Canadian Council of Ministers of the Environment
Le Conseil canadien des ministres de l'environnement

GUIDANCE DOCUMENT ON ACHIEVEMENT DETERMINATION FOR CANADIAN AMBIENT AIR QUALITY STANDARDS FOR OZONE

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BACKGROUND ON AIR QUALITY MANAGEMENT SYSTEM

Air quality is important for all Canadians and it affects many aspects of our lives and our society, including human health, the natural environment, buildings and infrastructure, crop production, and the economy. In Canada, air quality management is a responsibility shared between federal, provincial and territorial governments. Under the Canadian Council of Ministers of the Environment (CCME), federal, provincial and territorial governments are working collaboratively to improve air quality by implementing the Air Quality Management System (AQMS)[1]. Key elements of AQMS include:

1. Air zones – geographical areas that are used to manage local air quality within the provinces and territories in which they are located.
2. Airsheds – broad geographic areas that encompass a number of air zones and may cross provincial, territorial, and international boundaries. They provide a framework for inter-jurisdictional collaboration to address transboundary air quality issues.
3. Canadian Ambient Air Quality Standards (CAAQS) – health and environmental-based air quality objectives to further protect human health and the environment and to provide the drivers for air quality improvement across the country.
4. Air Zone Management Framework – a framework to manage air quality in air zones.
5. Base-level industrial emissions requirements (BLIERs) – emission requirements that are intended to apply to major industrial sectors or equipment types to ensure that significant industrial sources achieve a good base-level of performance.
6. Mobile Sources – work that builds on the existing range of federal, provincial and territorial initiatives aimed at reducing emissions from the transportation sector.

In addition to being endorsed by CCME, the CAAQS have also been established as ambient air quality objectives by the federal government under the *Canadian Environmental Protection Act, 1999*.

This document provides information on the CAAQS and management levels for ozone and information on the procedures, methodologies and criteria for determining whether the CAAQS for ozone are achieved or exceeded at monitoring stations and within air zones.

[1] Although Québec supports the general objectives of the AQMS, the province will not implement the system since the system calls for federal industrial emission requirements that duplicate Québec regulations. However, Québec is collaborating with jurisdictions on developing other elements of the system, notably air zones and airsheds.

1.0 INTRODUCTION

Under the Air Quality Management System (AQMS), provinces and territories have been delineated into one or more air zones by the respective jurisdiction. Air zones provide a defined area within which stakeholders, other interested parties and governments work together to improve local air quality and maintain air pollutant concentrations below the Canadian Ambient Air Quality Standards (CAAQS).

As part of AQMS, provinces and territories have agreed to regularly publish air zone reports for each of their air zones in a timely fashion. These reports are key to the integrity of AQMS and will include information on the achievement status of the CAAQS and their management levels. *Achievement status* means whether ambient concentrations of air pollutants are less than or equal to the corresponding standard (*CAAQS is achieved)* or greater than the standard (*CAAQS is exceeded*). To ensure that reporting on CAAQS achievement status is comparable among provinces and territories, guidance is needed on the monitoring, procedures and methodologies to use. This document outlines this guidance for ambient ozone[2] and its main purpose is to:

- present the CAAQS and management levels for ozone
- provide guidance on the ozone monitors and monitoring stations to use for reporting on the achievement status of the ozone CAAQS
- provide the procedures for calculating the concentrations to use for direct comparison to the ozone standard (called *metric values*)
- provide the procedures for determining if the ozone CAAQS is achieved or exceeded at monitoring stations and in air zones.

This document supersedes all the sections pertaining to ozone of the CCME 2012 Guidance Document on Achievement Determination, Canadian Ambient Air Quality Standards for Fine Particulate Matter and Ozone.

More information on AQMS and guidance on its implementation are available on ccme.ca.

2.0 CANADIAN AMBIENT AIR QUALITY STANDARDS FOR OZONE

CAAQS are health and environmental-based air quality objectives to further protect human health and the environment, and to provide the drivers for air quality improvement across Canada. All CAAQS consist of three inter-related elements:

1. an averaging time
2. a concentration "standard" (or "numerical value") associated with the averaging time
3. the statistical form for the standard.

[2] Throughout this document, "ambient ozone" or "ozone" refers to ground-level ozone.

CCME has established CAAQS for ozone for 2015, 2020 and 2025, listed in Table 2-1. The federal government established these CAAQS as ambient air quality objectives pursuant to sections 54 and 55 of the *Canadian Environmental Protection Act, 1999*. The 2015 and 2020 CAAQS were established on May 25, 2013[3] and the 2025 CAAQS was established on June 29, 2019[4]. The 2015 CAAQS were in effect from January 1, 2015 to December 31, 2019. The 2020 CAAQS came into effect on January 1, 2020 and will remain in effect until December 31, 2024. The 2025 CAAQS will become effective on January 1, 2025. The years 2015, 2020 and 2025 represent the years by which the associated standard should be achieved. The intended use of all CAAQS is discussed in the CCME Guidance Document on Air Zone Management (CCME 2019a).

Table 2-1: CAAQS for ozone

Averaging time[5]	**Standard** (numerical value)			**Statistical form of the standard**
	2015	**2020**	**2025**	
8-hour	63 ppb*	62 ppb	60 ppb	The 3-year average of the annual fourth highest of the daily-maximum 8-hour average concentrations

* ppb-parts per billion by volume

For ease of discussion, an ozone (O_3) 1-hour average concentration is denoted by "O_3 1-hour" and an ozone daily-maximum 8-hour average concentration as "O_3 Dmax 8-hour".

The averaging time in Table 2-1 refers to the averaging period over which the standard applies. The statistical form describes the calculation method for the specific concentration that should be used for comparison to the standard to determine whether the concentrations measured at a monitoring station exceed the standard. The 8-hour ozone standard of 60 ppb (for 2025) applies to O_3 8-hour average concentrations. The statistical form of the standard means that the concentration to be used to determine if 60 ppb was exceeded at a monitoring station is the 3-year average of the annual fourth highest of O_3 Dmax 8-hour measured at the station.

To simplify terminology, the concentrations measured at a monitoring station calculated in the statistical form of a standard are referred to as "CAAQS metric value" or simply "metric

3 Canada Gazette Part 1, Volume 147, no 21, May 25, 2013. http://gazette.gc.ca/rp-pr/p1/2013/2013-05-25/pdf/g1-14721.pdf

4 Canada Gazette Part 1, Volume 153, no 26, June 29, 2019. http://gazette.gc.ca/rp-pr/p1/2019/2019-06-29/pdf/g1-15326.pdf

5 This is referred to as "averaging period" in some jurisdictions.

value"[6]. An ozone CAAQS is achieved at a monitoring station if the corresponding metric value is less than or equal to the standard, otherwise it is exceeded. An ozone CAAQS is achieved in an air zone if the highest metric value in the air zone is less than or equal to the standard; otherwise the standard is exceeded. In other words, an ozone CAAQS is achieved in an air zone if the metric values at *all* ozone CAAQS reporting stations in the air zone are less than or equal to the standard.

For clarity, a 3-year average is to be computed backward in time. As such, the first formal achievement determination is based on metric values for 2013 to 2015 for the 2015 standard, from 2018 to 2020 for the 2020 standard, and from 2023 to 2025 for the 2025 standard.

Text Box 1 provides a simplified example for the calculation of the metric values in an air zone with two monitoring stations. Since the 3-year period for this example is 2018-20, the 2020 standard of 62 ppb applies. For this example, the ozone standard is achieved at Station A (since the metric value of 44 ppb is less than the standard of 62 ppb) and exceeded at Station B. Since the highest metric value in the air zone exceeds the standard, the air zone does not achieve the ozone standard.

To ensure that reporting on CAAQS achievement is comparable across provinces and territories, there are specific procedures to use for obtaining the annual fourth highest, the metric values and for number rounding. These are addressed in section 5.

Text Box 1: Example for calculating the ozone CAAQS metric value

	Annual fourth highest O_3 Dmax 8-hour		
	2018	**2019**	**2020**
Station A	39.4 ppb	55.6 ppb	38.0 ppb
Station B	92.7 ppb	85.6 ppb	70.5 ppb

	3-year average of the annual fourth highest	Ozone CAAQS metric value for 2018-2020
Station A	(39.4 + 55.6 + 38.0)÷3 = 133÷3 = 44.333 ppb	44 ppb
Station B	(92.7 + 85.6 + 70.5)÷3 = 248.8÷3 = 82.933 ppb	83 ppb

[6] It should be noted that the annual highest 8-hour average concentration and a single annual fourth highest of the O_3 Dmax 8-hour cannot be used to determine if the ozone standard is achieved or exceeded because neither of these correspond to the statistical form of the standard.

2.1 Basis for the Statistical Form of the Standards

CAAQS are established to further protect the health of Canadians and their environment. They are used to guide the air quality management actions to implement as part of the Air Zone Management Framework (AZMF, section 3). If ambient concentrations of air pollutants exceed their corresponding standard, the AZMF calls for the implementation of the most rigorous actions.

Exceedances of a standard, and generally variations in ambient concentrations from one year to the next, are influenced not only by changes in the quantity of emissions of air pollutants but also by variations in the prevailing meteorological conditions[7]. This implies that exceedances of a standard can at times be influenced by the occurrence of meteorological conditions that are conducive to elevated ambient concentrations of air pollutants even though emissions do not increase substantially. As such, an air zone can shift in and out of achievement of a standard because of variations in meteorological conditions rather than because of sustained changes in emissions. To reduce this risk, the statistical form of a standard is established considering not only the need to capture the associated health and environmental effects, but also the need that it not be overly influenced by variations in meteorological conditions.

For the ozone 8-hour CAAQS, studies indicate that the risk of adverse health impacts appears linear throughout the range of concentrations observed in Canada, with no clear threshold for such effects. Epidemiology studies examining associations of various short-term averages (from 1 to 24 hours) demonstrate effects of similar public-health consequence. Studies using various exposure times in controlled settings with human volunteers (up to 6.6 hours) indicate similar adverse effects, with most timeframes. Therefore, while the relevant evidence indicates causal associations with several adverse outcomes, it does not provide direct evidence of a preferred short-term averaging time.

The 8-hour averaging time was selected as it also aligns with the ozone standard of the United States, which allows direct comparison of ozone between the two countries. The fourth highest O_3 Dmax 8-hour was preferred over the annual highest O_3 Dmax 8-hour since data analyses indicate that the annual highest varies more from year to year than the annual fourth highest, likely because the annual highest is more sensitive to meteorological conditions. Given that the fourth highest varies less, and is also representative of the higher ozone concentrations, a fourth highest form was adopted for the CAAQS. The final form as a 3-year average of the fourth highest was selected to further reduce the variability between years.

[7] For example, hot and sunny weather leads to elevated ozone concentrations in one year, while cool and wet weather lead to low ozone concentrations in another year.

3.0 OZONE MANAGEMENT LEVELS

AQMS includes an AZMF, which provides guidance to jurisdictions on the monitoring, reporting and management actions to implement in air zones depending on the prevailing concentrations of air pollutants. The framework includes four air quality management categories, or levels, denoted by the colours green, yellow, orange and red. Each of these management levels is associated with a corresponding range of concentrations of air pollutants that have been established concurrently and under the same process as the corresponding CAAQS. The current ozone management levels are presented in Table 3-1.

The concentrations in Table 3-1 have the same statistical form as the corresponding CAAQS. Accordingly, the ozone CAAQS metric values discussed in section 2 are also used for comparison to the management levels to determine the management level into which the air zone falls. The procedures that provinces and territories use to assign management levels to each of their air zones are discussed in CCME 2019a.

Table 3-1: Management levels for ozone

Management level	2015	2020	2025
Red	> 63 ppb	> 62 ppb	> 60 ppb
Orange	57 to 63 ppb	57 to 62 ppb	57 to 60 ppb
Yellow	51 to 56 ppb		
Green	≤ 50 ppb		

4.0 MONITORS AND REPORTING STATIONS

This section provides guidance on the ozone monitors to use for reporting on the achievement status of the ozone CAAQS. It also provides guidance on the location of monitoring stations for reporting on the achievement status (CAAQS reporting stations).

4.1 Requirements for Monitors

The monitors for reporting on the achievement status of the ozone CAAQS should:

1. measure ozone concentrations on an hourly basis

2. be designated as either *Federal Reference Method* (FRM) or *Federal Equivalent Method* (FEM) by the United States Environmental Protection Agency (U.S. EPA 2016)
3. be subject to data validation procedures that meet (or exceed) the Ambient Air Monitoring and Quality Assurance and Quality Control Guidelines: National Air Pollution Surveillance Program (NAPS) (CCME 2019b).

The NAPS Program is a collaborative air quality monitoring network jointly operated and maintained by the provinces and territories and Environment and Climate Change Canada (ECCC). Metro Vancouver and Ville de Montréal also contribute to the NAPS Program.

4.2 CAAQS Reporting Stations

Provinces and territories are responsible for designating the ozone CAAQS reporting stations. Ideally, all CAAQS reporting stations should be planned to be operational for the long-term.

Provincial and territorial jurisdictions may determine that ambient monitoring for ozone is not required in an air zone, but ideally each air zone should have at least one ozone CAAQS-reporting station. From a population health perspective, as a minimum all communities with population of at least 100,000 should have one or more ozone CAAQS-reporting station. Jurisdictions without communities with population of at least 100,000 should have at least one ozone CAAQS-reporting station in a major urban centre. From an environmental perspective, stations could also be located in air pollution-sensitive ecosystems as priorities and resources allow. *Sensitive ecosystems* encompass national and provincial parks, protected areas, areas of cultural or heritage value and areas that are or may be susceptible to adverse effects from exposure to ozone.

To assist in identifying the communities that should have at least one ozone CAAQS-reporting station, Statistics Canada geographic units can be used. Statistics Canada utilizes geographic units for the *grouping* of municipalities that are closely interconnected with integrated economies. These geographic units include Census Metropolitan Area (CMA) and Census Agglomeration (CA)[8]. All CMAs have a population of at least 100,000, and only a few CAs have a population of at least 100,000. Based on the census data from Statistics Canada, in 2016 there were 35 CMAs and 6 CAs with population of at least 100,000 (Table 4-1). These CMAs and CAs covered approximately 73% of the Canadian population in 2016.

[8] For clarity, CMA and CA are not legal or administrative bodies. They are geographic areas used by Statistics Canada for census purposes only.

Table 4-1: List of CMAs and CAs with population of at least 100,000 in 2016

CMA-CA name	Type	Province	Population (2016)
Abbotsford - Mission	CMA	British Columbia	180,518
Chilliwack	CA	British Columbia	101,512
Kamloops	CA	British Columbia	103,811
Kelowna	CMA	British Columbia	194,882
Nanaimo	CA	British Columbia	104,936
Vancouver	CMA	British Columbia	2,463,431
Victoria	CMA	British Columbia	367,770
Calgary	CMA	Alberta	1,392,609
Edmonton	CMA	Alberta	1,321,426
Lethbridge	CMA	Alberta	117,394
Red Deer	CA	Alberta	100,418
Regina	CMA	Saskatchewan	236,481
Saskatoon	CMA	Saskatchewan	295,095
Winnipeg	CMA	Manitoba	778,489
Barrie	CMA	Ontario	197,059
Belleville	CMA	Ontario	103,472
Brantford	CMA	Ontario	134,203
Chatham-Kent	CA	Ontario	102,042
Greater Sudbury	CMA	Ontario	164,689
Guelph	CMA	Ontario	151,984
Hamilton	CMA	Ontario	747,545
Kingston	CMA	Ontario	161,175
Kitchener - Cambridge - Waterloo	CMA	Ontario	523,894
London	CMA	Ontario	494,069
Oshawa	CMA	Ontario	379,848
Ottawa (Ottawa-Gatineau CMA)	CMA	Ontario	991726
Peterborough	CMA	Ontario	121,721
St. Catharines - Niagara	CMA	Ontario	406,074
Thunder Bay	CMA	Ontario	121,621
Toronto	CMA	Ontario	5,928,040
Windsor	CMA	Ontario	329,144
Gatineau (Ottawa-Gatineau CMA)	CMA	Québec	332,057
Montréal	CMA	Québec	4,098,927
Québec	CMA	Québec	800,296
Saguenay	CMA	Québec	160,980
Sherbrooke	CMA	Québec	212,105
Trois-Rivières	CMA	Québec	156,042
Fredericton	CA	New Brunswick	101,760
Moncton	CMA	New Brunswick	144,810
Saint John	CMA	New Brunswick	126,202
Halifax	CMA	Nova Scotia	403,390
St. John's	CMA	Newfoundland and Labrador	205,955

Within communities, ozone CAAQS-reporting stations should be located in areas that reflect the “neighbourhood” or “urban” scale. The U.S. Environmental Protection Agency (U.S. EPA 1998) defines neighbourhood scale *as reasonably homogeneous urban sub-regions with dimensions of a few kilometres and of generally more regular shape than the middle scale* and urban scale as an *entire metropolitan or rural area ranging in size from 4 to 50 kilometres*. Neighbourhood or urban scale monitors should be located in residential, commercial and industrial or other areas where people live, work and play.

Ozone is a pollutant that mostly forms in the atmosphere as opposed to being directly emitted to the air. Most ozone at ground-level results from the photo-dissociation (or “splitting”) of nitrogen dioxide (NO_2) by sunlight into nitric oxide (NO) and a very reactive oxygen atom (O) which rapidly combines with oxygen (O_2) to form ozone (O_3). The combustion of fossil fuels, like those used in automobiles, releases nitrogen oxides (NO_X) which consists of approximately 90% NO and the rest is mostly NO_2. While direct emissions of NO_2 are small compared to NO, photochemical reactions involving NO and volatile organic compounds (VOCs) in the presence of sunlight transform the released NO into NO_2. As such, NO_X and VOCs are the main fast-reacting ozone precursors (or ozone-producing substances).

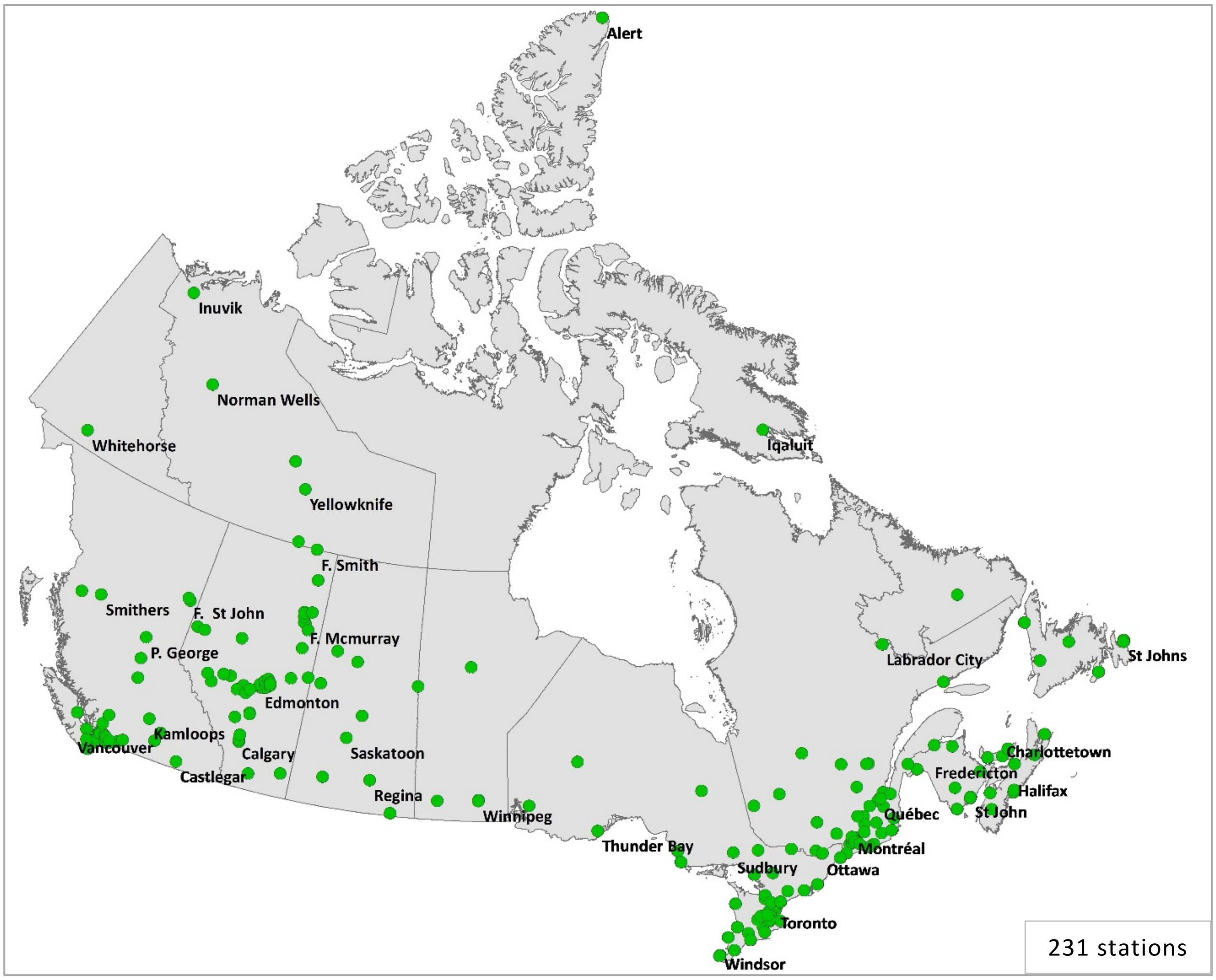
In addition to photochemical reactions involving VOCs, NO also reacts with the ozone in the air (known as ozone *titration* or *scavenging* by NO) to form NO_2. Through this titration reaction, ozone concentrations are typically lower in the vicinity of major sources of NO_X and higher at some distance downwind (because of the time required for ozone formation and accumulation). As such, in a large CMAs ozone concentrations are typically lower in the dense urban core (because the freshly emitted NO from traffic titrates ozone) and higher at downwind sub-urban or rural areas. Therefore, where possible an ozone CAAQS-reporting station should also be located in areas of expected high ozone concentrations, especially if these areas contain a population or a sensitive ecosystem.

In 2019, ozone was monitored on an hourly basis at 231 stations (Figure 4-1) which are part of NAPS and the Canadian Air and Precipitation Monitoring Network (CAPMoN) operated by ECCC. All 35 CMAs and 6 CAs with a population of at least 100,000 (Table 4-1) had one or more stations. As a starting point, all NAPS and CAPMoN ozone stations should be used as ozone CAAQS-reporting stations[9]. Most NAPS stations are located in urban areas while the CAPMoN stations are located in remote areas that are not influenced by significant anthropogenic emission sources. The NAPS and CAPMoN ozone data can be retrieved from the Government of Canada *Open Government* data base[10].

[9] The ozone monitors at NAPS and CAPMoN stations are all designated as either FRM or FEM by the EPA and they all meet the NAPS QA-QC guidelines.

[10] https://open.canada.ca/data/en/dataset/1b36a356-defd-4813-acea-47bc3abd859b

Figure 4-1: The NAPS and CAPMoN ozone monitoring stations for 2019



To augment spatial coverage, provinces and territories could also use additional stations that they deem appropriate, as long as the ozone monitors satisfy the requirements discussed in section 4.1. These additional stations can include, for example:

1. provincial and territorial non-NAPS stations
2. stations owned by air zone organizations[11]
3. stations owned by third parties.

For detailed information on siting ozone monitoring stations consult CCME 2019b.

[11] These are not-for-profit organizations with a multi-stakeholder membership and are established by some provinces and territories to address air quality within the air zone. Some organizations operate their own monitoring stations.

5.0 CALCULATION OF THE OZONE METRIC VALUES

This section provides guidance on the procedures for calculating the ozone CAAQS metric values, the data completeness criteria and the number of decimal places that measured concentrations and calculated values have to be reported. Appendix A provides an example for the calculation of the metric values. As mentioned in section 2, an ozone 1-hour average concentration is denoted by "O_3 1-hour" and the ozone daily-maximum 8-hour average concentration as "O_3 Dmax 8-hour".

Ozone CAAQS metric values can be calculated for any ozone monitoring station. However, for reporting on ozone-CAAQS achievement status and management level only stations designated by provinces and territories as *ozone CAAQS-reporting stations* should be used.

5.1 Calculation of the Annual Fourth Highest

The ozone metric value requires the calculation of three annual fourth highest O_3 Dmax 8-hour. An annual fourth highest is to be obtained based on the following four main steps:

Step 1: Calculate rolling (or moving) 8-hour average ozone concentrations (O_3-8-hr) from the O_3 1-hour for each hour of the day as per equation 5.1.

$$\mathbf{O_3\text{-}8\text{-}hr_J = (O_{3J} + O_{3J-1} + O_{3J-2} + O_{3J-3} + O_{3J-4} + O_{3J-5} + O_{3J-6} + O_{3J-7}) \div N} \quad \text{(eq. 5.1)}$$

In this equation,

O_3-8-hr_J = the 8-hour average ozone concentration for the period ending at hour J, with J = 1 to 24

O_{3J} = the O_3 1-hour for hour J

O_{3J-i} = the O_3 1-hour for hour J-i, with i = 1 to 7.

N = the number of available O_{3J} in the 8-hour period (6, 7, or 8).

N can vary from 6 to 8 because the data completeness criteria discussed in section 5-3 allows for the calculation of "8-hour" average concentrations if the 8-hour averaging period contains at least six O_3 1-hour in the period. Table 5-1 shows an example of the application of equation 5.1.

Table 5-1: Example of rolling O_3 8-hour average concentrations

Date	Hour	O_3 1-hour (ppb)	O_3 rolling 8-hour average (ppb)	O_3 Dmax 8-hour (ppb)
7-Jul-18	1:00	31	40.3	60.3
	2:00	28	36.3	
	3:00	28	33.0	
	4:00	27	31.0	
	5:00	27	29.5	
	6:00	26	28.4	
	7:00	22	27.4	
	8:00	25	26.8	
	9:00	29	26.5	
	10:00	30	26.8	
	11:00	39	28.1	
	12:00	45	30.4	
	13:00	58	34.3	
	14:00	61	38.6	
	15:00	66	44.1	
	16:00	70	49.8	
	17:00	68	54.6	
	18:00	60	58.4	
	19:00	54	60.3	
	20:00	43	60.0	
	21:00	39	57.6	
	22:00	35	54.4	
	23:00	30	49.9	
	24:00	30	44.9	
8-Jul-2018	01:00	NA	41.3	55.9
	02:00	24	34.3	
	03:00	19	28.0	
	04:00	14	23.5	
	05:00	9	19.0	
	06:00	5	16.3	
	07:00	4	12.5	
	08:00	10	12.1	
	09:00	21	13.3	
	10:00	24	13.3	
	11:00	39	15.8	
	12:00	54	20.8	
	13:00	74	28.9	
	14:00	76	37.8	
	15:00	55	44.1	
	16:00	46	48.6	
	17:00	61	53.6	
	18:00	42	55.9	
	19:00	35	55.4	
	20:00	39	53.5	
	21:00	29	47.9	
	22:00	15	40.3	
	23:00	22	36.1	
	24:00	26	33.6	

Equation 5.1 is applied to each hour for each day in a calendar year. For January 1, the first 8-hour average can be calculated for the hour (J=) 01:00 (1 a.m.) based on the 1-hour concentrations from 18:00 on December 31 of the previous year to 01:00 on January 1 of the current year. Alternatively, for January 1 the first average could also be calculated for the hour 06:00 as a 6-hour average for the hours from 01:00 to 06:00 and the second for the hour 07:00 as a 7-hour average based on the hours from 01:00 to 07:00. The first full 8-hour average would then start at 08:00 for the hours from 01:00 to 08:00. The inclusion of 6 and 7-hour averages for the hours 06:00 and 07:00 aligns with the data completeness criteria specified in Table 5-3 which allows the calculation of rolling averages if six or more O_3 1-hour are available in the corresponding 8-hour averaging period. The 06:00 start enables January 1 to meet the daily data completeness criteria for the consideration of the O_3 Dmax 8-hour (see Table 5-3).

For clarity, the O_3 1-hour and O_3-8-hr are both to be assigned to the ending hour of the averaging period. For example, the O_3 1-hour for the hour 04:00 is the average of the measurements between the hours of 03:00 to 04:00. The O_3-8-hr for the hour 04:00 is the average of the O_3 1-hour for the hours 21:00 of the previous day to 04:00.

Step 2: Select the O_3 Dmax 8-hour for each day in the year. For the example in Table 5-1, the O_3 Dmax 8-hour for 8 July 2018 is 55.9 ppb.

Step 3: Select the four highest O_3 Dmax 8-hour in the year and rank them in decreasing order of magnitude, repeating common values as often as they occur, as in the example in the Table 5-2.

Table 5-2: Example of four highest O_3 Dmax 8-hour in decreasing order

O_3 Dmax 8-hour (ppb)	Rank	Date measured
89.9	Highest	15-07-2018
60.3	second highest	7-07-2018
60.3	third highest	18-08-2018
58.5	fourth highest	18-05-2018

Step 4: Among the four highest O_3 Dmax 8-hour in the year, select the fourth highest. For the example in Table 5-2, the fourth highest O_3 Dmax 8-hour in 2018 is 58.5 ppb.

5.2 Calculation of Metric Values

The ozone CAAQS metric value at a monitoring station is the average of the three annual fourth highest O_3 Dmax 8-hour over three consecutive years and is calculated as per equation 5.2.

$$\textbf{Ozone metric value}_{Y1\text{-}Y3} = (4^{th}H_{Y1} + 4^{th}H_{Y2} + 4^{th}H_{Y3}) \div 3 \quad \text{(equation 5.2)}$$

In this equation, $4^{th}H_{Y1}$, $4^{th}H_{Y2}$ and $4^{th}H_{Y3}$ represent the annual fourth highest O_3 Dmax 8-hour for the consecutive calendar years Y1, Y2 and Y3 respectively, calculated as discussed in section 5.1.

5.3 Data Completeness Criteria and Exceptions

Generally, only data that meet completeness requirements should be used in the calculation of the ozone metric values and only metric values based on complete data should be used for CAAQS reporting. Table 5-3 specifies the data completeness criteria under which concentrations and metric values may be considered to be based on complete data.

There are exceptions to the data completeness criteria; these are indicated in column 3 of Table 5-3. These exceptions ensure that potential exceedances of a standard are captured. If a parameter in column 1 does not meet its completeness criteria in column 2 but meets the exception criteria in column 3, it will then still be used for CAAQS reporting. For example, at a given monitoring station there are less than eighteen O_3-8-hr in a given day and the O_3 Dmax 8-hour based on the available data is 70 ppb. Since this O_3 Dmax 8-hour exceeds the standard, it will be retained for the selection of the annual fourth highest even though the completeness criterion was not satisfied.

Table 5-3: Data completeness and exceptions criteria

Parameter (Column 1)	**Data completeness criteria** (Column 2)	**Exceptions to the data completeness criteria** (This parameter will always be considered in the calculation of metric values if the following conditions are satisfied) (Column 3)
O_3-8-hr	At least six of the eight O_3 1-hour are available in the corresponding eight-hour period[12].	No exceptions
O_3 Dmax 8-hour	At least 18 (75%) of the 24 O_3-8-hr are available in the day.	The O_3 Dmax 8-hour exceeds the standard
Annual fourth highest O_3 Dmax 8-hour	O_3 Dmax 8-hour are available for at least 75% of the days in the period April 1 to September 30.	The annual fourth highest exceeds the standard
Metric value	Two of the possible three annual fourth highest are available[13].	No exceptions

The data completeness for the annual fourth highest O_3 Dmax 8-hour applies only to the period April 1 to September 30 since this is the time of year where the annual fourth highest will likely be recorded in most of Canada[14]. However, in somewhat atypical conditions the annual fourth highest could be recorded outside of the April 1 to September 30 period. If the annual fourth highest is recorded in the period from January 1 to March 31 or in the period from October 1- December 31, it will be considered in the calculation of the ozone metric value only if: (1) the O_3 Dmax 8-hour are available for at least 75% of the days in the period April 1 to September 30; or (2) or it exceeds the standard (as per the exceptions criteria). Requiring the data completeness to be satisfied for the period April 1 to September 30 even when the fourth highest is recorded outside that period increases the confidence that the “true” annual fourth highest has been recorded.

As indicated in Table 5-3, the ozone metric value is considered to be based on complete data if two of the three annual fourth highest are available. However, for cases when a metric value is based on only two annual fourth highest, provinces and territories can nevertheless identify them as such in the air zone report. Cases where one or more of the exceptions criteria listed above were applied can also be indicated in the report. Section 7

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[12] The data completeness and other information for the O_3 1-hour are provided in CCME 2019b.

[13] If only two annual fourth highest are available, the divisor in equation 5.2 will be 2 instead of the indicated 3.

[14] This is because for most of Canada short-term (1 to 8 hours) concentrations of ozone produced from NO_X and VOC emissions are typically the highest in the warmer April 1 to September 30 period and sunlight is also more intense during this period.

provides suggestions on how to communicate CAAQS exceedances based on incomplete data.

5.4 Decimal Places and Rounding Rules

Calculated values, such as the 1-hour average concentrations[15], the O_3 8-hr and the CAAQS metric values can be reported to various decimal places. Table 5-4 specifies the number of decimal places that calculated values are to be reported, together with the rules for rounding the calculated values to the specified decimal places. It should be noted that the O_3 Dmax 8-hour and the annual fourth highest O_3 Dmax 8-hour are not calculated values but are instead directly obtained from the O_3 8-hr. As such, the O_3 Dmax 8-hour and the annual fourth highest O_3 Dmax 8-hour are also reported to one decimal place. Text Box 2 below provides an example for rounding the metric values to whole numbers.

[15] For most ozone monitors, the 1-hour average concentrations correspond to the average of concentrations measured over shorter time periods.

Table 5-4: Decimal place and rounding rules

Parameter	Decimal place of parameter	Rounding rule for the parameter
O_3 1-hour	No decimal place (whole number)	For the 1-hour average, first discard all numbers after the first decimal. This results in a number with one decimal place (a calculated average of 60.4999 ppb becomes 60.4 ppb). For the resulting number, if its decimal is: 1. ≥ 5, round upward to a whole number (60.5 ppb is rounded upward to 61 ppb) 2. ≤ 4, round downward to a whole number (60.4 is rounded downward to 60 ppb). The rounded number is then the O_3 1-hour to use in the calculation of O_3-8-hr.
O_3-8-hr*	1 decimal place	For the O_3-8-hr, first discard all numbers after the second decimal. This results in a number with two decimal places (a calculated average of 60.4599 ppb becomes 60.45 ppb). For the resulting number, if its second decimal is: 1. ≥ 5, round upward to one decimal place (60.55 ppb is rounded upward to 60.6 ppb) 2. ≤ 4, round downward to one decimal place (60.44 is rounded downward to 60.4 ppb). The rounded number is then the O_3-8-hr.
Ozone metric value (3-year average of the annual fourth highest O_3 Dmax 8-hour)	No decimal place (whole number)	For the 3-year average, first discard all numbers after the first decimal. This results in a number with one decimal place (a calculated 3-year average of 60.4999 ppb becomes 60.4 ppb). For the resulting number, if its decimal is: 1. ≥ 5, round upward to a whole number (60.5 ppb is rounded upward to 61 ppb) 2. ≤ 4, round downward to a whole number (60.4 is rounded downward to 60 ppb). The rounded number is then the metric value.

***** The O_3 Dmax 8-hour and the 4^{th} highest O_3 Dmax 8-hour are also reported to one decimal place since they are directly obtained from the O_3-8-hr.

Text Box 2: Example for rounding the ozone CAAQS metric value to a whole number

The annual fourth highest O_3 Dmax 8-hour at a monitoring station for the years 2018, 2019 and 2020 are 72.5, 60.5 and 55.9 respectively. Their 3-year average is 62.966…ppb*.

According to Table 5-4, the ozone CAAQS metric values are to be reported as a whole number (i.e. no decimal place) based on the specified rounding procedure.

The procedure first specifies to discard all numbers after the first decimal place. Based on this, the 3-year average of 62.966…ppb becomes 62.9 ppb. The rounding rule then specifies that if the first decimal of the resulting value is:

1. ≥ 5, round value upward to a whole number
2. ≤ 4, round value downward to a whole number.

Based on this rule, 62.9 ppb is rounded upward 63 ppb, which is the calculated ozone CAAQS metric value.

*The three dots is to signify that the number 6 repeats indefinitely.

6.0 TRANSBOUNDARY FLOWS AND EXCEPTIONAL EVENTS

Transboundary flows (TF) and exceptional events (EE) are influences on concentrations from sources over which a jurisdiction has little to no direct control and they are discussed in the CCME Guidance Document on Transboundary Flows and Exceptional Events (CCME 2019c). Under AQMS, provinces and territories can consider influences from TF and EE on CAAQS exceedances and management levels and the procedures for doing so are provided in CCME 2019c. Consideration of TF-EE can also be applied to exceedances resulting from exceptions to the data completeness criteria discussed in section 5.3.

7.0 COMMUNICATION AND REPORTING

Communicating with the Canadian public is an important component of the AQMS. Each province and territory will regularly publish reports on air quality containing information for each of their air zones. With respect to CAAQS metric values, these reports should include the following information:

1. the ozone CAAQS metric values at each ozone CAAQS reporting station
2. the ozone CAAQS achievement status for each CAAQS reporting station
3. the ozone CAAQS achievement status for the air zone.

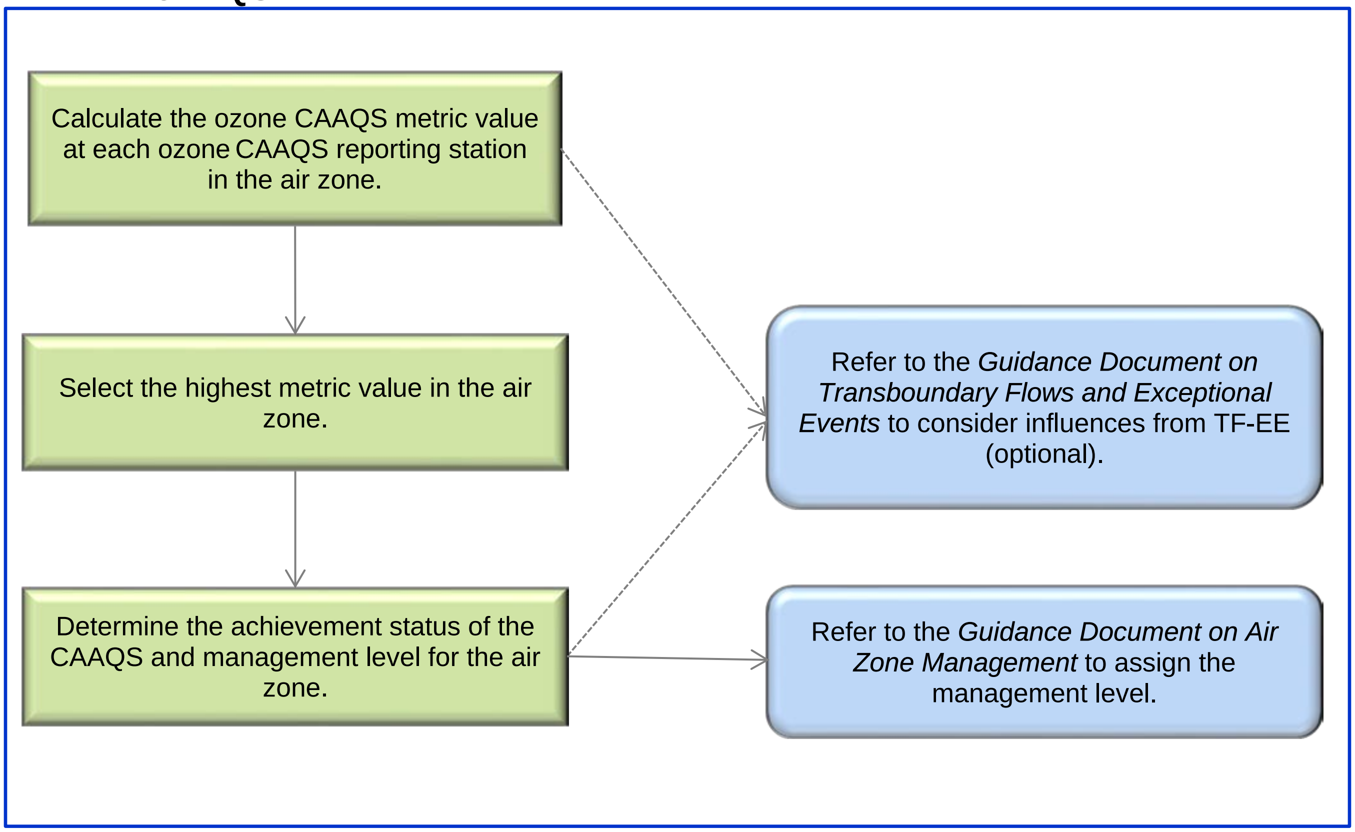
Including the metric values at each station will show the spatial variation in concentrations and will also serve to show that an exceedance may be limited to only some areas instead of the entire air zone. If an air zone has no ozone CAAQS-reporting station, the air zone report would clarify that the ozone CAAQS achievement status could not be determined. Exceedances of a standard under incomplete data may be identified as such in the air zone reports and be accompanied with a cautionary note. Information can also be included in regard to which concentration was based on the exceptions criteria outlined in Table 5-3.

The reporting requirements for air zone management levels are discussed in CCME 2019a.

8.0 SUMMARY OF GUIDANCE

The guidance provided in this document for the determination of the ozone CAAQS achievement status is summarized schematically in Figure 8-1.

Figure 8-1: Outline for determining the achievement status of the ozone CAAQS



9.0 REFERENCES

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APPENDIX A – EXAMPLE CALCULATION OF THE METRIC VALUE

This Appendix provides an example of the procedures for calculating the ozone CAAQS metric value at a monitoring station for the 3-year period 2018 to 2020.

Based on equation 5.2, the metric value is:

$$\textbf{Ozone metric value}_{2018\text{-}2020} = (4^{th}H_{2018} + 4^{th}H_{2019} + 4^{th}H_{2020}) \div 3$$

The annual fourth highest O_3 Dmax 8-hour for each of the years 2018 to 2020 ($4^{th}H_{Yi}$) are obtained by applying the four-step procedure described in section 5.1. An example is provided below for the fourth highest for 2018.

Step 1 – Calculate rolling 8-hour average ozone concentrations (O_3 8-hr)

The first step is to use equation 5.1 to calculate rolling O_3 8-hr for each hour of the day. Table A-1 provides an example for 7 July 2018. In this Table, the O_3 8-hr for hour 21:00 is the average of the O_3 1-hour at hour 21:00 and the previous 7 hours. Accordingly,

$$\mathbf{O_3\ 8\text{-}hr_{21:00}} = (39 + 43 + 54 + 60 + 68 + 70 + 66 + 61) \div 8 = 57.625 \text{ ppb.}$$

The O_3 8-hr are to be reported to one decimal place based on the rounding rule specified in Table 5-4. Accordingly, the O_3 8-hr for hour 21:00 is 57.6 ppb.

Step 2: Select the O_3 Dmax 8-hour each day in the year. For the example in Table A-1, the O_3 Dmax 8-hour for 7 July 2018 is 60.3 ppb.

Table A-1: Example of rolling 8-hour average ozone concentrations

Day	Hour of day	O_3 1-hour (ppb)	O_3 8-hr (ppb)	O_3 Dmax 8-hour (ppb)
7-Jul-2018	01:00	31	40.3	**60.3**
	02:00	28	36.3	
	03:00	28	33.0	
	04:00	27	31.0	
	05:00	27	29.5	
	06:00	26	28.4	
	07:00	22	27.4	
	08:00	25	26.8	
	09:00	29	26.5	
	10:00	30	26.8	
	11:00	39	28.1	
	12:00	45	30.4	
	13:00	58	34.3	
	14:00	61	38.6	
	15:00	66	44.1	
	16:00	70	49.8	
	17:00	68	54.6	
	18:00	60	58.4	
	19:00	54	**60.3**	
	20:00	43	60.0	
	21:00	39	57.6	
	22:00	35	54.4	
	23:00	30	49.9	
	24:00	30	44.9	

Step 3: Select the four highest O_3 Dmax 8-hour in the year and rank them in decreasing order of magnitude.

The four highest O_3 Dmax 8-hour in 2018 were selected and ranked in decreasing order and repeating common values as often as they occurred, and are shown in Table A-2.

Table A-2: The four highest O_3 Dmax 8-hour in 2018

O_3 Dmax 8-hour (ppb)	Rank	Date measured
89.9	Highest	15-07-2018
60.3	second highest	7-07-2018
60.3	third highest	18-08-2018
58.5	fourth highest	18-05-2018

Step 4: Among the four highest O_3 Dmax 8-hour in the year obtained in Step 3, select the fourth highest. For the example in Table A-2, the fourth highest O_3 Dmax 8-hour in 2018 is 58.5 ppb.

Calculation of the ozone CAAQS Metric Value

The same four steps were repeated for each of 2019 and 2020 and the obtained annual fourth highest O_3 Dmax 8-hour are 60.5 and 55.9 ppb respectively. Using equation 5.2 and the rounding rule in Table 5-4, the ozone metric value for the three-year period from 2018 to 2020 is calculated to be 58 ppb as shown below.

$$\textbf{Ozone metric value}_{\,2018\text{-}2020} = (4^{th}H_{2018} + 4^{th}H_{2019} + 4^{th}H_{2020}) \div 3$$

$$= (58.5 + 60.5 + 55.9) \div 3$$

$$= 58.3$$

$$\mathbf{= 58\ ppb}$$