Estimating the Benefits to Health of Improving Air Quality Using the BenMAP-CE Tool

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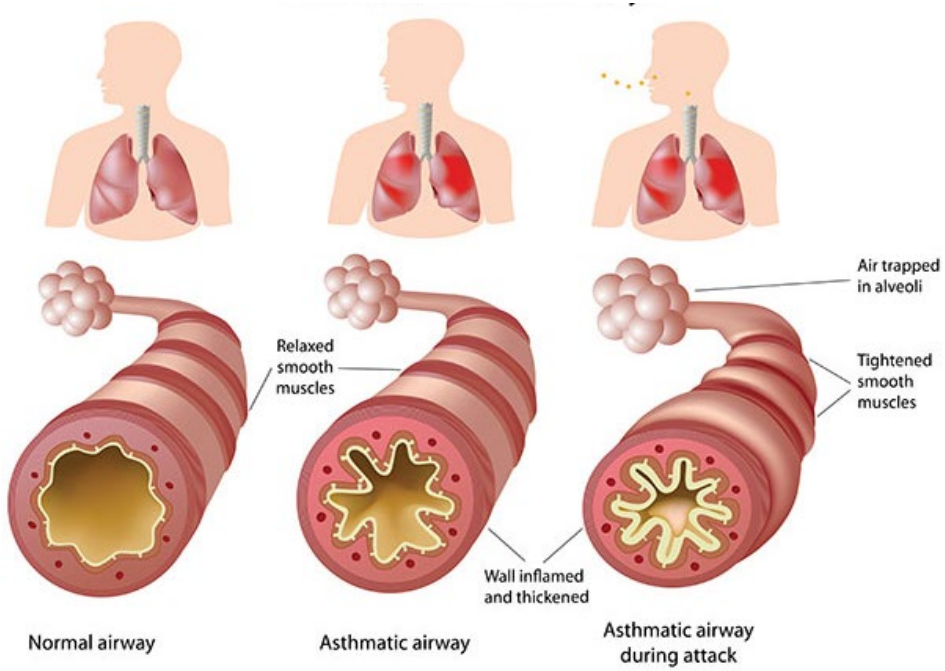
Disclaimer

The views expressed are those of the authors and do not necessarily reflect the views or policies of the U.S. EPA.

What Will You Learn?

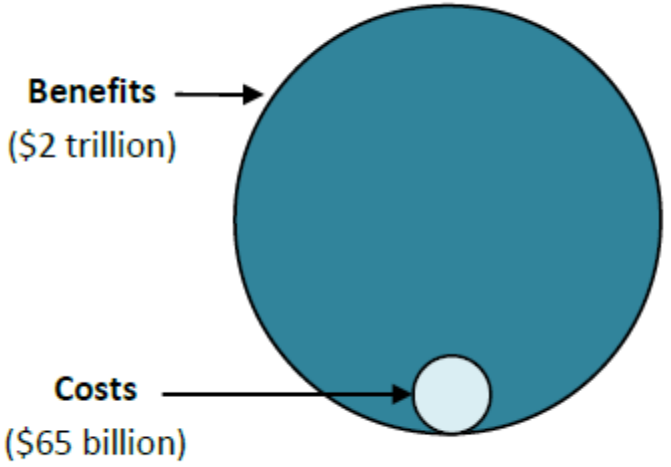
1. **What is a benefits analysis?**
   - What kinds of questions does it help answer?
   - How does it fit within a policy analysis?
2. **What are the steps in calculating air pollution-related health impacts?**
   - What are the air pollution-related effects?
   - What data sources are needed to estimate benefits?
3. **What tools are available?**
   - BenMAP – CE
   - Global Burden of Disease (GBD) Module



Why Estimate the Benefits of an Air Quality Policy?

- Answers the basic question:
  - What are the health and economic benefits of emissions controls and the associated improvements in air quality?
- To compare benefits against the costs of a policy
- Can help decide between different policies
- Can improve efficiency and effectiveness
- Can help determine if a particular policy is "worth it" to society

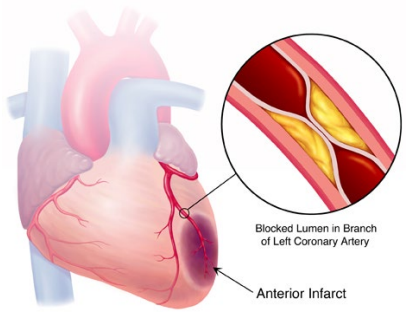
Benefits and Costs of the U.S. Clean Air Act

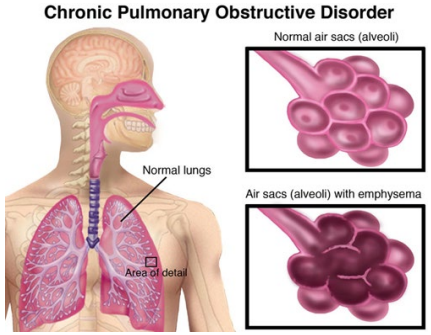


What are the Benefits of Improved Air Quality?

Health

- Reduces the risk of:
  - Early death
  - Chronic disease
  - Heart attacks
  - Asthma attacks
  - Hospital admissions
  - Bronchitis
  - School absences
  - Missed work





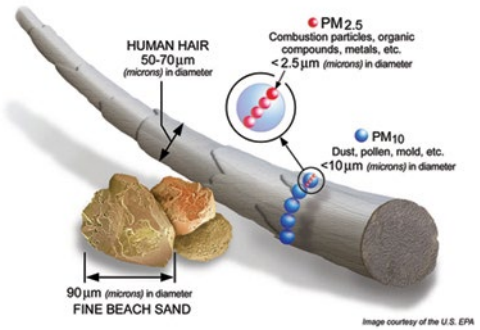
Environment

- Improved:
  - Visibility
  - Forest and crop yields
  - Water quality
  - Habitat

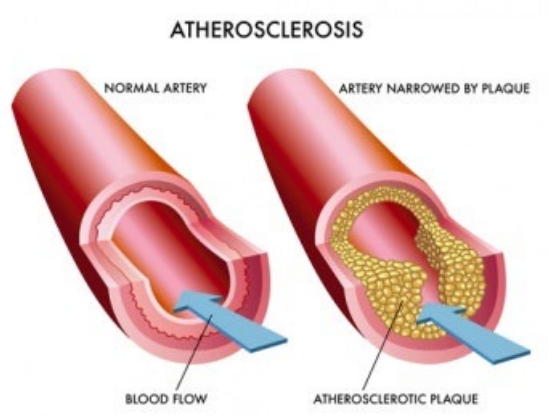
- Reduces:
  - Acid deposition
  - Leaf damage

How Can Air Pollution Affect Health?

Industrial emissions



Fine particles



Human health impacts

The Epidemiological Literature Helps Quantify the Magnitude of the Risk…

Changes in air pollution exposure

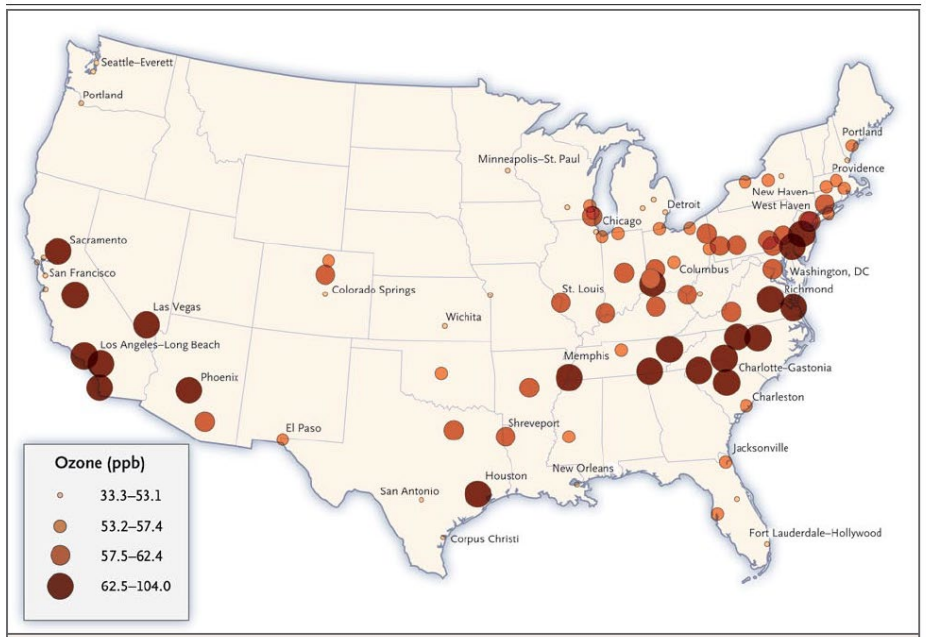


Figure 1. Ozone Concentrations in the 96 Metropolitan Statistical Areas in Which Members of the American Cancer Society Cohort Resided in 1982.

The average exposures were estimated from 1 to 57 monitoring sites within each metropolitan area from April 1 to September 30 for the years 1977 through 2000.

Concentration-response relationship

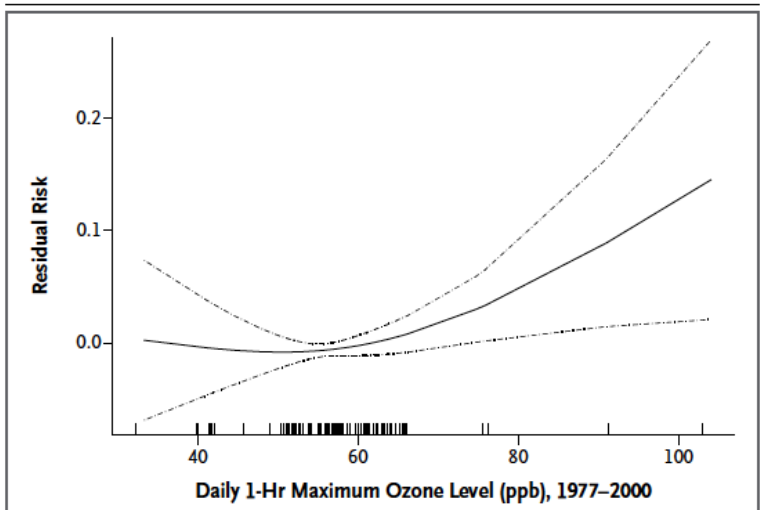
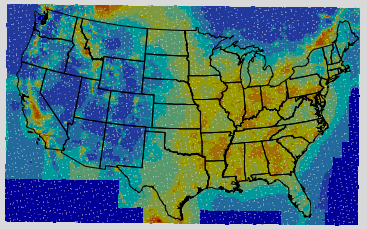


Figure 2. Exposure–Response Curve for the Relation between Exposure to Ozone and the Risk of Death from Respiratory Causes.

The curve is based on a natural spline with 2 df estimated from the residual relative risk of death within a metropolitan statistical area (MSA) according to a random-effects survival model. The dashed lines indicate the 95% confidence interval of fit, and the hash marks indicate the ozone levels of each of the 96 MSAs.

…While the Clinical and Toxicological Literature Help Us Understand the Biological Mechanisms

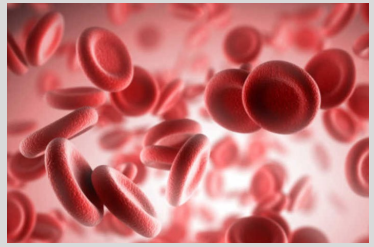
Ambient $PM_{2.5}$



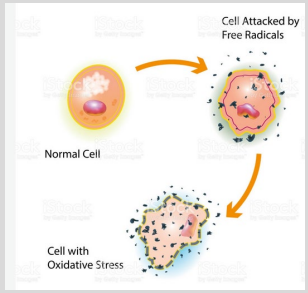
$PM_{2.5}$ inhaled

The body responds

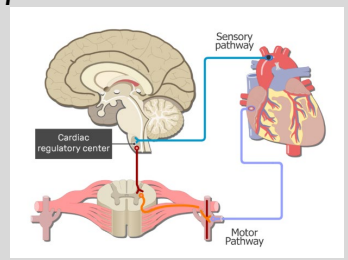
(1) Particles enter the blood stream…



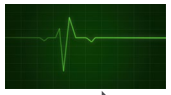
(2) …or Induce inflammation & oxidative stress…



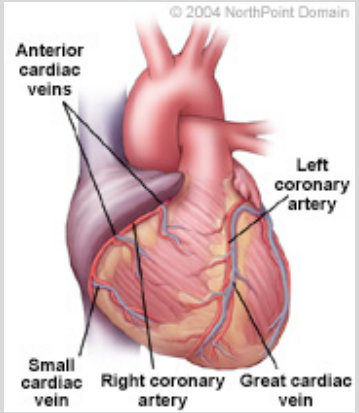
(3) …or perturb the autonomic nervous system



Sub-clinical effects



Observable and clinically significant health outcomes

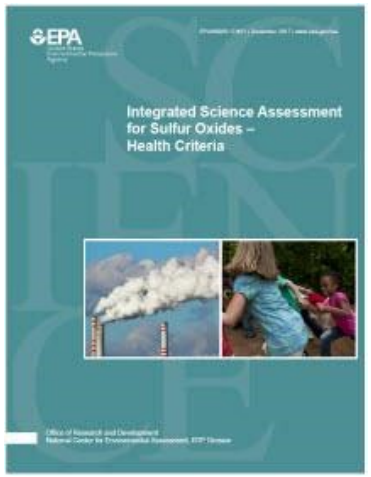


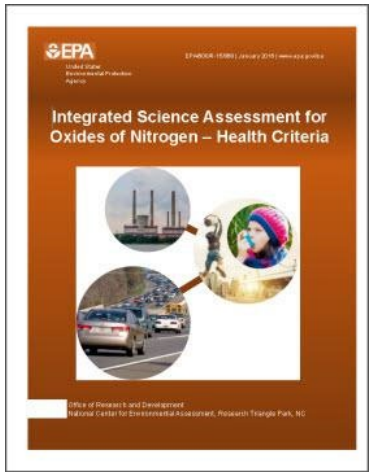
Hospital and ED visits for:

- *Non-fatal heart attacks*
- *Angina*
- *Congestive heart failure*

Integrated Science Assessments (ISA)

- Conducted by EPA's Office of Research and Development
  - Clean Air Act (CAA) mandates periodic review of the science
  - For the 6 criteria pollutants (PM, O_3, SO_2, NO_2, CO, and Pb)
- Provides scientific basis for the criteria pollutant health effects
  - Reviews, synthesizes, and evaluates the body of scientific evidence
  - Considers all relevant studies published since the last review
    - Health: epidemiology, human exposure, animal toxicology studies
    - Welfare: visibility impairment, ecological effects, climate, etc.
  - Key science judgments
- Peer-reviewed by the EPA's independent Science Advisory Board
  - Science Advisory Board review is mandated by Clean Air Act
  - Often multiple reviews during development
  - Peer review comments include consensus statements
  - Meetings open to public





Integrated Science Assessments (ISAs)

… doses or exposures generally w/in 1-2 orders of magnitude of recent concentrations

. . . chance, confounding, and other biases could be ruled out with reasonable confidence

. . . multiple high-quality studies by multiple research groups

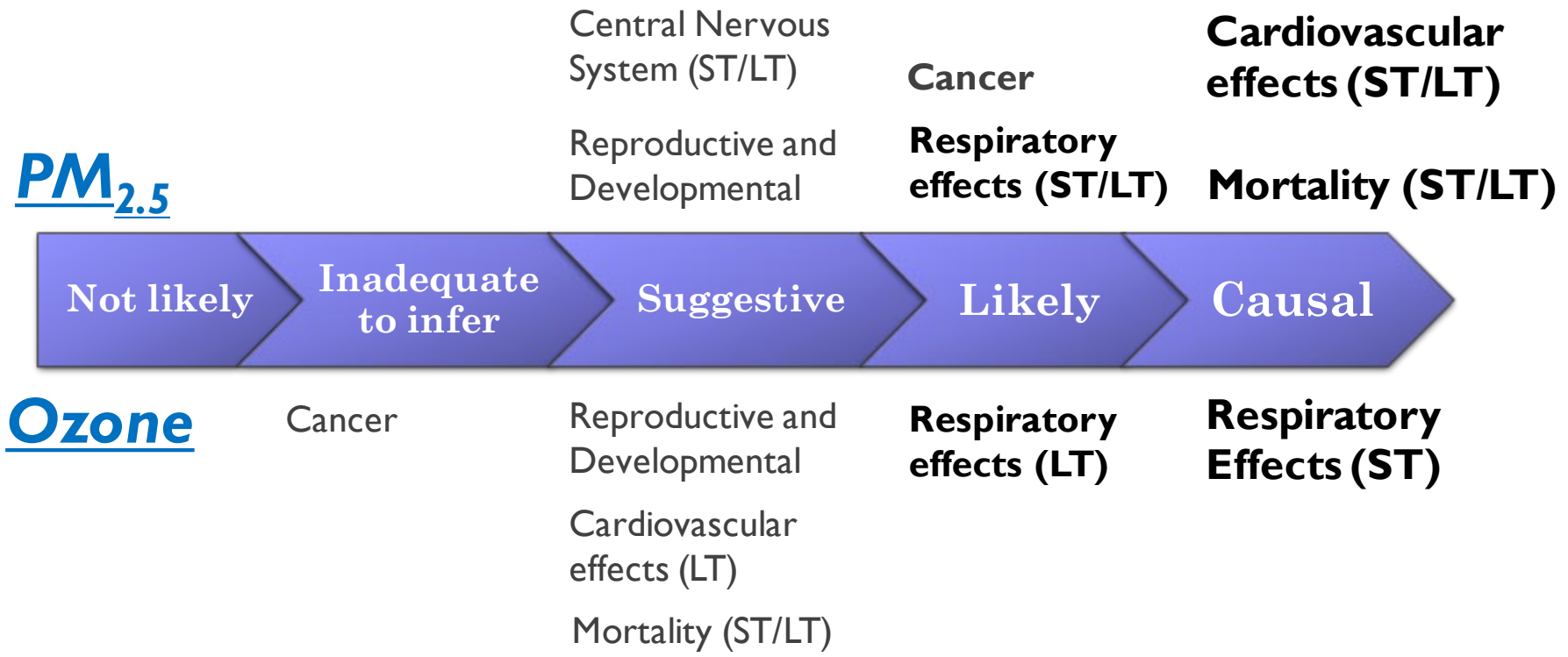
Weight-of-Evidence for Causal Determination

Table II Weight of evidence for causal determination.

	Health Effects	Ecological and Welfare Effects
Causal relationship	Evidence is sufficient to conclude that there is a causal relationship with relevant pollutant exp (e.g., doses or exposures generally within on orders of magnitude of recent concentrations) is, the pollutant has been shown to result in h effects in studies in which chance, confoundi other biases could be ruled out with reasonab confidence. For example: (1) co d huma exposure studies that demonstrate effects; or (2) observational studies that cann explained by plausible alternatives or that are supported by other lines of evidence (e.g., an studies or mode of action information). Gener determination is based on multiple high-qualit studies conducted by multiple research group	Evidence is sufficient to conclude that there is a consideration of many lines of evidence that reinforce each other.
Likely to be a causal relationship	Evidence is sufficient to conclude t causal relationship is likely to exist with relevant pollutant exposures. That is, the pollutant has been shown to result in health effects in studies not explained by chance, confou biases, but uncertainties remain overall. For example: (1) observ an association, but copollutant to address and/or other lines of human exposure, animal, or mo information) are limited or incon toxicological evidence from mul different laboratories demonstra or no human data are available. determination is based on multiple high-quality studies.	Evidence is sufficient to conclude that there is a likely causal association with relevant pollutant exposures. That is, an association has been
Suggestive, but not sufficient, to infer a causal relationship	Evidence is suggestive of a causal relationship with relevant pollutant exposures but is limited, and chance, confounding and other biases cannot be ruled out. For example, (1) when the body of evidence is relatively small, at least one high-quality epidemiologic study shows an association with a given health outcome and/or at least one high-quality toxicological study shows effects relevant to humans in animal species; or (2) when the body of evidence is relatively large, evidence from studies of varying quality is generally supportive but not entirely consistent, and there may be coherence across lines of evidence (e.g., animal studies or mode of action information) to support the determination.	Evidence is suggestive of a causal relationship with relevant pollutant exposures, but chance, confounding, and other biases cannot be ruled out. For example, at least one high-quality study shows an effect, but the results of other studies are inconsistent.
Inadequate to infer a causal relationship	Evidence is inadequate to determine that a causal relationship exists with relevant pollutant exposures. The available studies are of insufficient quantity, quality, consistency, or statistical power to permit a conclusion regarding the presence or absence of an effect.	The available studies are of insufficient quality, consistency, or statistical power to permit a conclusion regarding the presence or absence of an effect.
Not likely to be a causal relationship	Evidence indicates there is no causal relationship with relevant pollutant exposures. Several adequate studies, covering the full range of levels of exposure that human beings are known to encounter and considering at-risk populations and lifestages, are mutually consistent in not showing an effect at any level of exposure.	Several adequate studies, examining relationships with relevant exposures, are consistent in failing to show an effect at any level of exposure.

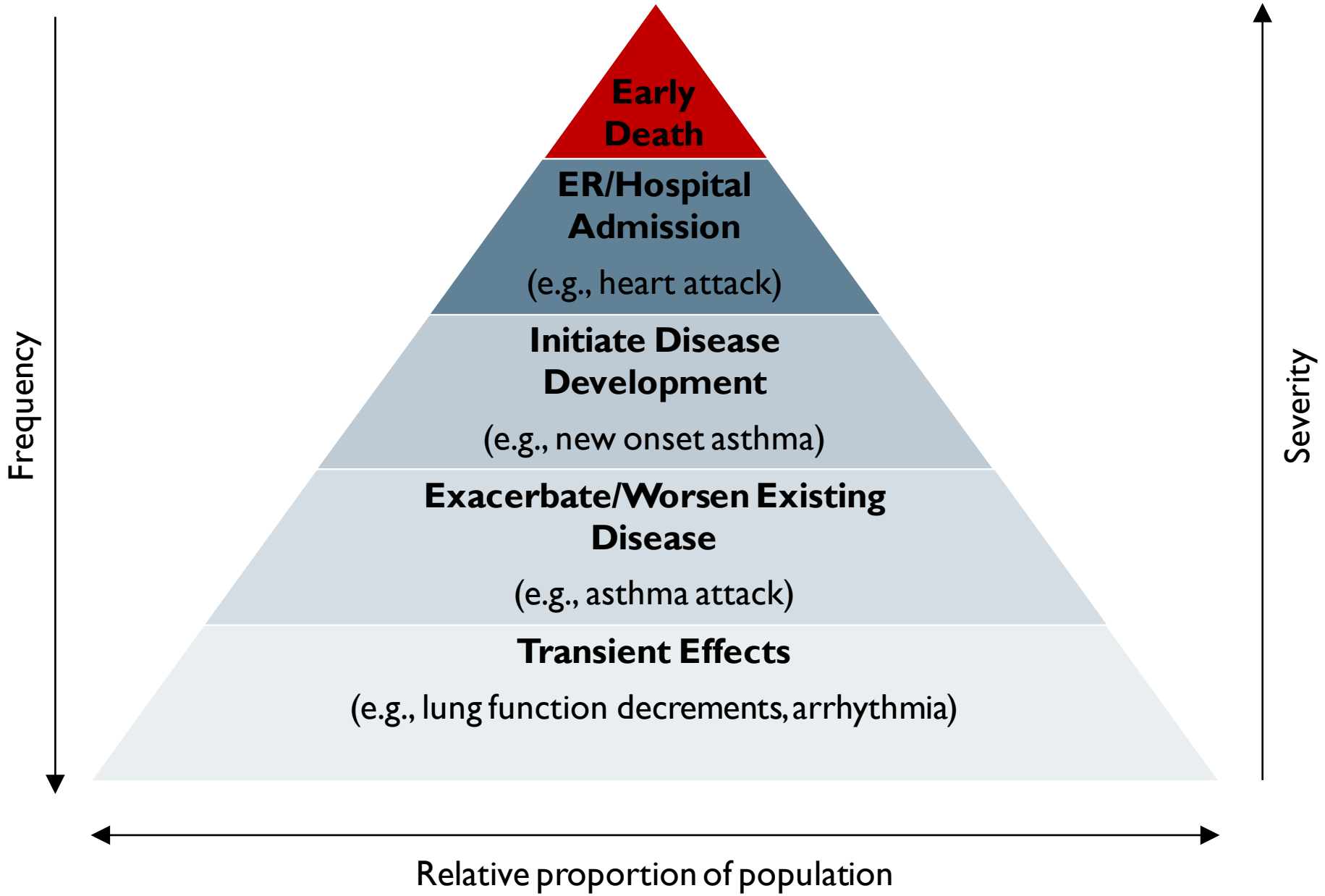
Source: Preamble to Integrated Science Assessments (https://www.epa.gov/isa)

ISA-Reported Causality for $PM_{2.5}$ and Ozone



ST = short-term exposure
LT = long-term exposure

Source: U.S. EPA, 2019 PM ISA, 2020 Ozone ISA (available at: https://www.epa.gov/isa)

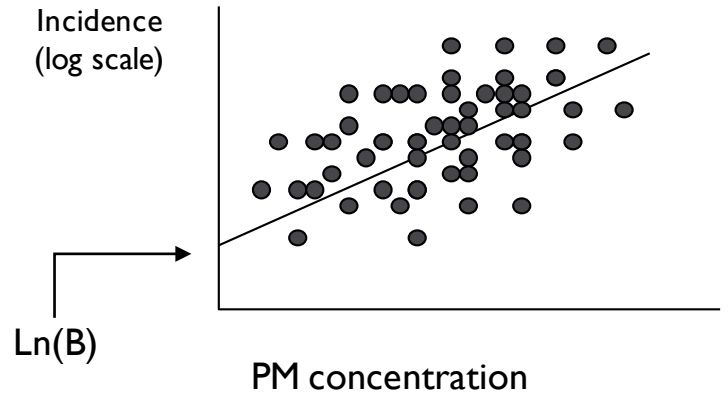

Early Death
ER/Hospital Admission
(e.g., heart attack)
Initiate Disease Development
(e.g., new onset asthma)
Exacerbate/Worsen Existing Disease
(e.g., asthma attack)
Transient Effects
(e.g., lung function decrements, arrhythmia)
Frequency
Severity
Relative proportion of population

How does EPA estimate the health and economic impacts associated with changes in air quality?

- U.S. EPA's Environmental Benefits Mapping and Analysis Program – Community Edition (BenMAP – CE)
  - Free and open source program that allows users to use data supplied by EPA or their own data to estimate the health and economic benefits of various air quality scenarios
  - Available at: https://www.epa.gov/benmap

Deriving a Health Impact Function from the Epidemiology Literature

Epidemiology study



$$Ln(y) = Ln(B) + \beta(PM)$$

Health impact function

$$\Delta Y = Yo\ (1 - e^{-\beta \Delta PM}) * Pop$$

Yo – Baseline Incidence

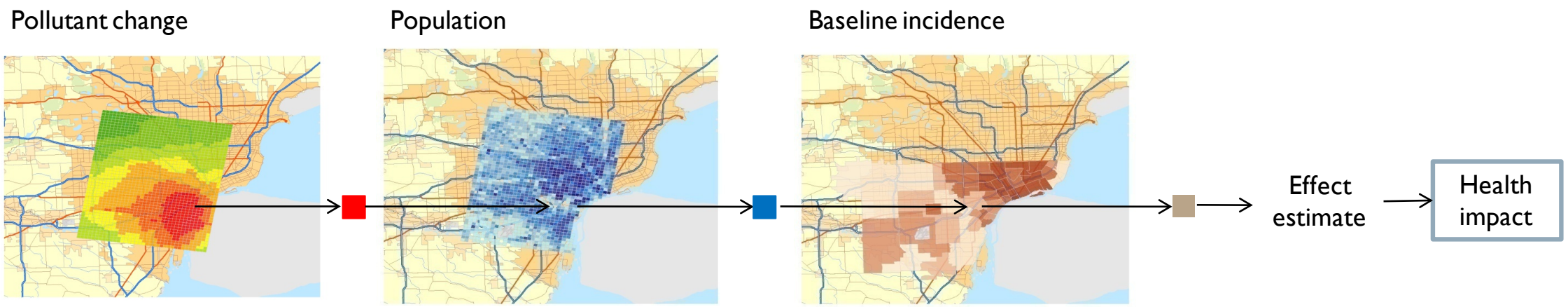
β - Effect estimate

ΔPM – Air quality change

Pop – Exposed population

Steps to Calculating Health Impacts

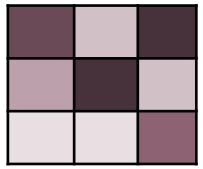
$$\Delta Y = Yo\ (1 - e^{-\beta \Delta PM}) * Pop$$



BenMAP-CE is One of Several Tools Available to Quantify Benefits

Air pollution data

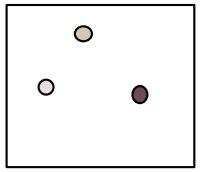
Import Modeled data



CMAQ
CAMx
GEOS-Chem

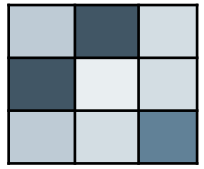
or

Select/Import Monitored data



2000-2013 AQS monitor data (interpolated to grid)

Population counts

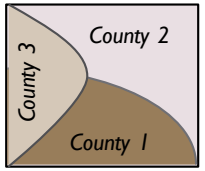


Year 2010 block-level census data Stratified by age/sex/race/ethnicity

Census data forecast out to 2060 using data from Woods & Poole

Aggregated from census block to air quality grid (e.g. 12km by 12km)

Baseline rates of death and disease

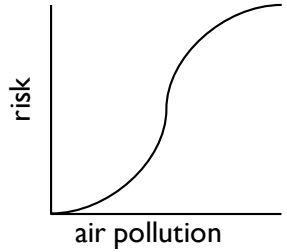


Centers for Disease Control 2000—2050 death rates

Agency for Healthcare Quality and Research 2014 hospital and ED visit rates

Rates available at county level

Concentration-response relationships



Ozone and $PM_{2.5}$ concentration-response relationships

Premature mortality, hospital visits, emergency department visits and other endpoints

Example Benefits: 2011 Policy Reducing Emissions from Power Plants in U.S.

Summary of health impacts avoided

Health endpoint	Value
$PM_{2.5}$-related mortality (Pope et al. 2002)	14,000 (4,000—25,000)
$PM_{2.5}$-related mortality (Laden et al. 2006)	36,000 (17,000—56,000)
O_3-related mortality (Bell et al. 2004)	50 (17—84)
O_3-related mortality (Levy et al. 2005)	230 (160—300)
$PM_{2.5}$-related chronic bronchitis	9,200 (320—18,000)
$PM_{2.5}$-related non-fatal heart attacks	22,000 (5,800—39,000)
$PM_{2.5}$ and O_3-related respiratory hospitalizations	4,200 (1,500—6,700)
$PM_{2.5}$ and O_3-related emergency department visits	14,000 (7,200—21,000)

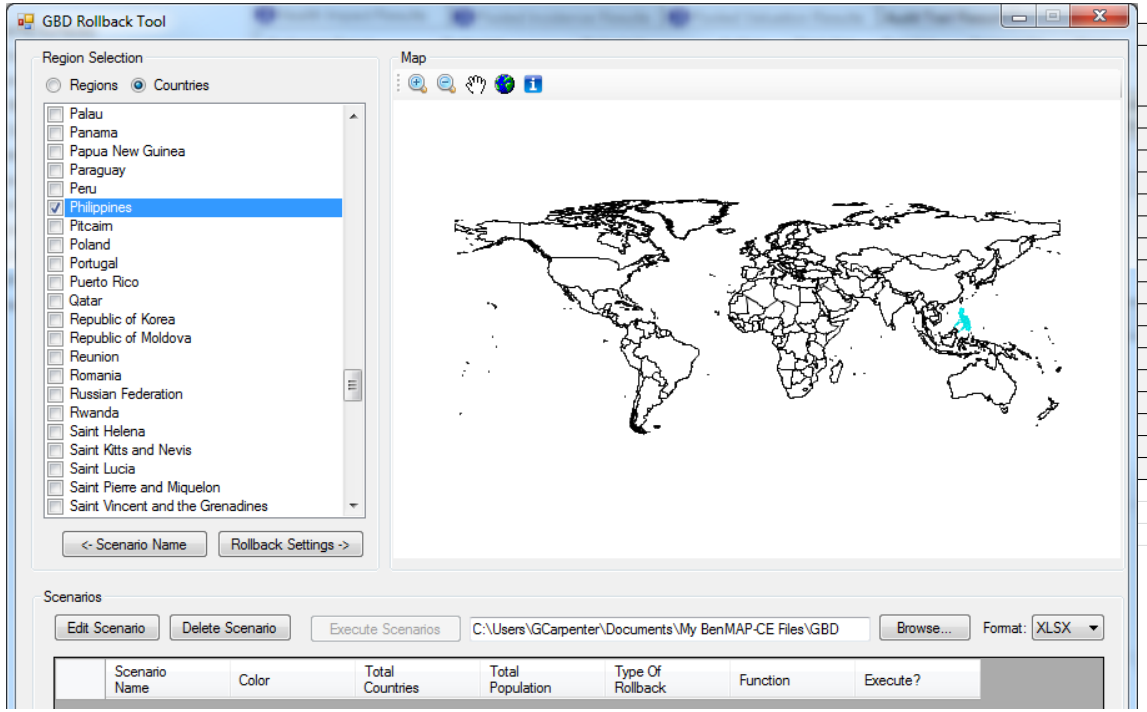
Monetized health and welfare benefits[A]

Endpoint	Value (billions of 2006$)
Human health[B]	
Pope et al. 2002 $PM_{2.5}$ and Bell et al. 2004 O_3 mortality estimates	$120 ($10—$360)
Laden et al. 2006 $PM_{2.5}$ and Levy et al. 2005 O_3 mortality estimates	$290 ($26—$840)
Visibility	$3.6
Total	
Pope et al. 2002 $PM_{2.5}$ and Bell et al. 2004 O_3 mortality estimates	**$120 ($10—$360)**
Laden et al. 2006 $PM_{2.5}$ and Levy et al. 2005 O_3 mortality estimates	**$290 ($26—$850)**

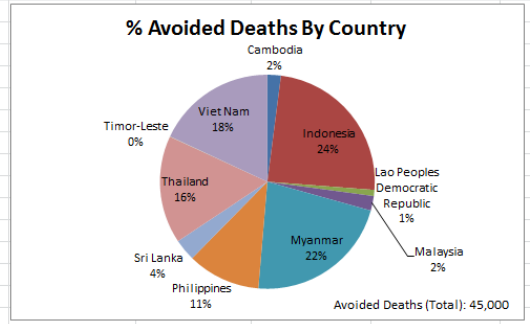
[A] All values rounded to two significant figures
[B] Discounted at 3%

Global Burden of Disease Rollback Tool

- Allows users to select a country, region, or group of countries and see the impact of lowering $PM_{2.5}$ emissions using data from the 2015 GBD study.
- Exports an Excel file with information about the avoided deaths in the country or region selected, as well as the $PM_{2.5}$ concentrations in the analysis.

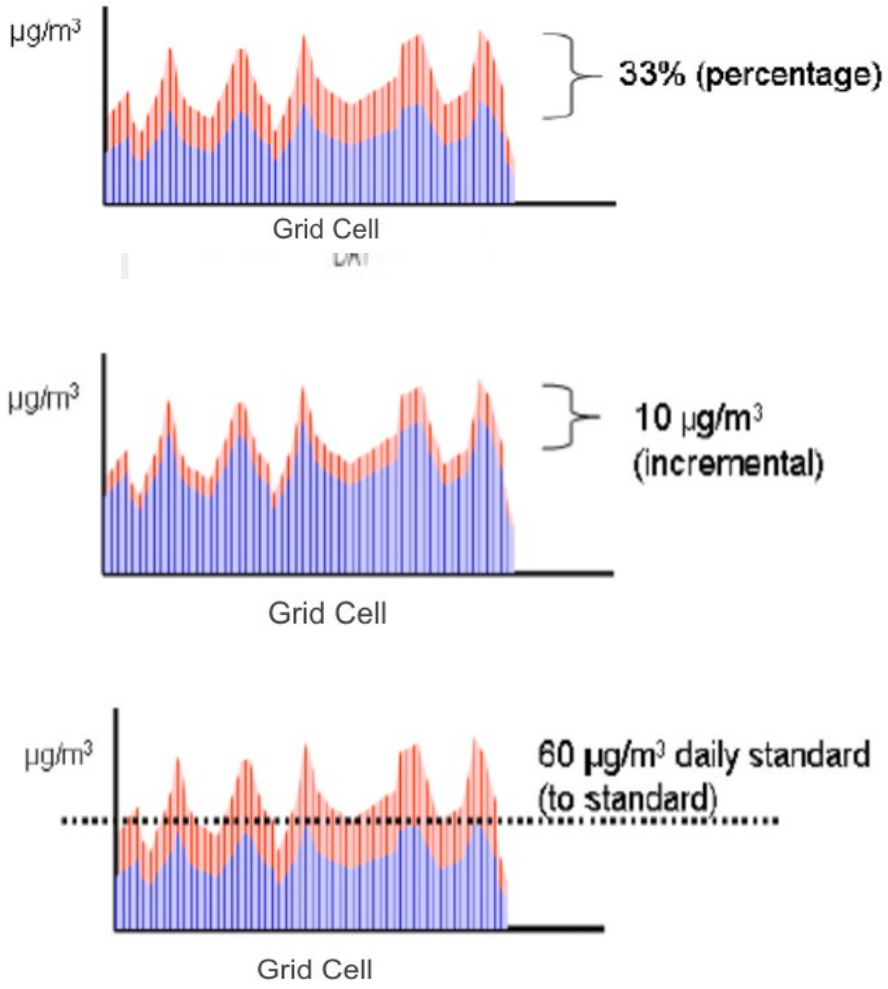


7/14/2017						
RegionalPct	Population Affected	Avoided Deaths (Total)	95% CI	% of Baseline Mortality	Deaths per 100,000	Avoided Deaths (% Population)
	290,000,000	45,000	31,000 - 60,000	1.388240317	15.43	0.015432632
2015						
PM 2.5						
5.8 µg/m³						
10% Rollback						
Krewski						
Southeast Asia						
Cambodia						
Indonesia						
Lao Peoples Democratic Republic						
Malaysia						
Myanmar						
Philippines						
Sri Lanka						
Thailand						
Timor-Leste						
Viet Nam						



What are the options for $PM_{2.5}$ rollbacks?

- **Percentage rollback** – decrease $PM_{2.5}$ concentrations by a percentage.
- **Incremental rollback** – decrease $PM_{2.5}$ by an increment measured in $\mu g/m^3$.
- **Rollback to a standard** – decrease $PM_{2.5}$ to 60 $\mu g/m^3$ level daily standard recommended by WHO.

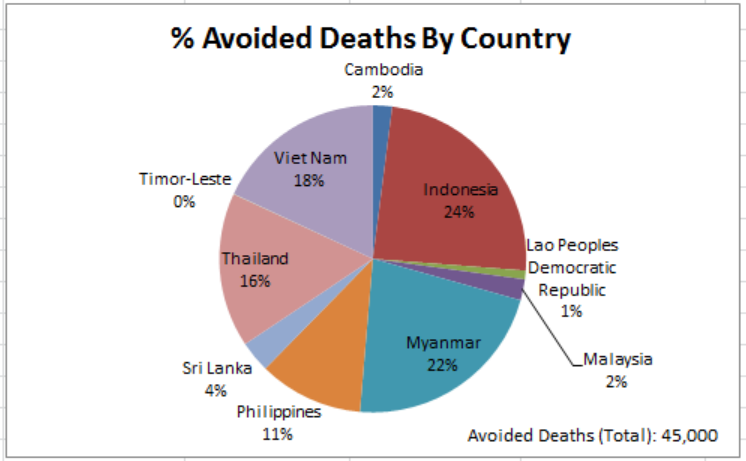


What are the results of the analysis?

- The GBD module exports an Excel file with information about the avoided deaths in the country or countries and region selected.
- The output includes the baseline and policy case $PM_{2.5}$ levels as well as the population-weighted air quality change.

Date	7/14/2017
Scenario Name	RegionalPct
Scenario Description	
GBD Year	2015
Pollutant	PM 2.5
Background Concentration	5.8 µg/m³
Rollback Type	10% Rollback
Function	Krewski
Regions and Countries	*Southeast Asia*
	Cambodia
	Indonesia
	Lao Peoples Democratic Republic
	Malaysia
	Myanmar
	Philippines
	Sri Lanka
	Thailand
	Timor-Leste
	Viet Nam

Population Affected	Avoided Deaths (Total)	95% CI	% of Baseline Mortality	Deaths per 100,000	Avoided Deaths (% Population)
290,000,000	45,000	31,000 - 60,000	1.388240317	15.43	0.015432632



BenMAP Resources

- BenMAP – CE
  - www.epa.gov/benmap
- Listserv
- Quarterly Webinars
  - Can obtain access to each through either:
    - benmap@epa.gov
    - www.epa.gov/benmap
      - Clicking on "Contact Us" at the bottom of the webpage