Combined Use of AERMOD, ArcGIS, and Risk Analyst for Human Health Risk Assessment

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Prepared By:

Aubrey Jones – Senior Consultant/ Meteorologist
Abhishek Bhat, PhD, EPI – Senior Consultant
Tiffany Gardner – BREEZE Product Specialist / Meteorologist

TRINITY CONSULTANTS
12770 Merit Drive
Suite 900
Dallas, TX 75251
(972) 661-8100
trinityconsultants.com

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Extended Abstract # 33578

Aubrey R. Jones, Abhishek Bhat, PhD., EPI, Tiffany Gardner
Trinity Consultants, 12770 Merit Drive, Dallas, TX 75251

ABSTRACT

Exposure to hazardous air pollutants (HAP) can result in acute and/or chronic health effects. Humans can be exposed to toxics either directly, through inhalation, or indirectly, through ingestion or dermal contact. The magnitude of the risk varies as a function of the meteorological conditions, geographical characteristics of the surrounding area, the emission characteristics of the facility, the age of the individuals exposed, as well as the exposure duration and frequency. The potential health impacts from specific exposure scenarios can be quantified by performing a human health risk assessment (HHRA). Full scale HHRA analyses are useful for evaluating the potential impacts of specific release scenarios or actual release events. The HHRA is also important for environmental compliance and mitigation actions applicable for maximum achievable control technology (MACT) standards. In addition, recent modeling studies conducted by U.S. EPA in support of Section 112 of the Clean Air Act (CAA) address stage two of the development of MACT standards. The first stage of MACT development required the review of technology-based alternatives to develop such emission standards. The second phase of MACT development requires EPA to assess the health and environmental risks that remain after implementation of the first stage technology-based standards. This second stage is called the residual risk stage. This presentation provides an overview of methodology using a combination of AERMOD, ArcGIS, and Risk Analyst developed to simplify the HHRA analysis. ArcGIS based Risk Analyst has directly integrated equations provided in the HHRA protocol (HHRA) and is well refined in its selection and use of coordinate systems, data handling, calculations, and management of georeferenced data systems. In addition to an overview of the methodology, this paper also examines a case study to demonstrate simplicity, usefulness, and accuracy of the techniques.

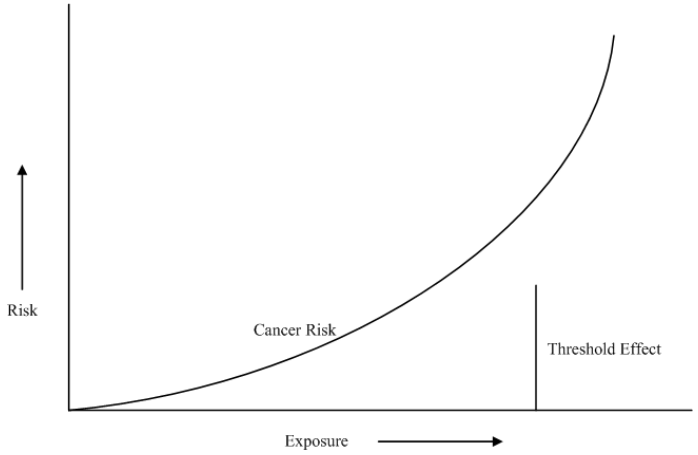
INTRODUCTION

Risk Assessment is defined as the scientific evaluation of potential health impacts that may result from exposure to a particular substance or mixture of substances under specified conditions.[1] The magnitude of risk varies as a function of the meteorological conditions, geographical characteristics of the surrounding area, the emission characteristics of the facility, the age of the individuals exposed, as well as the exposure duration and frequency.

Hazard is defined as an impact to human health by chemicals of potential concern (COPC), while risk is 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.[1] As exposure to a COPC increases, the risk also increases, as shown in Figure 1.

Figure 1. Relationship between Risk and Exposure



Exposure can either be direct, through inhalation, or indirect, as a result of contact between human receptors and soil, plants, or waterbodies on which the COPC has been deposited. Threshold levels of exposure are defined on an individual COPC basis. For many COPC, known exposure thresholds beyond which a carcinogenic effect may occur have been defined (e.g., reference dose and reference concentrations).

Full scale human health risk assessments (HHRA) are useful for evaluating the potential impacts of specific release scenarios or actual release events. The HHRA is also important for environmental compliance and mitigation actions applicable for maximum achievable control technology (MACT) standards. In addition, recent modeling studies conducted by the United States Environmental Protection Agency (U.S. EPA) in support of Section 112 of the Clean Air Act (CAA) address stage two of the development of MACT standards. The first stage of MACT development required the review of technology-based alternatives to develop such emission standards. The second phase of MACT development requires U.S. EPA to assess the health and environmental risks that remain after implementation of the first stage technology-based standards. This second stage is called the residual risk stage.

This study presents a methodology for conducting HHRA using the U.S. EPA Human Health Risk Assessment Protocol (HHRAP) and the BREEZE® Risk Analyst software. The HHRAP contains the methodology guidance, fate and transport, exposure and health risk algorithms for predicting the impacts of COPC released into the atmosphere from emission sources. BREEZE® Risk Analyst is an advanced software system designed and built upon a highly flexible and expandable geographic information system (GIS)-based analysis platform to perform multi-pathway human health risk assessments. The system seamlessly combines all the necessary tools, databases, GIS functionality, and fate and transport and exposure modeling equations into a single software application. The system is designed to provide a platform upon which to support the evolving requirements and environmental challenges of many of today's

most important regulatory and non-regulatory applications. The software includes full implementation of the U.S. EPA HHRAP guidance. Combining the use of air dispersion models, such as AERMOD, with ArcGIS, and the Risk Analyst tool can simplify and improve the accuracy of a risk assessment.

OVERVIEW OF HHRA METHODOLOGY

The human health risk assessment approach is split into 5 important steps, 1) identifying COPC(s), 2) identifying emission rates and sources, 3) selecting exposure scenario, 4) estimating media concentrations, exposure and risk, and 5) identifying and interpreting uncertainty. The HHRAP recommends that facility-, site-, and chemical-specific data be used as inputs in the fate and transport and exposure equations wherever possible. This approach is intended to reduce uncertainty; however, the HHRAP also provides numerous recommended default parameters, which are by design, intended to be conservative.

Step One: Identifying COPCs

It is necessary to understand what the specific COPCs are and the sources of emissions in order to determine the appropriate exposure pathways and resulting modeling methodologies. Per the HHRAP, COPCs include metals, products of incomplete combustion, and/or reformation products.[1] Appendix A of the HHRAP includes a list of compounds and indicates whether the compound has been identified as a potential COPC by the U.S. EPA and state risk assessment reference documents, emission test results that have identified the compound in the emissions from hazardous waste combustion facilities, or other literature that suggests that the risks from the compound may be significant. This list can be used as a reference for identifying COPCs from a specific source.

Step Two: Identifying Emission Rates and Sources

The identification of emission rates and sources may be completed in tandem with identification of COPCs. Site specific emissions data (i.e., stack testing) should be used whenever possible. For facilities that have not yet been constructed, it is generally recommended that stack test reports for facilities with similar technology, design, operation, capacity, fuels, waste feed type, and control devices be used to assist in estimating emissions.[1] Modeled emission rates and operating scenarios should be reflective of normal operating conditions.

Step Three: Selecting Exposure Scenarios

Exposure scenarios presented in the HHRAP are intended to estimate the type and magnitude of human exposure typical of emissions from combustion sources. An exposure scenario is a combination of exposure pathways to which a human receptor may be subjected. The exposure scenarios recommended in the HHRAP are designed with a level of protectiveness and are intended to be representative of not only the general public, but also populations with somewhat higher exposures.

The first step in determining the appropriate exposure scenario is to identify the exposure setting and define the dimensions of the study area. The current and potential human activities and land uses within the study area should be identified. Per the HHRAP, receptors (humans) come into contact with COPCs via two primary exposure routes: 1) directly (i.e., via inhalation), or 2) indirectly (i.e., via COPC deposition and subsequent ingestion of water, soil, vegetation, and animals that have been contaminated by COPCs through the food chain). The specific route a chemical takes from the source to the receptor is referred to as the exposure pathway. An exposure pathway is comprised of four components: 1) source of COPC release, 2) transport mechanism and/or retention medium (e.g., air dispersion, bioaccumulation), 3) point of contact between receptor and contaminated medium, and 4) an exposure route.

The HHRAP includes multiple predefined exposure scenarios, including Farmer, Farmer Child, Fisher, Fisher Child, Resident, and Resident Child. These specific scenarios were designed with an inherent level of protectiveness intended to cover potential receptors that are not directly evaluated, such as populations with higher exposures than the general public. These scenarios can also be modified to more closely resemble the specific circumstances of the actual receptors in the study area.

Risk Analyst allows for selection of any of the HHRAP predefined exposure scenarios as well as the development of custom scenarios based on different media types, exposure pathways, and human receptors.

Step Four: Estimating Media Concentrations, Exposure, and Risk

Depending on the specific COPC, it may be import to consider the following potential influences once the COPC has been released into the atmosphere from the emission source: 1) chemical transformation, 2) dispersion, 3) transport, 4) deposition, and 5) transfer between or binding by media including air, soil, water and sediment. Some COPC can be widely dispersed in the atmosphere upon release from a combustion source and can be transported thousands of miles from the initial point of release. The distance of transport and eventual deposition to the surface depends on source characteristics, local land use, the physical and chemical form of the COPC emitted and the influence of local, regional, and global meteorological conditions.

The movement of COPCs in the environment can be a complex process. Air dispersion modeling is performed to account for the transport, diffusion, and deposition of COPCs in the environment once emissions leave the stack. This step can be accomplished using the U.S. EPA approved air dispersion model, AERMOD. The AERMOD dispersion modeling system is a refined, steady-state, multiple source, Gaussian dispersion model. AERMOD was promulgated in December 2005 as the preferred model for use by industrial sources for regulatory applications.[2] AERMOD is designed to model stationary sources in simple or complex terrain. AERMOD is capable of representing both particle deposition and gaseous deposition (wet and dry), but cannot represent chemical transformations.

The results of the air dispersion modeling analysis, along with chemical-specific fate and transport variables, provide the necessary inputs into the estimating media and exposure

equations used in the HHRAP. These equations are specifically designed to account for the movement of chemicals within and between media including air, soil, water and sediment. Risk Analyst utilizes modeled impacts directly from AERMOD plot (plt) files.

Step Five: Identifying and Interpreting Uncertainty

Uncertainty is inherent in any risk assessment process primarily due to the complexities associated with modeling the movement of chemicals in the environment, through human exposure pathways, and quantifying exposure. Key assumptions should generally be designed to over-estimate, rather than under-estimate human health risks. Uncertainty can be introduced in every step of the risk assessment process, from determination of emission rates, inherent uncertainty in air dispersion models, assessing exposure, to estimation of media concentrations and so on.

METHODOLOGY FOR COMBINED USE OF AERMOD, ARCGIS, AND RISK ANALYST

A refined risk assessment was performed for a fictitious facility located in an urban setting. ArcGIS was used to analyze the study area and characterize the land use to identify potential exposure scenarios. The AERMOD model was used to quantify ambient concentrations. Risk Analyst was then used to implement the fate and transport equations from the HHRAP and to allow for seamless visualization of results.

Case Study

This study focuses on a fictitious manufacturing facility located in the state of North Carolina. The facility includes several combustion sources, specifically a boiler, several press vents and several dryers. The COPC for this facility is acrolein, which is emitted in vapor form as a product of combustion. Acrolein is considered a hazardous air pollutant (HAP) and regulated by the U.S. EPA.

Methodology

Air dispersion modeling for the combustion sources was completed using AERMOD to determine the maximum ambient concentration for the 1-hour and annual averaging periods. Modeling was completed using one year of meteorological data.

Exposure scenarios presented in the HHRAP are intended to estimate the type and magnitude of human exposure typical of emissions from combustion sources. An exposure scenario is a combination of exposure pathways to which a human receptor may be subjected. The exposure scenarios recommended in the HHRAP are designed with a level of protectiveness and are intended to be representative of not only the general public, but also populations with somewhat higher exposures. Since acrolein is only emitted in vapor phase, inhalation was the only pathway considered for this analysis. For this case study, both the acute and chronic inhalation exposure scenarios were evaluated. For the chronic inhalation scenario it is necessary to select an appropriate exposure duration and frequency.

The amount of time a human receptor spends indoors can influence the inhalation exposure concentrations. Although some amount of vapor enters buildings as a result of air exchange, concentrations outdoors are expected to be higher. For the purposes of this analysis, it is assumed that vapors are inhaled throughput the day, whether the receptor is indoors or outdoors. As recommended by the HHRAP, it was assumed that each receptor was exposed to acrolein emissions 350 days per year.[1] This is based on the conservative estimate that all human receptors spend a maximum of 2 weeks per year away from the study area.

Exposure duration is the length of time that a receptor is exposed to a COPC via a specific exposure pathway. Once an emission source ceases operation, a receptor is no longer exposed to COPCs via direct inhalation. A one year exposure duration was selected for this analysis.

Characterizing Risk and Hazard

The results of the assessment provide numerical estimates of potential human health risks. In order to evaluate potential human health risks, exposure estimates are compared with target health levels established by government and public health agencies. For acrolein, hazard, or non-cancer health effects are used to evaluate potential human health risks. Hazard is defined as the potential for developing *non-cancer* health effects as a result of exposure to COPCs. The calculated hazard value is compared as a ratio with a standard exposure level, or reference concentration (RfC), to ensure exposure to COPCs poses no appreciable likelihood of adverse health effects to potential human receptors, including special populations.

RfCs are developed to be protective of all human populations, including sensitive subpopulations such as children and the elderly, who may be exposed to concentrations continually over a lifetime. The RfC is an estimate of daily inhalation exposure that does not cause appreciable risk of deleterious effects during a lifetime.

The comparison of inhalation exposure estimates to the RfC are known as hazard quotients (HQ). The HQ for chronic inhalation of a COPC is calculated as follows:

Equation 1.

$$HQ_{inh(i)} = \frac{EC \times 0.001}{RfC}$$

EC = exposure concentration (µg/m^3)
RfC = reference concentration (mg/m^3)

EC is calculated as:

Equation 2.

$$EC = \frac{C_a \times EF \times ED}{AT \times 365\ days/yr}$$

where:

C_a = total COPC air concentration (µg/m^3)
EF = exposure frequency (days/year)
ED = exposure duration (years)
AT = averaging time (years)

Air dispersion modeling was performed using AERMOD to account for the transport of acrolein in the atmosphere once releases exit the stack. Results of the air dispersion modeling analysis completed for the annual averaging period were used as input to Equation 2 (C_a) to calculate potential human health risks associated with chronic inhalation of acrolein. The total air concentration for a COPC, (C_a), represents the sum of the vapor and particle phase. Acrolein is only emitted in vapor phases. The AT for noncarcinogens is numerically the same as the ED per Appendix C of the HHRAP.[1]

The RfC for acrolein was obtained from the companion database to the HHRAP. Table 1 summarizes the parameters used to estimate the HQ for the chronic inhalation exposure scenario.

Table 1. Summary of Exposure Parameters for Direct Inhalation Scenario

Parameter	Value	Units
Reference Concentration (RfC)	2.00E-05	mg/m^3
Exposure Duration	1	year
Averaging Time	1	year
Exposure Frequency	350	days/year

This case study also evaluated the impacts of acute acrolein inhalation. The HQ for acute inhalation of a COPC is calculated as follows:

Equation 3.

$$AHQ_{inh(i)} = \frac{C_{acute} \times 0.001}{AIEC}$$

where:

C_{acute} = acute air concentration (µg/m^3)
AIEC = air inhalation exposure criteria (mg/m^3)

Results of the air dispersion modeling analysis completed for the 1-hour averaging period were used as input to Equation 3 (C_{acute}) to calculate potential human health risks associated with acute inhalation of acrolein. The AIEC for acrolein (0.069 mg/m^3) was obtained from the EPA dose response table for screening risk assessments.[3]

The risk assessment was completed using the BREEZE® Risk Analyst software specifically designed to implement the HHRAP guidance. In order to evaluate the accuracy and compliance with the HHRAP, the analysis was also completed using spreadsheet calculations designed to be transparent by presenting individual equations, equation input parameters, and results for all

calculations. To ensure accuracy and compliance with the HHRAP, the BREEZE® Risk Analyst software was validated by comparing against results generated using spreadsheets. The acute and chronic inhalation results are visualized in ArcGIS using Risk Analyst and is presented in following figures.

Figure 1: Acute Inhalation Results in Children

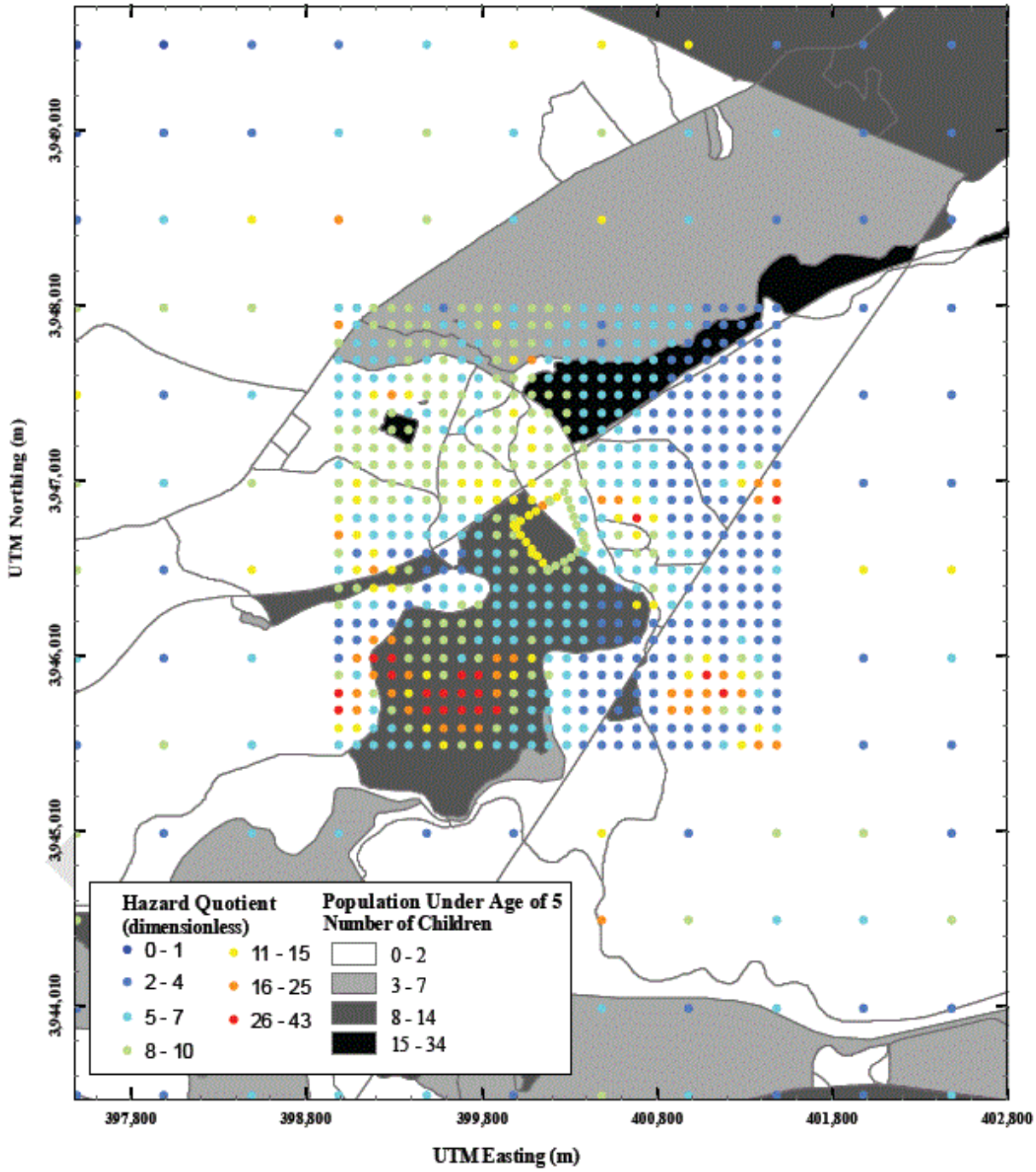


Figure 2. Chronic Inhalation Results in Children

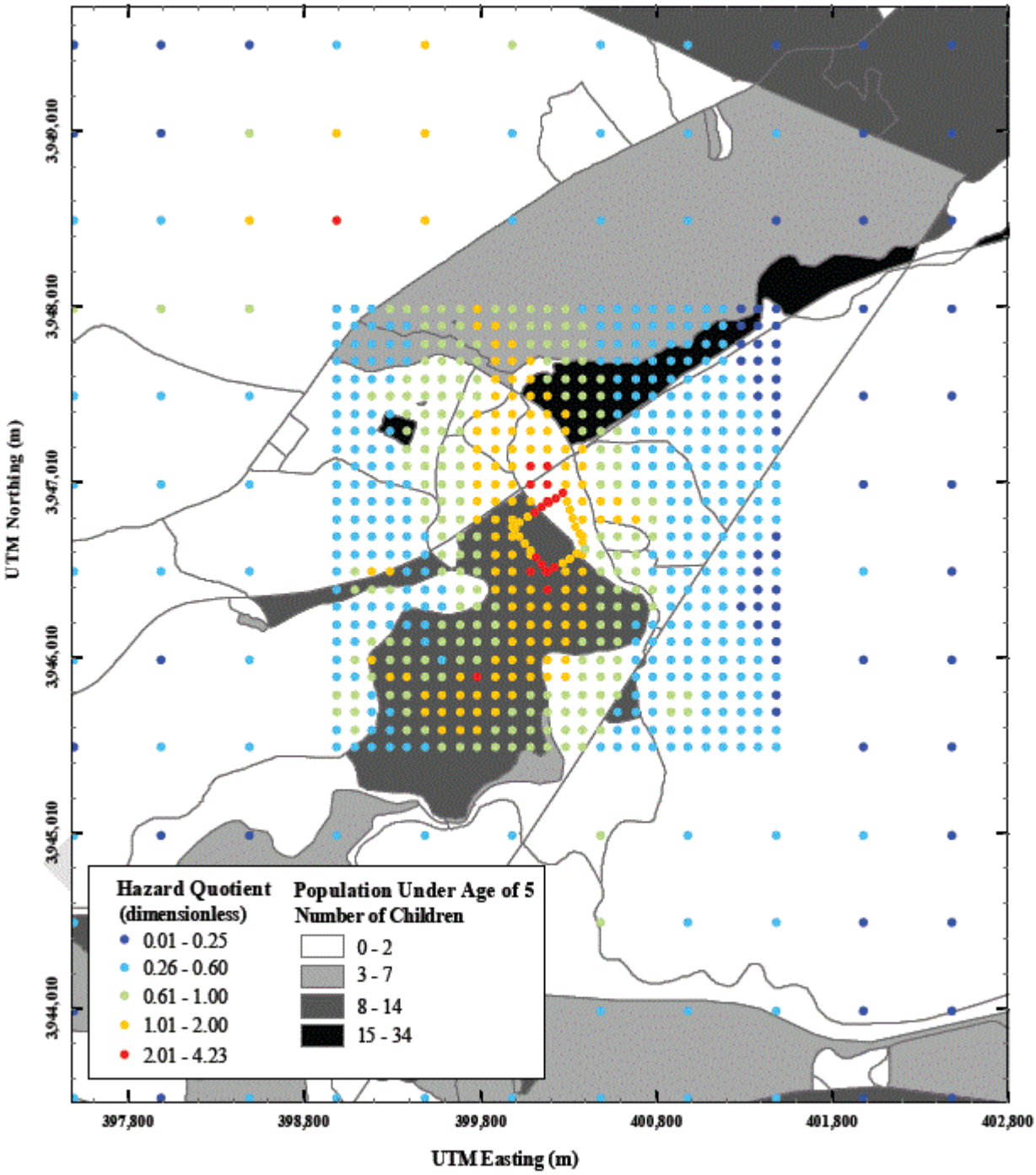


Figure 3. Acute Inhalation Results in Elderly

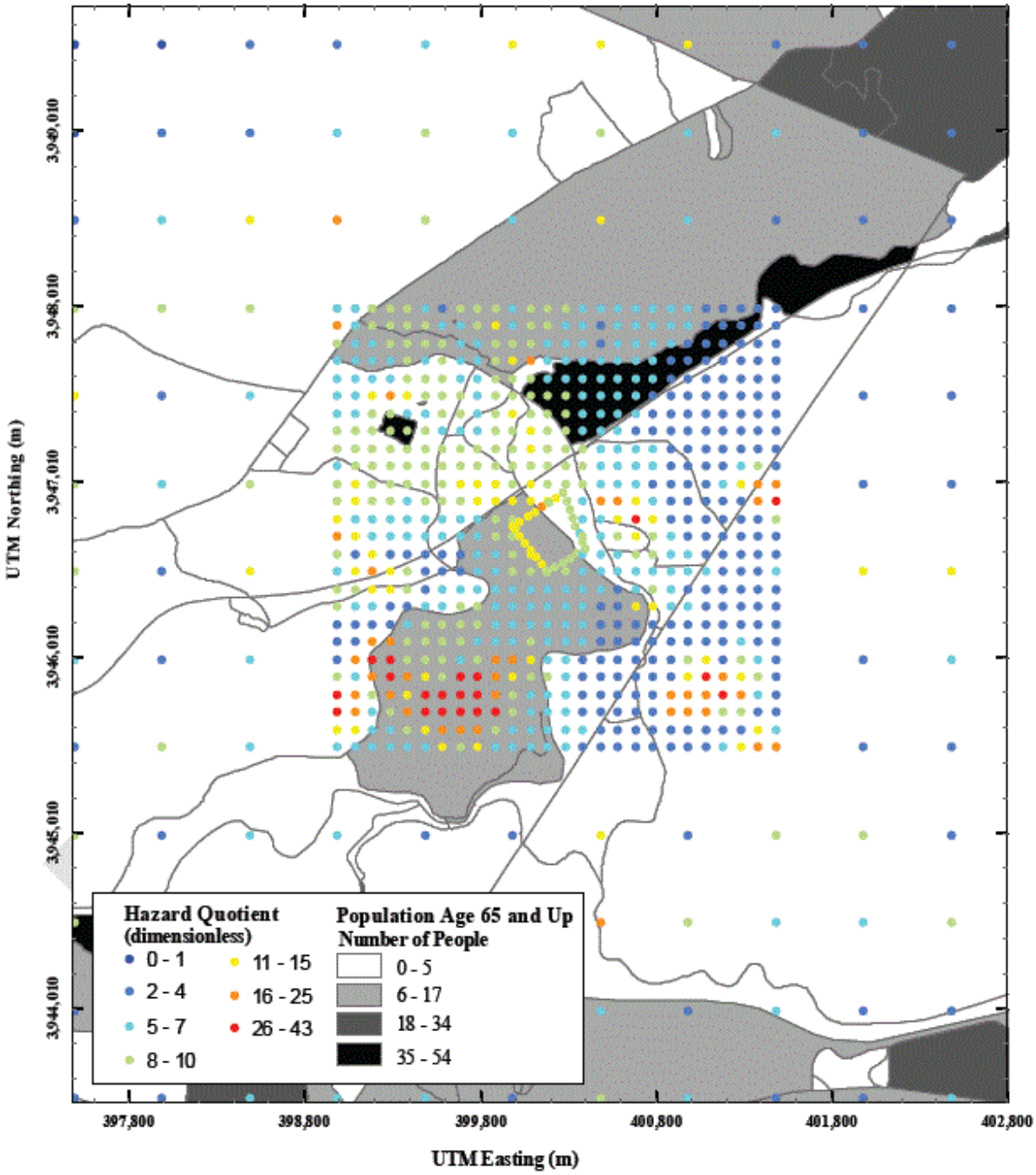
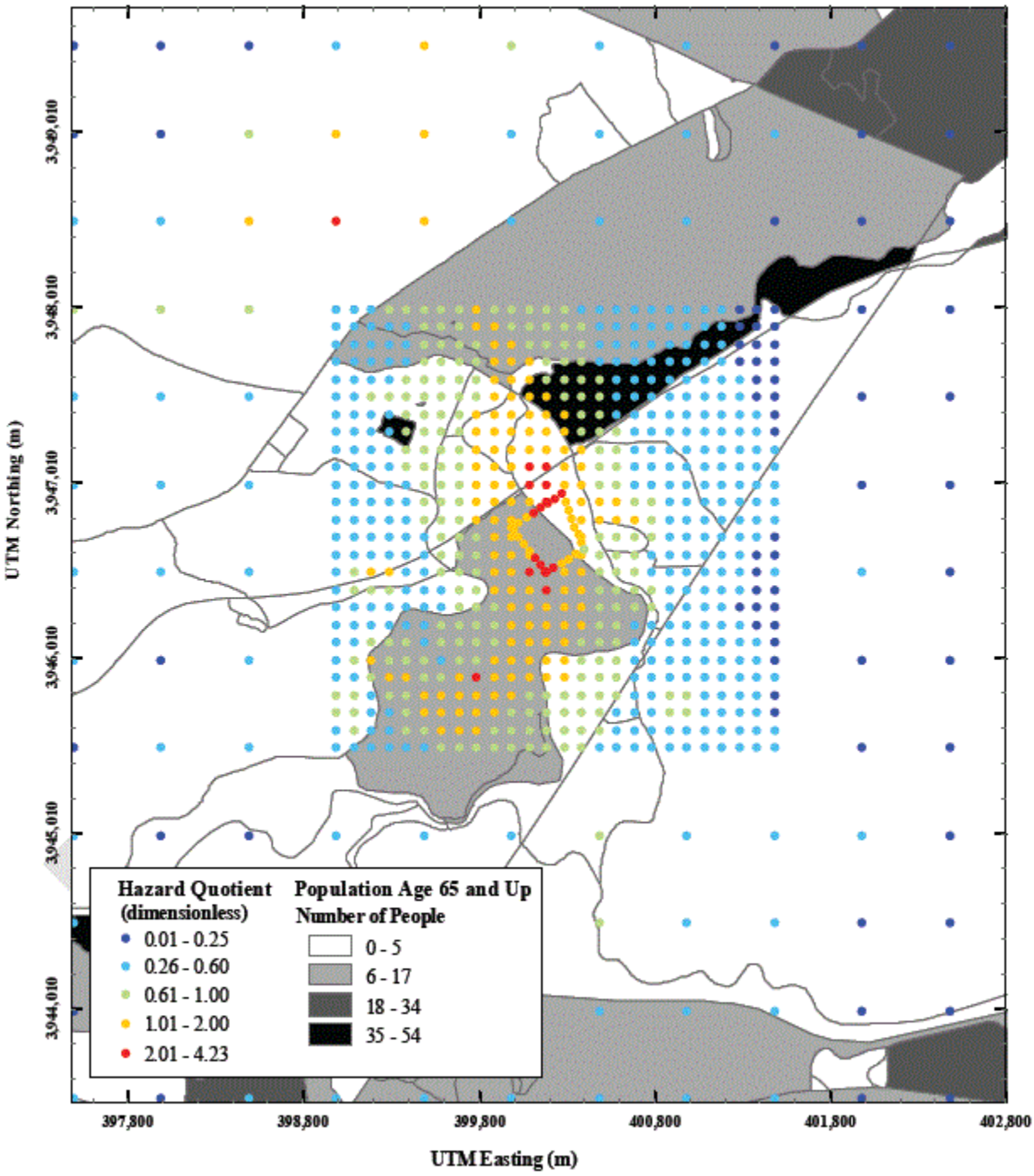


Figure 4. Chronic Inhalation Results in Elderly



SUMMARY

As an ESRI ArcGIS extension, BREEZE® Risk Analyst inherits the full functionality available in ArcGIS and allowing users to take full advantage of GIS's powerful capabilities including visualizing, managing, creating, and analyzing geographic data. Using ArcGIS, users can

understand the geographic context of their data allowing them to see relationships and identify patterns in new ways never before possible without geospatial awareness.

The features of BREEZE® Risk Analyst enable the HHRAP to be easily applied within Risk Analyst. Risk Analyst also includes other productivity tools and features that assist in the assessment and analysis. Additionally, Risk Analyst includes advanced error logging and numeric validation reporting options which provide fully transparent modeling results and error logging options that enable the efficient and transparent communication of risk results to stakeholders. Report options include equations, parameters inputs, intermediate calculations, and final results. These report options are extremely useful for identifying key input parameters and risk drivers.

REFERENCES

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2. 40 CFR Part 51, Appendix W Guideline on Air Quality Models, Appendix A.1 AMS/EPA Regulatory Model (AERMOD).
3. Acute Dose Response Values for Screening Risk Assessments (4/27/10). http://www.epa.gov/ttn/atw/toxsource/table2.pdf

KEYWORDS

Human health risk assessment, ecological risk assessment, ArcGIS, AERMOD, Risk Analyst