# Derivation of Diurnal & Seasonal Ozone Pattern

## Overview

While ground-level ozone is primarily a secondary pollutant formed from reactions between precursors, there are specific, and often specialized, sources that directly emit ozone gas (e.g. ozone generators and corona treaters). The Iowa DNR occasionally utilizes dispersion modeling to evaluate these direct emissions to assess their immediate, near-source impact on air quality. The existing (background) ozone levels are an important component of this analysis.

Ground-level ozone concentrations follow distinct diurnal (daily) and seasonal patterns, primarily driven by the availability of sunlight and the concentration of its precursor pollutants, such as nitrogen oxides (NOx) and volatile organic compounds (VOCs).

### Diurnal Pattern

Ozone concentrations are typically at their lowest before sunrise because sunlight is absent, preventing the photochemical reactions that create ozone. During the night, ozone is also destroyed through natural processes, including reactions with nitrogen monoxide (NO) and contact with surfaces.

- Morning: As the sun rises, photochemical reactions begin, and ozone starts to form.
- Afternoon: Concentrations peak in the afternoon, typically between noon and early evening. This is when solar radiation and temperatures are at their highest, accelerating the formation of ozone.
- Evening/Night: After sunset, the lack of sunlight stops ozone production. Ozone concentrations then decrease as it is destroyed by chemical reactions and deposition.

### Seasonal Pattern

Ozone concentrations are generally highest during the summer and lowest during the winter.

- Summer: The longer days, more intense sunlight, and higher temperatures in the summer create the ideal conditions for ozone formation. Heatwaves, which bring stagnant air and high temperatures, can lead to particularly high ozone levels.
- Winter: Shorter days, less intense sunlight, and lower temperatures in the winter significantly reduce the rate of ozone formation.

Spring is a transitional period, but can experience unexpectedly high ozone events due to stratospheric intrusions and the unleashing of precursors accumulated during winter. Fall sees a more straightforward decline as the key drivers of ozone formation wane. The seasonal pattern is also influenced by other factors, such as variations in precursor emissions (e.g., from heating systems in winter or increased air conditioning use in summer) and the transport of pollutants over long distances.

The DNR evaluated ozone monitoring data to determine a diurnal and seasonal pattern of the observed concentrations that can be used as background concentrations in dispersion modeling of direct ozone emissions.

## Data Analysis

All monitoring data within the state of Iowa was evaluated over the period 1/1/2015-12/31/2024. A total of 18 ozone monitors existed in the state during this period. Of those monitors, ten were active every year during that period. Most of those are only active during ozone season (April 1-October 31), with only a single monitor operating year-round. These ten monitors were included in the analysis (Table 1).

**Table 1. Ozone Monitors**

| AQS ID | Site | Coverage |
|---|---|---|
| 19-017-0011 | Waverly, Airport | Ozone season |
| 19-045-0021 | Clinton, Rainbow Park | Ozone season |
| 19-085-0007 | Pisgah, Forestry Office | Ozone season |
| 19-113-0033 | Coggon Elementary School | Ozone season |

| AQS ID | Site | Coverage |
|---|---|---|
| 19-113-0040 | Cedar Rapids, Public Health | Ozone season |
| 19-137-0002 | Viking Lake State Park | Ozone season |
| 19-147-1002 | Emmetsburg, Iowa Lakes CC | Ozone season |
| 19-163-0014 | Scott County Park | Ozone season |
| 19-163-0015 | Davenport, Jefferson School | Year-round |
| 19-177-0006 | Lake Sugema | Ozone season |

Short gaps in the hourly data for each site were filled using linear interpolation. Gaps longer than two hours were not filled. Data filling was mainly necessary because the first hour of each day was generally missing from the Davenport data, which is the only site with data during the non-ozone season months. The maximum and average hourly concentrations were then determined by time of day (Figure 1).

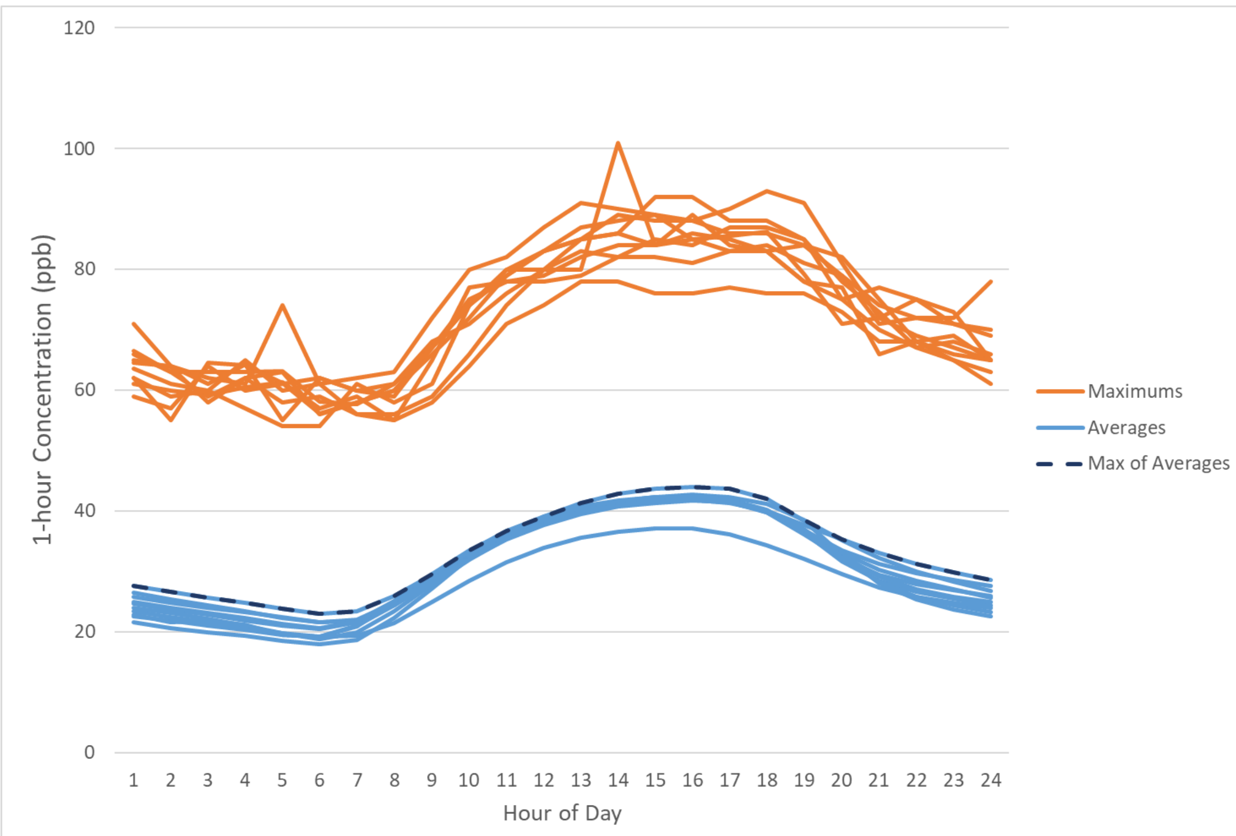


**Figure 1. Comparison of maximum and average concentrations at each monitor by hour of day**

Both the maximums (orange lines) and averages (blue lines) follow the expected pattern, with lowest concentrations occurring in the morning and highest concentrations in the late afternoon/early evening. The orange lines are prone to noise because they capture the highest-concentration events on any given day. The blue lines, being composites of data from many different days, smooth out the noise and highlight the underlying, consistent pattern. The maximum of these stable curves (dashed line) provides a clear, reliable representation of the fundamental physical and chemical processes at play. Taking this a step further, Figure 2 depicts the average maximums across all ten monitors by month and time of day.

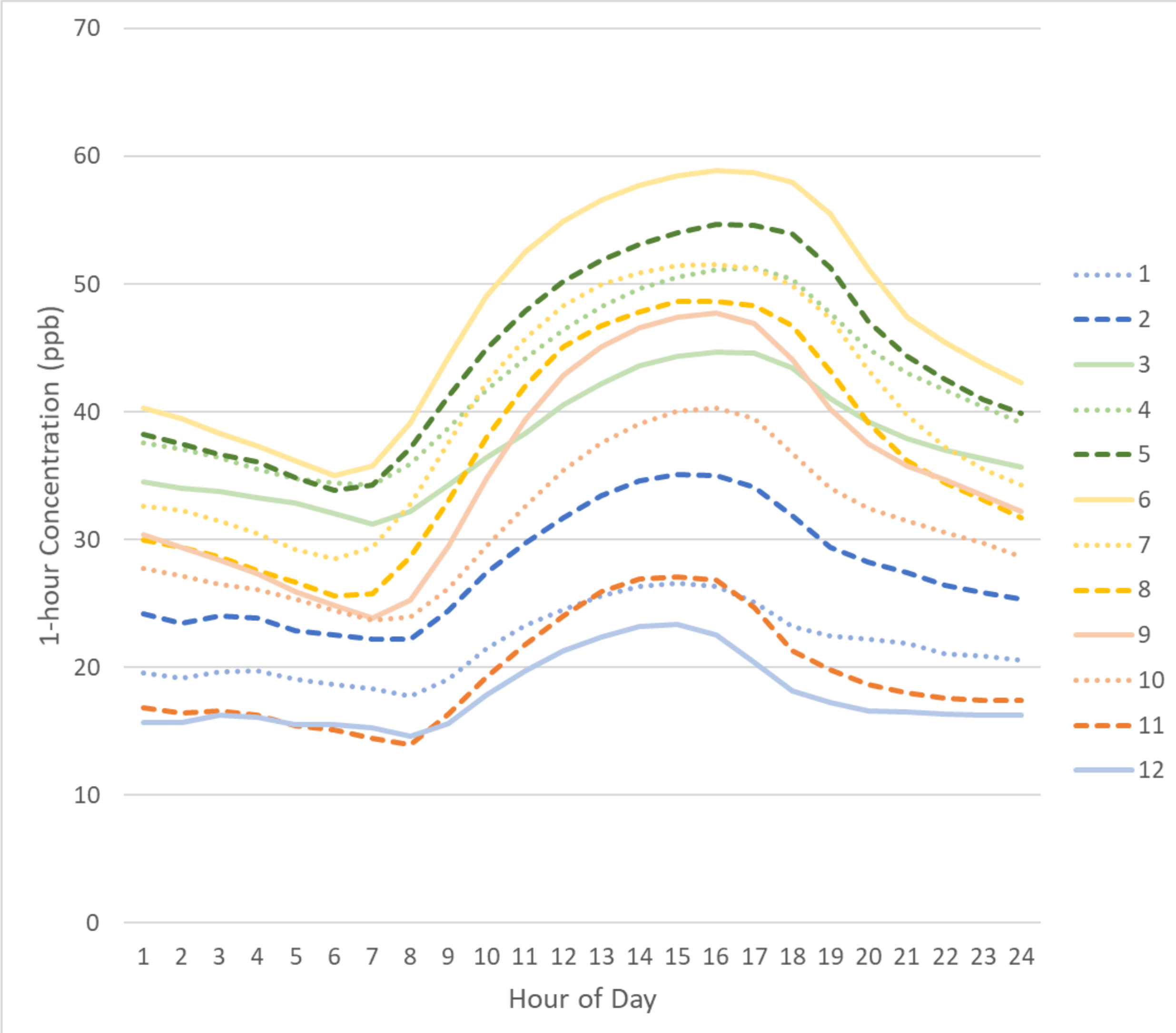


**Figure 2. Average of maximum concentrations by month and hour of day**

These data exhibit the expected pattern over the year. The months that have more daylight hours show extended periods of elevated concentrations and higher peak concentrations. Taking the maximum from the three months in each season by hour of day provides a representation of the diurnal and seasonal pattern. Figure 3 shows this pattern along with the corresponding 8-hour averages. The maximum resulting 8-hour average is 57.4 ppb during the summer, which is within the range of design values reported at these monitors over the period being evaluated (56 ppb-68 ppb).

These data provide a foundational diurnal and seasonal pattern that can be translated to a level that reflects an actual design value. For example, Figure 4 shows the pattern shifted up so the peak 8-hour average matches the average of the range of design values in the data that was evaluated. The resulting 1-hour concentrations can be input in the dispersion model as a time-varying background concentration instead of assuming the representative monitor design value applies to all hours and seasons being evaluated.

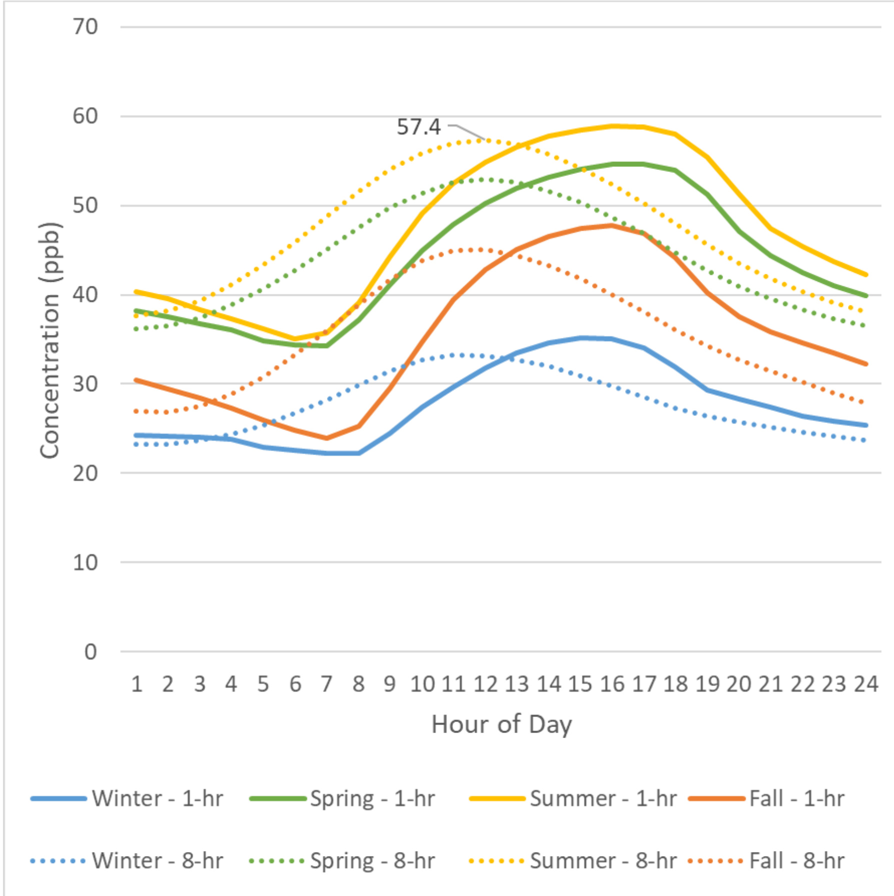


**Figure 3. Seasonal and Diurnal Pattern**

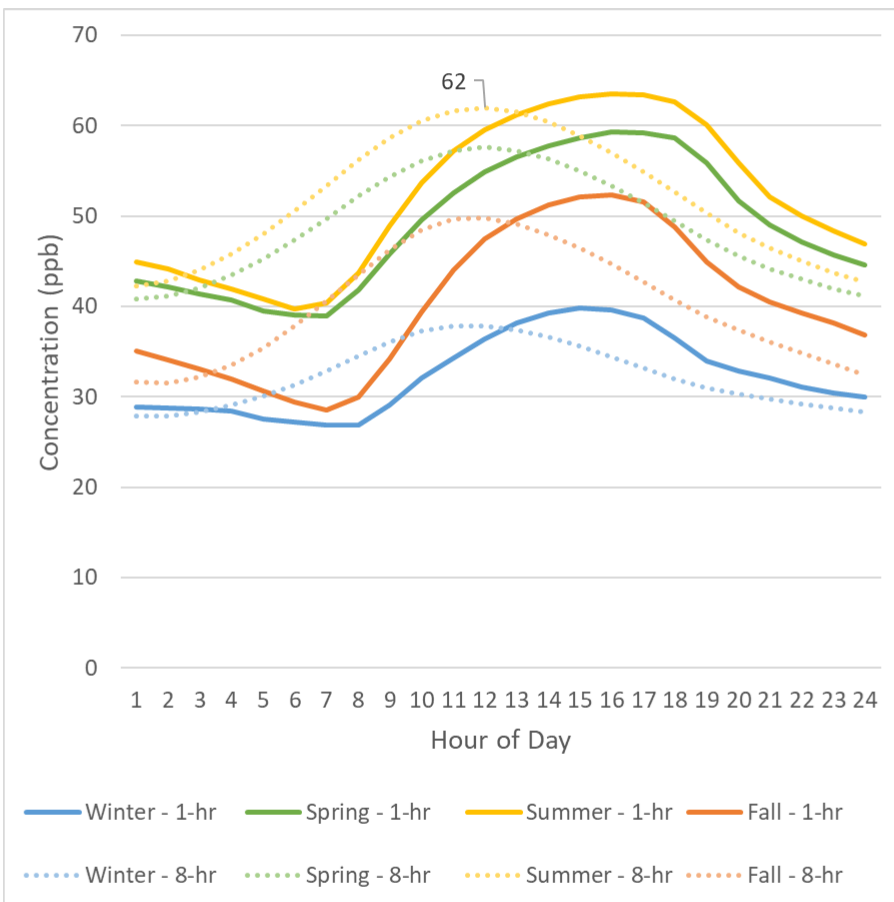


**Figure 4. Seasonal and Diurnal Pattern – Translated**

## Application of Ozone Background Data

This data has been used to create a spreadsheet tool that may be used to derive appropriate background concentration data for use in modeling direct ozone emissions. Applicants should first determine the most recent design value for the ozone monitor that is representative of the area being modeled. Design value reports are available on the Monitoring Ambient Air webpage. Enter the design value in the "Ozone Background Pattern Tool" which is available on the Background Data webpage. The tool will provide background concentrations for input into AERMOD by hour of day and season.