State of Utah

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DAQ-010-15

M E M O R A N D U M

TO: Air Quality Board

THROUGH: Bryce C. Bird, Executive Secretary

FROM: Bill Reiss, Environmental Engineer

DATE: February 19, 2015

SUBJECT: FINAL ADOPTION: New Rule, R307-311. Utah County: Trading of Emission Budgets for Transportation Conformity.

The rule proposed for the Board's consideration today would affect the way the metropolitan planning organization (MPO) for Utah County is able to demonstrate that the emissions associated with transportation plans, programs, and projects conform to emission budgets established in the PM_{10} State Implementation Plan (SIP) for Utah County.

It would alleviate a problem demonstrating conformity to the NO_x budget, brought on by EPA's release of a new mobile source emissions model. The new MOVES model predicts much more NO_x from tailpipes than the old MOBILE6. The old model was used to develop the NO_x budget in the 2002 PM_{10} SIP, but it is the new model that must be used by the MPO as it prepares its conformity demonstration.

The proposed rule would allow the MPO to apply a potential surplus in its budget for direct PM_{10} to a potential shortfall in its budget for NO_x, at a ratio of one-to-one.

It would not, however, allow such trading in the opposite direction (e.g. to apply a surplus of NO_x to a shortfall in direct PM_{10}.) The reasoning behind both the directional nature of the trading and the ratio specified is explained in the second attachment to this memo.

The proposed rule would essentially be a duplication of R307-310, which allows the same type of trading when demonstrating transportation conformity to the PM_{10} SIP for Salt Lake County.

A public comment period was held from January 1 to February 12, 2015. No comments were received on proposed rule R307-311; however, EPA did comment on the technical basis underlying the rule. Those comments may be summarized as follows:

1. DAQ's draft technical support document (TSD) had relied upon an EPA proposal from 1996 to support the direction of trade prescribed in proposed rule R307-311. The 1996 position was also used in support of a similar trading rule for Salt Lake County, which was approved in 2002, but since that time EPA has issued additional guidance: "Revised Policy to Address Reconsideration of Interpollutant Trading Provisions for Fine Particles (PM2.5), July 21, 2011." EPA recommends that DAQ make use of this more recent guidance in its TSD.

2. DAQ's draft TSD had also relied upon some sensitivity modeling from Utah's 2013 $PM_{2.5}$ SIP for the Provo nonattainment area. That modeling had determined an equivalence ratio between NO_x and $PM_{2.5}$, and the ratio had been used to support the one-to-one trading ratio prescribed in proposed rule R307-311. Application of the NO_x to $PM_{2.5}$ ratio was justified with an assertion that, in Utah County, wintertime $PM_{2.5}$ is sufficiently similar to wintertime PM_{10}.

   The 2013 SIP has since been superseded, and EPA recommends instead that DAQ use the modeling from the December 2014 $PM_{2.5}$ SIP revision. This more recent modeling would: a) more directly address the relationship between NO_x and PM_{10} in order to support proposed rule R307-311, and b) more correctly establish the relationship between NO_x and $PM_{2.5}$ for the additional purpose of evaluating any potential impacts due to the proposed rule with respect to attainment of the 24-hour $PM_{2.5}$ standard and reasonable further progress toward that end.

3. Concerning potential impacts due to proposed rule R307-311 with respect to attainment and reasonable further progress toward attainment of other National Ambient Air Quality Standards, EPA comments that DAQ should consider ozone and NO_2 in addition to CO and $PM_{2.5}$, the pollutants for which Utah County is (or was) designated as not attaining.

In response to those comments, DAQ has worked with EPA Region 8 to apply the community multi-scaled air quality modeling from the December 2014 SIP revision directly to the proposal for R307-311. The model was run using inventories of both PM_{10} and $PM_{2.5}$, and determinations of equivalence with respect to NO_x were made for each.

The modeling is consistent with the approach presented in EPA's July 21, 2011, guidance document, and its conclusions support both the one-to-one ratio and the direction of trade prescribed by proposed rule R307-311. In addition, the equivalence ratio determined for NO_x to $PM_{2.5}$ supports the conclusion that the proposed rule would not adversely affect 24-hour $PM_{2.5}$ concentrations in Utah County.

The revised TSD also includes an assessment of the proposed rule with respect to CO, ozone, and NO_2.

<u>Staff Recommendation</u>: Staff recommends the Board adopt R307-311, Utah County: Trading of Emission Budgets for Transportation Conformity, as proposed.

A copy of the proposal is attached, as is documentation describing the technical basis for the proposed rule.

R307. Environmental Quality, Air Quality.
R307-311. Utah County: Trading of Emission Budgets for Transportation Conformity.
R307-311-1. Purpose.

This rule establishes the procedures that may be used to trade a portion of the primary PM10 budget when demonstrating that a transportation plan, transportation improvement program, or project conforms with the motor vehicle emission budgets in the Utah County portion of Section IX, Part A of the State Implementation Plan, "Fine Particulate Matter (PM10)."

R307-311-2. Definitions.

The definitions contained in 40 CFR 93.101, effective as of the date referenced in R307-101-3, are incorporated into this rule by reference. The following additional definitions apply to this rule.

"Budget" means the motor vehicle emission projections used in the attainment demonstration in the Utah County portion of Section IX, Part A of the State Implementation Plan, "Fine Particulate Matter (PM10)."

"NOx" means oxides of nitrogen.

"Primary PM10" means PM10 that is emitted directly by a source. Primary PM10 does not include particulate matter that is formed when gaseous emissions undergo chemical reactions in the ambient air.

"Transportation Conformity" means a demonstration that a transportation plan, transportation improvement program, or project conforms with the emissions budgets in a state implementation plan, as outlined in 40 CFR, Chapter 1, Part 93, "Determining Conformity of Federal Actions to State or Federal Implementation Plans."

R307-311-3. Applicability.

(1) This rule applies to agencies responsible for demonstrating transportation conformity with the Utah County portion of Section IX, Part A of the State Implementation Plan, "Fine Particulate Matter (PM10)."

(2) This rule does not apply to emission budgets from Section IX, Part C.6 of the State Implementation Plan, "Carbon Monoxide Maintenance Plan."

R307-311-4. Trading Between Emission Budgets.

(1) The agencies responsible for demonstrating transportation conformity are authorized to supplement the budget for NOx with a portion of the budget for primary PM10 for the purpose of demonstrating transportation conformity for NOx. The NOx budget shall be supplemented using the following procedures.

(a) The metropolitan planning organization shall include the following information in the transportation conformity demonstration:

(i) The budget for primary PM10 and NOx for each required year of the conformity demonstration, before trading allowed by this rule has been applied;

(ii) The portion of the primary PM10 budget that will be used to supplement the NOx budget, specified in tons per day using a 1:1 ratio of primary PM10 to NOx, for each required year of the conformity

demonstration;

(iii) The remainder of the primary PM10 budget that will be used in the conformity demonstration for primary PM10, specified in tons per day for each required year of the conformity demonstration; and

(iv) The budget for primary PM10 and NOx for each required year of the conformity demonstration after the trading allowed by this rule has been applied.

(b) Transportation conformity for NOx shall be demonstrated using the NOx budget supplemented by a portion of the primary PM10 budget as described in (a)(ii). Transportation conformity for primary PM10 shall be demonstrated using the remainder of the primary PM10 budget described in (a)(iii).

(c) The primary PM10 budget shall not be supplemented by using a portion of the NOx budget.

KEY: air pollution, transportation conformity, PM10
Authorizing, and Implemented or Interpreted Law: 19-2-104

Technical Support Documentation for Conformity Budget Trading in Utah County

PM_{10} is particulate matter with diameters smaller than 10 micrometers. PM_{10} consists of solid and/or liquid particles of (1) primary particles: directly emitted PM or PM that quickly condenses upon release and (2) secondary particles: PM that is formed in the atmosphere from gaseous precursors. Important gaseous precursors to PM include sulfur dioxide ($S0_2$) which converts to sulfate ($S0_4^{=}$) particles, nitrogen oxides (NOx) which convert to nitrate ($N0_3^{-}$) particles, volatile organic compounds (VOCs), some of which convert to secondary organic aerosols, and ammonia (NH_3) which adds to the mass of sulfate PM and allows nitric acid to convert to PM_{10} in the form of ammonium nitrate.

Currently in Utah County, transportation plans must conform to emission budgets for PM_{10} and NOx that were derived from the 2002, EPA-approved, PM_{10} SIP. Since the regulatory goal is to achieve attainment of the NAAQS, it should not matter in a conformity analysis whether PM_{10} consists of directly emitted (primary) PM_{10} or (secondary) nitrate formed in the atmosphere from gaseous NOx emissions, a precursor to PM_{10}. This paper outlines the scientific rationale for why excess NOx emissions can be offset on a one-to-one (1:1) basis with available PM_{10} budget, and why proposed rule R307-311 is conservative (i.e., protective of the environment) in specifying both a one-way direction of trade and a trading ratio of 1:1.

What Fraction of the NOx Emissions Convert to PM_{10}?

Each ton of gaseous NOx that gets converted to PM_{10} creates more than a ton of PM_{10} because the molecular weight of ammonium nitrate PM_{10} is greater than the molecular weight of NOx gaseous emissions. Considering the ratio of the molecular weights of the NOx precursor gas and the resulting ammonium nitrate aerosol (PM_{10}), a ton of NOx that is converted from a gas to a particle can form as much as 1.74 tons of PM_{10}.

However, not all NOx emissions are converted because it takes time to convert NOx to nitric acid ($HN0_3$), which is the necessary gaseous precursor to ammonium nitrate PM_{10}. These reactions generally occur at rates of 1 to 10 percent per hour. Thus, it would take at least 10 hours to fully convert to nitric acid. After this initial conversion, only a fraction of the gaseous nitric acid will condense as ammonium nitrate PM_{10}, depending on equilibrium considerations. Finally, during the gas-to-particle conversion process, deposition will remove a significant amount of material. Throughout this process of NOx conversion to nitric acid, and then to PM_{10} with deposition, an equivalent amount of directly emitted PM_{10} is having a much larger effect on PM_{10} concentration. Directly emitted PM_{10} has an effect on ambient concentration immediately upon its release, while NOx emissions require hours to have an effect.

The conversion of NOx to PM_{10} has been discussed at EPA since at least 1996:

"The conversion process may depend on several variables, including the availability of chemical reactants in the atmosphere for the conversion process, and the difference in mass between the PM-10 precursor molecule and the PM-10 particle that the precursor reacts to become. Another concern is that the rate of conversion of the precursor to PM-10 may be so long that the precursor may not entirely convert to PM-10 within the same nonattainment area. Thus, there would be less counteracting effect and no net improvement to air quality in the area. Under the EPA's proposal, a source of a PM-10 precursor may offset its increased emissions with the same precursor type or PM-10 (or a combination of the two). In this situation, a net improvement in air quality would be assured. At this point, however, the EPA is not proposing to allow offsetting among different types of PM-10 precursors, or offsetting PM-10 increases with reduction in PM-10 precursors, because the Agency does not now have a scientific basis to propose conversion factors." (FR, Vo1.61 , No.142, page 38305, July 23, 1996, emphasis added)

EPA's most recent guidance (Revised Policy to Address Reconsideration of Interpollutant Trading Provisions for Fine Particles ($PM_{2.5}$), July 21, 2011) speaks to an earlier (2008) rule in which EPA had provided presumptive trading ratios between $PM_{2.5}$ and precursors, including NOx, that could be applied without any additional analysis to conclude that there would be no dis-benefit to overall $PM_{2.5}$ concentrations. As with the 1996 guidance, the ratio provided in the 2008 rule (200 tons of NOx being equivalent to 1 ton of $PM_{2.5}$) supported the one-way direction of trading offered in proposed rule R307-311. Legal challenges to the 2008 rule forced EPA to revisit the issue and agree that the presumptive ratios therein were not sufficiently conservative to ensure the net air quality benefit to ambient $PM_{2.5}$ concentrations across all areas of the country, and that the modeling behind the presumptive ratios was not applicable to situations involving 24-hour averaging periods. Thus, the Revised Policy from 2011 indicates that "states will be expected to develop separate $PM_{2.5}$ precursor offset ratios that are demonstrated to be suitable for addressing the particular precursor's relationship with ambient $PM_{2.5}$ concentrations for 24-hour averaging periods that are causing violations in that nonattainment area." "Each ratio will need to be supported by modeling or other technical demonstration to show that such ratio is suitable for the particular $PM_{2.5}$ nonattainment area of concern." It goes on to provide a general framework for such efforts, involving the following steps:

1) Definition of the appropriate geographical area
2) Sensitivity runs with appropriate air quality models
3) Calculation of interpollutant ratios, and
4) Quality assurance of the results

In support of proposed rule R307-311, UDAQ has applied this methodology to the Utah County PM_{10} nonattainment area. Although the guidance is specific to $PM_{2.5}$, it has direct applicability to the PM_{10} situation in Utah County, which was designated a nonattainment area for violations of the 24-hour standard (only). Exceedances of the 24-hour standard are characterized by spikes in secondary aerosol formation under conditions of wintertime temperature inversions which prevent good atmospheric mixing and facilitate conversion of secondary PM_{10}. A high percentage of the PM_{10} monitored in Utah County, during winter episodes of elevated concentration, lies also within the $PM_{2.5}$ fraction. The Utah County PM10 SIP identified both NOx and SO_2 as precursors to PM_{10}.

Parts of Utah County (the valley regions) are also designated as nonattainment for $PM_{2.5}$, and a SIP for that area was developed and submitted to EPA in December of 2014. The air quality modeling for that SIP was conducted using the Community Multi-Scale Air Quality model (CMAQ). CMAQ is capable of determining the relative importance of NOx and PM_{10}. The emission inventories that were developed for the 2014 SIP included $PM_{2.5}$, SO_2, NOx, VOC, and Ammonia, but PM_{10} was also inventoried at the same time. Thus, the sensitivity runs made for the purpose of supporting proposed rule R307-311 employed the CMAQ model, as developed for Utah County, with a substitution of PM_{10} emissions for $PM_{2.5}$. The model was also re-validated with respect to PM_{10} emissions data from the episode period prior to making the sensitivity runs.

Having made these adjustments, the model was run to provide a time-series plot (see Appendix A.) The ratio of NOx to PM_{10} equivalence was determined to be 5.702 to one. Since the ratio is greater than 1:1, it can be concluded that reducing primary PM_{10} is more beneficial than reducing NOx for improving Utah County's air quality.

This conclusion supports the proposed rule which would only allow the trading of the PM_{10} budget to the NOx budget, at a ratio of 1:1, but would not allow the substitution of NOx for primary PM_{10}. With these terms, there would be no adverse impact to overall ambient 24-hour PM_{10} concentrations within Utah County. Such terms are consistent with current and former EPA policy.

Impact of the Combined Budget Program on Other Pollutants

The analysis discussed in the preceding section made an evaluation with respect to the potential impact that proposed rule R307-311 could have on the overall levels of ambient PM_{10} in Utah County. There are several other pollutants to be concerned about as well in Utah County, and this next section will make some evaluations with respect to each of those.

Most importantly, Utah County is a nonattainment area for $PM_{2.5}$, and the Provo-Orem area within Utah County is a carbon monoxide (CO) maintenance area. Also of note however are the Ozone and NO_2 standards. Both could be affected by additional emissions of NOx. Each of these pollutants will be discussed in turn.

$PM_{2.5}$ - Parts of Utah County (the valley regions) are also designated as nonattainment for $PM_{2.5}$, and a SIP for the area was developed and submitted to EPA in December of 2014. As with PM_{10} (described above), sensitivity runs were made using the CMAQ model, as developed for the 2014 $PM_{2.5}$ SIP, in order to determine an equivalence ratio between NOx and $PM_{2.5}$. The resulting ratio of NOx to $PM_{2.5}$ was determined to be 13.09 to one. Like the result for PM_{10}, the ratio is greater than one to one, and therefore shows that reducing primary $PM_{2.5}$ is more beneficial than reducing the same quantity of NOx.

However, in order that this result supports a determination that the proposed rule R307-311 would not have an adverse impact on overall $PM_{2.5}$ concentrations in Utah County, it becomes necessary to look at the physical make-up of PM_{10} emissions from on-road mobile sources and determine the fraction thereof that would also be defined as $PM_{2.5}$. The following table considers PM emissions as they were inventoried, for the year 2015, in the 2014 $PM_{2.5}$ SIP, for the Provo, UT. nonattainment area.

Utah County; On-Road Mobile Source Emissions			
tpd in 2015	**PM10**	**PM2.5**	**%PM2.5**
Road Dust	3.950	0.99	25.1%
Direct PM	1.840	1.38	75.0%
Total	5.790	2.370	40.9%

Note that "direct" PM is the combined sum of brake wear, tire wear, and tailpipe emissions which include elemental carbon, organic carbon, and sulfate as SO_4.

The overall percentage of $PM_{2.5}$ emissions shows that for every ton of PM_{10} emissions due to on-road mobile sources, 0.409 tons would also be $PM_{2.5}$. Proposed rule R307-311 would allow a one-ton increase in NOx emissions to be offset by a one-ton decrease in the PM_{10} emissions. By extension, that

one-ton increase in NOx would be offset by a 0.409-ton decrease in $PM_{2.5}$ emissions. In terms of an equivalence ratio (NOx to $PM_{2.5}$), this could be expressed as 2.44 to one.

The NOx to $PM_{2.5}$ ratio determined for this area using CMAQ (13.09 to 1) is greater than 2.44 to 1. Therefore, it can be concluded that the proposed rule which would only allow the trading of the PM_{10} budget to the NOx budget, at a ratio of 1:1, and would not allow the substitution of NOx for primary PM_{10}, would have no adverse impact on overall ambient 24-hour $PM_{2.5}$ concentrations within Utah County.

As an additional point for consideration: The 2014 SIP for $PM_{2.5}$ includes an assessment of NOx emissions for the year 2015, even if there is no corresponding motor vehicle emissions budget. Within Utah County, on-road mobile sources are expected to account for 21.48 tons per winter weekday (based on MOVES2010a). It is perhaps worth noting that this estimate is greater than the combined sum of the 2020 MVEB for both PM_{10} and NOx. In other words, even if the entire PM_{10} budget were traded to increase the NOx budget as a result of proposed rule R307-311, the resulting total would still be less than the 2015 NOx estimate within the $PM_{2.5}$ SIP.

CO – As mentioned above, the Provo-Orem area is a carbon monoxide (CO) maintenance area. NOx emissions do not act as a precursor to carbon monoxide, and nothing in this proposal would be expected to impact the Provo-Orem area's current CO maintenance status. The CO maintenance plan has its own CO budget, which has been set at a level demonstrated to keep the Provo-Orem area in attainment with the CO standard. Nothing in this proposal changes this budget, and the MPO has been able to demonstrate compliance with this budget by a wide margin.

A look at recently monitored data from Utah County can also be useful in looking at any potential impact from proposed rule R307-311. The following table shows that Utah continues to monitor compliance with the NAAQS for CO, which is set at 35 ppm for a one-hour averaging period and 9 ppm for an 8-hour averaging period.

Utah County CO	Annual		3-Yr DV	
	CO 1-Hr (ppm)	CO 8-Hr (ppm)	CO 1-Hr (ppm)	CO 8-Hr (ppm)
Year	North Provo	North Provo	North Provo	North Provo
2007	3.8	2.4		
2008	3.9	1.8		
2009	3.9	2.5	3.9	2.2
2010	2.8	1.9	3.5	2.1
2011	2.9	2	3.2	2.1
2012	2.7	1.8	2.8	1.9
2013	3	2.1	2.9	2.0
2014	2.7	1.9	2.8	1.9

Ozone – Again, a look at recently monitored data from Utah County can be useful in looking at any potential impact from proposed rule R307-311. The following table shows that Utah continues to monitor compliance with the NAAQS for ozone, which is set at 75 ppb based on a three-year average of the annual 4th highest daily eight-hour average concentration.

Utah County Ozone	Annual O3 4th Max (ppb)		3-Yr DV O3 4th Max (ppb)	
Year	North Provo	Spinish Fork	North Provo	Spinish Fork
2007	75	77		
2008	74	71		
2009	68	69	72.3	72.3
2010	70	70	70.7	70.0
2011	65	65	67.7	68.0
2012	77	76	70.7	70.3
2013	77	70	73.0	70.3
2014	65	69	73.0	71.7

NO_2 - Again, it is useful to look at recently monitored data from Utah County. The following table shows that Utah continues to monitor compliance with the NAAQS for NO_2, which is set at 100 ppb for a one-hour averaging period and determined as the three-year average of annually determined, 98th percentile, one-hour values. Utah has never experienced difficulty with the NO_2 standard anywhere in the state, so it is no surprise that it is not an issue in Utah County.

Utah County NO2	Annual NO2 98% (ppb)	3-Yr DV NO2 98% (ppb)
Year	North Provo	North Provo
2007	63	
2008	57	
2009	56	58.7
2010	50	54.3
2011	58	54.7
2012	66	58.0
2013	75	66.3
2014	64	68.3

Note: There is also an annual standard of and 53 ppb for an annual averaging period, but the hourly standard is more constraining.

The preceding discussion shows that proposed rule R307-311 would not interfere with attainment or reasonable further progress toward attainment of any National Ambient Air Quality Standard. This is in keeping with section 110(l) of the Clean Air Act.

Furthermore, the projected trend in NOx emissions from on-road mobile sources is showing a significant decline. Looking at projected trends in NOx emissions from on-road mobile sources, EPA has just finalized an important rule designed to reduce air pollution from passenger cars and trucks. Starting in 2017, Tier 3 sets new vehicle emissions standards and lowers the sulfur content of gasoline. The tailpipe standards include different phase-in schedules that vary by vehicle class but generally phase in between model years 2017 and 2025. The vehicle emission standards combined with the reduction of gasoline sulfur content will significantly reduce motor vehicle emissions, including nitrogen oxides (NOx), volatile organic compounds (VOC), direct particulate matter ($PM_{2.5}$), carbon monoxide (CO) and air toxics. Compared to current standards, the non-methane organic gases (NMOG) and nitrogen oxides (NOx), presented as NMOG+NOx, tailpipe standards for light-duty vehicles represent approximately an 80% reduction from today's fleet average. Both of these pollutants contribute to the formation of ozone and secondary $PM_{2.5}$. Reductions of this magnitude suggest that the trends of ozone, PM_{10}, and $PM_{2.5}$ concentrations will reflect these improvements.

Conclusion

Based on both EPA's interpollutant policy and a current scientific analysis addressing the formation of secondary ammonium nitrate in Utah County, it may be concluded that reducing primary PM_{10} is more beneficial than reducing NOx for improving Utah County's overall 24-hour PM_{10} concentrations.

The modeling analysis shows that the equivalence ratio of NOx to PM_{10} is greater than 1:1. In doing so, it confirms that the terms of proposed rule R307-311, a) trading in one direction only (increases in NOx offset by decreases in PM_{10}), and b) at a ratio of 1:1, are conservative from the standpoint of ambient 24-hour PM_{10} concentrations.

Additionally, the rule does not adversely impact air quality, and will not interfere with attainment, maintenance, or reasonable further progress toward attainment, with respect to $PM_{2.5}$, CO, ozone, or NO_2.

Appendix A: CMAQ Air Quality Model Sensitivities used for Conformity Budget Trading in Utah County

The Utah Division of Air Quality performed a series of model sensitivity analyses to estimate the reductions in 24-hr PM_{10} and 24-hr $PM_{2.5}$ concentrations, given corresponding per-ton reductions of NOx, direct $PM_{2.5,}$ and direct PM_{10} emissions[1]. This analysis was used to assess the relative importance of NOx vs. PM, and to determine would-be budget trading ratios between the two for transportation conformity purposes in Utah County. These would-be ratios were compared to the actual budget trading terms of proposed rule R307-311, to assess whether or not the proposed rule would be protective of the 24-hour NAAQS for both PM_{10} and $PM_{2.5}$.

The simulations were performed using the Community Multiscale Air Quality (CMAQ) Model along with a Utah County emissions inventory for 2015. That inventory was prepared as part of a $PM_{2.5}$ SIP that was submitted to EPA in December of 2014.

In the simulations, CMAQ was successively run assuming a 1 ton per day (TPD) reduction from the on-road mobile source emissions inventory for (each of) NOx, direct $PM_{2.5,}$ and direct PM_{10} emissions. Each of these runs was then compared against a base-case simulation in which no emissions were eliminated.

Figure A.1 shows the results for PM_{10}. The modeled concentrations for the Base simulation are shown as a blue trace. The concentrations resulting from a corresponding 1-ton reduction in mobile source NOx emissions are shown as the red trace, and the concentrations corresponding to a 1-ton reduction in direct mobile source PM_{10} emissions are shown as the green trace.

Figure A.2 gives the results for $PM_{2.5}$ using the same color scheme.

From these modeling sensitivities, equivalence ratios between NOx and direct PM_{10}, and NOx and direct $PM_{2.5}$ can be determined. The resulting ratios are:

NOx to PM_{10} = 5.702

NOx to $PM_{2.5}$ = 13.09

In each case, the model sensitivities show that a 1-ton reduction in either direct PM_{10} or direct $PM_{2.5}$ emissions is more beneficial than a 1-ton reduction in NOx emissions.

[1] The term "direct" particulate matter refers to the sum of brake wear, tire wear and tailpipe emissions which includes: elemental carbon, organic carbon and sulfate as SO_4.

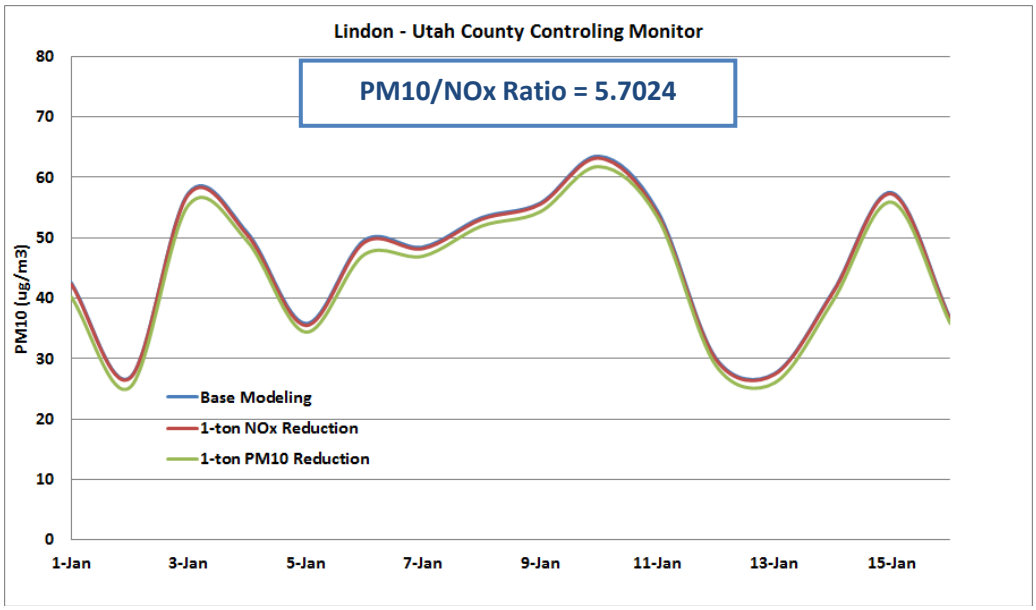

Figure A.1: CMAQ model times series for 24-hr PM10 concentrations for 2015 Base Emissions, 1-ton reduction in mobile NOx emissions (red trace), and a 1-ton reduction in direct mobile PM10 emissions (green trace).

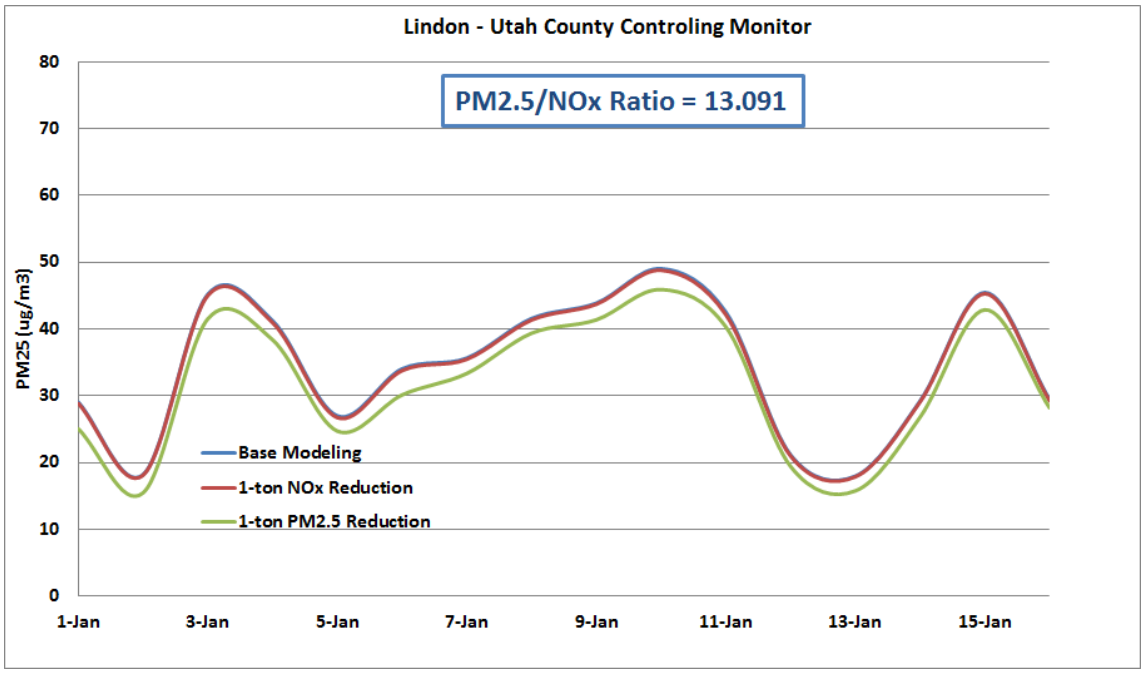

Figure A.2: CMAQ model times series for 24-hr $PM_{2.5}$ concentrations for 2015 Base Emissions, 1-ton reduction in mobile NOx emissions (red trace), and a 1-ton reduction in direct mobile $PM_{2.5}$ emissions (green trace).