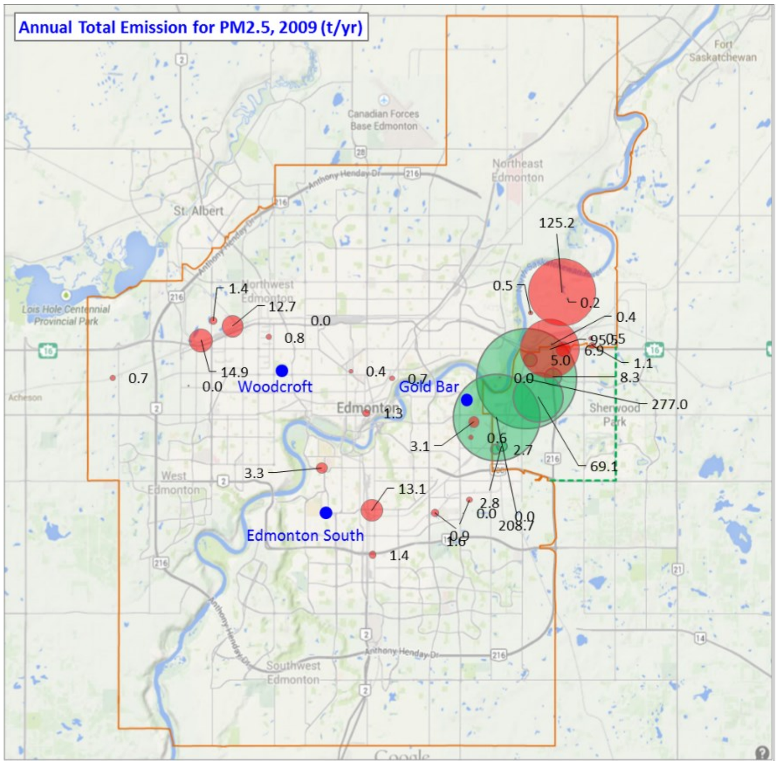

Figure C-18: Annual PM2.5 Emissions by Facility, 2009

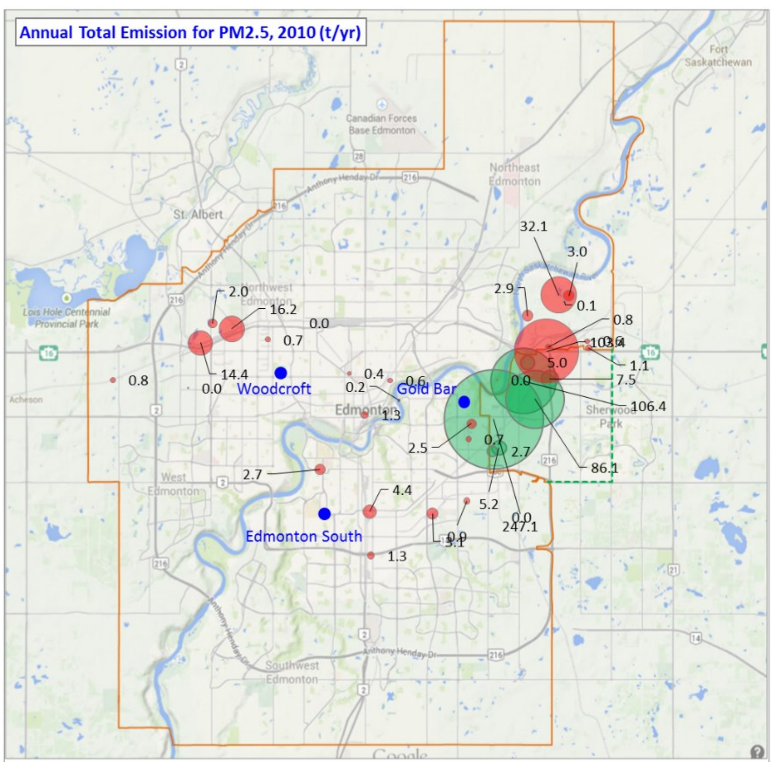

Figure C-19: Annual PM2.5 Emissions by Facility, 2010

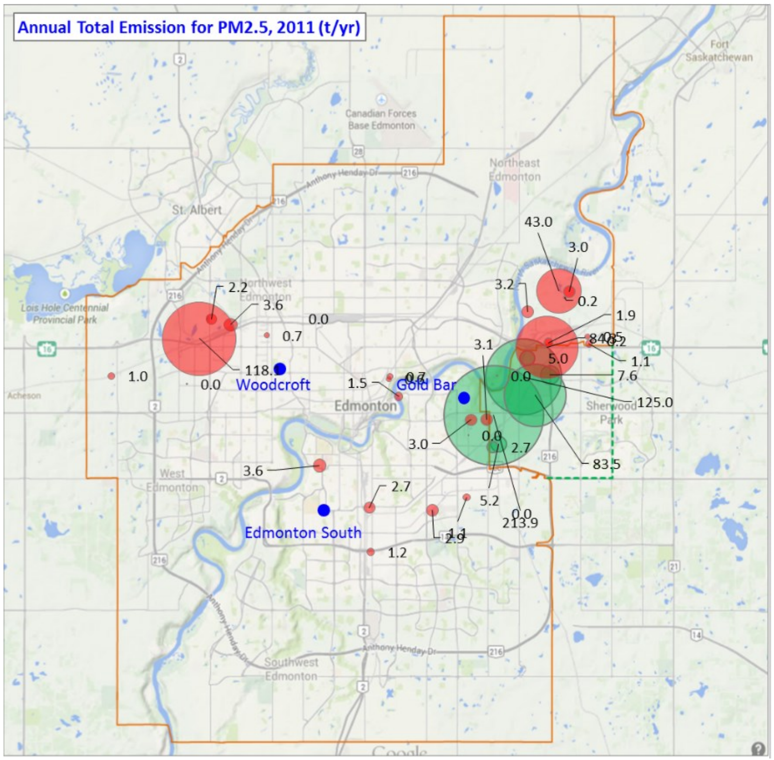

Figure C-20: Annual $PM_{2.5}$ Emissions by Facility, 2011

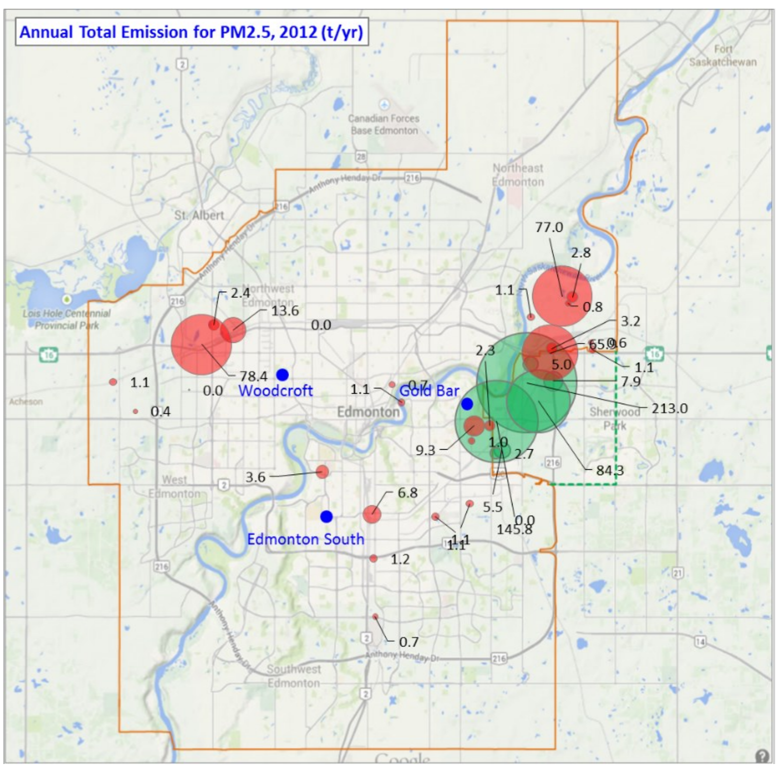

Figure C-21: Annual $PM_{2.5}$ Emissions by Facility, 2012

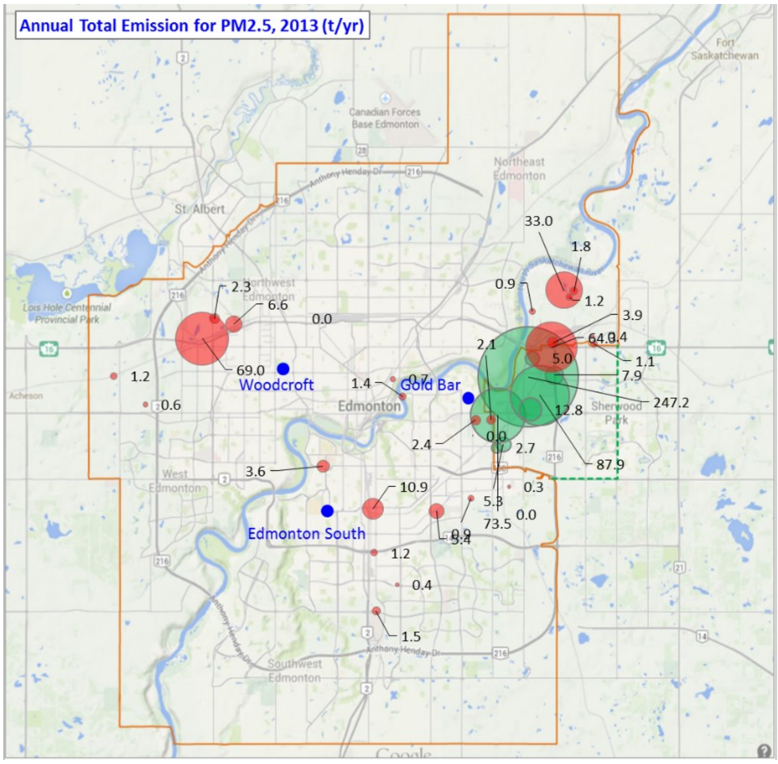

Figure C-22: Annual $PM_{2.5}$ Emissions by Facility, 2013

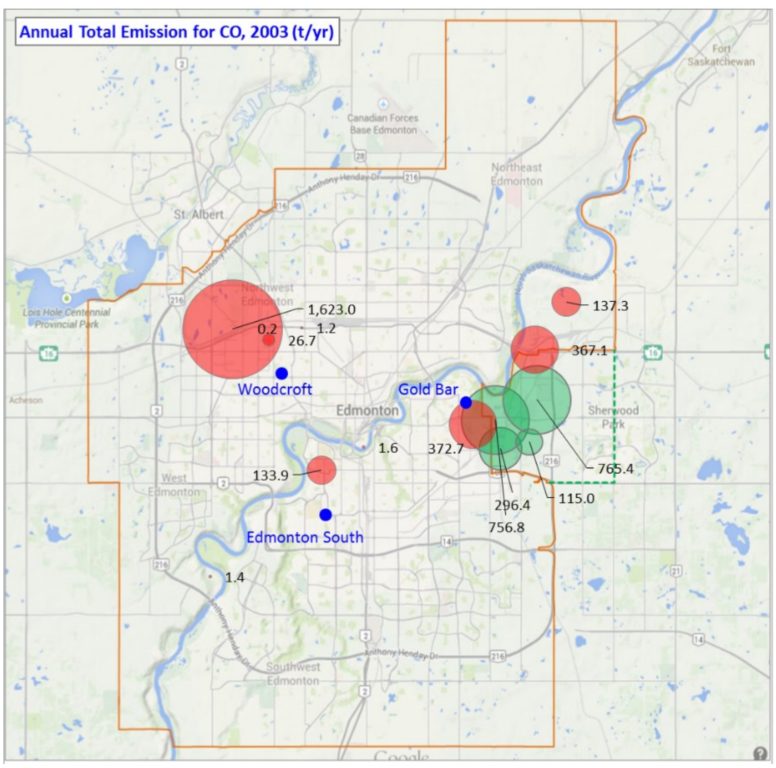

Figure C-23: Annual CO Emissions by Facility, 2003

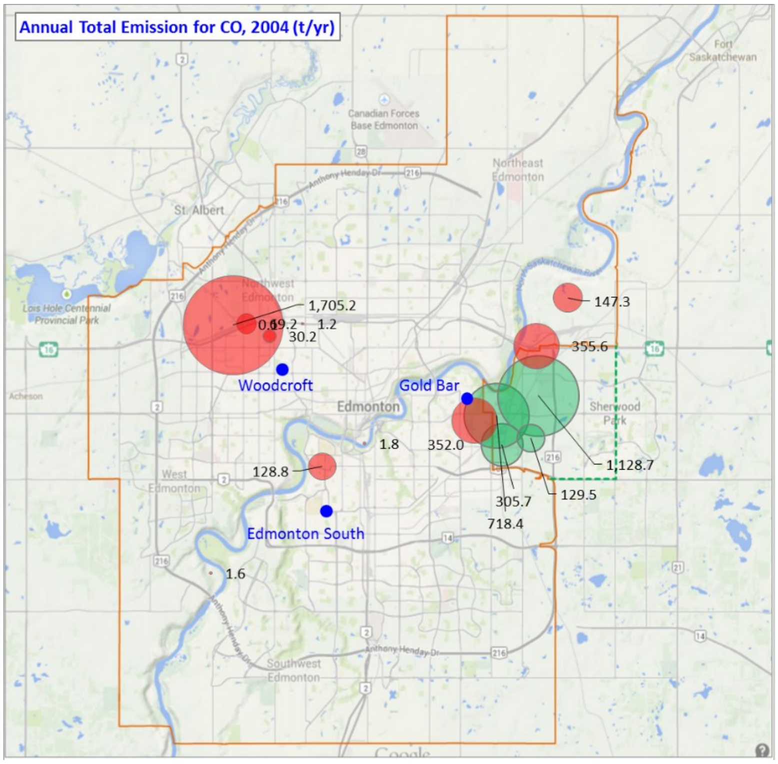

Figure C-24: Annual CO Emissions by Facility, 2004

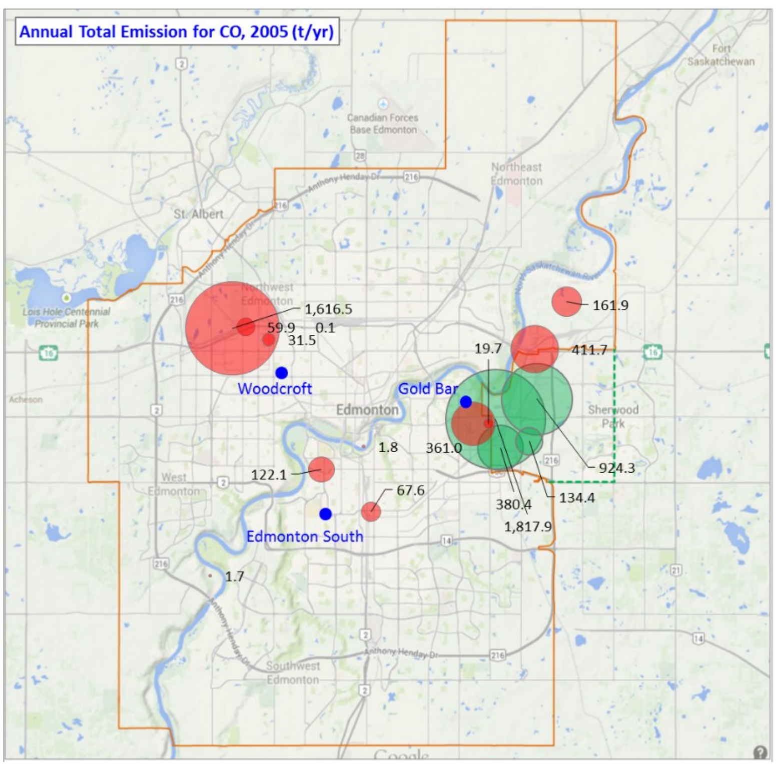

Figure C-25: Annual CO Emissions by Facility, 2005

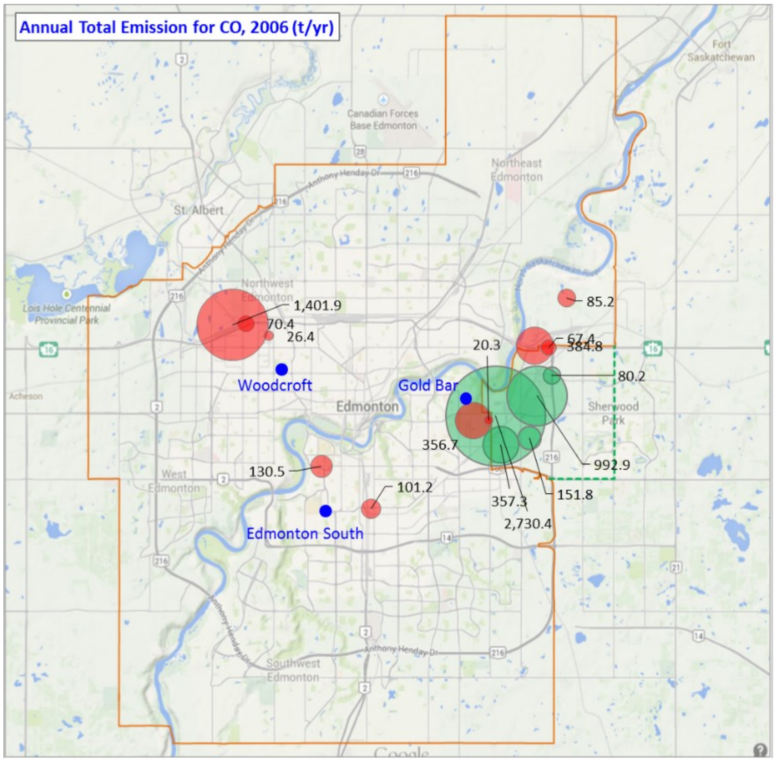

Figure C-26: Annual CO Emissions by Facility, 2006

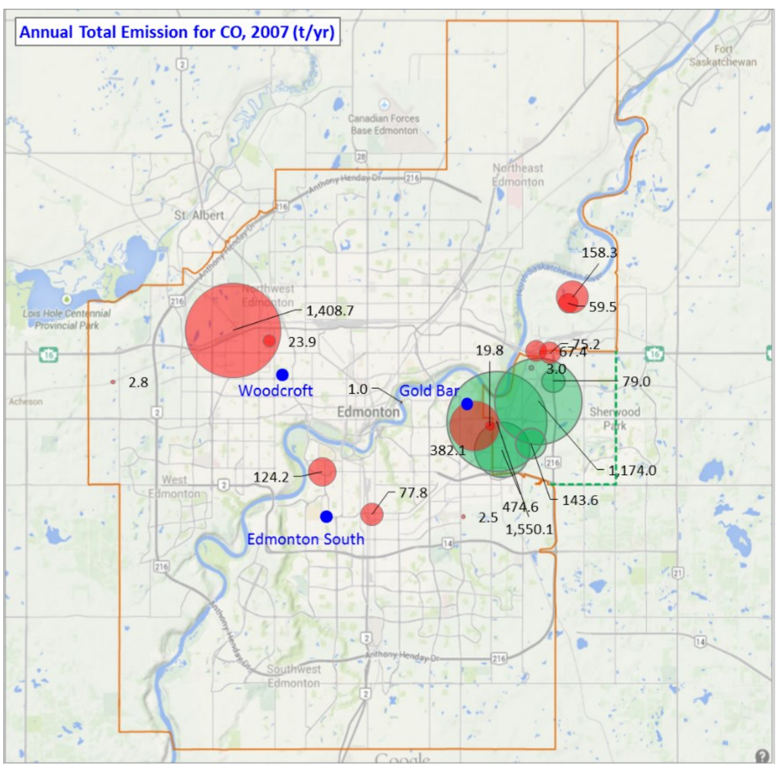

Figure C-27: Annual CO Emissions by Facility, 2007

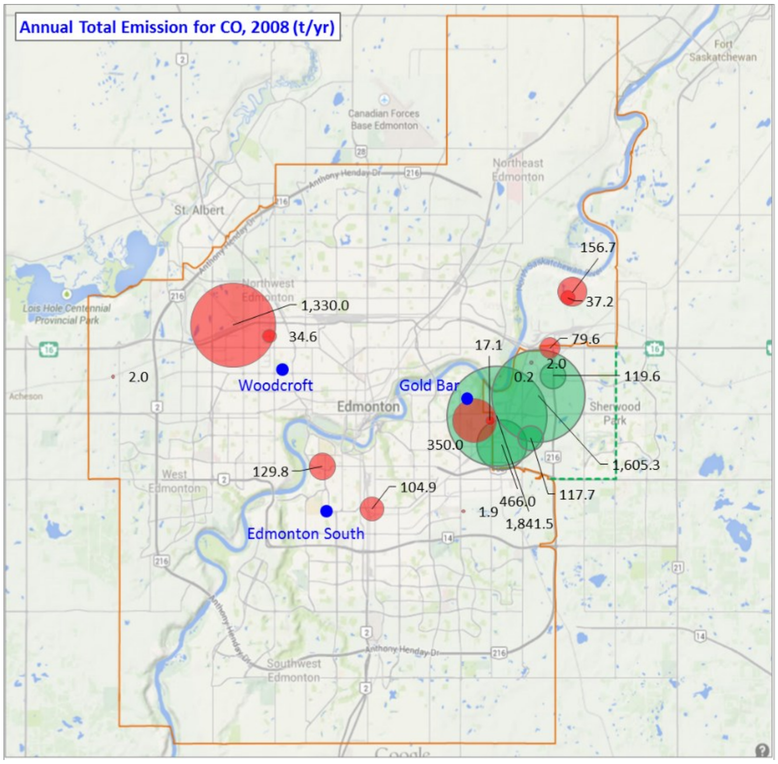

Figure C-28: Annual CO Emissions by Facility, 2008

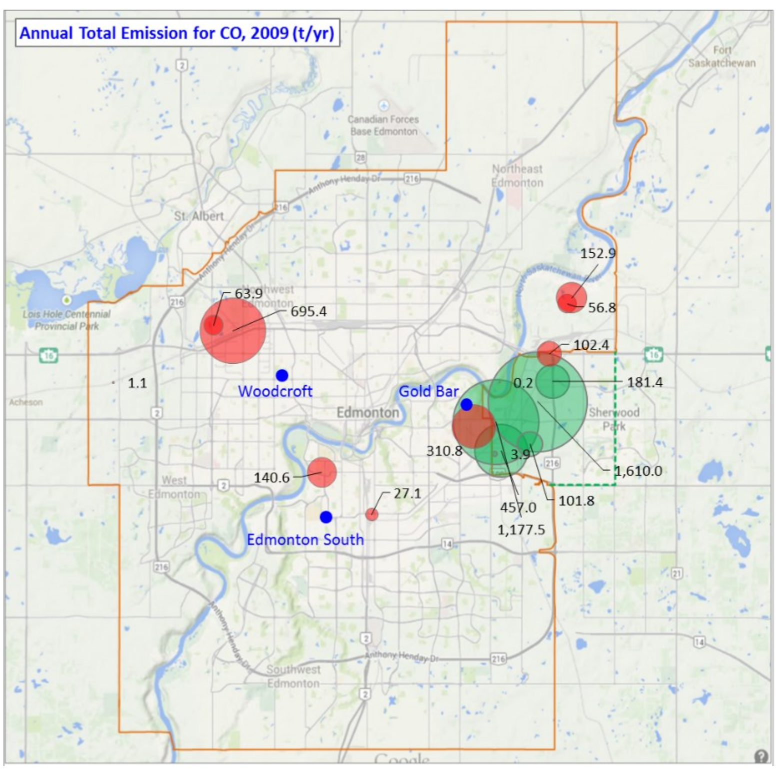

Figure C-29: Annual CO Emissions by Facility, 2009

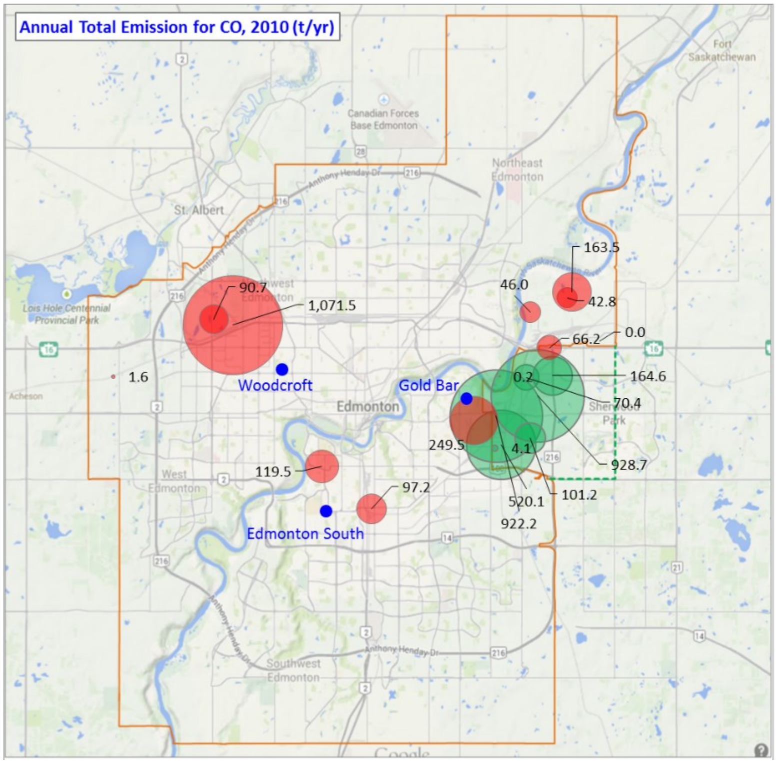

Figure C-30: Annual CO Emissions by Facility, 2010

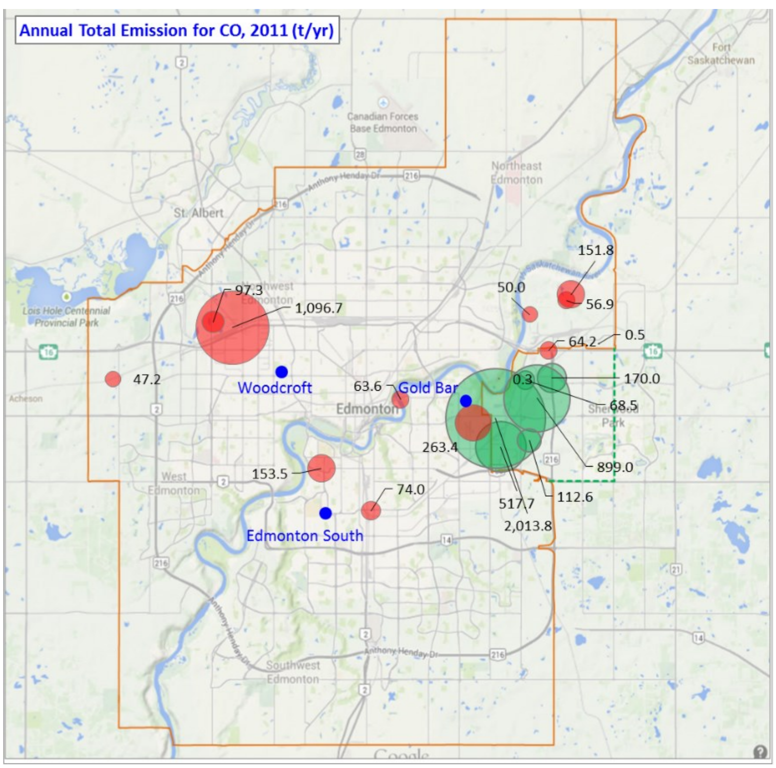

Figure C-31: Annual CO Emissions by Facility, 2011

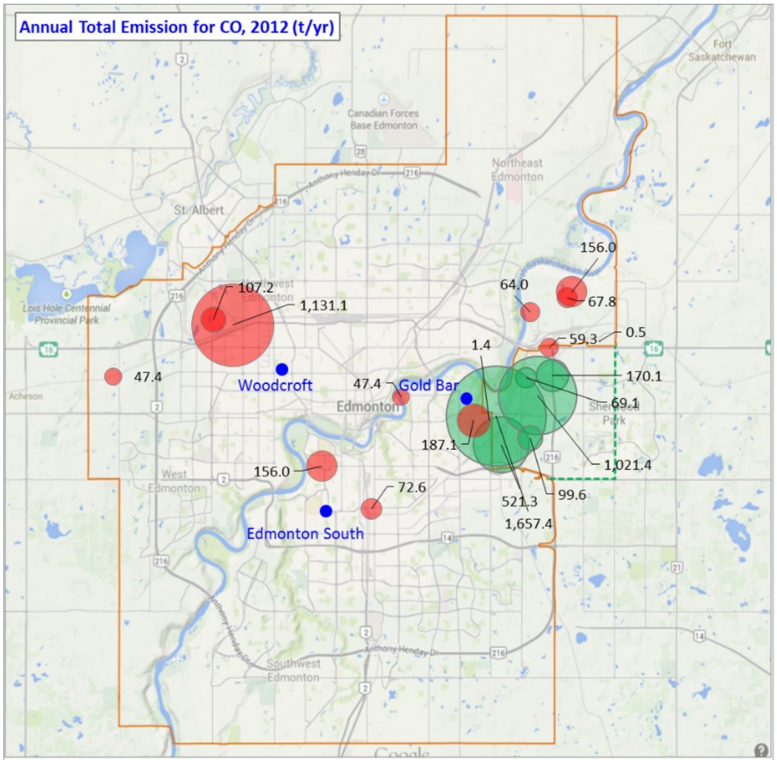

Figure C-32: Annual CO Emissions by Facility, 2012

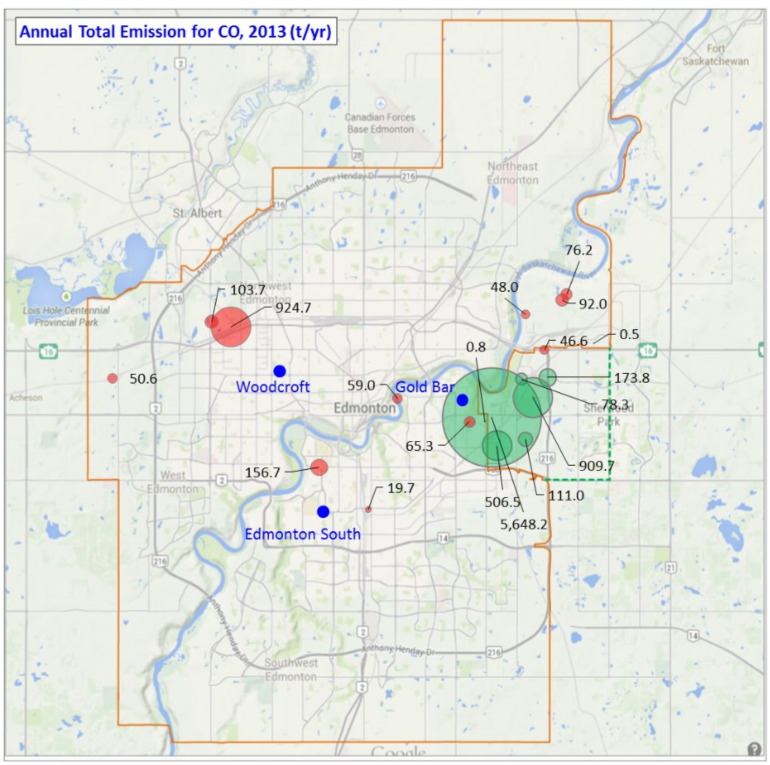

Figure C-33: Annual CO Emissions by Facility, 2013

Table C-3: NPRI emissions trend analysis: Mann-Kendall and Theil-Sen Slope summary (α=0.05)

Pollutant	Mann-Kendall Trend Analysis	Theil-Sen Slope: Tonnes per decade	LCL, UCL per decade
NO_2	↓	-2,490	(-3486, -1092)
$PM_{2.5}$	No Trend	-	(-181, 260)
CO	No Trend	-	(-191, 450)

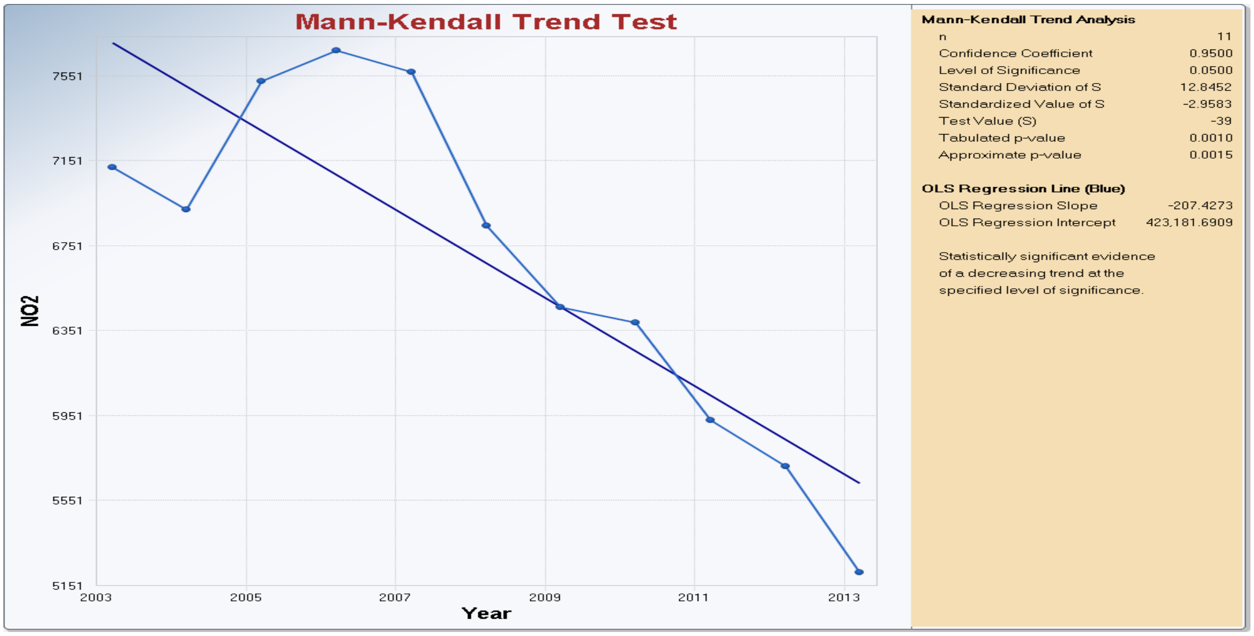

Figure C-34: NPRI NO2 Emissions Trend Analysis Mann-Kendall Trend Test Output

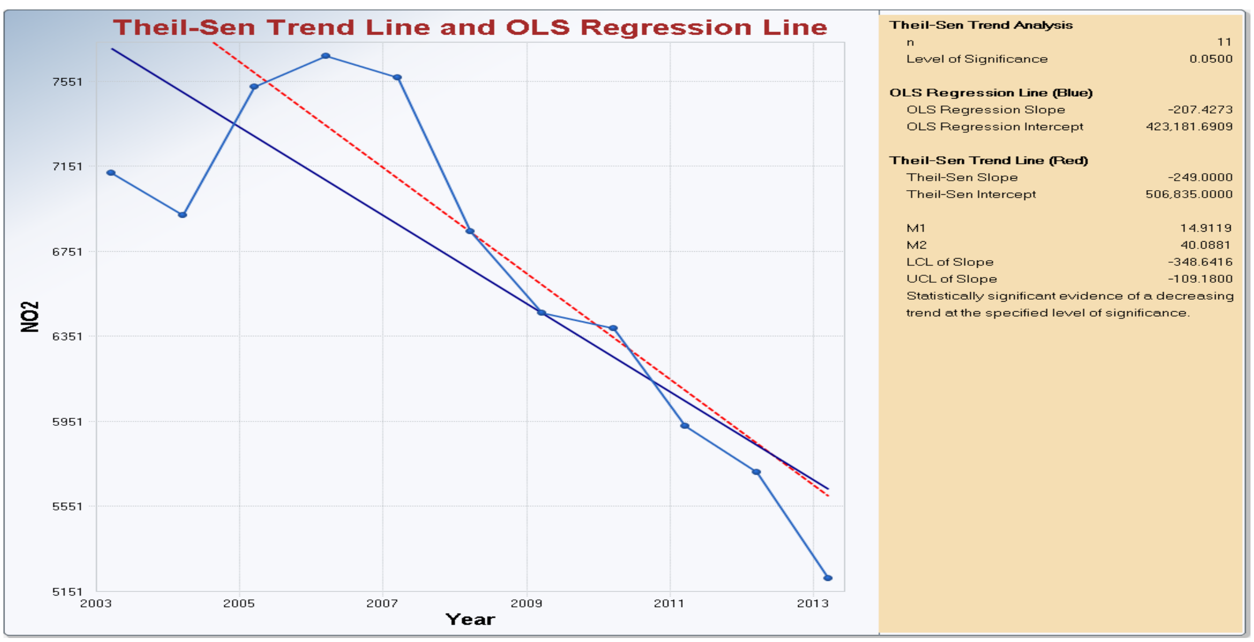

Figure C-35: NPRI NO2 Emissions Trend Analysis Theil-Sen Trend Line Output

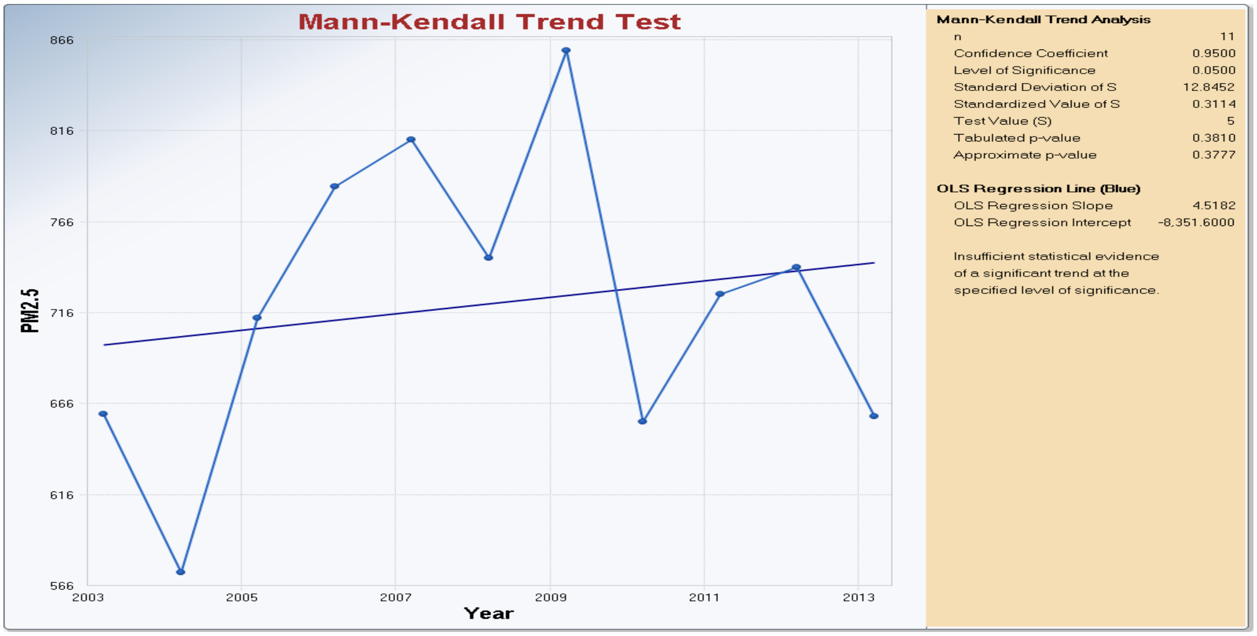

Figure C-36: NPRI $PM_{2.5}$ Emissions Trend Analysis Mann-Kendall Trend Test Output

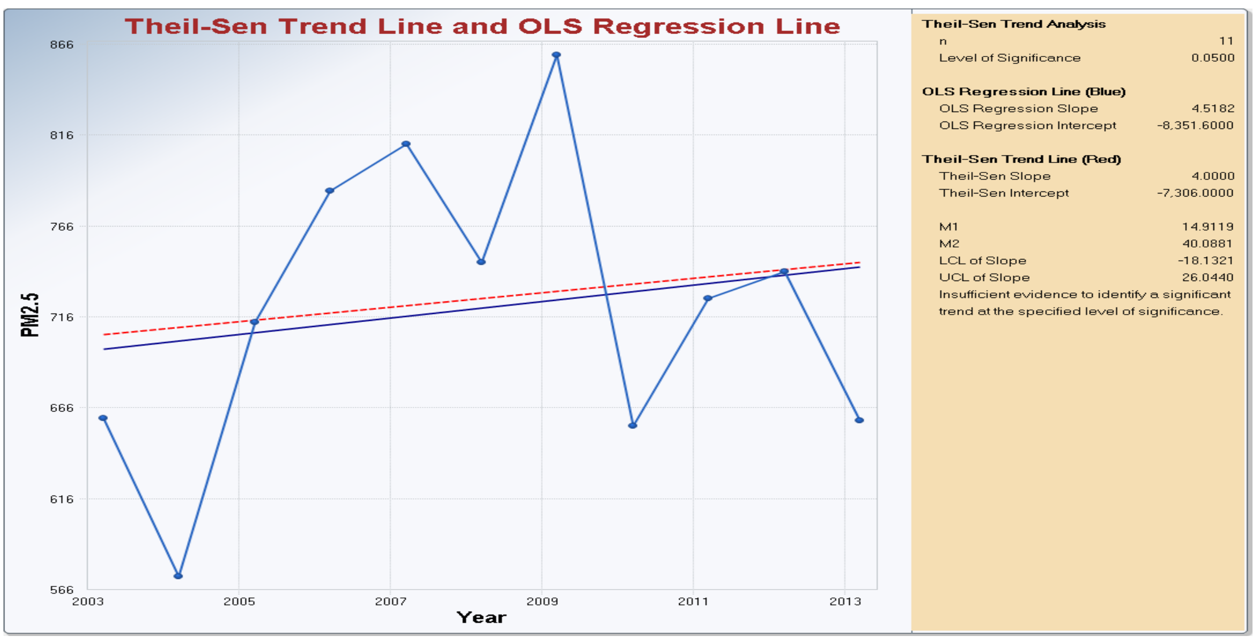

Figure C-37: NPRI $PM_{2.5}$ Emissions Trend Analysis Theil-Sen Trend Line Output

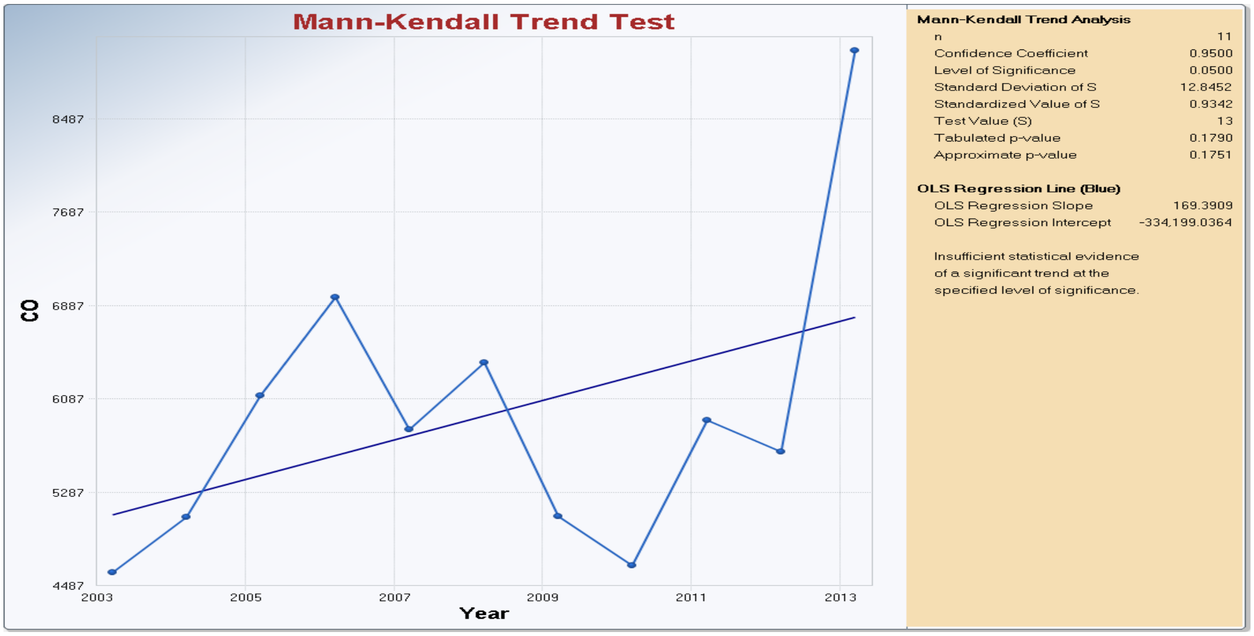

Figure C-38: NPRI CO Emissions Trend Analysis Mann-Kendall Trend Test Output

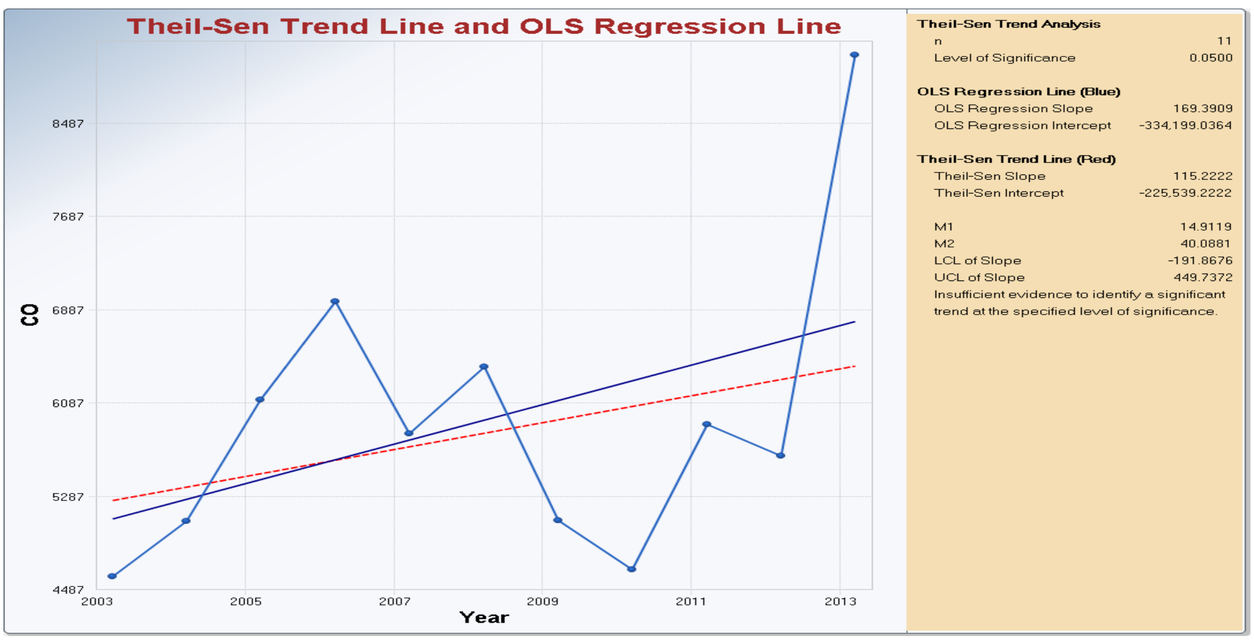

Figure C-39: NPRI CO Emissions Trend Analysis Theil-Sen Trend Line Output

APPENDIX D: AIR QUALITY DATA SET CHARACTERISTICS

Table D-1: Data characteristics for Edmonton South NO_2, 2006-2013

Year	Median (ppb)	Maximum (ppb)	Minimum (ppb)	% valid data
2006	10	62	0	100
2007	9	64	0	99
2008	9	79	0	97
2009	9	77	0	96
2010	8	83	0	99
2011	8	78	0	97
2012	8	59	0	96
2013	7	82	0	99

*Edmonton South NO_2 concentrations are reported to a different precision than Woodcroft and Gold Bar. Data in the CASA Data Warehouse is reported in parts per million (ppm) for Edmonton South NO_2, and was converted to parts per billion (ppb).

Table D-2: Data characteristics for Woodcroft NO_2, 2003-2013

Year	Median (ppb)	Maximum (ppb)	Minimum (ppb)	% valid data
2003	15.0	190.0	0.0	87
2004	13.9	77.0	1.0	94
2005	13.2	63.9	0.7	95
2006	13.4	62.7	1.0	95
2007	12.6	67.9	1.0	95
2008	12.6	69.6	0.0	93
2009	11.9	76.7	0.4	94
2010	12.0	83.1	0.2	93
2011	19.5	77.1	3.3	94
2012	10.9	68.1	1.1	95
2013	11.7	88.5	1.4	94

Table D-3: Data characteristics for Gold Bar NO_2, 2007-2013

Year	Median (ppb)	Maximum (ppb)	Minimum (ppb)	% valid data
2007	11.0	68.4	0.0	95
2008	10.5	73.6	0.0	95
2009	10.6	73.6	0.0	94
2010	11.2	75.9	0.0	94
2011	10.1	70.1	0.0	91
2012	9.5	61.4	1.0	94
2013	9.5	72.3	0.6	94

Table D-4: Data characteristics for Edmonton South $PM_{2.5}$, 2006-2013

Year	Median (µg/m³)	Maximum (µg/m³)	Minimum (µg/m³)	% valid data
2006	3.4	76.0	0.0	99
2007	3.9	100.7	0.0	92
2008	4.4	131.2	0.0	99
2009	4.4	94.3	0.0	73
2010	9.8	396.4	0.0	96
2011	7.4	153.9	0.0	95
2012	6.0	87.9	0.0	71
2013	4.0	63.0	0.0	89

Table D-5: Data characteristics for Woodcroft $PM_{2.5}$, 2003-2013

Year	Median (µg/m³)	Maximum (µg/m³)	Minimum (µg/m³)	% valid data
2003	4.8	71.0	0.0	91
2004	3.9	120.0	0.0	99
2005	3.1	42.8	0.0	100
2006	3.8	84.9	0.0	98
2007	3.8	58.5	0.0	99
2008	3.8	176.6	0.0	98
2009	3.6	84.0	0.0	99
2010	4.1	403.1	0.0	95
2011	3.3	129.1	0.0	98
2012	3.7	147.6	0.0	99
2013	5.4	72.6	0.0	98

Table D-6: Data characteristics for Edmonton South CO, 2006-2013

Year	Median (ppm)	Maximum (ppm)	Minimum (ppm)	% valid data
2006	0.2	2.8	0.0	100
2007	0.2	2.5	0.0	100
2008	0.2	2.1	0.0	99
2009	0.2	2.2	0.0	99
2010	0.2	1.9	0.0	99
2011	0.2	1.5	0.0	99
2012	0.2	1.3	0.0	99
2013	0.2	1.6	0.0	99

APPENDIX E: AIR QUALITY CONCENTRATION PERCENTILE DATA

Table E-1: Edmonton South NO_2 concentration percentiles, 2006-2013 (ppb)

NO_2	Concentration Percentiles (ppb)					
Year	**50th**	**65th**	**80th**	**90th**	**95th**	**98th**
2006	10	14	21	28	34	40
2007	9	14	22	30	36	42
2008	9	13	22	31	37	43
2009	9	14	22	31	39	45
2010	8	12	20	28	35	40
2011	8	12	19	27	34	40
2012	8	12	19	28	34	39
2013	8	11	18	28	36	44

*Edmonton South NO_2 concentrations are reported to a different precision than Woodcroft and Gold Bar. Data is the CASA Data Warehouse is reported in parts per million (ppm) for Edmonton South NO_2, and was converted to parts per billion (ppb).

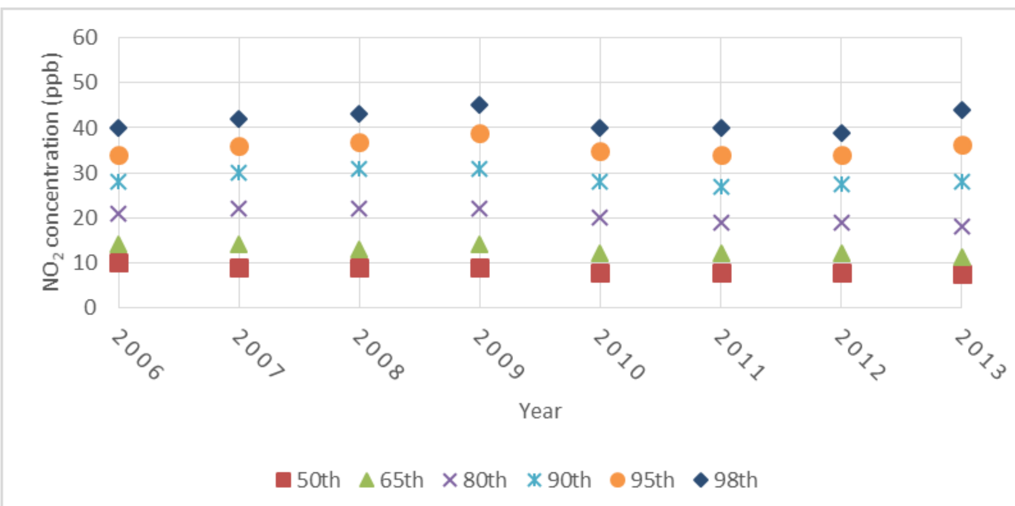

Figure E-1: Edmonton South NO_2 concentration percentiles, 2006-2013 (ppb)

Table E-2: Woodcroft NO_2 concentration percentiles, 2003-2013 (ppb)

NO_2	Concentration Percentiles (ppb)					
Year	**50th**	**65th**	**80th**	**90th**	**95th**	**98th**
2003	15.0	21.0	31.0	38.9	44.0	51.0
2004	13.9	19.0	27.0	35.0	41.0	47.0
2005	13.2	18.8	27.0	34.8	41.3	48.0
2006	13.4	17.9	25.0	32.8	38.4	44.2
2007	12.6	17.8	26.2	33.6	38.3	42.9
2008	12.6	17.7	26.2	34.3	40.0	47.5
2009	11.9	17.5	26.2	35.6	41.3	47.5
2010	12.0	16.5	25.7	34.5	40.3	47.2
2011	19.5	24.0	30.5	37.6	43.4	49.4
2012	10.9	14.7	21.8	29.4	35.3	40.1
2013	11.7	16.6	24.2	31.7	38.2	44.4

Figure E-2: Woodcroft NO_2 concentration percentiles, 2003-2013 (ppb)

Table E-3: Gold Bar NO_2 concentration percentiles, 2007-2013 (ppb)

NO_2	Concentration Percentiles (ppb)					
Year	**50th**	**65th**	**80th**	**90th**	**95th**	**98th**
2007	11.0	16.6	25.4	35.0	40.7	45.3
2008	10.5	15.6	24.0	33.6	40.3	46.1
2009	10.6	16.5	25.0	34.3	40.2	45.7
2010	11.2	17.0	25.4	33.6	39.3	44.7
2011	10.1	15.4	23.6	32.4	38.7	45.8
2012	9.5	13.9	21.7	30.9	37.3	42.8
2013	9.5	14.0	22.4	32.7	39.6	46.4

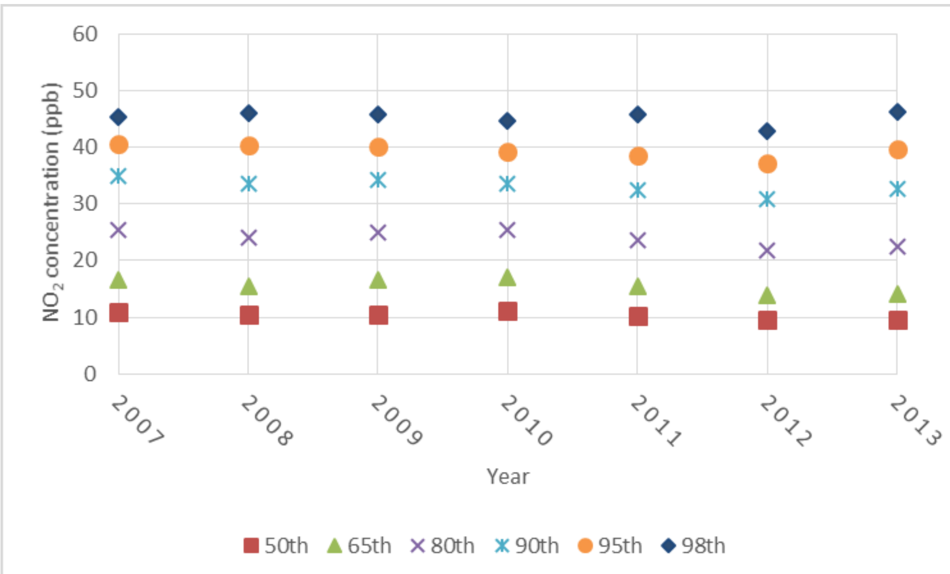

Figure E-3: Gold Bar NO_2 concentration percentiles, 2007-2013 (ppb)

Table E-4: Edmonton South $PM_{2.5}$ concentration percentiles, 2006-2013 (µg/m³)

$PM_{2.5}$	Concentration Percentiles (µg/m³)					
Year	**50th**	**65th**	**80th**	**90th**	**95th**	**98th**
2006	3.4	5.0	7.5	10.8	14.4	19.7
2007	3.9	5.7	8.2	11.9	15.8	21.4
2008	4.4	6.1	8.7	12.7	17.4	24.2
2009	4.4	6.3	9.8	14.3	19.7	26.1
*2010	9.8	12.9	18.8	26.3	35.5	47.8
2011	7.4	9.8	13.8	18.3	23.3	32.8
2012	6.0	9.0	13.0	17.5	22.0	28.0
2013	4.0	7.0	10.0	15.0	20.0	30.0

*2010 data set was not utilized in analysis as it was determined to be an outlier.

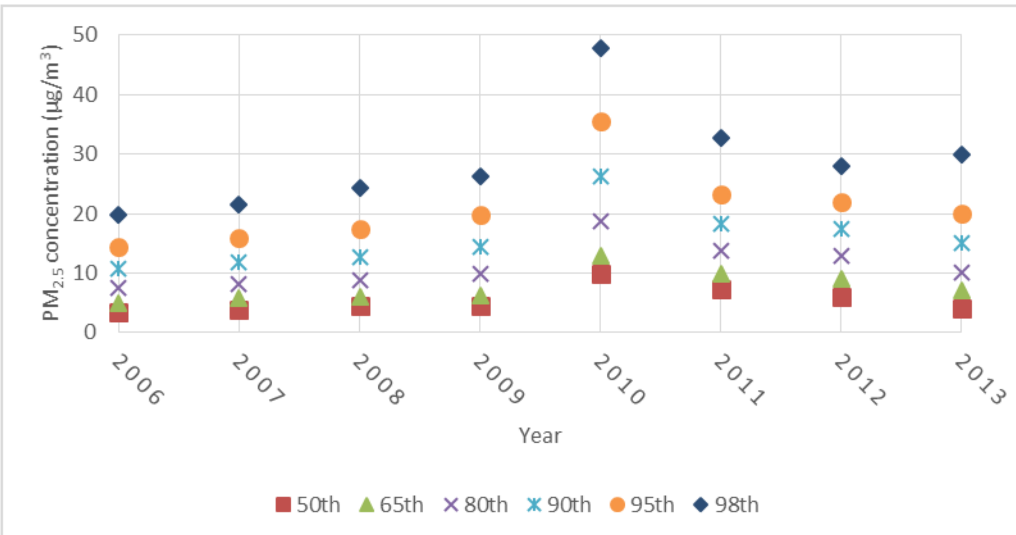

Figure E-4: Edmonton South $PM_{2.5}$ concentration percentiles, 2006-2013 (µg/m³)

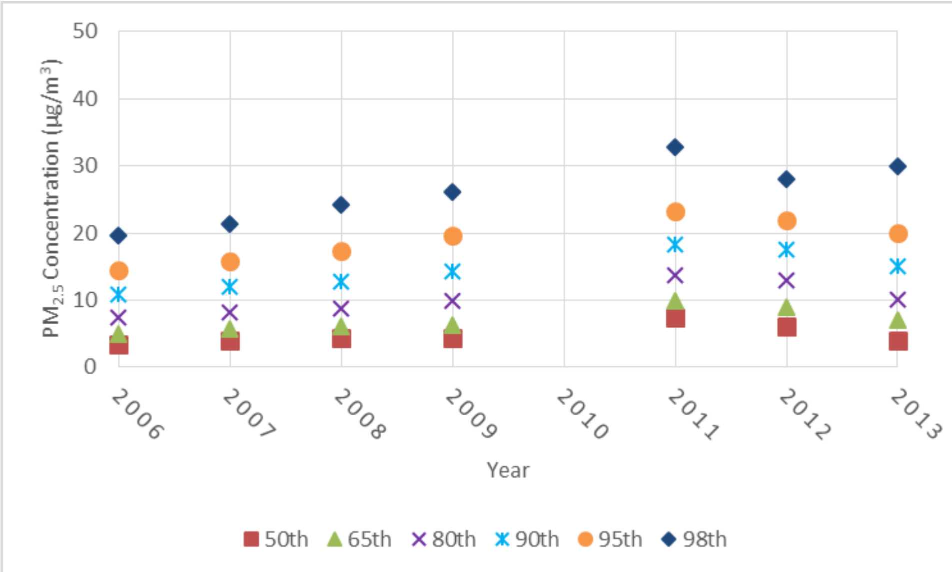

Figure E-5: Edmonton South $PM_{2.5}$ concentration percentiles, 2006-2013 excluding 2010 ($\mu g/m^3$)

Table E-5: Woodcroft $PM_{2.5}$ concentration percentiles, 2003-2013 ($\mu g/m^3$)

$PM_{2.5}$	Concentration Percentiles ($\mu g/m^3$)					
Year	**50th**	**65th**	**80th**	**90th**	**95th**	**98th**
2003	4.8	6.8	10.2	14.6	19.8	28.1
2004	3.9	5.8	8.7	13.3	17.7	23.9
2005	3.1	4.6	7.1	10.0	12.8	17.4
2006	3.8	5.5	7.9	11.4	15.2	20.9
2007	3.8	5.3	7.5	10.4	13.8	19.1
2008	3.8	5.4	7.7	11.2	14.9	19.9
2009	3.6	5.2	7.6	10.6	14.1	18.8
*2010	4.1	6.0	9.1	13.1	18.2	27.1
2011	3.3	4.9	7.2	10.5	14.2	20.3
2012	3.7	5.2	7.5	10.7	13.7	19.1
2013	5.4	7.5	10.5	14.1	17.8	22.0

*2010 data set was not utilized in analysis as it was determined to be an outlier.

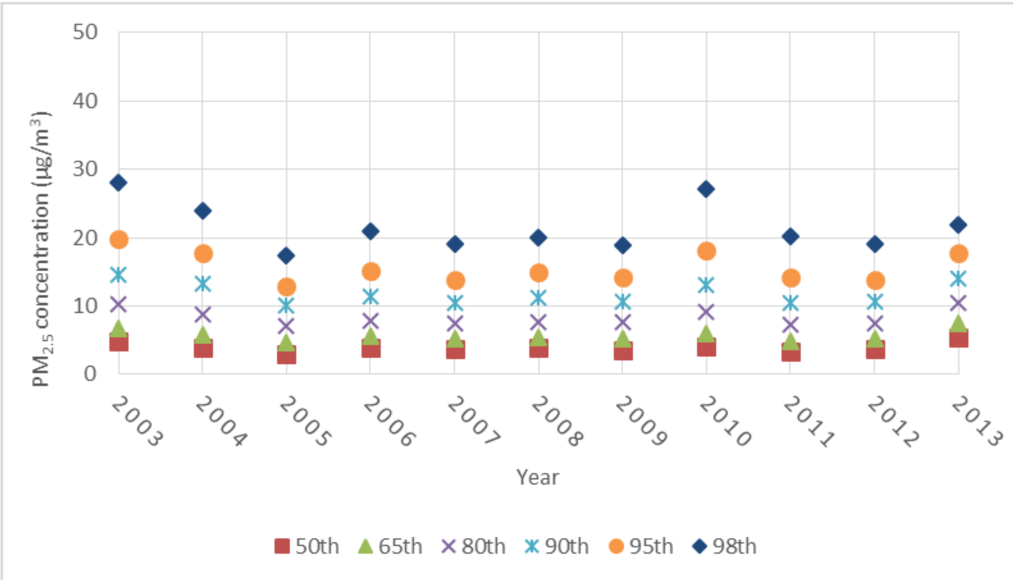

Figure E-6: Woodcroft $PM_{2.5}$ concentration percentiles, 2003-2013 (µg/m^3)

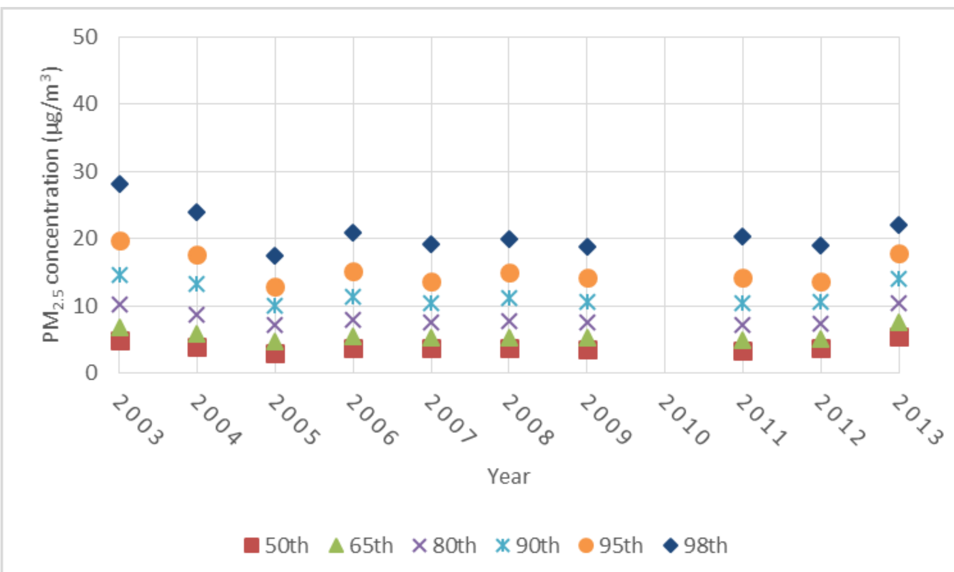

Figure E-7: Woodcroft $PM_{2.5}$ concentration percentiles, 2003-2013 excluding 2010 (µg/m^3)

Table E-6: Edmonton South CO concentration percentiles, 2006-2013 (ppm)

CO	Concentration Percentiles (ppm)					
Year	**50th**	**65th**	**80th**	**90th**	**95th**	**98th**
2006	0.2	0.3	0.3	0.4	0.6	0.8
2007	0.2	0.3	0.3	0.4	0.6	0.8
2008	0.2	0.3	0.3	0.4	0.6	0.8
2009	0.2	0.2	0.3	0.4	0.5	0.7
2010	0.2	0.3	0.3	0.4	0.6	0.8
2011	0.2	0.3	0.3	0.4	0.4	0.6
2012	0.2	0.3	0.3	0.4	0.6	0.7
2013	0.2	0.2	0.3	0.3	0.4	0.5

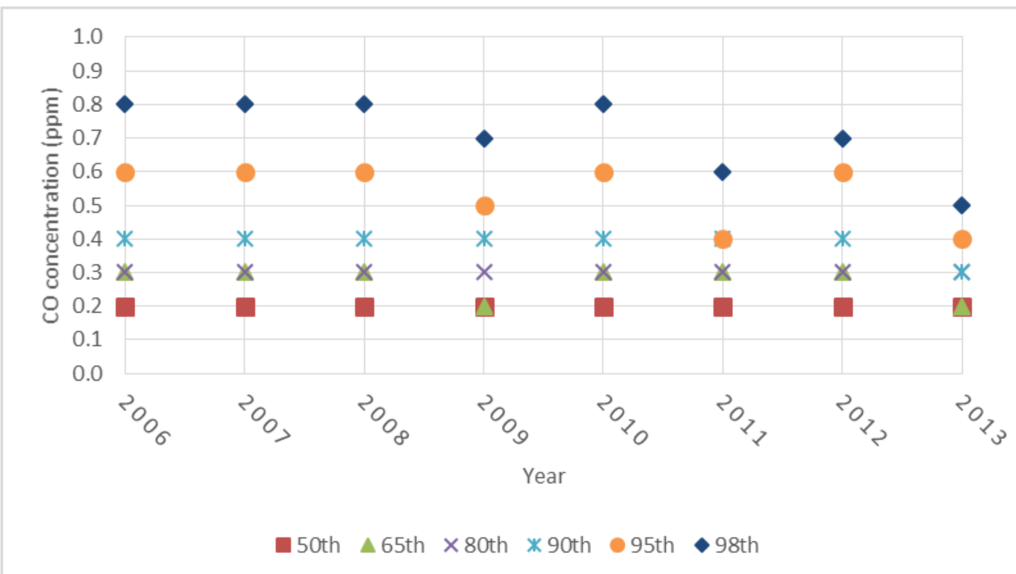

Figure E-8: Edmonton South CO concentration percentiles, 2006-2013 (ppm)

APPENDIX F: SAMPLE CUMULATIVE FREQUENCY DISTRIBUTIONS FOR EDMONTON SOUTH, 2008

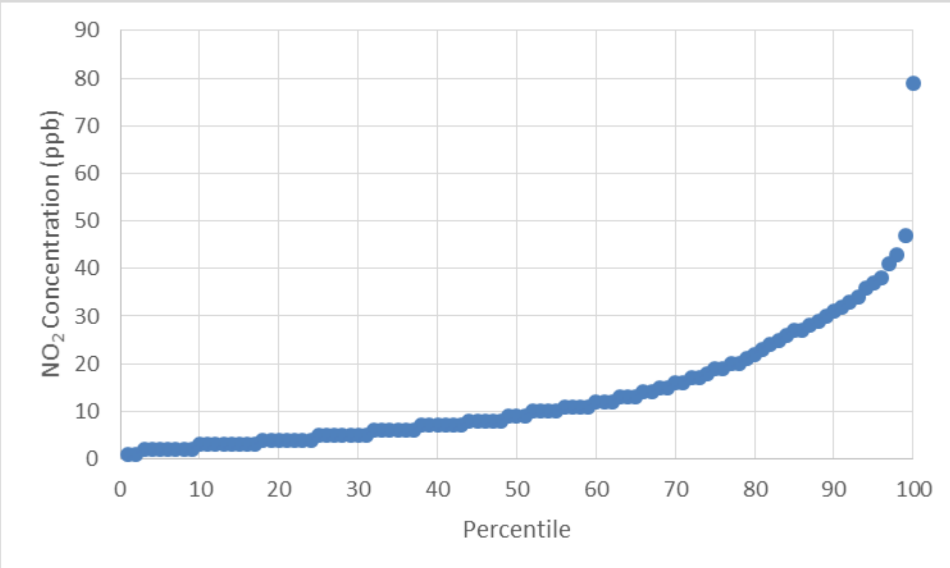

Figure F-1: Cumulative frequency distribution for NO_2 at Edmonton South station, 2008

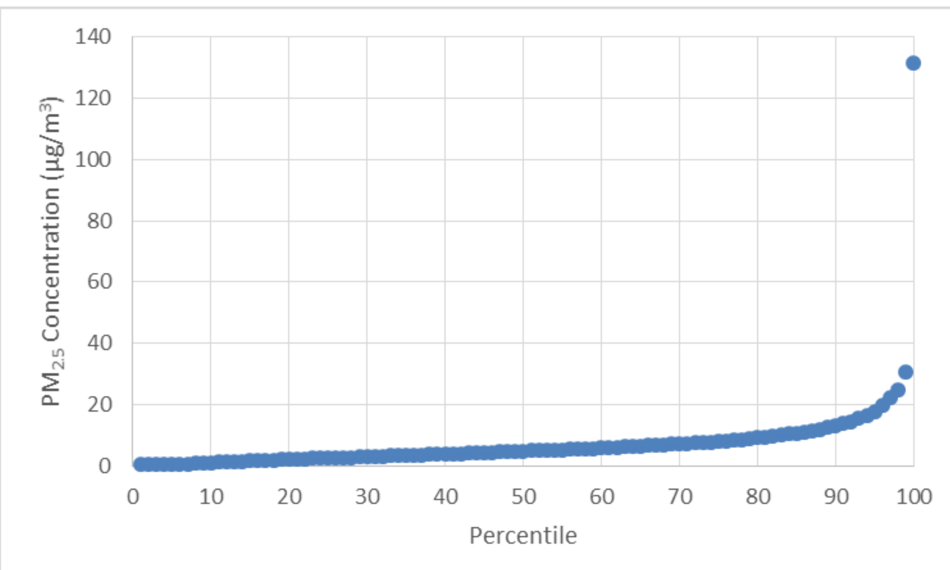

Figure F-2: Cumulative frequency distribution for $PM_{2.5}$ at Edmonton South station, 2008

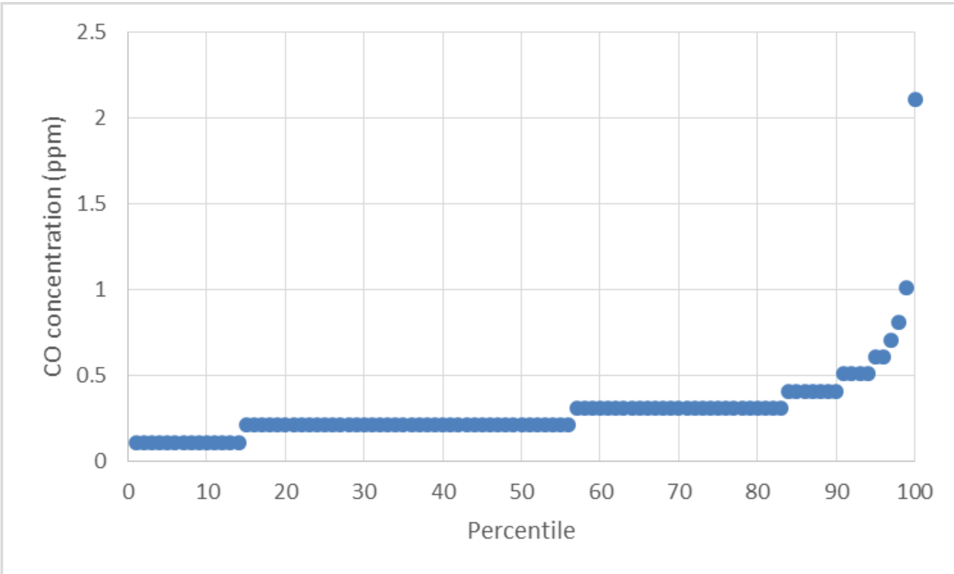

Figure F-3: Cumulative frequency distribution for CO at Edmonton South station, 2008

APPENDIX G: AIR QUALITY TREND ANALYSIS SUMMARY FOR NO_2: PROUCL MANN-KENDALL/THEIL-SEN OUTPUTS

Table G-1: NO_2 trend analysis: Mann-Kendall and Theil-Sen Slope summary (α=0.05)

Station	Concentration	Mann-Kendall Trend Analysis	Theil-Sen Slope: Magnitude per decade (ppb)	LCL, UCL per decade
Edmonton South 2006-2013	50th Percentile	↓	-3.3	(-4.5, -1.7)
	65th Percentile	↓	-3.9	(-6.2, -1.1)
	80th Percentile	↓	-6.3	(-10.0, -0.9)
	90th Percentile	No Trend	-	(-9.5, 5.0)
	95th Percentile	No Trend	-	(-9.2, 11.0)
	98th Percentile	No Trend	-	(-10.0, 14.5)
Woodcroft 2003-2013	50th Percentile	↓	-3.3	(-4.4, -1.7)
	65th Percentile	↓	-3.4	(-6.3, -1.9)
	80th Percentile	↓	-3.2	(-8.0, -0.5)
	90th Percentile	No Trend	-	(-9.4, 3.1)
	95th Percentile	No Trend	-	(-9.1, 3.2)
	98th Percentile	No Trend	-	(-12.2, 2.4)
Gold Bar 2007-2013	50th Percentile	No Trend	-	(-5.6, 0.4)
	65th Percentile	No Trend	-	(-10.5, 0.7)
	80th Percentile	No Trend	-	(-14.4, 0.1)
	90th Percentile	↓	-4.8	(-11.6, -1.8)
	95th Percentile	↓	-4.9	(-8.9, -1.3)
	98th Percentile	No Trend	-	(-9.3, 2.7)

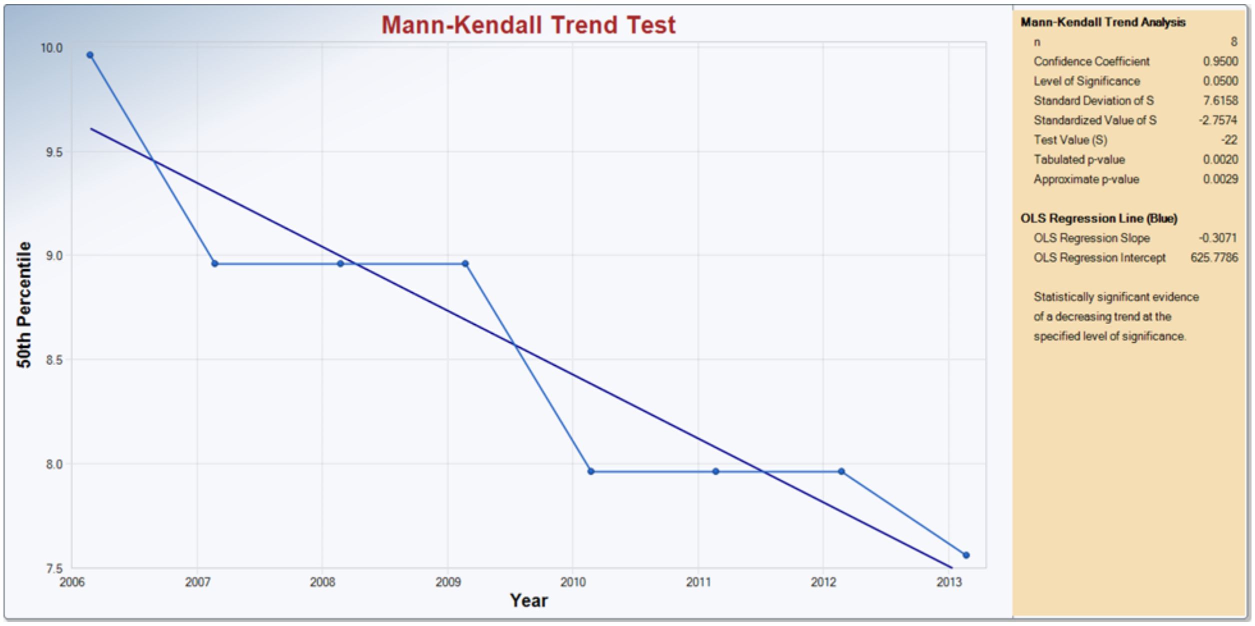

Figure G-1: Edmonton South NO_2 50th Percentile Mann-Kendall Trend Test Output

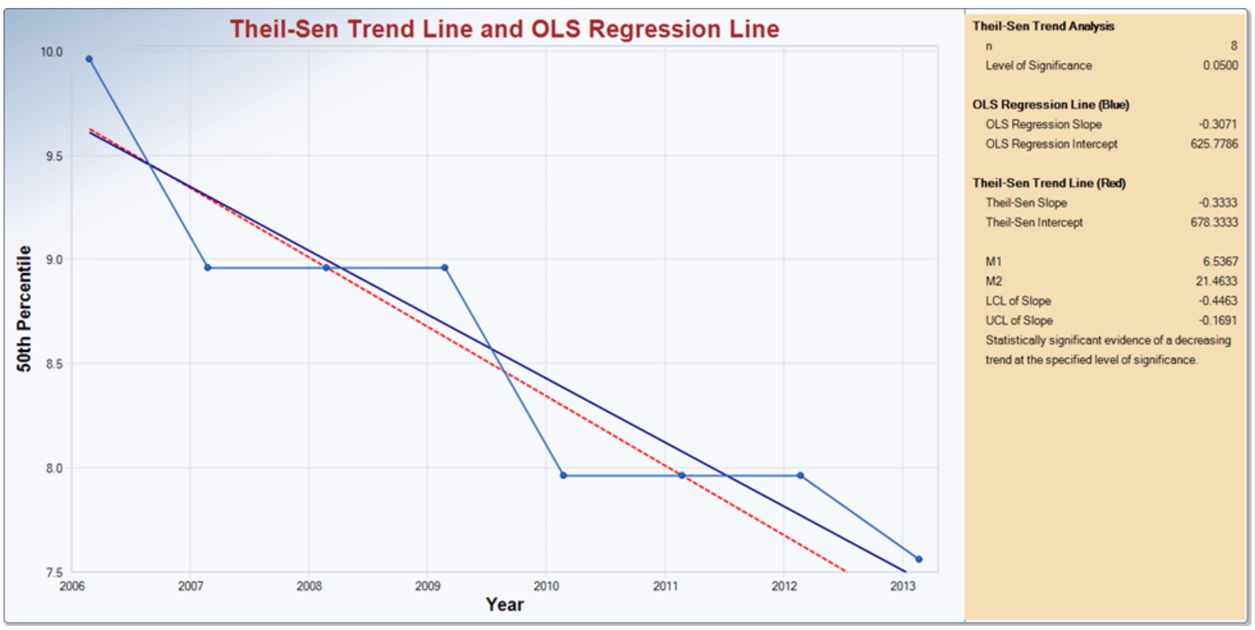

Figure G-2: Edmonton South NO_2 50th Percentile Theil-Sen Trend Line Output

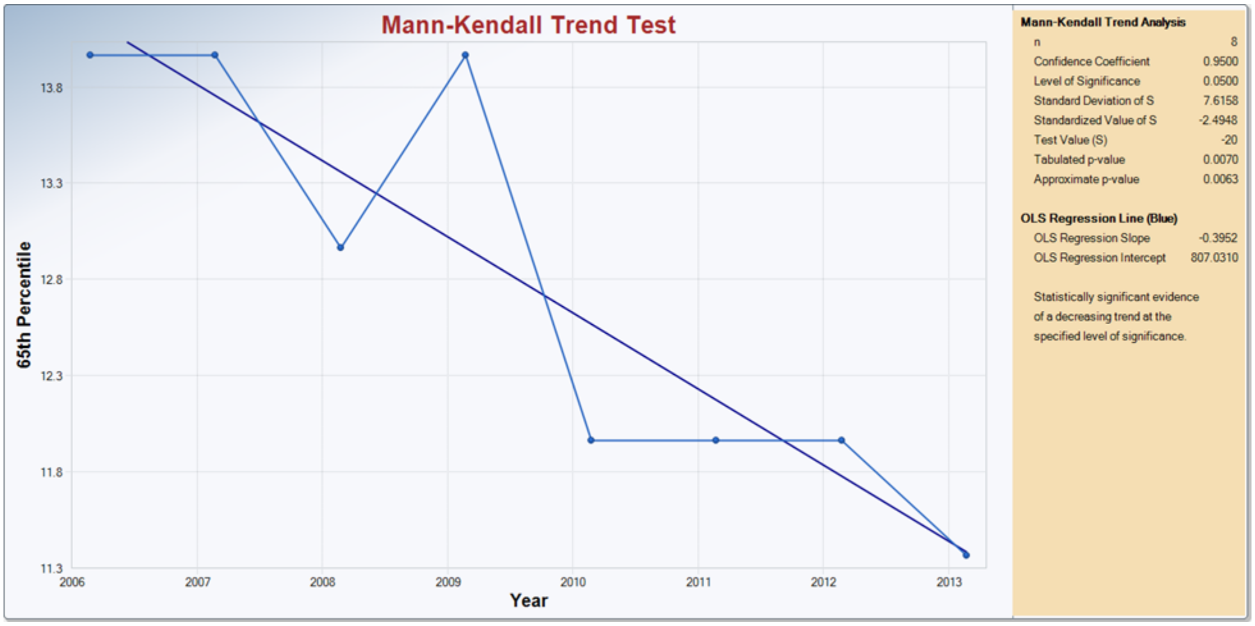

Figure G-3: Edmonton South NO_2 65th Percentile Mann-Kendall Trend Test Output

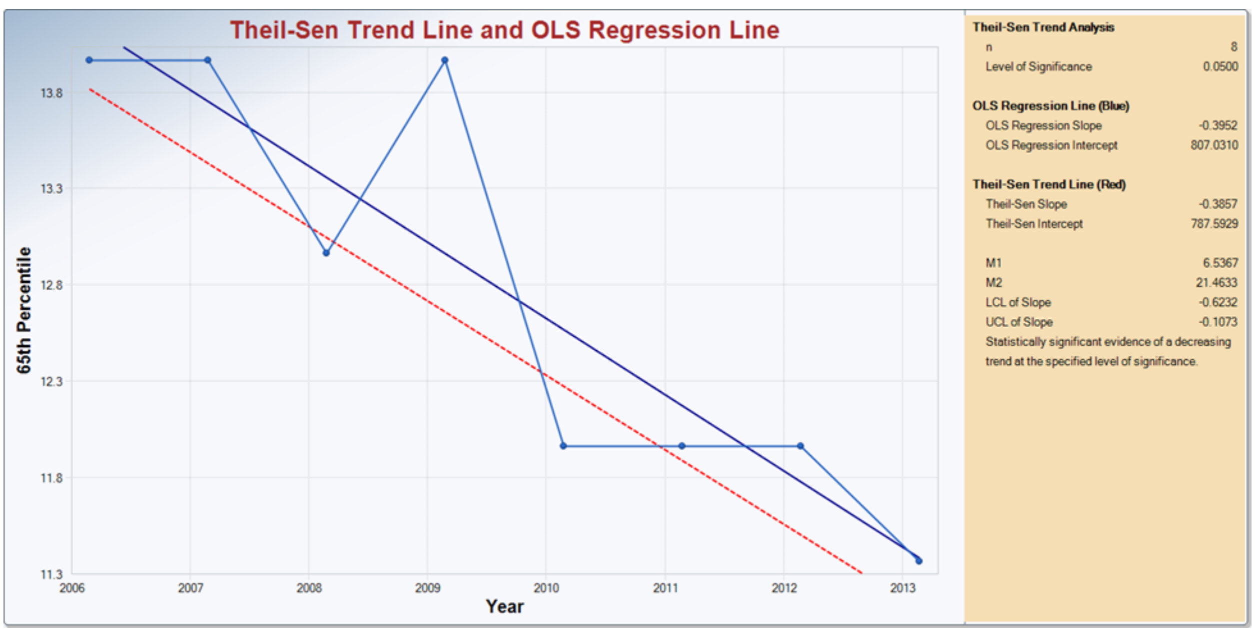

Figure G-4: Edmonton South NO_2 65th Percentile Theil-Sen Trend Line Output

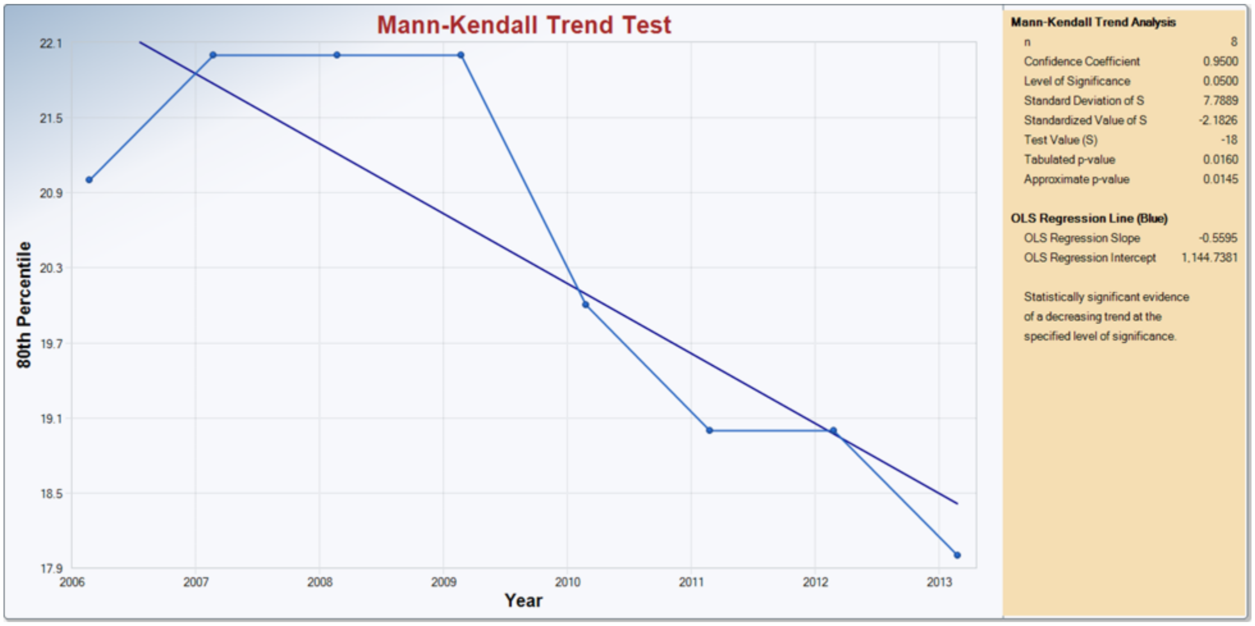

Figure G-5: Edmonton South NO_2 80th Percentile Mann-Kendall Trend Test Output

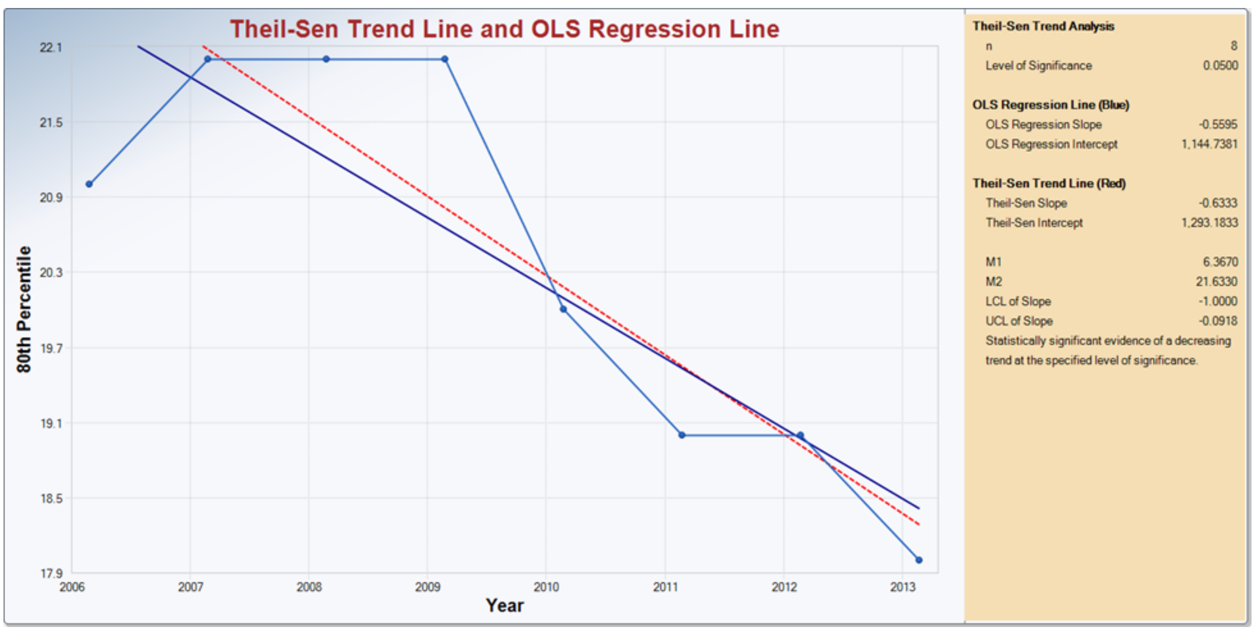

Figure G-6: Edmonton South NO_2 80th Percentile Theil-Sen Trend Line Output

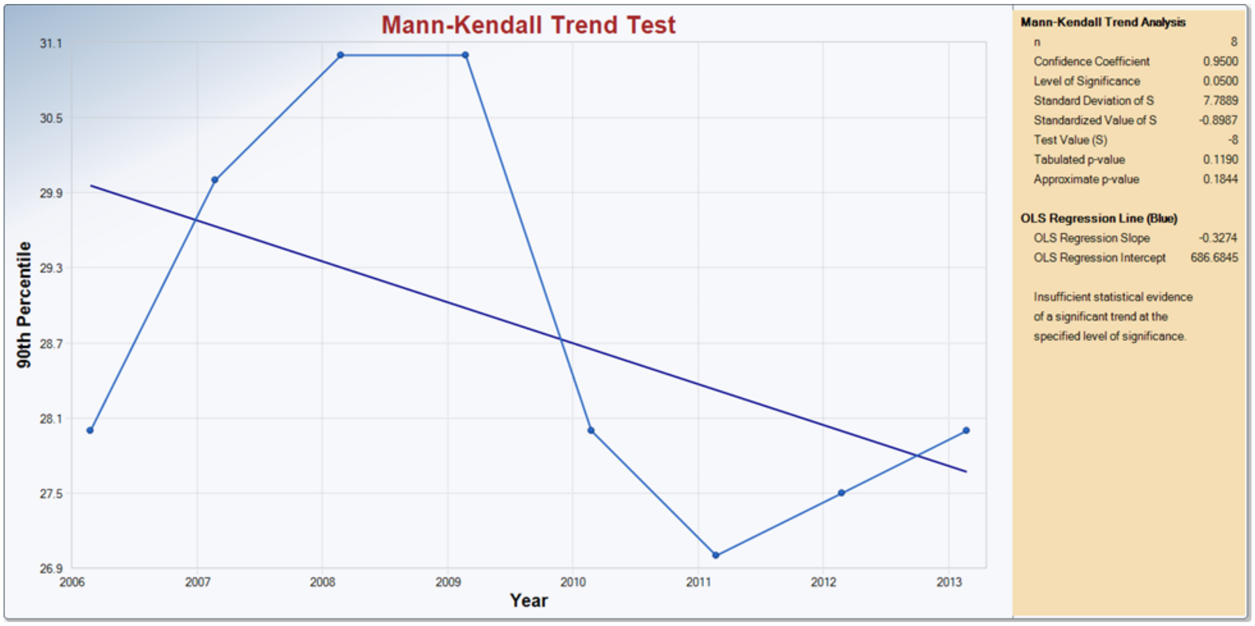

Figure G-7: Edmonton South NO_2 90th Percentile Mann-Kendall Trend Test Output

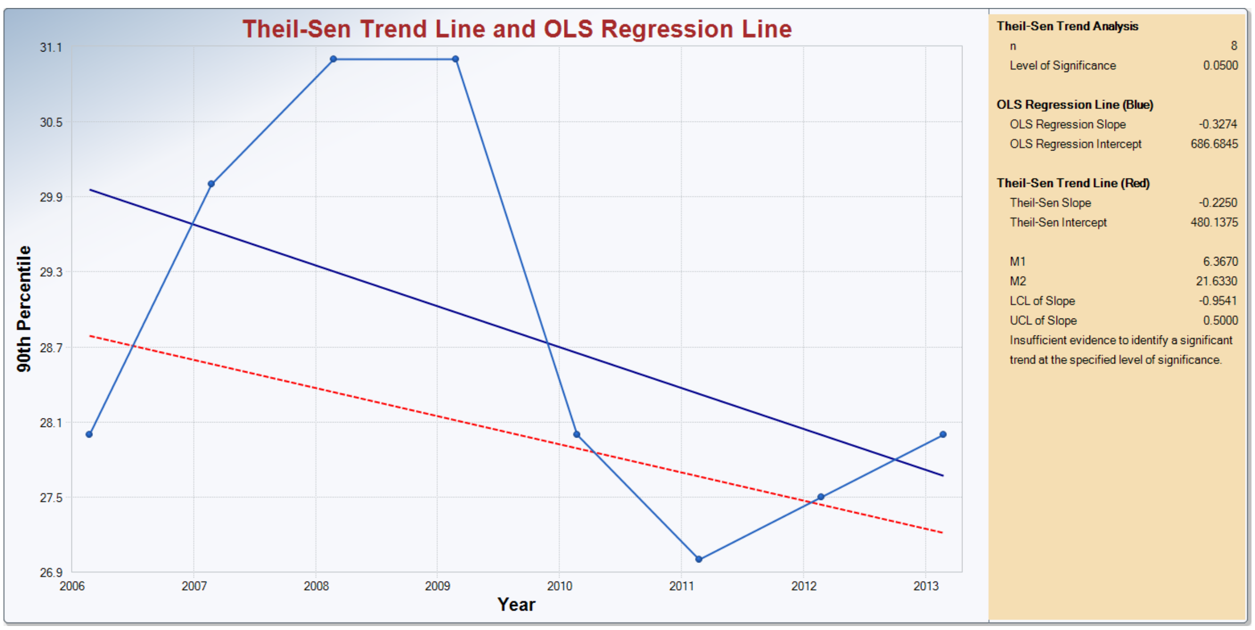

Figure G-8: Edmonton South NO_2 90th Percentile Theil-Sen Trend Line Output

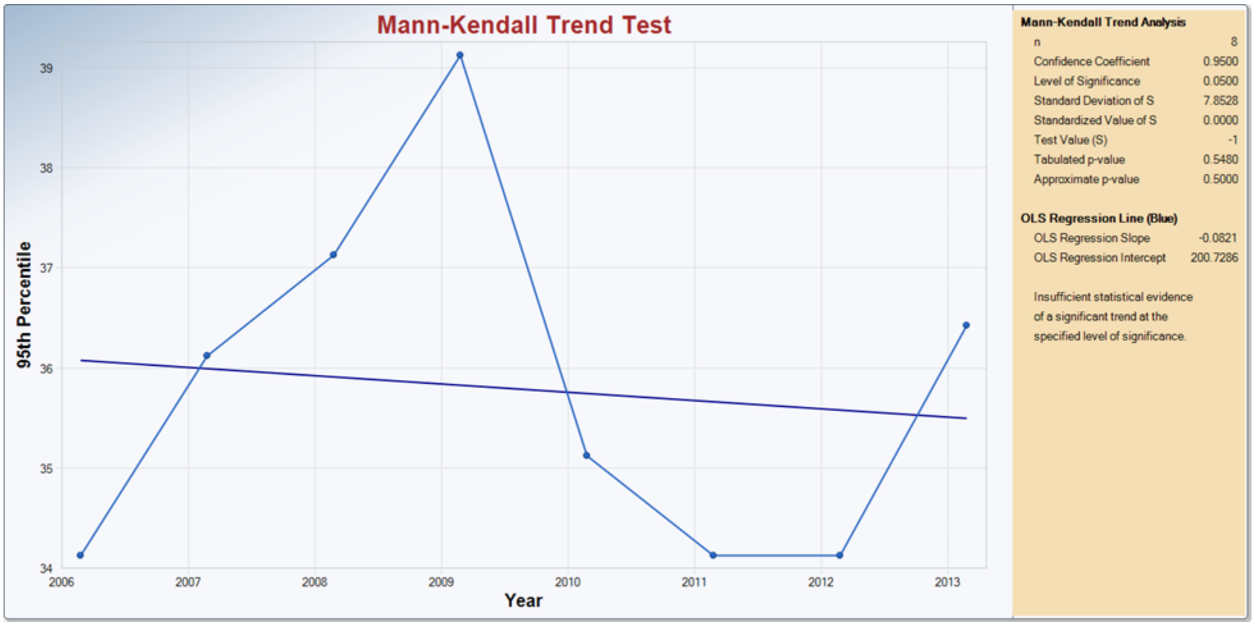

Figure G-9: Edmonton South NO_2 95th Percentile Mann-Kendall Trend Test Output

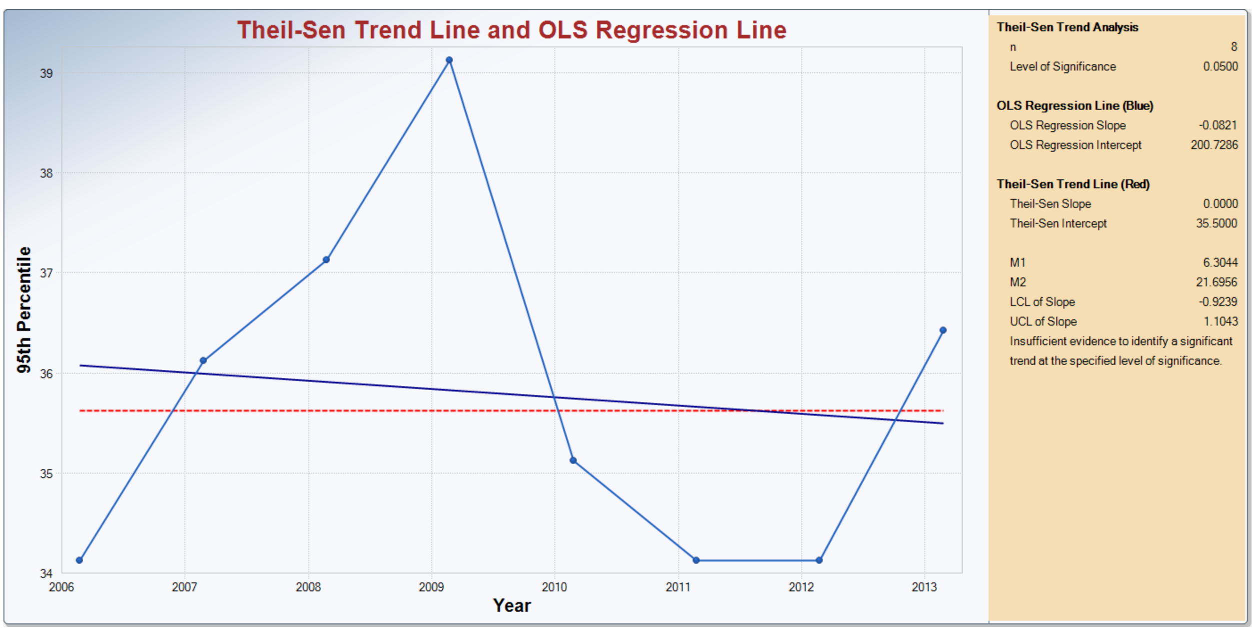

Figure G-10: Edmonton South NO_2 95th Percentile Theil-Sen Trend Line Output

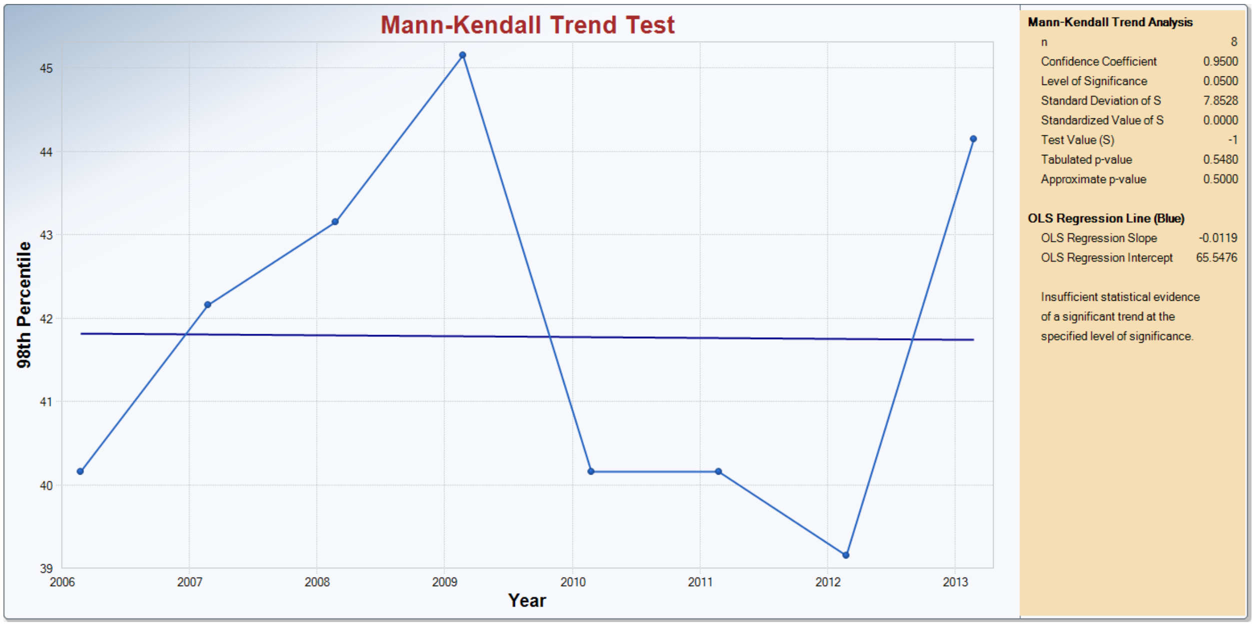

Figure G-11: Edmonton South NO_2 98th Percentile Mann-Kendall Trend Test Output

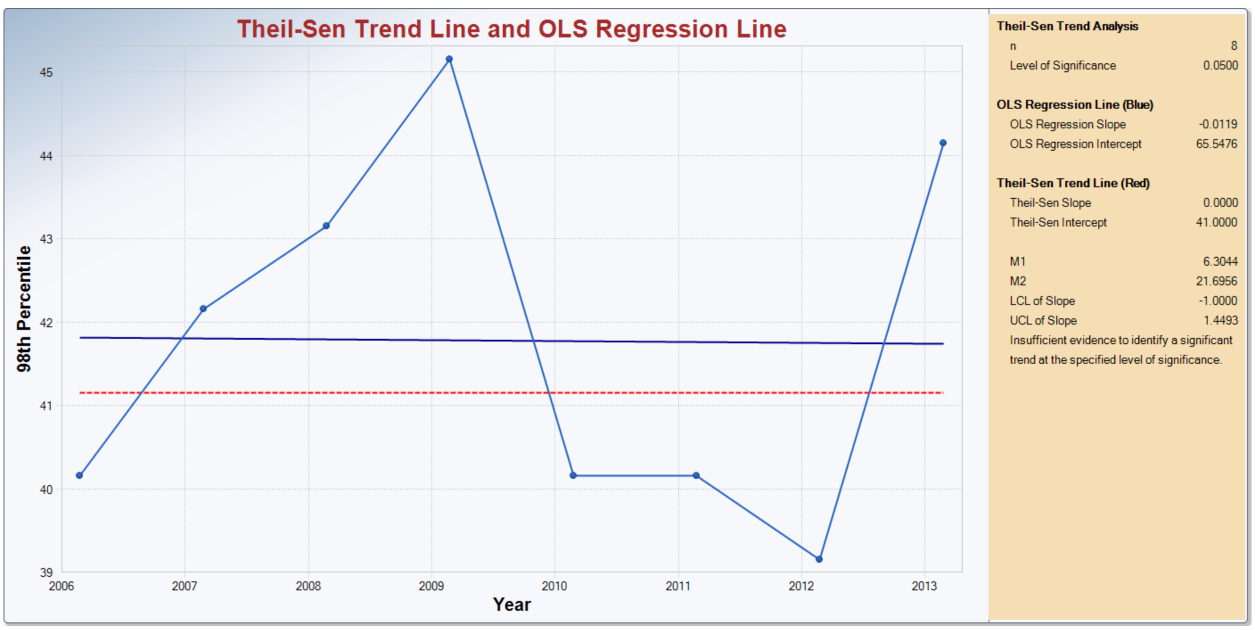

Figure G-12: Edmonton South NO_2 98th Percentile Theil-Sen Trend Line Output

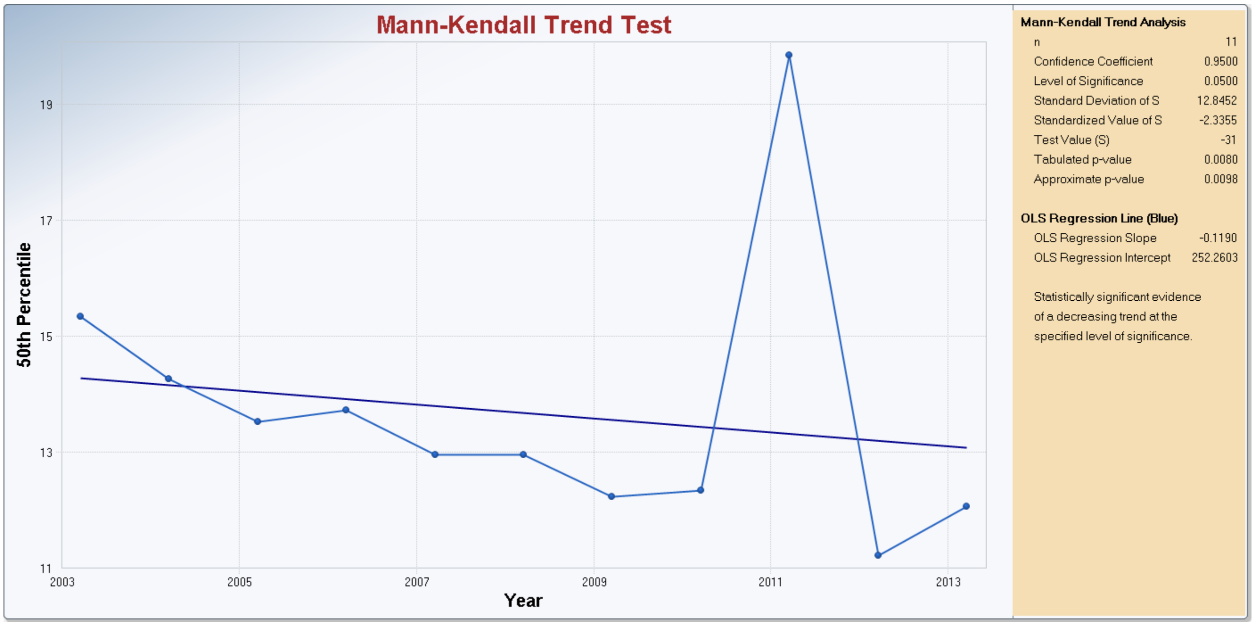

Figure G-13: Woodcroft NO_2 50th Percentile Mann-Kendall Trend Test Output

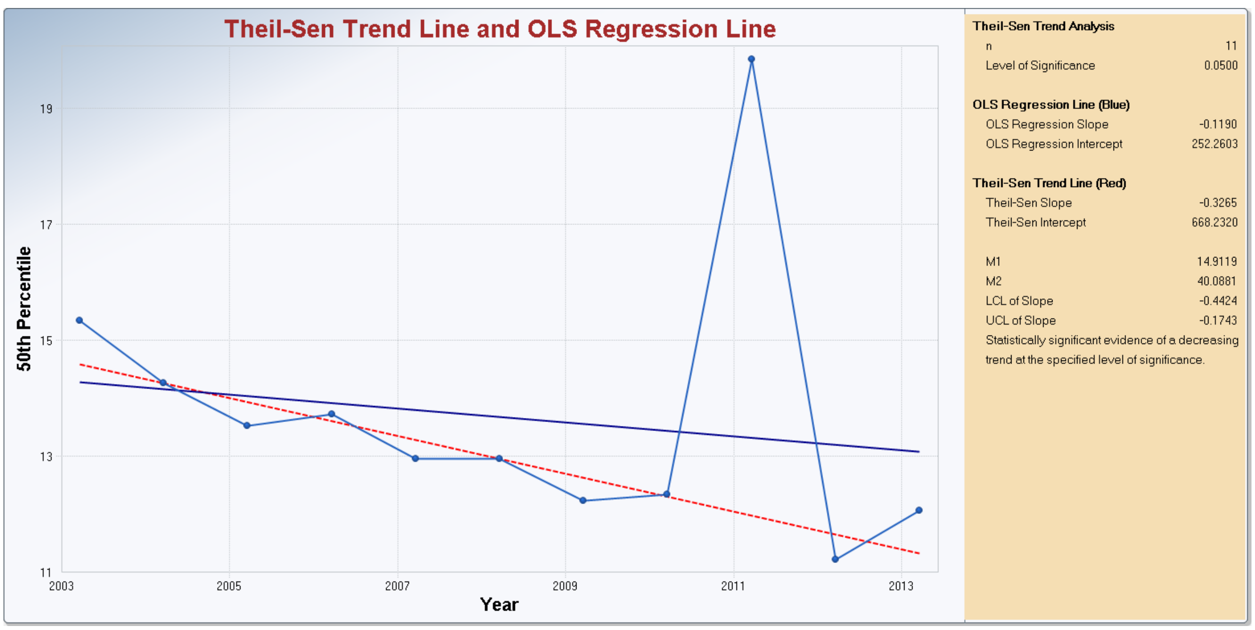

Figure G-14: Woodcroft NO_2 50th Percentile Theil-Sen Trend Line Output

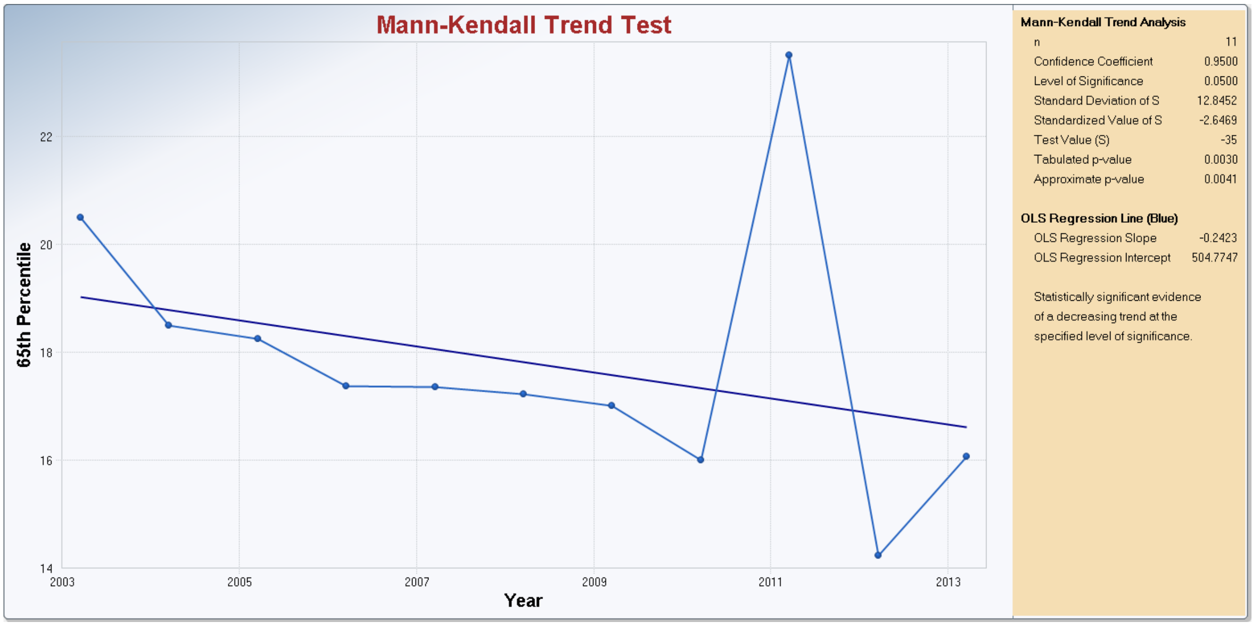

Figure G-15: Woodcroft NO_2 65th Percentile Mann-Kendall Trend Test Output

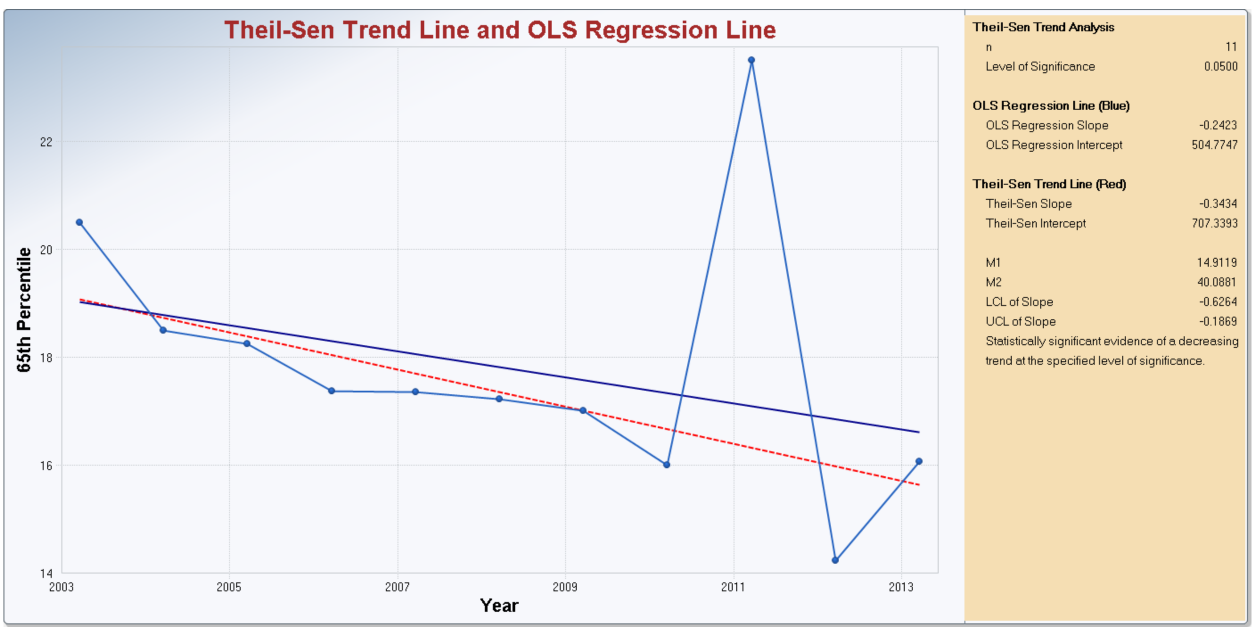

Figure G-16: Woodcroft NO_2 65th Percentile Theil-Sen Trend Line Output

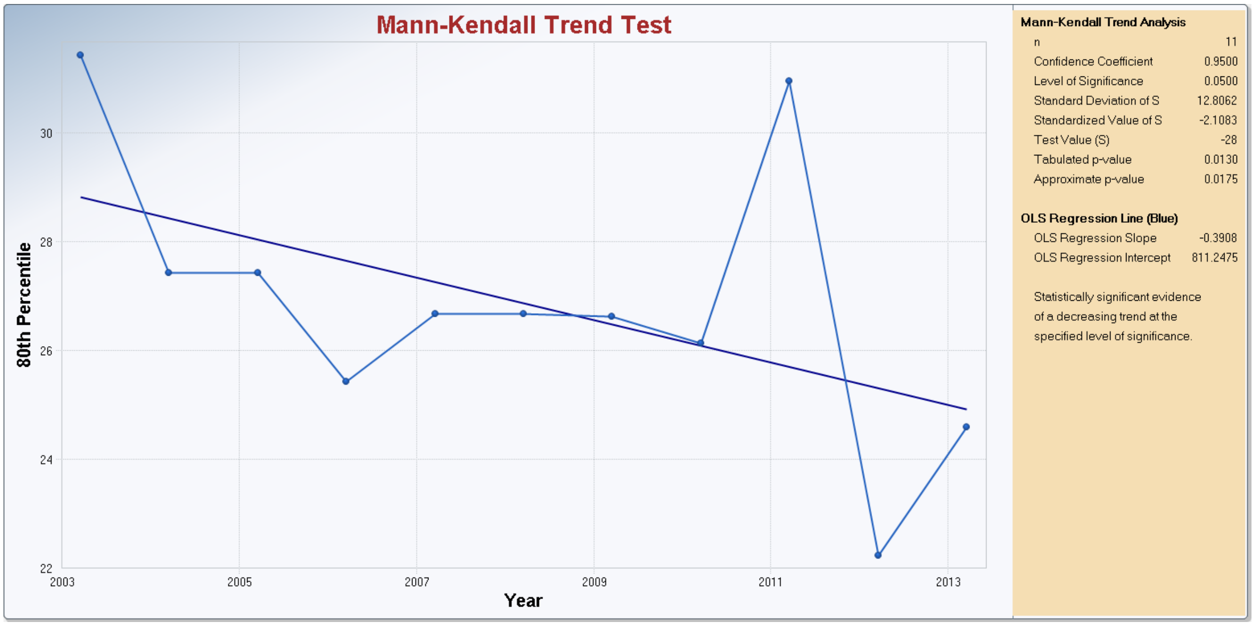

Figure G-17: Woodcroft NO_2 80th Percentile Mann-Kendall Trend Test Output

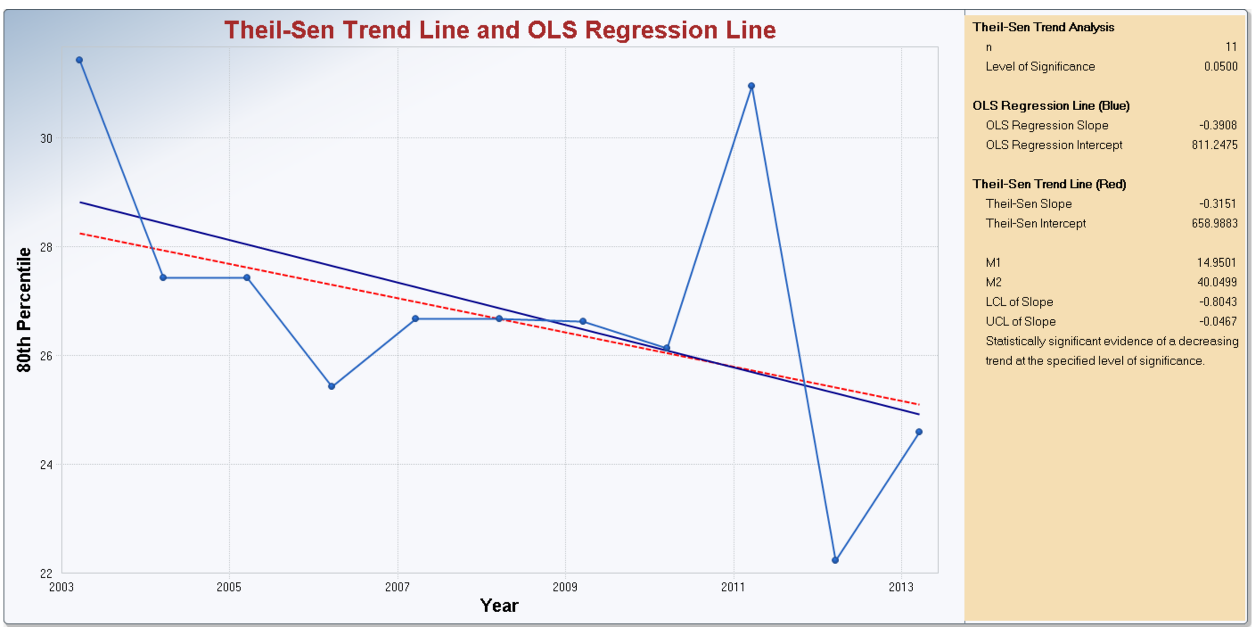

Figure G-18: Woodcroft NO_2 80th Percentile Theil-Sen Trend Line Output

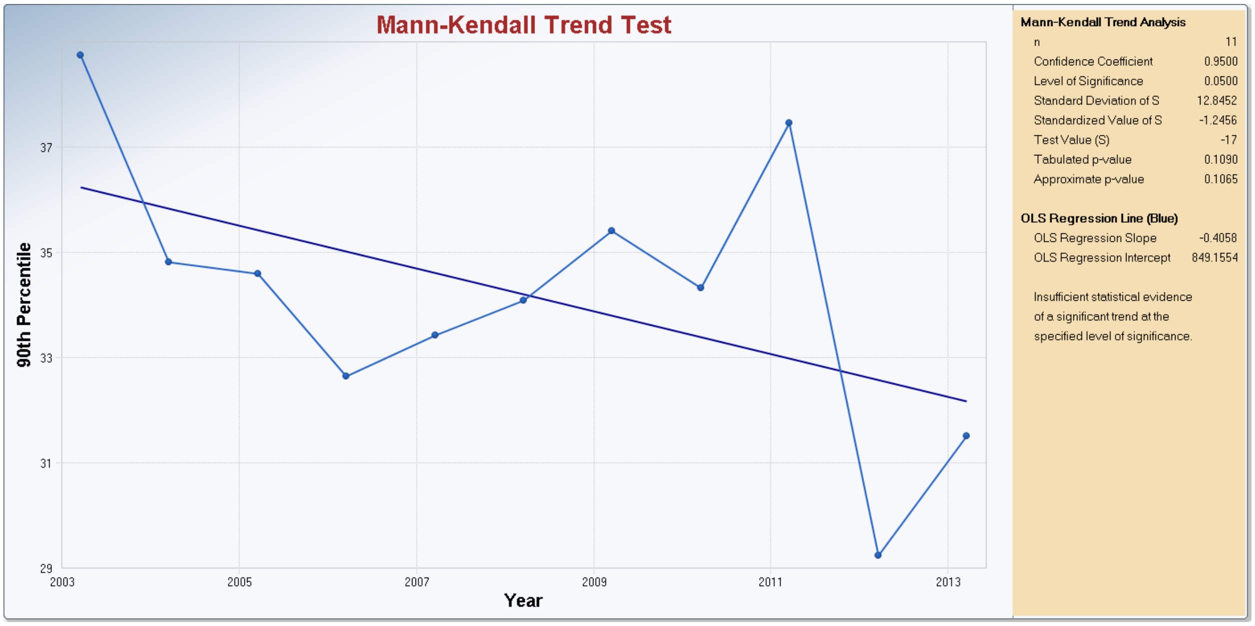

Figure G-19: Woodcroft NO_2 90th Percentile Mann-Kendall Trend Test Output

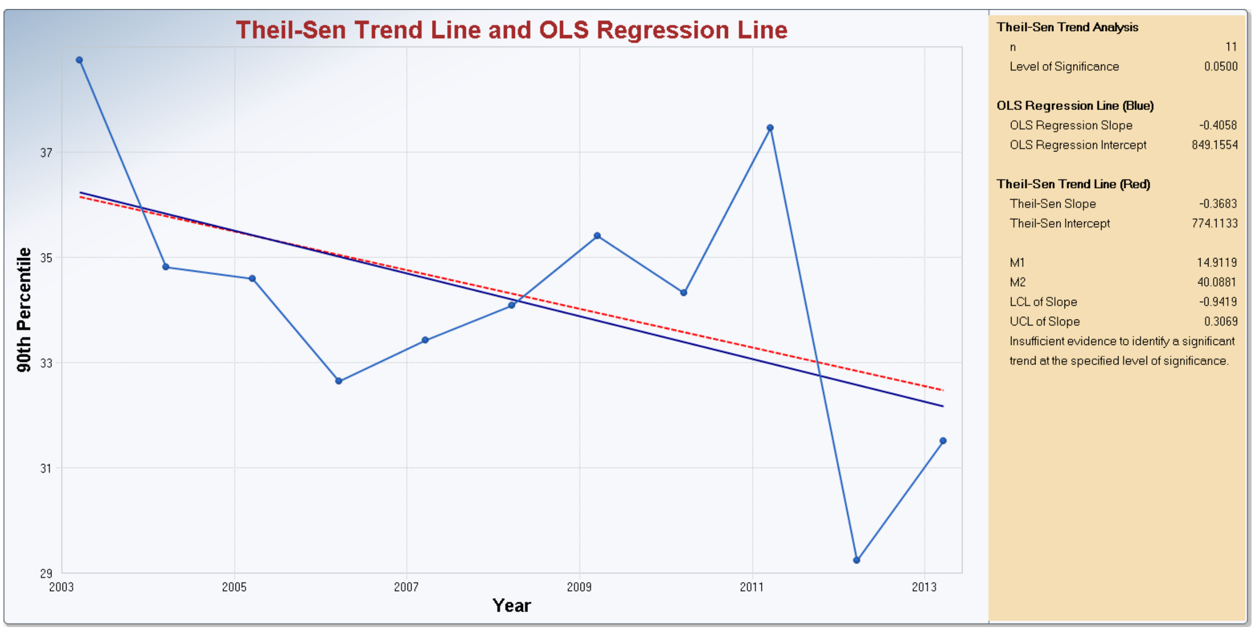

Figure G-20: Woodcroft NO_2 90th Percentile Theil-Sen Trend Line Output

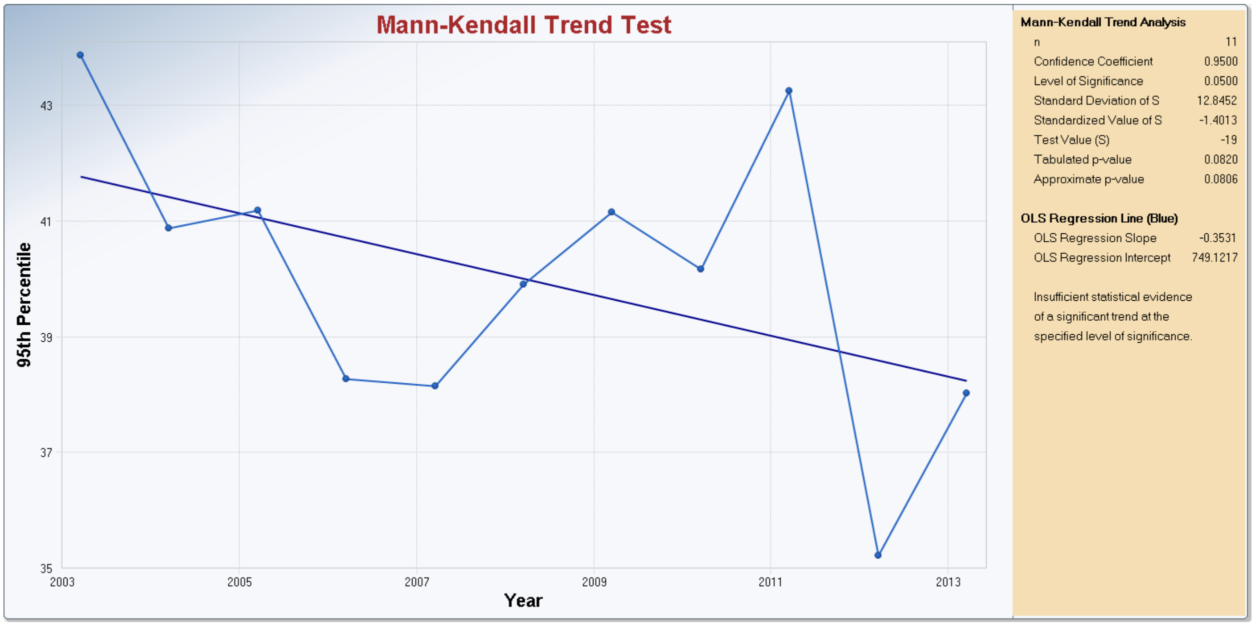

Figure G-21: Woodcroft NO_2 95th Percentile Mann-Kendall Trend Test Output

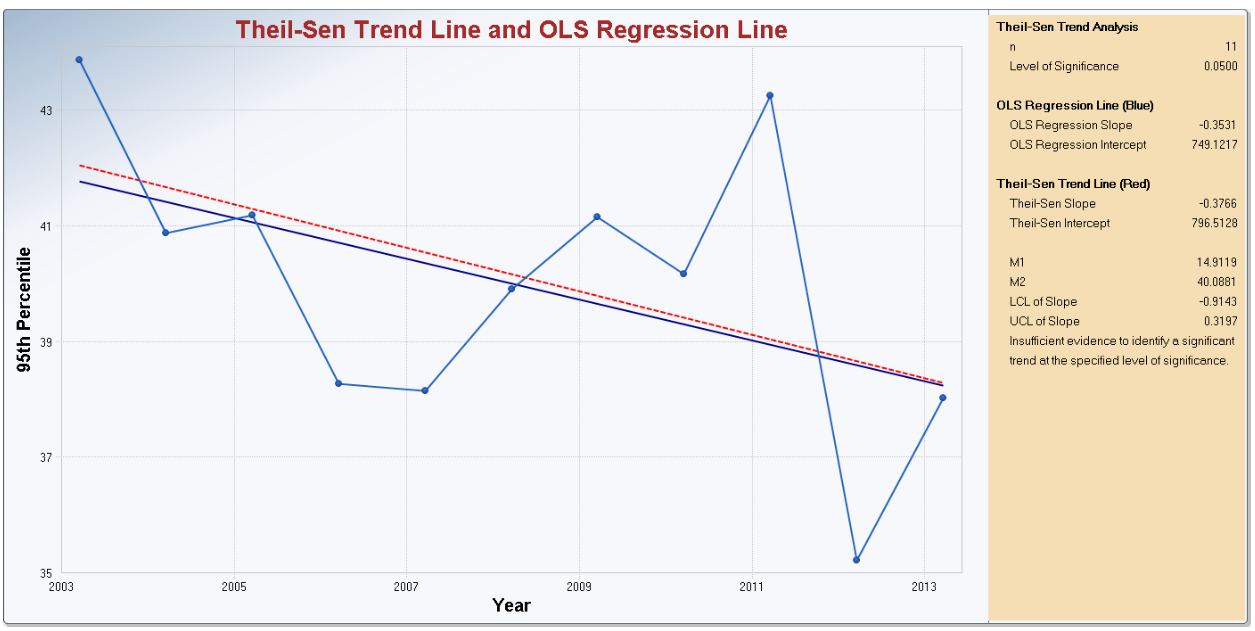

Figure G-22: Woodcroft NO_2 95th Percentile Theil-Sen Trend Line Output

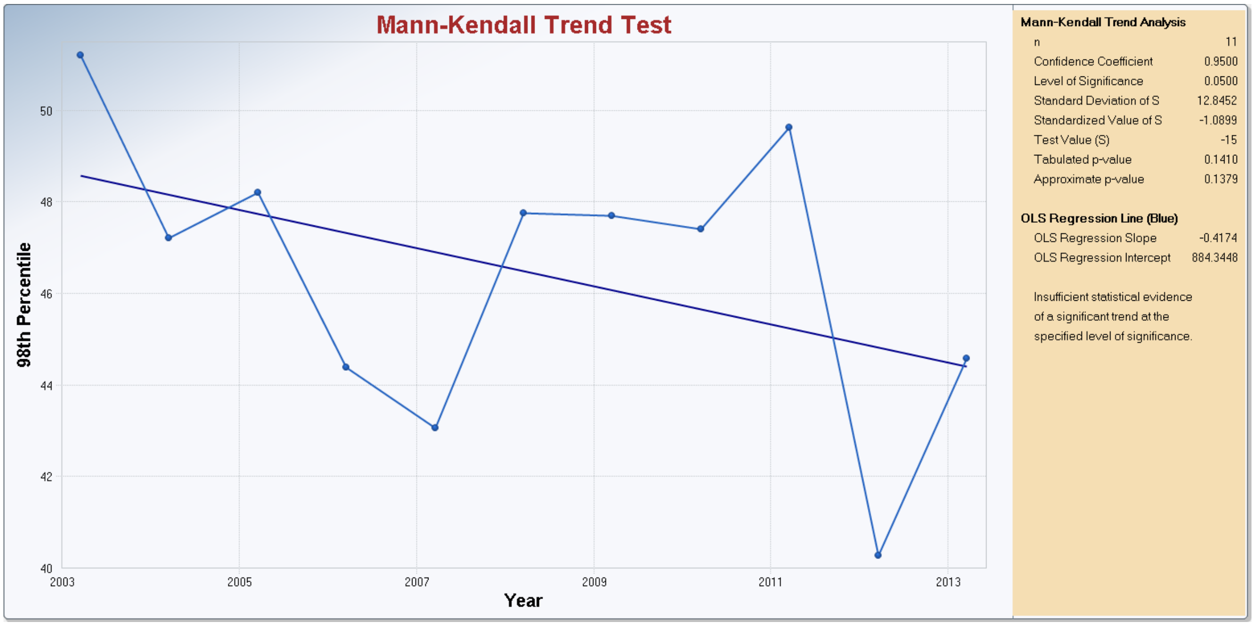

Figure G-23: Woodcroft NO_2 98th Percentile Mann-Kendall Trend Test Output

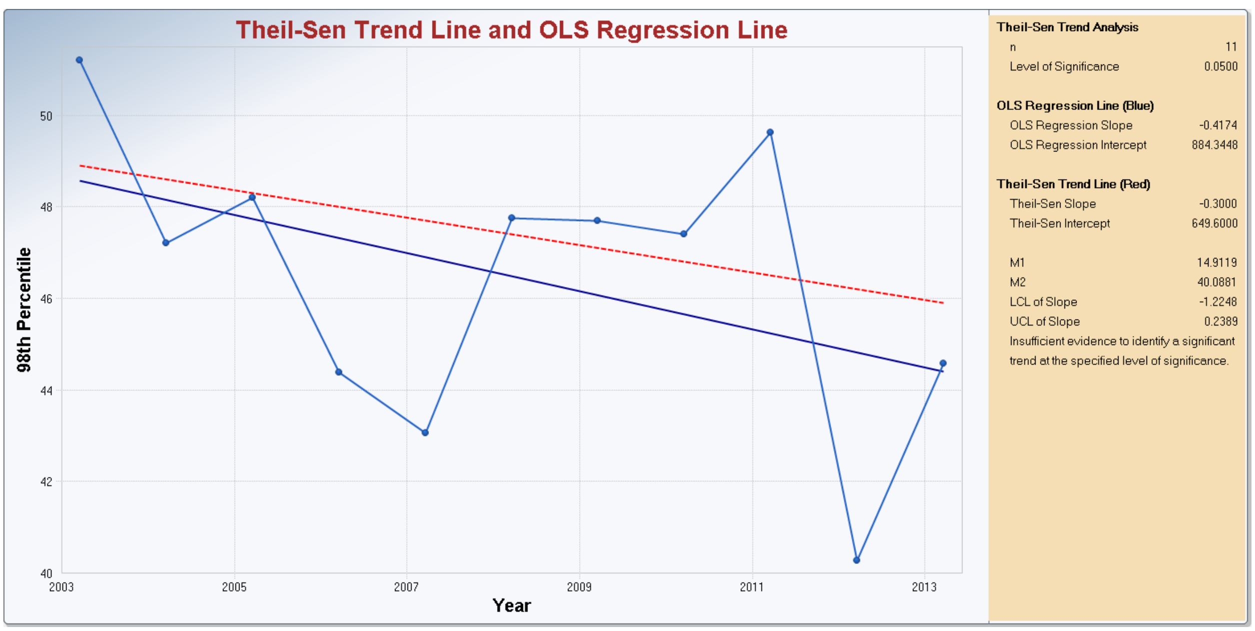

Figure G-24: Woodcroft NO_2 98th Percentile Theil-Sen Trend Line Output

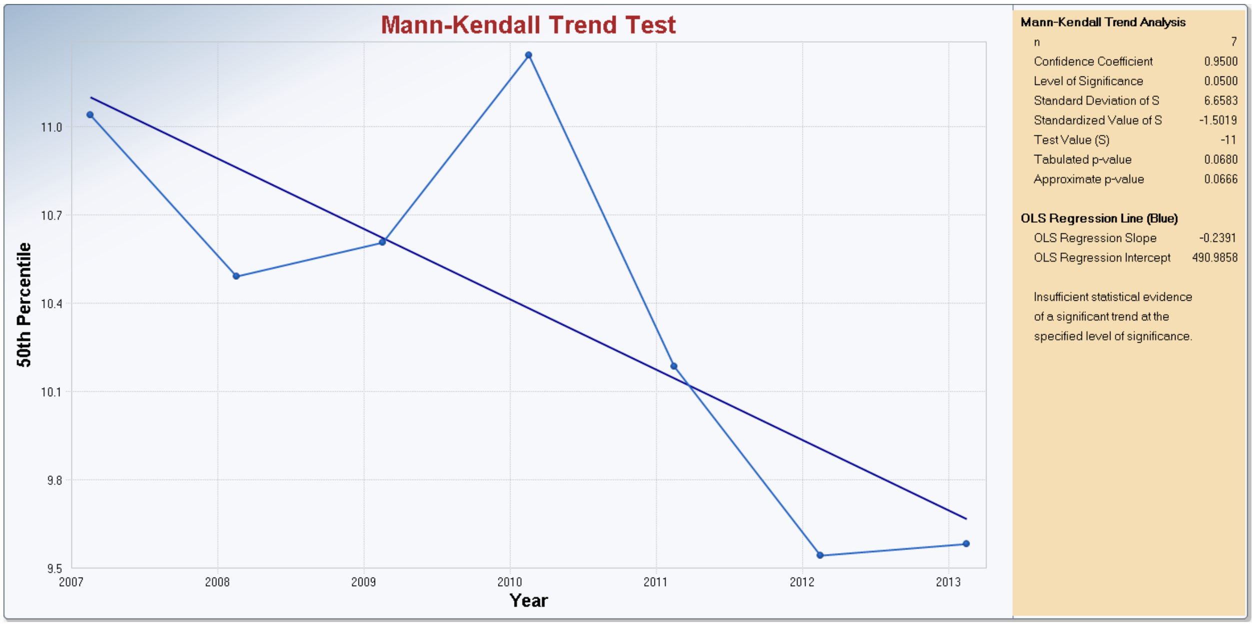

Figure G-25: Gold Bar NO_2 50th Percentile Mann-Kendall Trend Test Output

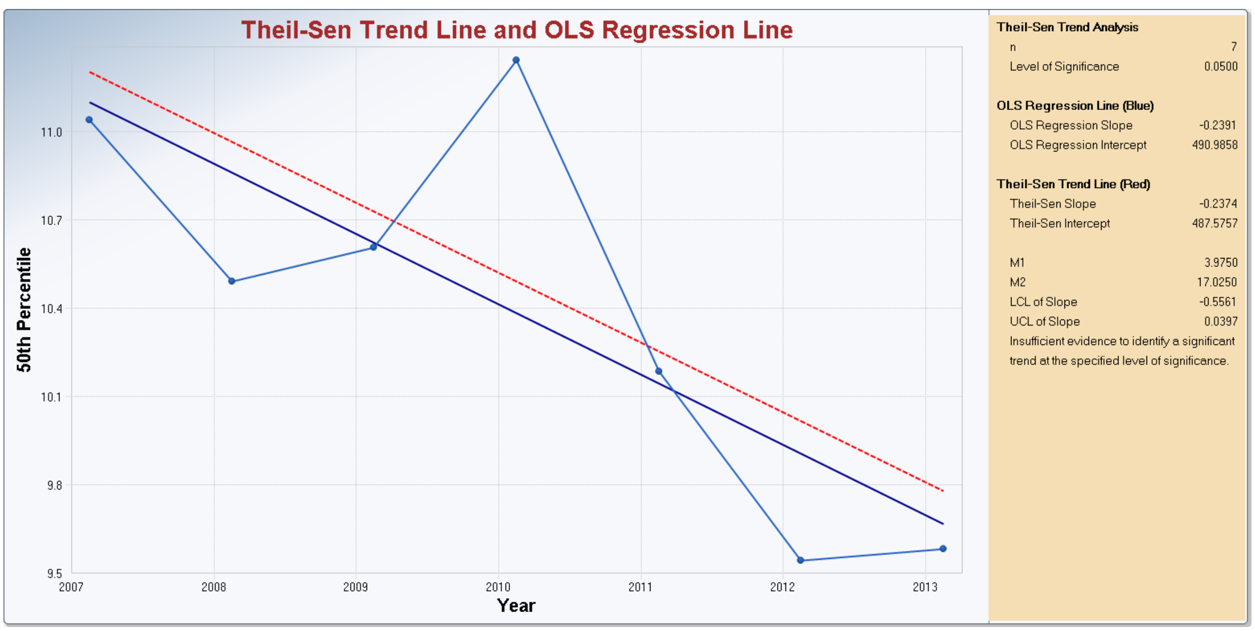

Figure G-26: Gold Bar NO_2 50th Percentile Theil-Sen Trend Line Output

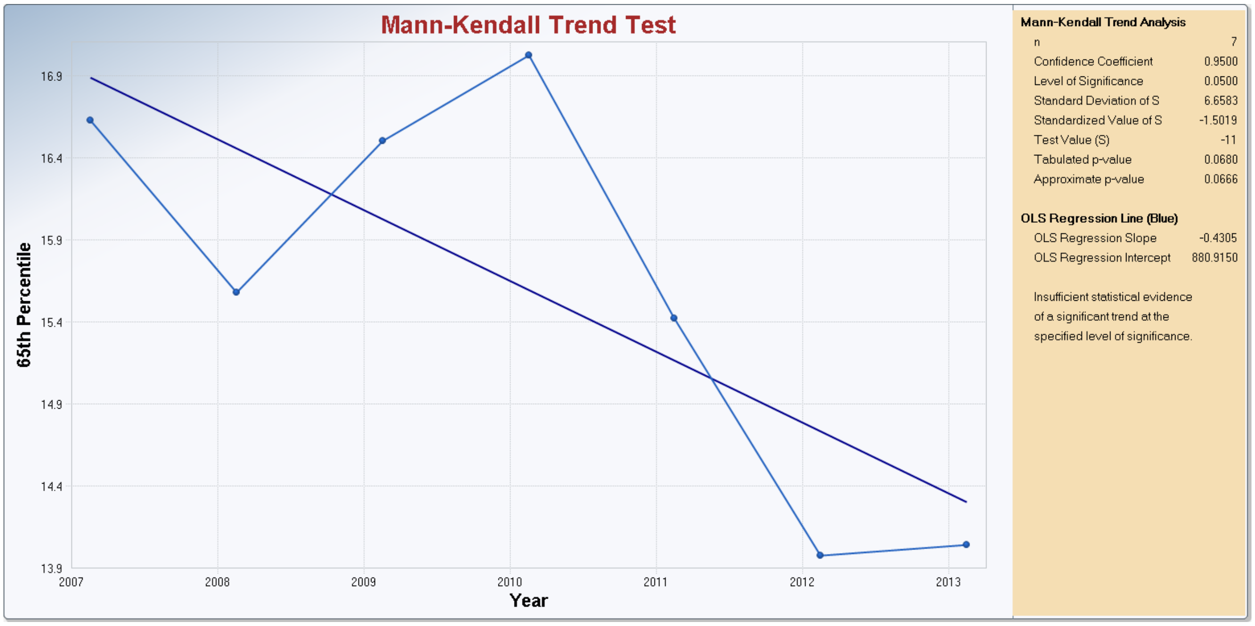

Figure G-27: Gold Bar NO_2 65th Percentile Mann-Kendall Trend Test Output

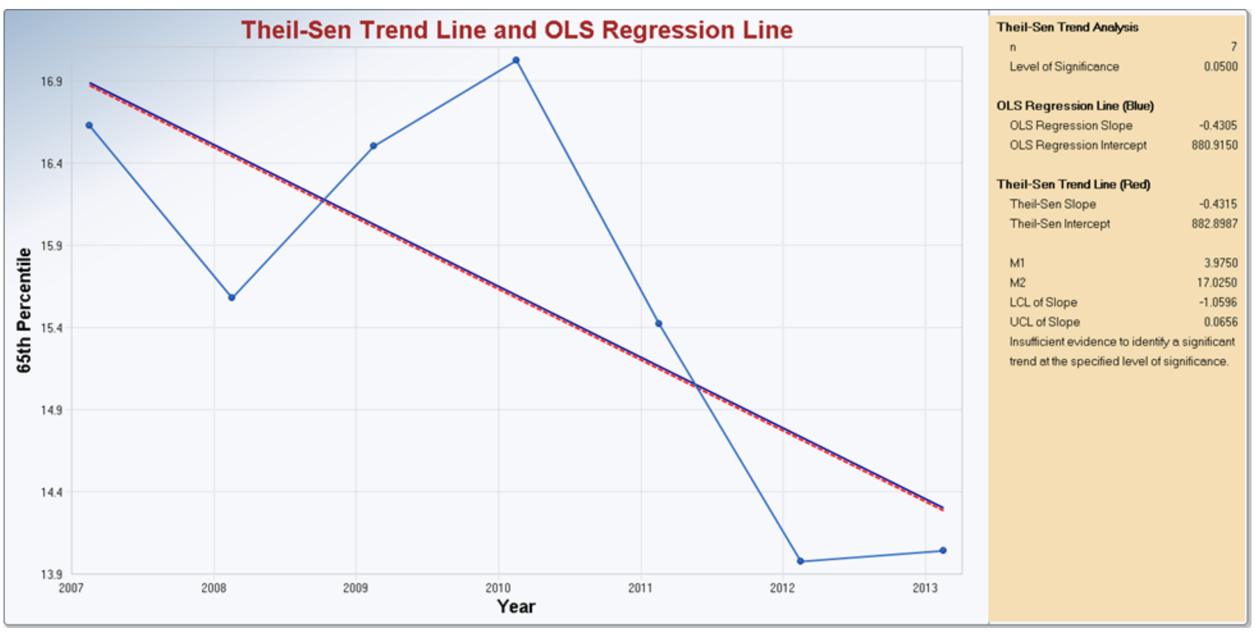

Figure G-28: Gold Bar NO_2 65th Percentile Theil-Sen Trend Line Output

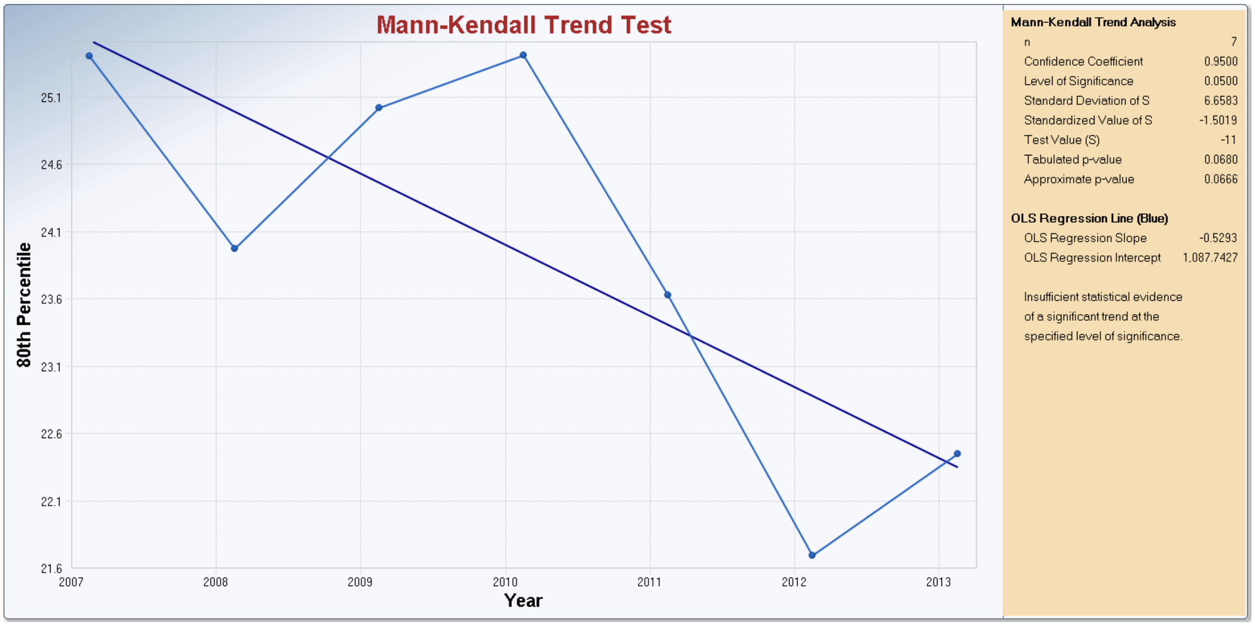

Figure G-29: Gold Bar NO_2 80th Percentile Mann-Kendall Trend Test Output

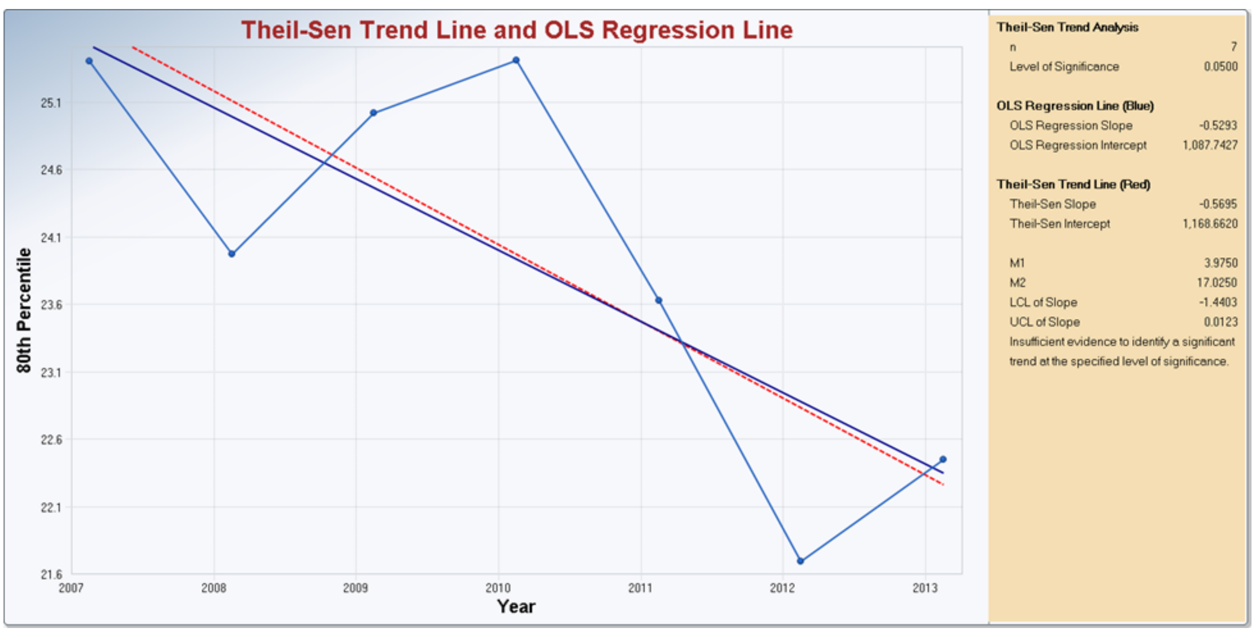

Figure G-30: Gold Bar NO_2 80th Percentile Theil-Sen Trend Line Output

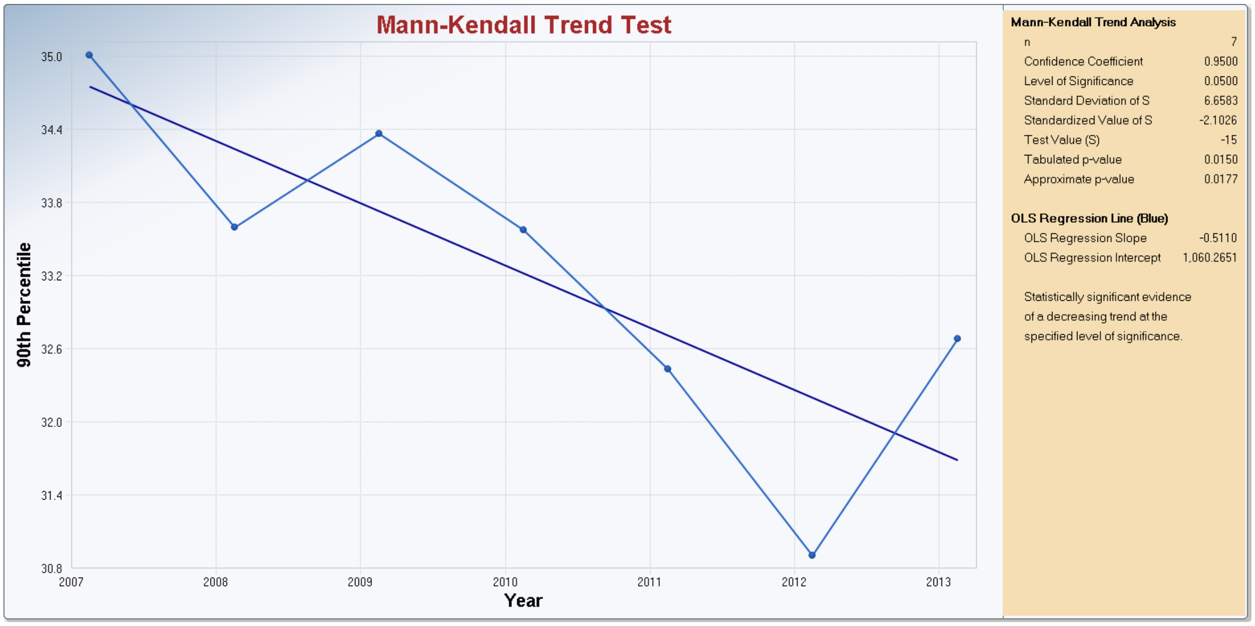

Figure G-31: Gold Bar NO_2 90th Percentile Mann-Kendall Trend Test Output

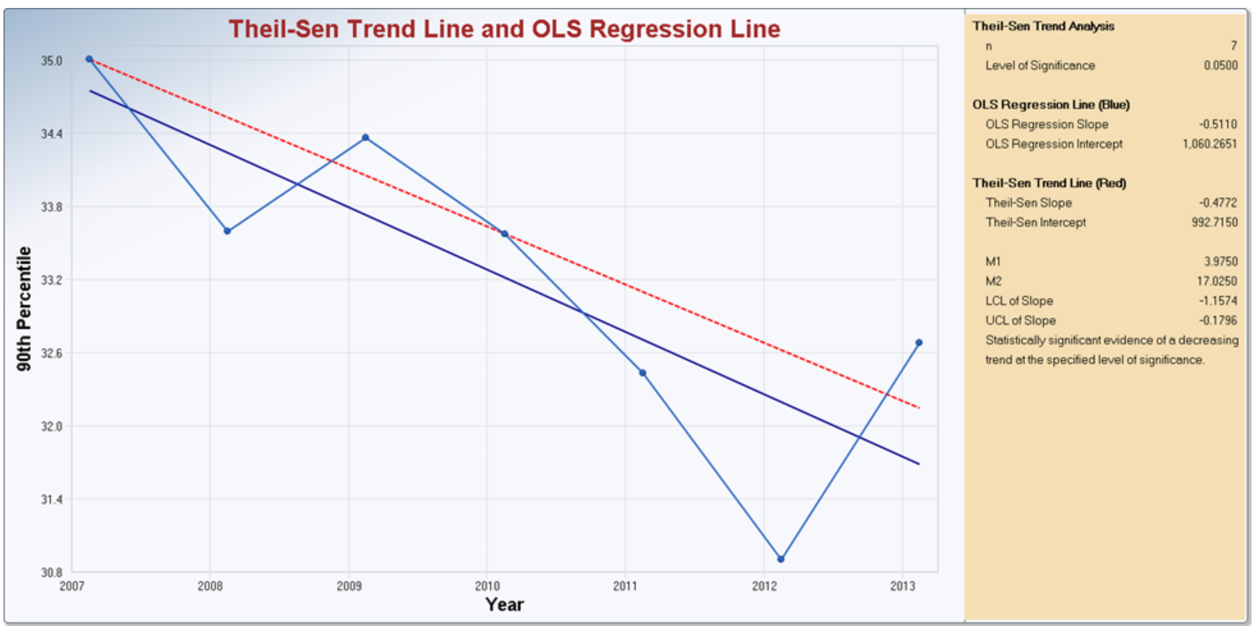

Figure G-32: Gold Bar NO_2 90th Percentile Theil-Sen Trend Line Output

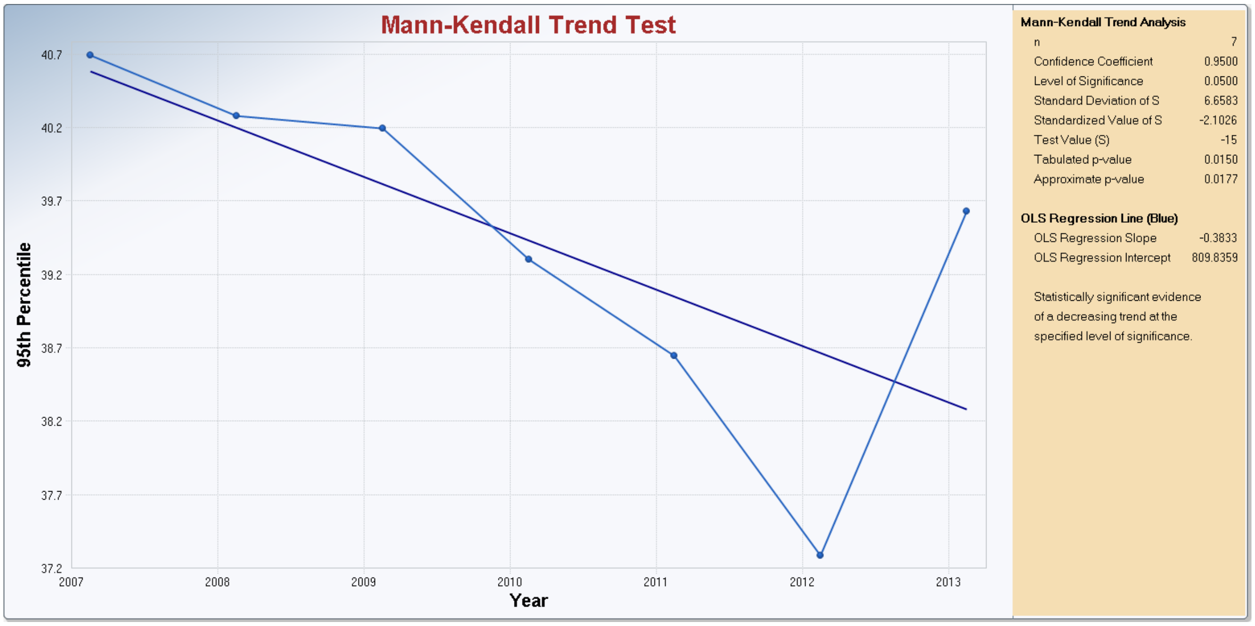

Figure G-33: Gold Bar NO_2 95th Percentile Mann-Kendall Trend Test Output

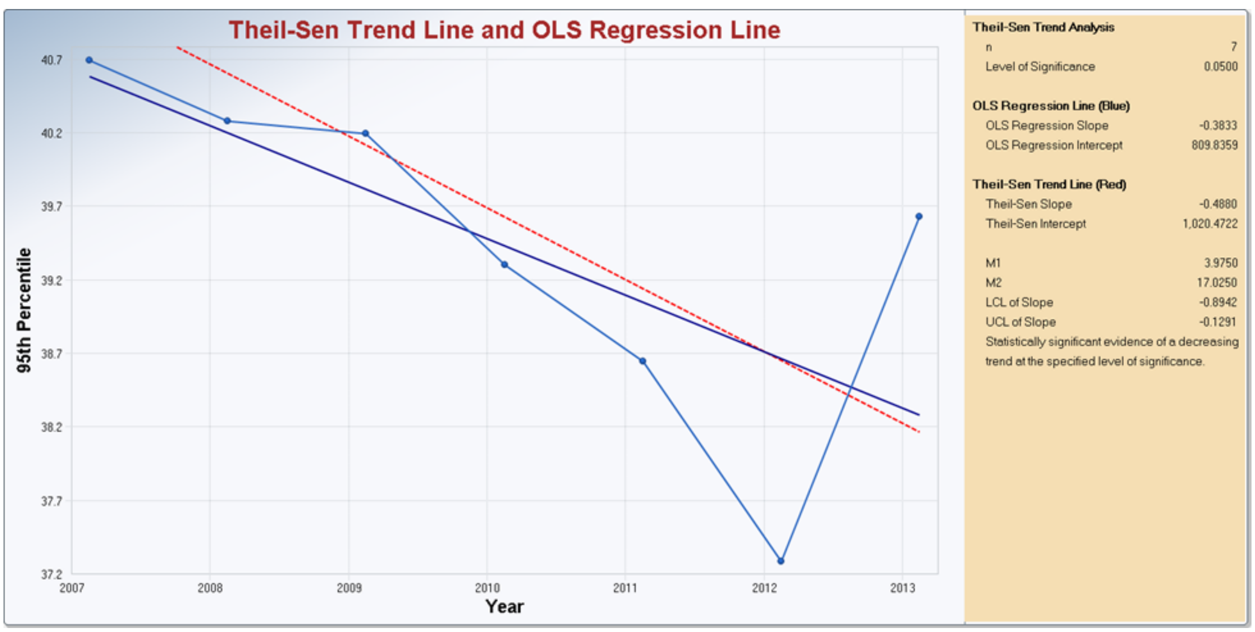

Figure G-34: Gold Bar NO_2 95th Percentile Theil-Sen Trend Line Output

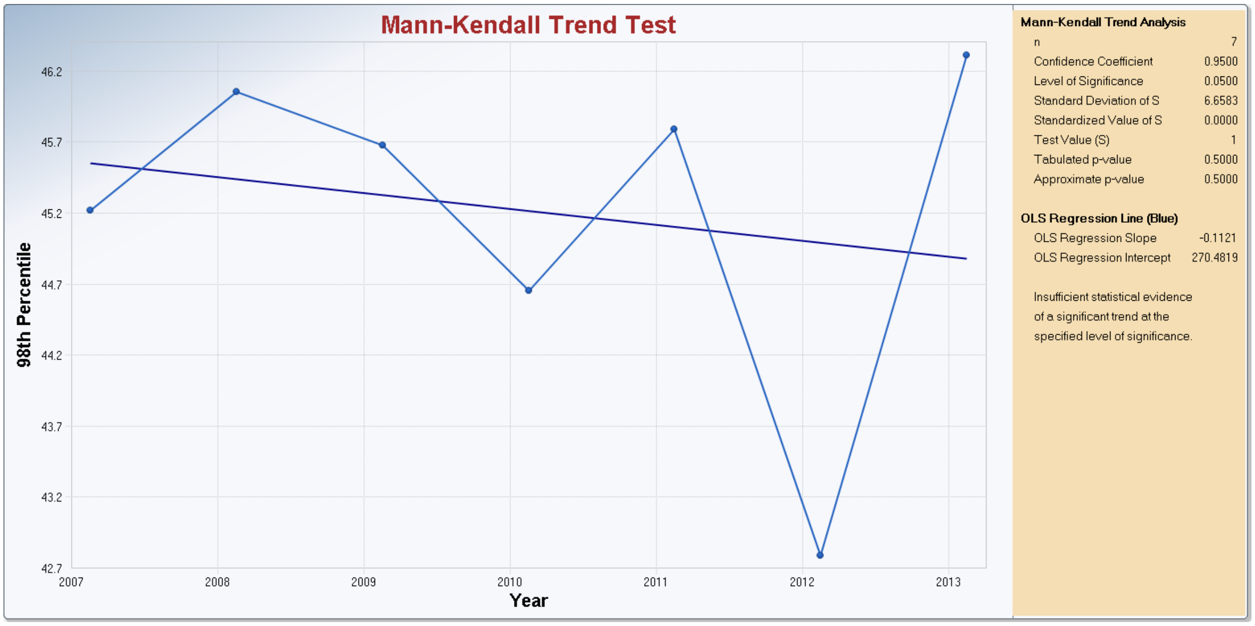

Figure G-35: Gold Bar NO_2 98th Percentile Mann-Kendall Trend Test Output

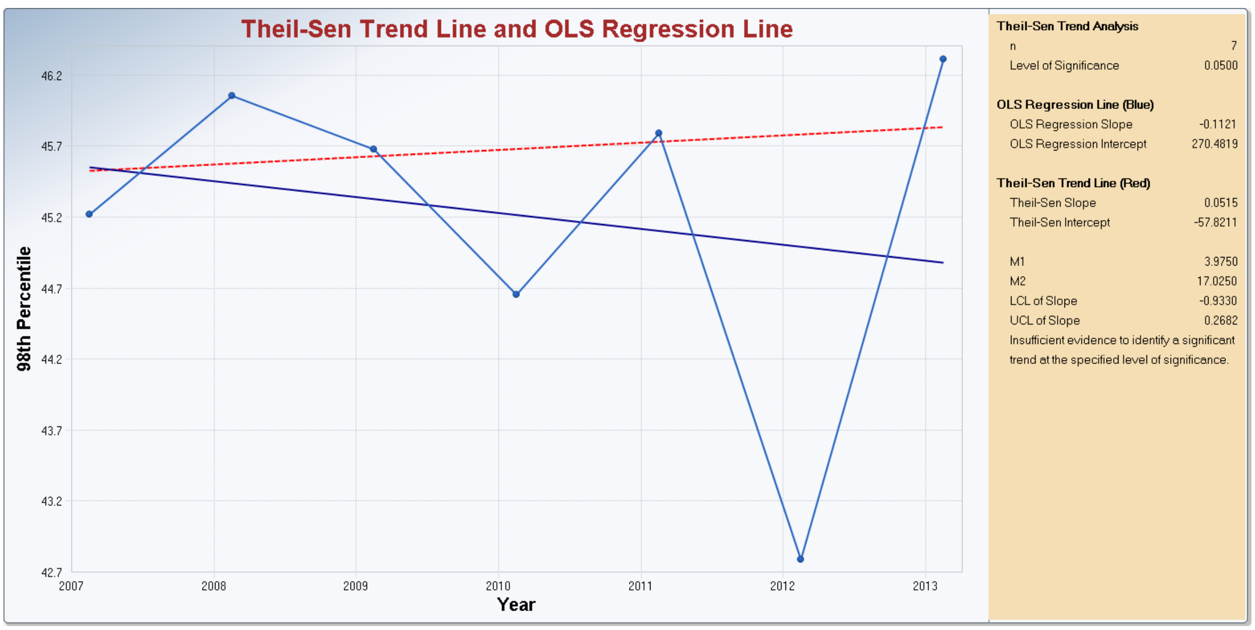

Figure G-36: Gold Bar NO_2 98th Percentile Theil-Sen Trend Line Output

APPENDIX H: AIR QUALITY TREND ANALYSIS SUMMARY FOR $PM_{2.5}$: PROUCL MANN-KENDALL/THEIL-SEN OUTPUTS

Table H-1: $PM_{2.5}$ trend analysis: Mann-Kendall and Theil-Sen Slope summary (α=0.05)

Station	Concentration	Mann-Kendall Trend Analysis	Theil-Sen Slope: Magnitude per decade (μg/m^3)	LCL, UCL per decade
Edmonton South 2006-2013	50th Percentile	No trend	-	(-0.9, 5.3)
	65th Percentile	↑	4.3	(1.5, 9)
	80th Percentile	↑	7.7	(0.2, 11)
	90th Percentile	↑	11	(1.5, 15)
	95th Percentile	↑	13	(0.4, 18)
	98th Percentile	↑	17	(9.4, 26.2)
Woodcroft 2003-2013	50th Percentile	No trend	-	(-1.4, 1.5)
	65th Percentile	No trend	-	(-1.6, 1.7)
	80th Percentile	No trend	-	(-3.4, 1.9)
	90th Percentile	No trend	-	(-5.8, 1.8)
	95th Percentile	No trend	-	(-7.5, 2.7)
	98th Percentile	No trend	-	(-11.4, 3.8)

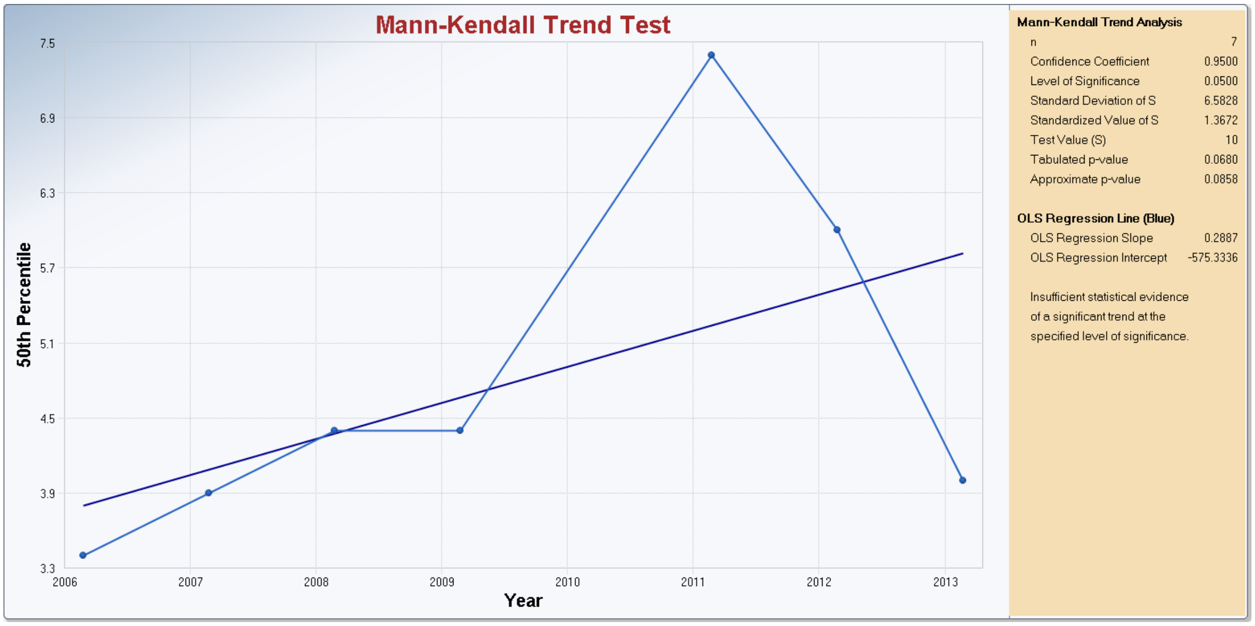

Figure H-1: Edmonton South $PM_{2.5}$ 50^{th} Percentile Mann-Kendall Trend Test Output

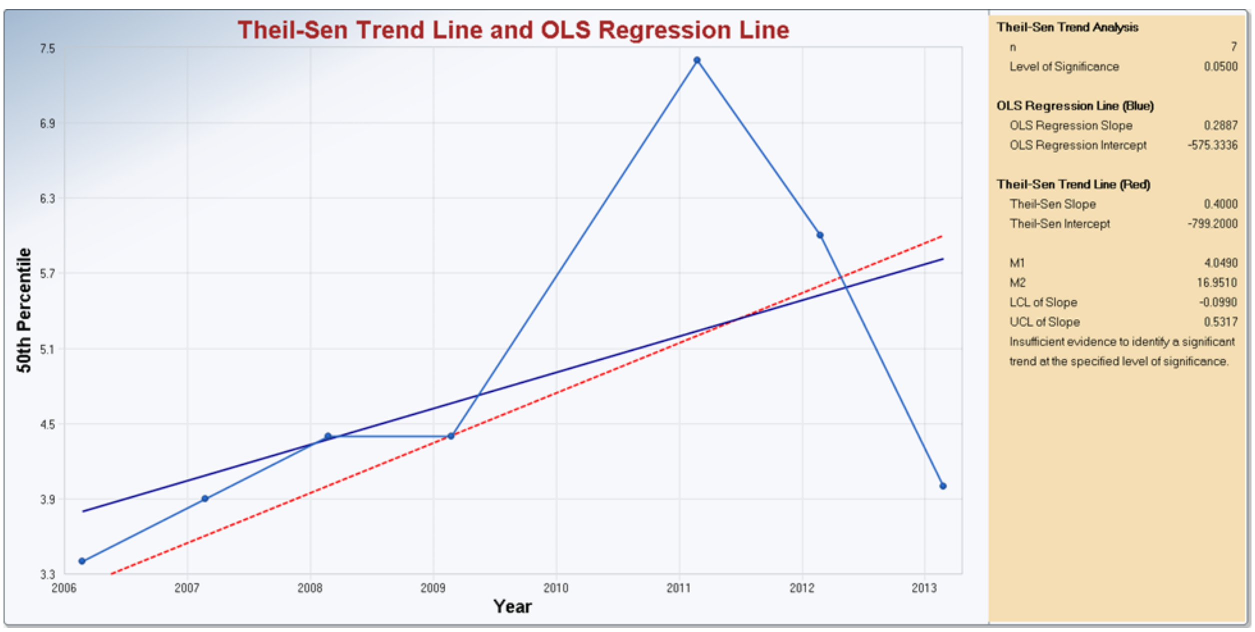

Figure H-2: Edmonton South $PM_{2.5}$ 50^{th} Percentile Theil-Sen Trend Line Output

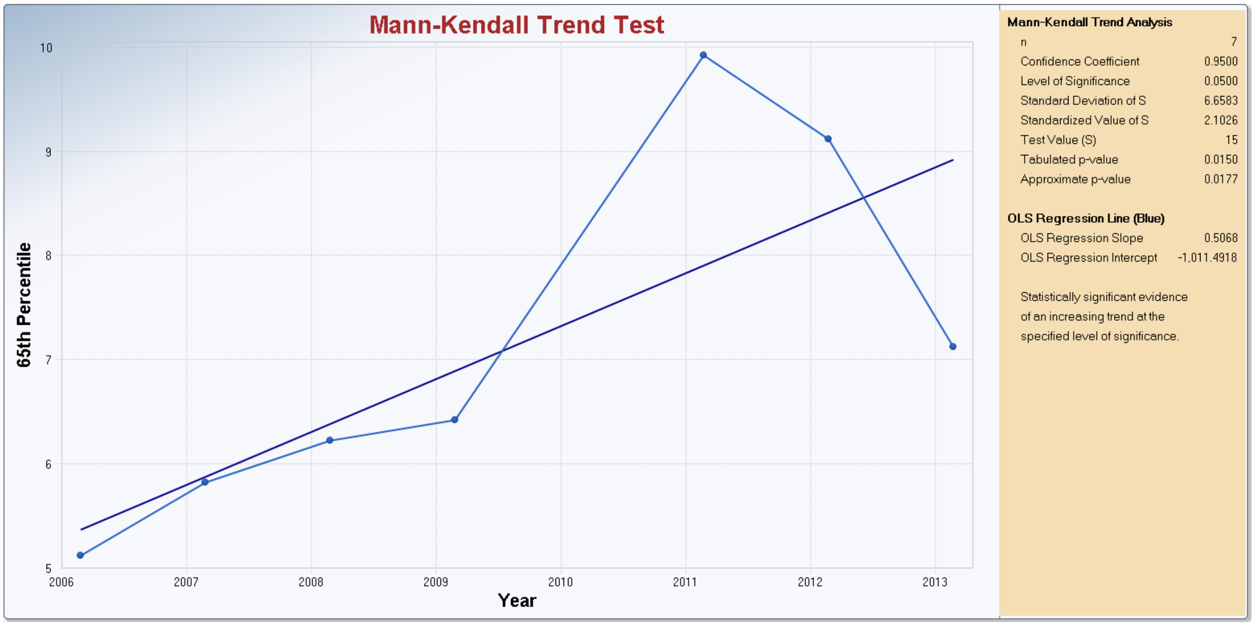

Figure H-3: Edmonton South $PM_{2.5}$ 65th Percentile Mann-Kendall Trend Test Output

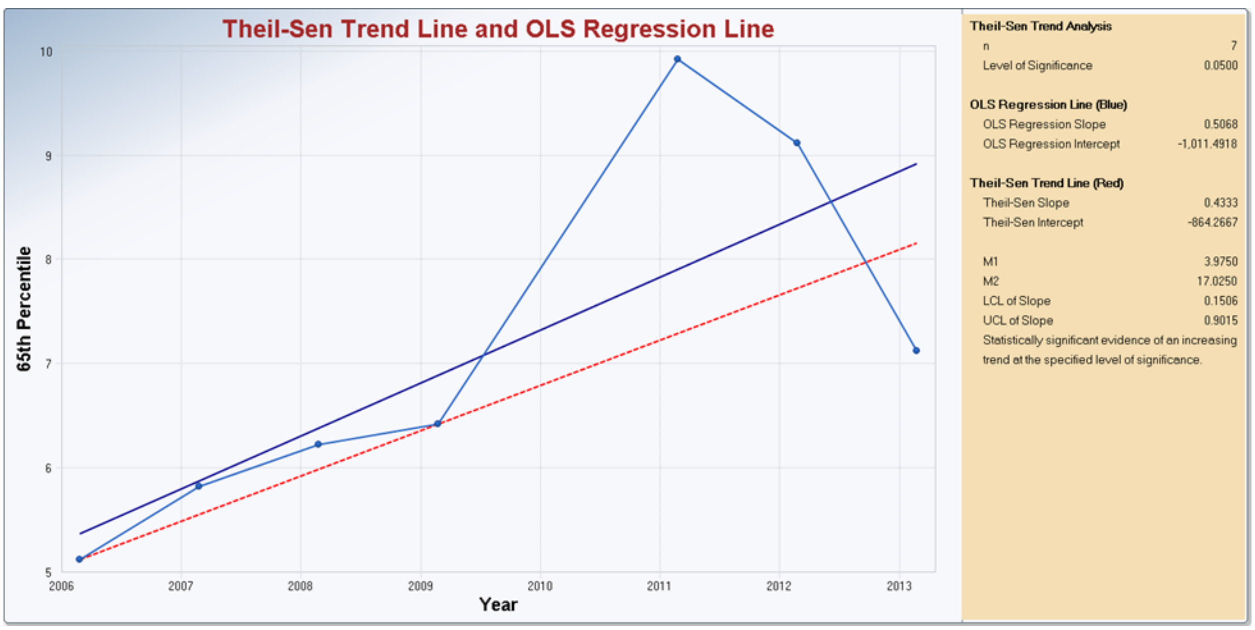

Figure H-4: Edmonton South $PM_{2.5}$ 65th Percentile Theil-Sen Trend Line Output

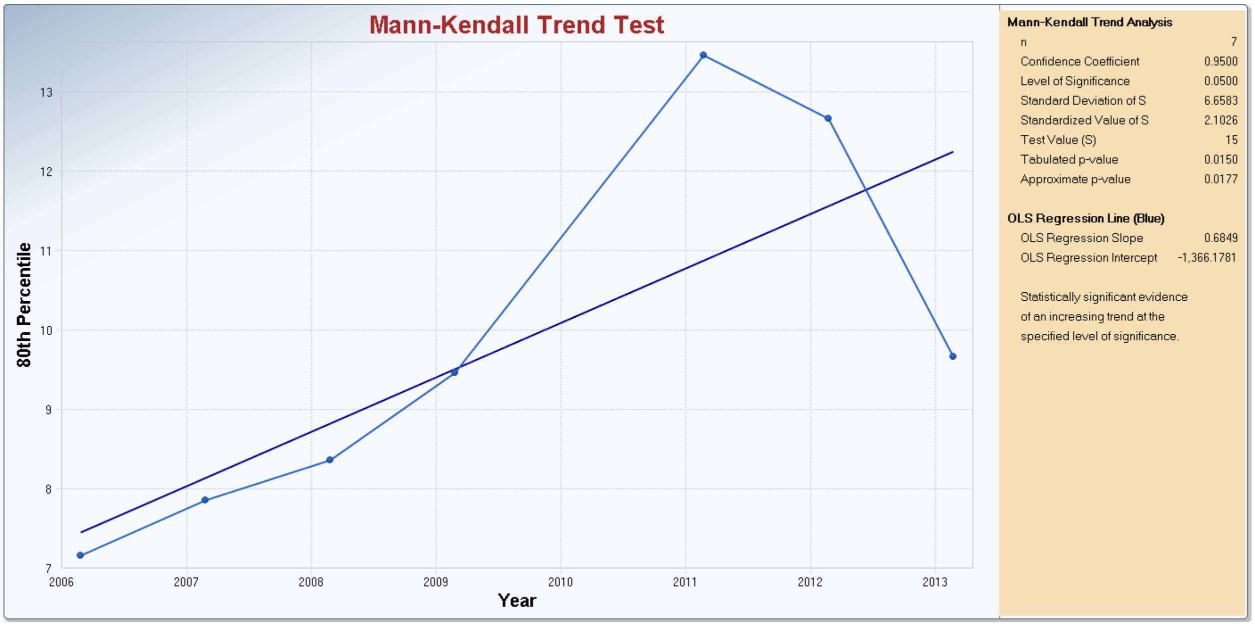

Figure H-5: Edmonton South $PM_{2.5}$ 80th Percentile Mann-Kendall Trend Test Output

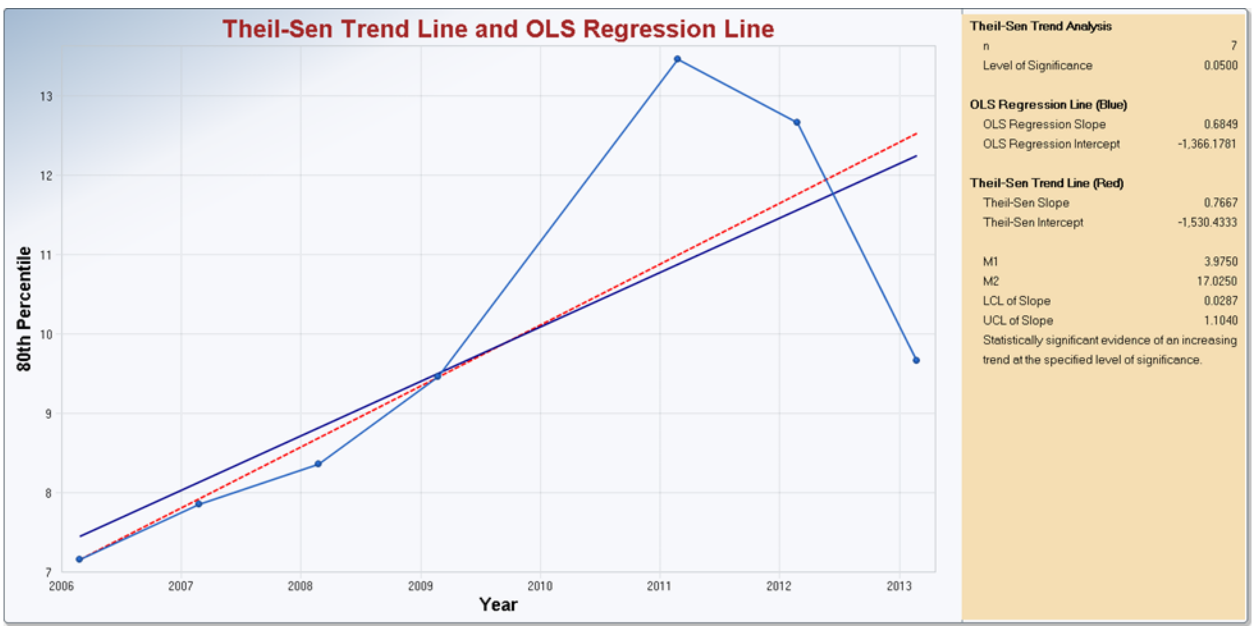

Figure H-6: Edmonton South $PM_{2.5}$ 80th Percentile Theil-Sen Trend Line Output

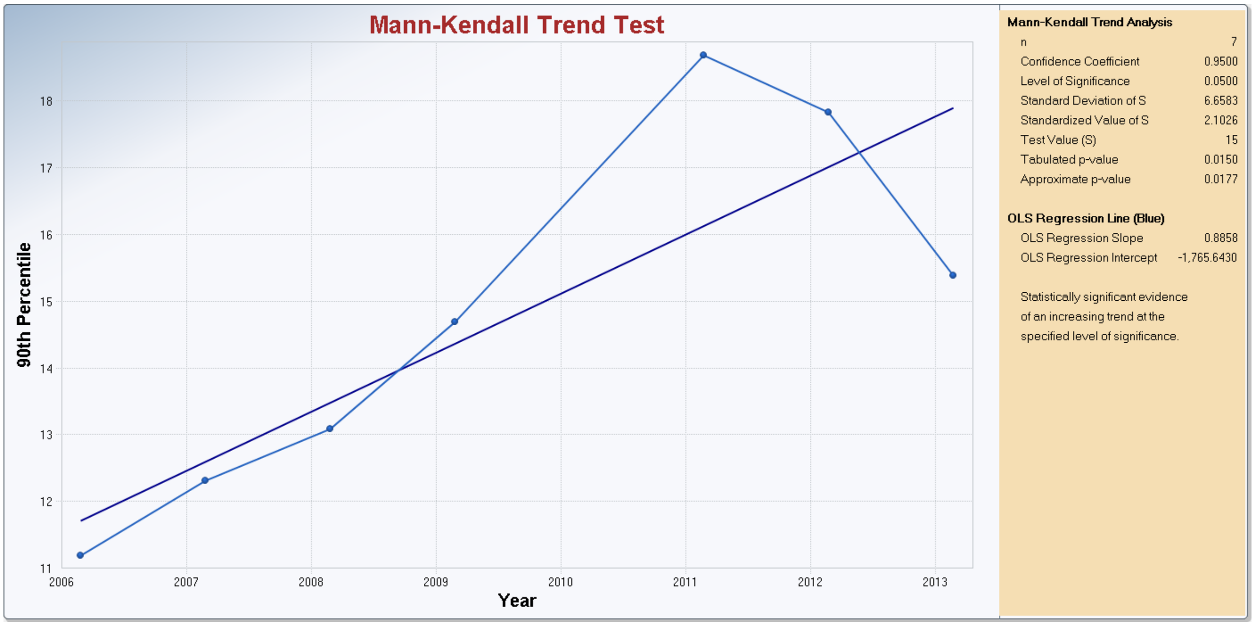

Figure H-7: Edmonton South $PM_{2.5}$ 90th Percentile Mann-Kendall Trend Test Output

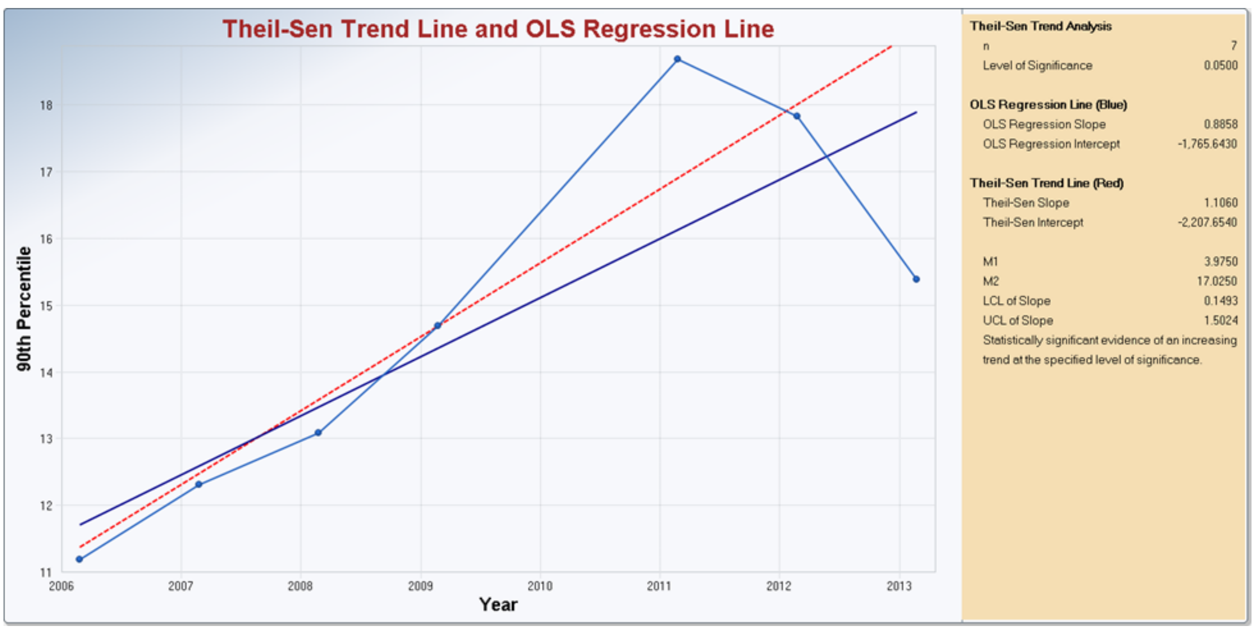

Figure H-8: Edmonton South $PM_{2.5}$ 90th Percentile Theil-Sen Trend Line Output

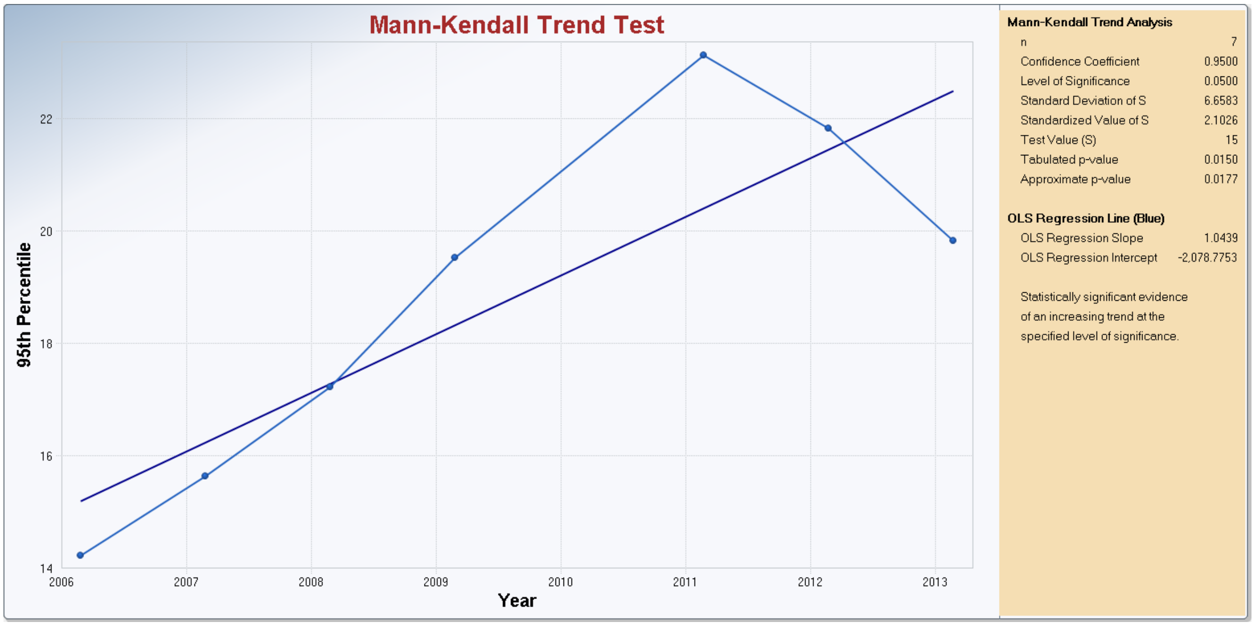

Figure H-9: Edmonton South $PM_{2.5}$ 95th Percentile Mann-Kendall Trend Test Output

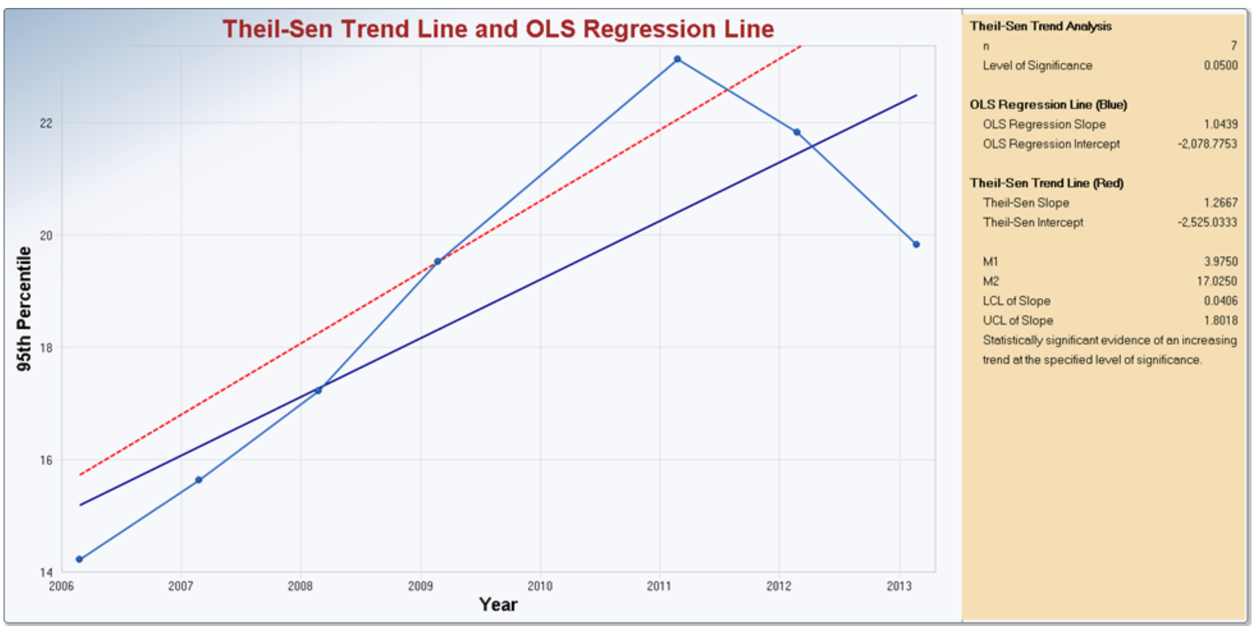

Figure H-10: Edmonton South $PM_{2.5}$ 95th Percentile Theil-Sen Trend Line Output

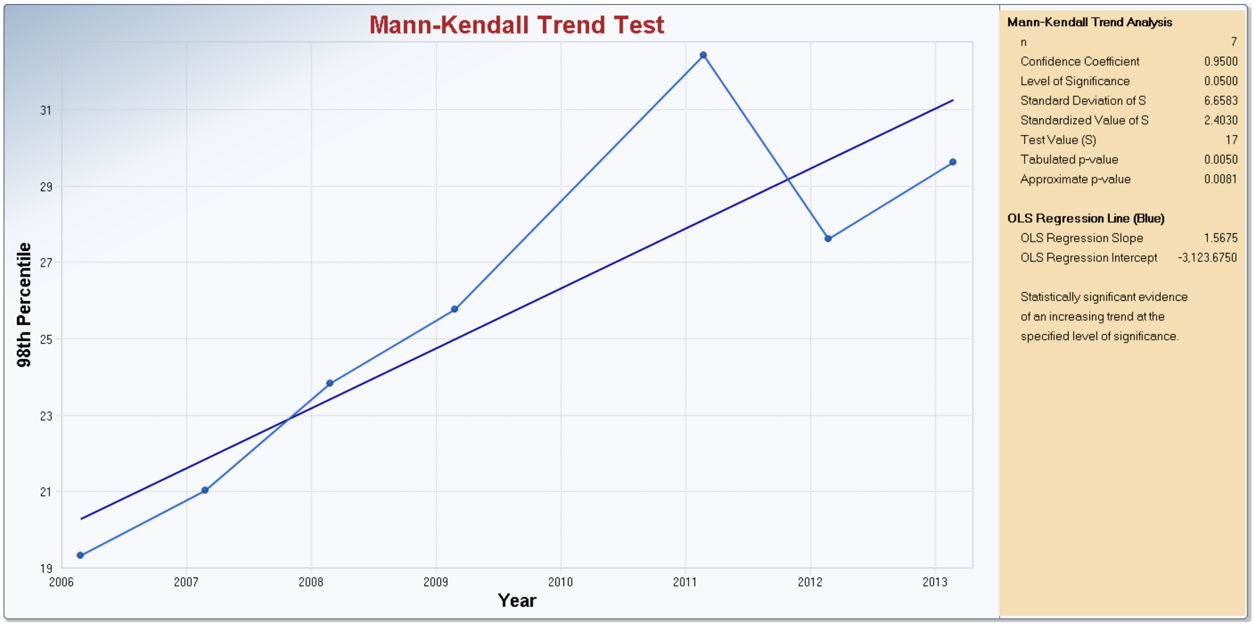

Figure H-11: Edmonton South PM2.5 98th Percentile Mann-Kendall Trend Test Output

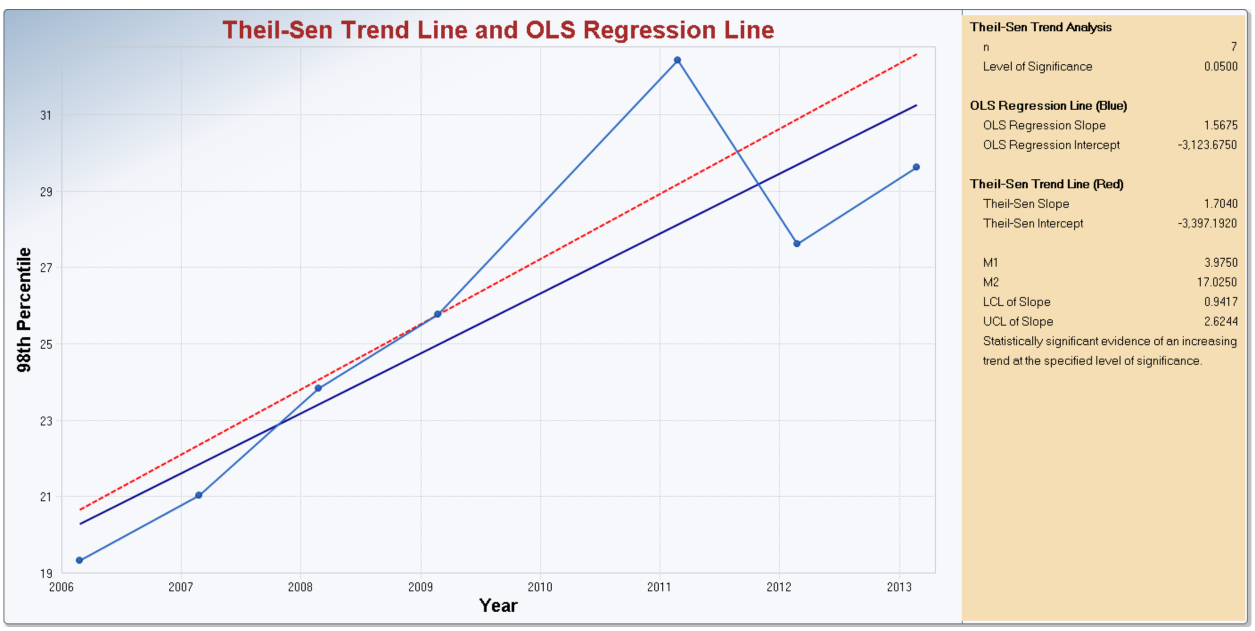

Figure H-12: Edmonton South PM2.5 98th Percentile Theil-Sen Trend Line Output

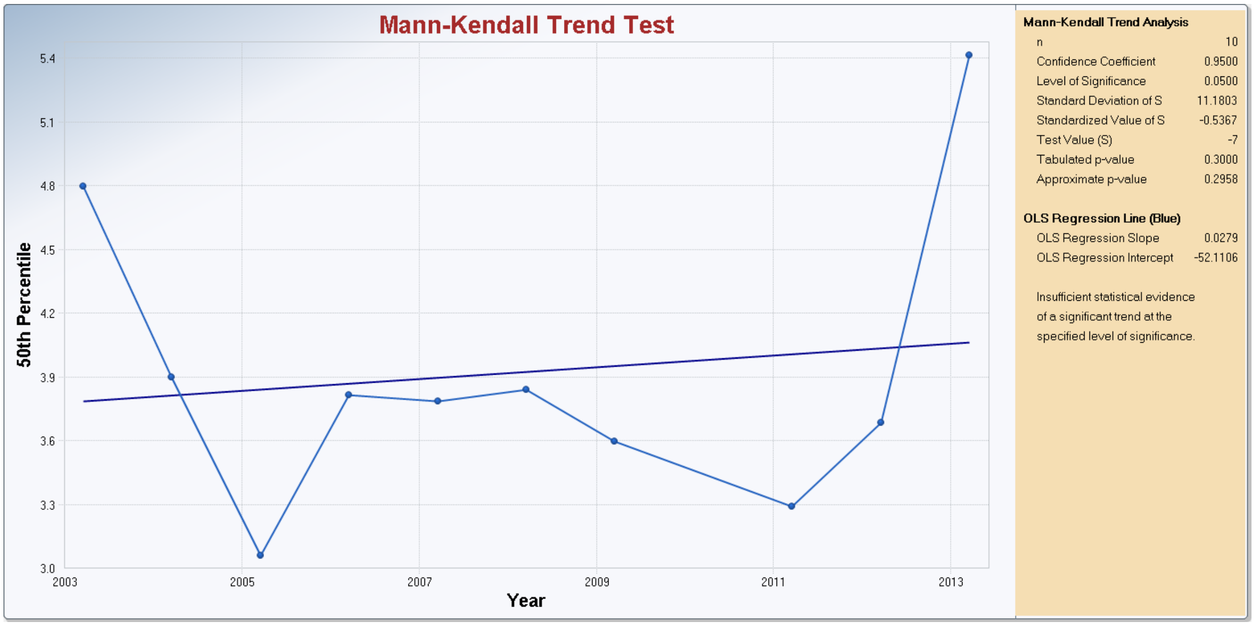

Figure H-13: Woodcroft $PM_{2.5}$ 50th Percentile Mann-Kendall Trend Test Output

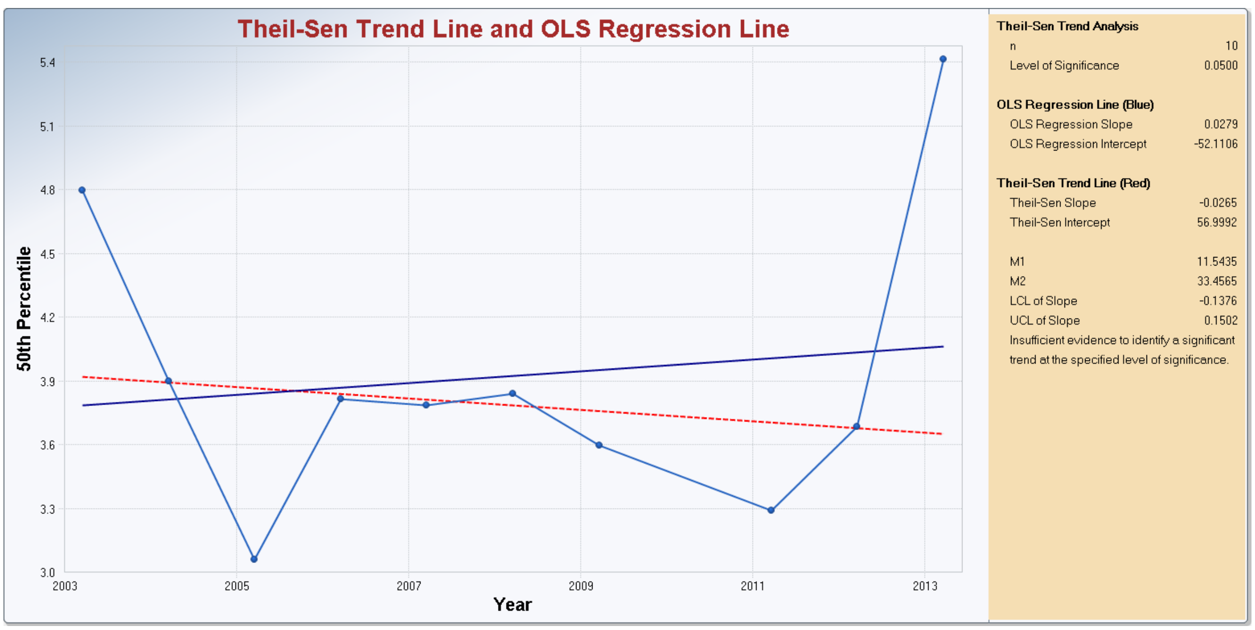

Figure H-14: Woodcroft $PM_{2.5}$ 50th Percentile Theil-Sen Trend Line Output

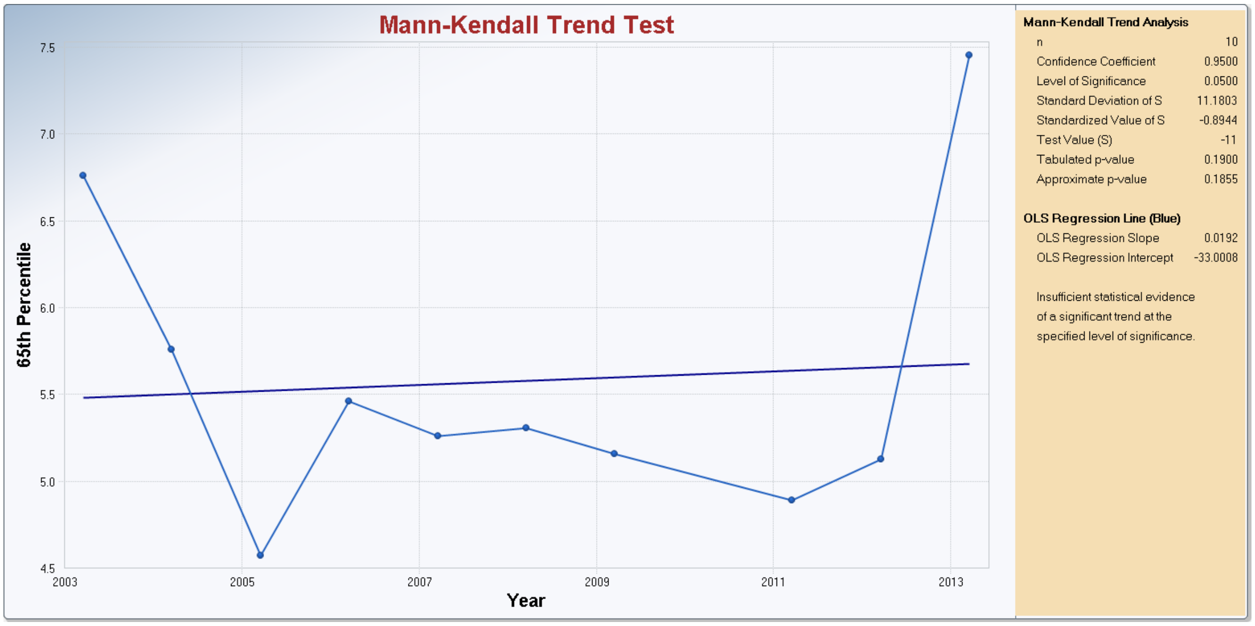

Figure H-15: Woodcroft $PM_{2.5}$ 65th Percentile Mann-Kendall Trend Test Output

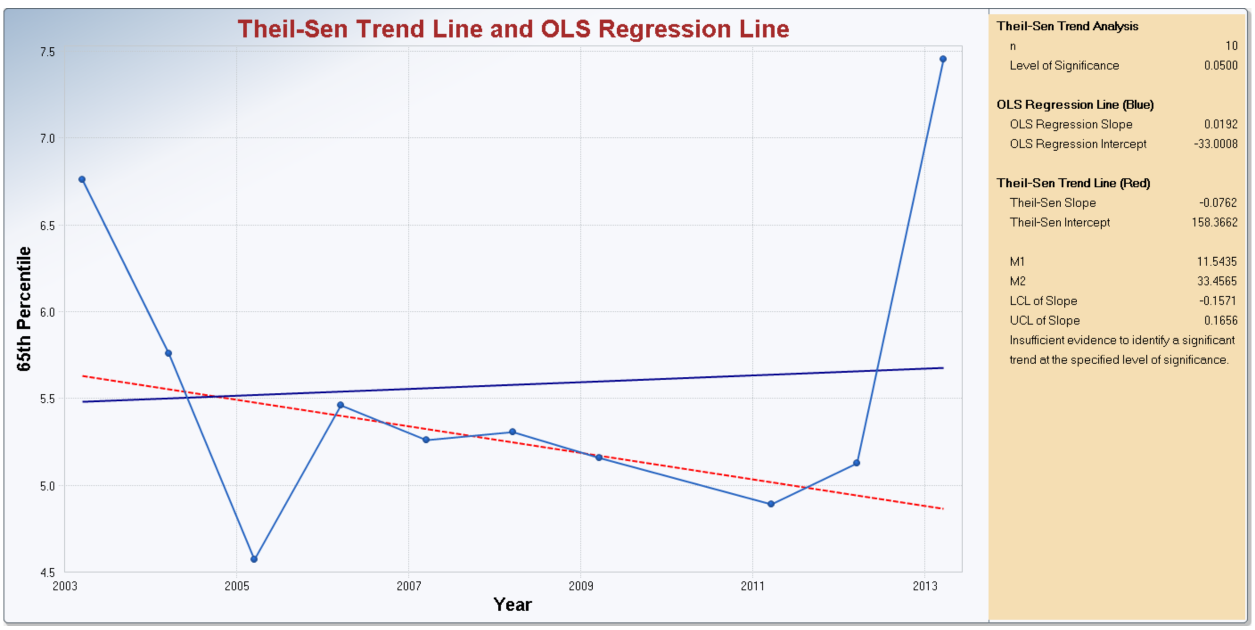

Figure H-16: Woodcroft $PM_{2.5}$ 65th Percentile Theil-Sen Trend Line Output

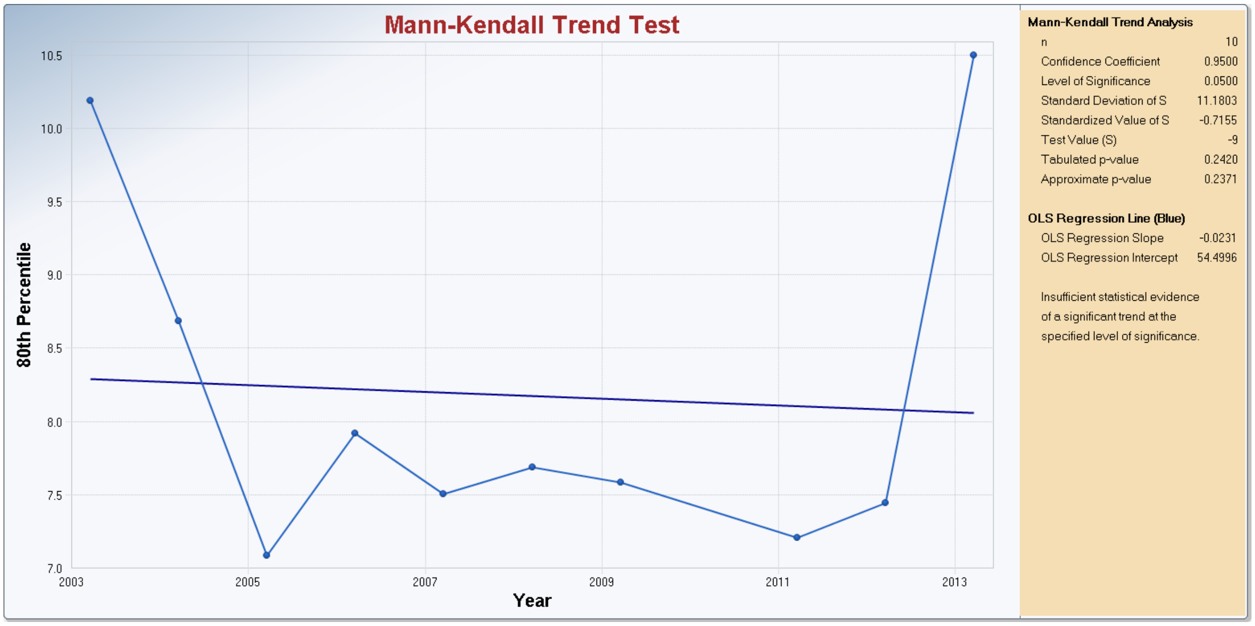

Figure H-17: Woodcroft $PM_{2.5}$ 80th Percentile Mann-Kendall Trend Test Output

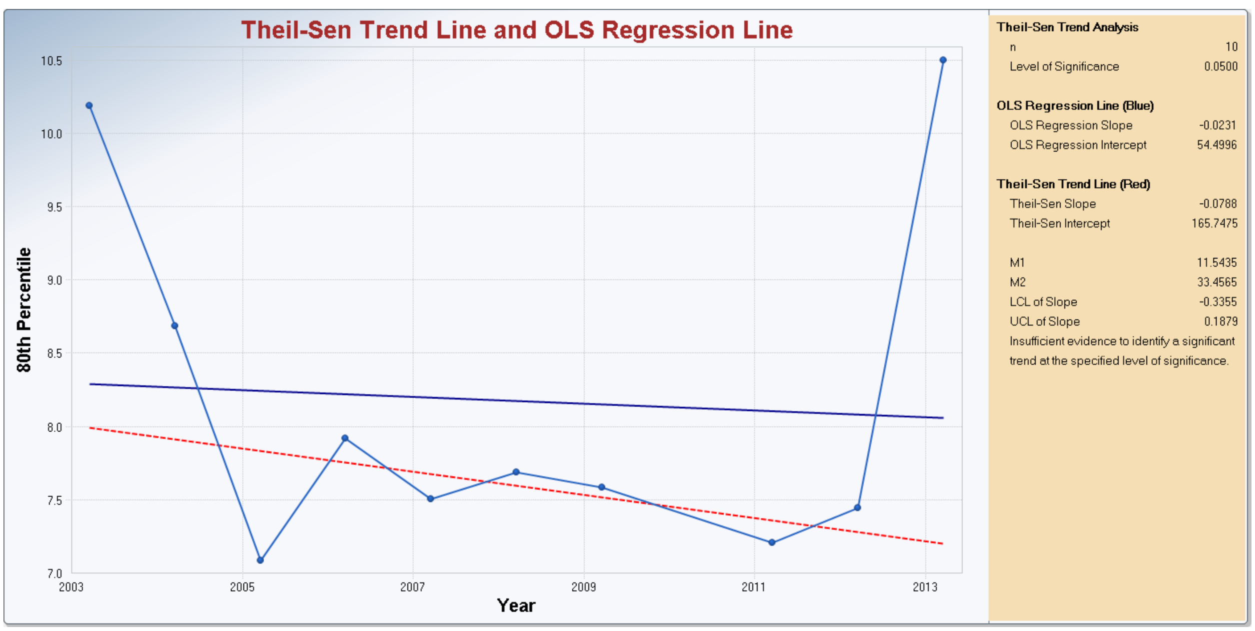

Figure H-18: Woodcroft $PM_{2.5}$ 80th Percentile Theil-Sen Trend Line Output

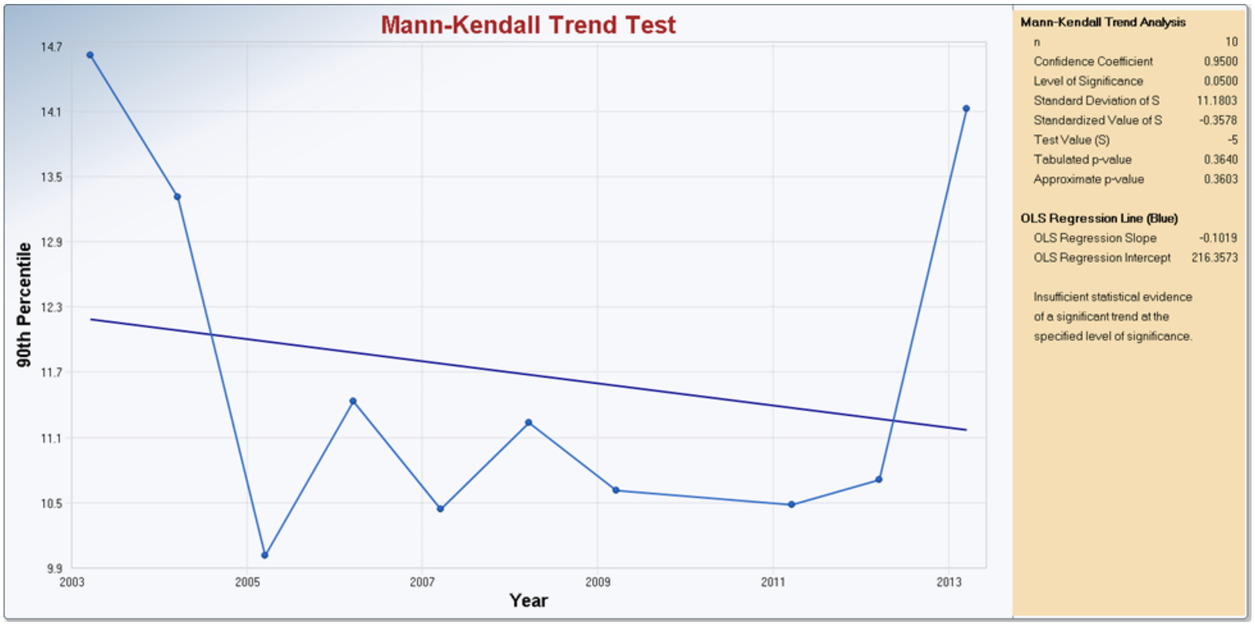

Figure H-19: Woodcroft $PM_{2.5}$ 90th Percentile Mann-Kendall Trend Test Output

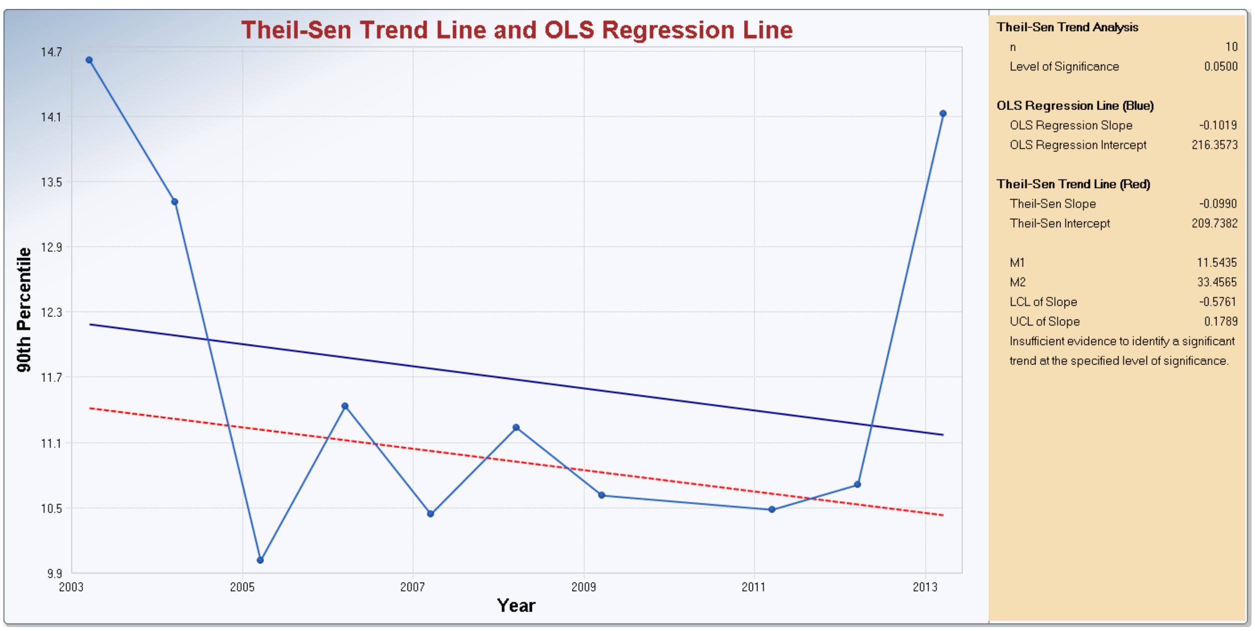

Figure H-20: Woodcroft $PM_{2.5}$ 90th Percentile Theil-Sen Trend Line Output

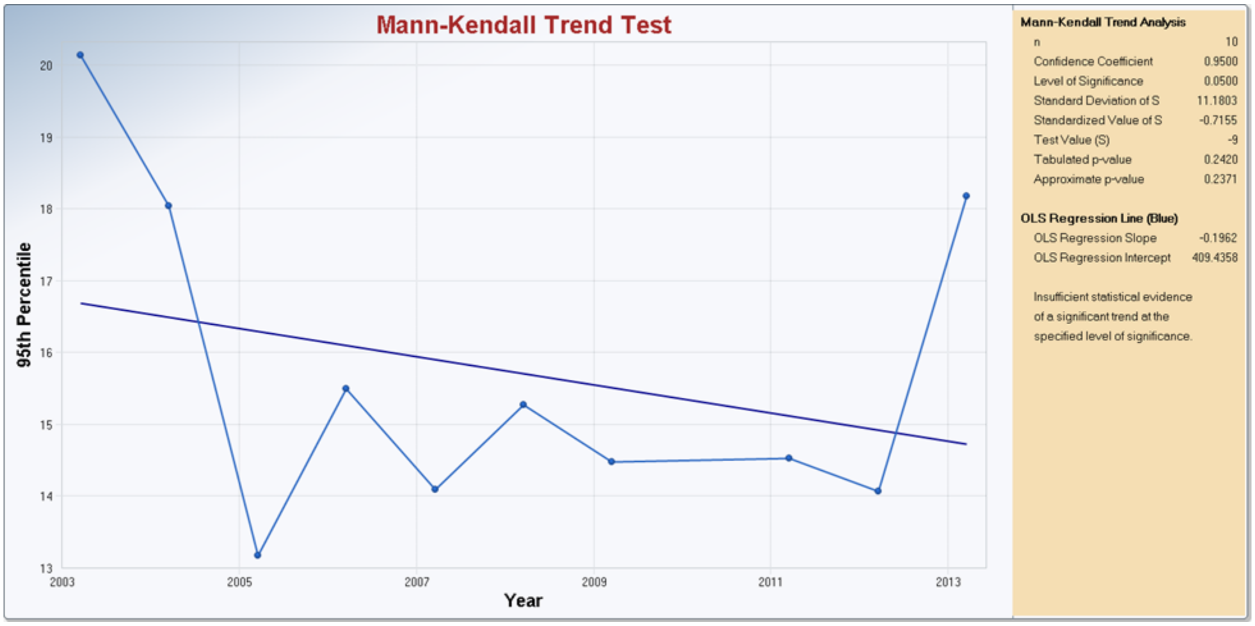

Figure H-21: Woodcroft $PM_{2.5}$ 95^{th} Percentile Mann-Kendall Trend Test Output

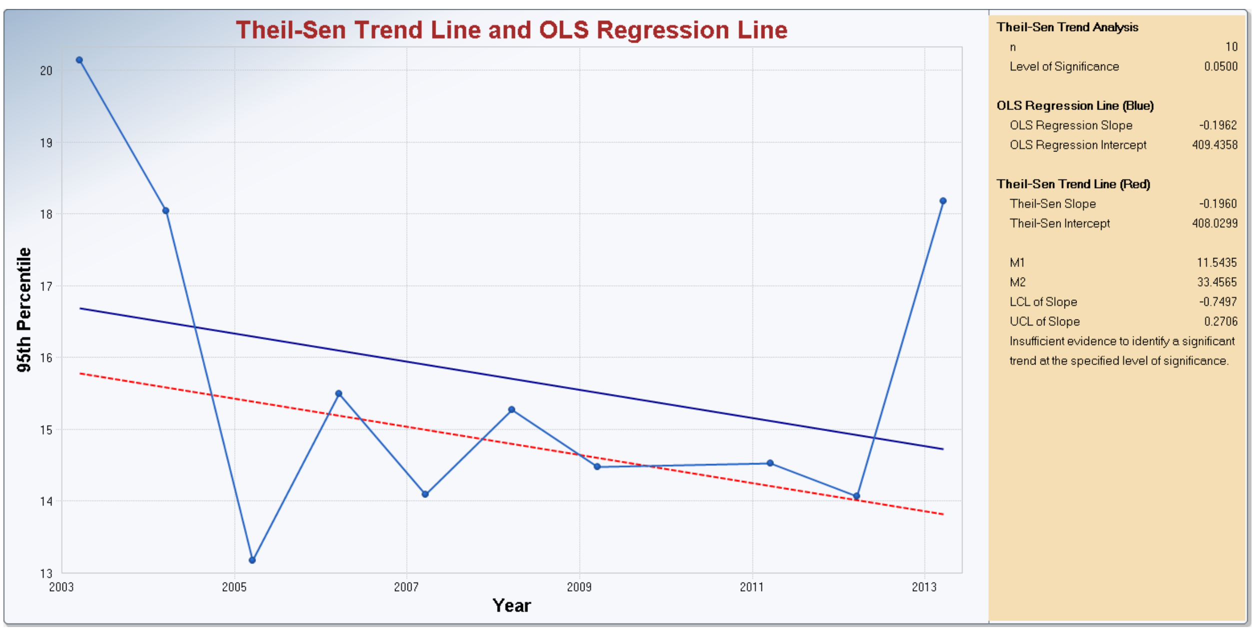

Figure H-22: Woodcroft $PM_{2.5}$ 95^{th} Percentile Theil-Sen Trend Line Output

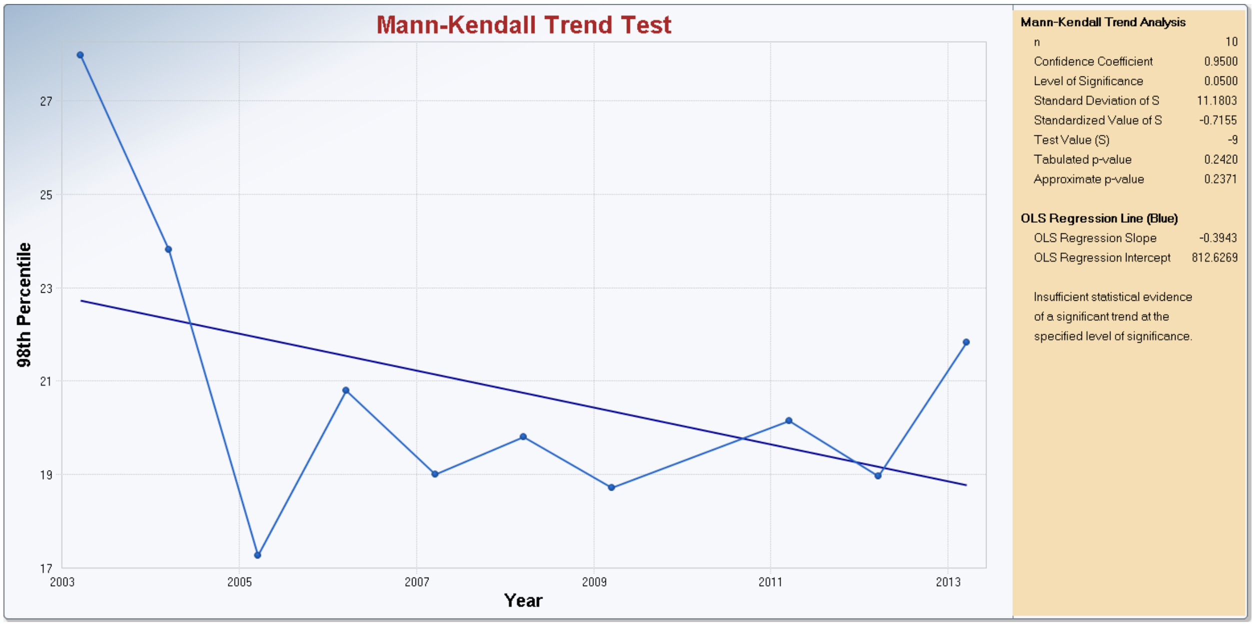

Figure H-23: Woodcroft $PM_{2.5}$ 98th Percentile Mann-Kendall Trend Test Output

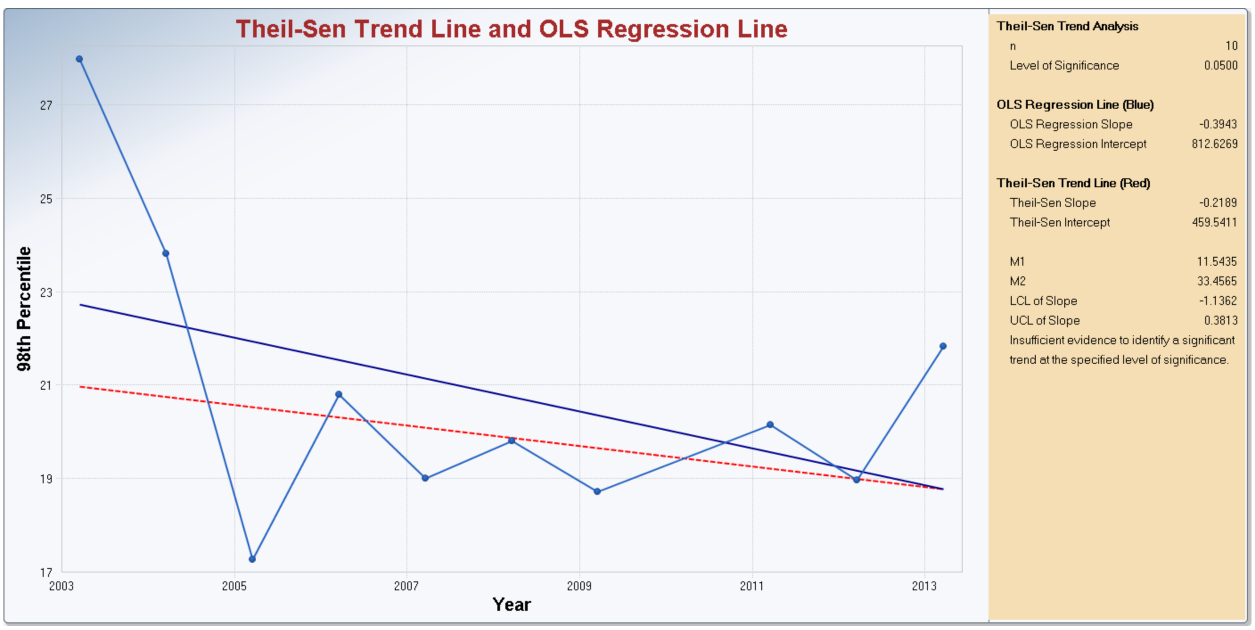

Figure H-24: Woodcroft $PM_{2.5}$ 98th Percentile Theil-Sen Trend Line Output

APPENDIX I: AIR QUALITY TREND ANALYSIS SUMMARY FOR CO: PROUCL MANN-KENDALL/THEIL-SEN OUTPUTS

Table I-1: CO trend analysis: Mann-Kendall and Theil-Sen Slope summary (α=0.05)

Station	Concentration	Mann-Kendall Trend Analysis	Theil-Sen Slope: Magnitude per decade (ppm)	LCL, UCL per decade
Edmonton South 2006-2013	50th Percentile	No Trend	-	(0.0, 0.0)
	65th Percentile	No Trend	-	(-0.2, 0.0)
	80th Percentile	No Trend	-	(0.0, 0.0)
	90th Percentile	No Trend	-	(0.0, 0.0)
	95th Percentile	No Trend	-	(-0.5, 0.0)
	98th Percentile	↓	Insignificant	(-0.5, 0.0)

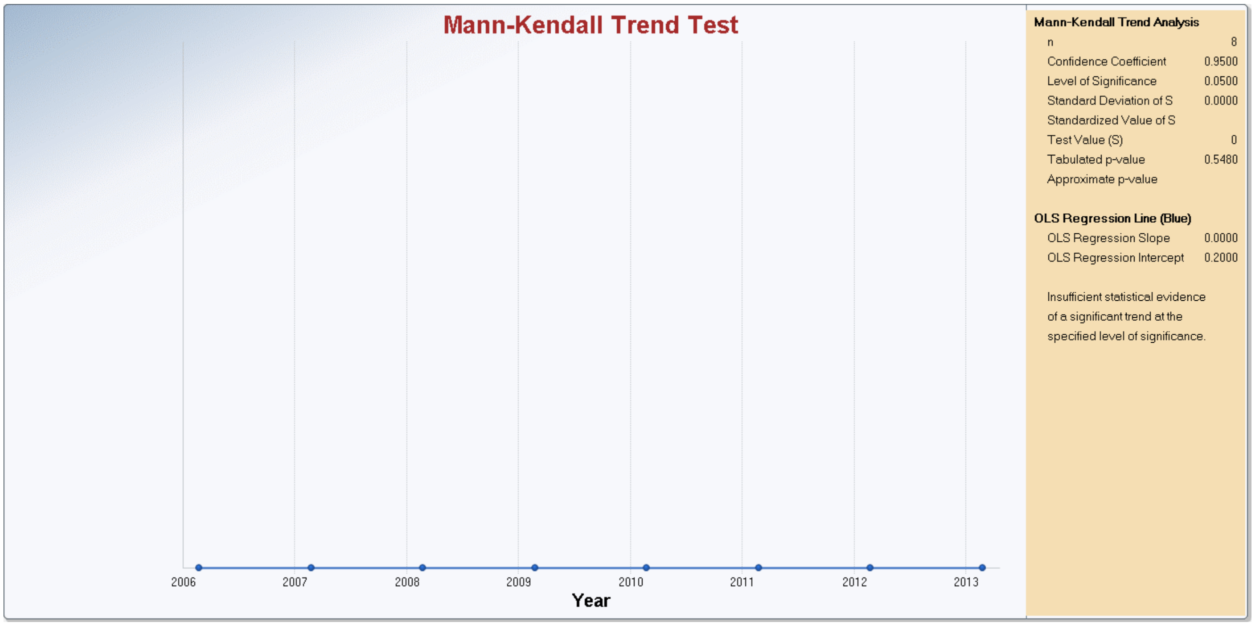

Figure I-1: Edmonton South CO 50th Percentile Mann-Kendall Trend Test Output

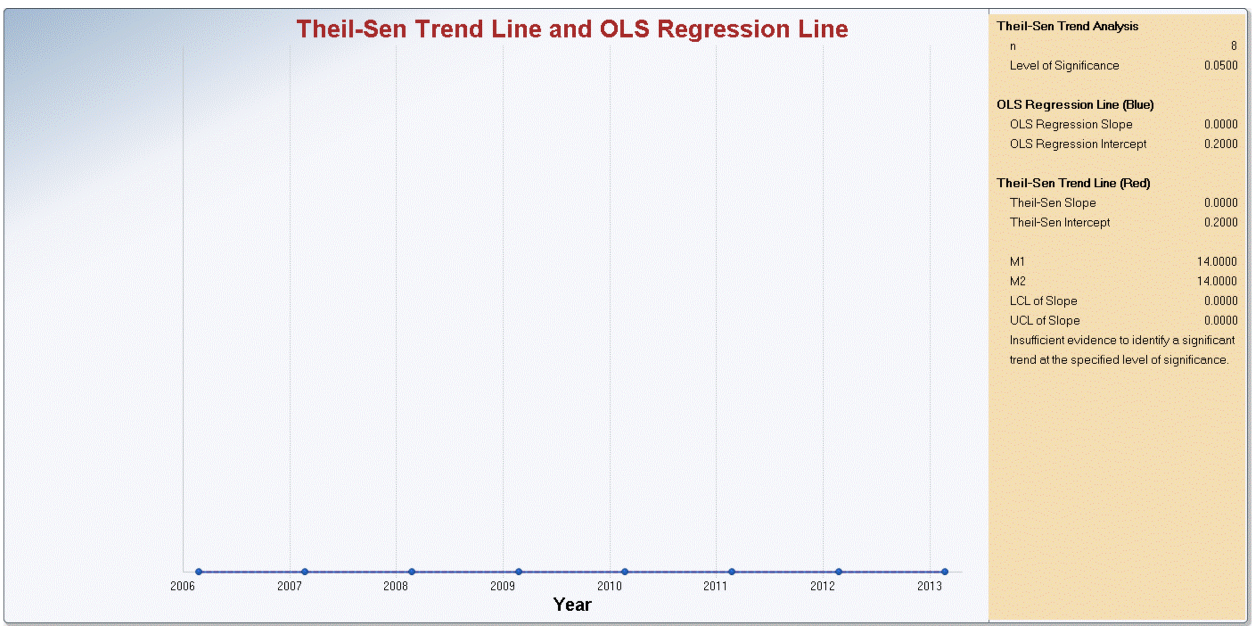

Figure I-2: Edmonton South CO 50th Percentile Theil-Sen Trend Line Output

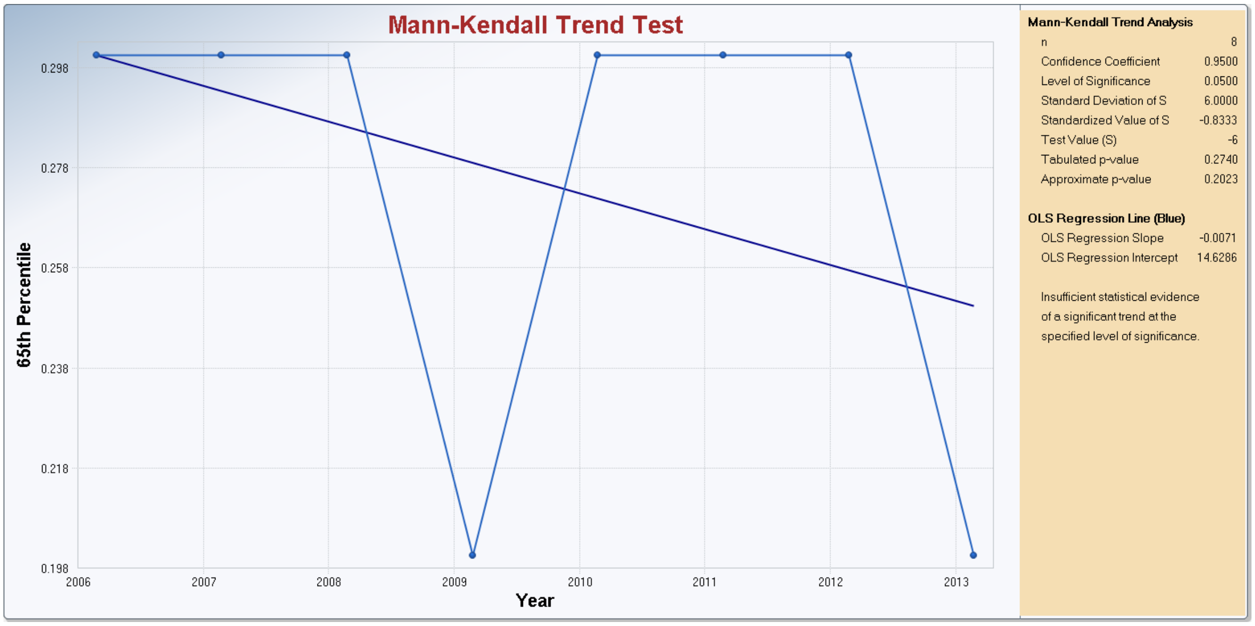

Figure I-3: Edmonton South CO 65th Percentile Mann-Kendall Trend Test Output

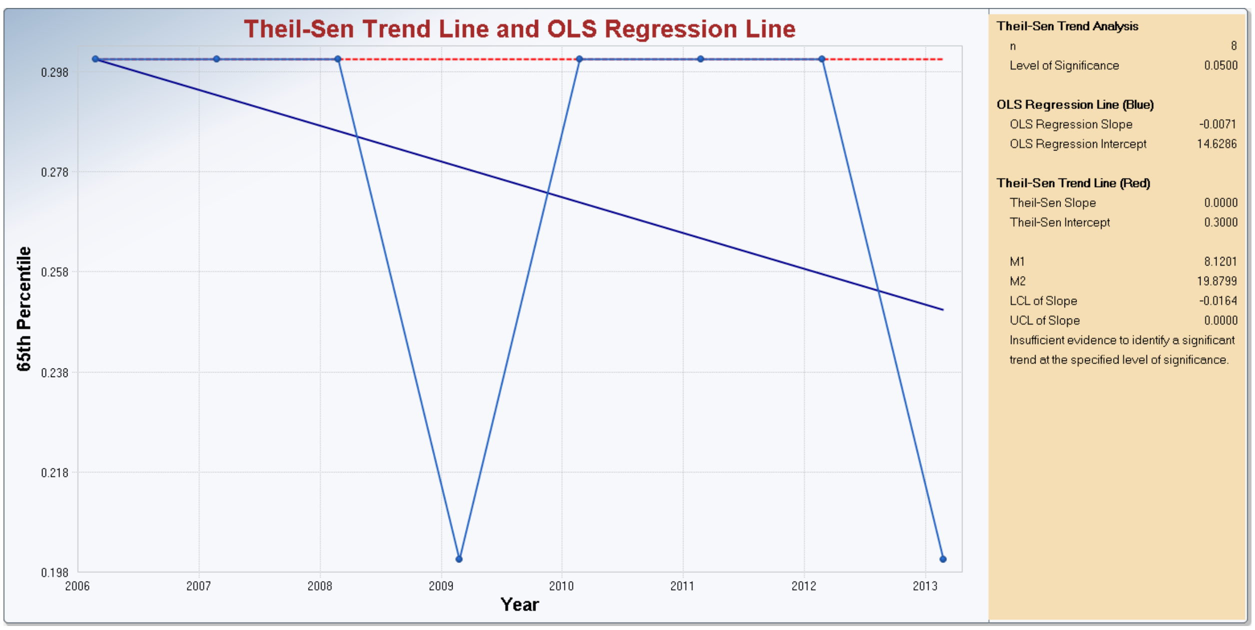

Figure I-4: Edmonton South CO 65th Percentile Theil-Sen Trend Line Output

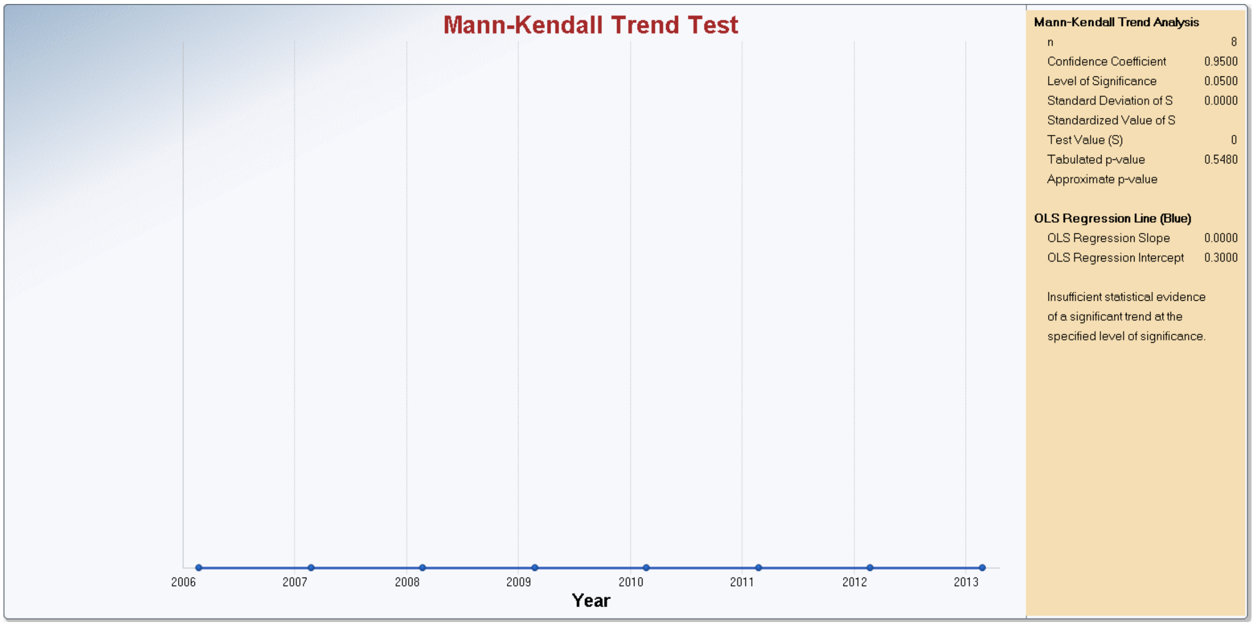

Figure I-5: Edmonton South CO 80th Percentile Mann-Kendall Trend Test Output

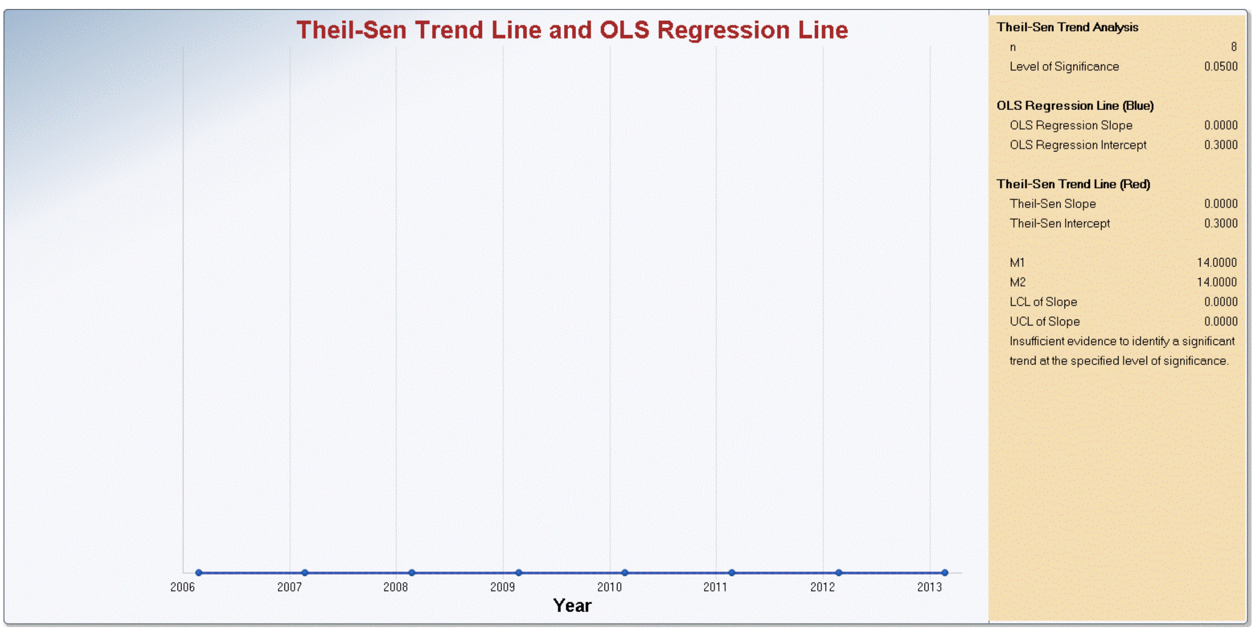

Figure I-6: Edmonton South CO 80th Percentile Theil-Sen Trend Line Output

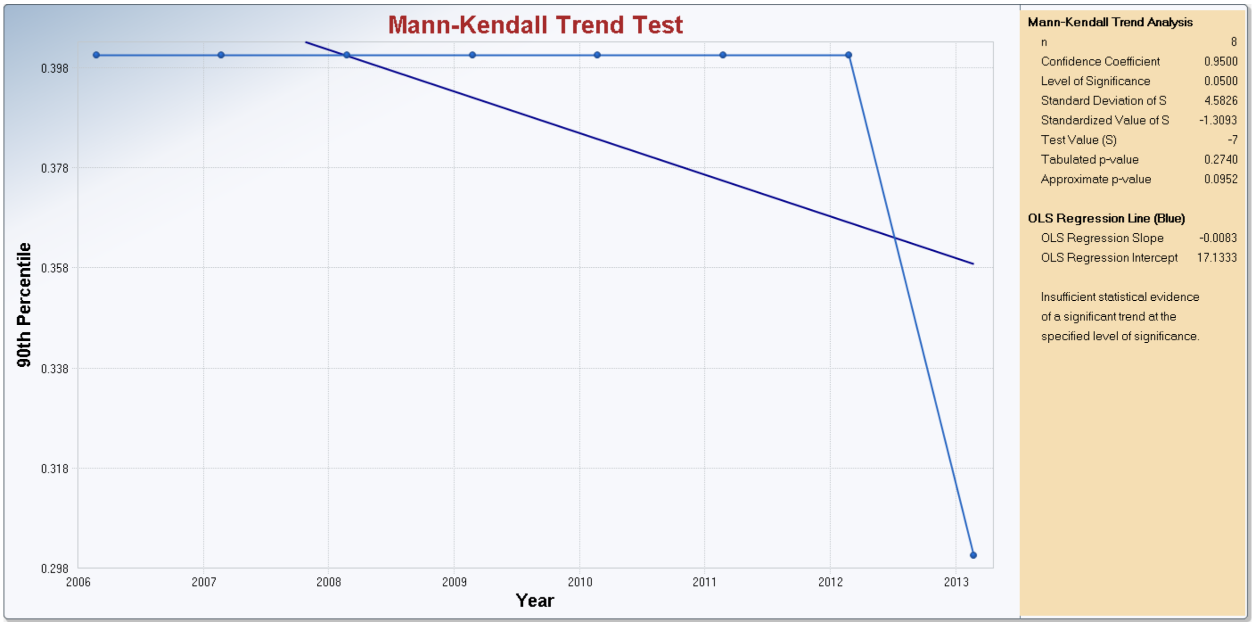

Figure I-7: Edmonton South CO 90th Percentile Mann-Kendall Trend Test Output

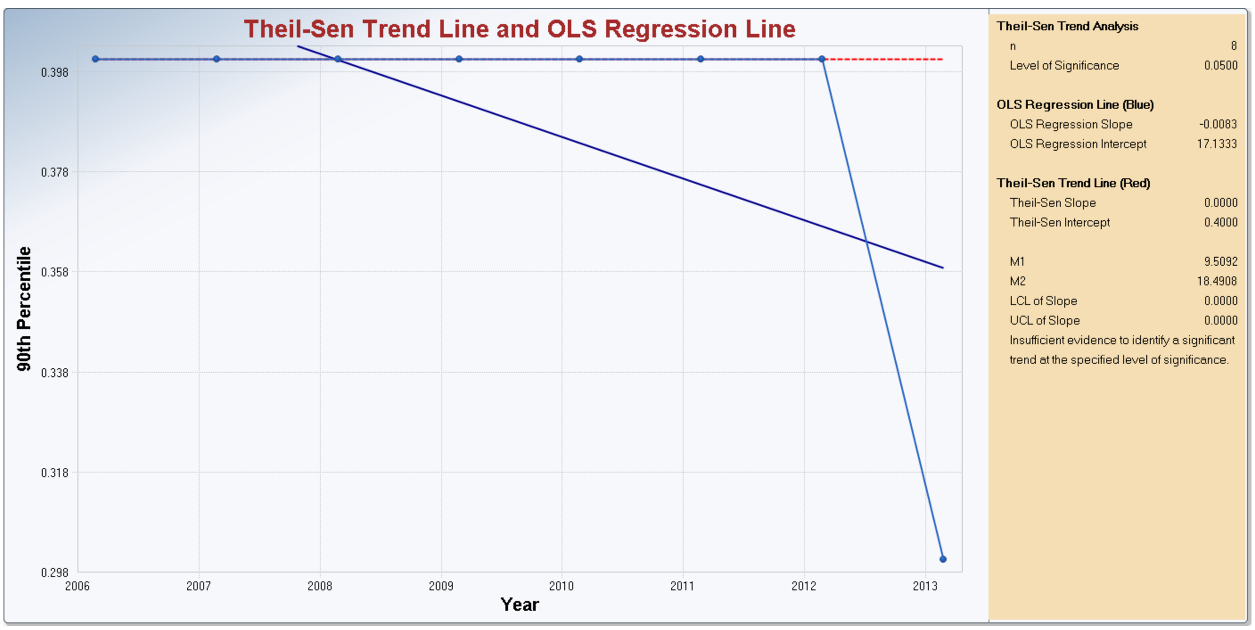

Figure I-8: Edmonton South CO 90th Percentile Theil-Sen Trend Line Output

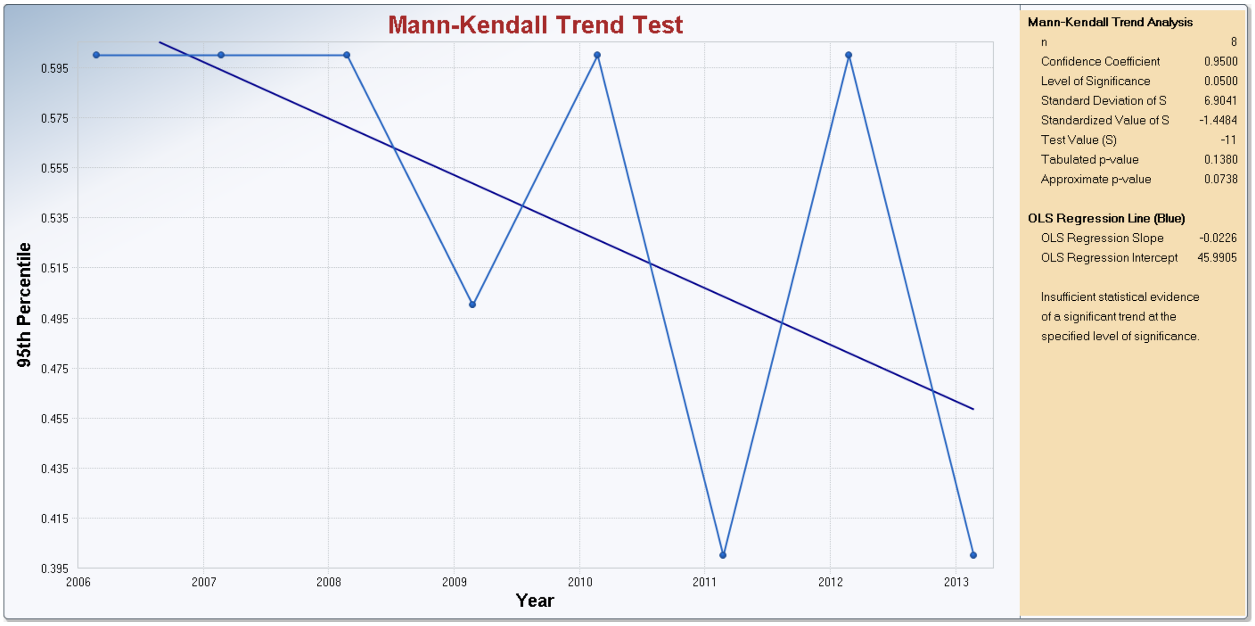

Figure I-9: Edmonton South CO 95th Percentile Mann-Kendall Trend Test Output

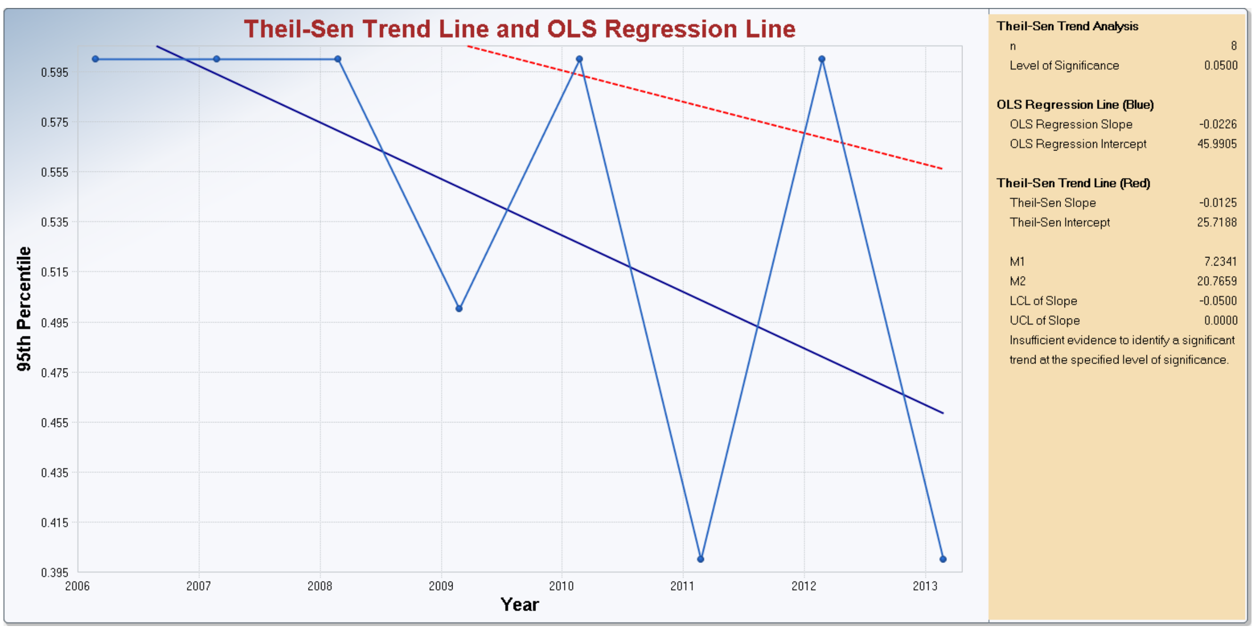

Figure I-10: Edmonton South CO 95th Percentile Theil-Sen Trend Line Output

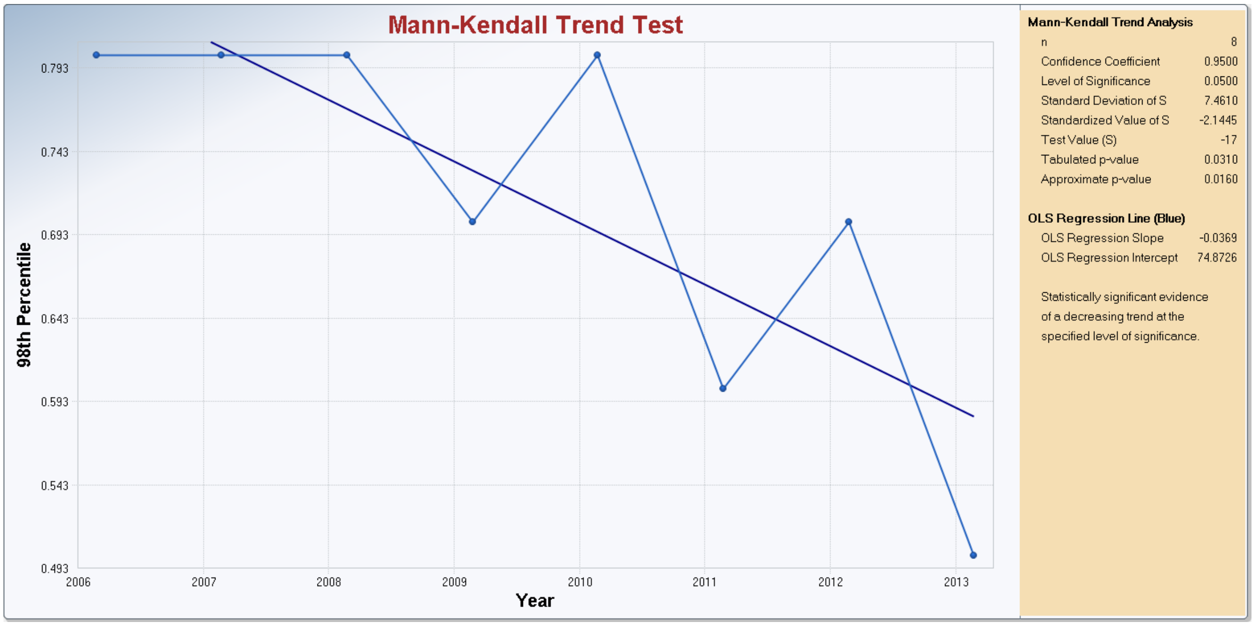

Figure I-11: Edmonton South CO 98th Percentile Mann-Kendall Trend Test Output

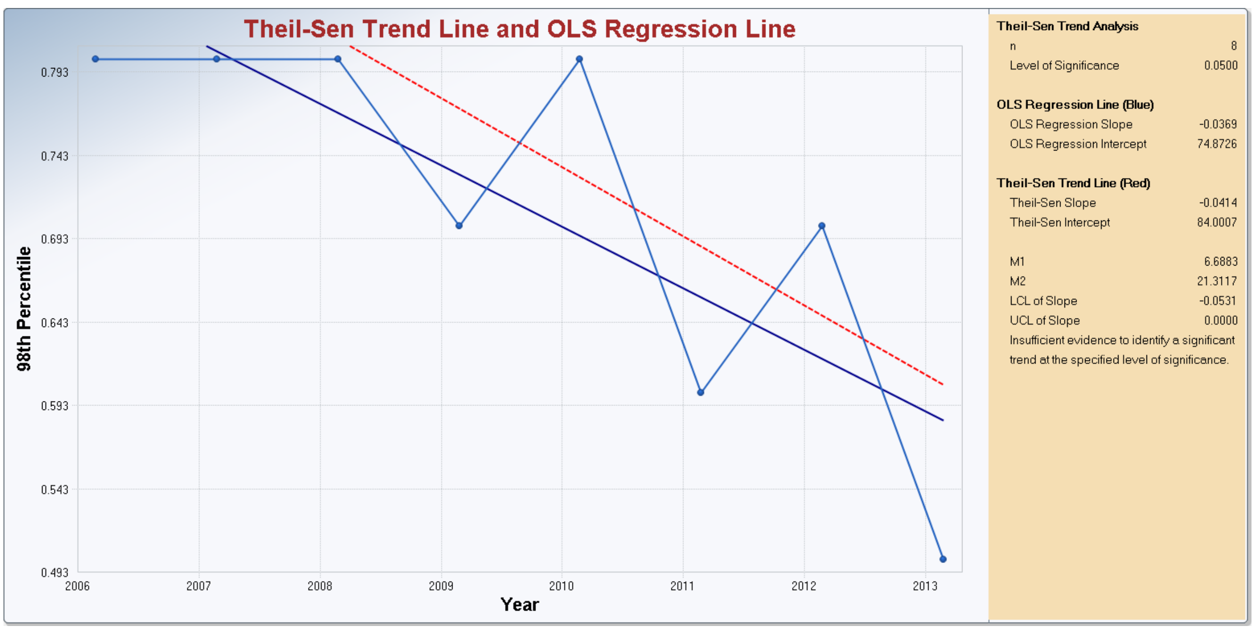

Figure I-12: Edmonton South CO 98th Percentile Theil-Sen Trend Line Output