# BenMAP Community Edition

An Open-Source Platform to Quantify the Health Impacts and Economic Value of Stressors

Briefing for Office of Water
October 30th, 2013

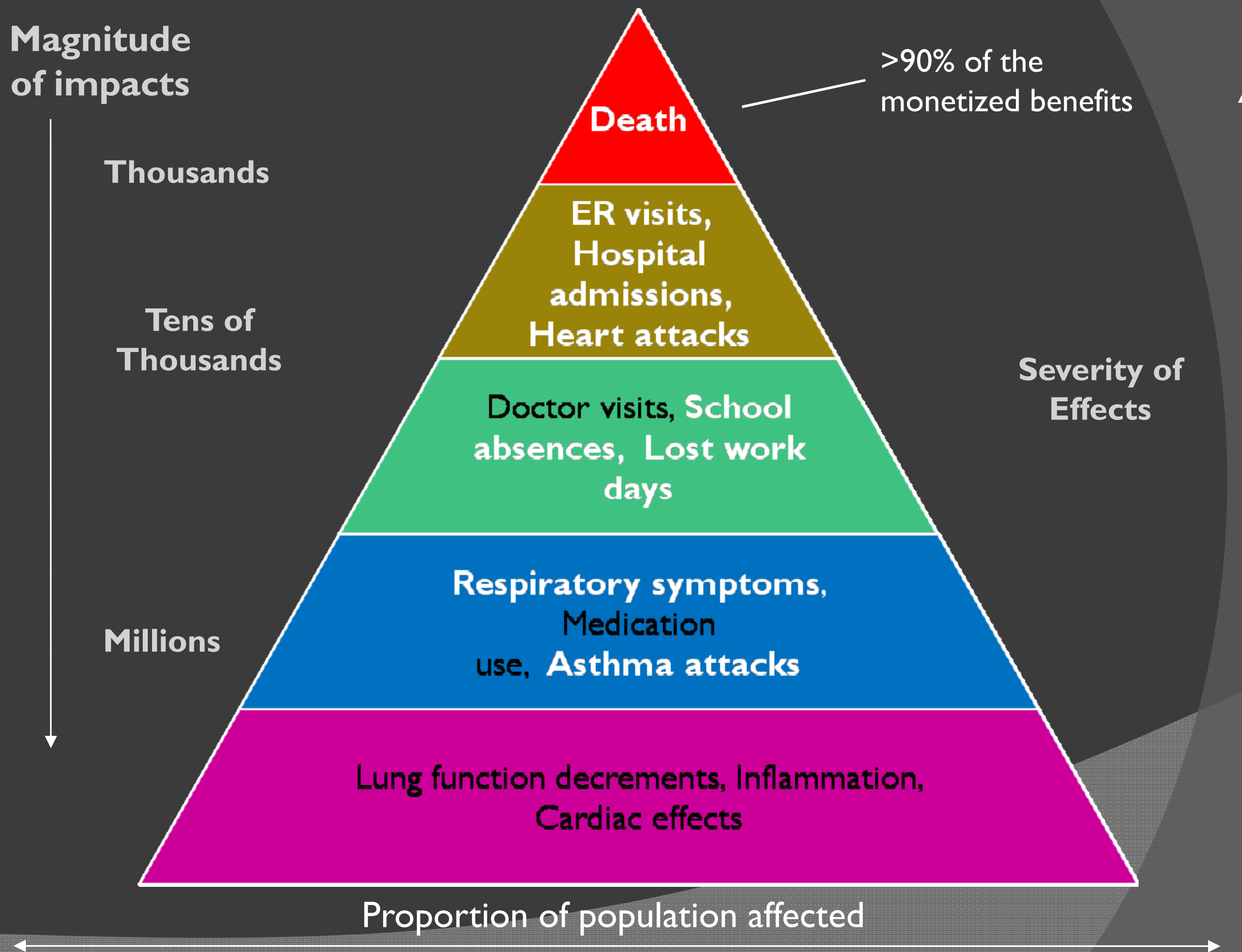
# Overview

- Core concepts of air pollution health impact assessment
- A brief history of the BenMAP program
- Program demonstration
- Next steps

BenMAP-CE Platform

# Core Concepts of Air Pollution Benefits Analysis

# A "Pyramid of Effects" from Air Pollution



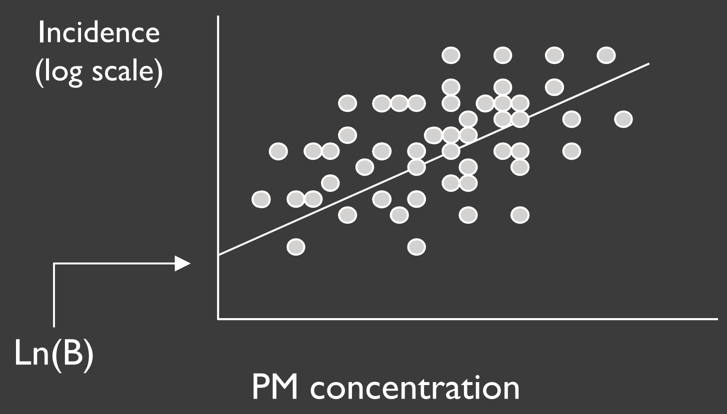
# What Health Endpoints do we Include in Our Central Benefits Estimate?

| ***Health Endpoint*** | ***$PM_{2.5}$*** | ***Ozone*** |
|---|---|---|
| Premature mortality* | ✓ | ✓ |
| Nonfatal heart attacks | ✓ | |
| Hospital admissions | ✓ | ✓ |
| Asthma ER visits | ✓ | ✓ |
| Acute respiratory symptoms | ✓ | ✓ |
| Asthma attacks | ✓ | ✓ |
| Work loss days | ✓ | |
| School absence rates | | ✓ |

*Long term $PM_{2.5}$-related mortality and short-term $O_3$-related mortality

# Deriving a Health Impact Function from the Epidemiology Literature

**Epidemiology Study**




$$\text{Ln}(y) = \text{Ln}(B) + \beta(\text{PM})$$

**Health impact function**

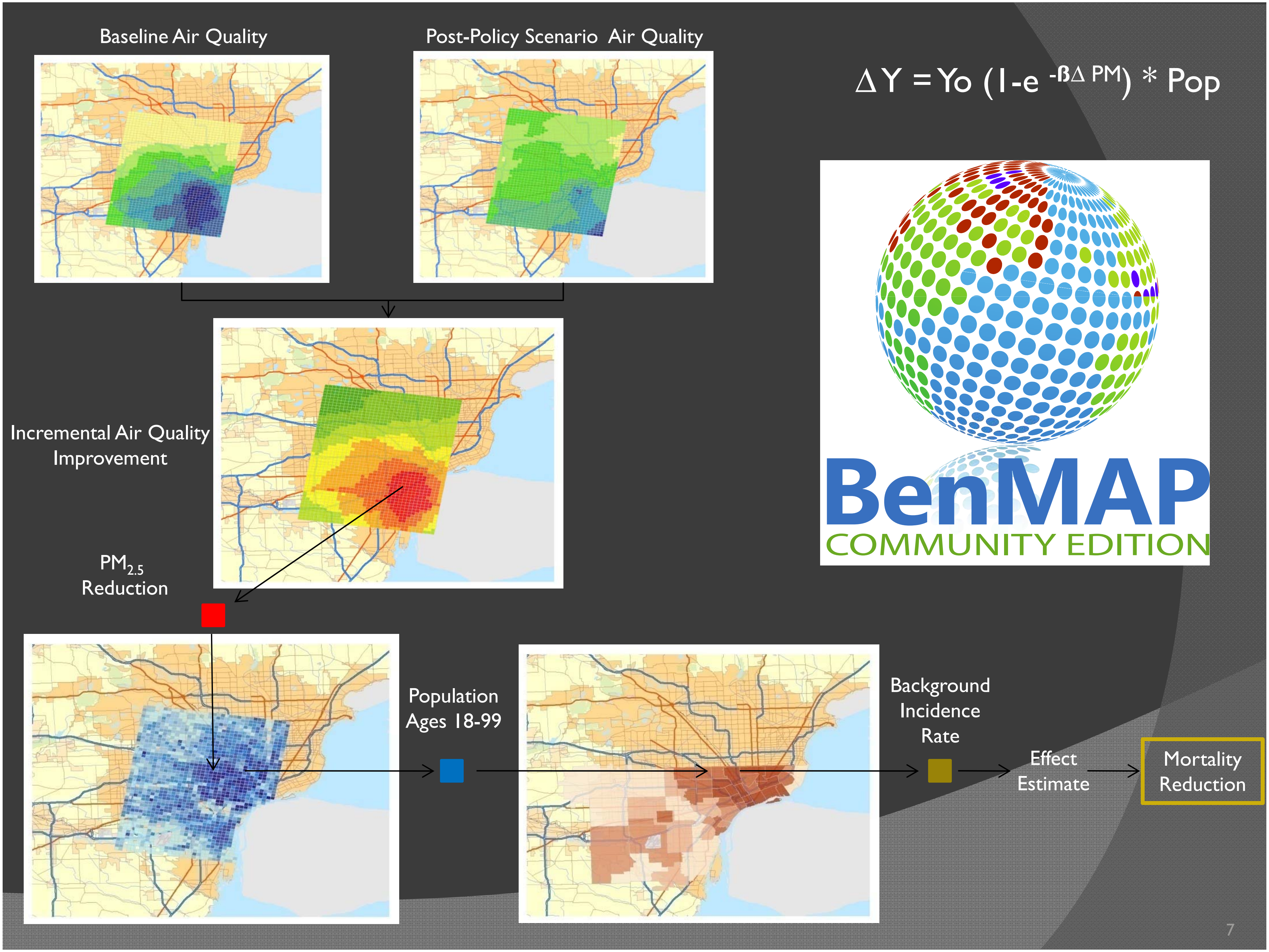
$$\Delta Y = Y_o\,(1 - e^{-\beta \Delta PM}) * Pop$$

**Yo – Baseline Incidence**

**ß - Effect estimate**

**ΔPM – Air quality change**

**Pop – Exposed population**



Baseline Air Quality
Post-Policy Scenario Air Quality
$\Delta Y = Yo\,(1-e^{-\beta \Delta PM}) * Pop$
Incremental Air Quality Improvement
PM$_{2.5}$ Reduction
BenMAP
COMMUNITY EDITION
Population Ages 18-99
Background Incidence Rate
Effect Estimate
Mortality Reduction

BenMAP-CE Platform

# Why Redevelop the BenMAP Software?

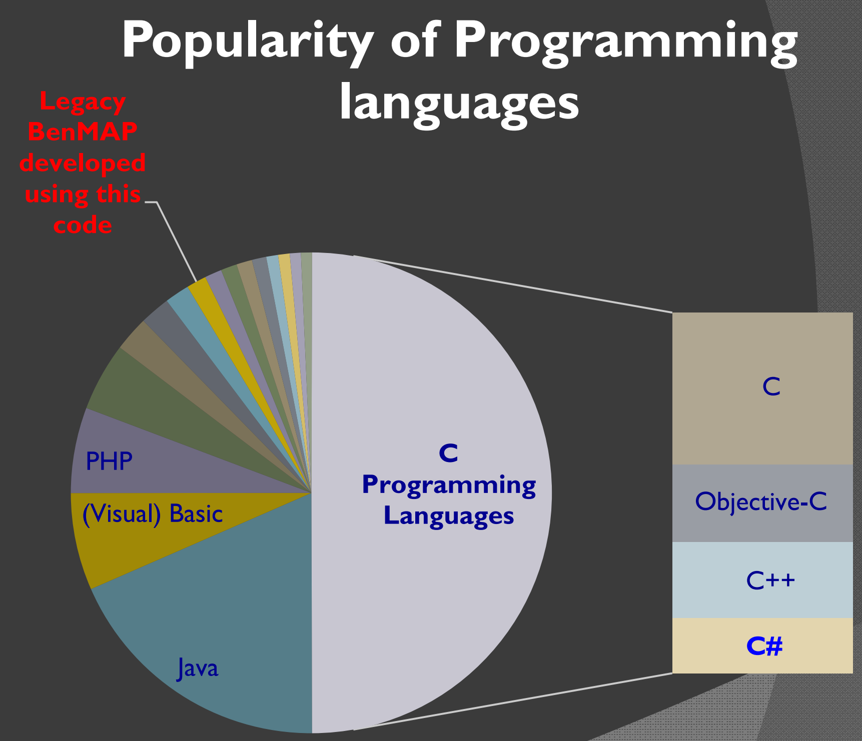
# A Brief History of Air Pollution Benefits Software at EPA

| | |
|---|---|
| 1997 | Criteria Air Pollution Modeling System (CAPMS)<br>Spreadsheet-based<br>Error prone<br>Generally used contract support to run (~$150k/rule) |
| 2003 | Environmental Benefits Mapping and Analysis Program (BenMAP) **v1 to v4**<br>Generally run by EPA staff<br>Proprietary code<br>Program first used for non-road diesel RIA<br>Wider adoption by states, stakeholders and international users<br>Used in >50 RIA's, >25 journal articles and several policy proposals (e.g. climate bills) |
| 2013 | BenMAP-CE beta v0.63<br>Public release version<br>Feature complete<br>Beta tested<br><br>BenMAP-CE v1.0<br>Public release version<br>Source code posted<br>Addressed 164 unique "bugs" to date |

→BenMAP allowed more work to be performed in-house, saving OAR millions of contract dollars

# Legacy BenMAP Was At the End of Its Useful Life

- Needed to address significant weaknesses in Legacy BenMAP
  - Proprietary and obsolete code
  - Contractor owned and managed all revisions to program
  - Computational inefficiencies
- Legacy BenMAP continued to be a reliable tool for regulatory analysis

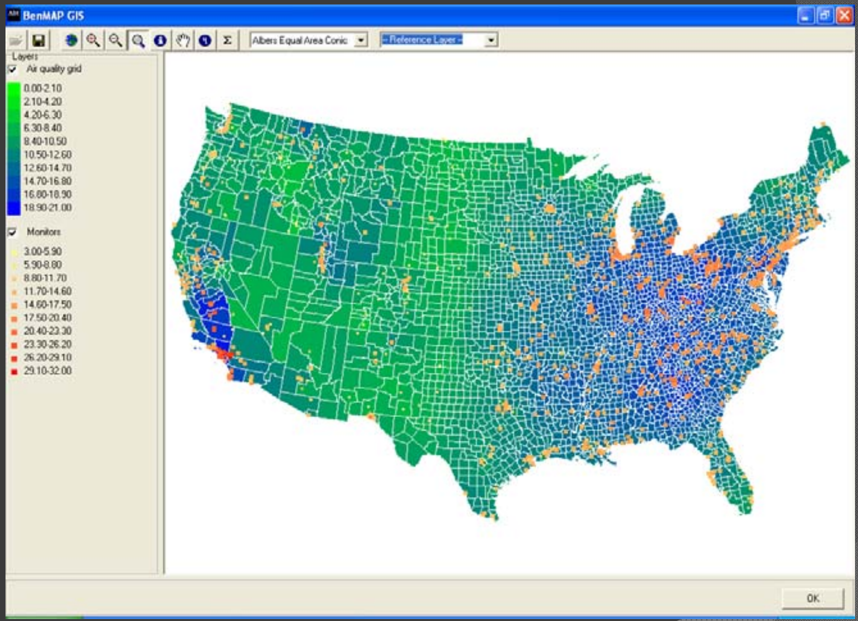



Source: tiobe.com. July 2012 community index.

# We Built on the Core Strengths of Legacy BenMAP

- A credible tool for performing health impact assessments
- Integrated the individual steps of a health benefits assessment in a unified framework
  - Automated the calculations
  - Reduced QA/QC issues
- A GIS and database that worked together
  - Included a large volume of health impact functions, population data, baseline health data and monitor data
  - Users could add their own data

Legacy BenMAP Geographic Information System



# Creating the New BenMAP—Community Edition

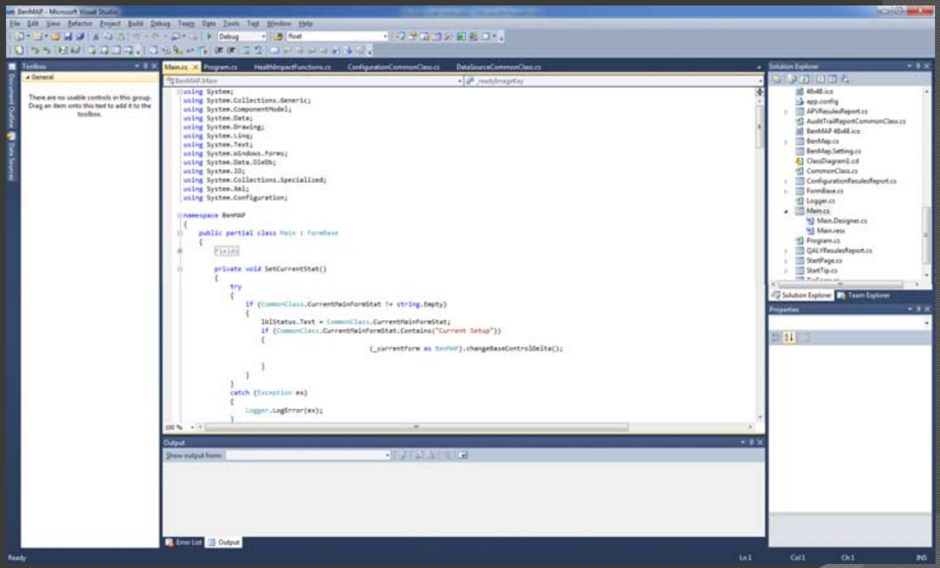
- Project goals:
  - Build an entirely new program using a modern and broadly-used language
  - Make the program easier to use
  - Calculate benefits in less time
- The new BenMAP should:
  - accommodate—and not inhibit—methodological improvements
  - be sustainable through periods of fiscal austerity
- Open source software integral to achieving goals

BenMAP
COMMUNITY EDITION

# What is "Open Source" Software?

- Open source software
  - Provides a free* license to the software code
  - Allows the code to be distributed freely to others
- Examples of open source software:
  - CMAQ model
  - Android operating system
  - Linux operating system
  - Firefox browser

*BenMAP-CE source code*

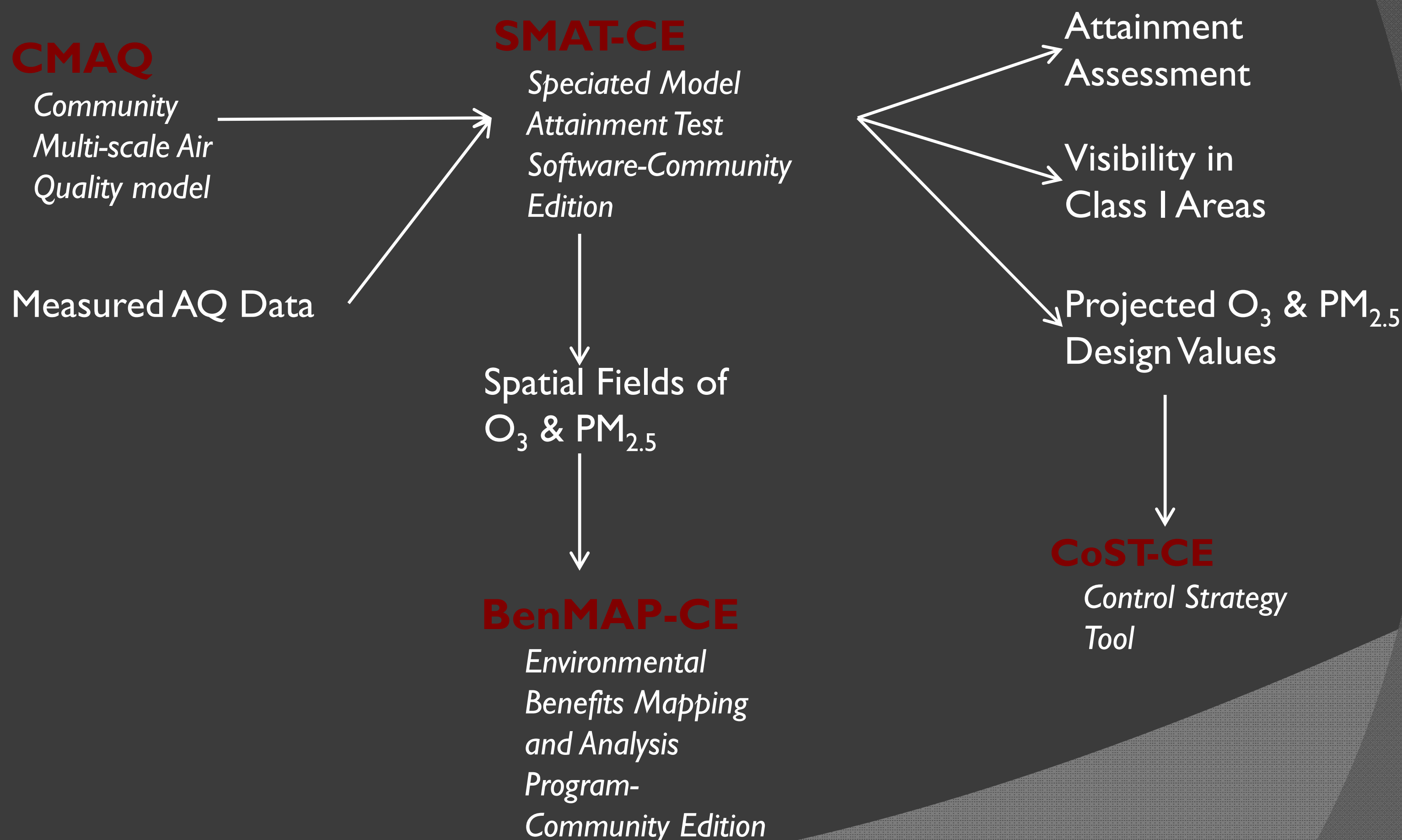


*Terms vary by open source license

# What are the Trade-Offs Associated with Going Open Source?

| ***Attribute*** | U.S. Version BenMAP Environmental Benefits Mapping and Analysis Program | BenMAP COMMUNITY EDITION |
|---|---|---|
| **Transparency** | • Only the contractor can see the code | • Code freely available to the public |
| **Reproducibility** | • Challenging due to lack of code | • All algorithms available |
| **Credibility** | • Earned over time | • Readily open to scrutiny |
| **Community** | • Network of users | • Network of users and developers |
| **Efficiency** | • One developer<br>• Contractor managed code | • Potentially, many developers<br>• **But, someone must manage the code** |

# BenMAP-CE is One Component of an Integrated Suite of Open Source Tools

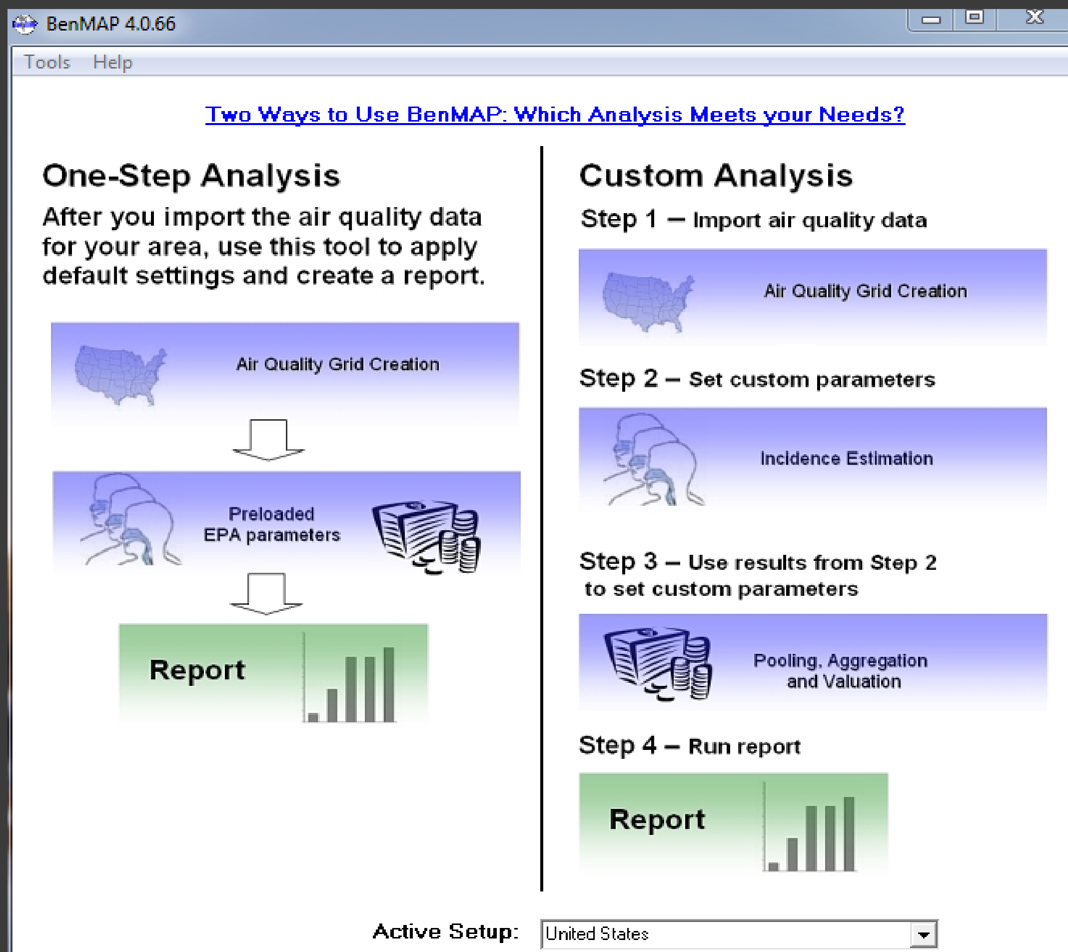



Open Source Models & Tools

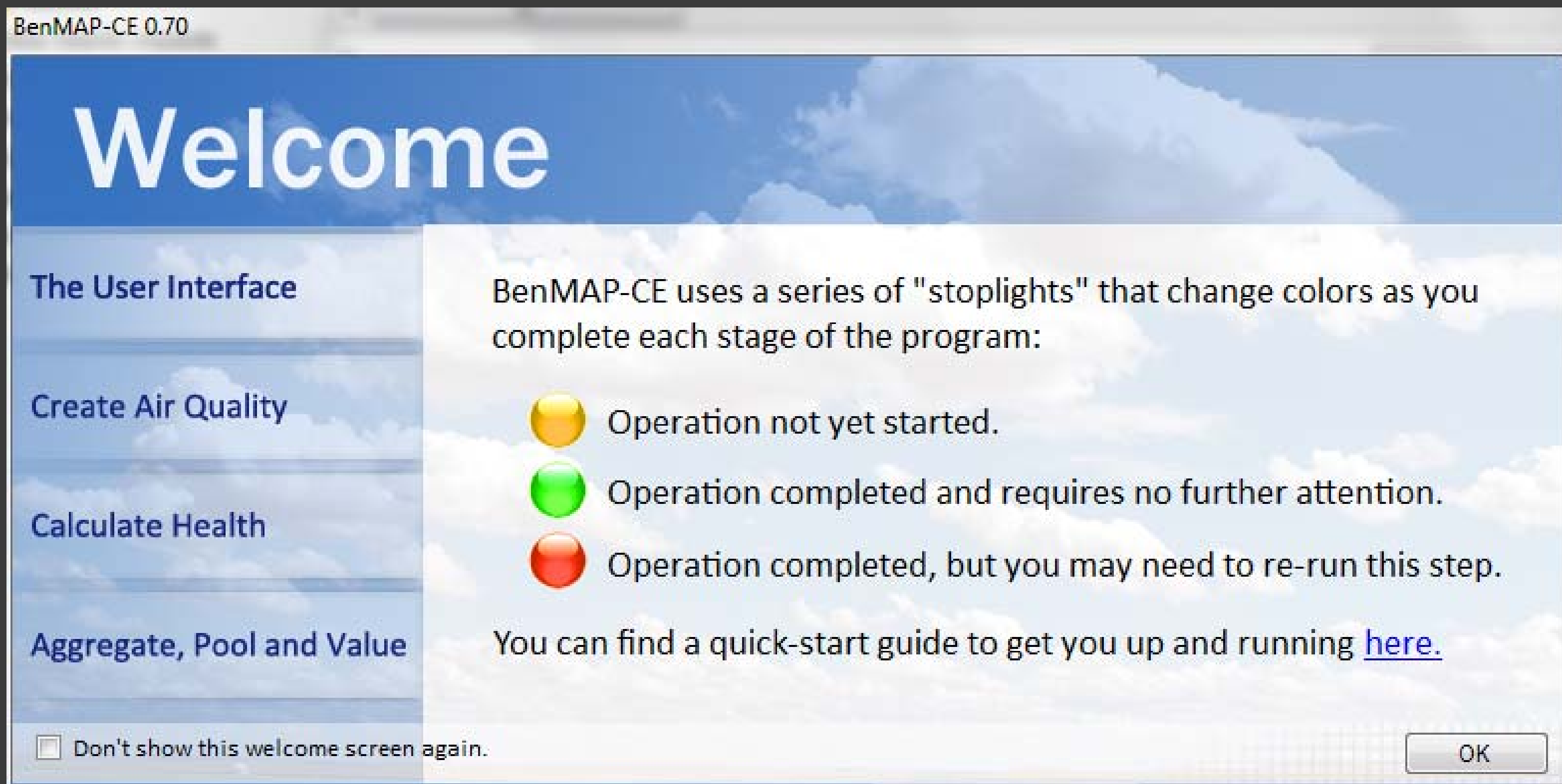
BenMAP-CE Platform

# Program Demonstration

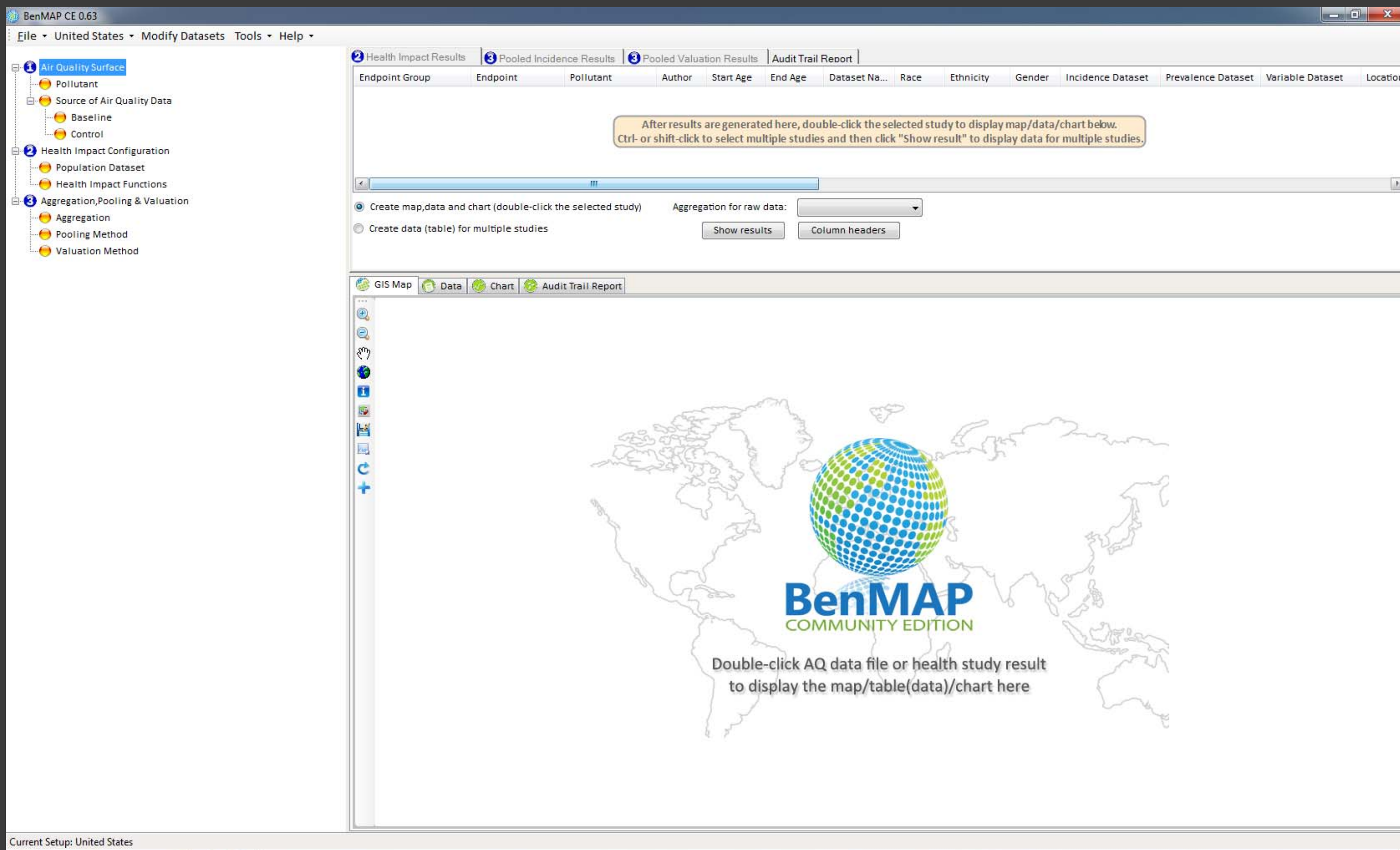
# BenMAP v4


BenMAP 4.0.66
Tools Help
Two Ways to Use BenMAP: Which Analysis Meets your Needs?
One-Step Analysis
After you import the air quality data for your area, use this tool to apply default settings and create a report.
Air Quality Grid Creation
Preloaded EPA parameters
Report
Custom Analysis
Step 1 – Import air quality data
Air Quality Grid Creation
Step 2 – Set custom parameters
Incidence Estimation
Step 3 – Use results from Step 2 to set custom parameters
Pooling, Aggregation and Valuation
Step 4 – Run report
Report
Active Setup:
United States

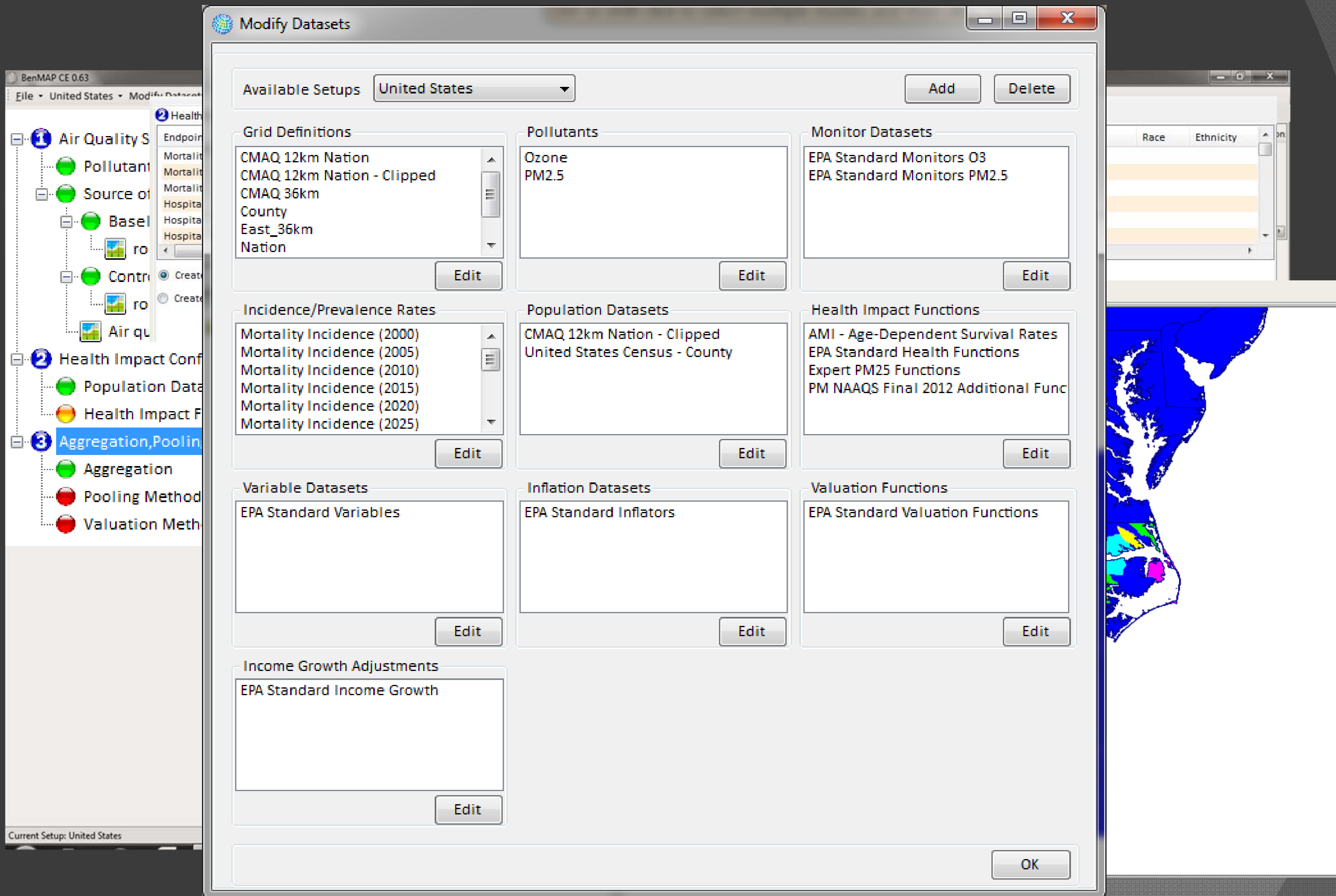
# Making the Program More Accessible to New Users



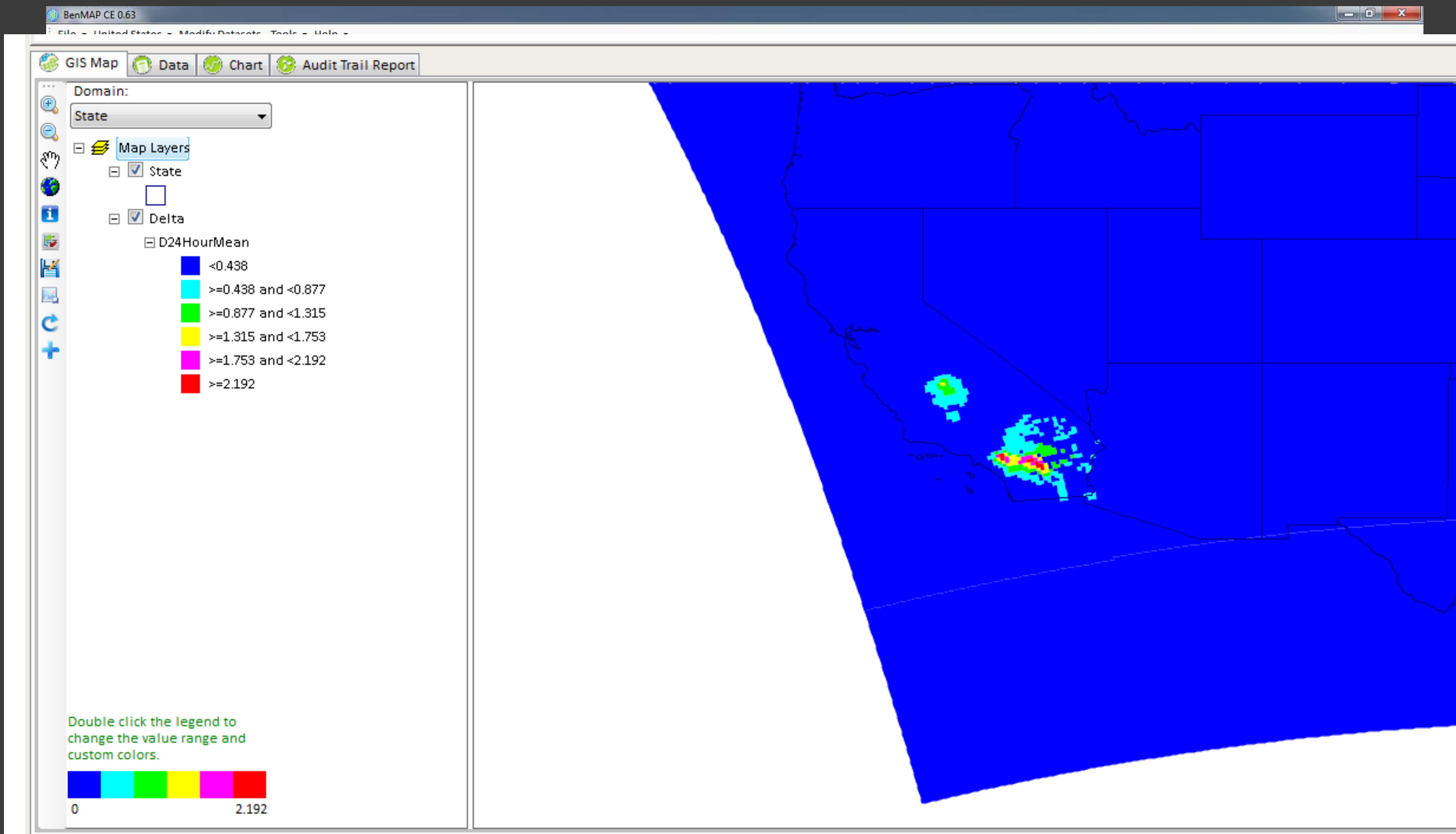
# The Main Window



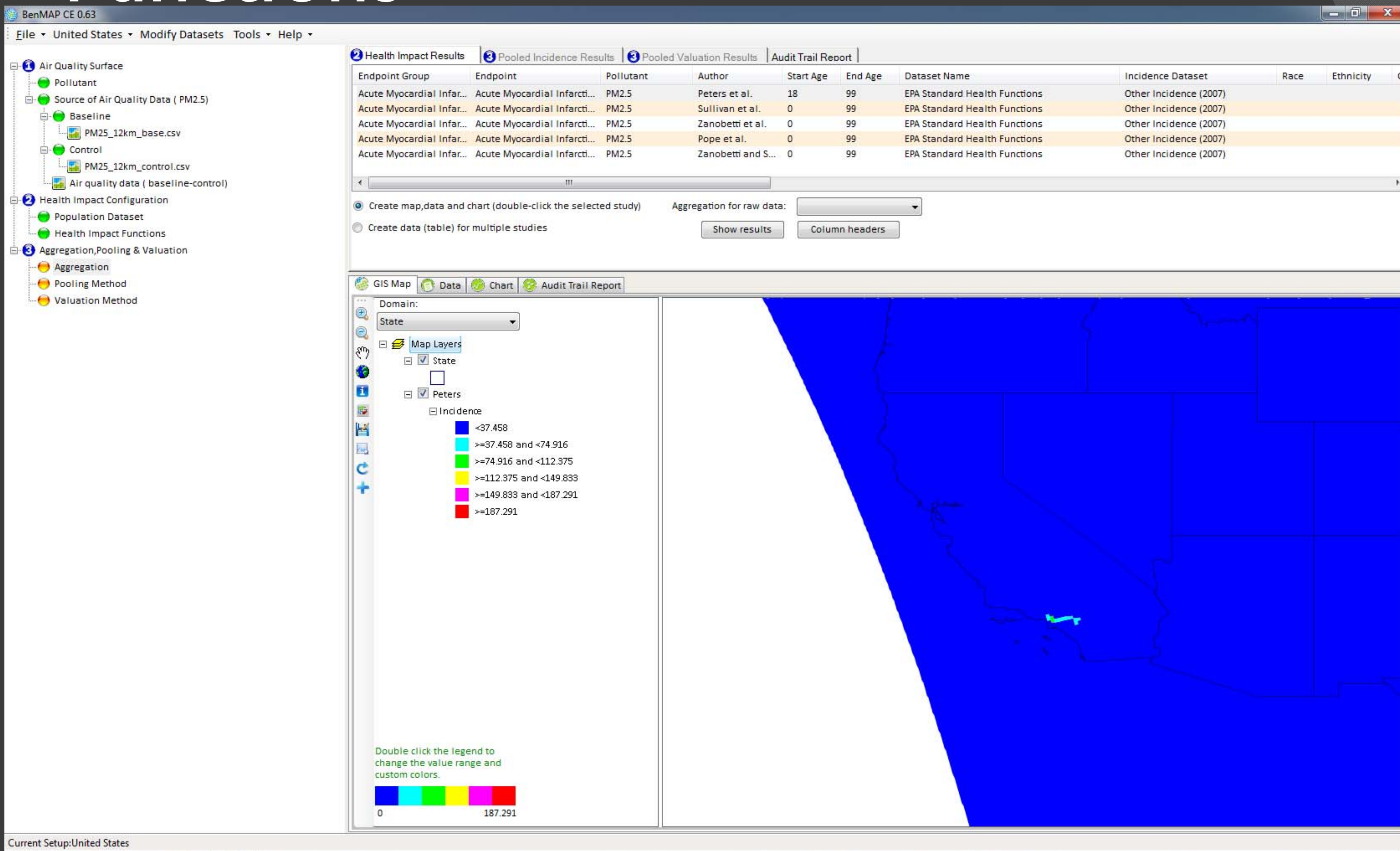
# Key Features of the Main Window



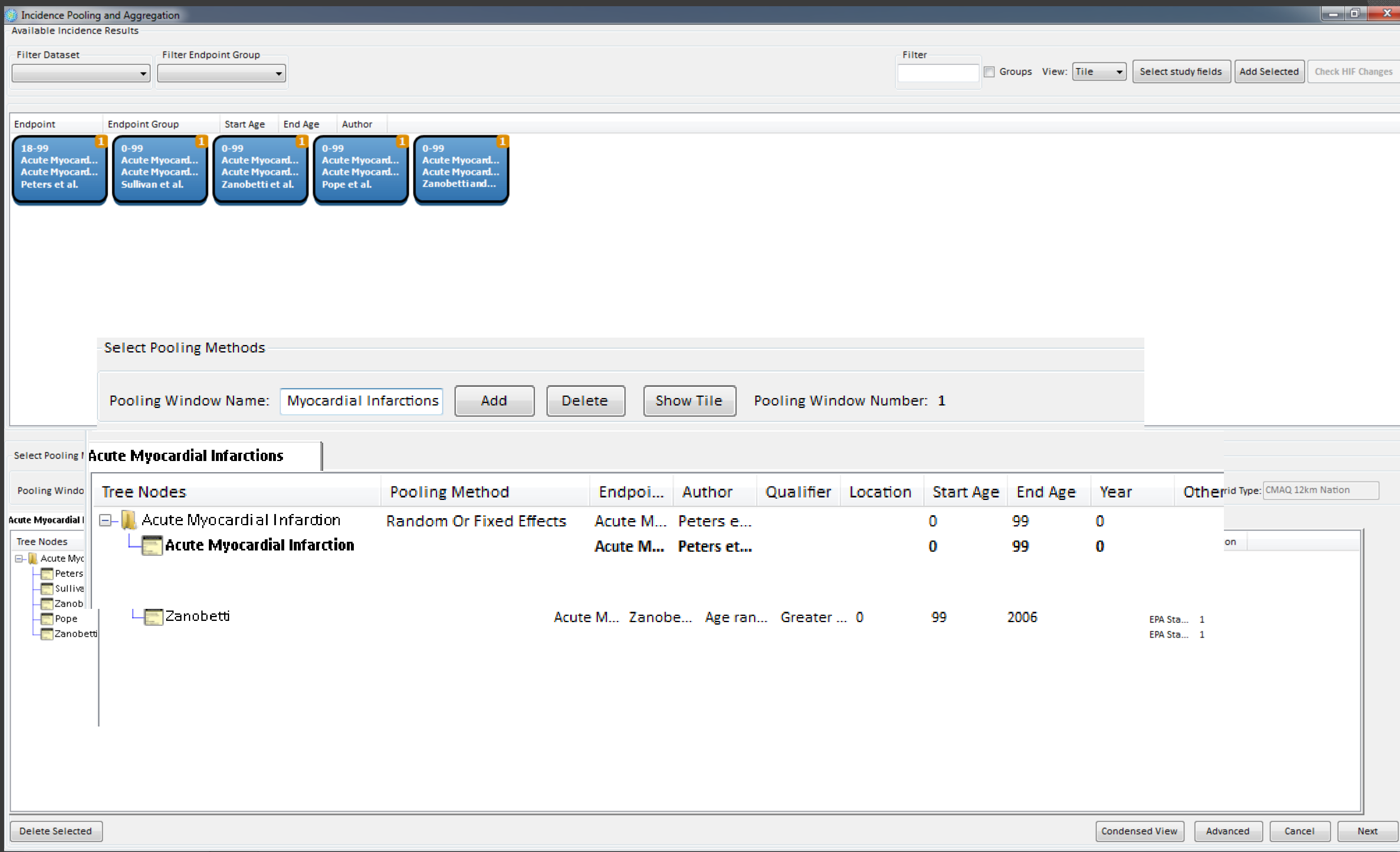
# Step One: Specifying Air Quality Data



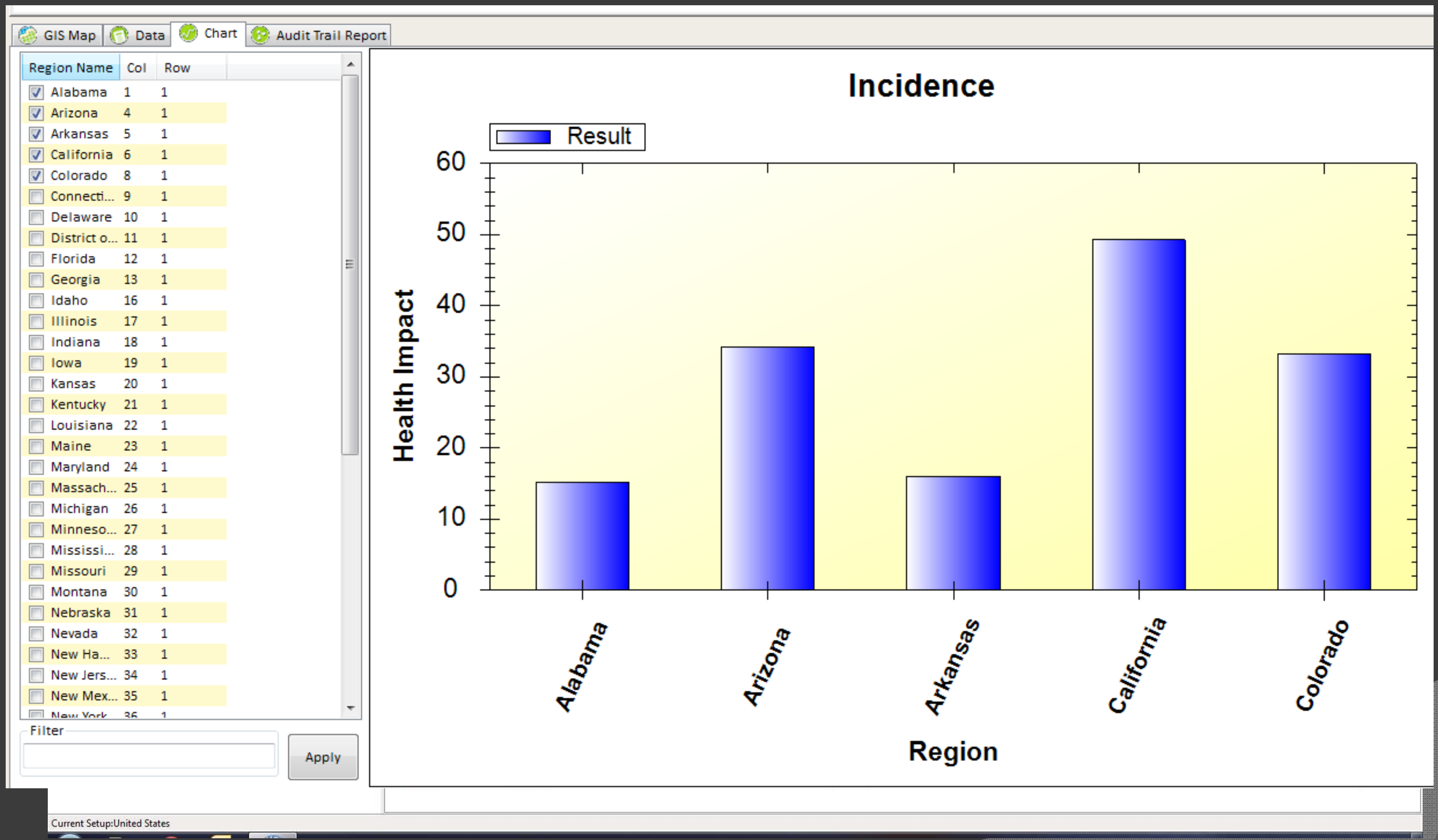
# Step Two: Selecting Health Impact Functions



# Step Three: Aggregate, Pool and Value



# Step Four: Report Results

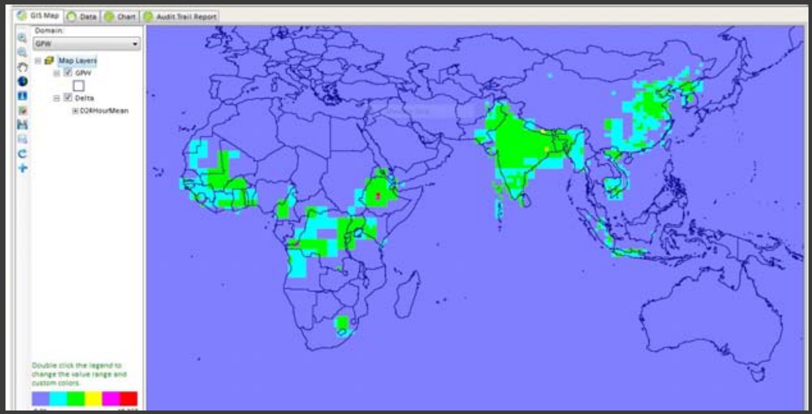


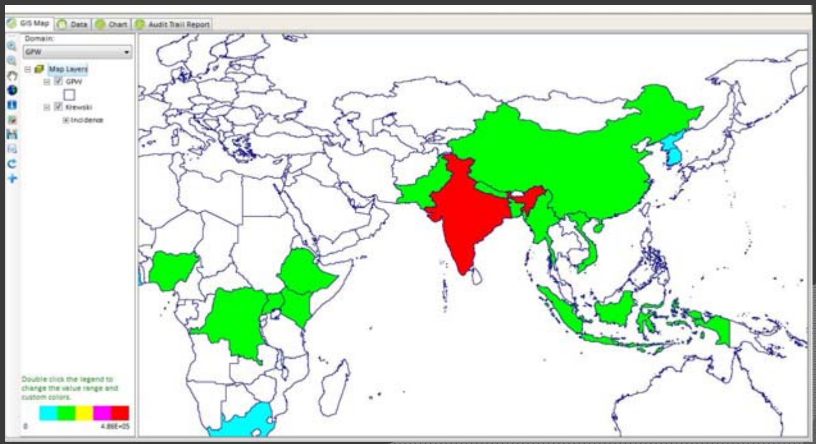
BenMAP-CE Platform

# Developing Modules

# Global Benefits Assessments

- Features
  - Ability to perform benefits analyses globally
  - Incorporates data from Global Burden of Disease project
  - Perform hypothetical "what-if" benefits assessments in various countries
- Status
  - Developing Global Burden of Disease data
- Partners
  - U.S. State Department
  - Climate and Clean Air Coalition





# Climate Assessments

- Features
  - Temperature-mortality/morbidity functions
  - Ability to estimate temperature-air pollution impacts
  - Population projections accounting for climate change
- Status
  - Developed proof of concept (BenMAP Legacy v4.1)
- Partners
  - U.S. EPA Office of Research and Development

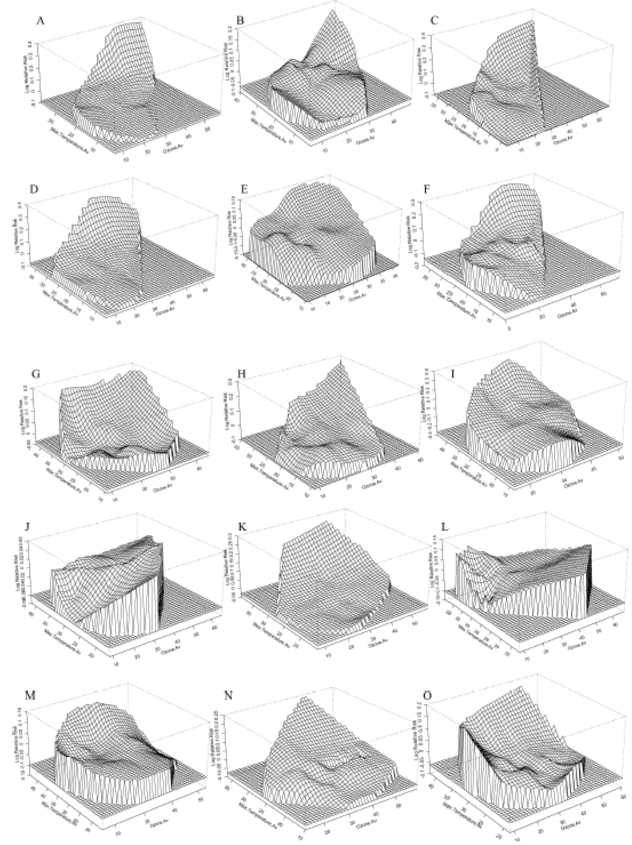
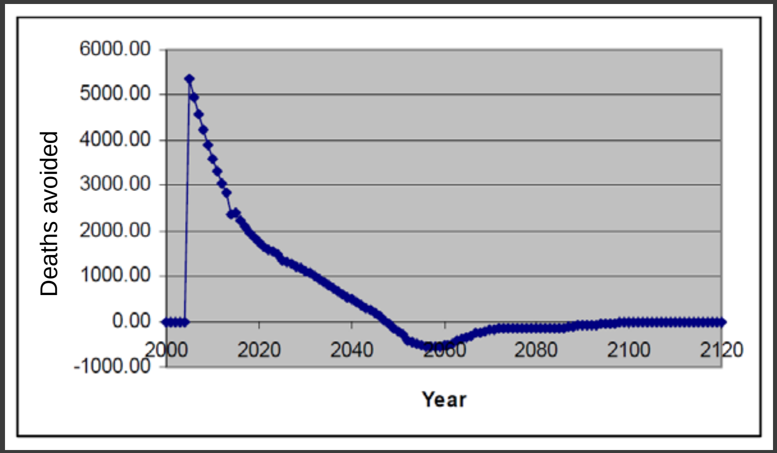


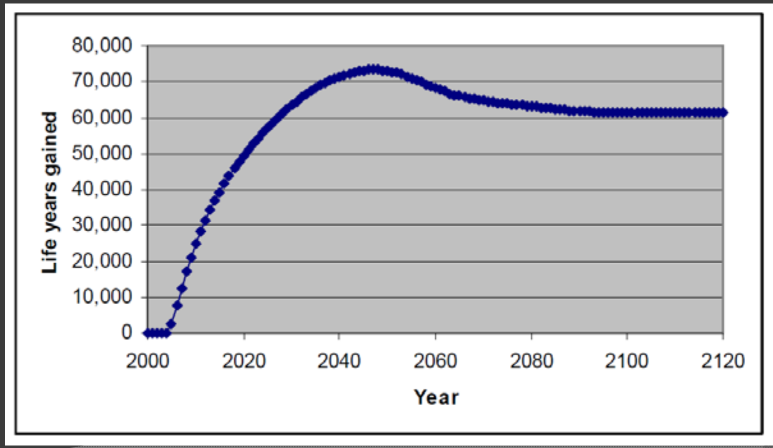

**Fig. 1.** Joint response surfaces of ozone and temperature on cardiovascular mortality in: (A) Chicago, (B) Denver, (C) Detroit, (D) New York, (E) Oakland, (F) Philadelphia, (G) San Jose, and (H) Seattle (the 8 largest northern communities); and (I) El Paso, (J) Houston, (K) Los Angeles, (L) Oklahoma City, (M) Phoenix, (N) San Diego, and (O) Santa Ana/Anaheim (the 7 largest southern communities) between May and October, 1987–2000.

From: Ren et al. 2009

# Life Table Assessment

- Features
  - Estimates risk over a multi-year period
  - Provides a more accurate estimate of air pollution mortality risk over long time periods
- Status
  - Exploring feasibility of incorporating the "PopSim" tool
- Partners
  - Office of Policy Analysis and Review



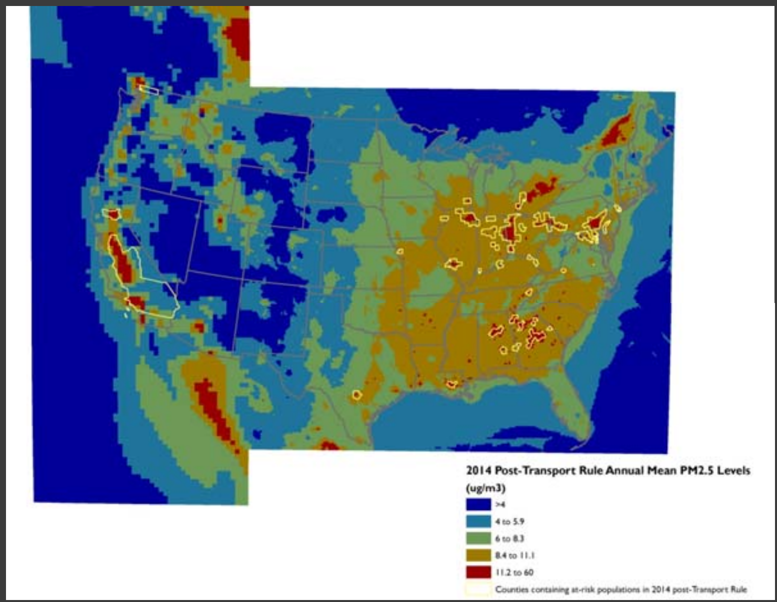




Source: Miller & Hurley, 2006

# Distributional Assessments

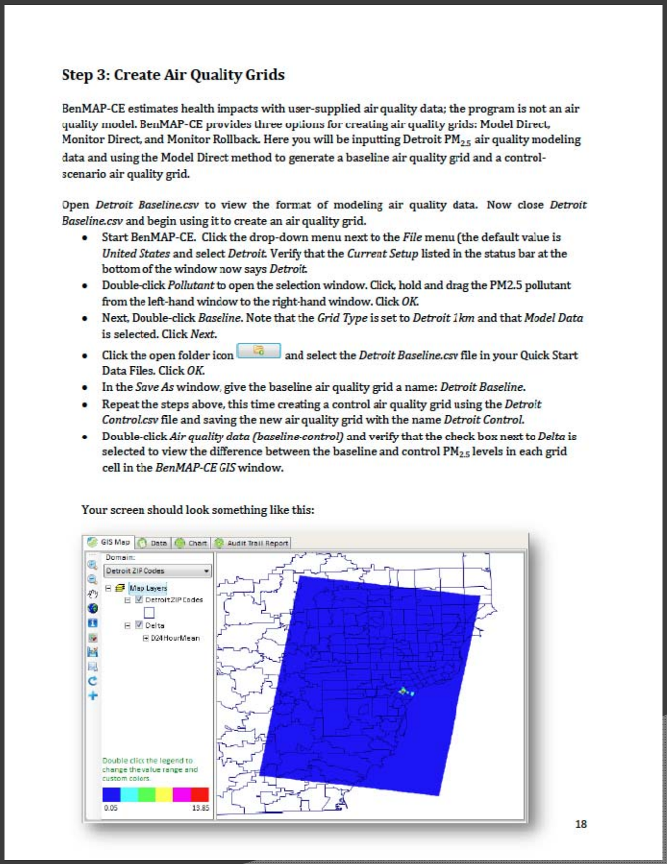
- Features
  - Identify and map populations by attribute: baseline health status, race, ethnicity, socio-economic status
  - Estimate the change in the distribution of risk among these populations
- Status and schedule
  - Procuring more spatially resolved health and socioeconomic data
- Partners
  - Office of Environmental Justice?

*Distributional Assessment*



# Usability Improvements

- Features
  - Data import wizard
  - Additional mapping features
  - User manual
  - Online and instructor-led training
- Status
  - Beginning Fall 2013
- Partners
  - Climate and Clean Air Coalition
  - Student intern support



**Step 3: Create Air Quality Grids**

BenMAP-CE estimates health impacts with user-supplied air quality data; the program is not an air quality model. BenMAP-CE provides three options for creating air quality grids: Model Direct, Monitor Direct, and Monitor Rollback. Here you will be inputting Detroit $PM_{2.5}$ air quality modeling data and using the Model Direct method to generate a baseline air quality grid and a control-scenario air quality grid.

Open *Detroit Baseline.csv* to view the format of modeling air quality data. Now close *Detroit Baseline.csv* and begin using it to create an air quality grid.

- Start BenMAP-CE. Click the drop-down menu next to the *File* menu (the default value is *United States* and select *Detroit*. Verify that the *Current Setup* listed in the status bar at the bottom of the window now says *Detroit*.
- Double-click *Pollutant* to open the selection window. Click, hold and drag the PM2.5 pollutant from the left-hand window to the right-hand window. Click *OK*.
- Next, Double-click *Baseline*. Note that the *Grid Type* is set to *Detroit 1km* and that *Model Data* is selected. Click *Next*.
- Click the open folder icon and select the *Detroit Baseline.csv* file in your Quick Start Data Files. Click *OK*.
- In the *Save As* window, give the baseline air quality grid a name: *Detroit Baseline*.
- Repeat the steps above, this time creating a control air quality grid using the *Detroit Control.csv* file and saving the new air quality grid with the name *Detroit Control*.
- Double-click *Air quality data (baseline-control)* and verify that the check box next to *Delta* is selected to view the difference between the baseline and control $PM_{2.5}$ levels in each grid cell in the *BenMAP-CE GIS* window.

Your screen should look something like this:



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BenMAP-CE Demonstration

# Appendix

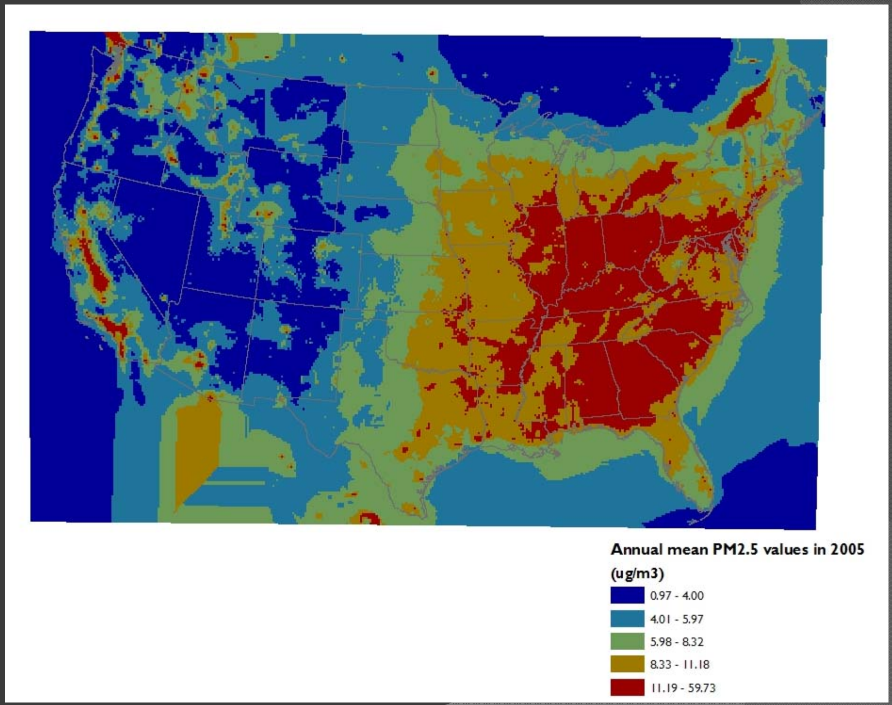
BenMAP-CE Status Demonstration

# Specifying the Air Quality Data

# Identifying Appropriate Air Quality Inputs

- The "right" air quality data depends on the policy question
  - Prospective analysis?
  - Retrospective analysis?
  - Local? Regional?
- BenMAP will accept:
  - Photochemical grid model data
  - User-provided or built-in monitoring data, which it interpolates to create a surface
  - "Rolled-back" monitoring data that simulates a concentration change.
- Air quality data must be at same time step as the epidemiological data (e.g. annual mean, 8hr max, etc.)
- In the future, "SMAT-CE" will manage all air quality data

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




2005 CMAQ-modeled $PM_{2.5}$ Levels

BenMAP-CE Status Demonstration

# Selecting Health Endpoints, Impact Functions, Population and Incidence Rates

# $PM_{2.5}$ Causal Determinations in the Integrated Science Assessment

*Long term exposures*

Cancer, Mutagenicity, and Genotoxicity

Reproductive and developmental

Respiratory effects

Cardiovascular effects

Mortality


Central Nervous System

Respiratory effects

Cardiovascular effects

Mortality

*Short term exposures*

# What Health Endpoints do we Include in Our Central Benefits Estimate?

| *Health Endpoint* | *$PM_{2.5}$* | *Ozone* |
|---|---|---|
| Premature mortality* | ✓ | ✓ |
| Nonfatal heart attacks | ✓ | |
| Hospital admissions | ✓ | ✓ |
| Asthma ER visits | ✓ | ✓ |
| Acute respiratory symptoms | ✓ | ✓ |
| Asthma attacks | ✓ | ✓ |
| Work loss days | ✓ | |
| School absence rates | | ✓ |

*Long term $PM_{2.5}$-related mortality and short-term $O_3$-related mortality

# What Health Endpoints do we Include in Our Sensitivity Analyses?

| *Health Endpoint* | *$PM_{2.5}$* | *Ozone* |
|---|---|---|
| Long- Term Premature mortality* | | ✓ |
| Education-modified premature mortality | ✓ | |
| Ischemic and hemorrhagic stroke | ✓ | |
| Cardiovascular emergency department visits | ✓ | |
| Worker productivity | | ✓ |
| Chronic bronchitis | ✓ | |

*Long term $O_3$-related mortality

# Criteria for Selecting the Studies We Use to Quantify Air Pollution Risks

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

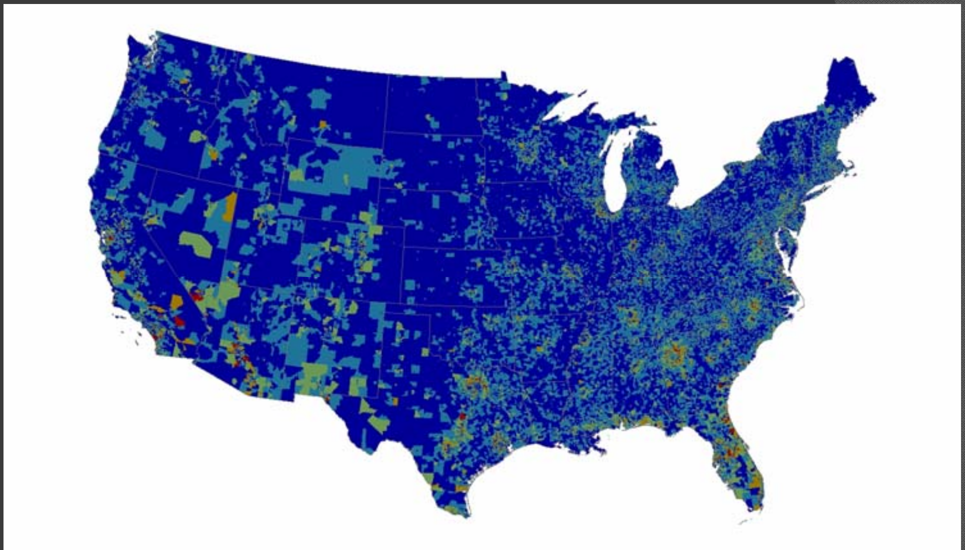
- Minimum requirements:
  - North American populations
  - Non-overlapping endpoints/ICD codes
  - Time-series, case-cross-over or cohort studies.
- Prefer:
  - US populations
  - Population attributes similar to those affected by air pollution
  - Sufficient study population size
  - Multi-city studies
  - Multi-pollutant models
- Generally apply the best array of studies available
  - Frequently "pool" across studies to generate a best estimate for each endpoint
- BenMAP CE contains over a hundred health impact functions*

*199 as of November 2012

# Selecting Population Data

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

- BenMAP population data stratified by 304 age/race/sex/ethnicity groups
  - Uses 2010 census data as baseline
  - Population aggregated up from the census block to resolution of the air quality modeling grid (e.g. 12km)
- Users can select population data projections to 2040
  - Woods & Poole economic forecasting model accounts for future changes in the size and distribution of the population
  - ORD "gravity model" predicts population growth in response to climate change scenarios
- Goal is to match the population characteristics of the epidemiological studies

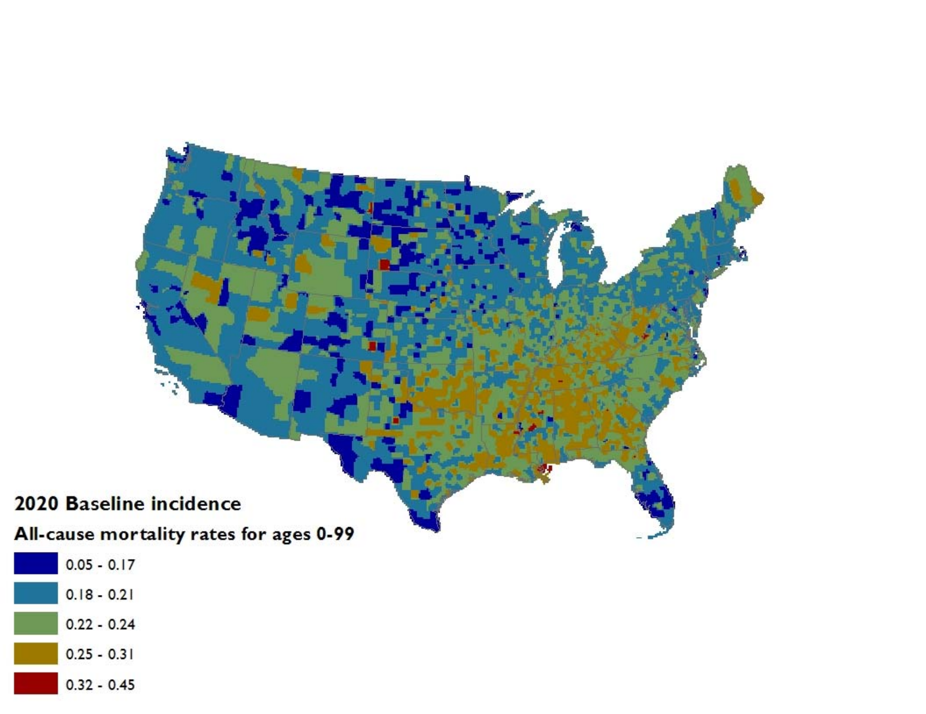


Total U.S. Population at Census Block Groups

# Selecting Incidence Rates

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

- BenMAP contains baseline incidence rates matched to each health impact function
- Mortality rates
  - Recent-year CDC-WONDER county-level cause specific rates by age
  - Projected through 2050 in 5-year increments using census forecast of national mortality rates
- Morbidity rates
  - Hospital and ED visits a mix of county, state and national level data
  - Other morbidity impacts (e.g. acute respiratory symptoms) are national-level
- National asthma prevalence provided by ALA




All-cause mortality rates for all ages projected to 2020

BenMAP-CE Status Demonstration

# Pooling, Aggregating and Valuing the Results

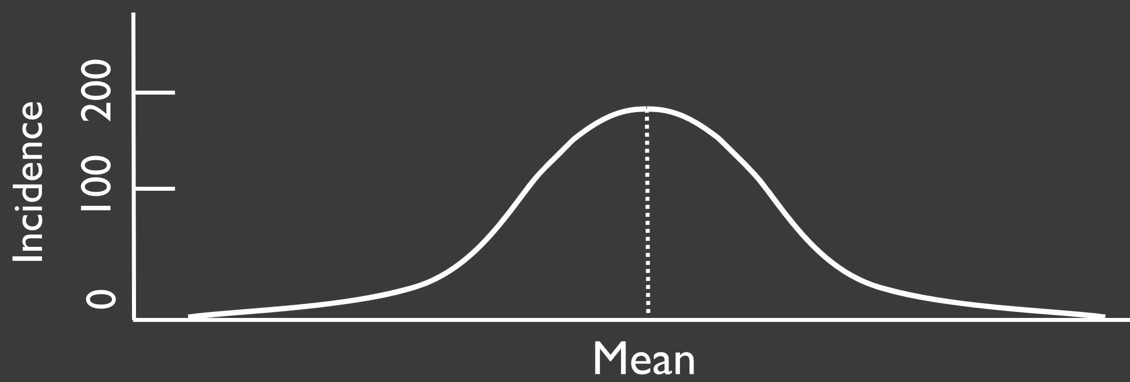
# What is Pooling?

- Pooling is a type of meta-analysis that:
  - Allows users to combine or aggregate study estimates
  - Can account for heterogeneity across studies
- BenMAP offers several alternate options:
  - Addition
  - Subtraction*
  - User-assigned weights
  - Random-Effects Model
  - Fixed-Effect Model*

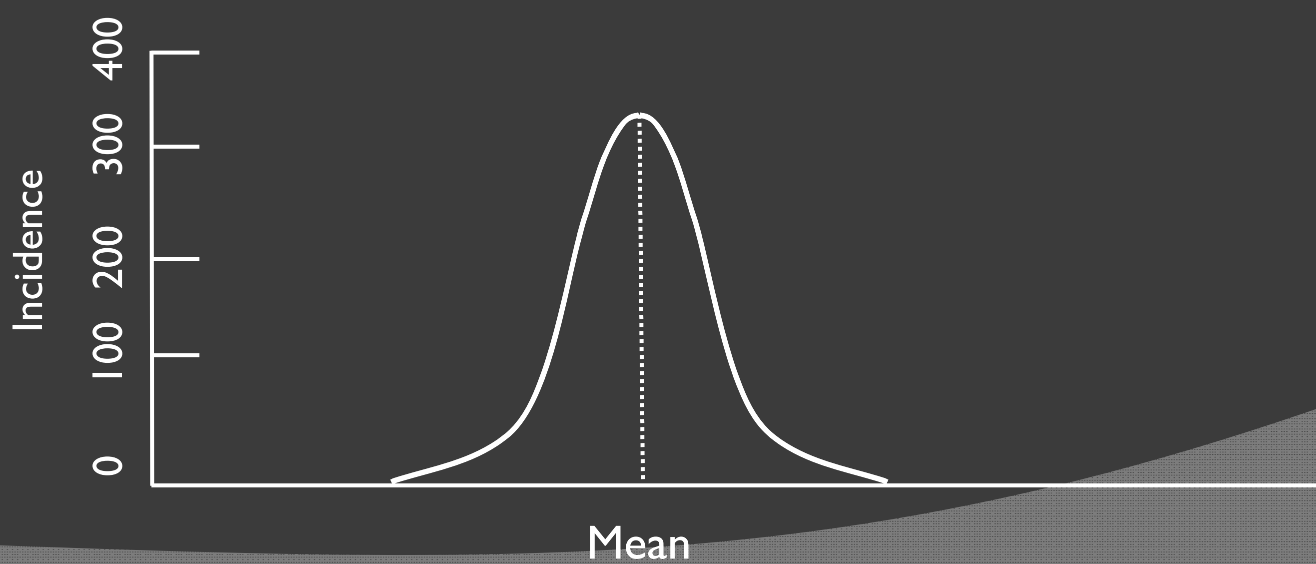
*Rarely used approaches

# Pooling: Addition

*Hospital visits for ischemic heart disease (ICD-9: 410-414)*



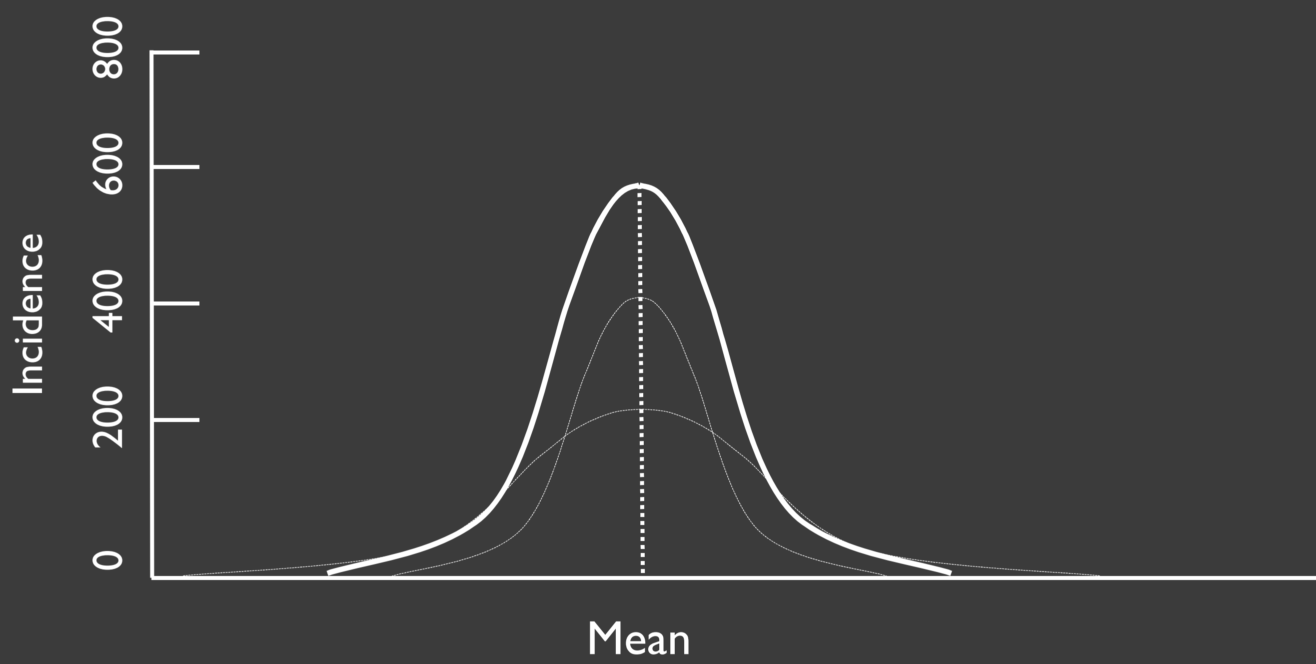

*Hospital visits for dysrhythmia (ICD-9: 427)*




Addition allows us to combine non-overlapping estimates of a common health endpoint

# Pooling: Addition

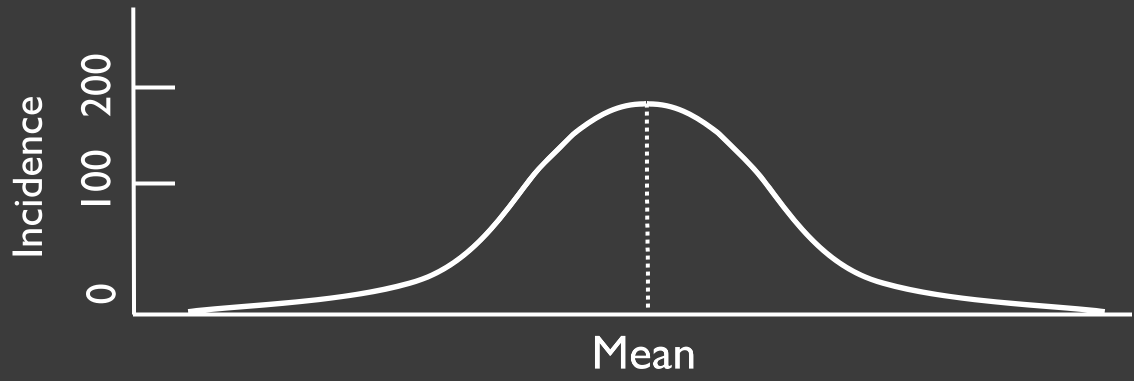
*Hospital visits for ischemic heart disease **and** dysrhythmia*




The sum of ischemic heart disease and dysrhythmia is provides a better overall characterization of the effects of air pollution on cardiovascular outcomes than either endpoint alone.

# Pooling: Subtraction

*Hospital visits all cardiovascular outcomes (ICD-9: 390-459)*



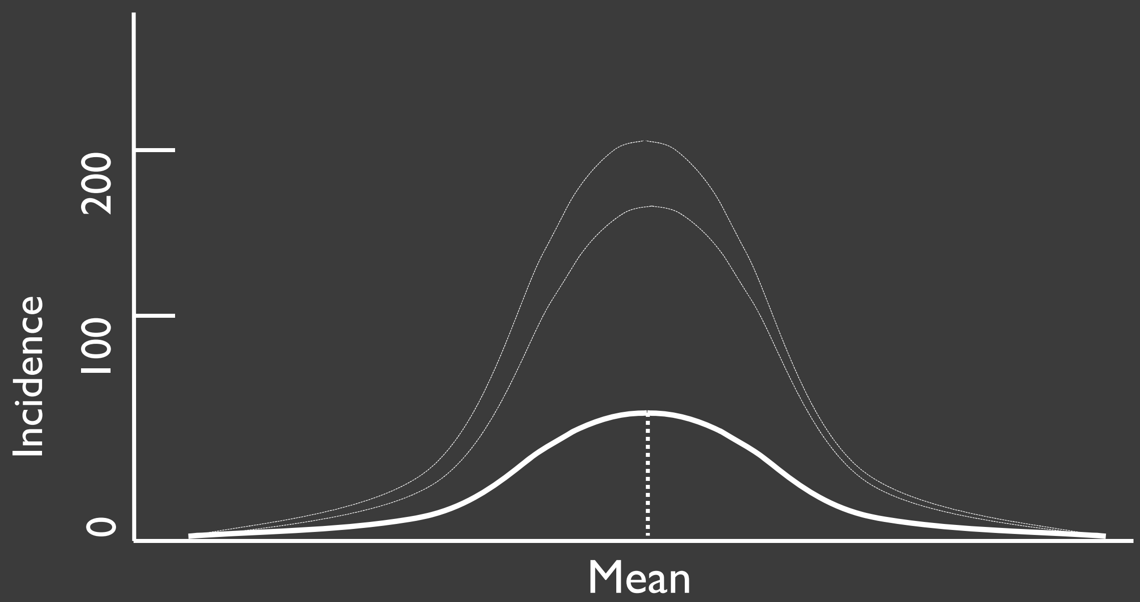

*Hospital visits for all cardiovascular outcomes except stroke (ICD-9 390-440)*


Subtraction allows us to "net out" the incidence of a health endpoint from two or more studies

In this example, the only difference between these two studies is that study one includes all cardiovascular outcomes, while study two excludes strokes

# Pooling: Subtraction

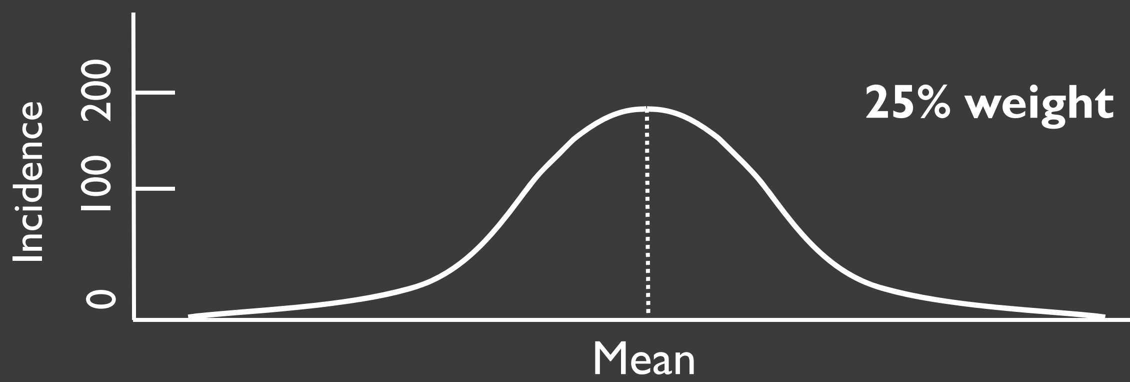
*Hospital visits for stroke (ICD-9: 440-449)*



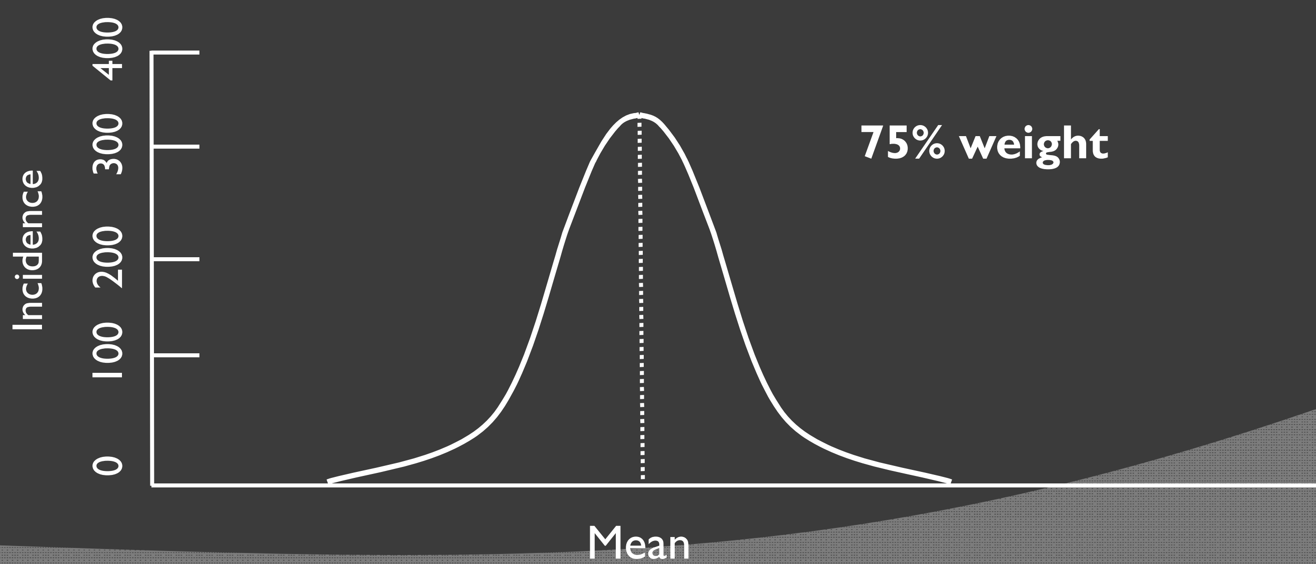

Subtracting the results of study two from study one yields an estimate of stroke

# Pooling: User-Assigned Weights

*Peng et al. 2009 Multi-City Study of Cardio Hospital Admissions*




*Bell et al. 2008 Multi-City Study of Cardio Hospital Admissions*

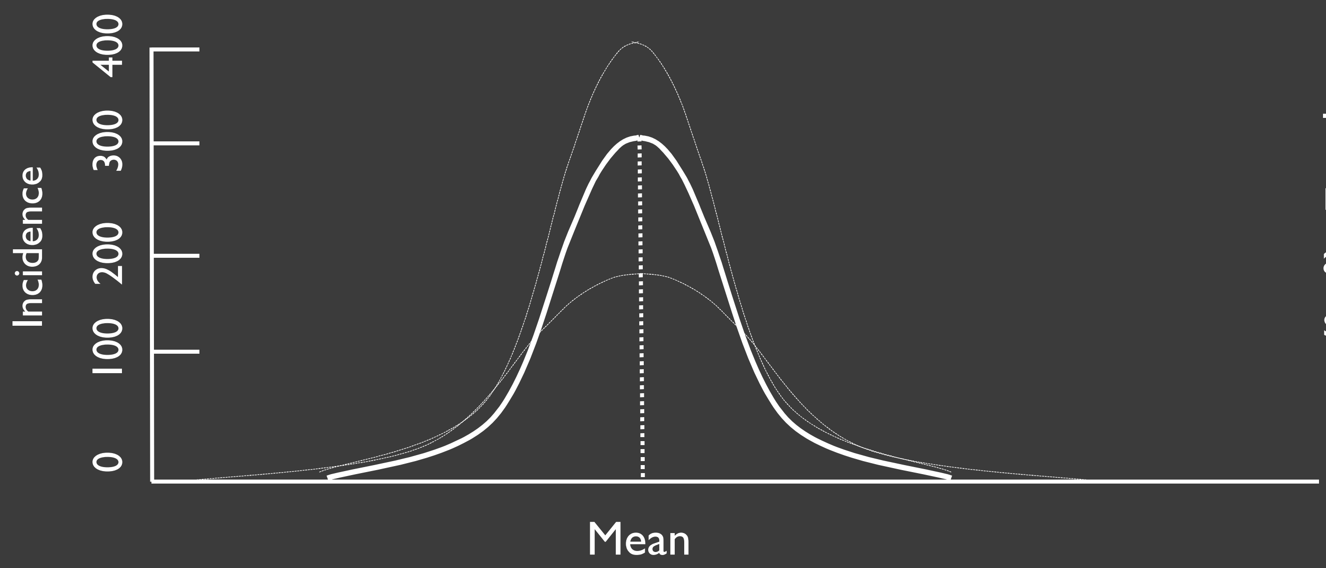



Some studies examine a common health endpoint and share a similar methodology, but may differ slightly in the populations examined

Users may wish to combine these study estimates together using equal weights

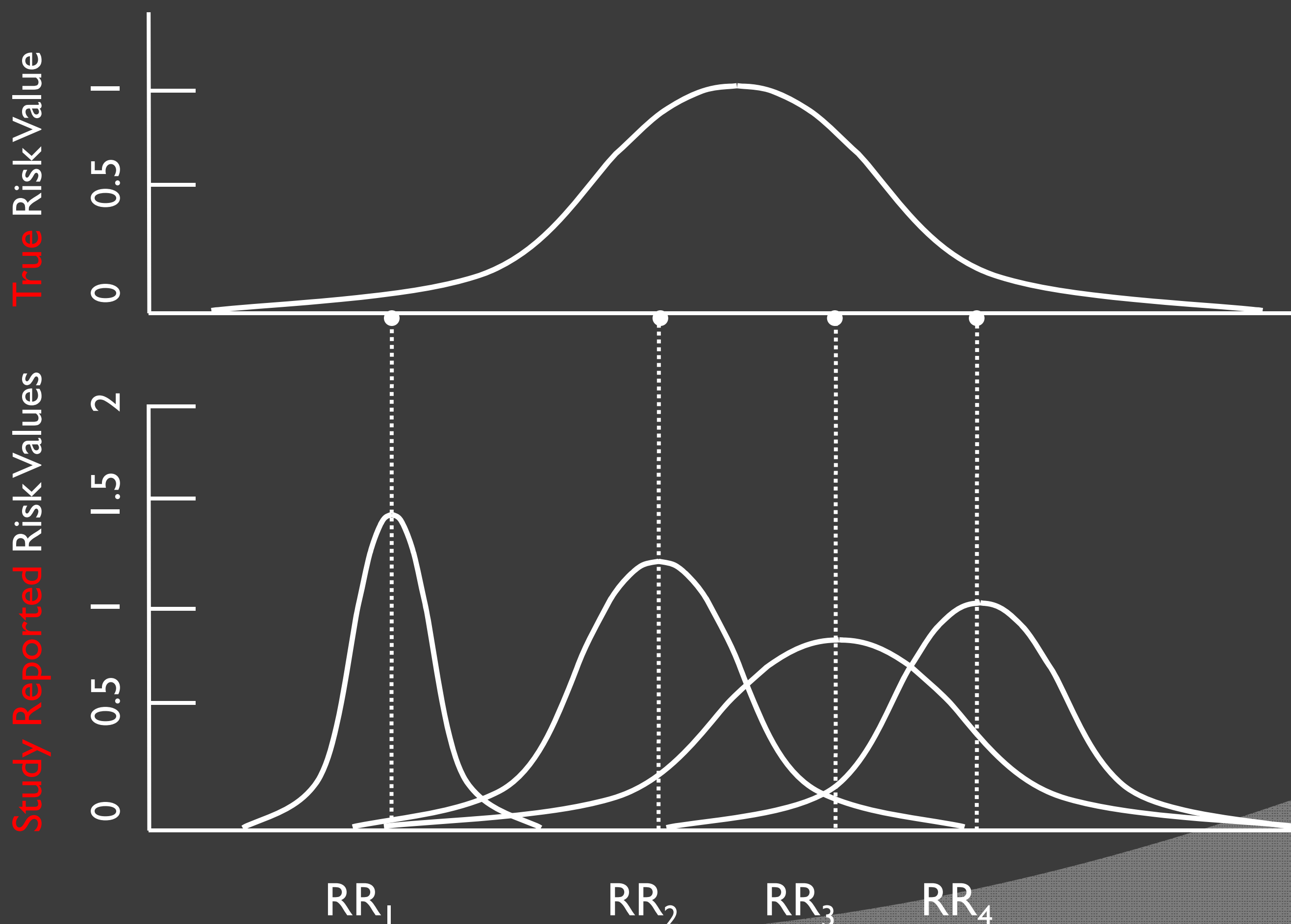
# Pooling: User-Assigned Weights

*Pooled estimate of Peng & Bell*




The pooled value reflects a weighted average of the two studies

# Pooling: Random-Effects



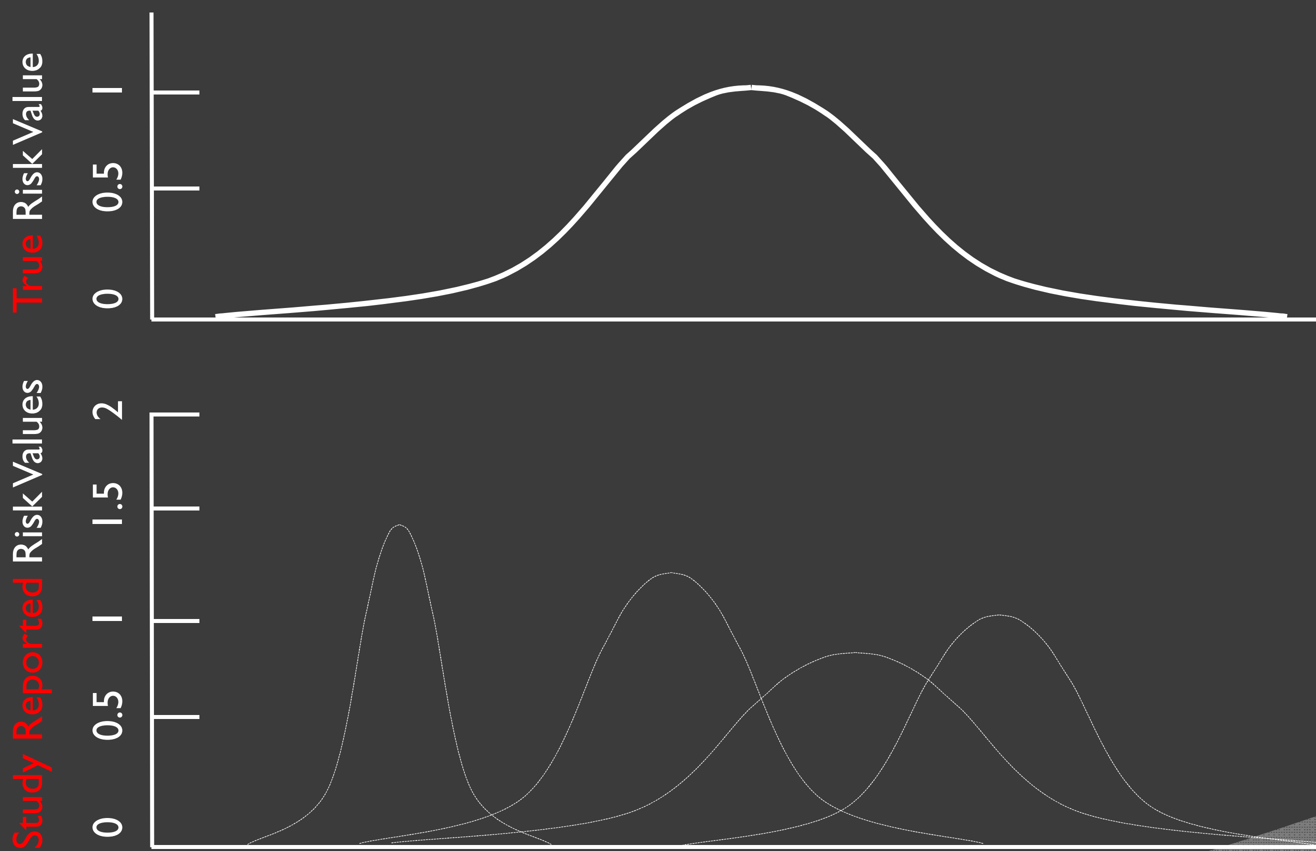

For the risks of a given health outcome there is a **true** but **unknown** distribution

The individual studies in the literature report individual risk estimates from that distribution

Random effects pooling accounts for heterogeneity in the individual risk estimates to generate a single mean risk estimate

Adapted from: Mosteller and Colditz (1996); Charles Poole EPID 731

# Pooling: Random-Effects

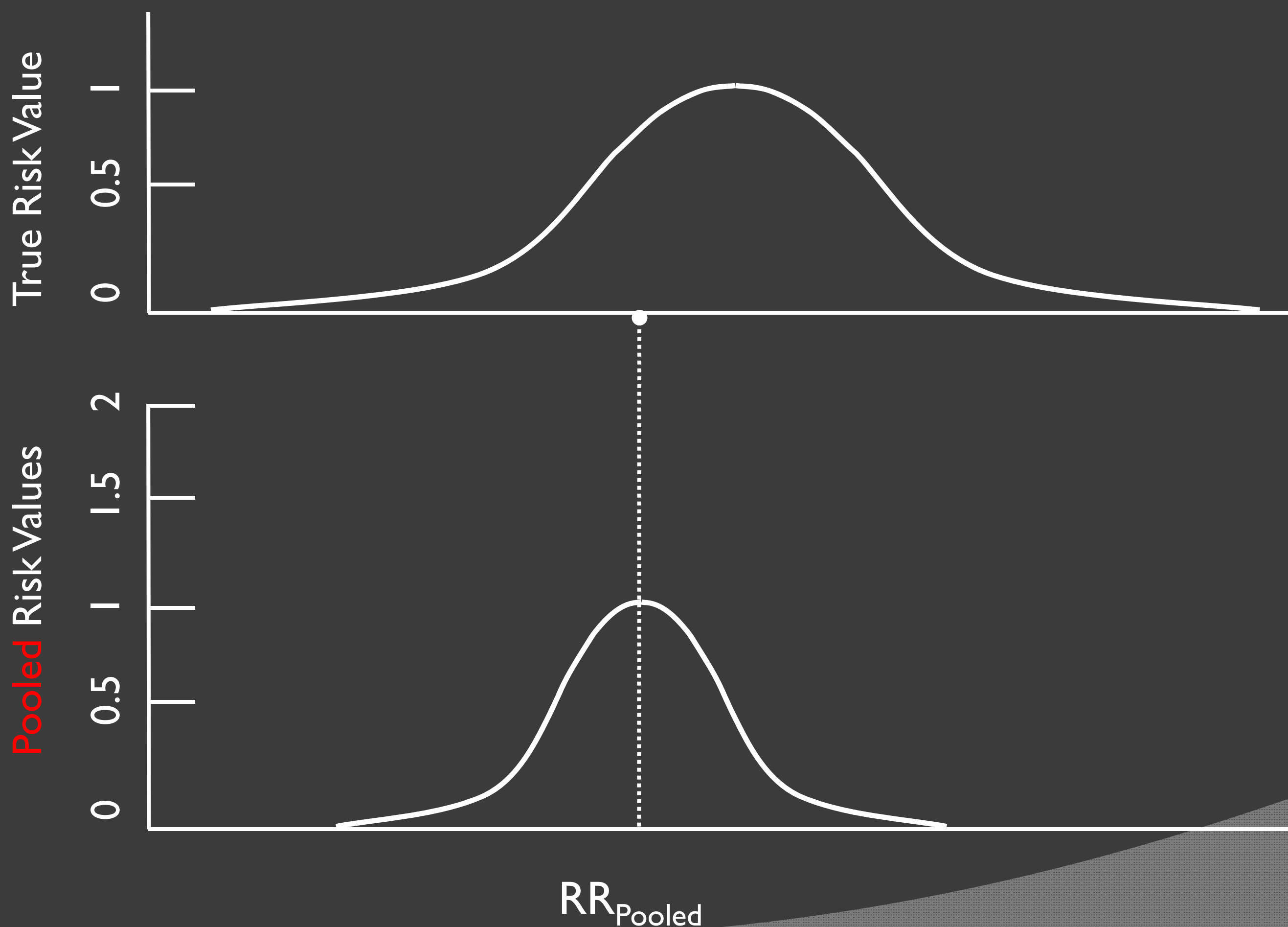



The Random-Effects model assigns each study a weight based on two factors:

1. The spread of estimates reported by each study (i.e. the variance)
2. How much that spread of estimates differs from spread reported by the other studies

Adapted from: Mosteller and Colditz (1996); Charles Poole EPID 731

# Pooling: Random-Effects




The Random-Effects model assigns each study a weight based on two factors:

1. The spread of estimates reported by that study (i.e. the variance)
2. How much that spread of estimates differs from the other studies

Finally, the Random-Effects model calculates a weighted average of the studies

# Step Three: Assign a $ Value

- Cost of Illness (COI)
  - Medical expenses for treatment of illness
  - Captures the money savings to society of reducing a health effect
  - Ignores the value of reduced pain and suffering
  - Indexed to cost year

- Willingness To Pay (WTP)
  - Lost wages, avoided pain and suffering, loss of satisfaction, loss of leisure time, etc.
  - Measures the complete value of avoiding a health outcomes
  - Indexed to cost year and adjusted for changes in personal income

- OMB requires that we report monetized benefits at discount rates of 3% and 7%

# Adjusting Valuation Estimates for Cost Year and Income Growth

- Example 1: Cost of illness estimate for asthma hospital visit in 2008
  - Recent-year medical costs + recent-year lost wages

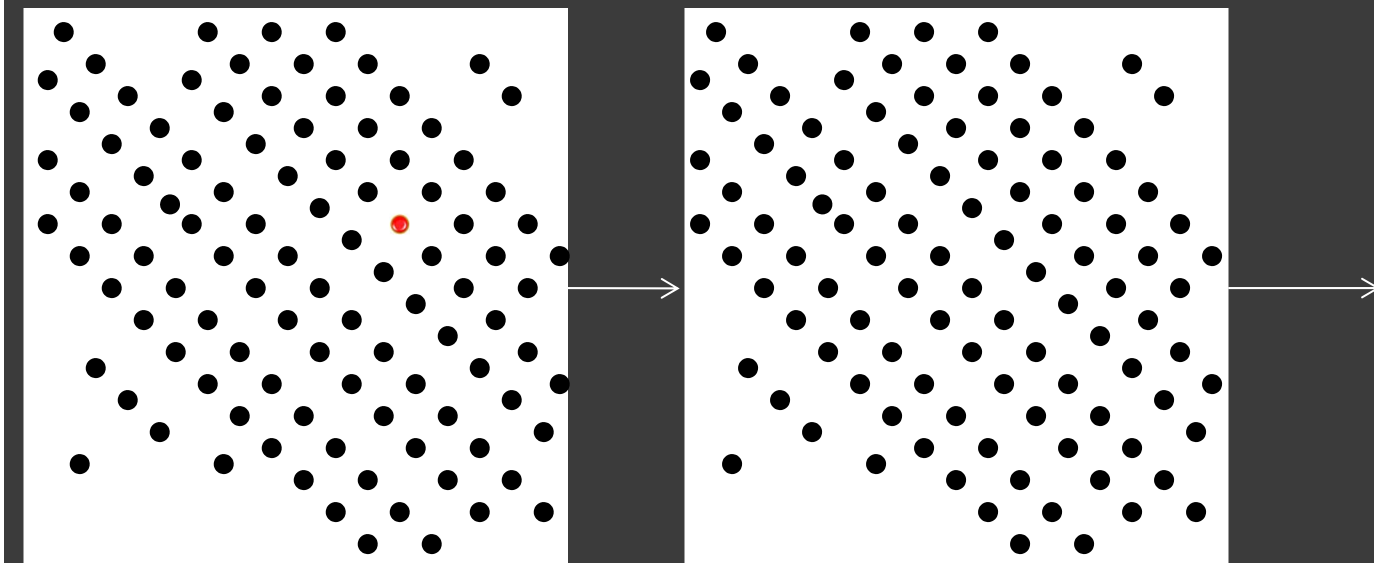
| Charge | | | Cost |
|---|---|---|---|
| *Hospital charge* | | | |
| Room charge in 2000$ | Medical consumer price index to 2008$ | | |
| $12,000 | 20% | | **$14,400** |
| *Lost wages* | | | |
| Length of stay | Median daily wage in 2000$ | Wage index to 2008$ | |
| 5 days | $160 | 13% | **$900** |
| | | ***Grand Total*** | ***$15,300*** |

# Adjusting Valuation Estimates for Cost Year and Income Growth

- Example 2: Willingness to pay to avoid asthma exacerbation in 2020
  - Willingness to Pay * Adjustment for Future Income

| Willingness to Pay in 2000$ | Income growth adjustment to 2020 | Cost year adjustment to 2008$ |
|---|---|---|
| $160 | 1.07 | 1.25 |
| | ***Grand Total*** | ***$214*** |

# Calculating the Value of a Statistical Life



\$500 • 10,000 = \$5m

In a population of 10,000, reducing pollution would avoid one premature death (i.e. reduce risk by 1 chance in 10,000)

Each of 10,000 are willing to pay \$500 to reduce risk of death by 1 chance in 10,000

VSL is then WTP multiplied by the inverse of the risk reduction