Environmental Modeling and Health Risk Assessments

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Overview

- Almost since its inception, the EPA has used modeling:
  - To anticipate the effectiveness of new/proposed "command and control" regulations
  - To design and fill-in "gaps" in ambient monitoring networks
  - To evaluate SIP revisions
  - To evaluate the impacts of new/modified sources of emissions
- Human health risk evaluations use modeling results and apply dose/response statistics across specified segments of the population
- The broadest use of health risk modeling occurs when the EPA considers changes to the National Ambient Air Quality Standards (NAAQS)

Background

- The regulatory “workhorse” air pollution models range from relatively simple “Gaussian” plume models (not used beyond 50 kilometers from the source) to significantly more complex “gridded” 3D models (used across domains measuring on the order of 1,000 kilometers)
- The amount and sophistication of the model input data (meteorology, terrain, source, boundary conditions, etc) vary significantly across the complexity spectrum
- An intuitive or common sense notion about how air pollutants might behave in the atmosphere is not often a good guide to rationalizing measured or modeled concentrations

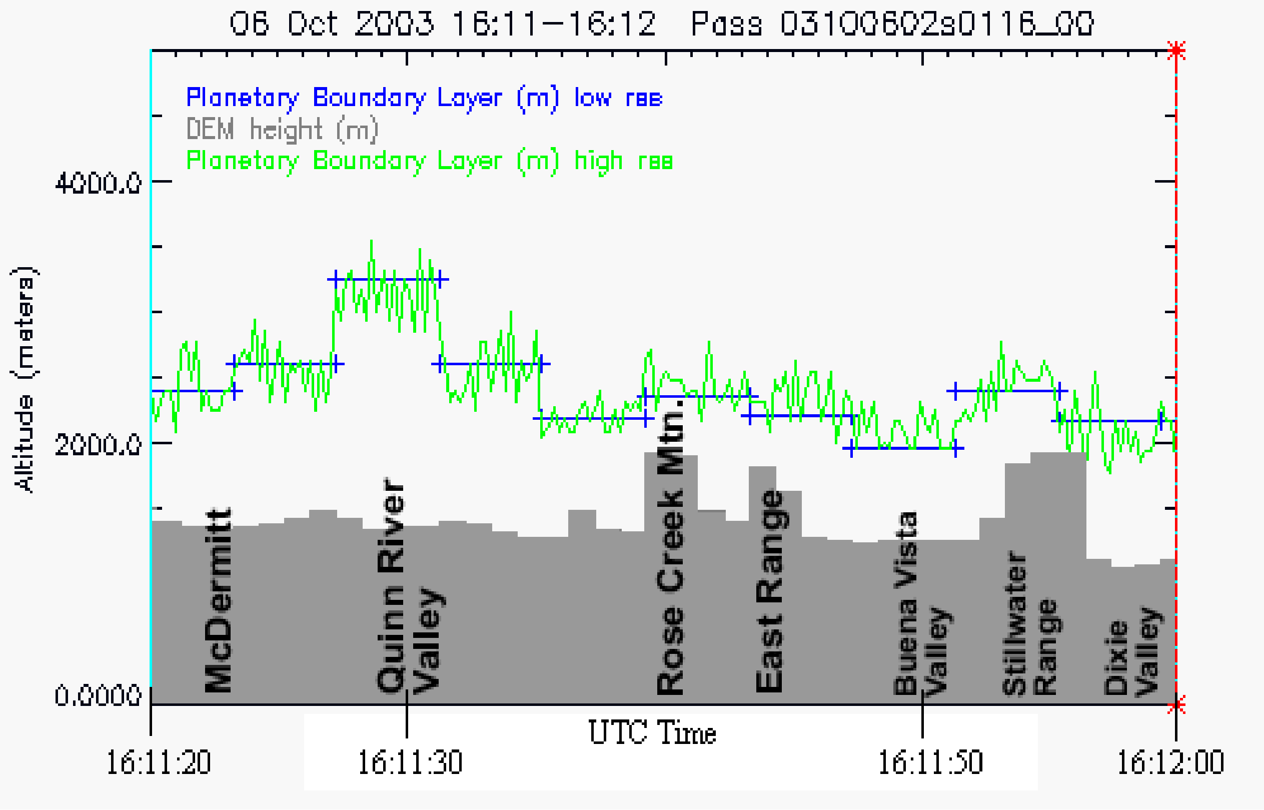
Some Myths about Modeling

- EPA’s models are intentionally biased to produce high estimates of atmospheric concentrations
- EPA’s models can be “finagled” to produce any results you want
- All sources can be modeled with essentially equally accurate results. Problematic situations:
  - Irregular terrain - mountainous regions (near and far fields)
  - Dense urban areas (mainly near field)
  - Land/sea interface

Some Interesting Aspects of the Earth's Atmosphere

- The dynamics of the daytime and nighttime atmospheres (particularly over land and in the summer) are very distinct
  - Buoyancy derived turbulence (density fluctuations mixing air parcels both horizontally and vertically) dominates during the day
  - Mechanical turbulence becomes a more significant factor at night – typically much weaker
- During summer days in the continental US, the lower atmosphere is well mixed vertically to between 1,000 and 2,000 meters above the local ground level (Daytime Planetary Boundary Layer)

Planetary Boundary Layer



More Interesting Aspects of the Earth's Atmosphere

- At night over land, the degree of mixing in the lower atmosphere dramatically crashes (no more buoyancy derived turbulence). The PBL may range from 200 to 300 meters above the surface.
- Overall the lowest 100 km of the atmosphere is not in "diffusive equilibrium due to effective long-term mixing!
- The lower atmospheric chemistry is complex and varies significantly between day and night

Short Stacks vs. Tall Stacks?

What Happens to NOx in the Atmosphere

- NOx = NO + NO2
- NOx is a trace compound in the atmosphere with both anthropogenic and non-anthropogenic sources
- In a “clean” (relatively void of ozone and VOCs) lower troposphere both NO and NO2 are moderately stable (particularly at night) – half-life of “NOx” is on the order of several hours to a day
- In a “polluted” lower troposphere, NO is tends to be scavenged by O3 to form NO2 (and O2). Because NO emissions are generally ground based (up to several hundred feet), O3 is eliminated from ground up by this mechanism. Some NO3 radicals are also formed – but these are unstable and can also react with NO to re-form two NO2 molecules.

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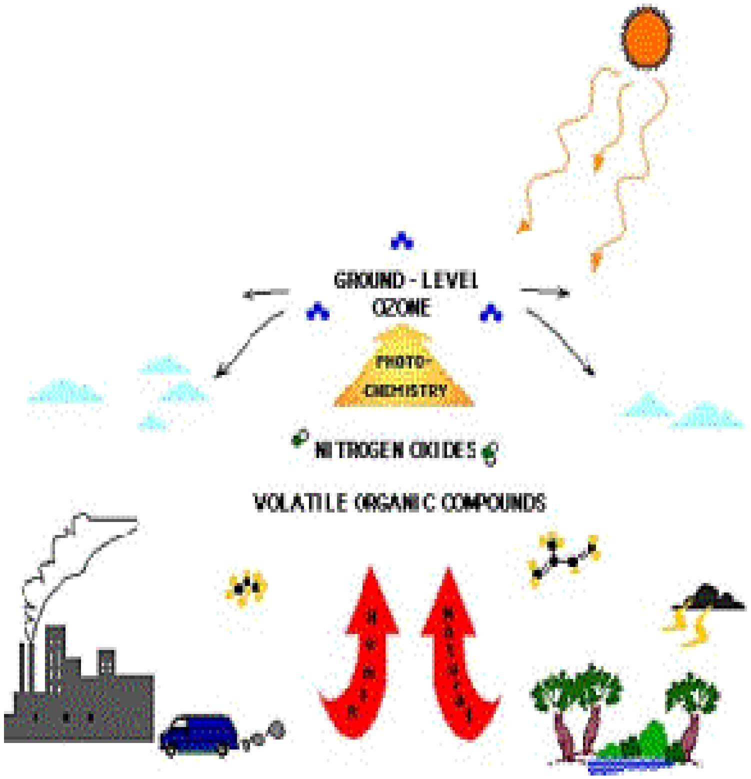
Planetary Boundary Layer



Key chemical reactions influencing the levels of O3, NO2 and “Ox” in a polluted BL at night

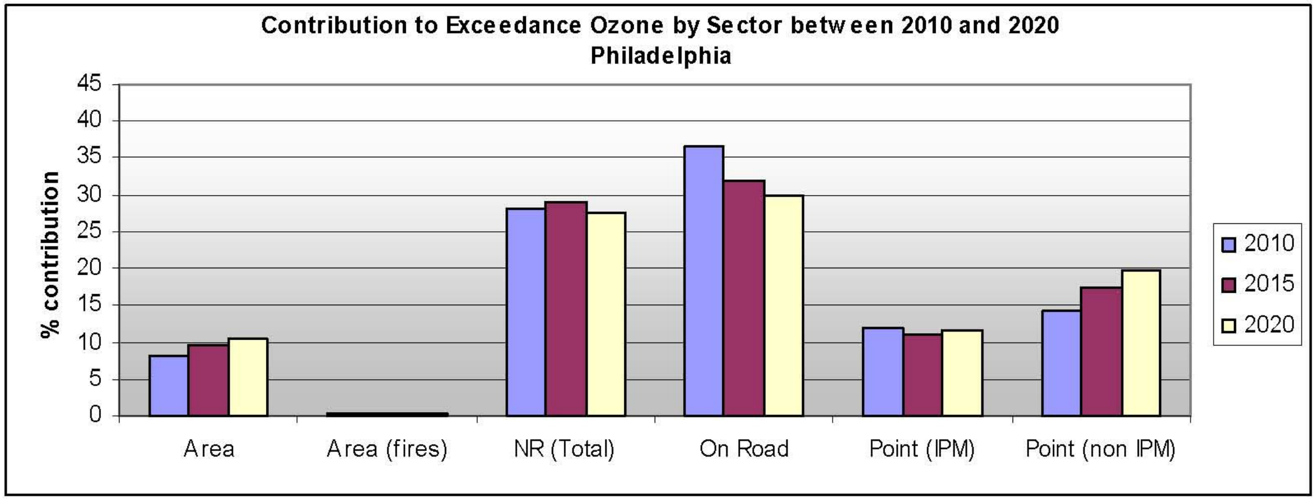
- NO + O3 → NO2 + O2
- NO2 + O3 → NO3 + O2
- NO3 + NO → NO2 + NO2
- NO3 + VOCs . . .. . . → organic nitrate + other products
- NO3 + NO2 +M → N2O5 +M
- N2O5 + H2O [aerosols] → 2HNO3

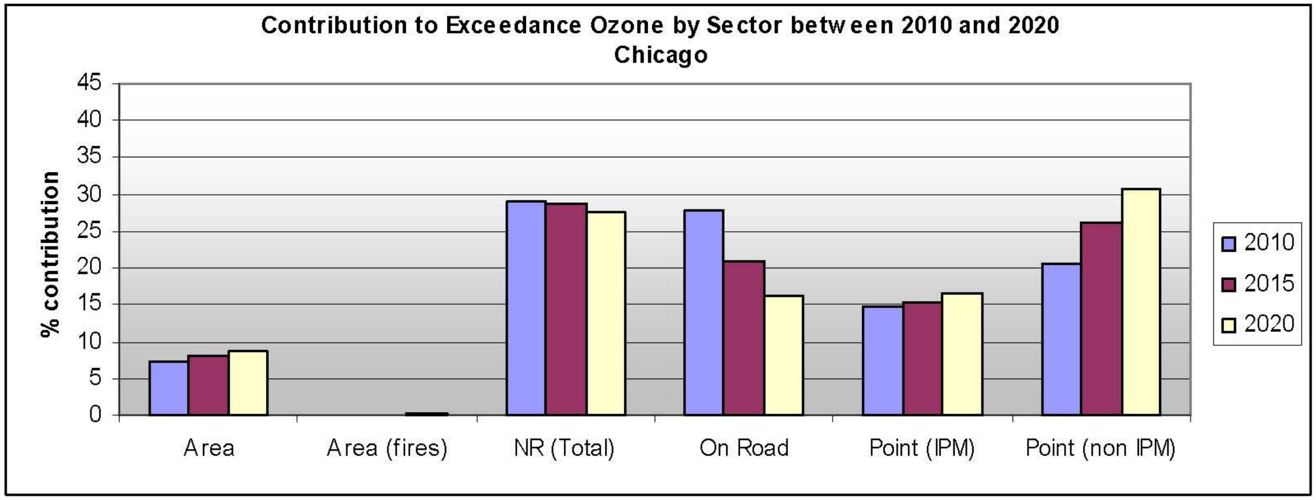
Night-time “Ox” Profile

- “Ox” is the sum of O3 and NO2.
- According to Wang et. al. (2006), the vertical profile of “Ox” above Phoenix at night in the lower troposphere is essentially flat (no vertical distribution of “Ox”) most nights – Leading one to believe NO2 is not rapidly depleted at the ground
- However, the surface depletion rate of NO2 is not particularly well understood under all surface and atmospheric conditions

Changes in relative O3 contribution by sector between 2010, 2015, and 2020

Remember: Ozone is projected to decrease over this period





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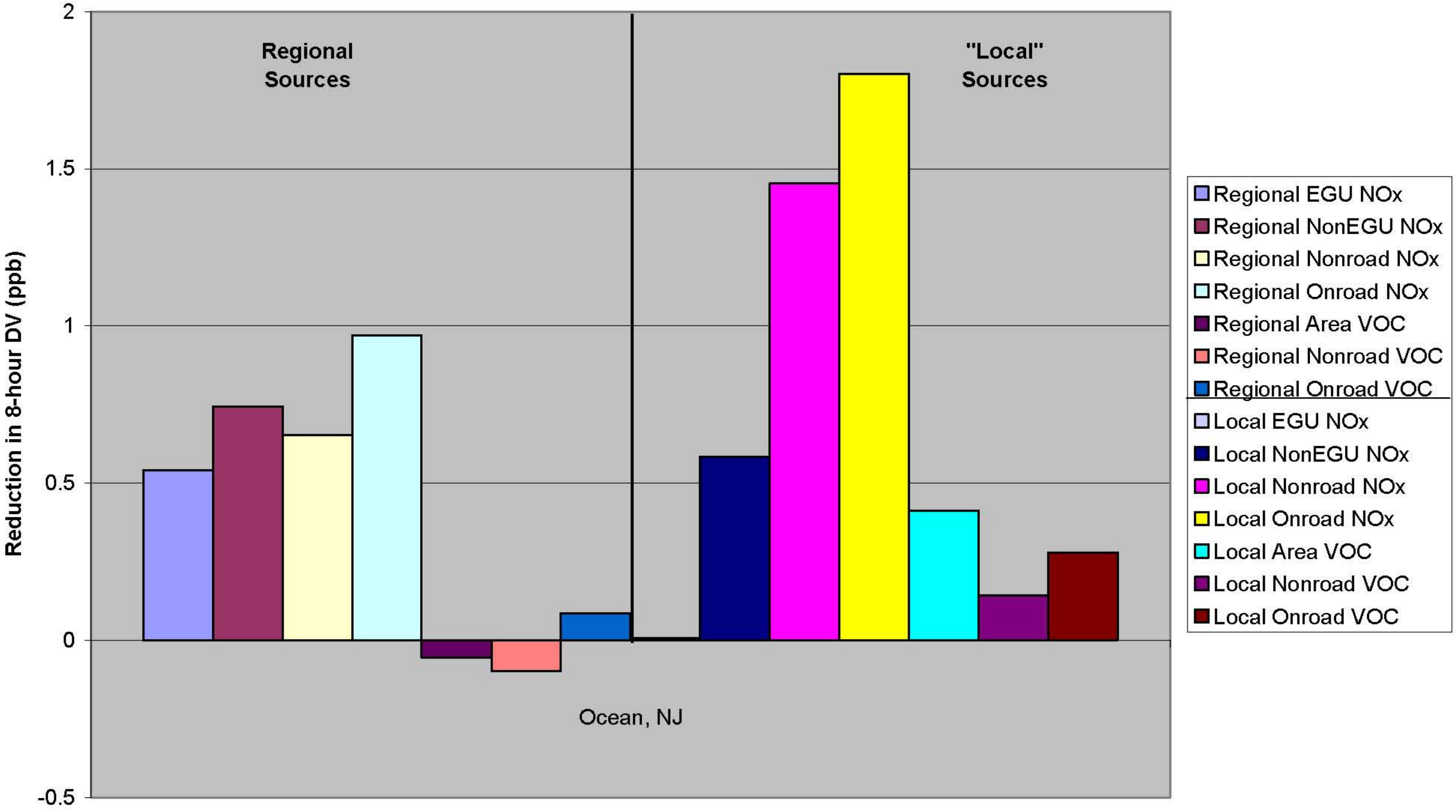
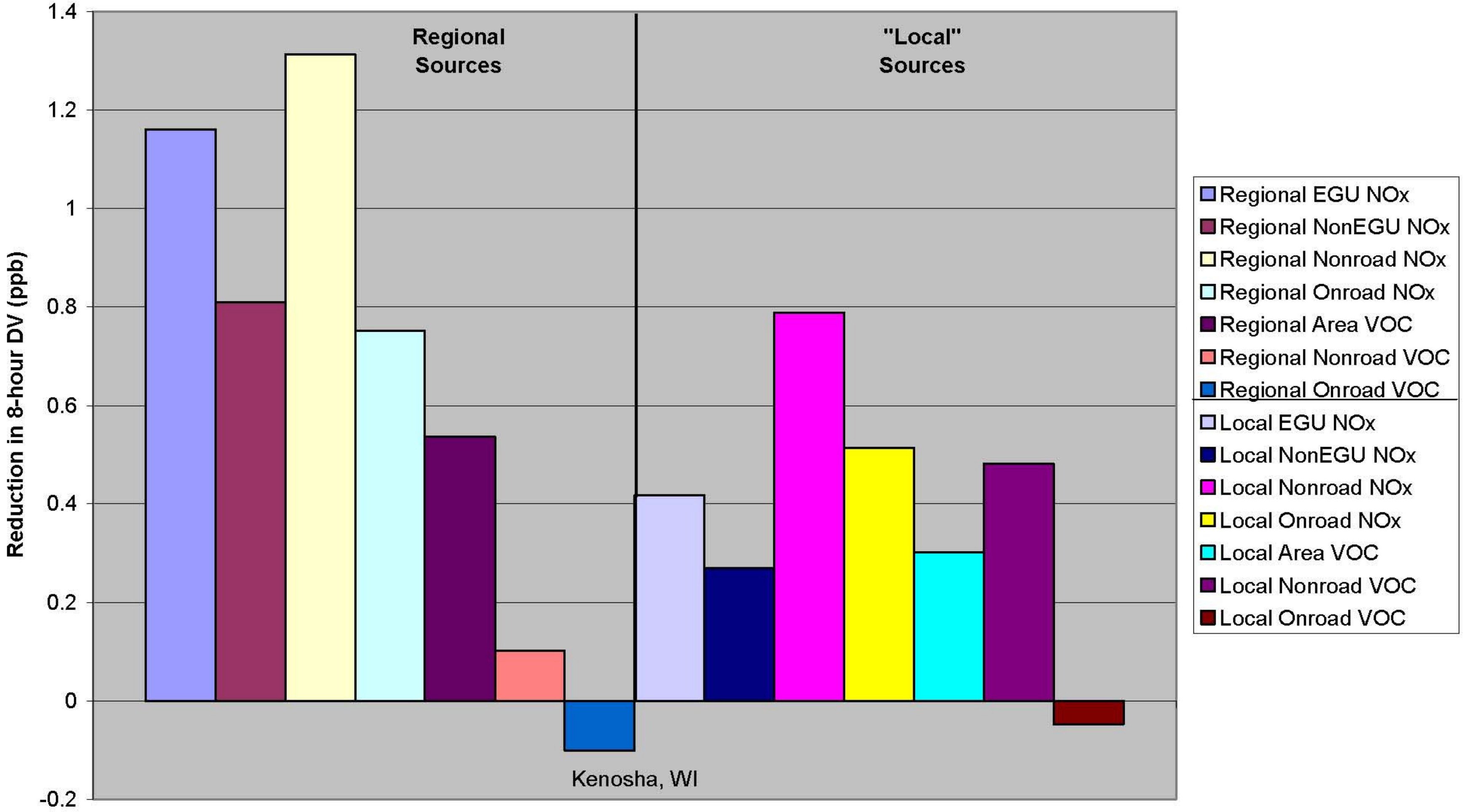
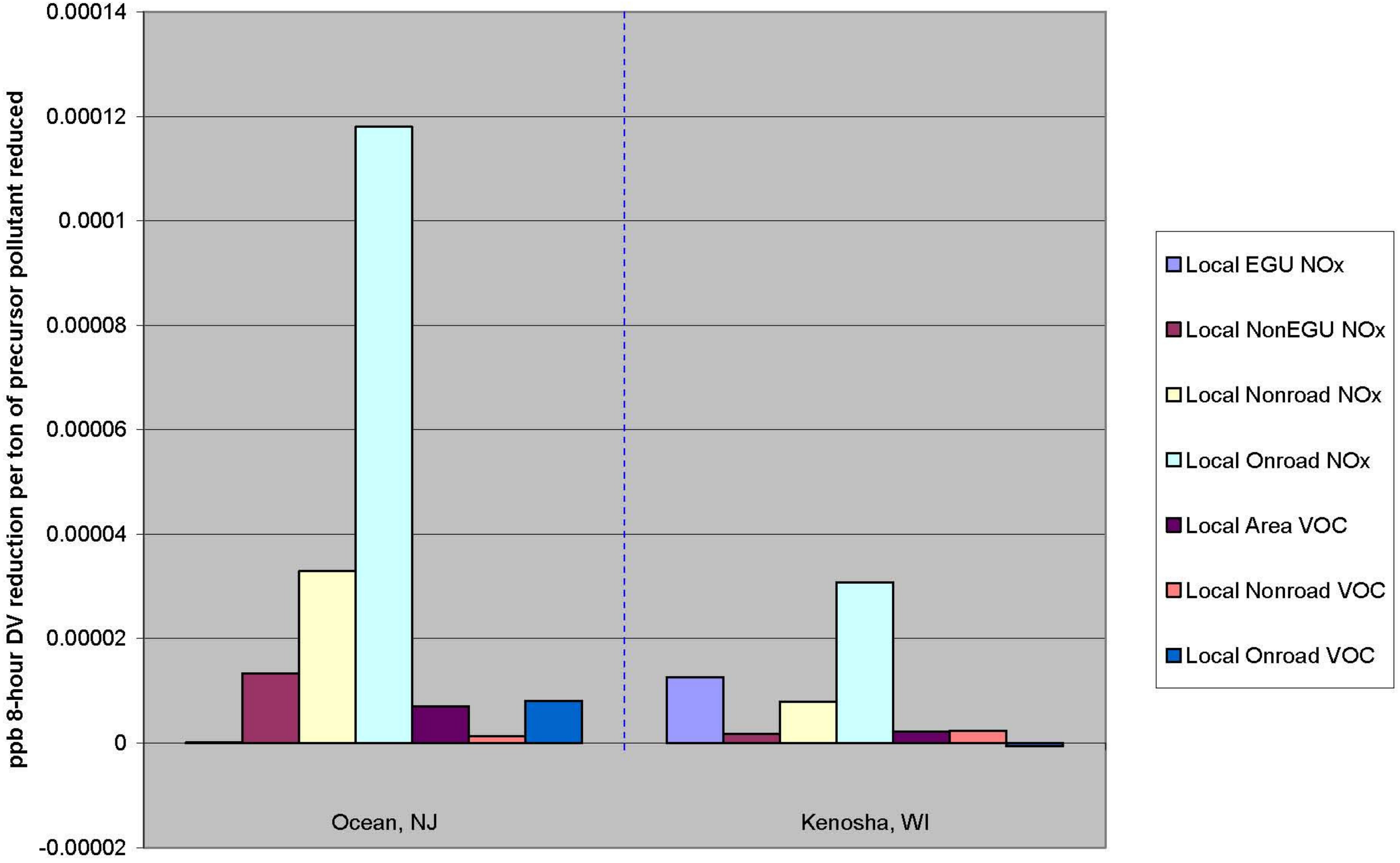
Impact on New York/New Jersey Ozone Nonattainment Area of 30 Percent Reduction in Emissions Across Sectors and Pollutants for Regional and Local Sources (Ocean County Post-CAIR 2015 DV = 96.9)



Impact on Milwaukee Ozone Nonattainment Area of 30 Percent Reduction in Emissions Across Sectors and Pollutants for Regional and Local Sources
(Kenosha County Post-CAIR 2015 DV = 88.8)



Relative Effectiveness Per Ton of "Local" Emission Reductions Across Sources and Precursor Pollutants



Summary

- The long-range transport (100+ kilometers) of ozone is well documented due to the stability of ozone aloft at night
- Due to horizontal mixing, the ozone formation impact of any NOx source decreases with downwind distance (travel time)
- All sources of NOx (NO/NO2) contribute to ozone formation during the day in the well mixed lower atmospheric layer (assuming sufficient peroxy radicals and/or VOCs are present)
- It is unlikely the NOx release height is a strong factor in the formation and/or transport of regional ozone

Risk Assessment Overview

- Environmental Risk Assessments – Why and When?
  - Social, Economic, and Political Factors
  - Risk Management Decision – Technical Analysis
  - Regulatory Action

Risk Assessment Overview Regulatory Drivers

- Air Toxics Permitting
- Cumulative Risk
- RCRA Hazardous Waste Combustion Permitting
- MACT Health-Based Compliance Alternatives (HBCA)
- Environmental Justice
- Environmental Impact Statements (EIS)
- Ecological Risk
- Toxic Tort and Odor/Nuisance Litigation
- Residual Risk

Risk Assessment Overview – How?

- Air Dispersion Modeling
  - NAAQS
  - State Ambient Air Standards
  - Air Toxics Standards/Guideline Concentrations
- Pathway-specific Risk Analysis Protocols and Models
  - Hotspots Analysis and Reporting Program (HARP)
  - Total Risk Integrated Methodology (TRIM)
  - Human Health Risk Assessment Protocol (HHRAP)

Air Dispersion Modeling

- Source parameters
  - Emission rate
  - Stack location and height
  - Exhaust temperature/velocity/flowrate
- Building dimensions
- Property line
- Land use
- Receptor locations and elevations
- Meteorological observations

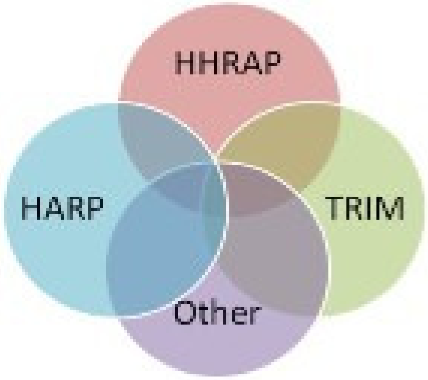
Air Dispersion Modeling

- Limitations
  - Single Pathway – ambient air concentrations
  - Models are not effective at reproducing accurate concentration estimates when matched with data reported at specific monitor locations or at specific times.
  - Currently do not incorporate population data into results interpretations.

Definition of HHRA

'The scientific evaluation of potential health impacts that may result from exposure to a particular substance or mixture of substances under specified conditions.'

- Direct inhalation (i.e., inhalation pathway)
- Ingestion of soil (i.e., soil-ingestion pathway)
- Consumption of above- and below-ground produce (i.e., garden pathway)
- Consumption of animal products (including, beef, milk, pork, eggs, and chicken)
- Consumption of drinking water
- Consumption of fish
- Infant exposure to breast milk



Important Definitions

- **Hazard**

  An impact to human health by chemicals of potential concern.

- **Risk**

  An estimation of the probability that an adverse health impact may occur as a result of exposure to chemicals in the amount and by the pathways identified.

- **Dose**

  Amount of a substance available for interaction with metabolic processes or biologically significant receptors after crossing the exchange boundary of an organism.

Important Definitions (Cont.)

- **Compound of Potential Concern (COPC)**

  Compound being considered for the HHRA process

- **Exposure**

  The condition of a chemical contacting the exchange boundary of an organism

- **Indirect Exposure**

  Contact with soil, plants, or water bodies (Chemical has deposited)

  Includes Ingestion.

- **Direct Exposure**

  Exposure via inhalation

Important Components of HHRA

Media

- Water / Drinking Water
- Air
- Soil
- Above ground produce
- Animals (Fish, Chicken, Beef, Milk, Eggs)

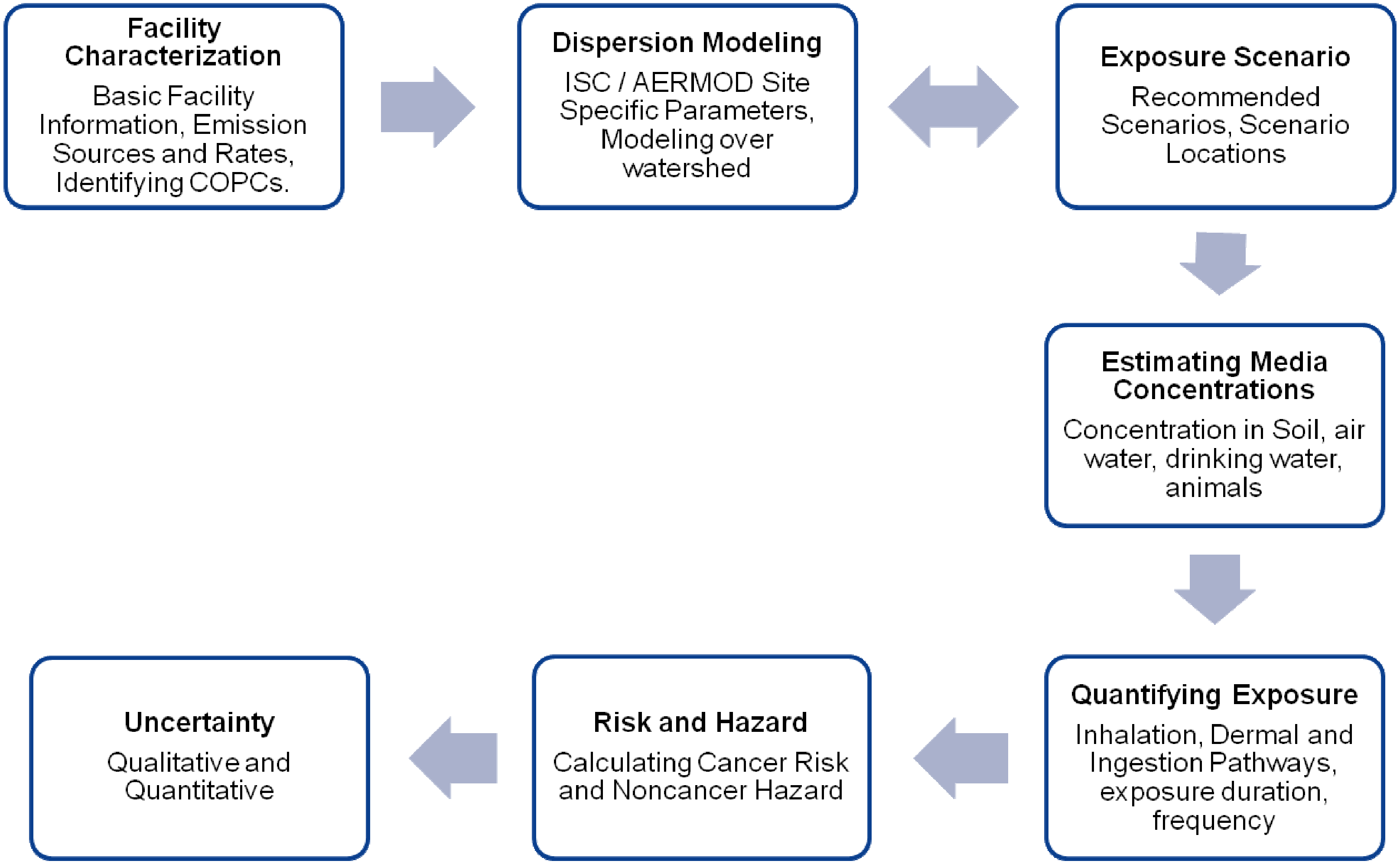
Pathways

- Inhalation
- Ingestion
- Dermal

Exposure Scenarios

- Farmer and Farmer Child
- Resident and Resident Child
- Fisher and
- Fisher Child
- Acute Receptor

HHRA Process



Facility Characterization
Basic Facility Information, Emission Sources and Rates, Identifying COPCs.

Dispersion Modeling
ISC / AERMOD Site Specific Parameters, Modeling over watershed

Exposure Scenario
Recommended Scenarios, Scenario Locations

Estimating Media Concentrations
Concentration in Soil, air water, drinking water, animals

Quantifying Exposure
Inhalation, Dermal and Ingestion Pathways, exposure duration, frequency

Risk and Hazard
Calculating Cancer Risk and Noncancer Hazard

Uncertainty
Qualitative and Quantitative

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Cancer Risk and Hazard Quotient

- **Individual Cancer Risk (Indirect Exposure, Carcinogens):**

$$Cancer\ Risk_i = \frac{I \cdot ED \cdot EF \cdot CSF}{AT \cdot 365}$$

- **Hazard Quotient (Non - Carcinogens)**

$$HQ = \frac{I \cdot ED \cdot EF}{RfD \cdot AT \cdot 365}$$

- Where,
  - I = Daily intake of a COPC, mg COPC/kg BW-day
  - ED = Exposure duration, yrs
  - EF = Exposure Frequency, days/yr
  - AT = Averaging Time, yrs
  - CSF = Cancer Slope Factor (COPC specific value), $(mg/kg\text{-}day)^{-1}$
  - RfD = Reference Dose (COPC Specific value), mg /kg-day

Total Cancer Risk and Hazard Index

- **Individual Cancer Risk (Indirect Exposure, Carcinogens):**

$$Total\ Cancer\ Risk = \sum_i Cancer\ Risk_i$$

  - Total Cancer Risk is the sum of cancer risk for all *'i'* COPC carcinogens

- **Total Hazard Index (Non - Carcinogens):**

$$Total\ Hazard\ Index = \Sigma_j\ HI_j$$

$$HI = \Sigma_i\ HQ_i$$

  - Hazard Index (HI) is the sum of hazard quotients for all *'i'* non – carcinogenic COPCs through a single pathway
  - Total Hazard Index is sum of hazard indices across all *'j'* pathways

Target Levels

- **Individual Cancer Risk (Indirect Exposure, Carcinogens):**
  - Total Cancer Risk of 10^{-4} - 10^{-6} (Acceptable Range Risks, Superfund Value)
  - Incremental (over background) probability of an exposed individual's getting cancer
- **Total Hazard Index (Non - Carcinogens):**
  - Target Hazard Index level of 1.0 (Health protective, Superfund Value)
  - HI greater than 0.25, increased scrutiny
  - Non-cancer hazard estimates only identify the exposure level below which adverse effects are unlikely;
  - Reference dose or concentration does not say anything about incremental risk for higher exposures

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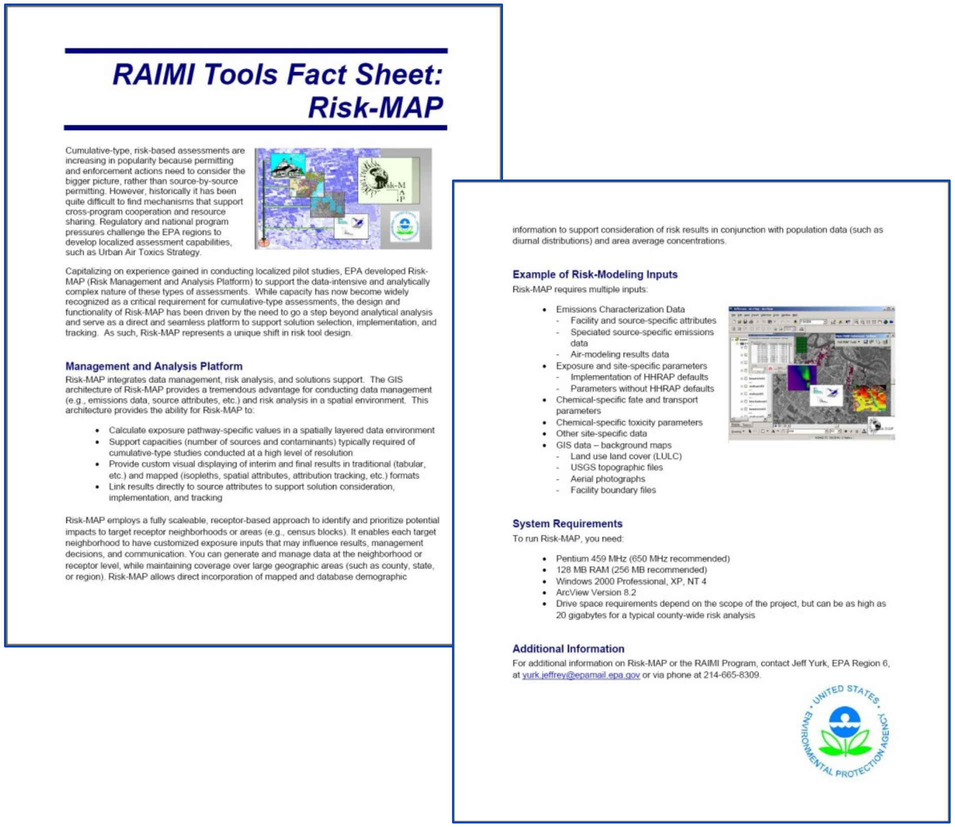
HHRA Tools
U.S. EPA Risk-MAP

- Developed by EPA Region 6
- HHRAP Compliant
- Fully Validated
- Fully Transparent
- Software Architecture - ESRI ArcView Extension



RAIMI Tools Fact Sheet: Risk-MAP

Cumulative-type, risk-based assessments are increasing in popularity because permitting and enforcement actions need to consider the bigger picture, rather than source-by-source permitting. However, historically it has been quite difficult to find mechanisms that support cross-program cooperation and resource sharing. Regulatory and national program pressures challenge the EPA regions to develop localized assessment capabilities, such as Urban Air Toxics Strategy.

Capitalizing on experience gained in conducting localized pilot studies, EPA developed Risk-MAP (Risk Management and Analysis Platform) to support the data-intensive and analytically complex nature of these types of assessments. While capacity has now become widely recognized as a critical requirement for cumulative-type assessments, the design and functionality of Risk-MAP has been driven by the need to go a step beyond analytical analysis and serve as a direct and seamless platform to support solution selection, implementation, and tracking. As such, Risk-MAP represents a unique shift in risk tool design.

Management and Analysis Platform

Risk-MAP integrates data management, risk analysis, and solutions support. The GIS architecture of Risk-MAP provides a tremendous advantage for conducting data management (e.g., emissions data, source attributes, etc.) and risk analysis in a spatial environment. This architecture provides the ability for Risk-MAP to:

- Calculate exposure pathway-specific values in a spatially layered data environment
- Support capacities (number of sources and contaminants) typically required of cumulative-type studies conducted at a high level of resolution
- Provide custom visual displaying of interim and final results in traditional (tabular, etc.) and mapped (isopleths, spatial attributes, attribution tracking, etc.) formats
- Link results directly to source attributes to support solution consideration, implementation, and tracking

Risk-MAP employs a fully scaleable, receptor-based approach to identify and prioritize potential impacts to target receptor neighborhoods or areas (e.g., census blocks). It enables each target neighborhood to have customized exposure inputs that may influence results, management decisions, and communication. You can generate and manage data at the neighborhood or receptor level, while maintaining coverage over large geographic areas (such as county, state, or region). Risk-MAP allows direct incorporation of mapped and database demographic information to support consideration of risk results in conjunction with population data (such as diurnal distributions) and area average concentrations.

Example of Risk-Modeling Inputs

Risk-MAP requires multiple inputs:

- Emissions Characterization Data
  - Facility and source-specific attributes
  - Speciated source-specific emissions data
  - Air-modeling results data
- Exposure and site-specific parameters
  - Implementation of HHRAP defaults
  - Parameters without HHRAP defaults
- Chemical-specific fate and transport parameters
- Chemical-specific toxicity parameters
- Other site-specific data
- GIS data – background maps
  - Land use land cover (LULC)
  - USGS topographic files
  - Aerial photographs
  - Facility boundary files

System Requirements

To run Risk-MAP, you need:

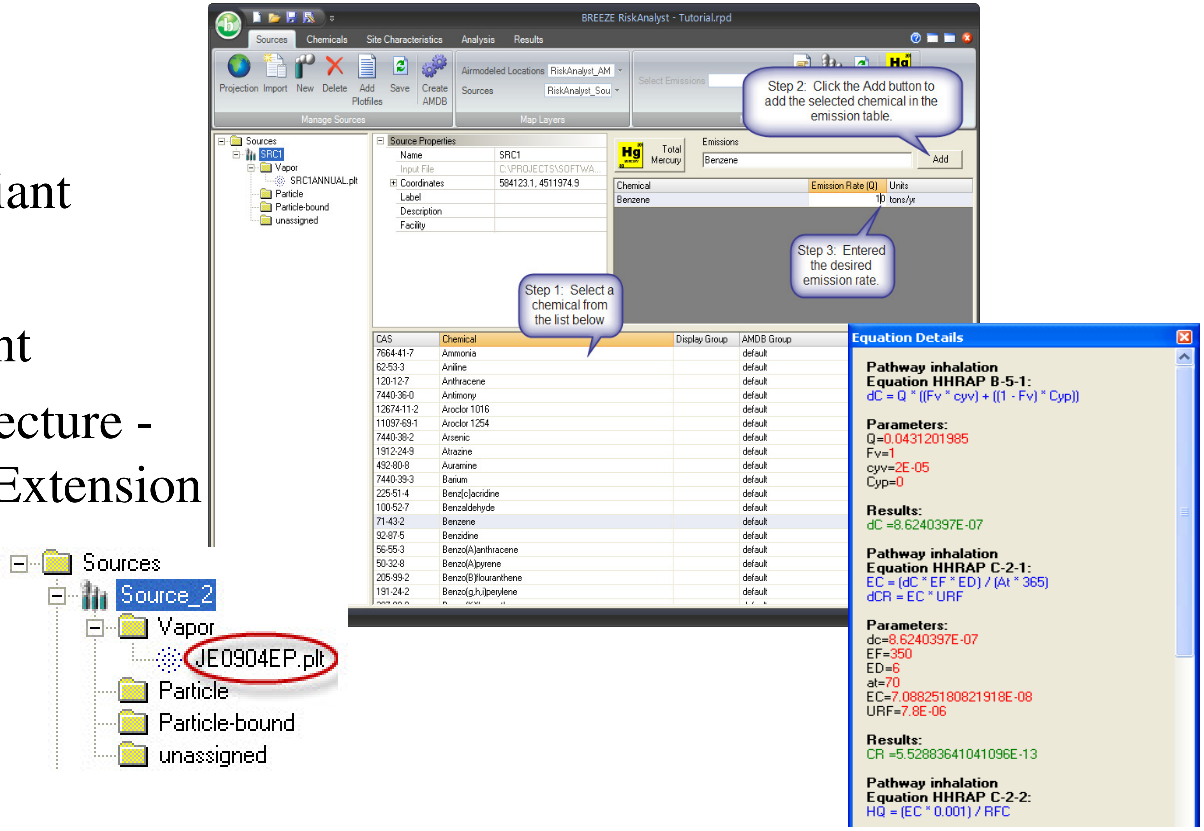
- Pentium 459 MHz (650 MHz recommended)
- 128 MB RAM (256 MB recommended)
- Windows 2000 Professional, XP, NT 4
- ArcView Version 8.2
- Drive space requirements depend on the scope of the project, but can be as high as 20 gigabytes for a typical county-wide risk analysis

Additional Information

For additional information on Risk-MAP or the RAIMI Program, contact Jeff Yurk, EPA Region 6, at yurk.jeffrey@epamail.epa.gov or via phone at 214-665-8309.

HHRA Tools
BREEZE Risk Analyst

- HHRAP Compliant
- Fully Validated
- Fully Transparent
- Software Architecture - ESRI ArcView Extension



Source Properties	
Name	SRC1
Input File	C:\PROJECTS\SOFTWA...
Coordinates	584123.1, 4511974.9
Label	
Description	
Facility	

Emissions: Benzene

Chemical	Emission Rate (Q)	Units
Benzene	10	tons/yr

Step 1: Select a chemical from the list below

Step 2: Click the Add button to add the selected chemical in the emission table.

Step 3: Entered the desired emission rate.

CAS	Chemical	Display Group	AMDB Group
7664-41-7	Ammonia		default
62-53-3	Aniline		default
120-12-7	Anthracene		default
7440-36-0	Antimony		default
12674-11-2	Aroclor 1016		default
11097-69-1	Aroclor 1254		default
7440-38-2	Arsenic		default
1912-24-9	Atrazine		default
492-80-8	Auramine		default
7440-39-3	Barium		default
225-51-4	Benz[c]acridine		default
100-52-7	Benzaldehyde		default
71-43-2	Benzene		default
92-87-5	Benzidine		default
56-55-3	Benzo(A)anthracene		default
50-32-8	Benzo(A)pyrene		default
205-99-2	Benzo(B)flouranthene		default
191-24-2	Benzo(g,h,i)perylene		default

Pathway inhalation
Equation HHRAP B-5-1:
dC = Q * ((Fv * cyv) + ((1 - Fv) * Cyp))

Parameters:
Q=0.0431201985
Fv=1
cyv=2E-05
Cyp=0

Results:
dC =8.6240397E-07

Pathway inhalation
Equation HHRAP C-2-1:
EC = (dC * EF * ED) / (At * 365)
dCR = EC * URF

Parameters:
dc=8.6240397E-07
EF=350
ED=6
at=70
EC=7.08825180821918E-08
URF=7.8E-06

Results:
CR =5.52883641041096E-13

Pathway inhalation
Equation HHRAP C-2-2:
HQ = (EC * 0.001) / RFC

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Uncertainty in Risk Assessment

- The HHRAP, like other U.S. EPA guidance, is constructed in a conservative manner, meaning, the uncertainties are generally resolved in a way that likely leads to higher-than-actual predictions

- Uncertainty characterized with respect to wide range of inputs
  - Model input accuracy
  - Model performance accuracy
  - Scenario representativeness (actual vs. modeled exposures)
  - Risk level uncertainty

Case Study

Mercury Impacts from Proposed Boilers

Outline

1. Compound of Potential Concern (COPC)
2. Identify emission rates and sources
3. Select exposure scenario
4. Estimate media concentration
5. Quantify and estimate exposure
6. Characterize risk and hazard
7. Review uncertainty

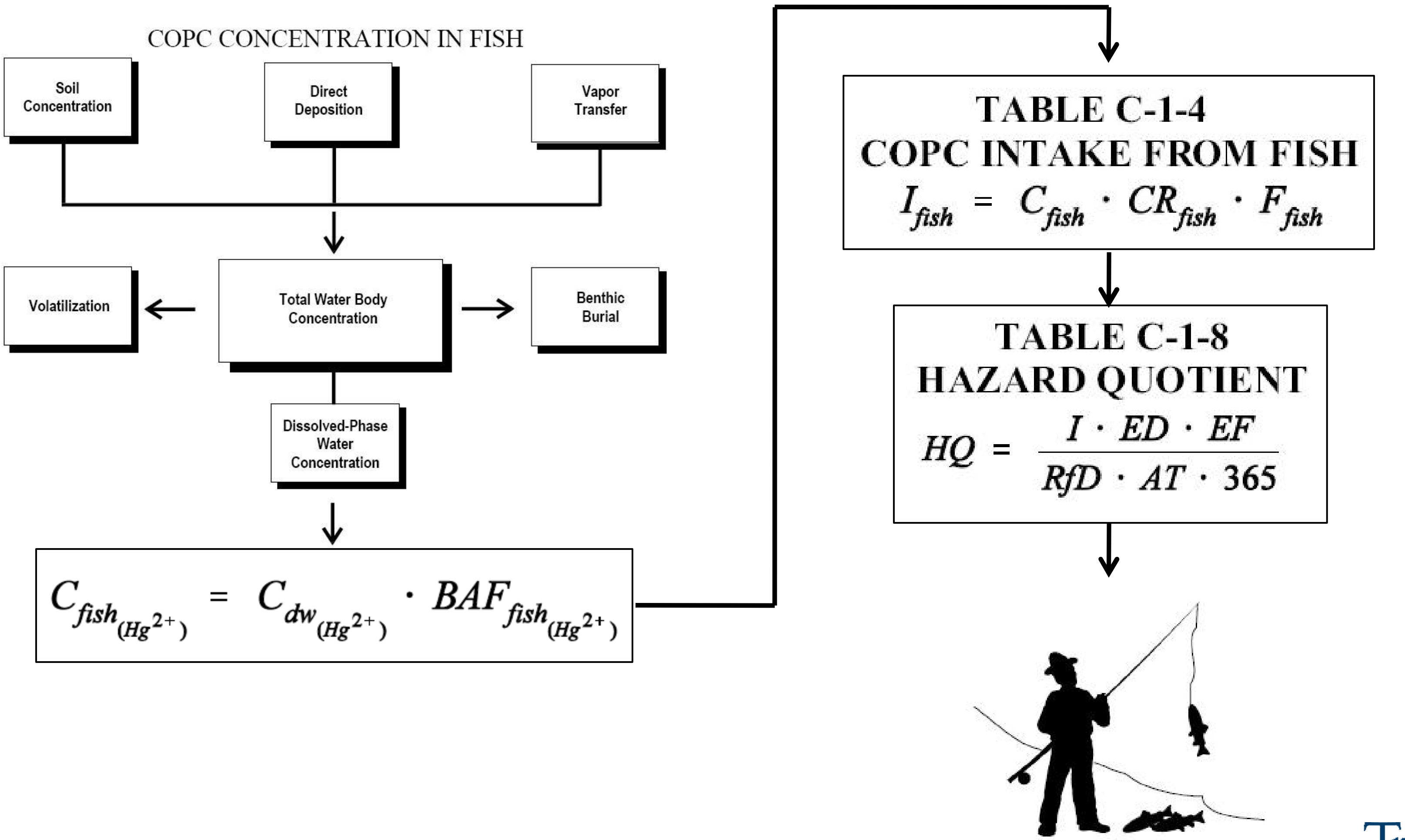
Compound of Potential Concern

- Mercury, specifically methylmercury (MeHg) is the COPC

Emission Rates

- Mercury is emitted from the boilers
- Proposed limit is 60 lb/yr per boiler
- Three forms may be emitted
- Speciation based on test data for similar units
    - Elemental Hg (79.6%)
    - Particulate Hg (0.4%)
    - Divalent Hg (20%)

Mercury Modeling Overview



COPC CONCENTRATION IN FISH

Soil Concentration

Direct Deposition

Vapor Transfer

Volatilization

Total Water Body Concentration

Benthic Burial

Dissolved-Phase Water Concentration

$$C_{fish_{(Hg^{2+})}} = C_{dw_{(Hg^{2+})}} \cdot BAF_{fish_{(Hg^{2+})}}$$

TABLE C-1-4

COPC INTAKE FROM FISH

$$I_{fish} = C_{fish} \cdot CR_{fish} \cdot F_{fish}$$

TABLE C-1-8

HAZARD QUOTIENT

$$HQ = \frac{I \cdot ED \cdot EF}{RfD \cdot AT \cdot 365}$$

Exposure Scenario Selection (1 of 2)

- EPA indicates that 99.9% of methyl mercury exposure is via fish ingestion
- Fish ingestion pathway is focus
- Examine average fish consumption and “fisher” fish consumption for adult and child
  - Average Consumption
    - 15 g/day adult
    - 6 g/day child
  - Fisher Consumption
    - 88 g/day adult
    - 13 g/day child
- Calculate impact over site’s watershed

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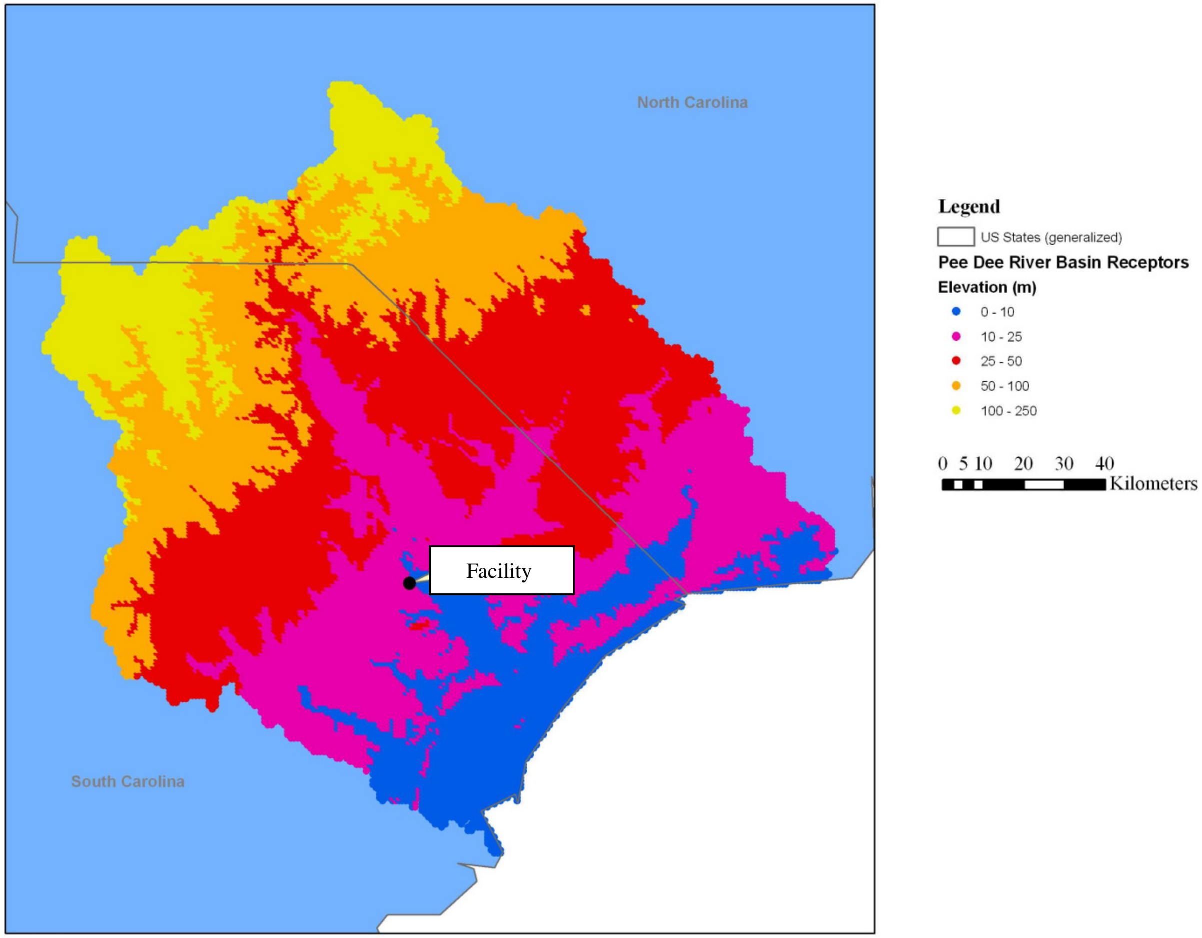
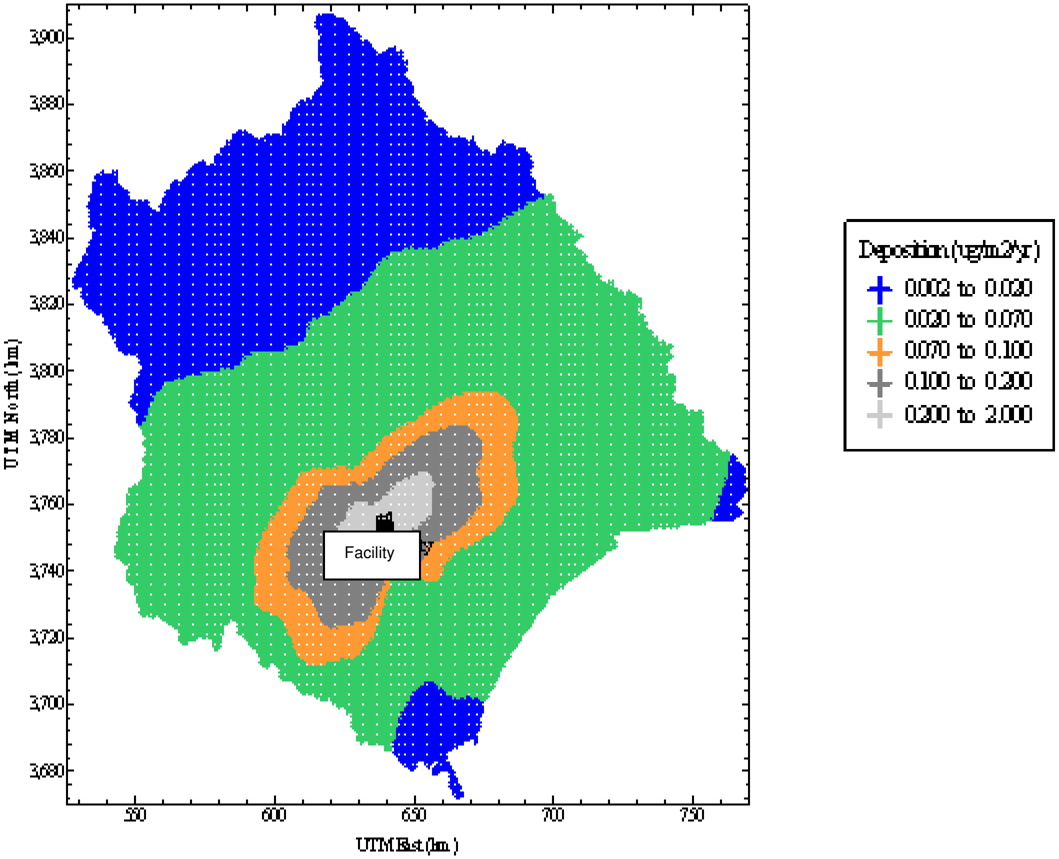
Exposure Scenario Selection (2 of 2)
Selection of Watershed



Estimate Media Concentrations (1 of 3)

- Calculate predicted dry and wet deposition of elemental, divalent, and particulate Hg to watershed
  - EPA-approved ISC or AERMOD model
  - Primarily follow regulatory model settings
  - Approved 5-year meteorological data
  - Deposition parameters based on EPA guidance for particulate, elemental, and divalent mercury

Estimate Media Concentrations (2 of 3)



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Estimate Media Concentrations (3 of 3)

- Based on deposition predictions, estimate mercury concentration in water. Calculations assume:
  - All deposited mercury reaches the river
  - 15% of total mercury in water converts to methylmercury
    - HHRAP (Human Health Risk Assessment Protocol) recommends 15%
    - Measurements in state average 11%
- Calculate fish concentration based on water concentration
  - Use of default bioaccumulation factor (BAF)
  - BAF = Fish MeHg concentration/water MeHg concentration

Exposure and Risk Estimates

- Human Health Risk
  - Fish ingestion calculations based on EPA (HHRAP) guidance
  - Exposure assessed against reference dose for protection of human health
    - Reference dose is daily oral intake that is estimated to pose no appreciable risk of adverse health effects even to sensitive populations
  - Hazard quotient calculated to assess risk
    - Hazard quotient (risk) is the ratio of predicted dose to reference dose
    - Is preliminary predicted risk is well below 1 due to mercury emissions from facility in question?
- Water Quality
  - Is preliminary predicted mercury fish levels from site below detection limit and USEPA methylmercury water quality criterion?

Model Uncertainty – Hg in Water/Fisher Pathway

- Model Assumptions and Uncertainty
  - ISC/AERMOD model
    - Limited chemistry and deposition algorithms
  - Assume all mercury deposited enters the water
    - None enters global cycle
    - None retained in soils
  - Bioaccumulation factor
    - Based on worst case fish
  - Fish ingestion rates
    - Incorporates subsistence fisher
    - Assumes always consume worst case fish
    - Assumes fish are 100% contaminated
- Generally used worst case assumptions in model to calculate maximum predicted risk. Measured values in rivers would be lower than model predictions.

Selected References

- U.S. EPA, *Draft Guidance for Implementing the January 2001 Methylmercury Water Quality Criterion*, August 2006, EPA 823-B-04-001.
- U.S. EPA, *Human Health Risk Assessment Protocol (HHRAP) for Hazardous Waste Combustion Facilities*, September 2005, EPA 530-R-05-006.
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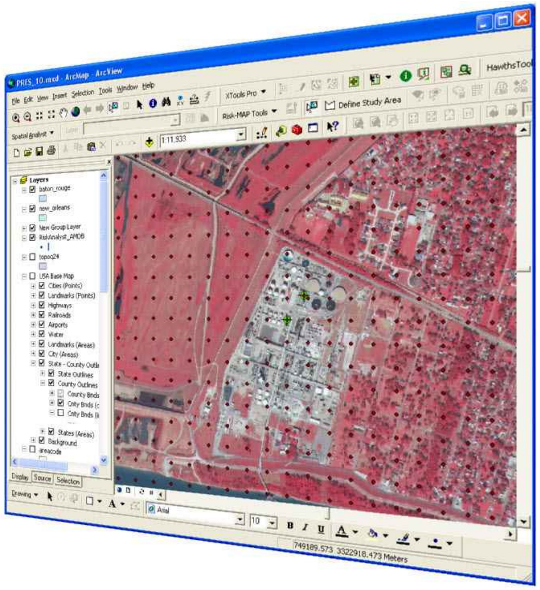
- Wesley, M. L., P. V. Doskey, and J.D. Shannon , *Deposition Parameterizations for the Industrial Source Complex (ISC3)* June 2002.
- U.S. EPA, *Addendum – User's Guide for the AMS/EPA Regulatory Model – AERMOD*, December 2006 EPA-454/B-03-001.

For More Information



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