Appendix E

BenMAP Health Benefit Analysis

This page intentionally blank.

Appendix E: BenMAP Analysis

This section of the report presents the empirical results of the District's estimation of the health benefits from the *2012 PM2.5 Plan* via application of the BenMAP model developed by US EPA. BenMAP is a sophisticated computer software model that is well-suited for estimating the regional health benefits from improved air quality resulting from controls and incentives put in place by the *2012 PM2.5 Plan* as well as concurrent controls on PM2.5 originating from other plans.[1] [2] The timeframe for the analysis extends from the base year of 2007 until the attainment date of 2019. In short, the BenMAP analysis seeks to answer two questions: First, given the reductions in population exposure to PM2.5 by 2019 that will result from this combined body of control and incentive measures, how much reduction in specific measures of disease and premature mortality (such as daily hospital admissions for asthma) will occur by 2019 when compared to what was observed in 2007? And second, what is the economic value of those avoided cases of disease, aggravated symptoms, lost work, and premature mortality?

E.1 Background

Over course of the past decade, ongoing progress in the fields of epidemiology and geographic information systems (GIS) have resulted in the development of computer models that are capable of estimating the health benefits of improved air quality with reasonable accuracy when properly applied. These models estimate the number of avoided cases of certain diseases and other health impairment categories, known as health endpoints, which result from a specified reduction in exposure to criteria air pollutants, e.g. ozone and fine particulates (PM2.5). This reduction could be the result of an individual emission control rule with a substantial reduction in annual population exposure or, in this case, a set of controls comprising a regional component of a SIP.

For example, a BenMAP application to an individual rule has been conducted by the Central Valley Health Policy Institute, California State University, Fresno under contract to the District.[3] The study isolated the reduction in annual PM 2.5 exposure in the Bakersfield and Fresno/Clovis metro areas that results from daily restrictions in

---

[1] See Abt Associates Inc. (2012) BenMAP Environmental Benefits Mapping and Analysis Program: User's Manual. Prepared for the Office of Air Quality Planning and Standards, U.S. EPA, Research Triangle Park, NC (October). Available at: http://www.epa.gov/air/benmap/models/BenMAPManualOct2012.pdf. See http://www.epa.gov/air/benmap/ for more information on BenMAP, downloading the program, and for technical documents. BenMAP version 4.0 was used in this analysis.

[2] SJVAPCD Health Science Advisor, David Lighthall, Ph.D., received BenMAP training from the Community Modeling and Analysis System in Chapel Hill, NC under contract to the U.S. EPA. Additional technical assistance for this analysis was provided to the District by Charles Fulcher and Neal Fann, EPA Office of Air Quality Planning and Standards.

[3] Lighthall, D., D. Nunes, and T. Tyner. (2008) Environmental Health Evaluation of Rule 4901: Domestic Wood Burning in the San Joaquin Valley. Central Valley Health Policy Institute, California State University, Fresno. Conducted for and funded by the San Joaquin Valley Air Pollution Control District. See http//www.cvhpi.org

domestic wood burning imposed by Rule 4901 and the resultant health benefits. Rule 4901's restrictions in wood burning were estimated to provide a large (13% or more) reduction in annual exposure to PM 2.5 in the study areas, resulting in substantial estimated reductions in premature mortality and other health endpoints such as asthma attacks and chronic bronchitis. A comparable health benefit estimation model was employed by Hall et al. (2008) to estimate the health and economic benefits of achieving federal ozone and PM2.5 standards in the San Joaquin Valley and South Coast air basins.[4]

E.2 How BenMAP Works

There are two central objectives in BenMAP analyses. First, the program estimates reductions in the incidence rates[5] of what are known as health endpoints (i.e. avoided cases of disease, premature death, impaired health, and aggravation of symptoms) based on a specified improvement in ambient air quality for a target area and its population. The degree of improvement is based on statistical relationships between exposure to a given criteria pollutant and health that are derived from previously published epidemiological studies (see further discussion below). The second objective involves assigning an economic value to those avoided cases of health problems, again based on previously published economic analyses of the health endpoints in question.

For example, in order to accurately estimate reductions in daily asthma ER admissions attributable to improved air quality, it is necessary to determine the incremental decrease in the incidence rate for asthma ER admissions that occurs in response to an incremental decrease in exposure to PM2.5. This metric, known as a concentration response function or CRF, is derived from studies that compare daily or annual rates of disease with variations in exposure to PM2.5. Examples of CRFs derived from various epidemiological studies are depicted in Figure E-1 below. Note that, for the most part, the relationship between PM2.5 concentrations and incidence levels are linear, meaning that each incremental increase in PM2.5 results in the same incremental increase in the disease incidence rate irrespective of the PM2.5 concentration. EPA has incorporated into BenMAP CRFs for a range of health endpoints selected from among the top peer-reviewed epidemiological studies in the U.S. As a result, BenMAP users are able to estimate with reasonable accuracy the reductions in daily or annual incidence of a given health endpoint that would be expected from a given reduction in exposure to PM2.5.

Key elements of the BenMAP analytical process include the following: First, BenMAP users must specify the percentage improvement in ambient air quality for the area in question, typically counties. PM2.5 or ozone concentration data is either imported from external modeling sources or generated from a national set of air pollution monitoring data that is pre-loaded into BenMAP. The latter was used in this analysis. Rather than

[4] Hall, J., V. Brajer, and F. Lurmann. (2008) The Benefits of Meeting Federal Clean Air Standards in the South Coast and San Joaquin Valley Air Basins. California State University--Fullerton, Institute for Economic and Environmental Studies. See http://business.fullerton.edu/centers/iees/

[5] The incidence rate is defined by the percentage of a given population, e.g. 10,000 or 100,000 people, who experience the health endpoint on a given day, year, or other time period.

rely on a single monitor to determine average county exposure, BenMAP also has the ability to estimate overall county PM2.5 exposure by averaging observed concentrations from all monitors in the county. At the same time, this averaging takes into consideration any differences in population density surrounding each monitor in the county. The net result are two air quality grids or population exposure surfaces for each county. First, a baseline grid is created that contains the pre-existing pollutant exposure level and baseline incidence rates for health endpoints as well as a control grid containing reductions in average pollutant exposure as specified by the analyst.

Next, the BenMAP analyst must select appropriate CRFs for target endpoints prior to estimating the reduction in negative health effects that results from reduced county-level exposure to ozone or PM 2.5. This requires the analyst to select CRFs from one or more prior health studies for each health endpoint. With technical assistance from EPA staff, the District has been able to import into BenMAP the CRFs for five endpoints that are derived from the 2010 San Joaquin Valley epidemiological study (based on the combined populations of Bakersfield, Fresno, and Modesto).[6] The endpoints, depicted in shaded boxes in Table E-1, include myocardial infarction, asthma ER admissions for ages 0-19, asthma ER admissions for ages 20+, asthma hospital admissions for ages 0-19, and asthma hospital admissions for ages 20+.

In the next step, BenMAP estimates the county-level reduction in health effects, as defined by incidence reductions for each health endpoint, for the target county populations and timeframe that results from the specified decline in PM2.5 exposure. Custom demographic information can be employed or default population data contained within BenMAP can be used for past, current, and future years based on population growth functions in the program. A simplified example of estimating the health effect can be summarized as follows:

Health Effects = Health Baseline Incidence × Air Quality Change × Health Effect Estimate × Exposed Population

1. Health Baseline Incidence: The health incidence rate is an estimate of the average number of people that die or become ill over a given period of time and for a standard population unit that exists prior to any change in air quality, e.g. 220 cases of asthma per 1,000 individuals per year.
2. Air Quality Change (Delta): The air quality change is the difference between the starting air pollution level (i.e. the baseline), and the air pollution level due to reduced exposure (i.e. the control).
3. Health Effect Estimate: The health effect estimate is an estimate of the percentage reduction in adverse health effects due to unit reductions in ambient air pollution. CRFs from prior epidemiological studies provide the source for effect estimates in BenMAP.

[6] Capitman, J.A., & Tyner, T.R. (2011). *The Impacts of Short-Term Changes in Air Quality on Emergency Room and Hospital Use in California's San Joaquin Valley*. Fresno, CA: Central Valley Health Policy Institute for the San Joaquin Valley Air Pollution Control District. Retrieved from http://www.fresnostate.edu/chhs/cvhpi/publications/index.html

4. Exposed Population: The exposed population is the number of people affected by the improvement in air quality.

Finally, BenMAP calculates the economic value of avoided health effects due to reduced ozone or PM2.5. To summarize:

Economic Value = Health Effect × Value of Health Effect

There are several ways to calculate the economic value of health effect changes depending on the nature of the health endpoint. For example, the value of an avoided premature death is generally calculated using the Value of a Statistical Life (VSL). The VSL is an economic estimate of the social value of premature death that is used to guide policy makers in making public investments in public health or safety. VSL estimates range from $3.8 to $8.9 million per case.[7] VSL estimates are based on either contingent valuation surveys or wage risk studies.[8] In the case of non-fatal health endpoints, the economic benefits are based on (1) cost of illness (COI) estimates from national healthcare datasets, (2) lost wages based on San Joaquin Valley wage rates, or (3) estimates from survey research regarding what individuals are willing to pay to avoid an illness such as acute bronchitis, known as willingness to pay (WTP). These economic valuation functions for key health endpoints are contained within BenMAP and can also be imported for custom analyses.

E.3 Summaries of Health Endpoints Used in the Analyses

1. Acute Bronchitis (Children 8-14): Acute bronchitis is an inflammation of the large bronchi (medium-size airways) in the lungs that is usually caused by viruses or bacteria and may last several days or weeks.[9] PM 2.5 exposure has the effect of increasing vulnerability to infection. Health savings in BenMAP are based on health surveys of patients' willingness to pay (WTP) estimates for their child avoiding a six day illness.
2. Acute Myocardial Infarction (AMI or non-fatal heart attack; Adults over 19; *Valley-Based CRF*): Reflecting the large body of experimental, clinical, and epidemiological evidence of cardiovascular (CV) impacts from elevated PM2.5, AMI is a key health endpoint in assessing the health benefits from reduced PM2.5. AMI results from reduced blood supply to the heart, typically from a

[7] For a further discussion of the VSL, see BenMAP Technical Appendices. Office of Air Quality Planning and Standards, U.S. EPA. Prepared by Abt Associates, Inc. September 2008. Available at: http://www.epa.gov/air/benmap/docs.html

[8] Contingent valuation studies are based on surveys that ask how much individuals would be willing to pay to avoid a given health problem. Wage risk studies estimate the value of a single life by looking at the premium paid to workers in occupations that face an increased risk of occupational mortality. For example, a high rise steel worker accepts a 1 in 1,000 (0.001 probability) greater chance of occupational mortality in return for an annual wage premium of $5,000. The VSL in this situation is then based on multiplying that incremental risk to equal a probability of 1, i.e. 1,000 X $5,000 = $5,000,000.

[9] Wenzel RP, Fowler AA (2006). "Clinical practice. Acute bronchitis". *N. Engl. J. Med.* **355** (20): 2125–30. doi:10.1056/NEJMcp061493.

blocked coronary artery. In this case, the CRF was based on the 2011 Valley Epidemiological Study referenced above, which relied on observed hospital admissions in Bakersfield, Fresno, and Modesto. Valuation estimates for AMI are based on lost wages and cost of illness (COI).

3. Acute Respiratory Symptoms (Adults 18-64): Individuals with pulmonary vulnerability such as asthmatics often experience respiratory impairment that does not result in medical treatment or lost work but are nonetheless results in a restriction of activity or other impairment. Studies have shown that the frequency of these symptoms, including wheezing, coughing, and shortness of breath, is relatively high. Valuation is based on WTP to avoid symptoms for a day.
4. Asthma Exacerbation (Children 6-18): This endpoint is defined by incidence of shortness of breath and/or experiencing an asthma attack. The valuation estimate is based on parents' WTP for their child avoiding one or more symptoms on a given day.
5. Emergency Room Visits, Asthma (Ages 0-19 and 20-99, *Valley-Based CRF*): The incidence reduction estimate is divided into two age groups. However, these age groups are combined in the valuation (health savings) estimate. Health savings are derived from COI surveys.
6. Hospital Admissions, Asthma (Ages 0-19 and 20-99, *Valley-Based CRF*): The incidence reduction estimate is divided into two age groups. However, these age groups are combined in the valuation (health savings) estimate. Health savings are derived from COI surveys.
7. Hospital Admissions, Cardiovascular (Adults 18-99): This endpoint is based on increases in admission rates for all CV cases except acute myocardial infarction for ages 18-99. Valuation results are based on COI and wage loss estimates.
8. Hospital admissions, Respiratory (Adults 18-64): This endpoint is based on admissions due to chronic lung disease. Health costs are based on average COI.
9. Lower Respiratory Symptoms (Children 7-14): This endpoint is defined by the existence of two or more symptoms including chest tightness, coughing up phlegm, and wheeze. The valuation estimate is based on parents' WTP for their child avoiding two or more symptoms on a given day.
10. Upper Respiratory Symptoms (Children 9-11): This endpoint is defined by the existence of two or more symptoms including throat congestion, coughing, shortness of breath, wheezing, and several others. The valuation estimate is based on parents' WTP for their child avoiding two or more symptoms on a given day.
11. Work Loss Days (Adults 18-64): This is an estimate of work days lost due to short-term illness, most typically due to respiratory impairment. Valuation is based on the county median daily wage.
12. Premature Mortality (Adults 30-99): Premature death is defined in epidemiological studies as a death from an air pollutant-related cause prior to

their expected age of death, the latter based on actuarial research. Typically this period falls between 10 and 15 years before normal life expectancy. There are a number of epidemiological studies that have analyzed the mortality impact of elevated PM2.5 exposure in relatively large samples of the U.S. urban population. Because the most robust statistical relationships with premature mortality have been found with ischemic heart disease[10] and lung cancer, CRFs for these endpoints were selected. Conversely, there is less compelling statistical evidence regarding elevated PM2.5 and all-cause mortality and this CRF option was not selected. BenMAP valuation of the social cost of avoided mortality was based on the average of 26 VSL studies.

E.4 Incidence Results

Mean 2019 annual incidence reductions by county for the full set of endpoints used in the analysis are presented in Table E-1.[11] The results for the non-fatal endpoints are displayed in Figure E-2 and E-3 and the avoided fatality results are shown in Figure E-4. These reductions are based on county by county estimates of reduced annual daily exposure to PM2.5 that are derived from ARB's modeling estimates of cumulative emission reductions and lower design values resulting from control measures in the *2012 PM2.5 Plan* and related controls from previously adopted plans. As noted, the base year for estimating reduced annual daily exposure is 2007. Differences across county estimates reflect the combined effect of (1) population differences ranging from a high in Fresno County to a low in Madera County and (2) different percentage reductions in annual daily PM2.5 for each county depending on the ARB modeling results. In general, counties with the highest design values experienced proportionally higher percentage reductions in annual daily PM2.5 by 2019.

Of note is the BenMAP estimate of 671avoided cases of pre-mature mortality. This estimate is roughly consistent with comparable estimates of mortality reductions from PM2.5 reductions that were conducted by ARB (2010) and Hall et al. (2008; cited above).[12] It should be noted that for several of the health symptom endpoints, incidence reductions are based on the relatively narrow age ranges—reflecting the studies upon which the CRF was based. As a result, these endpoint results reflect a proportional underestimation of health benefits for the entire Valley population, both in terms of the actual incidence reductions and the corresponding economic benefits.

---

[10] Ischemic heart disease is characterized by reduced blood supply to the heart muscle usually due to coronary artery disease (atherosclerosis of the coronary arteries). Its risk increases with age, smoking, hypercholesterolaemia (high cholesterol levels), diabetes, and hypertension (high blood pressure), and is more common in men and those who have close relatives with ischemic heart disease. See: http://en.wikipedia.org/wiki/Ischaemic_heart_disease

[11] Standard deviations for incidence estimates are not included here but are available upon request.

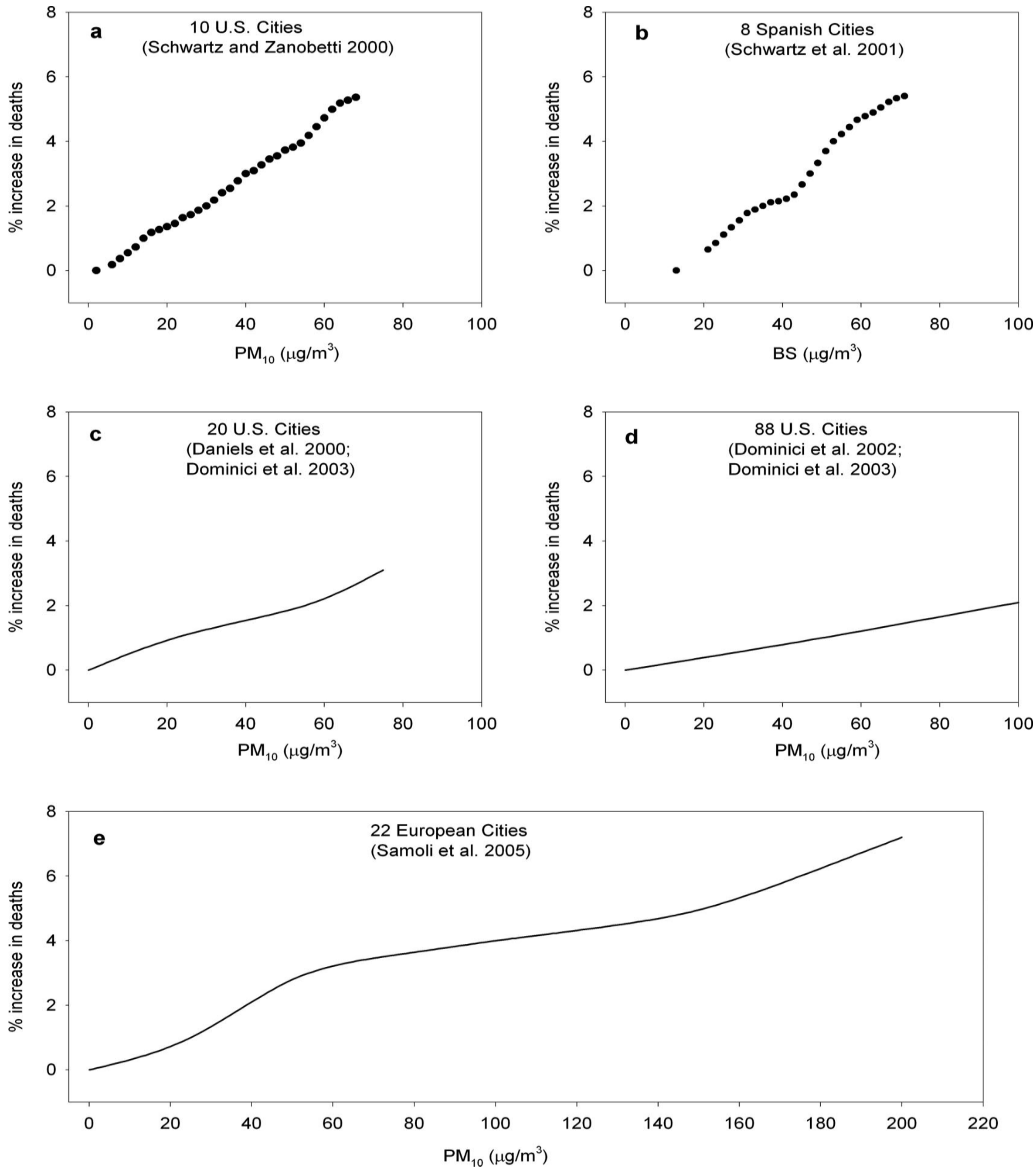
[12] CARB (2010) *Estimate of Premature Deaths Associated with Fine Particle Pollution (PM2.5) in California Using a U.S. Environmental Protection Agency Methodology.* Sacramento, CA: California Air Resources Board. Available at: http://www.arb.ca.gov/research/health/pm-mort/pm-report_2010.pdf

E.5 Valuation Results

Subsequent to estimating the annual reductions in incidence of the selected health endpoints, BenMAP assigns a dollar value to each endpoint for each county based on the cost factors applicable to the endpoint in question. The valuation results for the non-fatal endpoints are displayed in Table E-2 and the county fatality valuation is shown in Figure E-5. By 2019, county by county reductions in PM2.5 attributable to total emission reductions from the *2012 PM2.5 Plan* and related PM2.5 control measures are estimated to result in over $102.15 million in annual avoided health costs associated with non-fatal health endpoints. Because BenMAP cannot capture the full range of health impacts and costs, such as foregone career or recreational benefits due to impaired health, as well as the constricted age range for some symptom-related endpoints as discussed above, this figure most certainly underestimates the full benefits of attaining the 2006 PM2.5 standard in 2019 by a substantial margin.

In the case of premature mortality, a VSL of $7.99 million per case in 2010 dollars was used. The estimated social benefit from the 671 cases of avoided deaths is approximately $5.36 billion. Irrespective of the logic of assigning a dollar value to each case of avoided death in BenMAP, the intrinsic value of saving over 600 lives annually by 2019 is arguably the single most compelling justification for the *2012 PM2.5 Plan*.

Figure E-1 Selected Concentration Response Functions



Reprinted from Pope, C.A., and D. Dockery (2006, p. 720) *Health Effects of Fine Particulate Air Pollution: Lines that Connect.* Journal of Air and Waste Management Association 56: 709-742.

Table E-1 BenMAP Estimates of Mean Annual Reductions in Health Effects Under the Plan by 2019

Health Endpoint	**Totals**	Fresno	Kern	San Joaquin	Stanislaus	Tulare	Merced	Kings	Madera
Acute Myocardial Infarction	**93**	29	25	9	7	11	3	4	4
HA, Asthma 0-19	**131**	56	28	9	11	13	4	4	6
HA, Cardiovascular	**175**	47	51	16	14	26	6	10	5
HA, Asthma 20-99	**246**	64	77	30	16	35	11	7	6
ER Visits, Asthma 20-99	**407**	123	94	48	28	53	22	23	16
ER Visits, Asthma 0-19	**699**	252	160	47	44	90	36	35	37
Acute Bronchitis	**1,498**	404	406	149	127	222	72	64	54
Upper Respiratory Symptoms	**15,523**	4,206	4,294	1,482	1,260	2,334	728	667	552
Lower Respiratory Symptoms	**19,011**	5,093	5,207	1,887	1,595	2,829	912	807	681
Asthma Exacerbation	**114,376**	31,144	31,124	11,269	9,469	17,037	5,445	4,867	4,021
Work Loss Days	**125,138**	34,816	35,300	11,752	10,077	16,882	5,367	6,303	4,641
Mortality	671	172	207	72	61	86	26	23	24

Note: Shaded health endpoints are based on concentration response functions (CRF) derived from the 2011 Valley Epidemiological Study conducted by CSU Fresno and UCSF-Fresno.

Figure E-2 Avoided Disease Incidence by 2019 due to Lower PM2.5 Exposure

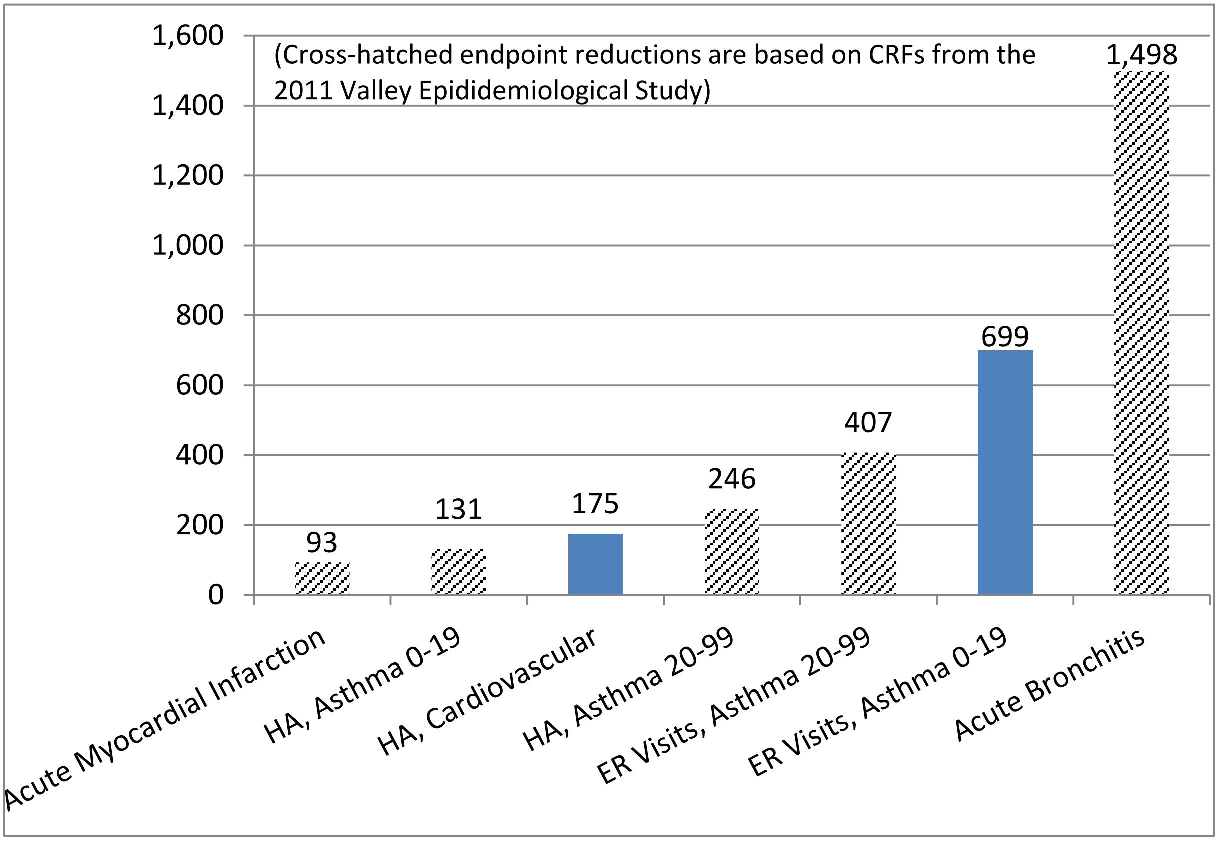


Figure E-3 Reduced Disease Symptoms and Lost Work by 2019

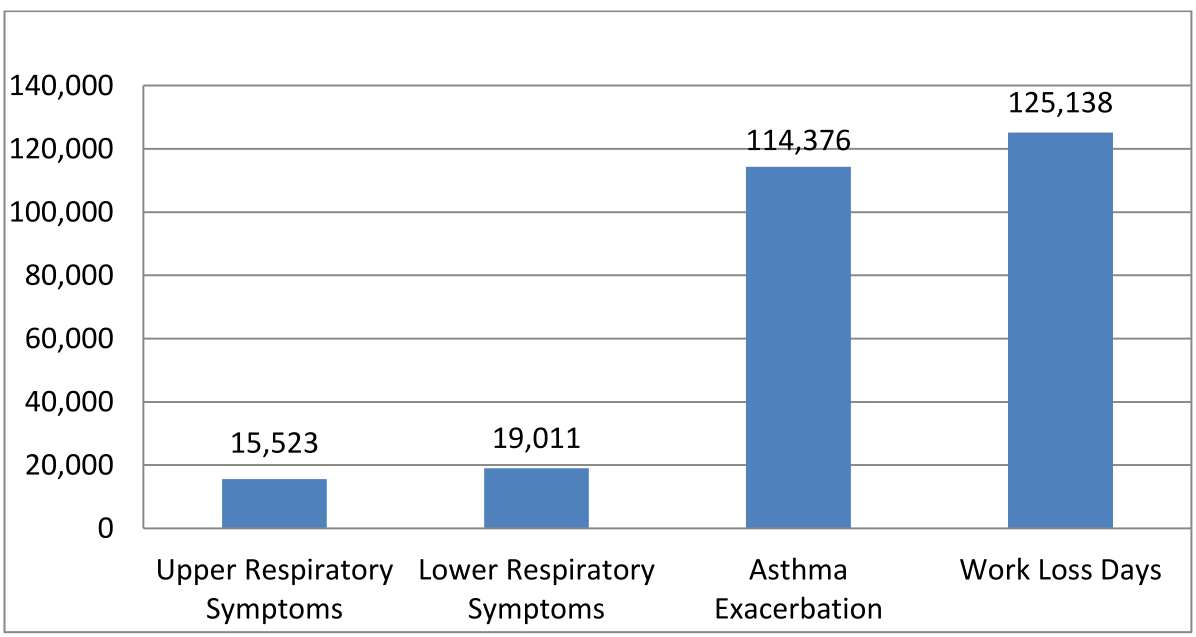


Figure E-4 County Annual Avoided Deaths due to Premature Mortality by 2019

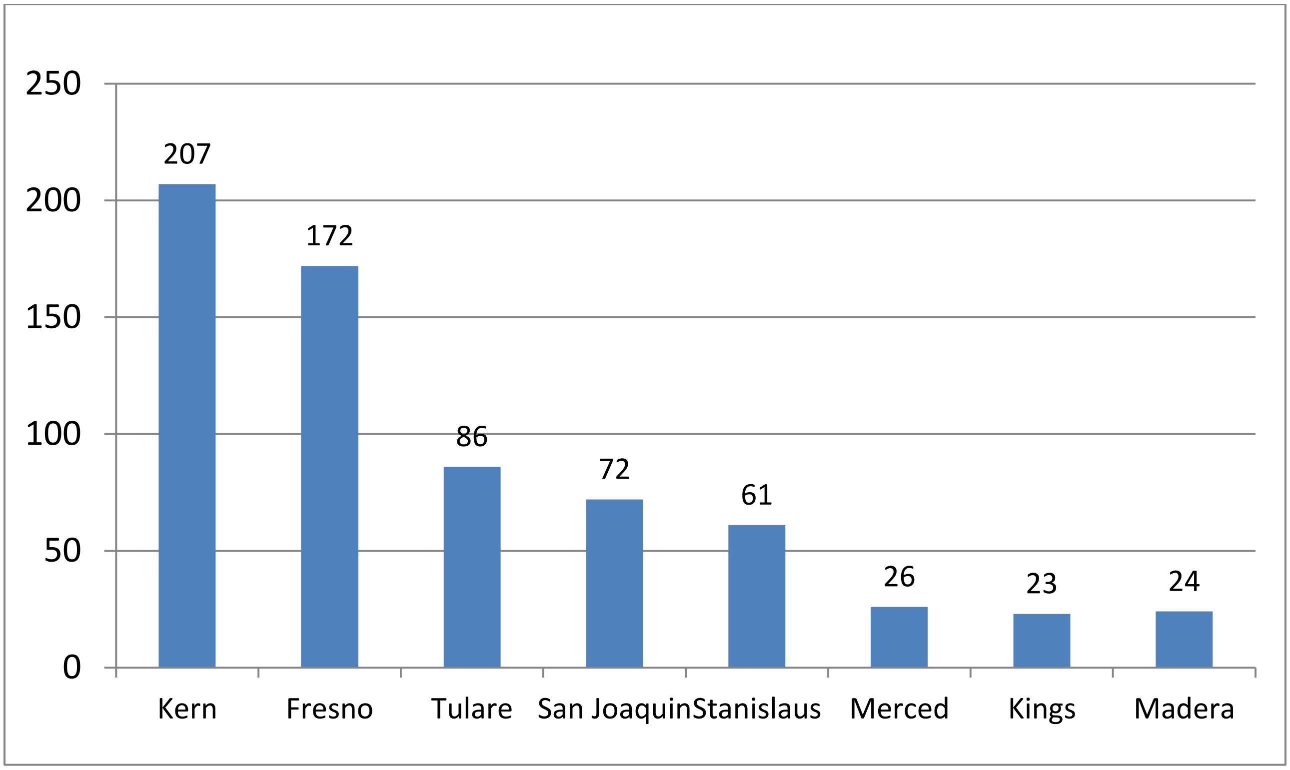
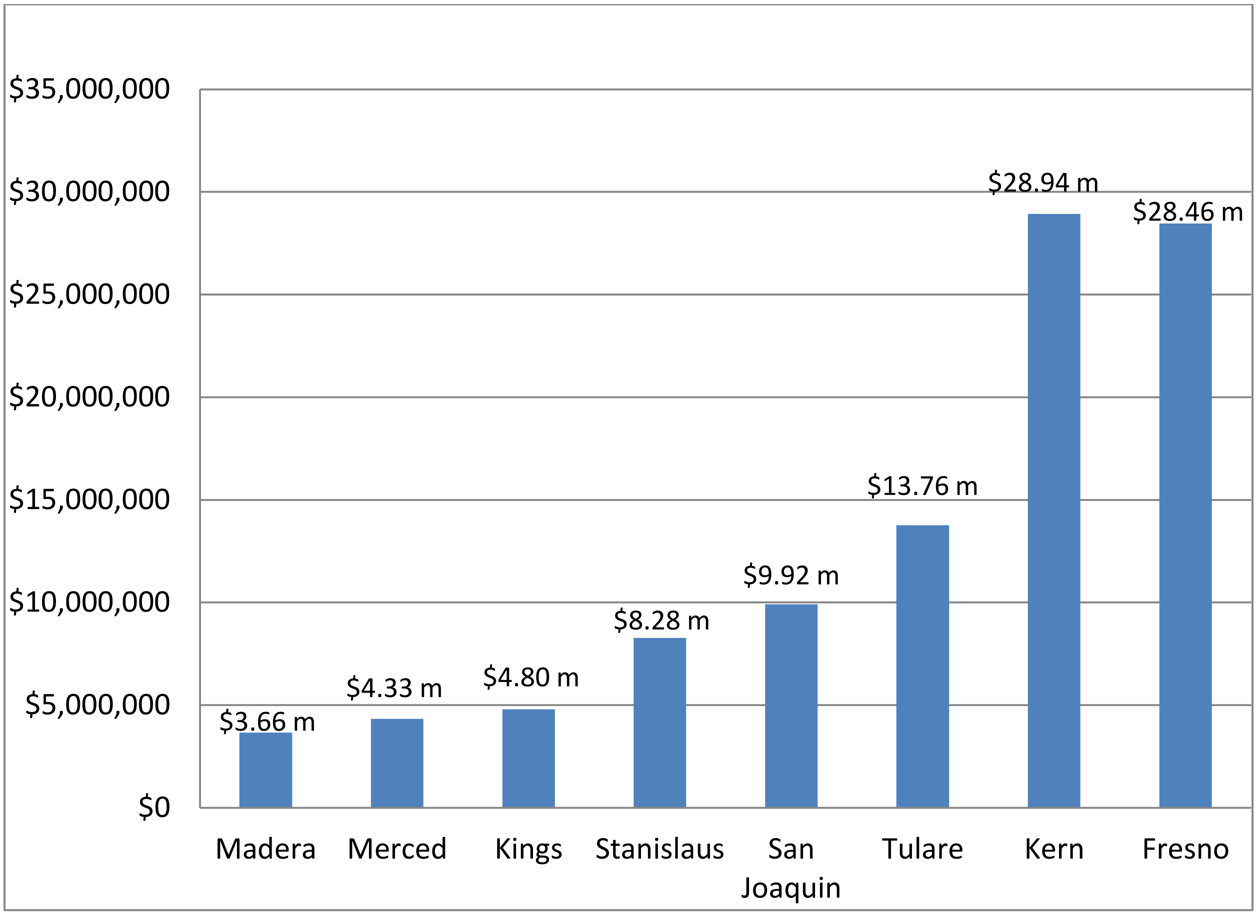


Table E-2 Annual Estimated Reductions in Non-Fatal Health Costs by 2019 for Each Health Endpoint

	Madera	Merced	Kings	Stanislaus	San Joaquin	Tulare	Kern	Fresno	Endpoint Totals
Hospital Admissions, Respiratory	$11,977	$8,624	$10,620	$30,716	$34,483	$53,035	$168,286	$69,212	$386,955
Emergency Room Visits, Asthma	$20,191	$22,534	$22,412	$27,826	$37,031	$55,680	$98,426	$145,396	$429,496
Acute Bronchitis	$25,948	$34,690	$30,587	$60,626	$71,573	$106,243	$194,735	$193,358	$717,759
Acute Myocardial Infarction	$135,234	$116,189	$137,330	$236,316	$292,119	$357,647	$842,946	$963,904	$3,081,686
Upper Respiratory Symptoms	$130,833	$172,385	$157,888	$298,416	$351,078	$552,944	$1,017,185	$996,355	$3,677,083
Lower Respiratory Symptoms	$161,316	$215,913	$191,203	$377,829	$446,874	$670,151	$1,233,296	$1,206,413	$4,502,994
Hospital Admissions, Asthma	$199,604	$255,334	$192,114	$446,696	$655,726	$787,629	$1,749,358	$1,992,572	$6,279,033
Hospital Admissions, Cardiovascular	$204,764	$247,980	$374,376	$548,160	$607,102	$987,523	$1,969,346	$1,828,704	$6,767,955
Asthma Exacerbation	$374,797	$507,524	$453,618	$882,581	$1,050,305	$1,587,928	$2,900,901	$2,902,789	$10,660,442
Work Loss Days	$695,183	$767,170	$909,471	$1,641,778	$2,010,104	$2,391,386	$5,810,543	$5,313,370	$19,539,004
Acute Respiratory Symptoms	$1,704,678	$1,981,334	$2,324,078	$3,728,577	$4,360,359	$6,209,217	$12,950,455	$12,850,859	$46,109,557
County Totals	$3,664,525	$4,329,677	$4,803,697	$8,279,521	$9,916,754	$13,759,382	$28,935,476	$28,462,931	$102,151,964

Figure E-5 County Annual Avoided Non-Fatal Health Costs by 2019



This page intentionally blank.