Assessing the Site-Specific and Region-wide Probability of Attainment Level Ozone Air Quality under varying seasonal conditions using the results of 2002 (Round 4) and 2005 (Round 5) Regional Modeling

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To support the current regional Weight-of-Evidence (WOE) analysis, I crafted a simplified method to look at the potential impact of 2009, 2012 and 2018 on-the-books (OTB) strategies on site-specific attainment for the years since 2000. The technique applies an adjusted relative reduction factor to each site-year 4th high concentration to help assess if particularly anomalous years (such as 2002 or 2004) used in the base year design values unduly skew findings of future year attainment. The technique considers the modeled impact in the same way as the formal attainment test and presents an integrated assessment of ozone attainment probability using both 2002 and 2005 RRFs.

The intention of the analysis is crafting a picture of the relative probability under seven different ozone season conditions (2001-2007) of actually experiencing attainment level air quality at each of nine key ozone sites in the Lake Michigan basin. The information includes a site-specific probability along with a compound assessment of regional attainment probability.

Initial Findings

The implication regarding WOE for 2009 is pretty clear. More than one site has a pretty low probability of actually showing attainment air quality by the end of the 2009 ozone season (EPA's official target year for June 2010 attainment demos). Beyond that, the probability of attainment on a region wide basis (by region wide I am only talking about the Lake Michigan basin) appears to be approximately 1 in 7 (14%)...with a basic repeat of 2004 necessary to actually get region wide attainment air quality. Under conditions similar to the other six seasons, the assessment suggests one or more sites in the Basin will show residual nonattainment by 2009.

Based on preliminary Round 4 and Round 5 emissions projections, individual site probabilities for demonstrating attainment during the 2012 ozone season are better – ranging in value from 57% (4 in 7) at Holland, Sheboygan and Chiwaukee to 86%+ at three sites – Manitowoc, Kewaunee and Muskegon. Region-wide the modeling suggests a 29% (2 in 7) probability of attainment in 2009 – this is a much tougher metric because during individual years some sites are more impacted than others. As a consequence, regional air quality below the level of the standard is projected for 2006 conditions as well as 2004 conditions. By 2018, the region-wide probability is substantially higher at 71% (5 in 7) and the individual site probabilities range between 86% and 100% with only three sites showing a probability of 4th high concentrations above the level of the standard under any of the seasonal conditions. Not surprisingly, the 2002 and 2005 seasonal patterns are those most likely to result in 4th high concentrations above the level of the standard. However, given the design value averaging presumption, an attainment demonstration should be defensible for 2018, and may be supportable for 2012 for all but Sheboygan, Holland and Chiwaukee based on consideration of their attainment probabilities and average projected 4th high concentrations.

Methodology

The basic approach is pretty simple. RRFs for 2009 are calculated for each season since 2000 based on the Round 4 (2002 base year – Base K emissions) and Round 5 (2005 base year – Base M emissions) modeling results. I apply the estimated site-specific RRFs to the 4th high values monitored at each site for the appropriate season. This produces a projected 2009 4th high value related to that season and the level of emission reductions expected to occur by 2009. The ratio of RRFs between the 2002 and 2005 assessments range from just less than 0.94 to just more than 0.96 for the 2009 air quality projections. For 2002 (2005) the actual RRFs range from 0.935 (0.972) in the southeastern part of the basin to 0.888 (0.945) at the more northern sites.

The projected values reflect an approximation of the modeled impact on 2009 ozone concentrations under the relative emission and meteorology conditions associated with each season (as characterized by the 4th high values). The estimates are inherently sensitive to the specific base year meteorology conditions of 2002 and 2005, but primarily reflect the expected impact of emission reductions assumed between each assessment year and 2009, in part because the two seasons (2002 and 2005) produced proportionate levels of ozone.

The slopes of the RRF lines (between 2001 and 2007) flex slightly at 2005 (steeper before and less steep after)... probably the best we can estimate w/o further inventories of the intermediate years. I believe that this reflects the accelerated nature of emission reductions earlier this decade...as the NOx SIP controls came on line between 2003 and 2005. 2001 is a backward extension of the reduction (RRF) slope between the 2002 and 2005 base year emissions. 2006 and 2007 RRFs fall on a linear slope between the 2005 base RRF for 2009 and the 2009 RRF of 1.0. Basically, reductions in the specific emission sectors may have been non-linear....but beyond the EGU's, emission reductions occurred more linearly in aggregate over the period. Though accomplished using a variety of updated inventory assumptions, the two sets of 2009 emission projections are remarkably consistent for aggregate NOx in the 5 states. Hence the rationale for using both Round 4 and Round 5 RRFs.

While some significant projection error would be expected for the years least similar to 2002 and 2005 (eg - 2004 and 2006), the magnitude of these errors is not expected to be large. Higher levels of ozone were not formed due mostly to the meteorology of these two seasons. As a consequence you could argue that a lessened impact on projected concentrations would be expected for those two years. As such the analysis is probably a bit optimistic regarding the average projected 2009 4th highs when those two non-conducive ozone seasons are averaged with the rest...but only by a small amount.

To account for the potential under-estimation of 2009 “average” ozone, and acknowledging the lack of a bright line test in the WOE assessment, this analysis was further structured to produce a simple probability metric. The probability metric is a bit more robust (with the exception of Manitowoc) and is probably the best aggregate indicator of the likelihood of reaching attainment at the end of the 2009 ozone season.

A similar technique is applied for developing season-specific projections for 2012 and 2018. Without having immediate access to the Round 4 RRFs for 2002, and noting that the projected 2018 NOx emission inventory is somewhat lower under Round 5 (Base M) assumptions, I applied a consistent site-specific RRF ratio to the 2005 factor to calculate a “surrogate” factor for 2002 to assess 2012 and 2018. This ratio will need to be checked against the actual Round 4

output for the two additional future years. However, there is no reason to assume that the modest additional emission reductions reflected in those scenarios would cause a non-linear model response….especially in a 12 km grid with the analysis focused on higher ozone concentrations.

[see Methodology Appendix for Example Calculation using Kewaunee Co site]

Uncertainties and Anomalies

As I note in the table, a couple of anomalies due show up.....

Manitowoc data for 2002 was just a problem, no way around it. The monitor wasn't operating during some key periods and the 4th high is just weird there for that specific year. We would normally expect ozone to average between that of Sheboygan and Kewaunee. The modeling of Round 4 suggests some higher ozone concentrations were missed as well.

Chiwaukee Prairie also remains a partial puzzle...but, that shouldn't be surprising given its location. It is particularly sensitive to time-of-day and day-within-episode chemistry (balance between VOC and NOx), is a less certain site for lake breeze based transport and is probably very sensitive to the 3x3 matrix presumption in modeling....reflected in the alternating divergence in modeled 2002 and 2005 base values (these are in light blue on the sheet). Under one set of meteorology (2005) the model appears to have picked up high values in the modeled 3x3 grid while the monitor did not pick up those concentrations at the actual site. Just the opposite appears to have occurred in Round 4 (2002) modeling. The fact that the model can account for high values at the site under similar conditions (as reflected in the generally good model performance metrics for elevated ozone) is important to the overall assessment confidence.

Implications

My personal concern remains defending a 2009 attainment demonstration in the near term for the entire western shoreline of Lake Michigan (WI). During 2007, of the six WI sites noted, one site had 3 days at or above 85 ppb, one had 4 days at or above, 2 had 5 days at or above and two had six days at or above. I believe the key Michigan sites are in a similar circumstance. This means critical values during 2009 may be below the level of the standard (2006 will be out of Design Value calculations by then). So, while the 2005 modeling suggests we might be there....this type WOE evaluation of the actual recent year data along with the met-adjusted trend analyses suggest otherwise. This assessment suggests to me that we better address that reality regardless of EPA's modeled attainment demonstration guidance unless we really feel comfortable attempting to demonstrate future attainment with only a 14% probability of success. Perhaps the good news remains that while we may not actually be there yet, the probabilities of demonstrating attainment in the not too distant future, after 2009, appear much better than after the Round 4 modeling.

Later Follow-up…..

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There is no magic to the RRFs...they merely indicate an approximate
(average) ozone concentration change related to a different set of
emissions inputs.  The RRF is derived by averaging the differences
predicted for all ten days (actually, anywhere from 4 to 10 days)under
the two scenarios - base year and test scenario.  This is why the RRFs
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are so consistent and have a very clear regional pattern. In theory, the 4 to 10 days will reflect high ozone generated under different conditions (much like Donna's "bins"). Hence, I'm not so concerned about the year-to-year variability in "average" meteorology. The only leap of faith...which I note as a limit to the assessment, is that the ozone concentrations will proportionately reduce between 70 ppb and values approaching 100 ppb (averaged over 8 hours). My own sense is that as the values approach and fall below 70 ppb, the relative reduction will taper a bit...hence my caution regarding the impact of the projected 2004 and 2006 4th high concentrations...I really don't think they will drop proportionately and therefore I expect the generated "average" statistic to be a bit low. That said...I'm pretty comfortable with the probability characterization for sites like Kewaunee. We could test that concern by analyzing the RRFs of some lakeshore monitor sites exhibiting lower design concentrations in the base year conditions.

Methodology – Application of Two Modeled RRFs to alternate Base Years to Approximate the Air Quality Improvement for Non-modeled Years

1) Establish from air quality monitoring record the 4th high concentration for each site of concern. In this case the years of concern are 2001-2007.

2) For the modeled years – 2002 and 2005 – insert the raw modeled "base" concentration calculated for the site in support of the formal attainment test. This value is the average of the ten highest modeled 8-hour concentrations that span 85 ppb, or the average of all concentrations above 85 ppb if they number more than 10, or, if fewer than 10 such concentrations are shown, the 4-to-10 highest concentrations above 70 ppb.

3) For the modeled years – 2002 and 2005 – insert the model predicted concentrations that result from the scenarios being tested. The ratio between the concentrations in 2) and 3) is the Relative Reduction Factor – RRF – being used in the formal attainment demonstration test as the fraction of residual ozone from whatever design value is chosen for that process. The RRF is used here to reduce the monitored 4th high concentration – but is the same model-produced ratio.

4) Craft a linear relationship between the two modeled RRFs – for 2003 and 2004 – to account for the inventory differences between base year 2002 and 2005.

5) Craft a linear relationship between the 2005 RRF and the RRF of 1.0 assumed for the test year – here that is 2009. This provides the basis for projected 2006 and 2007 RRFs. The RRF for 2006 lies 25% of the way along that line and the RRF for 2007 lies half-way along that line.

6) Extend the linear relationship shown for 2002-2005 for 2001. The result is a double slope line of RRF that flexes slightly at 2005, becoming less steep.

7) Apply the calculated RRFs for the non-Base Years to the 4th high concentrations monitored for each year. The produces a rough approximation of expected 4th high ozone concentrations that would have occurred in that year if the control levels used to craft the RRFs had been in place.

8) To determine the rough probability of attainment under the seven varying seasonal conditions, calculate the number of seasons where the projected 4th high concentration under the scenario of concern (here the OTB) would have met or exceeded the level of the standard. The ratio of that number to 7 is the fractional probability of achieving a 4th high concentration below the level of the standard in 2009.

9) To provide an additional piece of information I have included the calculated "average" of the 7 controlled 4th high concentrations for the key sites noted in the table. For some sites, this value is quite sensitive to the outlier values of 2002 (high) and 2004 (low). The probability metric is less sensitive because each "season" is weighted as a single input.

EXAMPLE CALCULATION:
Kewaunee Co Monitor Site….

1. 4th High Ozone Concentrations are listed for each of the seven years…
2. Modeled base concentration is 91.5 for 2002 and 97.1 for 2005….
3. The model-predicted raw projection for the 2009/10 OTC scenario was 83.0 in Round 4 (2002 Base) and 91.8 in Round 5 (Base 2005). This resulted in RRFs of 0.907 (83.0/91.8) from Base 2002 to OTB 2009 and 0.945 (91.8/97.1) from Base 2005 to OTB 2009……
4. The linear trend from the 2002 RRF to the 2005 RRF results in calculated RRFs of 0.920 for 2003 and 0.932 for 2004…..
5. Calculated RRFs for the period between 2005 and 2009 are 0.959 for 2006 and 0.973 for 2007 assuming a linear trend from 2005 to 2009…..
6. The back-cast linear projection results in an RRF of 0.895 for 2001….
7. Projected 4th high 2009 OTB based on each year are calculated by applying the individual year RRF as a multiplier (factor) to the actual 4th high concentration….
8. Because 6 out of 7 of the test seasons result in projected 4th high concentrations for 2009 OTB at or below the effective level of the standard (84.9 ppb) the projected probability of a 4th high ozone concentration below the level of the standard is 6/7 or 86%.
9. The "average" projected 4th high concentration for the 2009 OTB scenario is 80 ppb.

I think the rest of the description speaks to most of the uncertainties in the approach. Reiterating….

a. The purpose of the approach is to account for the main inventory reduction trends that occurred over the period. This is why a single (2005) RRF value is not applied to each year.

b. There is some direct, but limited impact on the RRFs of the individual season meteorology (2002 and 2005). However, the factors are relatively robust between the model years. Were this not the case, the entire ozone modeling effort should be in question. Where the RRFs are probably overstated are the seasons where ozone is not produced to the same level – 2004 and in some sites 2006. Hence my caution regarding the averaging calculation.

c. While the probability of attainment might shift by 1/7 for some sites depending on the absolute RRFs used, the major impact is the seasonal effects – such as the difference in 2005 and 2006 4th highs projected to 2009. Note that the seasonal variation causes projected values to vary by 15 ppb+ while the widest swing in RRFs in one year is on the order of 1-to-1.5 ppb.