ASSESSMENT OF LONG-TERM TRENDS IN EMISSIONS, LOCOMOTIVE ACTIVITY, AND CONTROL MEASURE EFFECTIVENESS AT THE UNION PACIFIC J. R. DAVIS RAILYARD

Revised June 4, 2009

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BACKGROUND AND OBJECTIVES

The Union Pacific Railroad (UPRR) operates the J. R. Davis Yard in Roseville, California (Yard). It is the largest of UPRR's classification yards[1] in the western United States. At the request of the Placer County Air Pollution Control District (PCAPCD), the California Air Resources Board (ARB) conducted a study of locomotive emissions of diesel particulate matter (DPM) at the Yard, including dispersion modeling to assess long-term population exposure and health risks (ARB, 2004). UPRR cooperated in this study by analyzing and providing detailed data on the various types of locomotive operations occurring within the Yard, and providing guidance and assistance to the ARB in the development of the emissions and modeling estimates.

The ARB study was based on railyard activity data and operating practices during the 12-month period between December 1999 and November 2000. Following the completion of the ARB study, the UPRR and PCAPCD entered into an agreement addressing both entities' longer-term plans and interests. The agreement requires, among other things, reductions in DPM emissions from yard operations. To better evaluate the effectiveness of reduction measures undertaken to date, estimates of emission trends over time resulting from such factors as replacement of older locomotives with newer units with lower emissions, installation of locomotive retrofit controls, fuel changes, operational changes within the Yard, and trends in freight traffic by rail have been developed. These estimates may also be useful in interpreting the results of the Roseville Railyard Air Monitoring Program (RRAMP). This document presents the results of this analysis, updated to include emissions through 2008.

SUMMARY

The results of this analysis indicate that UPRR has achieved a 39% reduction in DPM emissions and a 37% reduction in NOx emissions between the 1999-2000 base period evaluated in the ARB study and calendar year 2008. Emission trends within the 2005-2008 period covered by the RRAMP study reflect emission reductions achieved from improved technology, as well as changes in activity levels and locations. Technology improvements included the use of new, low-emitting GenSet switch locomotives at the hump beginning during the second quarter of 2008 , and 2008 in-yard activity, expressed

[1] There are a variety of different types of railyards. A classification railyard has the primary function to separate rail cars of arriving trains according to their ultimate destinations, and to recouple them into new trains for the next leg of their trip.

as total trailing tons of freight, was the 12% lower than 2007 and 8% lower than the 1999-2000 base period.

METHODOLOGY

The methodology for DPM and NOx emission estimation followed the procedures developed for estimating railyard locomotive emissions as part of UPRR's analyses of eight California railyards under the 2005 Memorandum of Understanding (MOU) with the ARB.[2] These procedures are based on the approaches originally developed for the ARB Roseville study,[3,4] but have been extended and refined, particularly in identifying locomotive activity on trains and during maintenance, and locomotive model distributions and control technologies. Explicit treatment of fuel sulfur effects has also been added. Locomotive DPM and NOx emissions estimates are developed separately for three types of activities:

- Locomotive consists[5] on trains ("road power"), including movements into and out of the Yard, idling on arrival and departure, and consist movements in the Yard to and from service;
- Locomotive activities in the service area, including idling before, during, and after service, as well as movements to and from the shop, and idling and higher throttle settings associated with shop maintenance and load testing; and
- Yard switching activities, which at Roseville include the hump sets used to break trains into the Bowl, and trim sets used to build train sections and move them to their departure tracks.

For each of these, activity data were developed as described in the following sections. Activity data include the number of different types of events (e.g., westbound freight train arrivals), the average number of locomotives and the locomotive model and technology tier distributions for each type of event, the track segments or yard areas where the activities occur, the duration of each type of event, and the locomotive duty cycle that best represents each activity.

Emissions for each type of activity were calculated using these activity inputs and model- and notch-specific emission factors. Fuel sulfur content was estimated for different types of activities, and the DPM emission factors were adjusted using the methods developed for the ARB MOU railyard analyses.

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[2] Sierra Research (2007). *Toxic Air Contaminant Emission Inventory and Dispersion Modeling Report for the Commerce Rail Yard*, Los Angeles., California. (available at *http://www.arb.ca.gov/railyard/hra/hra.htm*)

[3] CARB (2004). Roseville Rail Yard Study. (Available at *www.arb.ca.gov/diesel/documents/rrstudy/rrstudy101404.pdf*)

[4] Ireson, R.G., M.J. Germer, L.A. Schmid (2005). *Development of Detailed Rail yard Emissions to Capture Activity, Technology, and Operational Changes*. Proceedings of the USEPA 14th Annual Emission Inventory Conference, Las Vegas NV, April 14, 2006. (Available at *www.epa.gov/ttn/chief/conference/ei14/session8/ireson.pdf*)

[5] The term "consist" refers to the group of locomotives (typically between one and four) that provide power for a specific train.

Locomotive Consists on Trains

The procedures for developing activity estimates and emissions for locomotive consists on trains followed those developed for the ARB/UPRR MOU. Yard-specific information on the routes and handling of different train types was included in the processing of these data. Full calendar-year data for train arrivals and departures at the Yard were processed to identify the following characteristics of each train:

- Number, model, and control technology of operating locomotives in the consist;
- Direction;
- Whether it originates, terminates, enters and leaves the Yard, or bypasses the Yard;
- For through (bypassing) trains, whether there is a crew change event resulting in idling; and
- For trains entering or leaving the Yard, which area of the Yard is used (Departure Yard, Receiving Yard, City Yard, or Rockpile).

These train data were grouped according to train type and direction, and aggregate statistics were developed for each train type, such as average consist size and model distribution.

Idling durations for arriving, departing, and through trains with crew changes were estimated based on information provided by Yard operating personnel. Adjustments of any idling periods greater than 30 minutes were made based on the fraction of each locomotive model equipped with ZTR or AESS automatic start/stop systems.[6] This fraction was determined by cross-referencing individual UPRR locomotive ID numbers to a database identifying current equipment status and the date (if applicable) of retrofit.

Consists for originating and terminating trains were assumed to have moved from or to the Service Track along routes appropriate to the departure or arrival location in the Yard. The number of locomotives in a consist that are operating, as well as the speeds and throttle settings used along these routes, were based on information provided by UPRR Roseville operating personnel. The duration of these movements was calculated based on track length and speed.

Locomotives in Service

The procedures for developing activity estimates and emissions for locomotives followed those developed for the 2005 MOU; these procedures are more advanced than, and somewhat different from, those used to develop the 1999 inventory for the ARB report. In addition, changes were made in UPRR database content and format as well as in service and maintenance event logging practices between 1999 and 2008. Although these changes prevent a precise assessment of the comparability of activity estimates between the ARB report and the current analysis, a procedure for classifying service event codes was developed in consultation with UPRR Roseville service and shop personnel that

[6] Two types of automatic idling control equipment are in use: ZTR SmartStart (typically retrofit equipment used on low horsepower units) and AESS (typically factory installed on newer high horsepower units). Both are programmed to automatically shut off the engines of idling parked locomotives after a specified period of time, and to restart the unit if any of a number of operating parameters (battery state, air pressure, coolant temperature, etc.) reach specified thresholds.

provides the best estimates possible for refueling and load test events spanning all of the analysis years, data formats, and methodologies.

Locomotive release data for the Service Track and Shop releases for each calendar year were processed to identify the number, model, and control technology for locomotives handled at the Service Track, Shop, and, when applicable, at the Subway (in-yard refueling). In addition, the data were processed to identify the number and type of locomotive load test events. Locomotive model and technology distributions were developed for activities in each area, including a separate distribution for locomotives that are load-tested. Information provided by UPRR Roseville service and shop personnel were used to verify or update estimates of the average duration of idling before, during, and after service at the Service Track and Subway, as well as estimates of idling duration and operation at higher throttle settings for load testing. Estimates of the duration of movements and throttle settings during movements between the Service Track, Shop, and Ready Track were also developed based on speed and track length. Adjustments in idling estimates were made for idling events lasting longer than 30 minutes based on the fraction of locomotives of each model equipped with auto start/stop technology in the same manner as for idling of arriving and departing train consists. Notch-specific emission factors adjusted for the expected average sulfur content of fuel for each locomotive model and technology were applied to the number, duration, and model distribution of different events to estimate total emissions.

Yard Switching

Classification is accomplished at the "Hump and Bowl," an area where the cars from an arriving train are pushed over a raised section of track (literally, a hump) and selectively uncoupled and allowed to roll downhill into the Bowl. The Bowl is a large area with numerous parallel track segments, and the cars rolling into the Bowl are automatically switched onto an appropriate track based on their ultimate destination. Arriving train cars are pulled back to the southwest end of the yard by locomotives referred to as "hump sets," and then pushed slowly across the Hump into the southwest end of the Bowl. Yard switchers referred to as "trim sets" operate on the northeast end of the Bowl, connecting groups of cars together to build new train segments and then pulling or pushing these segments to the appropriate track for departure.

Both hump and trim operations are shift-based activities. Information from Yard operating personnel was used to estimate the average characteristics of hump sets and trim sets (locomotive model and technology), as well as the number of such sets operating during different shifts, for the original Roseville analysis. Duty cycle information for the various activities was based on information from UPRR personnel. For hump sets, this included estimates of the duration and throttle settings for pullback and pushing, as well as average duration of idling during a shift. Adjustments in expected idling duration for extended idling events were made based on a best estimate of the fraction of units of each type equipped with auto start/stop equipment. Notch-specific emission factors for the specific locomotive models, adjusted for the expected fuel sulfur content, were applied to the activity data to estimate total emissions. Since these emission calculations were based on shift durations and duty cycles as developed for the 1999-2000 ARB emission inventory, adjustments have been made for the nominal 2005 through 2008 emissions estimates based on changes in the trailing tons of freight on terminating and originating trains during each 12-month period. In effect, this adjustment ensures that a constant value of yard switcher horsepower-hours of work per trailing ton of freight is used for each year of analysis. The ULEL gen-set hump units' DPM and NOx emissions are approximately 85% lower than traditional locomotives on a gram per brake horsepower-hour basis. The four gen-set hump units were delivered between March and June 2008, but were estimated to have had only 40% availability due to training and maintenance issues. Annual hump emissions for 2008 were therefore assumed to have been reduced by 23% from those that would have occurred using traditional locomotives.

Differences in Emission Calculation Procedures from Those Used in the ARB Roseville Study

Since the development of activity data for the original ARB study, developments in both data completeness and analysis procedures have occurred. The original database for trains included data for one week per month from December 1999 through November 2000, necessitating extrapolation to estimate annual activity and emissions. Data for that full 12-month period are now available. After reviewing current train activity data and identifying changes in data coding practices during and since the 1999-2000 base year, it was determined that the procedures followed for classifying and characterizing trains for the ARB MOU inventories could be applied to the 1999-2000 period. Portions of the earlier database did not explicitly identify locomotive status as "working" or other. For these portions, locomotives without a status code were assumed to be working. This approach gave the most consistent results for working locomotives per consist—a key metric input to emission calculations.

The model- and notch-specific emission factors available for the original ARB study have since been revised and updated by ARB and others. In addition, no adjustments were included in the original 1999-2000 inventory for fuel sulfur content. The methods developed for sulfur content adjustments in the UPRR MOU railyard analyses were applied to Roseville for all scenario years in the current analysis. This required estimates of the sulfur content of fuel delivered at Roseville (and elsewhere in California), as well as the fraction of this fuel being used. Fuel sulfur contents for 49-state fuel for all years and for California fuel in 1999-2000 were taken from the EPA Regulatory Impact Analysis for its 2004 non-road engine rulemaking (see Attachment B). These values for 2000, 2005, 2006, 2007 and 2008 were 2641, 2639, 2616, 1328 and 408 ppm, respectively. California fuel sulfur contents for 2005, 2006, 2007 and 2008 as reported by California refineries delivering fuel to UPRR, were 221, 74, 4.8, and 5.1 ppm, respectively.

There have been significant changes in the UPRR road power fleet distribution since 2000, including the retirement of older, lower horsepower units and the addition of new units. The new units include Tier 0, 1, and 2 locomotives, many of which are equipped with AESS auto start/stop idling reduction technology. Additionally, UPRR has been actively retrofitting lower horsepower units, particularly in the Sacramento and Placer County areas, with ZTR idling reduction technology. A database is now available listing the tier and auto start/stop technology of all UPRR locomotives, including, if applicable, the retrofit date. This database was used to directly identify the fraction of locomotives so-equipped for both the 1999-2000 and 2005-2008 periods.

The emission inventory for the ARB Roseville study was developed in a series of spreadsheets requiring substantial manual input of data. The general calculation approach followed in these spreadsheets has been automated to allow rapid processing of updated activity databases with limited manual data input. This development allows the generation of directly comparable emission estimates for different time periods without the risk of errors associated with manual inputs. For example, travel routes for consists and trains within the Yard change over time, such as the shift of local train activity from the City Yard to other parts of the Yard. The ARB study inventory based consist movement emissions on estimates of the travel time between points, rather than direct calculations from distance and average speed. For the current analysis, major track segments and work areas within the Yard were digitized and a node-and-link network of track segments with specified speeds was developed to calculate operating times for moving locomotives. The updated results cannot be directly compared to the ARB study inventory, but overall results are quite similar. This automated processing allows this calculation to be done based on the coordinates of the track segments associated with each movement digitized from geo-referenced aerial orthophotographs and provides a consistent basis for estimating emissions from moving locomotives from year to year.

To avoid possible inconsistencies in calculations and assumptions in emissions calculations for different periods, the data for 1999-2000 were reprocessed using the current methodology to provide an appropriate emissions baseline for estimating trends. Calendar year 2005-2008 data were processed based on the same assumptions and inputs as for the reprocessed 1999-2000 data, updated to reflect changes in activity that occurred between 2000 and later years.

RESULTS

Activity Trends

There are a variety of measures of rail yard activity. The following tables show the primary activity measures for the Roseville Yard for the four one-year periods analyzed.

Table 1. Train Activity Measures

Type	’99-‘00	2005	2006	2007	2008
Through Trains	4166	5634	5302	4528	4773
Trains Making Setouts	1639	1947	1955	1274	1336
Freight Originating & Terminating	13476	12954	13252	13137	11591
Locals Originating & Terminating	799	946	1780	1923	1631
Work Trains Originating & Terminating	54	82	45	49	78
Power Moves Through	582	108	72	56	71
Power Moves Originating and Terminating	2252	772	877	1101	1177
Through Train MM Trailing Tons	29.8	38.6	34.6	28.1	30.0
Line Haul & Local MM Trailing Tons	73.1	74.1	70.8	76.2	67.1

The last two lines of Table 1 are based on data for trains identified as either "through" or terminating or originating. They do not reflect the trailing tons of freight handled in the yard as a result of setouts (through trains that enter the yard and depart with either higher or lower trailing tons or working locomotive horsepower). The data do not allow an accurate calculation of the trailing tons handled in the yard as a result of setouts.

Table 2. Locomotive Activity Measures

Activity	'99-'00	2005	2006	2007	2008
Originating Units on Trains	25023	22262	24471	25978	23911
Units in Service and Subway	26980	30198	30853	29742	26707
Units Fueled in Service and Subway*	22962	20429	22456	23839	22585
Units in Shop	11260[b]	15299	11767	12036	10852
Load Tests	4982	5638	5479	6301	5177
Service Events per Originating Unit	1.08	1.36	1.26	1.14	1.12
Fueling Events per Originating Unit[a]	0.92	0.92	0.92	0.92	0.94
Load Tests per Day	13.6	15.4	15.0	17.3	14.2

[a] Fueling counts for 1999-2006 adjusted upward to 92% of originating units to reflect apparent under-reporting prior to 2007.

[b] 1999 Shop events estimated at 45% of originating units due to data ambiguities.

The footnotes on Table 2 describe adjustments made based on comparisons of parameters that should remain fairly constant from year to year (e.g., the fraction of serviced locomotives that were actually fueled during service). Reporting practices changed over time, including changes in the point during service when specific events were logged. Fueling events are believed to have been under-reported prior to 2007, so the fueled fraction for previous years was adjusted to 92% (the observed value in 2007) for consistency. Similarly, changes in reporting practices precluded directly comparable estimates of shop fractions of service events between 1999-2000 and later years. The earlier year shop count was adjusted to be consistent with data observed in later years.

As discussed previously, a revised logic for identifying load test events was devised based on discussions with shop personnel responsible for testing and work code reporting. The duration of load tests was also increased from the values used in the ARB Roseville study based on these discussions.

Trends in Locomotive Characteristics

As discussed above, UPRR has been actively acquiring new, high-horsepower locomotives meeting current emissions standards and retiring older, lower horsepower units. The new units are equipped with factory installed Auto-Engine Start Stop (AESS) technology, which shuts engines down after short periods of idling. UPRR has also been actively installing retrofit ZTR SmartStart idling control technology in many of its older low and medium horsepower units (primarily GP-3x class locomotives). These changes are reflected in the locomotive fleet observed at the Roseville Yard, as shown in the following figures. There is a consistent trend toward increased fractions of cleaner, high horsepower Tier 2 locomotives and a significant increase in the fraction of units equipped with ZTR/AESS. Figure 1 shows the relative fraction of locomotive model groups operating at the Roseville rail yard in each year and the fraction of each equipped with idle controls. Figure 2 shows the increasing penetration of Tier 0 retrofits and new Tier 1 and Tier 2 units within the fleet operating at the Roseville rail yard in 2005 through 2008. All of the units shown in Figure 1 for 1999-2000 are pre-Tier 0.

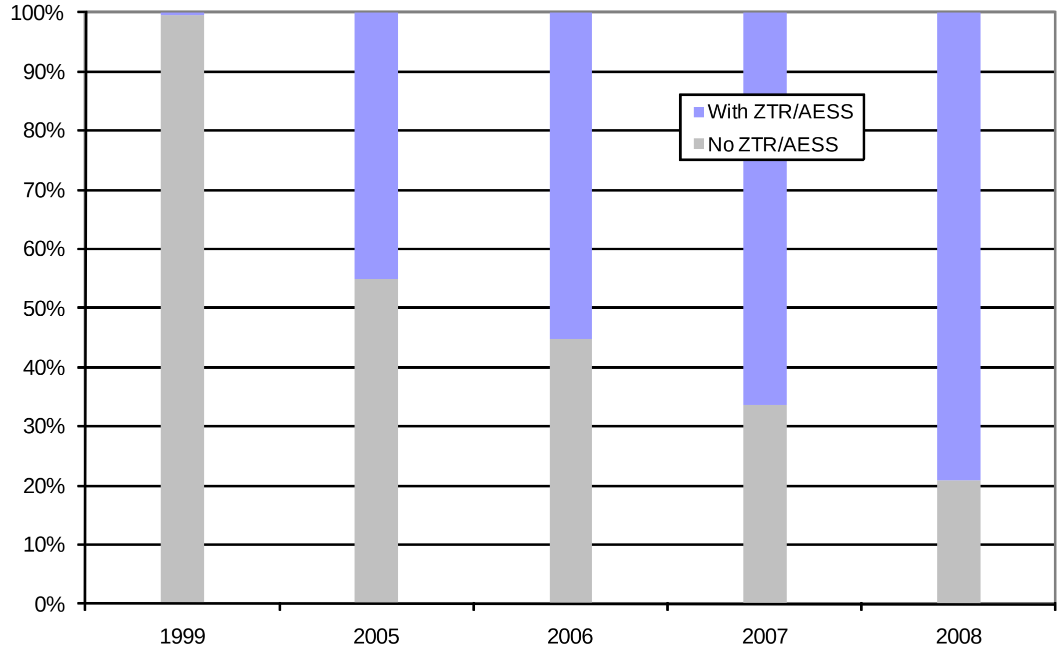

Figure 1. Roseville Locomotive Fleet and Idle Control Fractions

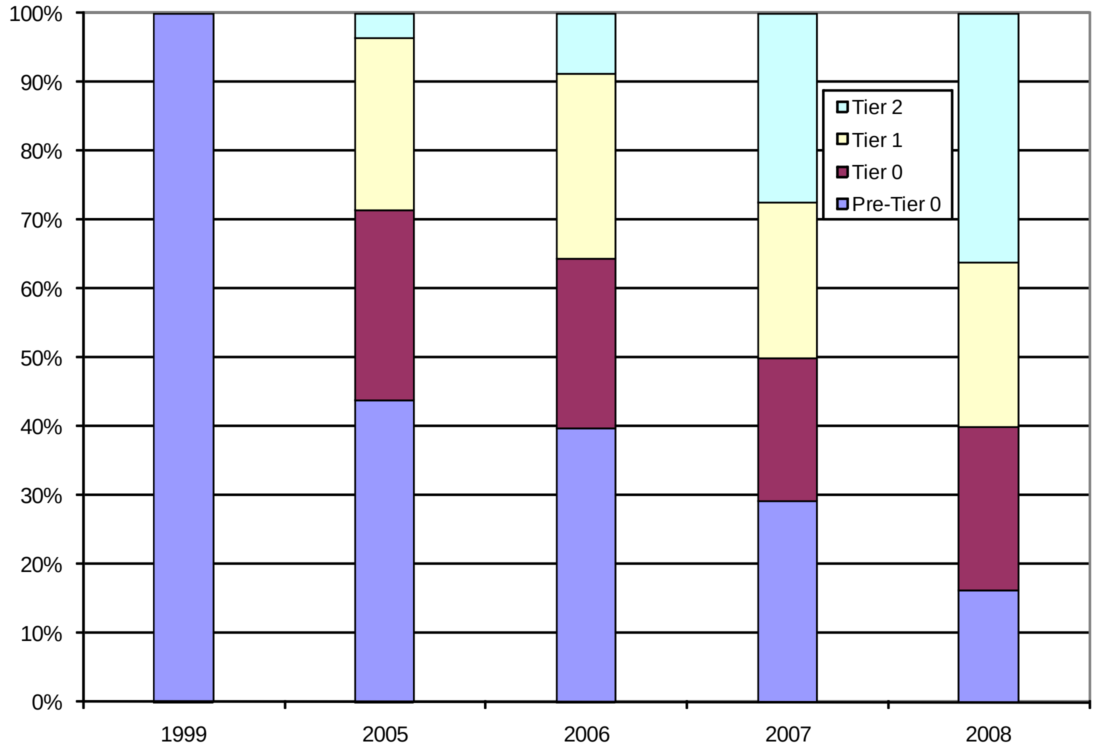

Figure 2. Roseville Locomotive Fleet Control Technology Tier Fractions

Emission Trends

The following tables show the DPM and NOx emissions estimates for different activities at Roseville based on the previously described methods and activity levels. Table 3 shows the emissions for each year by activity, including a grand total and a total for in-yard activity only (i.e., excluding through trains and power moves). The DPM estimates from the ARB Roseville study based on a subset of the total 1999-2000 data are included for comparison. Table 4 shows the best estimate of 1999-2000 DPM and NOx emissions and the percent change by activity type for 2005 and 2008 for each pollutant.

Table 3. Estimated Emissions Trends for the UPRR Roseville Railyard

Activity	DPM (tpy)						NOx (tpy)				
	CARB ’99-‘00[a]	**’99-‘00**	**2005**	**2006**	**2007**	**2008**	**1999**	**2005**	**2006**	**2007**	**2008**
Thru Total	1.03	1.28	2.50	1.54	1.13	1.11	60.5	106.2	64.5	46.5	45.3
Freight (idling and movement)	5.66	4.22	2.92	3.06	2.70	2.17	155.6	108.9	112.5	94.7	70.8
Local, Rockpile & Power	0.94	0.30	0.20	0.41	0.37	0.29	12.1	7.9	15.6	14.4	10.8
Hump & Trim	7.15	8.25	7.06	6.75	7.22	6.00	345.7	319.9	306.2	328.4	275.6
Service Idling and Movement[b]	6.18	4.80	3.19	3.11	2.53	1.81	153.5	98.5	99.6	86.0	61.9
Shop Idling[b]	0.83	1.44	0.72	0.71	0.57	0.35	42.4	20.9	21.6	18.5	11.2
Load Tests[b]	1.62	3.11	3.20	3.09	3.53	2.77	151.0	143.7	134.4	143.3	109.2
TOTAL	23.4	23.4	19.8	18.7	18.1	14.5	921	806	754	732	585
TOTAL - In-Yard Only	22.4	22.1	17.3	17.1	16.9	13.4	860	700	690	685	540

[a] CARB estimates from Roseville are based on 12 nominal one-week train data samples projected to 12 months. Other columns are full year.

[b] Service Track and Shop idling, movement and load tests adjusted to reflect suspected under-reporting prior to 2007; load tests occur at a variety of locations throughout the yard.

Table 4. Estimated Changes in Emissions Since 1999-2000

	DPM TPY	DPM Change (%)		NOx TPY	NOx Change (%)	
Activity	**1999**	**2005**	**2008**	**1999**	**2005**	**2008**
Thru Total	1.28	96%	-13%	60.5	75%	-25%
Freight (idling and movement)	4.22	-31%	-49%	155.6	-30%	-54%
Local, Rockpile & Power	0.30	-34%	-5%	12.1	-35%	-11%
Hump & Trim	8.25	-14%	-27%	345.7	-7%	-20%
Service Idling and Movement[a]	4.80	-34%	-62%	153.5	-36%	-60%
Shop Idling[a]	1.44	-50%	-76%	42.4	-51%	-74%
Load Tests[a]	3.11	3%	-11%	151	-5%	-28%
TOTAL	23.4	-15%	-38%	921	-12%	-36%
TOTAL - In-Yard Only	22.1	-22%	-39%	860	-19%	-37%

[a] Service Track and Shop idling, movement and load tests adjusted to reflect suspected under-reporting prior to 2007; load tests occur at a variety of locations throughout the yard.

Discussion

The DPM and NOx emission totals shown, other than the CARB 1999 values, are based on improved full-year data sets for train activity and improved data analysis logic. Although the individual activity emissions for the CARB and the updated 1999 emissions differ in some cases, the total is quite close and the major activity categories remain the same—i.e., yard operations (hump & trim), service idling and train idling and movement (in that order) remain the primary contributors. Service and Shop database formats and reporting practices changed between 1999 and 2005, resulting in some difficulty in assuring comparability of activity estimates. Service event logging was reported to have been inconsistent in 2005. The data suggest that under-reporting may have continued into 2006, in that the number of fueling events per originating locomotive increased steadily to 0.92 in 2007. Service Track activity data for previous years were scaled to match this fraction. A new set of criteria for identifying load test events based on performance-related maintenance work codes was applied, and a revised estimate of load test durations was used, both of which result in higher estimated load test emissions relative to the methods used in the original CARB estimates.

Calendar year 2008 in-yard emissions are estimated to be 39% lower for DPM and 37% lower for NOx than the 1999-2000 base year period emissions. The largest tonnage reductions come from reduced idling and a reduction in yard operations emissions due to the introduction of gen-set hump units and the switch to low sulfur fuel. Reduced idling emissions result primarily from the significant penetration of AESS-equipped road power units between 1999 and 2008. Additional emission reductions are associated with fleet turnover to newer, lower emitting locomotives.

RRAMP Inventory Analysis

For purposes of evaluating the trends in observed ambient concentrations from the RRAMP program, it is important to consider the emission sources most likely to contribute to observed concentrations at the RRAMP monitoring sites. Figure 3 shows the locations of the primary emission source areas in the Yard, as well as the RRAMP monitoring sites (shown as red squares). Large portions of the Yard's emissions are located to the southwest of these stations, including much of the trim set emissions, all of the hump set emissions, approximately one half of the Receiving Yard emissions, and all of the Departure Yard emissions. Changes in Service idling emissions (including in-bound, in-Service, and Ready Track idling) can be expected to be the primary influence on emission trends for the Denio/Pool monitoring pair. Shop idling and load testing may have the greatest influence on the Church/Vernon pair, but this influence is likely to be less apparent than changes for Denio/Pool. Table 4 shows the four-year (2005-2008) emission trends for activities most likely to have influenced the Pool/Denio and Vernon/Church monitoring pairs.

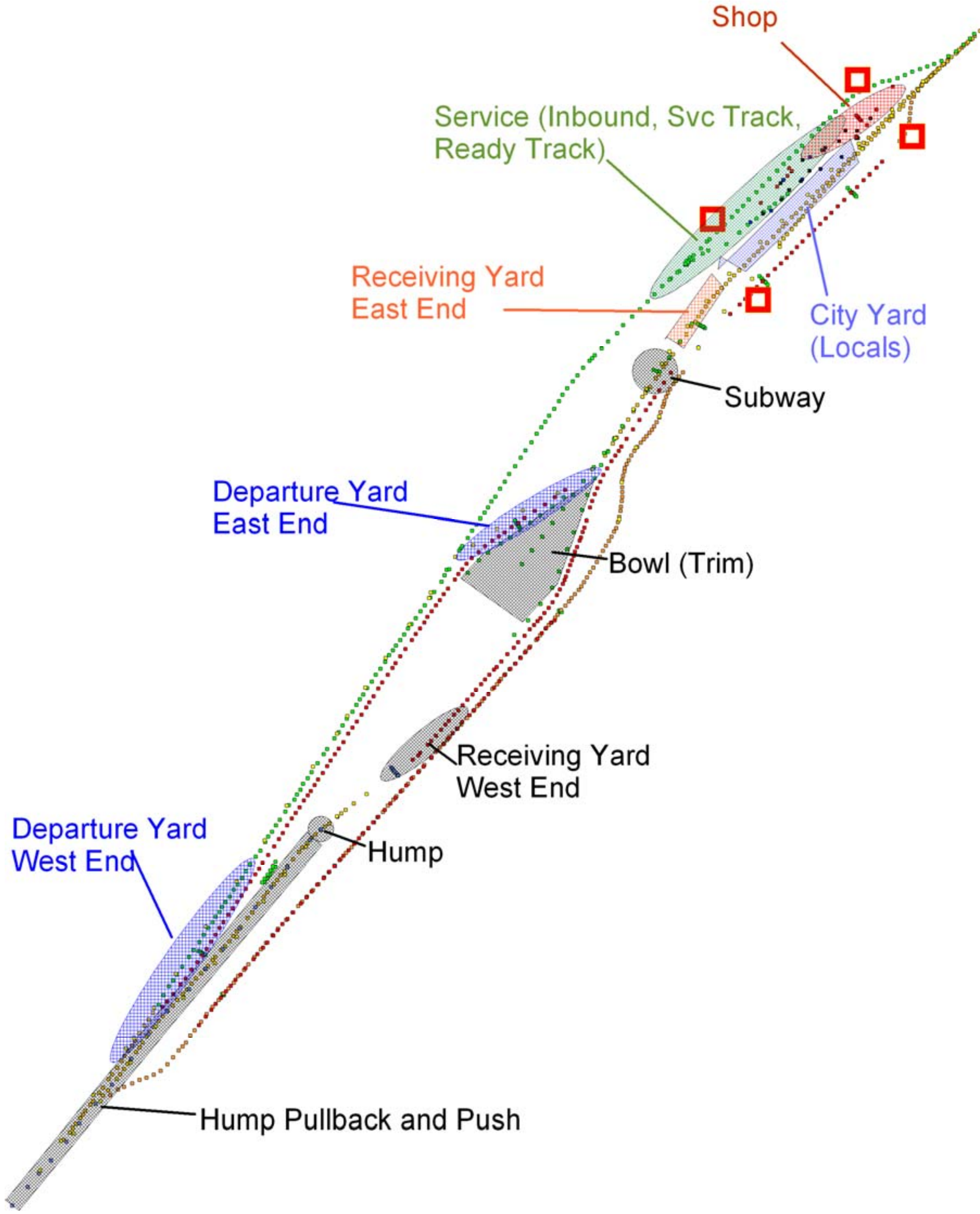

Figure 3. Principal Emission Source Areas and RRAMP Monitoring Station Locations

Table 5. Estimated Emissions Trends for Activities Influencing RRAMP Stations

Activity	DPM				NOx				
	2005	**2006**	**2007**	**2008**	**2005**	**2006**	**2007**	**2008**	**RRAMP Stations**[a]
Thru Total	2.50	1.54	1.13	1.11	106.2	64.5	46.5	45.3	Both
Freight (idling and movement)	2.92	3.06	2.70	2.17	108.9	112.5	94.7	70.8	P-D (minimal)
Local, Rockpile & Power	0.20	0.41	0.37	0.29	7.9	15.6	14.4	10.8	P-D (primarily Local)
Hump & Trim	7.06	6.75	7.22	6.00	345.7	319.9	306.2	275.6	Neither
Service Idling and Movement	3.19	3.11	2.53	1.81	98.5	99.6	86.0	61.9	P-D
Shop Idling	0.72	0.71	0.57	0.35	20.9	21.6	18.5	11.2	C-V
Load Tests	3.20	3.09	3.53	2.77	143.7	134.4	143.3	109.2	Both
TOTAL	19.8	18.7	18.1	14.5	806	754	732	585	--
Subtotal, Sources Influencing P-D[b]	12.0	11.2	10.3	8.2	465	427	385	298	--
Subtotal, Sources Influencing C-V[b]	6.4	5.3	5.2	4.2	271	221	208	166	--

[a] Both – activity affects both Pool/Denio and Church/Vernon monitor pairs
Neither – activity does not significantly affect either monitor pair
P-D – activity affects Pool/Denio monitor pair
C-V – activity affects Church/Vernon monitor pair

[b] Thru train and load test emissions totals are included in both P-D and C-V subtotals, although substantial portions of through train emissions and some fraction of load test emissions will affect neither pair. Load tests will affect C-V more than P-D.

ATTACHMENTS

A. Methodology for Estimating Locomotive DPM Emissions

B. Development of Adjustment Factors for Locomotive DPM Emissions Based on Sulfur Content

Attachment A

Methodology for Estimating Locomotive DPM Emissions

Overview

This attachment describes the details of the development of activity inputs, DPM emission factors, and DPM emission estimates for locomotive operations at the Union Pacific J.R. Davis rail yard in Roseville, California. Separate procedures are followed for estimating activity associated with locomotives on trains, locomotive consist movements within a yard, service and shop activity, and yard switching operations within a yard. Emission factors are developed for each type of locomotive activity based on the model and technology distribution of locomotives involved in each activity. DPM emission estimates are then developed for the activities and specific areas of the yard in which each activity occurs.

Train Activity

Train activity data for emissions calculations includes a number of separate components:

- The number of trains arriving, departing, or passing through a yard, broken down by type of train;
- The average composition of working locomotives in each consist,[1] including the fraction of locomotives of different models, emissions technology tier, and automatic idling control equipment;[2]
- The identification of routes followed for different types of train activities; and
- Identification of the speeds and throttle settings for different types of train activities in different locations.

The primary source of information for estimating train activity is a database identifying the arrival and departure of locomotives at a specific yard. This database identifies locomotives by their ID numbers and models, the status on the train (working or not working), and the specific train to which they are connected. From these data, the total numbers of trains of different types are identified based on train symbols, train dates, train origination and termination indicators, and dates and times of arrival and departure. For each type of train and activity, the average number of locomotives per consist is calculated along with the distribution of locomotive models, emission technology tiers, and automatic idling control equipment. A separate database of UPRR locomotives is consulted based on locomotive ID to determine the tier and date of any retrofits of automatic idling controls to complete the development of these model distributions.

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[1] The term "consist" refers to the group of locomotives (typically between one and four) that provide power for a specific train.

[2] Two types of automatic idling control equipment are in use, known as ZTR SmartStart (typically retrofit equipment on low horsepower units) and AESS (typically factory installed on newer high horsepower units). Both are programmed to automatically shut off the engines of parked idling locomotives after a specified period of time, and to restart the unit if any of a number of operating parameters (battery state, air pressure, coolant temperature, etc.) reach specified thresholds.

The types of trains to be identified can vary from yard to yard. For all yards, through trains (which bypass the yard itself on mainline tracks adjacent to the yard) are identified. Depending on the yard, trains entering or departing from the yard can be of several types, including:

- Intermodal trains;
- Automobile trains;
- "Manifest" or freight trains;
- Local trains; and
- Power moves.

Power moves are trains consisting only of locomotives that are either arriving at the yard to be serviced or used for departing trains, or departing from the yard to be serviced at another location or used for trains departing from another location. The routes followed by each type of train on arrival and departure are identified in consultation with UPRR yard personnel, along with estimates of average speeds and duty cycles (fraction of time spent at different throttle settings) for different areas.

Specific track subsections are identified by UTM coordinates digitized from georeferenced aerial photographs. For each train type, direction, and route, a listing of track segments, segment lengths, and duty cycles is developed. This listing, along with the number of locomotives per consist and number of trains of each type, allows the number of locomotive hours in each duty cycle to be calculated for each section of track. For arriving and departing trains, estimates of the duration of idling were developed in consultation with UPRR personnel. These idling periods were divided into two parts: the assumed amount of time that all locomotives in a consist would idle on arrival or departure, and the amount of time that only locomotives not equipped with automatic idle controls would idle. Idling periods were assigned to a segment of the arrival or departure track one fifth of the length of the track at the appropriate end.

Service and Shop Activity

If there is a service track and/or shop at a yard, locomotives (including both road power from trains as well as yard switchers) undergo a variety of activities at these locations. Specific locomotive activities involve idling while awaiting or undergoing routine service (cleaning, refueling, oiling, sanding, and other minor maintenance), movement and idling between service and maintenance areas, and stationary load testing associated with specific types of maintenance events. A database of service events at individual yards identifies the number of service events during the year, the locomotive ID and model, and the nature of servicing performed. Routine servicing involves periods of idling prior to and during service, and additional idling prior to movement of consists to departing trains in the yard. Estimates of the duration of idling associated with servicing are developed in consultation with UPRR personnel. As was done for trains, these idling periods were separated into two parts: the average total duration of idling by all locomotives, and the average duration of additional idling by locomotives not equipped with automatic idling controls.

Since the development of the original 1999-2000 emission inventory for the Roseville Yard, UPRR has updated and revised the data base and maintenance work code logging procedures. A revised procedure based on these new coding procedures and practices has been applied in the calculation of 2005 to 2007 load test emissions as well as recalculating load test emissions for the 1999-2000 period. Locomotive maintenance events involving load tests are identified by whether any of a number of specific work codes are listed. The work codes for which load tests are assumed to take place include specifically coded load tests, certain types of planned maintenance events (e.g., semiannual inspections), and work codes indicating an engine performance-related repair requiring testing after completion. The duration of load test events in each throttle setting was developed in consultation with UPRR personnel.

A total number of events (servicing and load testing by location and type) are developed from these data, as are locomotive model and technology distributions for all locomotives serviced and for those specific locomotives undergoing load testing (if applicable). From these event counts and durations, the total number of locomotive hours of idling and higher throttle settings in different portions of the service areas are calculated for each of the two model distributions.

Yard Switcher Activity

In each yard, there are routine jobs assigned to individual switchers or sets of switchers. These activities are generally not tracked from hour to hour, but they occur routinely within yard boundaries during specified work shifts. Similarly, the specific yard switcher locomotive IDs assigned to these jobs are not routinely tracked, but these yard jobs are generally assigned to a specific model of low horsepower locomotive. From the assigned yard switcher jobs and shifts, and in consultation with UPRR personnel, an estimate of the hours per day of switcher operation in the yard for the base year (1999-2000) was developed, along with the specific times of day when these activities occur (time of day assignments are made only if operation was less than 24 hour per day). Duty cycles for switching operation are also developed in consultation with local UPRR personnel. Depending on the type of activity and type of trains being handled in a yard, duty cycle estimates may vary. In the absence of more detailed information, the USEPA switcher duty cycle is assumed to be representative of each switcher's operation.[3] For Roseville, trim set operation was assumed to follow a duty cycle derived from the EPA switcher cycle, but with no notch 7 or 8 operation. Hump set operations during the base year were assumed to follow a specific duty cycle developed in consultation with UPRR personnel and the ARB. Both the base year trim set and hump set duty cycles are documented in the ARB Roseville Railyard report. The total number of locomotive hours of operation for each model is calculated and assigned to the areas in which the units work. In some cases, yard jobs are assigned to specific areas within the yard and specific models of locomotives. In these cases, the switcher activities are assigned specifically to these areas of the yard.

For 2005 through 2007, a preliminary calculation was made for hump and trim set emissions following the same overall procedures. However, since the total volume of

[3] USEPA (1998). Locomotive Emission Standards –Regulatory Support Document. (Available at *www.epa.gov/otaq/regs/nonroad/locomotv/frm/locorsd.pdf*)

freight handled in the Yard changes from year to year, these preliminary emissions estimates were adjusted based on the ratio of each year's total trailing tons of freight entering and leaving the Yard to the trailing tons during the base year. In effect, this approach maintains a constant ratio of horsepower-hours of yard switcher operation per trailing ton of freight.

DPM Emission Factor Development

The locomotive model and technology group distributions derived in the development of activity data are grouped by type or types of activity with consideration for the level and nature of the activity. For example, a single distribution is used for through trains of all types, including power moves, while consist model distributions for different types of trains within a yard may be treated as separate distributions if they are handled in different areas of a yard. Model-group-specific emission factors by throttle setting were developed based on emission test data and sulfur content adjustment factors. From these emission factors and the locomotive model and technology distributions for different types of trains and activities, weighted average emission factors are calculated for the "average" locomotive for that train type or activity on a gram per hour basis. For each train type or activity, two separate idle emission rates are calculated. The first is the straight weighted average emission rate for all locomotives, while the second is the weighted average only for the fraction of locomotives without automatic idle controls. Mathematically,

$$\overline{Q}(l) = \sum_{i=1}^{11} \sum_{j=1}^{4} \sum_{k=1}^{2} F(i, j, k) \cdot Q(i, j, l) \quad (1)$$

for l corresponding to idle through N8, and

$$\overline{Q}(l^*) = \sum_{i=1}^{11} \sum_{j=1}^{4} F(i, j, 1) \cdot Q(i, j, l^*) \quad (2)$$

for idling emission rate during periods when only locomotives without automatic idle controls are idling

where

$\overline{Q}(l)$ = weighted average emission factor for throttle setting l, g/hr

$\overline{Q}(l^*)$ = weighted average emission factor for locomotives without automatic idle controls for throttle setting l^*, g/hr

$Q(i,j,l)$ = the base g/hr emission factor of a particular model group/technology class and throttle setting

$Q(i,j,l^*)$ = the base g/hr emission factor of a particular model group/technology class of locomotive at idle

$F(i,j,k)$ = the fraction of locomotives of a particular model group/technology class

i = model group index (Switcher, GP-3x, GP-4x, GP-50, GP-60, SD-7x, SD-90, Dash 7, Dash 8, Dash 9, or C60-A)

j = technology tier index (pre-Tier 0, Tier 0, Tier 1, Tier 2)

k = automatic idle control status index ($k = 1$ for without, $k=2$ for with)

l = throttle setting index(idle for non-auto idle locomotives, idle for all locomotives, DB, N1, N2, N3,. . ., N8)

l^* = index for idle throttle of locomotives without automatic idle controls.

Thus, for each defined locomotive model distribution, gram per hour emission factors are generated for each throttle setting.

DPM Emission Calculations – Locomotive Movements

From the train activity analysis, the following data are available for each segment of track: track length of segment $L(i)$; speed $V(i)$; movement duty cycle $\boldsymbol{D}(i)$ (a vector of fractions of time spent in each throttle setting); number trains of each type $N(j)$; and number of working locomotives per consist for each train type $C(j)$. For each type of train j, there is a set of throttle-specific emission factors $Q_j(l)$ for the "average" locomotive used on that train type. If a particular type of train or consist movement can follow multiple paths within the yard, the activity is allocated to sequences of track segments representing each such path. Total annual emissions $q_{tot}(i)$ for each segment are then calculated as

$$q_{tot}(i) = \frac{L(i)}{V(i)} \cdot \sum_j N(j) \cdot C(j) \sum_l D(i,l) \cdot Q_j(l) \qquad (3)$$

where

$q_{tot}(i)$ = total annual emissions for track segment i, g/yr

$L(i)$ = track length of track segment i (miles)

$V(i)$ = speed on track segment i (mph)

$N(j)$ = number of trains of train type j

$C(j)$ = number of working locomotives per consist for train type j

$D(I,l)$ = fraction of time spent at throttle setting l while on track segment i

$Q_j(l)$ = emission factor for the "average" locomotive used on train type j at throttle setting l (g/hr)

DPM Emission Calculations – Locomotive Idling

Locomotive idling is calculated in a similar manner for road power and locomotives in service. For each train type and for service events, activity data provide a number of annual events $N(i)$, duration of idling per event by locomotives with ($T_{all}(i)$) and without ($T_{nZTR}(i)$) automatic idle control, and gram per hour emission rates for the "average" locomotive $Q_{all}(i)$, and the "average" locomotive excluding those with automatic idle controls $Q_{nZTR}(i)$. Total annual emissions are calculated as follows:

$$q_{idle} = \sum_i N(i) \cdot C(i) \cdot (T_{all}(i) \cdot Q_{all}(i) + T_{nZTR}(i) \cdot Q_{nZTR}(i)) . \qquad (4)$$

If a particular type of activity occurs at multiple locations within the yard (e.g., on multiple arrival or departure tracks), then the idling time is allocated to different segments of track as appropriate so that segment-specific emissions are obtained.

DPM Emission Calculations – Load Testing

Load testing emissions are calculated separately for each throttle setting (idle, N1 and N8) using the weighted average emission factors for the load-tested units, the number of load tests of different types, and the duration of testing in each throttle setting for each type of test.

DPM Emission Calculations – Yard Switcher Operations

Activity data provide the number and model group information for yard switchers, and the number of operating hours per day. Model-group-specific emission factors are multiplied by the duty cycle to generate weighted average gram per hour emissions for idling and for combined emissions from operation in notch 1 through notch 8. Emissions are calculated directly from the number of units, hours per day working, and duty cycle weighted emission factors for both idle and non-idle throttle settings during work shifts. As described above, these emissions for 2005 through 2008 were then adjusted in proportion to the change in trailing tons of freight in those years, relative to the trailing tons of freight in the 1999-2000 base year. In addition, for 2008, a further adjustment was made in hump emissions to reflect the percent of time that ULEL gen-set hump units were in use (40% of 8 months) and their 85% lower DPM and NO_x emission rates.

Attachment B

Development of Adjustment Factors for Locomotive DPM Emissions Based on Sulfur Content

Wong (2007) provides equations for estimating g/bhp-hr DPM emission rates for 4-Stroke (GE) and 2-Stroke (EMD) locomotives. Rather than using these statistically derived estimates for absolute emissions when model- and notch-specific emission factors are available, we used these equations to develop *relative* emission rate changes for different sulfur levels. The basic form of the equation is

$$q = a \cdot S + b \qquad (1)$$

where

q is the predicted g/bhp-hr emission rate of a locomotive at a specific throttle setting and sulfur content;

a and b are coefficients specific to a locomotive type (2- or 4-stroke) and throttle notch; and

S is the fuel sulfur content in ppm.

Thus, to calculate the emission adjustment factor for a specific fuel sulfur content, it is necessary to calculate the nominal emission rate q_0 for the baseline fuel sulfur content S_0, and the emission rate q_i for the fuel of interest with sulfur content S_i. This adjustment factor k_i is simply

$$k_i = 1 - \frac{(q_0 - q_i)}{q_0}, \qquad (2)$$

where q_0 and q_i are calculated using the equation above. Tables B-1 and B-2 give the values of the a and b coefficients for 4-stroke and 2-stroke locomotives. For throttle settings below notch 3, sulfur content is not expected to affect emission rates (Wong, 2007). The baseline emission rates from which actual emissions are estimated were derived from emission tests of different locomotive models. Although full documentation of fuels is not available for all of these tests, they are assumed to be representative of actual emissions of the different models running on 3000 ppm sulfur EPA non-road Diesel fuel. For the purposes of estimating current emissions, these factors are needed to adjust the baseline emission factors to emission factors representative of current fuel sulfur levels. As an example, calculations are provided for two fuels—221 ppm and 2,639 ppm—which are used to estimate UPRR fleet emissions in California for the 2005 calendar year. Table B-3 shows the resulting correction factors for these two fuels by notch and engine type. To generate locomotive model-, throttle-, tier-, and fuel-specific emission factors, the base case (nominal 3,000 ppm S) emission factors in Table B-4 are multiplied by the corresponding correction factors for throttle settings between notch 3 and notch 8.

Table B-1
Sulfur Correction Coefficients for 4-Stroke Engines[a]

Throttle Setting	*a*	*b*
Notch 8	0.00001308	0.0967
Notch 7	0.00001102	0.0845
Notch 6	0.00000654	0.1037
Notch 5	0.00000548	0.1320
Notch 4	0.00000663	0.1513
Notch 3	0.00000979	0.1565

Notes:
[a] From Wong (2007).

Table B-2
Sulfur Correction Coefficients for 2-Stroke Engines[a]

Throttle Setting	*a*	*b*
Notch 8	0.0000123	0.3563
Notch 7	0.0000096	0.2840
Notch 6	0.0000134	0.2843
Notch 5	0.0000150	0.2572
Notch 4	0.0000125	0.2629
Notch 3	0.0000065	0.2635

Notes:
[a] From Wong (2007).

Table B-3
DPM Emission Adjustment Factors for Different Fuel Sulfur Levels[a]

Throttle Setting	4-Stroke (GE)		2-Stroke (EMD)	
	2639 ppm	221 ppm	2639 ppm	221 ppm
Notch 8	0.9653	0.7326	0.9887	0.9131
Notch 7	0.9662	0.7395	0.9889	0.9147
Notch 6	0.9809	0.8526	0.9851	0.8852
Notch 5	0.9867	0.8974	0.9821	0.8621
Notch 4	0.9860	0.8924	0.9850	0.8844
Notch 3	0.9810	0.8536	0.9917	0.9362

Notes:
[a] See Wong (2007) for derivation of values.

Table B-4
Base Case Locomotive Diesel Particulate Matter Emission Factors (g/hr)
(3,000 PPM Sulfur Assumed)

Model Group	Tier[g]	Throttle Setting										Source
		Idle	DB[h]	N1	N2	N3	N4	N5	N6	N7	N8	
Switchers	N	31.0	56.0	23.0	76.0	138.0	159.0	201.0	308.0	345.0	448.0	EPA RSD[a]
GP-3x	N	38.0	72.0	31.0	110.0	186.0	212.0	267.0	417.0	463.0	608.0	EPA RSD[a]
GP-4x	N	47.9	80.0	35.7	134.3	226.4	258.5	336.0	551.9	638.6	821.3	EPA RSD[a]
GP-50	N	26.0	64.1	51.3	142.5	301.5	311.2	394.0	663.8	725.3	927.8	EPA RSD[a]
GP-60	N	48.6	98.5	48.7	131.7	284.5	299.4	375.3	645.7	743.6	941.6	EPA RSD[a]
GP-60	0	21.1	25.4	37.6	75.5	239.4	352.2	517.8	724.8	1125.9	1319.8	SwRI[b] (KCS733)
SD-7x	N	24.0	4.8	41.0	65.7	156.8	243.1	321.1	374.8	475.2	589.2	SwRI[c]
SD-7x	0	14.8	15.1	36.8	61.1	230.4	379.8	450.8	866.2	1019.1	1105.7	GM EMD[d]
SD-7x	1	29.2	31.8	37.1	66.2	219.3	295.9	436.7	713.2	783.2	847.7	SwRI[e] (NS2630)
SD-7x	2	55.4	59.5	38.3	134.2	271.7	300.4	335.2	551.5	672.0	704.2	SwRI[e] (UP8353)
SD-90	0	61.1	108.5	50.1	99.1	255.9	423.7	561.6	329.3	258.2	933.6	GM EMD[d]
Dash 7	N	65.0	180.5	108.2	121.2	359.5	327.7	331.5	299.4	336.7	420.0	EPA RSD[a]
Dash 8	0	37.0	147.5	86.0	133.1	291.4	293.2	327.7	373.5	469.4	615.2	GE[d]
Dash 9	N	32.1	53.9	54.2	108.1	219.9	289.1	370.6	437.7	486.1	705.7	SWRI 2000
Dash 9	0	33.8	50.7	56.1	117.4	229.2	263.8	615.9	573.9	608.0	566.6	Average of GE & SwRI[f]
Dash 9	1	16.9	88.4	62.1	140.2	304.0	383.5	423.9	520.2	544.6	778.1	SwRI[b] (CSXT595)
Dash 9	2	7.7	42.0	69.3	145.8	304.3	365.0	405.2	418.4	513.5	607.5	SwRI[b] (BNSF 7736)
C60-A	0	71.0	83.9	68.6	78.6	277.9	234.1	276.0	311.4	228.0	362.7	GE[d] (UP7555)

Notes:
[a] EPA Regulatory Support Document, "Locomotive Emissions Regulation," Appendix B, 12/17/97, as tabulated by ARB and ENVIRON
[b] Base emission rates provided by ENVIRON as part of the BNSF analyses for the Railyard MOU (Personal communication from Chris Lindhjem to R. Ireson, 2006) based on data produced in the AAR/SwRI Exhaust Plume Study (Personal communication from Steve Fritz to C. Lindhjem, 2006).
[c] SwRI final report "Emissions Measurments – Locomotives" by Steve Fritz, August 1995.
[d] Manufacturers' emissions test data as tabulated by ARB.
[e] Base SD-70 emission rates taken from data produced in the AAR/SwRI Exhaust Plume Study (Personal communication Steve Fritz to R. Ireson, 2006).
[f] Average of manufacturer's emissions test data as tabulated by ARB and data from the AAR/SwRI Exhaust Plume Study, tabulated and calculated by ENVIRON.

[g] Refers to the emission standards the locomotive or locomotive engine is required to meet. Units designated at "N" are uncertified, pre-1973 locomotive and 1973 through 2001 locomotives that have not yet been rebuilt to Tier 0 standards. Tier 0 standards apply to locomotives and locomotive engines originally manufactured from 1973 through 2001, any time these units are remanufactured. Tier 1 standards apply to locomotives and locomotive engines originally manufactured from 2002 through 2004. These locomotives and locomotive engines are required to meet the Tier 1 standards at the time of the manufacture and each subsequent remanufacture. Tier 2 standards apply to locomotives and locomotive engines originally manufactured in 2005 and later. Tier 2 locomotives and locomotive engines are required to meet the applicable standards at the time of original manufacture and each subsequent remanufacture.

[h] DB = Dynamic Braking, in which a moving locomotive's traction motors are energized so as to generate electricity from the locomotive's kinetic energy, thereby braking the train. Due to the low speeds, dynamic braking rarely if ever occurs within rail yards.

References:

EPA (2004). "Final Regulatory Impact Analysis: Control of Emissions from Nonroad Diesel Engines," EPA 420-R-04-007, Table 3.4-5 (p. 3-52), Assessment and Standards Division, Office of Transportation and Air Quality, USEPA, May 2004.

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