



DEPARTMENT OF
ECOLOGY
State of Washington

**Health Effects and Economic Impacts
of Fine Particle Pollution in Washington**

Washington State Department of Ecology

Air Quality Program

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Executive Summary

Since 1990, a large number of scientific studies have documented the negative health effects of air pollution on people, especially the health effects of particle and fine particle pollution - particles smaller than 2.5 microns in size. Just as these health effect studies have been used to determine the health and financial consequences of air pollution for the national population, they can be used to better understand the consequences for citizens and communities in Washington State. This report describes a Department of Ecology (Ecology) analysis to quantify the health and monetary impacts of fine particle pollution in the state. The analysis was done by comparing estimates of the impacts at existing pollution levels to estimates of health effects at a “clean air” or background level.

Estimating costs/benefits

Ecology used a tool developed by the US Environmental Protection Agency (EPA) to analyze and estimate the benefits of regulating air pollution. This tool, called Environmental Benefits Mapping and Analysis Program (BenMAP), estimates the health effects and health care costs of disease resulting from air pollution. To make these estimates, BenMAP uses:

- population data,
- air quality measurement information,
- information on the relationship between PM_{2.5} exposure health effects from a variety of epidemiological studies of air pollution,
- disease incidence and prevalence rates, and
- information from economic studies of the monetary benefits of reducing the incidence of these health impacts .

Ecology limited its analysis to the health effects of fine particle air pollution - also called PM_{2.5}. Ecology focused on PM_{2.5} because it is a pollution problem in many Washington communities, has received the largest volume of national and international research, and has been associated with significant adverse human health effects. PM_{2.5} has been strongly associated with increases in heart, circulatory and lung diseases that sometimes result in death.

Results of analysis

Numerous national and international studies show an association between increases in PM_{2.5} and increases in premature death. Ecology selected five different studies to model the relationship between PM_{2.5} and an increase in premature death in Washington. These studies estimate between 300 and 4,300 additional deaths in Washington each year. Using one of the most widely-cited studies in the health effects literature (Pope, et al. 2002), Ecology estimates conservatively that approximately 1,100 people die each year in Washington due to PM_{2.5}. Numerous other studies show an association

between increases in $PM_{2.5}$ and the incidence of serious diseases. Based on studies included in the BenMAP model, Ecology estimates that, every year in Washington, $PM_{2.5}$ contributes to approximately:

- 1,500 nonfatal heart attacks,
- 450 incidents of different heart diseases not resulting in heart attacks,
- 1,900 incidents of acute bronchitis,
- 100 cases of chronic lung disease,
- 250 incidents of pneumonia,
- 400 emergency room visits for asthma, and
- thousands of incidents of worsened asthma.

Ecology estimates that the direct and indirect costs of these diseases for citizens, businesses and state health care institutions approach \$190 million each year.

Health Effects and Economic Impacts of Fine Particle Pollution in Washington

Since 1990, there has been a significant increase in information about the health effects of air pollution on people, especially the health effects of particle and fine particle pollution. Hundreds of such studies have been conducted in the U.S. and worldwide. The results of these studies have been used to inform decisions by the World Health Organization and national environmental organizations about clean air guidelines and standards. These studies have consistently shown that fine particle pollution is more dangerous to human health than originally thought. Exposure to levels previously believed to be safe can result in a range of diseases and, in some cases, death. In 2007, the Environmental Protection Agency (EPA) used the results of these studies to establish more protective pollution limits for fine particles in the United States.

Just as the health effect studies have been used to determine the health and financial consequences of air pollution for the national population, they can be used to better understand the same consequences for citizens and communities of Washington State. Ecology has undertaken an effort to better understand the health and economic effects of air pollution in Washington. Understanding these effects can help inform state and local government policy decisions about air quality.

Ecology's analysis seeks to answer the question "What are the health effects and economic costs of the existing levels of fine particle air pollution in Washington?" We did this by comparing estimates of the impacts at existing pollution levels to estimates of health effects at a "clean air" or background level.

Initial Analysis

Ecology limited its initial analysis to the health effects of fine particle air pollution - also called PM_{2.5}. PM_{2.5} comes from burning fossil fuels and organic matter. It is a pollution problem in many communities in Washington. It is also the pollutant that has received the bulk of academic study over the past two decades. Fine particles are easily inhaled and, because of their small size, are not filtered by the nose. The smaller these particles are, the more deeply they penetrate into the lungs, where they can cause damage. Breathing fine particles is associated with most types of respiratory illness, cardiovascular disease (heart disease and strokes), and even death. Extensive research studies consistently show that exposure to elevated fine particle concentrations is associated with:

- Death and mortality:
 - Increased total number of deaths
 - Increased number of deaths from respiratory illnesses
 - Increased cardiovascular deaths
 - Increased lung cancer
 - Increased risk of premature births and infant mortality

- Hospitalization:
 - Increased hospital admissions and emergency room visits
 - Increased hospital admissions, emergency room visits for respiratory and cardiovascular conditions
- Respiratory illness:
 - Increased risk of pneumonia
 - Increased risk of post-neonatal mortality from respiratory disease
 - Increased pneumonia, bronchitis and chronic obstructive pulmonary disease
 - Increased respiratory symptoms in both the lower and upper respiratory tract
 - Decreased lung function
 - Increased incidence of rhinitis (respiratory allergic reactions) and sinusitis.
- Asthma:
 - Worsened asthma attacks
 - Increased bronchodilator use
 - Increased hospital admissions due to asthma attacks
- Lost work days and quality of life:
 - Increased absences from work or school
 - Increased number of days of restricted activity

In Ecology's initial analysis, we estimated the likely number of some of these effects in Washington. We used information from epidemiological studies, along with monitored and modeled PM_{2.5} data, to develop our estimates.

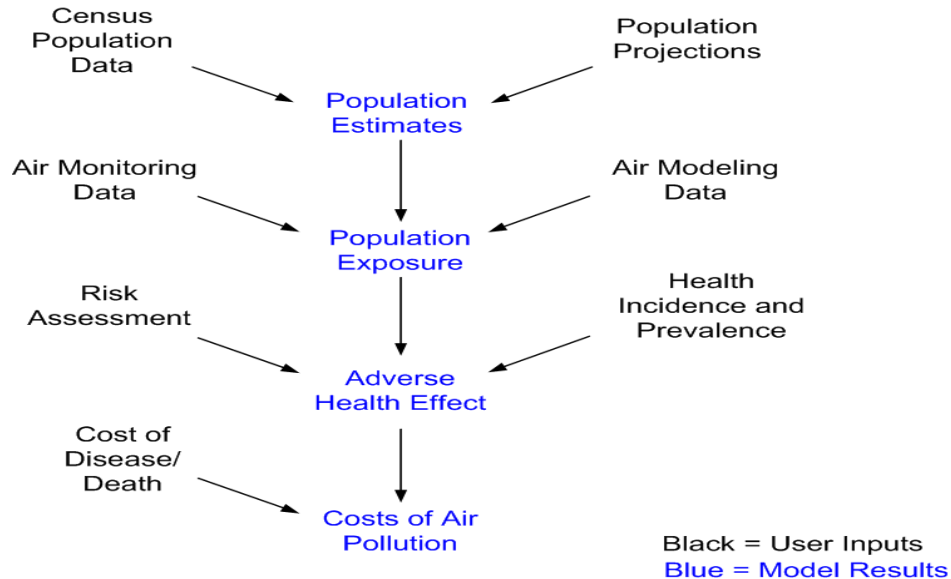
Regulatory benefit analysis

Ecology used a tool developed by EPA to analyze the benefits of national air quality regulations. This tool, called Environmental Benefits Mapping and Analysis Program (BenMAP), uses:

- geographic population data
- air quality measurement information
- information on health effects from a variety of epidemiological studies of certain types of air pollution, and
- information from economic studies of the costs of disease.

BenMAP combines this information to estimate the health effects, health care costs and economic impacts of disease resulting from air pollution within geographic areas.

BenMAP Data Flow



Using BenMAP

Team

Ecology assembled a technical team of specialists to select appropriate data for the model and learn how to use the tool. The agency sought initial guidance from the developer of BenMAP. We developed a team of specialists in air quality monitoring and modeling, toxicology, epidemiology, emissions inventory, policy analysis, information technology, and economics. The team included relevant Ecology Air Quality Program staff and representatives of the state Department of Health and the Puget Sound Clean Air Agency, as well as a research professor from the University of Washington.

Data

We have run the model using Washington-specific population and air pollution information, as well as Washington health care cost data, when available.

For purposes of estimating health effects, we believe it is acceptable to apply national- or regional-level health data to Washington's population and air quality conditions (Hubbell et. al. 2009). Several of the national-level studies, while not specific to Washington, nevertheless included Washington cities in the analyses of health effects. To help verify the results, we have compared the estimates generated by the model to the number of hospitalizations and deaths in Washington. This provides an indication of how reasonable the modeled estimates were compared to the total number of recorded health effects. Therefore, we believe our results reflect reasonable estimates of the health effects of fine particle pollution.

Methods

EPA developed the BenMAP tool specifically to compare the health impacts and economic benefits of implementing particular policy choices. Therefore, the models used in the tool are set up to compare current air pollution conditions to changed air pollution conditions to estimate a change in health and cost outcomes. The team estimated PM_{2.5}'s health and corresponding monetary costs to Washington by essentially comparing existing air pollution levels to "clean" air quality conditions. We defined "clean air" as the average of the cleanest 20% of days per monitored area.

Conditions that affect human exposure to PM_{2.5}, such as weather patterns, can vary considerably from year to year. In an effort to minimize this variability, we used calendar day median values from five recent, continuous years of air pollution readings to create a "representative year" for this analysis.

Population

The team used 2007 county census population projections from the state Office of Financial Management. We separated these data into 18 different age groups. Note that BenMAP uses these age groups to more closely match the age groups targeted by each health study. This improves the accuracy of the health effect impact estimates.

Monitoring

Ecology has a network of over 50 continuous PM_{2.5} monitors statewide. The data from these monitors meets all the EPA guidelines for the collection and use of such data. We loaded five years of Washington State PM_{2.5} monitoring data (2004 through 2008) into BenMAP for this study. In order to align monitoring data with health effects information from the epidemiological studies, we calculated daily PM_{2.5} averages (midnight to midnight). From the five years of daily data, we then calculated median values for each calendar day, effectively creating a complete "representative" year for each location.

Modeling

BenMAP uses modeled data to estimate PM_{2.5} concentrations in areas between air quality monitoring sites. Washington State University models the statewide PM_{2.5} concentrations on a daily basis. We obtained three years of model data (2006-2008) and calculated the daily PM_{2.5} averages at each 12 kilometer grid location of the state. Medians at each grid point were then computed for each calendar day of the "representative" year. We think the resulting dataset of the "representative year" is a robust estimate of PM_{2.5} in Washington State, and is not unduly influenced by year-to-year variations.

Health functions

A major branch of environmental epidemiology concerns the effect of air pollution on humans. This research examines whether there are significant associations between exposure to certain air pollutants and certain diseases or death, and how strong such associations are. To different degrees, studies also

account for other factors that may influence the results. The BenMAP tool comes pre-loaded with information from a number of studies that show the adverse health effects of air pollutants.

The technical team evaluated the studies in BenMAP to determine which appeared to be the most relevant to Washington. We selected several studies and their related health impact functions (also called concentration-response functions, or CRFs) from the hundreds preloaded in BenMAP. We also reviewed the most recent epidemiology literature to make sure we included any important studies not yet in BenMAP. As a result of this review, we added data based on Jerrett et. al. 2009. All of the studies used have been published in major scientific journals following peer review. Our intent was to choose the most relevant and appropriate studies to predict outcomes in Washington. Including confidence intervals in BenMAP allows results to be expressed as ranges for each possible health outcome among populations exposed to PM_{2.5}. Note that the epidemiological studies differ in their conclusions, and that the estimates we report are on the low end of the scale. In other words, the incidence rates and associated costs may be considerably higher than we estimate.

BenMap also includes disease incidence and prevalence rates. Pre-loaded rates within the tool were used for all analyses. Mortality (death) rates were available by counties in each state. BenMap used regional rates for hospitalization for four regions of the United States: northeast, mid-west, south, and west. The west coast regional rates used in our analyses include combined rates from Montana, Idaho, Wyoming, Colorado, New Mexico, Arizona, Utah, Nevada, Washington, Oregon, California, Alaska, and Hawaii. BenMap obtained prevalence or incidence rates of chronic and acute diseases and respiratory symptoms from national databases, surveys, and research investigations.

Health care costs and economic impacts

In addition to health effect studies, the BenMAP model has a number of pre-loaded economic and health care cost studies. The technical team's economist evaluated those studies and selected the ones that were most appropriate for the health effects we estimated. In addition, where possible, the economist looked for Washington-specific health care costs and updated all costs to reflect 2009 dollars.

Costs of death and illness

Studies in BenMAP include estimates of direct costs of illness and indirect costs associated with pollution-caused illness:

- Direct costs are those tangible costs for hospitalization, medical tests and services, medicines, doctor visits, etc. Direct costs are estimated using actual charges billed by hospitals and medical establishments.
- Indirect costs are sometimes less tangible, and can include lost work days due to illness or caring for a sick child, lost productivity or education, pain and suffering, and the cost of death. Indirect costs can also be costs to society – not just the sick individual – when they impact families, employers and production, or long-term educational attainments. To estimate indirect costs (or combined direct and indirect costs) economists use estimates of willingness to pay – the amount an individual would be willing to pay to avoid illness or death.

- Willingness to pay is estimated using widely accepted survey techniques that reveal willingness to pay through experiments, or by asking people directly. Willingness to pay estimates can include various direct, indirect, and societal costs at the same time, because they are based on the set of costs perceived by respondents.

Ecology included the most appropriate estimates of costs based on available data, and gave preference to direct costs where available, since they are easier to accurately quantify and provide a conservative base estimate of the costs of illness. However, it should be noted that some of the valuation studies include both direct costs and indirect/willingness to pay estimations.

Uncertainty

Models are tools developed and used to indirectly estimate outcomes when direct measurements are not possible. BenMAP is a model that relies on a variety of inputs and the inputs are subject to varying degrees of uncertainty: Population data is a forecast of people living within geographic areas; 2) monitors provide highly accurate, direct measurement of air pollution at individual monitoring sites – however, in between monitoring sites and at the community scale monitored and modeled data provide only estimates of air pollution levels; health-effect data are estimates with ranges of uncertainty based on studies that estimate the link between certain health end points and exposure to air pollution; rates of disease and hospitalizations are often not state or county specific; and health care cost data is the estimated value of treatment and impact for symptoms and disease which could be expected to vary between patients and communities. Even given these uncertainties, BenMAP is an internationally recognized and accepted tool for estimating health effects and health care costs of exposure to air pollution. Ecology recognizes these uncertainties in the model's outputs and has chosen to use reliable, conservative inputs to the model to generate conservative estimates of outcomes.

Results

General

Because PM_{2.5} is created mostly from combustion in industrial, commercial and residential activities near population centers, higher pollution levels and therefore greater health impacts will occur in and around those areas. Wildfires that occurred in eastern Washington during our study period also generate high PM_{2.5} concentrations; however, the health impacts are smaller than in urban areas since these areas are usually less populated (see mapped results in Appendices).

Incidence of mortality/death

Numerous national and international studies show an association between increases in PM_{2.5} and increases in premature death. Ecology selected five different studies to investigate the relationship between PM_{2.5} and an increase in premature death in Washington. Study findings (at the 50th percentile) ranged from 900 additional deaths (Jerrett, et al. 2009) to 2,800 additional deaths (Laden, et al. 2006) each year. Using one of the most widely-cited studies contained in BenMAP (Pope, et al. 2002), Ecology estimates that approximately 1,100 people die each year in Washington due to PM_{2.5}.

Study	Ages	Number of Deaths 50 th Percentile	Range
Pope et. al. (2002)	30-99	1,100	300-1,900
Laden et. al. (2006)	25-99	2,800	1,300-4,300
Jerrett et. al. (2009) PM	30-99	900	500-1,300
Jerrett et. al. (2009) PM/O ₃	30-99	1,500	900-2,000
Woodruff et. al. (2006)	0-1 (Infant)	5	4-14

Rounded to two significant figures

Of note, a late breaking study by Krewski et. al. published by the Health Effects Institute in June 2009, re-evaluated the data used in the 2002 Pope study. Those results strengthen Pope's conclusions.

Incidence of morbidity/disease

PM_{2.5} has been strongly associated with increases in heart, circulatory and lung diseases. Some of these health impacts are serious enough to result in the premature deaths reflected above. Estimates of nonfatal health impacts for more serious diseases are shown in the table below. The table below shows disease, study used for the CRF, ages of population included, and the midrange of the number of people affected. Different studies result in different findings, therefore there may be some difference or overlap between the studies in this table of results. The BenMAP model allows the user to choose, compare, and/or pool relevant studies.

Disease	Study	Ages of Patients	Incidence (50 th Percentile)
Heart Attack (Nonfatal)	Peters et al. 2001	18-99	1,500
All Cardiovascular (less Heart Attack)*	Moolgavkar et al. 2000	18-64	160
All Cardiovascular (less Heart Attack)*	Moolgavkar et al. 2000	65-99	280
Congestive Heart Failure*	Ito et al. 2003	65-99	150
Dysrhythmia*	Ito et al. 2003	65-99	43
Ischemic Heart Disease*	Ito et al. 2003	65-99	87
Chronic Lung Disease (Less Asthma)*	Moolgavkar et al. 2000	18-64	39

Chronic Lung Disease*	Moolgavkar et al. 2003	65-99	66
Chronic Lung Disease*	Ito et al. 2003	65-99	41
Pneumonia*	Ito et al. 2003	65-99	260
Acute Bronchitis*	Dockery et al. 1996	8-12	1,900
Asthma Hospitalization*	Sheppard et al. 2003	0-64	100
Asthma, Emerg. Rm. Visits	Norris et al. 1999	0-17	400
Asthma Exacerbation, Cough	Ostro et al. 2001	6-18	13,000
Asthma Exacerbation, Cough	Vedal et al. 1998	6-18	63,000
Asthma Exacrb, Short of Breath	Ostro et al. 2001	6-18	18,000
Asthma Exacrb, Wheeze	Ostro et al. 2001	6-18	29,000

Rounded to two significant figures

*Hospital admissions

Monetary benefits (Ecology-selected estimates)

Ecology estimated Washington State-specific values whenever possible, and otherwise maintained consistency with the Environmental Protection Agency's (EPA, 2003) methodology and sources, when a more appropriate or precise state-specific methodology was not available. This means some estimates are entirely Washington State-specific, others are based on national valuations, and some combine national and state-level data.

Overall, Ecology's goal in developing these numbers was to calculate the most state-appropriate values, while maintaining a high degree of confidence in the representativeness and reliability of the results. All dollar valuations are in 2009 inflation-adjusted dollars.

The table below shows the disease, the study used for the valuation, the mid-range of the number of people affected, and cost estimates based on Ecology's estimates of costs in Washington State.

Disease	Valuation Function	Incidence (50 th %)	Estimated Cost
Heart Attack (Nonfatal)	Russel, et al. (1998)	1,500	\$70,000,000
All Cardiovascular (less Heart Attack)*†	CHARS 2006 – 2008Q3 (WA-DOH, 2008)	450	\$17,000,000
Chronic Lung Disease*	CHARS 2006 – 2008Q3 (WA-DOH, 2008)	100	\$ 2,000,000
Pneumonia*	CHARS 2006 – 2008Q3 (WA-DOH, 2008)	250	\$ 5,000,000
Acute Bronchitis	Dickie, et al. (1987), Tolley, et al. (1986), and Loehman, et al. (1979)	1,900	\$ 850,000
Asthma*	CHARS 2006 – 2008Q3 (WA-DOH, 2008), U.S. Bureau of Labor and Statistics, (2009b)	100	\$ 1,200,000
Asthma, Emerg. Rm. Visits	Stanford, et al. (1999)	400	\$ 150,000
Work Loss Days	US Bureau of Labor Statistics (BLS, 2007)	174,000	\$31,000,000
Minor Restricted Activity Days	IEc (1993) ⁱ and Tolley, et al. (1986)	1,000,000	\$64,000,000
Total Costs			\$190,000,000

Rounded to two significant figures

* Hospital admissions

†The above table combines incidence estimates from studies of similar disease and non-overlapping age groups. Because the combined estimates of incidence listed above were derived using pre-rounded numbers, the number of incidents may vary slightly from those listed in the previous table.

Appendices

Figures

BenMAP uses a 12-kilometer grid scale to represent spatial information. The following figures show population, estimated annual fine particle concentrations and the estimated number of annual deaths attributable to fine particles within the state.

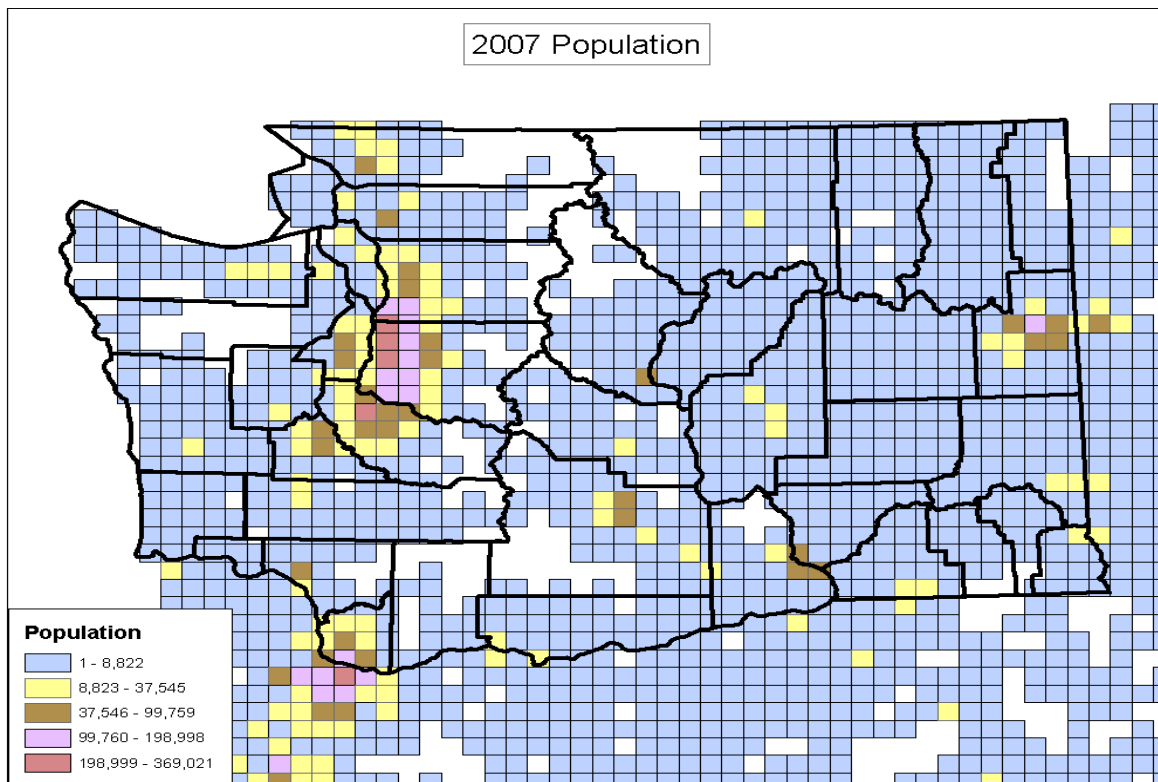


Figure 1: Estimated 2007 Washington State population (data from Washington State Office of Financial Management forecasts)

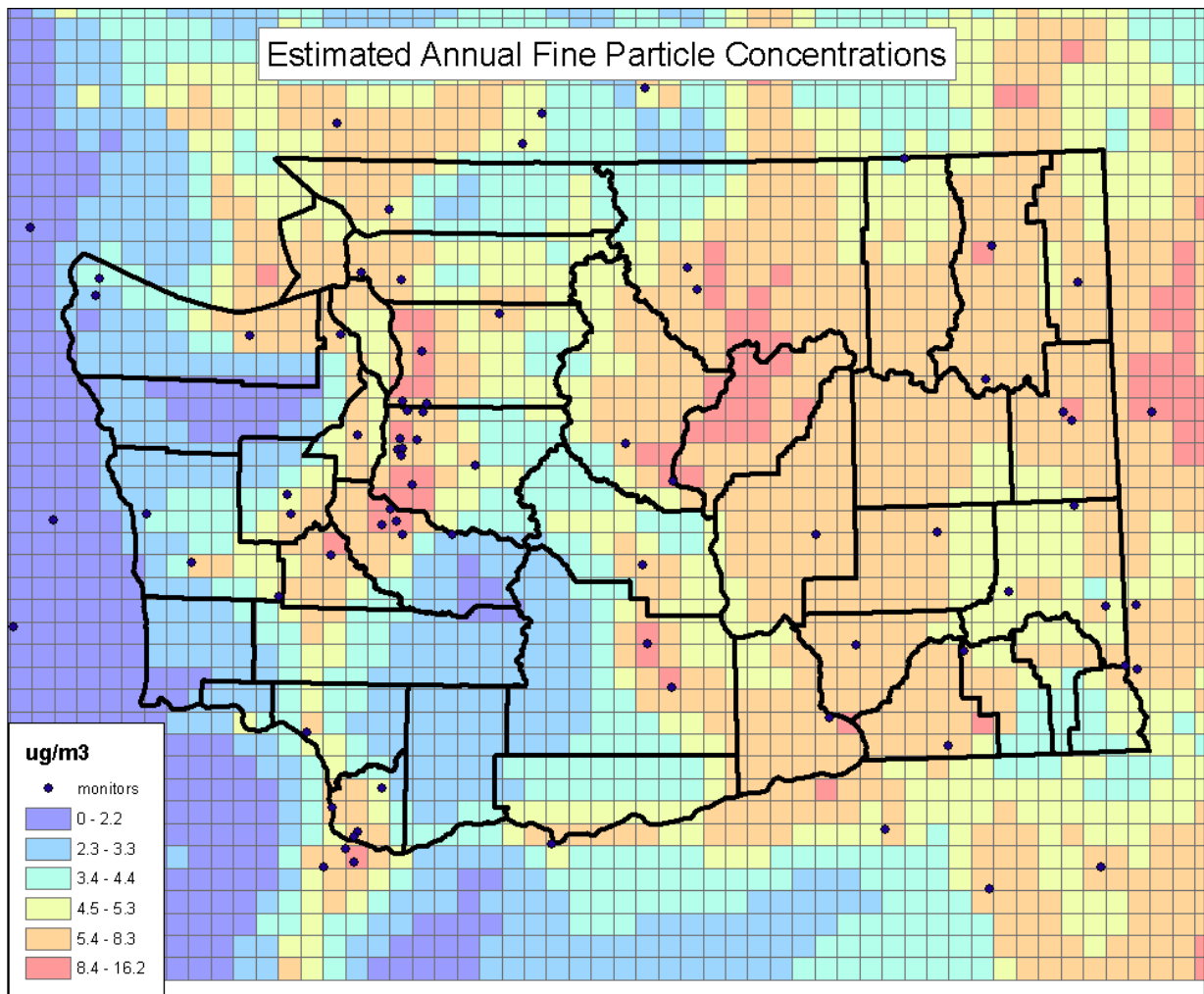


Figure 2: Estimated annual fine particle concentrations (average of 2004-2008 monitored data daily medians scaled with 2006-2008 modeled data daily medians)

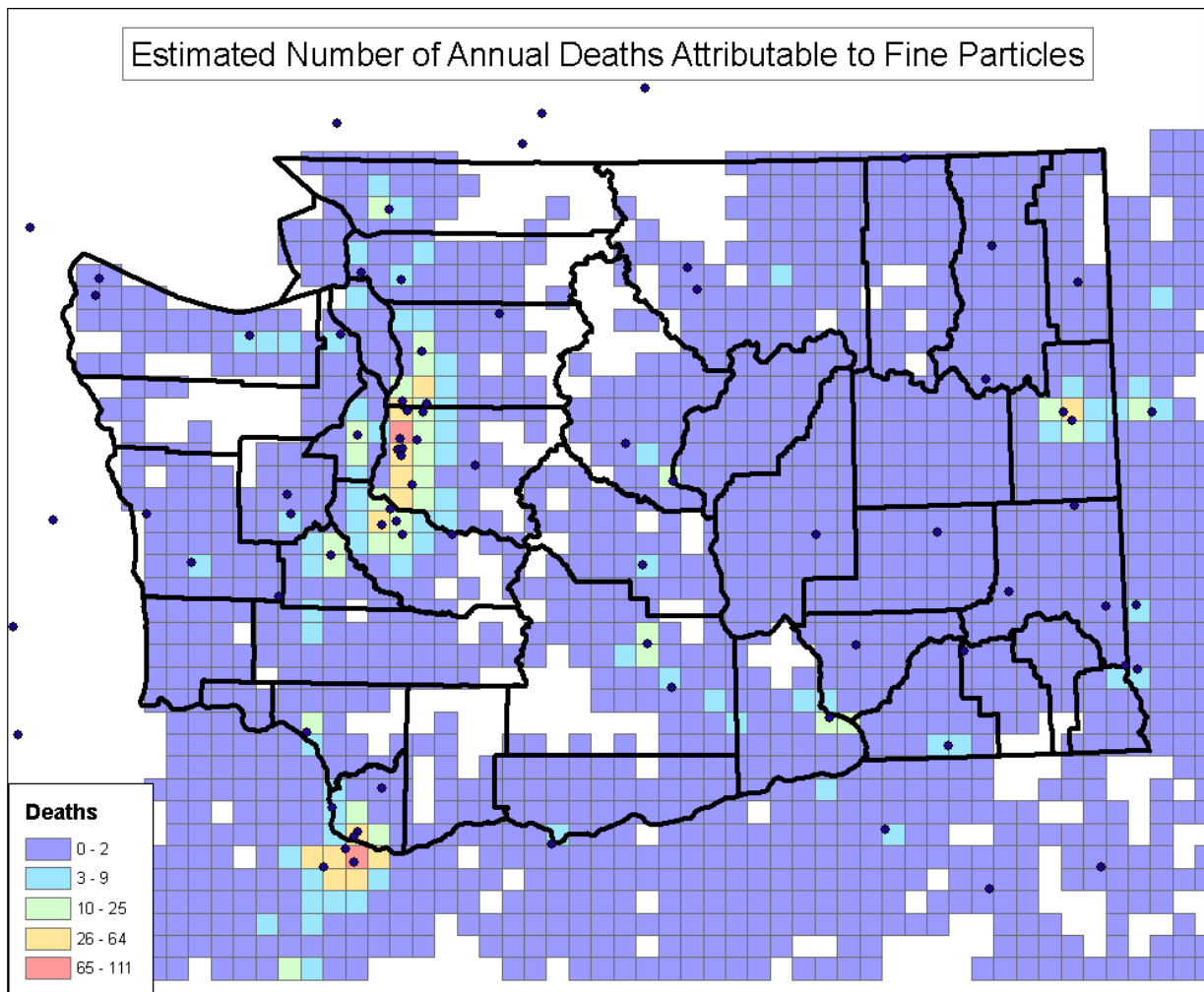


Figure 3: Estimated number of annual deaths of people between the ages of 30 and 99 attributable to fine particle pollution (Pope, et al. 2002)

For more information

On BenMAP:

Go to <http://www.epa.gov/air/benmap/>

On health effects studies:

For descriptions of individual studies contained in BenMAP, see BenMAP User Manual Appendices E & F. The User Manual Appendices is at:

<http://www.epa.gov/air/benmap/models/BenMAPappendicesSept08.pdf>

Other studies include:

“Long-Term Ozone Exposure and Mortality,” Dr. Michael Jerrett et al., New England Journal of Medicine, March 12, 2009.

“Extended Follow-up and Spatial Analysis of the of the American Cancer Society Study Linking Particulate Air Pollution and Mortality,” Dr. Daniel Krewski et al., Health Effects Institute, June 2009

On economic studies and evaluation:

Please request a copy of Ecology’s Technical Report for details on the economic analyses by emailing Ecology at BenMap@ecy.wa.gov.

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Contact us

If you have comments or questions about this report, please contact our technical team through the following e-mail address. Your thoughts or questions will be forwarded to the appropriate staff for response. Thank you. E-mail: BenMap@ecy.wa.gov

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ⁱ Industrial Economics Incorporated (IEc) (1993). Memorandum to Jim DeMocker, US EPA, Office of Air and Radiation, Office of Policy Analysis and Review. 30 September.