Peer Review of BenMAP Software

Peer Review Report

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Section 1. Introduction

This report compiles the results of an objective peer review of the environmental Benefits Mapping and Analysis Program (BenMAP), which is the U.S. Environmental Protection Agency's (EPA's) new health impact and benefits assessment software. RTI arranged for reviews by three leading experts, each of whom has distinct and particularly relevant experience for evaluating the scientific accuracy, credibility, objectivity, and technical appropriateness of BenMAP. The experts are:

- **Dr. Alan Krupnick** (Resources for the Future). Dr. Krupnick is an environmental economist and one of the leading experts in the field of benefits assessment and nonmarket valuation for environmental policy. Through his extensive research in the field and his participation in EPA's Science Advisory Board (SAB) Subcommittee for Review of the 812 Cost-Benefit Study, USEPA (1998–99), he is particularly knowledgeable about the context and challenges related to developing this type of national-scale benefits assessment model.

- **Dr. Nino Künzli** (University of Southern California). Dr. Künzli is an environmental epidemiologist with an emphasis on air pollution epidemiology. As a member of both the National Research Council's Committee on Estimating the Public Health Benefits of Proposed Air Pollution Regulations and EPA's SAB Advisory Council on Clean Air Compliance Analysis, he has a particularly strong understanding of how the results from existing epidemiological studies can best be applied in a national-scale model like BenMAP.

- **Dr. George Christakos** (University of North Carolina). Dr Christakos is an environmental scientist and engineer with a broad multidisciplinary background in environmental modeling. He offers particular expertise in the application of geospatial statistics and uncertainty analysis in integrated environmental models.

Additional information about each of the reviewers' backgrounds and qualifications is provided in Appendix B.

The reviewers were provided with an executable version of the model, the *BenMAP User's Manual*, and a general description of the model's main objectives. With these objectives in mind, they were asked to review the model software and documentation and to provide us with their assessment of the model. They were also provided with a list of both general and specific questions to serve as a guide in preparing their review. They were asked to address as many of the questions as possible, but to focus primarily on areas that correspond best with their technical expertise and interests. The specific letter describing their charge and including the list of questions is provided in Appendix B.

The review comments received from the reviewers are included (with only minor editing) in the following three sections.

Section 2. Review by Alan J. Krupnick, Senior Fellow, Resources for the Future

I have organized this review by simply filling in responses to the questions asked of me by RTI. Overall, this effort is astonishing in its comprehensiveness and flexibility. That said, I do have a number of concerns about it and suggestions for making it better, detailed below.

1. General:

a) Does BenMAP provide a useful and sensible structure for addressing policy analysis needs?

BENMAP provides many of the key pieces for addressing the benefits side of policy analysis, although it is limited to health effects and several pollutants, can only analyze one pollutant at a time and does not provide any help in linking concentrations changes back to emissions. Although these are limitations, no other available model overcomes them.

b) Does it provide adequate flexibility to users for addressing important policy questions?

Although BenMAP provides enormous flexibility in the construction and use of C-R functions and the treatment of monitored and modeled air quality data, this flexibility in the model may not be utilized by most users, who may not have the sophistication or the need for utilizing the flexibility provided. On the other hand, it provides limited flexibility for doing what I think many users will want – pulling C-R and valuation functions in and out of the model – and easily seeing the effect this has on total benefits. It is not as if the model cannot perform this task. It is just that one needs to take a significant number of steps to get to this point. And another area I think users will care about – simply seeing how air quality concentrations change in response to various rollback or standard meeting scenarios – doesn't appear to be available with this model, even though it contains the air quality data. (In other words, given the time I had to fool around with the model, I couldn't get this information out of it.)

My suggestion is that a new sub-component of the air quality/population part of the model be created which collapses this information into tables that do not need to be recomputed (which takes several minutes at least). Then users, if they wish, can focus on the effect of using alternative C-R functions and valuation functions and on the effects of simple air quality change scenarios.

c) Are the different components of the model appropriately defined and linked to one another?

Most components of the model are appropriately defined and linked. An exception is the mapping functions, which I find problematic (see below).

2. Input Databases: Keeping in mind that some of the input databases are fixed in the model and some can be adapted or supplemented…

a) Are the fixed input databases appropriately selected and defined using

- Census and projected demographic data?
- Modeled air quality data?
- Baseline incidence data?

I don't see why these components (particularly the population and baseline risk data) need to be hard-wired. It seems like it would be simple to give users the option here. This would increase the research use for the model and its applicability to use in other *countries*.

b) Are the adaptable input databases appropriately selected and defined for

- Monitored air quality data?
- Concentration-response functions?
- Valuation functions?

You have completely "punted" on the valuation component, particularly the VSL. This model is supposed to be both a policy analysis and research tool and should therefore reflect the wide ranging literature on the VSL and VSLY, as well as producing life year change estimates. As it is now, the model appears to embody the traditional EPA agenda, which I think is not very helpful to many users. Also, I couldn't find numbers from Mrozek and Taylor in Exhibit H-1. Perhaps "based loosely" is supposed to provide cover for this omission, but I would urge more directness here.

On the C-R functions, the included set seems reasonably comprehensive, although it is unclear from the table to the left (when one uses the DATA menu) which functions are for ozone and which are for PM or something else. And there ought to be a way for all functions on the left panel to be displayed at the touch of a button, rather than having to click on everything. My overriding philosophy about such models is to make the manual as little needed as possible. I think you have a different philosophy.

Also, it might be more enlightening if only unique functions were shown. Now, you have artificial age breakdowns for many of the functions. This adds clutter to the list and gives the impression there are more independent functions than there really are.

It would help if the C-R functions viewable through the Data menu were grouped by pollutant. At present I couldn't easily figure out the list of PM2.5 and ozone functions.

One or more sulfate functions are listed. Can these be used by the model in actual calculations? If so, how?

Also, I am a bit unclear about the criteria for including functions and results. For instance, Ito and Thurston (1996) is included for ozone ST mortality and the manual says that they considered PM along with ozone. But the manual does not list Ito and Thurston's results under the PM C-R functions. Further deepening the mystery, BenMAP notes that Ito and Thurston estimated a model for ozone with PM, but also doesn't list any of the PM results. Is this just an oversight? I found the same problem for Kinney et al and Samet et al. While the answer may be that you have decided to only include PM2.5 results and the functions listed above are for PM10 or TSP, I think this is a bad idea and that all PM results should be included. In any comparison of ozone and PM importance, one should have results from studies that looked at the multiple pollutants, not limited to PM2.5 on the particle side. Also, more generally, why is there only one C-R function in the PM C-R ST mortality appendix listing multiple pollutants?

I would like more explanation about how incidence and prevalence (Exhibit 9-1) are used in the functions.

I got error messages when I tried to click on most of the variables listed under Available County Variables. I tried to get a look at the raw data but couldn't figure out how to do it.

3. Exposure Estimation Algorithms: To spatially and temporally align population, air quality, and incidence data as inputs to the concentration-response functions, BenMAP uses several estimation and interpolation algorithms.

a) Are these methods scientifically sound and appropriate for
- interpolating and projecting population estimates for non-Census years?
- estimating population subgroups (e.g., by age, gender, ethnicity, etc.)?
- estimating the spatial distribution of populations and linking them to air quality grids?
- spatial and temporal interpolation of pollutant monitoring data?

It is very difficult to comment on these issues because the model is not designed to report out monitor, population and exposure information.

b) Does BenMAP offer an appropriate menu of interpolation options for estimating exposures?

I have no expertise here.

c) Do these methods provide appropriate inputs for the class of concentration-response functions allowable in the model?

I have no expertise here.

4. Aggregation and Pooling Methods: BenMAP offers alternative approaches for spatially aggregating health effects estimates and for pooling separate estimates of health effects for valuation.

a) Does BenMAP offer an appropriate menu of aggregation and pooling options?

I am not clear how the values are aggregated in a way that avoids double-counting. The section on interdependent/dependent/addition/subtraction may be where these operations are intended, but there should be a default endpoint aggregation routine with the list of default endpoints. Then the user can start here and be able to move functions in and out and also edit the aggregation equation. I would also add an example to explain to readers what these “summing distribution” functions (pg. I-9 and also earlier in the body of the text) really do.

b) Do these methods provide appropriate inputs for the class of valuation functions allowable in the model?

Yes.

5. Uncertainty Analysis Methods: BenMap offers options for including and evaluating how uncertainty regarding (1) C-R relationships and (2) valuation functions affect model outputs?

a) Does BenMAP allow the user to adequately and appropriately specify uncertainty for these two areas?

Yes.

b) Are the uncertainty routines properly specified and incorporated in the model?

Yes.

c) Without greatly complicating the structure of the model, are there additional areas or types of uncertainty that could or should be incorporated in BenMAP?

My first issue with the handling of uncertainty in BenMAP concerns aggregation. I believe the ultimate purpose of the uncertainty analysis is to enable computation of a probability distribution on the aggregate benefits. This is evidently accomplished through the Add Sums button. This fact took me a long time to figure out and should be much more apparent in the write-up and on the software screens. It would help if ADD SUMS were not an option, but was a default. How this would be done, I don't know. Maybe the first row would automatically be checked so the user can see that the total line is filled in.

As for other areas of uncertainty to incorporate, it would not be difficult to add population uncertainty to the model, as the Census publishes various population scenarios. Baseline mortality and other baseline health rates are probably estimated with uncertainty and, if so, could be easily added. Uncertainties in air quality would be a very important addition to the model, but the literature is probably not rich enough to support such a step.

6. Report and Mapping Results: BenMAP offers several options for reporting and mapping air quality, population, incidence, and valuation data and results.

a) Do these options provide an adequate and appropriate framework for displaying results?

As noted above, I had lots of trouble figuring out how to get data reports for air quality and population, although the maps would give monitor location and readings.

b) Are the results displays appropriately specified and configured to address the intended uses and analytical needs of BenMAP (as defined above and in the model documentation)?

The mapping function is a cool idea but it is badly executed in some respects. The most glaring Problem is the color scheme. By shading/blending colors between two different primary colors at the ends of the range of the variable being displayed, the observer cannot discern differences in the map. I think it is pretty useless. I would argue that discreet colors be assigned to different binned values of the variable being mapped, or at least that such an option be available.

7. User Interface and User Guide: BenMAP is a menu driven interactive software tool with multiple options and features, as described above.

a) Is the user interface appropriately organized, easy to use, and easy to follow? Through the user interface, are the options and features well described and easy to navigate?

I found the set up intimidating and not that helpful.

b) Is the user guide appropriately organized, easy to use, and easy to follow?

I took two hours to carefully go through the chapter 3 tutorial, which was well-written and clear and led me through flawlessly. I ran into lots of trouble when I tried to stray from the tutorial. I had most problems with the mapping guidance, which was too brief and not helpful. I had trouble getting the various buttons to work and am not sure what some of them really are for.

c) Does the user guide appropriately complement and correspond with the user interface?

The User Guide is essential for learning to use the model, unlike friendlier software where the guide is mostly a backup. This should be made clear to people.

d) Does the user guide provide the necessary explanation and background for installing and running the model, selecting options, and displaying results?

See above.

e) Does the user guide adequately explain the model's objectives and the model's underlying structure, assumptions, data, methods, and routines?

I still don't know who the audience is for this product. Thinking more about that and modifying the manual to meet the needs of those groups individually might help.

Section 3. Review by Nino Künzli, Associate Professor at Keck School of Medicine, University of Southern California

It was a pleasant experience to test this BenMap version. The product is very ambitious and both technically and scientifically on a very high standard. There is obviously superb expertise and a strong professional commitment behind this impressive product.

Below are my comments, mostly related to the *specified questions* (as received from RTI), sometimes integrated at the end of several questions.

1. General:

a) *Does BenMAP provide a useful and sensible structure for addressing policy analysis needs?*

The overall structure is useful. The program is, however, a very ambitious collection of complex data and scientific issues, ultimately packed in a 'black box'. This raises the question about the needs and skills of users (target audience) of BenMap. The choices appear to be endless, thus, the determination of some default functions (or choices) might be needed (among less specialized users). E.g., if risk assessors in county health departments will use BenMap: given the many choices, it might be useful to have some clear defaults to make results across counties comparable.

b) *Does it provide adequate flexibility to users for addressing important policy questions?*

There is ample flexibility. As mentioned above, there might be too much. In making choices along the process of combining exposure models and C-R-functions, the user remains in the dark about how decisions may affect the results.

c) *Are the different components of the model appropriately defined and linked to one another?*

Yes, the components are. Related to the above concerns, within the components it is less easy to keep the overview.

2. Input Databases: *Keeping in mind that some of the input databases are fixed in the model and some can be adapted or supplemented…*

a) *Are the fixed input databases appropriately selected and defined using*
- *Census and projected demographic data?*
- *Modeled air quality data?*
- *Baseline incidence data?*

b) *Are the adaptable input databases appropriately selected and defined for*
- *Monitored air quality data?*
- *Concentration-response functions?*
- *Valuation functions?*

Given that the whole process is a 'moving target', given the never ending flux in research activities, I wonder what strategy BenMap will implement to update both the fixed input databases as well as the available defaults for the adaptable input databases. E.g., as of 2004, the software still projects demographic data from 2000. It might be useful to determine a concept of updating BenMap.

The Manual mentions the selection process in choosing studies for the C-R-functions. These choices are usually not clear-cut but a continuum, and I wonder how new studies will be fed in, and how/when/why studies that are currently used will be dropped. E.g., the study year was one criterion; nevertheless, a very old asthma study still plays a dominant role (1980). This choice appears somewhat contradicting the selection criterion. Do we really need this study, although air quality, populations, and baseline incidence of asthma (and treatment) changed substantially over the last 25 years?

As a general rule, the most valid results originate from models where the exposure period, pollutant, exposure assignment methods, population choice and aggregation, outcome definition, and outcome measurement procedures in the original epi studies are as close or similar (in time and methods) as possible to those used in the benefit model. It is currently not easy to understand the 'validity score' of all the input options.

3. Exposure Estimation Algorithms: *To spatially and temporally align population, air quality, and incidence data as inputs to the concentration-response functions, BenMAP uses several estimation and interpolation algorithms.*

a) Are these methods scientifically sound and appropriate for

- *interpolating and projecting population estimates for non-Census years?* YES
- *estimating population subgroups (e.g., by age, gender, ethnicity, etc.)?* YES – see below
- *estimating the spatial distribution of populations and linking them to air quality grids?* YES – see below
- *spatial and temporal interpolation of pollutant monitoring data?*

The proposed methods are, in it self, appropriate. There is not enough discussion/caveats given for the user to emphasize the discrepancies between the many options offered by BenMAp to specify populations and exposure on very small scales (grids; subgroups), and the often much cruder level in the studies that provide the C-R-functions (e.g., in Appendix B, Population Data issues and Appendix C Exposure).

It is not discussed that the uncertainty in the final results also depends on the choices of grid size and/or group definition (e.g., age range) and the level of aggregation. The users should be aware that the most valid assessment can be derived from a model that uses population definitions and exposure assignments on exactly the same level of specification and aggregation as done in the underlying epidemiological studies. This is often not possible, but an important concept to communicate to not misguide the user. Although appealing to go to the smallest possible units of aggregation, this is not necessarily better or more appropriate given that the C-R-function may not be known at this level of specification. BenMap should deal with this issue in some way and educate the user. The problem will become more apparent as soon as C-R-functions get published using different scales of aggregation, such as the 'crude' approach taken in the Pope et al. ACS studies which is soon complemented by a Jerrett et al. model using exposure information on a much smaller geographic scale, derived from PM2.5 surfaces of a Western metropolitan area. Such studies will give the empirical evidence for an issue that is obvious from a theoretical perspective but difficult to quantify without data: namely that C-R-functions depend on the level of geographic aggregation in the exposure domain and the population definition. So far, most epidemiological studies assume that all people living in a rather large area – larger than some grid cells – experience the same exposure; or effects are reported for a group of mixed ages.

b) *Does BenMAP offer an appropriate menu of interpolation options for estimating exposures?*

c) *Do these methods provide appropriate inputs for the class of concentration-response functions allowable in the model?*

I repeat my concerns mentioned above. The models may provide much better estimates of true exposure; but epi studies might have used other models to derive the C-R-function. Thus, the C-R-function for otherwise determined (more sophisticated, better) exposures is in essence unknown (in a strict sense).

4. Aggregation and Pooling Methods: BenMAP offers alternative approaches for spatially aggregating health effects estimates and for pooling separate estimates of health effects for valuation.

a) *Does BenMAP offer an appropriate menu of aggregation and pooling options?*

Yes; but some guidance for a "default" would be helpful.

The pooling across the many studies offered for some outcomes makes it a challenge (or requires in-depth knowledge) to make adequate choices. This is particularly the case in such diverse outcomes as the asthma attack domain. Different studies determine asthma attacks or exacerbations or symptoms in very different ways, leading to rather different baseline incidences (and probably also different C-R-functions). Accordingly, the incidence rates vary substantially for the various input studies. It is not clear which of all these studies might be pooled or better not.

The D-15 comments on single pollutant versus multipollutant: the arguments are debatable, thus the choice of the multipollutant results should be made with some caution. Not sure that a single pollutant overestimates by default. One could argue the other way round and trash the multipollutant models, even – or particularly – under a PM policy perspective. E.g., assuming high collinearity between two pollutants (from same sources), the single PM model is the much more relevant whereas the two-pollutant model would adjust for a major part of the exposure of interest and potentially create meaningless estimates. I see no problem for PM and/versus O3, but would not generalize or too enthusiastically promote the multipollutant choice beyond these two.

Section D-16 ff. is very much written from a time-series perspective. If the user wants to generalize to other designs, things get somewhat less straightforward.

b) *Do these methods provide appropriate inputs for the class of valuation functions allowable in the model?*

5. Uncertainty Analysis Methods: *BenMap offers options for including and evaluating how uncertainty regarding (1) C-R relationships and (2) valuation functions affect model outputs?*

a) *Does BenMAP allow the user to adequately and appropriately specify uncertainty for these two areas?*

To specify, yes. Several of my comments mentioned above refer, however, to uncertainties and I think that for most users the current Manual may give an insufficient or somewhat hidden perspective on uncertainties.

Uncertainty is currently mostly an Appendix. It might get a more prominent position.

b) *Are the uncertainty routines properly specified and incorporated in the model?*

See above.

c) *Without greatly complicating the structure of the model, are there additional areas or types of uncertainty that could or should be incorporated in BenMAP?*

See above. Some guidance about what to pool and what not, or sources of not quantified uncertainties, or defaults of 'least uncertainty' would be helpful.

6. Report and Mapping Results: *BenMAP offers several options for reporting and mapping air quality, population, incidence, and valuation data and results.*

a) *Do these options provide an adequate and appropriate framework for displaying results?*

b) *Are the results displays appropriately specified and configured to address the intended uses and analytical needs of BenMAP (as defined above and in the model documentation)?*

- I thought the mapping (on screen) is very nice and easy to use. I could not figure out how to see the county names when clicking in the map nor is this shown in the output tables.
- The meaning of the results (such as the annual increase in cases) is so important that I recommend making this more obvious on the screen (e.g., while clicking into the grid map to see results). This key information is currently only stated in the Manual on page 3-21.
- The default labels ResultX, POP_X etc.: not very user friendly outputs.

7. User Interface and User Guide: *BenMAP is a menu driven interactive software tool with multiple options and features, as described above.*

a) *Is the user interface appropriately organized, easy to use, and easy to follow? Through the user interface, are the options and features well described and easy to navigate?*

- In general, it is easy to use or easy to learn within rather short time. The Manual is, however, a crucial source in the process of use. Some key aspects of that guidance might be integrated directly on screen. E.g., the gray boxes in the Manual could be important "pop-ups".

- Some steps do not explicitly offer a 'back' function button, other windows do. It happened to me that I chose CANCEL instead of closing a window when I was not sure how to go back (e.g., in Step 3 of example, p. 3-3). This cancelled all the previous steps, thus I had to start all over.

- In case where tables get much bigger than the screen, choosing functions within the table (e.g., pooling method) moves the table to the start position (top), thus one has to scroll down again to search for the next line. This is inconvenient.

- Step 6: Dragging several groups into the right screen (Select Pooling Methods) seems not to be possible yet. It has to be done one by one. Would be nice to drag many lines at once.

- Step 6 B) 3-9: very repetitive action to chose valuation methods over dozens of lines.

- Elements in Preview (display option): not so clear what this really is (e.g., p. 3-15).

b) *Is the user guide appropriately organized, easy to use, and easy to follow?*

I found it well done. Issues are complex and cross various chapters, thus some Index will certainly be welcomed by users.

c) *Does the user guide appropriately complement and correspond with the user interface?*

Yes.

d) *Does the user guide provide the necessary explanation and background for installing and running the model, selecting options, and displaying results?*

Yes. The front-up example is a good idea. There could be some more references to the in-depth chapter while going through the example (as it raises many questions some might like to read more about directly). E.g., Step 2 could refer to the chapter where Grid Creation Model is explained; similarly Step 3 etc.

e) *Does the user guide adequately explain the model's objectives and the model's underlying structure, assumptions, data, methods, and routines?*

- In general, yes. My main comments above, however, did not get much room in the manual and may need some paragraphs.

- The default functions could be communicated, with arguments for their choice, advantages, or disadvantages. It is currently difficult to understand what the defaults or best choices are and why. A table or flow chart with a few defaults might help.

- It might be useful to provide a few examples (e.g., one table for one single outcome) showing the results for various choices in the input functions (e.g., all the exposure model choices). It could give some idea about which choices make a big difference and which are just a question of style, preferences or availability of data.

- 5-1 summarizes the choices. A flow chart (similar to Exh 01 , p ii) might be helpful to see the tree of choices and where to save what aspects of the configuration.

- 5-1 gray box: per person per year. Other sections provide numbers per 100 persons. Might be confusing and become a source of errors.

- 5-3 Threshold section: it might helpful to explain what happens in the calculation if one uses a non-0 threshold. It ignores all the effects that one can assign for exposure between 0 and the threshold. Given that almost everybody is exposed to these low levels, it can have a very substantial effect on the estimates (Künzli N, Eur Respir J 2002; 20:198-209), unless they cancel out for *difference* measures.

- 5-4: May clarify: is there any single value in the Latin Hypercube Points results exactly identical to what we get with the Point Mode? It reads as if this were true; I doubt it is.

- 5-7 last paragraph could start with: As shown in the next figure…. (reads as if it relates to previous figure – but it does not apply there at all).

- 8-18: how can I export a shapefile?

- E-9: E.7.1 specify whether this is the attack rate per year per 100 people with asthma or per 100 people in the population.

- F1.1. page F-3 and F-6: Pope et al is not necessarily the better study, and the advantages provided could be seen also as disadvantages. It is certainly the largest and best to generalize across U.S.

- "Historical air quality trends discussed above": where? Read paragraph again.

- It was not clear to me what the rational was to order all these F1.X chapters the way they are. By year? Relevance? Size?

- It is, in general, a very long chapter, some what repetitive and not easy to keep track (structure). Some subheadings might help to organize this better?

- Exhibit F-3 p F-19: add prevalence and incidence, respectively as this is very important (and well discussed in the chapter).

A few typos/edits such as:

- 3-7: first line
- 5-11 Last question
- 6-11 If you pool… First bullet
- B-6, first sentence "To estimate…."
- D-1, first sentence
- D-22, last para, first sentence.
- E-6 top, line 4 (per)

A few other minor points:

- Baseline and Control could be explained in the Common Terms section.
- I was not too happy with the choice of the Y_0 label for the baseline, thus to see the Y_0 in the numerator of the RR. The 0 is very often used as the 'non exposed' or 'less exposed', thus, appears in the denominator.
- E7.9, page E-11 Exh. E-8: it is not clear how the last line was used. Male +27 versus the above total population estimates.

Section 4. Review by George Christakos, Professor, Department of Environmental Science & Engineering, University of North Carolina

Part I: SUMMARY:

The goals of BenMAP are directed toward a customized *human exposure assessment* (HEA). HEA is a subject of great importance, from a scientific and a societal point of view. It is also a subject of considerable difficulty, at the levels of methodology, theory and application. Unfortunately, BenMAP does not achieve its goals to a satisfactory degree, especially considering today's advancements in HEA. In my view, the BenMAP approach suffers from a number of conceptual, methodological and practical drawbacks and, thus, it needs a major revision and redesign. More specifically:

§1. **Methodology**: BenMAP's approach lacks a sound *methodological* support in the context of *integrated* HEA (IHEA). In BenMAP, health impact assessment as a whole is achieved solely from knowledge of its parts (air quality monitoring/modelling, population projections, exposure, health effects, etc.; see p. *ii* of the manual). However, the IHEA has a strong *holistic* component, i.e., health impact assessment as a whole cannot be achieved solely from knowledge of its parts –it emerges from the integrated whole itself. Indeed, BenMAP fails to realize that human exposure is an interdisciplinary science that requires a deep understanding of the *epistemic processes* (critical reasoning, cognitive states, logic rules, etc.) of synthesizing information from different scientific disciplines (atmospheric physics, chemistry, biology, toxicology, statistics, epidemiology, demographics, etc.).

§2. **Internal consistency**: BenMAP does not provide an adequate consideration of the *internal consistency* between the formal part (mathematical theory, techniques etc.), on the one hand, and the interpretive part (physical meaning of mathematical terms, justifications for the formal assumptions, etc.), on the other. The lack of an internal consistency account does not allow the BenMAP user to gain valuable insight regarding crucial connections of the formal methods with experience (including physically testable hypotheses, interpretation of the exposure maps, experimentation guidance, etc.).

§3. **Exposure estimation/interpolation**: BenMAP's discussion of salient *spatiotemporal data analysis* and *processing* issues is weak and seriously outdated. This is true as regards interpolation techniques, composite space-time analysis, and uncertainty assessment alike. In particular:

- BenMAP employs either *simplistic* algorithms (e.g., closest points, neighborhood averaging) or a *primitive* geostatistical technique (i.e., the ordinary/block kriging). The latter technique is used as a panacea, even in cases in which the underlying geostatistical assumptions are not physically meaningful.

- Other (than ordinary kriging) and more powerful members of the *kriging family* are ignored by BenMAP, including intrinsic, simple and disjunctive kriging. Intrinsic kriging is much more appropriate than BenMAP's use of ordinary kriging, when one deals with spatially non-homogeneous and/or temporal non-stationary air pollutant distributions. Disjunctive kriging is much more powerful than ordinary kriging, when one deals with non-linear pollutant estimates (a common situation in exposure studies). Thus, BenMAP did not realize that not the same type of kriging applies to all physical problems, and this is why other types of kriging have been developed.

- BenMAP considers one attribute at a time. However, many times in real-world exposure studies one needs to consider several attributes acting in s*ynergy*. The situation could be handled, at least at an introductory level, by vectorial Wiener-Kolmogorov estimators or cross-kriging, which are also ignored by BenMAP.

- BenMAP disregards *modern temporal GIS* techniques, which are often more adequate for interpolation or prediction purposes than any member of the kriging family. This group includes the Bayesian maximum entropy (BME), the generalized functions, and the Kalman filter techniques (classical and extended). These techniques are more adequate than kriging when physical, toxicological, epidemic, etc. models need to be incorporated in the IHEA study, or the kriging assumptions are physically meaningless, etc. It is strongly recommended that the "Modern Spatiotemporal Geostatistics," as well as the "Temporal GIS," literature be reviewed in the process of revising BenMAP.

- The most salient space-time *correlation assessment* tools of exposure mapping (covariances, variograms, etc.) are not part of the current BenMAP analysis and modelling. Instead, BenMAP requires that these tools are obtained using "external" programs. This approach can cause a host of problems, including compatibility issues, the lack of an integrated framework, and the danger of deriving "black-box" results. One may recall, e.g., the embarrassing situation in which an environmental health research group found itself by using for years an "external" computer package to calculate (erroneously) the effects of airborne soot on human health (see, "Statistical error leaves pollution data up in the air." In *Nature*, 417: 667, 2002; and "Data revised on soot in air and deaths." In *New York Times*, June 5, 2002). This incident shows that even experienced research groups, when required to use "external" computer packages, tend to do it in an uncritical manner (considering them as "black-boxes", without checking whether changing certain parameters affects the outcome, and neglecting to adjusting them, if necessary).

- *Composite* space-time analysis is essentially absent in BenMAP. Important aspects of a composite analysis, such as metrics (distances in space-time), cross-correlations and dependencies between spatial and temporal exposure processes, are not covered in the BenMAP manual. Similarly, spatial and temporal *differentiation* (micro-environment variations at a specific geographical location vs. space-time cross-correlations between different locations and time periods) is not a topic addressed in BenMAP.

- Simple ratios are used as the methods of choice for space- and time-*scaling* (see, p. *C-3-6*). These simplistic methods are highly questionable, especially when the forecasting of exposure variables is considered.

- BenMAP only maps *annual averages*. But this averaging is usually a simple arithmetic mean (p. *C-13*) rather than a weighted integration that adequately accounts for the functional form of the space-time domain and cross-dependencies between pollutant values across space-time.

§4. **Uncertainty evaluation:** BenMAP treats *uncertainty* basically in terms of variability among different studies (see, e.g., Appendix I). This is an inadequate definition of an extremely important concept.

- Uncertainty is an epistemic concept describing one's state of incomplete knowledge. The epistemic interpretation of uncertainty distinguishes it from *natural variability*, which is rather an ontologic concept describing the space-time distribution of a real-world phenomenon.

- The term "pooling," on the other hand, is associated with the so-called *study variability*, which is evaluated by combining the results of different studies. According to BenMAP, using study variability to improve the estimation of human exposure parameters constitutes "a second-best but still valuable way to synthesize information" (see, p. *I-3*). This claim is highly questionable and should be reconsidered. Deriving uncertainty about exposure parameters on the basis of the outcomes of similar studies begs the question of what is meant by the term "similar" (e.g., distinctive features of the studies included in the uncertainty analysis, and appraisal of the C-R models considered). It is not clear how many of these "similar" studies are needed for an adequate assessment of uncertainty. It is not specified how one can be sure that variability between studies is not associated with uncertainty sources but rather with natural changes (natural trends, etc.). Also, important effects associated with the exposure environment under consideration (space-time patterns, structure, etc.) are not accounted for in the pooling-based definition of uncertainty.

- The Latin Hypercube mode employed by BenMAP is a primitive way to look at uncertainty by generating histograms of possible incidence changes. Among other things, such a histogram does not account for the effects on the incidence change at the grid-cell i of (highly correlated) incidence changes at other space-time points $j \neq i$, and does not assess the contribution of other exposure parameters acting in synergy.

- An obvious, first recommendation is to express uncertainty in the air quality distribution across space-time in terms of the *prediction error* or the space-time *integration probability density* (see, also, §8 of Part II below).

- Another recommendation is a *law-based* derivation of uncertainty. E.g., the uncertainty in the expected health effect can be derived as an analytical function of the exposure parameters (concentration, etc.) through the C-R and toxicokinetics laws. The former often have an algebraic form, whereas the latter usually involve a physiology-based differential equation.

- The consequences of uncertainty transcend the domains of the two most significant constituents of scientific development: explanation and prediction. Thus, this part of the BenMAP manual needs to undergo a major revision seeking a scientifically strong analysis of uncertainty.

§5. **Estimation of adverse health effects:** The main issues of our current ignorance concerning adverse health effects are related to causality (concrete sources), biological mechanisms, susceptible subgroups and the existence of thresholds. In view of these considerations, the discussion of the subject of adverse health effects in the BenMAP manual is uneven. In particular:

- The BenMAP manual offers, indeed, an extensive list of the empirical *concentration-response* (C-R) functions available mainly in the epidemiologic literature (this is, perhaps, the most thoroughly discussed component of the BenMAP approach). However, in the vast majority of cases these C-R functions have been derived statistically based on "black-box" associations between central-site exposure measurements and population-wide health endpoints rather than on sound scientific reasoning. Characteristic of the situation is that a large number of C-R functions exist in the epidemiological literature for the same pollutant and health end-point. This situation is reflected in the BenMAP manual, as well.

- There is no discussion in the BenMAP of physiology-based *toxicokinetic* models. These models provide the very important bridge between the exposure of an individual to a pollutant and the resulting health effect (in fact, there is a *continuum* of events between exposure and health effect; each biomarker represents an event in the continuum; see, also, §7 in Part II below). Toxicokinetic models predict biomarker distribution in human organs and tissues and, thus, they can have serious effects on the outcome of the (empirical) C-R analysis. By omitting the toxicokinetics component of IHEA, BenMAP seriously weakens its health damage assessment efforts.

- The impression is given that BenMAP's listing of C-R functions is done in a "sponge" kind of way (i.e., different kinds of functions are listed without any deeper examination of their relative biophysical values and mathematical properties), rather than in a more critical "sieve" fashion (in which only the most significant C-R functions are listed and critically evaluated, their relative advantages and disadvantages are considered, and insightful recommendations regarding their applicability are made). The fact that the C-R models should never be extrapolated beyond the limits imposed by their actual values without any knowledge of the underlying biological causes is a fact to be kept in mind when using the BenMAP list of C-R models. Also, a scientific interpretation of the C-R model parameters should be considered before employing any model from the BenMAP list. E.g., do they express the rate of exposure-damage change in the specified case study? Or, their meaning is better understood in terms of an elasticity indicator? Or, something else?

- *Scale effects* are not discussed. However, a meaningful characterization of health impacts (mortality, incidence rate, etc.) often involves the assessment of their spatiotemporal variation at multiple scales. An adequate space-time estimation method, e.g., should depend on the scale at which the health impact is considered (city, county, state, etc.) rather than being limited by the scale at which the data are available. The change-of-scale phenomenon should affect the shape of the correlation tools used (covariance, variogram, etc.). The significant impact of all these issues in IHEA is not taken into consideration in BenMAP.

- Other crucial health impact *factors* (e.g., duration and frequency of exposure, intake and uptake pathways, compartmental analysis, and summary biomarkers) are not given due attention.

- Certain *population estimates* (p. *B-9-10ff*) are non-scientific, but rather constitute a crude way to generate numbers. E.g., the demographic definition currently in use involves a science-based differential equation, rather than the naïve numerics used by BenMAP. Several other population parameters play an essential role in population forecasting. A revised BenMAP should employ science-based formulas of population dynamics, which can be found in the "Applied Mathematical Demography" literature.

- A relevant complicating element of IHEA not adequately recognized in the BenMAP manual is the question of *susceptible subgroups*. One of the reasons for a dynamically evolving influence of air pollution on health could be a changing susceptibility in the population due its evolving demographic features. During a period of decades, the fraction of asthmatics in the population, age distribution, disease status, Quetlet Index, numbers of diabetics, and number of people with cardiovascular diseases have all changed. Such demographical changes can make the total population more or less responsive to air pollution and, thus, temporally change the *relative risk* (RR) value (e.g., at year t compared to year t-10 or t-20). It is recommended that a BenMAP revision think of RR for environmental factors as being variable in time and space rather than as a static measure.

- Problems associated with the RR as defined in BenMAP include the fact that often it is not obvious what the appropriate baseline and control incidence rates should be, what the relevant covariates are, etc. A reasonable suggestion could be to assess RR by means of the *holistic space-time human exposure assessment* or a stochastic *physico-epidemiologic predictability* criterion (see, also, §§12-17 of Part II below).

§6. **Presentation:** There are certain presentation elements that need improvement, including:

- The BenMAP manual lacks a general chapter with rigorous discussion of objectives, assumptions, theories, and methods independently of the programming details.

- The framework for displaying results is satisfactory for many spatial environments, whereas it is rather inadequate in the case of space-time analysis and mapping.

- The manual does not have an index, which is a useful tool in routine applications of BenMAP.

§7. **Computer programs:** The computer programs have certain drawbacks and need re-design. Some of these drawbacks are direct consequences of the preceding methodological and theoretical observations, whereas some others have a different source. The latter include:

- The BenMAP computer library does not seem particularly user friendly (this is my own conclusion as well as that of my associates whom I asked to test-run the library). An introductory course may be needed to prepare the user if he/she is to avoid spending a significant amount of his/her time to implement the programs properly.

- While the user interface is appropriately organized, the user guide does not appropriately complement and correspond with the user interface. While testing the programs, we obtained several error messages but the manual did not offer sufficient assistance to navigate through the programs successfully.

- The BenMAP computer programs are designed to specifically handle annual changes of air quality in USA and do not constitute a tool of wide applicability, which was the impression given in the first few paragraphs of the manual (p. *i*). Also, BenMAP does not allow printing directly from the program (see *p. 8-18*).

- The usefulness of the BenMAP computer library is limited by the fact that some of its most important components (e.g., exposure estimation) cannot be used without certain "external programs" (e.g., see p. *C-14*) This being the case, certain of BenMAP's claims could be deceiving. Indeed, in the case of exposure estimation, the most important Step 1 of kriging is the modelling of the spatial correlation functions (covariance or variogram); the subsequent Step 2 is merely the straightforward solution of a linear system of equations. BenMAP, however, cannot perform Step 1, being limited to Step 2. Hence, the BenMAP user is asked to seek an "external" geostatistics computer library to perform Step 1. Most well-known libraries (GSlib, BMElib etc.) perform both kriging steps, in which case one wonders why one needs to use BenMAP just for Step 2, especially since the existing geostatistics computer libraries are more advanced/complete/tested and, thus, much more reliable than BenMAP, in this respect.

§8. By way of a summary, BenMAP could have been a useful tool at the initial, purely inductive level of human exposure assessment, which basically involved piling up data and then fitting elementary mathematical functions to these data. Unfortunately, this approach is clearly inadequate at the higher IHEA level of scientific explanation and prediction. In this case, BenMAP needs to be considerable revised in order to account for the sophisticated IHEA concepts, models and techniques currently available.

<u>Part II</u>: MORE DETAILED COMMENTS AND SUGGESTIONS

§1. Broadly speaking, BenMAP's two-fold goal is (*a*) *human exposure assessment* (HEA) and (*b*) its *economic/policy consequences*. We focus on the former without under-evaluating the importance of the latter. Let us focus on the methodological issues of BenMAP. There are a number of interesting connections involved in or resulting from attempts to link research taking place in different disciplines. In the HEA context, a central issue is to lay out *conceptual* and *methodological frameworks* through which cross-disciplinary research can proceed. The reason for this focus is rather obvious. One of the chief problems is that researchers from different fields approach problems with different conceptual tools and methodological orientations. Thus, high priority should be given to the need to develop integrating conceptual and methodological frameworks in which cross-disciplinary HEA research can proceed. Methodological standards are important for the additional reason that they act like teachers: they give marks to human exposure models and evaluate the adequacy of their techniques.

§2. Since HEA links research taking place in different scientific disciplines, it becomes necessary to employ an *integrated HEA* (IHEA) methodology. Indeed, a scientific IHEA ought to be based on a good "integration framework," i.e., a framework involving the main components of the environmental causal chain (ECC): pollutant fate and transport across space-time, exposure theories, physiology-based toxicokinetics, cohort-based health effects, demographics-based population risk assessment, etc. Unfortunately, the approach of the BenMAP manual is rather black-box, lacking any such *integration* framework. Therefore, the manual needs to be revised considerably, starting with a carefully considered IHEA framework that can offer a sound methodological basis to the subsequent health benefit techniques and computer programs.

§3. Furthermore, IHEA scientists are typically faced with the so-called *internal consistency* challenge, that is, the challenge of providing for any given space-time domain simultaneously acceptable formal and interpretive analyses that are also internally consistent. Indeed, in almost all cases the challenge arises of reconciling a plausible account of what is involved in the truth of formal statements referring to the exposure situation with a credible account of how we come to know and interpret these statements. Such an internal consistency element is missing in BenMAP.

§4. The use of interpolation techniques by BenMAP to study air pollution distributions across space-time could be much more complete. E.g., important *concepts* in need of better description are:

a. Vital concepts like "spatial variability," "uncertainty," "spatial interpolation," and "space-time cross-effects" are not adequately conceived and used.
b. Underlying the geostatistical interpolation techniques used in the manual is the fundamental concept of random field or function. I.e., the interpolated attribute (air pollutant, population effect, etc.) is represented by a random function. However, the manual makes no reference to the specific features that the random function must possess in order to provide a physically meaningful model of the interpolated attribute.
c. No sufficient information is given about the main geostatistical interpolation tools used in air pollution and their conceptual link to space-time estimation and interpolation.

In view of the conceptual concerns a-c above, the attempted interpolation can lack any physical interpretation and can generate inaccurate maps.

§5. Important *practical* issues of spatial variation to be accounted for by BenMAP include the following:

- Covariance, variogram or structure function shape and its physical interpretation,
- correlation ranges (local or global, directionality, etc.),
- covariance or variogram behavior at the origin and at large distances (directly related to the *in situ* behavior of the stressor fields),
- spatial anisotropy (geometric, etc.),
- local diversions from spatial homogeneity/stationarity (trend assessment, etc.),
- restrictive modeling assumptions (like normality and linearity).

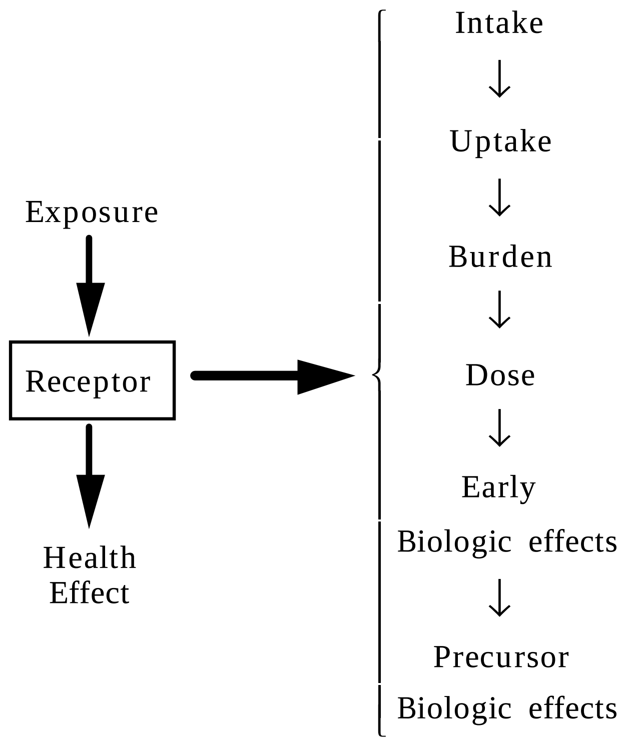
All these issues seem to be "pushed under the carpet," although an adequate assessment of space-time variation of the pollutants considered in the BenMAP manual does constitute the very foundation of IHEA.

§6. For several years, the IHEA literature has introduced space-time exposure functions that are theoretically more advanced and practically more powerful than those presented in the manual. A few of these functions are listed below:

(1) relative area of excess contamination (RAEC),
(2) mean excess differential contamination (MEDC) and conditional MEDC,
(3) contaminant indicator dispersion (CID),
(4) functional and cumulative spatiotemporal exposures (F-CE),
(5) summary biomarkers across space-time (SB),
(6) environmental causal chain (ECC) and exposure-response curves (ERC),
(7) population health damage indices (PHD, local and global), and
(8) population exposure-damage elasticity (PEDE).

The authors of the BenMAP manual should familiarize themselves with the elaborate theories existing in the IHEA literature regarding functions such as (1)-(8) above as well as their relations and dependencies (often expressed in a rigorous and systematic manner by means of algebraic and differential equations).

§7. As is depicted in the following figure, there is a *continuum* of events between exposure and health effect. Each biomarker represents an event in the continuum. The relationships between biomarkers depend on genetic and other characteristics of the



individual; in fact, biomarkers calculated on the basis of similarly exposed people may show significant variation. The study of the continuum biomarkers provides the means for improved environmental health analysis and management. For example, critical disease-related events may be detected earlier on a smaller scale, which makes it possible to focus on preclinical rather than clinical intervention approaches. Also, valuable hints may be obtained regarding the mechanisms relating exposure and health effect. To any component of the continuum, *susceptibility* markers can be assigned, which are considered as indicators of increased or decreased risk for the particular component. For example, genetic and acquired factors (DNA repair, differences in metabolism, nutritional deficiencies, etc.) may lead to individual susceptibility to cancer.

§8. *Uncertainty* in the BenMAP manual is considered merely as variability among different studies (e.g., Appendix I). This is an inadequate definition of an extremely important term. Uncertainty is of far greater importance in scientific thought. It can be a technical notion reflecting error measurements and observation biases; it may also possess a deep conceptual meaning in epistemic terms (incomplete understanding, subjective kind of a variable associated with decisions and preferences, limited computational capabilities, etc.). Variability, on the other hand, is mostly linked to ontologic notions (inherent fluctuations of the system under consideration, lack of well-defined patterns, etc.). BenMAP needs to completely revise this part, aiming at a scientifically strong analysis of uncertainty that takes into account all important factors. E.g., while at the level of independent clinical trials, an interpretation of data uncertainty in terms of frequencies could be adequate in most cases. At the level of natural phenomena that vary in space-time, the same interpretation proves to be clearly inadequate, and a different physical theory-laden interpretation of uncertainty is needed. As a first step, BenMAP could include uncertainty estimation in terms of space-time prediction error, or as a parameter of the integration probability density function. At a later stage, the proper interpretation of uncertainty should depend on the level of the *hierarchy* that the human exposure system is associated with.

§9. In reality, the population health risk characterization is somewhat more complicated than it may be suggested by the concentration-response (C-R) functions of BenMAP. The unit risk is often defined as a quantitative measure of risk increase per concentration increment, assuming an empirical C-R function. Most often in practice the unit risk calculation (of, e.g., cancers caused by environmental exposure) is not made for ambient measurements at a central site monitor, but is rather based on much higher occupational exposures that have been translated into the lower ambient concentrations. What remains to be done for many pollutants is the quantitative characterisation of the personal exposure to ambient pollution levels during the normal daily life (e.g., personal exposure to benzene comes from several other sources than merely the ambient ones). A second complication that should be considered in the BenMAP manual is that for a number of ambient components for which the risk assessment in the local environment is a central policy issue (e.g., PM and Ozone), there have not yet been found mechanisms and sources or fractions that could be called causal of the observed health effects, such as mortality at current ambient concentrations. The observed health effects have been established statistically, based on "black box" associations between central-site exposure measurements and population-wide health endpoints (e.g., mortality and morbidity) rather than on sound scientific reasoning. At a minimum, it would be interesting to discuss the scientific interpretation of the C-R model parameters. (Do they express the rate of exposure-damage change, an elasticity index etc.?). Here, hazard identification is based on ambient concentration measurements at a central site, which are considered representative of the exposures of all people living within a radius of a few tens up to 100 Km from that central site. Ideally, health effects measures of ambient pollution would be the *personal exposures* of the different people living in that area, instead of assigning the same exposure level to all members of the population.

§10. Exposure studies show that daily differences in ambient concentrations appear to be associated with daily differences in mortality and morbidity. This is seen consistently and coherently in virtually every place of the world where this kind of research has been done using time-series analysis and classical Bayesian statistics. Traditional epidemiological research leads to time and place-depended concentrations and relative risks of health endpoints, but as yet the details of the whole chain of events lying in between remain an enigma, in most cases. Thus, the expression 'black-box' is justifiably used. The results of these traditional epidemiological studies are essentially (multiple linear) regressions, which should never be extrapolated beyond the limits imposed by their actual values without any knowledge of the underlying biological causes, which is a fact to be kept in mind in any BenMAP revisions.

§11. The implementation of kriging as an air pollution space-time interpolation technique by BenMAP needs improvement:

- *Why does BenMAP use only ordinary kriging for interpolation*?

  The presentation in the manual is limited to a brute-force implementation of some kind of ordinary kriging computer code without any rigorous justification. In many air pollution cases the assumptions underlying ordinary kriging (linearity, Gaussian, homogeneity, etc.) are inadequate to describe the physical environment under consideration, in which case using ordinary kriging makes absolutely no sense. BenMAP fails to include other members of the kriging family (simple, intrinsic, disjunctive, etc.) that can be more appropriate, depending on the spatial and temporal variation characteristics of the environment. The "black box" implementation of a computer code is never justified in a science-based exposure assessment.

- *How are local trends taken into consideration*?

This is an important issue, which can seriously affect the interpolation results (air pollution maps, etc.). No clear description of the methods available to deal with trend problems is given by BenMAP.

- *What about modern space-time exposure estimation and interpolation algorithms*?

  BenMAP seems to be unaware of the various techniques existing in the literature that can handle space-time exposure estimation and interpolation situations in a mathematically rigorous and physically meaningful manner. The BenMAP authors should consult the extensive literature on space-time estimation, interpolation and prediction (including the spatiotemporal random field theory, Bayesian maximum entropy prediction techniques, and Kalman filtering).

- *Why is a composite space-time analysis not considered by BenMAP*?

  Powerful stochastic techniques have been developed for the rigorous analysis and modelling of IHEA systems in a *composite* space-time domain. The underlying methodology is based on a science-based critical reasoning process that integrates knowledge bases from various disciplines (physical, biological, epidemiological, etc.), derives useful mathematical expressions of exposure variables (exposure rate profile, cumulative exposure, functional or summary biomarker, time-cumulative intake and uptake, biologically significant burden, health effect threshold indicator, etc.), and generates accurate predictions of population health effects across space and time. These stochastic techniques are very general, having a wide range of applications. E.g., spatiotemporal random field models have been employed to study environmental exposure-health effect associations between environmental exposures (PM or temperature) and mortality distributions. This model is used as the tool of choice for rigorously accounting for important spatiotemporal variations and uncertainties related to exposures and effects. Within this modelling framework, the BME technique neatly synthesizes various sources of physical and epidemiological knowledge (scientific theories, soft data, uncertain observations, physical and biological laws, higher-order spatiotemporal moments, etc.) into IHEA. Thus, an interesting feature of the BME approach is the integration of the physical processes of exposure with the epidemiologic processes of effect in a space-time continuum. This essential feature is not shared by previous statistical approaches to the exposure-health effect problem that have been based on classical statistics techniques (spatial regression, multivariate statistics, etc.). By ignoring important knowledge bases and scientific reasoning principles, these techniques have been proven seriously inadequate in establishing exposure-effect associations in a realistic space-time context.

- *Why is spatial and temporal differentiation not investigated in BenMAP*?

  Generally speaking, spatiotemporal differentiation in IHEA can be subdivided into two main classes: (*a*) one that considers variation in micro-environments when assessing the health impact at a specific geographical location; and (*b*) one that considers correlations across space and time when assessing the health impact at different geographical areas and at different time periods.

§12. Another interesting feature of modern IHEA that should be considered by BenMAP is that the space-time association between exposure and health effect distributions can be studied by means of a stochastic *physico-epidemiologic predictability* (PEP) criterion. While stochastic associations of this kind do not always imply necessary and sufficient causation conditions, the PEP criterion relates physical knowledge with epidemiologic distribution, accounts for inter-subject and intra-subject variabilities, and offers valuable insight regarding the existence of a causation relationship. In light of the PEP criterion, an environmental exposure-health effect association can be established in the stochastic sense above, given the available knowledge bases processed by the stochastic PEP criterion. If an improved understanding of the biological or toxicological mechanism leads to new knowledge bases, the PEP criterion will rigorously account for these bases in deriving its conclusions. However, for many compounds there still is no established biological or toxicological mechanism behind the associations used in the C-R relationships.

§13. When BenMAP constructs environmental risk indicators in terms of some simple average, many important elements have been ignored, including:

(1) the temporal aspect of exposure,
(2) its duration and frequency,
(3) the scale of exposure,
(4) the space-time filters (incorporating summarizing effects, etc.),
(5) the intake and uptake pathways, as well as
(6) the type of cohorts considered (age, sex, pre-existing medical conditions, activity characteristics, etc.).

The scale issue, e.g., is closely linked to the decision regarding the size of the indicator design area. If the temporal effect has been averaged out, the technique used for this purpose must be described. Instead, the BenMAP manual does not even make a single reference to the crucial elements (1)-(6) of human exposure assessment. A much more realistic indicator analysis would result by replacing the basic formulas of the manual with a formula that accounts for just a few of the exposure elements above – the relevant equations have existed in the human exposure literature for several years. Valuable insight is offered by the well-known *exposure-damage elasticity indicator*, which measures the ratio of the fractional change in health damage over the fractional change in exposure across space and time. Yet another important issue is the so-called "time-delayed" factor, i.e., accounting for the time elapsing between the exposure and the resulting health effect. These issues are quantified in the context of exposure assessment and expressed in terms of integral equations (see "Spatiotemporal Environmental Health Modelling" literature).

§14. It is suggested that a revised BenMAP pay more attention to the significance of using a mathematically rigorous and physically meaningful/consistent definition of relative risk (RR). The population health effects of ambient compounds may be characterized by the RR measure, indicating how often the incidence of a certain health endpoint is augmented by a unit increase in concentration (□C). Establishing the health impact assessment (HIA) for such compounds is often done by calculating the population attributable fraction in combination with the incidence (INC=base rate) of the considered population health endpoint, namely HIA=PAF×INC. The PAF is calculated from the RR per unit concentration and the average ambient concentration C by PAF=(RR-1)×C/RR. From these equations, it follows that HIA is a function of C, INC and RR, and that changes in one of these parameters have numerical consequences for the others. E.g., a INC difference leading to an opposite effect on RR was recently reported in the context of a project in which the authors looked at the confounding and effect modification of ambient particles on total mortality for a number of cities. The numerical values of the RR can be assessed by an epidemiological time series analysis of population mortality or morbidity during the time period in question. Such analyses can be done for the whole population, for susceptible subgroups or cohorts, or for specific geographical areas, and could be the focus of a revised BenMAP. The numerical C-values can be measured by a monitoring program or may be assessed by models when these have been thoroughly validated. The values of the health incidences (INC) in a population have to be established by a health monitoring program or a representative scheme of data collection for statistical purposes. As regards the transfer of an exposure-response association into a new population context for health impact assessment, the conclusion often is that whenever the baseline occurrence of the health endpoint in question differs across study populations, the result of pooling the relative risks from the respective studies may be misleading.

§15. Unfortunately, the RR assessment for exposure cannot be made in the same manner as that of a physical constant. As far as our modest information allows us to derive conclusions, we have to think of RR for environmental factors as being variable in time and space. When a certain exposure C has a health impact HIA in a population, it follows that any change in INC automatically leads to a similar change in RR in the opposite direction. As the incidences of health effects, whether being mortality or morbidity, are not constant in a population and change permanently, the RR will not be constant as well. When the C and the HIA also change in time, the necessity of a regular assessment of RR in populations becomes even clearer. In many cases it is necessary to use information for an HIA that is tailored to the conditions in the USA, meaning using RR that are representative for the time and place. Therefore, the most recent local estimates for RR always have to be used to make a reliable HIA. When an HIA for some other time period is required, we do not only have to estimate the future concentrations C at time t, but also we have to estimate the future RR at time t in order to arrive at a reliable HIA.

§16. One of the reasons for a dynamically evolving influence of air pollution on health could be a changing susceptibility in the population due its evolving *demographic* features. During a period of decades the fraction of asthmatics in the population, the age distribution, disease status, Quetlet Index, numbers of diabetics, and number of people with cardiovascular diseases have all changed. Such demographical changes can make the total population more or less responsive to air pollution and, thus, temporally change the RR_i value (e.g., at year i compared to year i-10 or i-20). Also the population dynamics are important in the calculation of the base incidence rates INC_i over time. These values can and will change for a differently structured population and values of INC_{i+10} and INC_{i+20} for specific health effects may be quite different in 10 or 20 years from the incidence rates that we currently see.

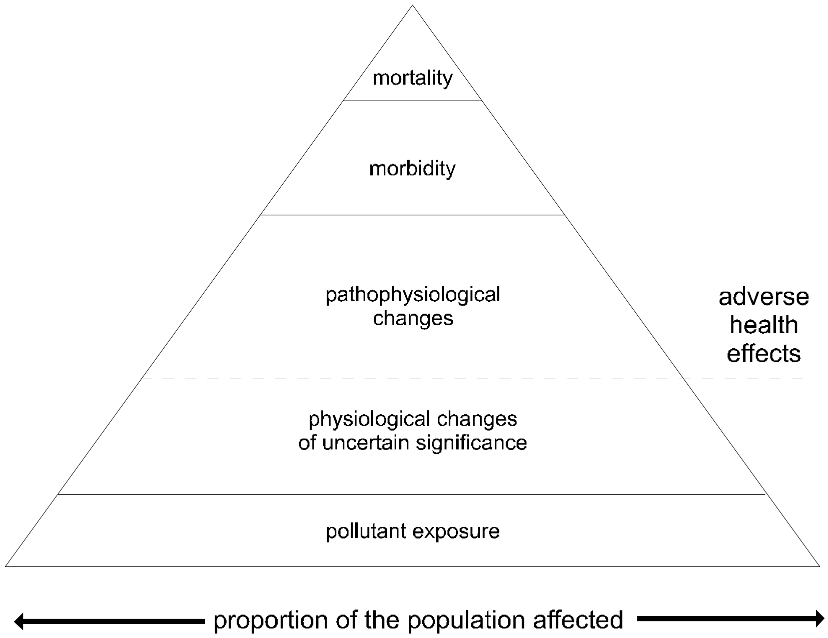
§17. The BenMAP authors may find it useful to look at developments related to the *holistic space-time human exposure assessment* methodological framework. This is a very general, ECC-based framework that studies the impact of spatiotemporal exposure distributions on the health of human populations. It acknowledges the inadequacies of older approaches and makes a serious effort to improve health impact analysis by means of the horizontal integration among sciences relevant to human exposure, which leads to accurate and informative spatiotemporal maps of exposure and effect distributions and an integrative analysis of the whole *risk* case. Important characteristics of this framework are holisticity and stochasticity. Holisticity emphasizes the functional relationships between composite space/time pollutant maps, toxicokinetic models of burden on target organs and tissues, and health effects. These relationships offer a meaningful physical interpretation of the exposure and biological processes that affect human exposure. Stochasticity involves the rigorous representation of natural uncertainties and biological variations in terms of random fields. The stochastic perspective introduces a deeper epistemic understanding in the development of improved models of spatiotemporal human exposure analysis and mapping. Also, it explicitly determines the knowledge bases available and develops logically plausible rules and standards for data processing and human exposure map construction (more details can be found in the “Spatiotemporal Environmental Health Modelling” literature).

§18. Due to our behaviour, humans constitute a complicating factor in the modelling of the ECC. We tend to spend most of our time indoors and some of it inside vehicles, whereas much less time is spent outside in the ambient environment. For exposure purposes, therefore, it is very important to take into account these various *micro-environments*, each with quite different levels of exposures. Also, exposures at the workplace may interfere with environmental exposures. Generally speaking, workplace standards tend to be an order (or orders) of magnitude higher than environmental standards. For these different micro-environments the indoor/outdoor ratio (which provides a measure of ambient pollution penetration into the indoor environment) is an important descriptor not considered in the BenMAP manual. Personal exposure is also influenced by the level of activities and the nature of the activities assumed for the representative individual (usually defined as an individual belonging to a specific cohort: age range, sex group, health state, pre-existing health conditions, activity range etc.). Note that, to some extent these activities and the ensuing exposures have a seasonal component, as well.

§19. For ambient compounds, such as the PM and Ozone considered in the BenMAP manual and central to policy issues, the current state of affairs is that they should be seen as indicators or surrogates of something else in the environment. Because of the current uncertainty in mechanisms and causal factors concerning PM and summer smog (Ozone), the range of health endpoints reported in epidemiological studies is rather broad. They range from minor complaints to more extensive use of medicines, to morbidity and hospital admissions, and even to extra mortality. The figure below presents a model of how these environmental effects might affect public health. Mortality is more or less the top of a pyramid of underlying health problems. Large parts of the population are exposed to ambient air pollution, while mortality affects only a small fraction. In recent epidemiological studies the entire pyramid has been studied and the various health endpoints have been found to be more or less logical in the way that they relate to medical events linked to the respiratory and cardiovascular system (and not, e.g., with mortality due to stomach problems). A revised BenMAP will greatly benefit by presenting its adverse health effect functions (C-R, etc.) in view of the above pyramid.

§20. For the specific data sets considered in the BenMAP, considerable insight can be gained by calculating stochastic exposure indicators like the distribution of the binary-valued exposure field (for thresholds calculated on the basis of environmental and health requirements), and the associated one- and two-point exposure indicators, such as:

(1) the expected exposure indicator,
(2) the expected exposure indicator,
(3) the expected excess exposure above the threshold at each space-time point,
(4) the expected excess differential exposure across space-time (which is equal to the expected difference between exposure and threshold if exposure exceeds the threshold, and zero otherwise),
(5) the conditional mean excess exposure over the threshold,
(6) the exceedance odds indicator (expressing the probability ratio of excess over below-threshold exposure at each point in space-time,



as well as several others that can be found in the “Spatiotemporal Environmental Health Modelling” literature.

§21. Generally, the number of health effects occurring in a population seems to decrease with the severity of the effects. E.g., the number of hospital admissions for a certain cause of death attributed to ambient pollution is generally higher than the actual number of deaths. The crucial issue then is the level of medical or epidemiological detail required in order to be able to take effective policy measures to reduce the health impact of environmental exposures. For the field of environmental safety, this question has been answered in the past by choosing mortality as the risk indicator, while at the same time acknowledging that for every death there is an underlying number of less serious health consequences that, for simplicity, is not expressed by a specific measure or compared to some (policy) yardstick. In the BenMAP context, one could suggest mortality as a health risk indicator for the environmental exposures considered (PM, Ozone) without loosing track of the fact that there is an underlying web of population health effects which cannot be addressed by mortality alone.

§22. In addition to the above, there are certain serious issues related to susceptible subgroups. Currently, the elderly and, under certain circumstances, children are considered to be susceptible subgroups of PM effects. Other susceptible subgroups that have been suggested include people with cardio-vascular diseases, diabetics, and asthmatics. Historically, the health status of the population changes rapidly (e.g., in certain areas the numbers of diabetics and asthmatics have risen dramatically during the past decades). Also, it could be speculated that because of the improved health care systems in some regions of the country that manage to keep people alive longer, the numbers of very frail and possibly more susceptible persons are on the increase. To take this speculation even further, if this rise in the number of susceptible persons is larger than the decrease in the levels of environmental pollution, the population health impact could well be on the rise despite a gradual improvement of environmental quality. A second element concerning susceptibility to ambient pollution not considered by BenMAP is the *socio economic status* (SES). For chronic PM exposure, relations have been established between SES and health effects.

Whether such relationships are mediated by food status (e.g., anti-oxidants), a better access to medical care or some other cause is not yet clear. In time-series analysis, SES is not an issue, since everybody is under his/her own control.

<u>Part III</u>: PEER REVIEW QUESTIONS AND ISSUES

1. General:

a) Does BenMAP provide a useful and sensible structure for addressing policy analysis needs?

- *N/A*

b) Does it provide adequate flexibility to users for addressing important policy questions?

- *N/A*

c) Are the different components of the model appropriately defined and linked to one another?

- *Generally, yes*.

2. Input Databases: Keeping in mind that some of the input databases are fixed in the model and some can be adapted or supplemented…

a) Are the fixed input databases appropriately selected and defined using

- Census and projected demographic data?

  - *Some problems with the simplistic methods of choice, see Reviewer's Report*.

- Modeled air quality data?

  - *It focuses solely on O3, PM2.5 and PM10 for 1966* (*e.g., p. A-1*). *Some problems with choice of model, see Reviewer's Report*.

- Baseline incidence data?

  - *Background level* (*see, e.g., p. A-13*).

b) Are the adaptable input databases appropriately selected and defined for

- Monitored air quality data?

  - *Yes, but limited to certain pollutants*.

- Concentration-response functions?

- A wide selection is considered, although in a rather uncritical manner; see, Reviewer's Report for a detailed analysis of the situation.

- Valuation functions?

  - Including raw incidence, pooled incidence, pooled valuation etc.

3. Exposure Estimation Algorithms: To spatially and temporally align population, air quality, and incidence data as inputs to the concentration-response functions, BenMAP uses several estimation and interpolation algorithms.

a) Are these methods scientifically sound and appropriate for

- interpolating and projecting population estimates for non-Census years?

  - Only simple ratios are considered that offer a rather poor assessment of the situation (p. B-9-10), see, also, Reviewer's Report.

- estimating population subgroups (e.g., by age, gender, ethnicity, etc.)?

  - Suffers from the use of simplistic formulas, which are rather crude ways to generate numbers that do not always have a scientific meaning, see, also, Reviewer's Report.

- estimating the spatial distribution of populations and linking them to air quality grids?

  - Serious problems, see Reviewer's Report.

- spatial and temporal interpolation of pollutant monitoring data?

  - Scaling factors are discussed (p. C –15-18); the analysis is theoretically weak; see Reviewer's Report.

b) Does BenMAP offer an appropriate menu of interpolation options for estimating exposures?

- Idefinitely no, due to a number of issues discussed in detail in Reviewer's Report. The interpolation options in the menu are very inadequate for today's IHEA standards. The menu is limited to either naive techniques (e.g., closest point and Voronoi neighborhood averaging), or a poorly developed geostatistics technique of ordinary kriging. The menu is limited to one pollutant at a time. Etc.

c) Do these methods provide appropriate inputs for the class of concentration-response functions allowable in the model?

- For a certain class of functions, yes.

4. Aggregation and Pooling Methods: BenMAP offers alternative approaches for spatially aggregating health effects estimates and for pooling separate estimates of health effects for valuation.

a) Does BenMAP offer an appropriate menu of aggregation and pooling options?

- *Yes, in terms of "Create" and "Reuse" (see, in p. 3-8).*

b) Do these methods provide appropriate inputs for the class of valuation functions allowable in the model?

- *In a rather formal manner, perhaps. The interpretive element is lacking due to the methodological, theoretical and applied concerns mentioned in my Reviewer's Report.*

5. Uncertainty Analysis Methods: BenMap offers options for including and evaluating how uncertainty regarding (1) C-R relationships and (2) valuation functions affect model outputs?

a) Does BenMAP allow the user to adequately and appropriately specify uncertainty for these two areas?

- *No. It merely uses N-point Latin Hypercube. For further suggestions see Reviewer's Report.*

b) Are the uncertainty routines properly specified and incorporated in the model?

- *They are included, but they are inadequate (from a conceptual and practical viewpoints).*

c) Without greatly complicating the structure of the model, are there additional areas or types of uncertainty that could or should be incorporated in BenMAP?

- *This part of the manual is weak and needs to undergo considerable revision, see Reviewer's Report for a detailed discussion and suggestions. The uncertainty issue is much more serious than what it seems to be the suggested in the BenMAP manual.*

6. Report and Mapping Results: BenMAP offers several options for reporting and mapping air quality, population, incidence, and valuation data and results.

a) Do these options provide an adequate and appropriate framework for displaying results?

- *Mostly yes, although these options are of limited use in the case of space-time analysis and mapping (see, p. 7-3, 8-1, and 8-2). Of course, the inadequacies of the display framework in the space-time domain can be directly related to the corresponding inadequacies of the theory and methods employed in BenMAP.*

b) Are the results displays appropriately specified and configured to address the intended uses and analytical needs of BenMAP (as defined above and in the model documentation)?

- *Yes, but BenMAP only maps annual averages and does not allow printing directly from the program (see p. 8-18).*

7. User Interface and User Guide: BenMAP is a menu driven interactive software tool with multiple options and features, as described above.

a) Is the user interface appropriately organized, easy to use, and easy to follow? Through the user interface, are the options and features well described and easy to navigate?

   - *Not as efficient as other similar menus I am aware of.*

b) Is the user guide appropriately organized, easy to use, and easy to follow?

   - *Things could be improved with some kind of an Index.*

c) Does the user guide appropriately complement and correspond with the user interface?

   - *No, I got several error messages. The manual does not provide sufficient guidance for an easy navigation.*

d) Does the user guide provide the necessary explanation and background for installing and running the model, selecting options, and displaying results?

   - *No. A short course would help considerable, see Reviewer's Report.*

e) Does the user guide adequately explain the model's objectives and the model's underlying structure, assumptions, data, methods, and routines?

   - *The BenMAP manual lacks a general chapter with objectives, assumptions and methods, independent of the programming details.*

Appendix A: Peer Reviewers' Charge

The following letter and instructions were sent by RTI to each of the three reviewers in February 2004.

Dear [Reviewer Name]

Thank you for agreeing to serve as a peer reviewer of EPA's **Environmental Benefits Mapping and Analysis Program (BenMAP**).

BenMAP is an interactive computer model designed as tool for environmental policy analysis. It provides users with a platform for conducting customized analyses of the health benefits associated with selected changes in air quality levels across the country.

BenMAP is designed to provide users with a flexible framework for integrating data and models from various sources. For example, it allows users to incorporate monitored or modeled air pollutant concentrations estimates in various forms as key inputs for analysis. It also allows users to choose and adapt concentration-response functions for health effects estimation and valuation functions for economic analysis.

As described in the User's Manual, some of the more specific intended uses of BenMAP are for

- generation of population/community level ambient pollution exposure maps;
- comparing benefits associated with regulatory programs;
- estimating health impacts and costs of existing air pollution concentrations;
- estimating health benefits of alternative ambient air quality standards;
- performing sensitivity analyses of health or valuation functions, or of other inputs; and
- screening analyses.

With these design objectives in mind, we request that you review the model software and documentation and provide us with your assessment of the model's scientific accuracy, credibility, objectivity, and technical appropriateness.

Below you will find a list of both general and specific questions that we would like you to consider in conducting your review. We do not expect you to answer each question individually, but we would like you to use them as a guide in preparing your review. Please address as many of these issues as possible, but feel free to focus on areas that correspond best with your technical expertise and interests.

We request that you submit a written review no later than **March 26**. You can email the review to me at gvh@rti.org. Please organize the review in the form of a memorandum or a short report (preferably in WordPerfect, but otherwise in MSWord), beginning with your general impressions of the model and then moving to your more specific comments.

Thanks again for your participation. If you have any questions, please feel free to contact via email or at (919) 541-7150 or Cate Corey at (919) 541-3767.

Sincerely,

George Van Houtven
Senior Economist
Environmental and Natural Resource Economics Program
RTI International

Peer Review Questions and Issues

1. General:

a) Does BenMAP provide a useful and sensible structure for addressing policy analysis needs?
b) Does it provide adequate flexibility to users for addressing important policy questions?
c) Are the different components of the model appropriately defined and linked to one another?

2. Input Databases: Keeping in mind that some of the input databases are fixed in the model and some can be adapted or supplemented…

a) Are the fixed input databases appropriately selected and defined using
   - Census and projected demographic data?
   - Modeled air quality data?
   - Baseline incidence data?

b) Are the adaptable input databases appropriately selected and defined for
   - Monitored air quality data?
   - Concentration-response functions?
   - Valuation functions?

3. Exposure Estimation Algorithms: To spatially and temporally align population, air quality, and incidence data as inputs to the concentration-response functions, BenMAP uses several estimation and interpolation algorithms.

a) Are these methods scientifically sound and appropriate for
   - interpolating and projecting population estimates for non-Census years?
   - estimating population subgroups (e.g., by age, gender, ethnicity, etc.)?
   - estimating the spatial distribution of populations and linking them to air quality grids?
   - spatial and temporal interpolation of pollutant monitoring data?

b) Does BenMAP offer an appropriate menu of interpolation options for estimating exposures?

c) Do these methods provide appropriate inputs for the class of concentration-response functions allowable in the model?

4. Aggregation and Pooling Methods: BenMAP offers alternative approaches for spatially aggregating health effects estimates and for pooling separate estimates of health effects for valuation.

a) Does BenMAP offer an appropriate menu of aggregation and pooling options?

b) Do these methods provide appropriate inputs for the class of valuation functions allowable in the model?

5. Uncertainty Analysis Methods: BenMap offers options for including and evaluating how uncertainty regarding (1) C-R relationships and (2) valuation functions affect model outputs?

a) Does BenMAP allow the user to adequately and appropriately specify uncertainty for these two areas?

b) Are the uncertainty routines properly specified and incorporated in the model?

c) Without greatly complicating the structure of the model, are there additional areas or types of uncertainty that could or should be incorporated in BenMAP?

6. Report and Mapping Results: BenMAP offers several options for reporting and mapping air quality, population, incidence, and valuation data and results.

a) Do these options provide an adequate and appropriate framework for displaying results?

b) Are the results displays appropriately specified and configured to address the intended uses and analytical needs of BenMAP (as defined above and in the model documentation)?

7. User Interface and User Guide: BenMAP is a menu driven interactive software tool with multiple options and features, as described above.

a) Is the user interface appropriately organized, easy to use, and easy to follow? Through the user interface, are the options and features well described and easy to navigate?

b) Is the user guide appropriately organized, easy to use, and easy to follow?

c) Does the user guide appropriately complement and correspond with the user interface?

d) Does the user guide provide the necessary explanation and background for installing and running the model, selecting options, and displaying results?

e) Does the user guide adequately explain the model's objectives and the model's underlying structure, assumptions, data, methods, and routines?

Appendix B. Curriculum Vitae of BenMAP Peer Reviewers

B.1 Alan J. Krupnick

Resources for the Future
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Washington, DC 20036
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Education:

University of Maryland, Ph.D., Economics, June 1980 (Dissertation Title: *The Optimal Control of Pollution with Endogenous Labor Supply*)

University of Maryland, M.A., Economics, 1972-1974

Columbia University, Graduate School of Business, International Business, 1969-1970

Pennsylvania State University, B.S., Finance, With Distinction, 1965-1969

Professional Experience:

1998-Present	Director, Quality of the Environment Division, Resources for the Future
1990-Present	Senior Fellow, Resources for the Future
1980-1990	Fellow, Resources for the Future
1993-1994	Senior Economist, Council of Economic Advisers; on leave from Resources for the Future
2002	Consultant, USEPA
2001	Consultant: USEPA, Health Canada
2000	Consultant: European Community, Environment Directorate.
1999	Consultant: World Bank.
1998	Consultant: World Bank, Europe and Central Asia Division; PacifiCorp, Great Lakes Commission; Canadian Energy Research Institute.
1997	Consultant: World Health Organization; World Bank, Industry and Energy Division and Europe and Central Asia Division; Environment Canada; Industry Canada.
1996	Consultant: USAID; Harvard Institute for International Development; World Bank, Latin America Division; Environment Canada; Health Canada, Industry Canada
1995	Consultant: Ontario Hydro; World Bank, Latin America Division; American Petroleum Institute, Southern Appalachian Management Initiative
1993	Consultant: World Bank, Asia Division; Office of Technology Assessment
1990-1992	Consultant, World Bank Latin America Region, Public Economics Division (Country Department), World Development Report
1989-1990	Consultant, World Bank, Environment Department, Asia Region, Infrastructure and Urban Development Department; NERA; U.S. Department of Energy; Geomet, Inc.

1987-1988	Consultant, Office of Technology Assessment, U.S. Congress
1987-1988	Consultant, Viking Systems, Inc.; Exeter Assoc.
1980-1982	Consultant, University of Missouri, State of Maryland
1977-1980	Faculty Research Associate, Bureau of Business & Economic Research, University of Maryland
1976-1977	Instructor, University of Maryland: International Economics, Macroeconomics, and Microeconomics
1976-1976	Consultant, National Commission on Water Quality
1974-1976	Autonomous Teaching Assistant, University of Maryland
1972-1974	Research Assistant, Bureau of Business & Economic Research, University of Maryland
1970-1972	Research Assistant, The Federal Reserve Bank of Philadelphia
1970-1970	Research Analyst, City University of New York, Faculty Senate

PUBLICATIONS

"Trading Cases: Is trading credits in created markets a better way to reduce pollution and protect natural resources?" lead article in *Environmental Science and Technology*, **37** (11) pp. 217-23 June, 2003 (with Dallas Burtraw, Karen Palmer, Richard Newell, Margaret Walls, Ginny McConnell, Jim Boyd, and Jim Sanchirico).

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"Benefits Analysis of Alternative National Ambient Air Quality Standards for Photochemical Oxidants: Phase I Report," for U.S. Environmental Protection Agency, September 1984.

"Air Pollution and Lung Function in Children" (with Winston Harrington), for U.S. Environmental Protection Agency, July 1984; RFF Discussion Paper QE84-12.

"Assessment of Nonpoint Source Pollution Control Policies" (with Henry Peskin and Winston Harrington), report prepared for the Office of Policy, Planning, and Evaluation, U.S. Environmental Protection Agency, March 1984.

"Acute Respiratory Disease and Exposure to NO_2: Construction of Exposure-Response Functions Using CHESS Data from Chattanooga, Tennessee" (with Winston Harrington), report prepared for Office of Policy and Resource Management, U.S. Environmental Protection Agency, October 1983.

"Assessment of the Chattanooga Acute Respiratory Disease Survey" (with Winston Harrington), report prepared for Office of Air Quality Planning and Standards, U.S. Environmental Protection Agency, April 15, 1983.

"Cost per Exposure Reduction Analysis of Alternative NO_2 NAAQS" (with Winston Harrington), report prepared for Office of Air Quality Planning and Standards, U.S. Environmental Protection Agency, Research Triangle Park, N.C., August 3, 1982.

"Appendix to Chapter VI of the NO_2 Regulatory Impact Analysis: Deriving Damage Functions for the Effects of NO_2: An Evaluation of Selected Studies" (with Winston Harrington), August 1982.

"Federal Regulation: A Statistical Analysis" (with Winston Harrington, Wesley Magat, and Henry M. Peskin), May 1982.

"Simulating Alternative Air Pollution Control Policies: Nitrogen Oxides in the Baltimore Air Quality Control Region," report to the Department of Economic and Community Development, State of Maryland, December 1981.

"Innovative Technology Compliance Extensions: A Qualitative Economic Analysis of Section 301(k) of the 1977 Clean Water Act Amendments" (with David R. Yardas), prepared for U.S. Environmental Protection Agency, January 1981.

BOOK REVIEWS

In *Nature*, review of W. Beckerman, *Small Is Stupid: Blowing the Whistle on the Greens* Duckworth Press, London. 1995.

In *Environment International*, review of A.L. Nichols, *Targeting Economic Incentives for Environmental Protection*, The MIT Press, Cambridge, Mass., 1984.

OTHER

Reviewer for:

Review of Economics and Statistics
American Journal of Agricultural Economics
Journal of Environmental Economics and Management
Journal of Applied Policy and Management
Land Economics
Contemporary Policy Issues
Marine Resource Economics
Environmental Science and Technology
Operations Research
Journal of the Air Pollution Control Association
Journal of Industrial Economics
Journal of Regional Studies
Oxford University Press
Journal of Forestry
National Science Foundation

Co-Chair, Interagency Steering Committee on Valuing Health Outcomes, 2002-2003

Invited to serve on the Advisory Committee to the Center for Environmental and Resource Policy, North Carolina State University, 2002

Editorial Board, *Land Economics,* 2001-2002

Member, CMAQ NAS Committee, 1999-2002

Member, STPP NAS Committee, 1999-2002

Member, Expert Panel on Reviewing the Canadian Proposed Ozone and PM Standards, Royal Society of Canada, 1999-2001

Alan Krupnick

Co-Chair of the Workshop on the Convergence of Risk Assessment and Socioeconomic Analysis to Better Inform Chemical Risk Management Decisions, sponsored by USEPA, OECD, and Health Canada, Arlington, VA, May 1-2, 2000

Member, Subcommittee of the EPA Science Advisory Board for Review of the 812 Cost-Benefit Study, USEPA, 1998-1999

Co-chair of the Subcommittee for Development of Ozone, Particulate Matter and Regional Haze Implementation Programs, Clean Air Act Advisory Committee to USEPA, 1995-1997

Member of the National Research Council’s Review Team for the Federal Highway Cost Allocation Study, 1995-1997

Member of the National Research Council’s Committee on Research and Peer Review at the Environmental Protection Agency, 1994-1997

Member of Scientific Advisory Board, Maryland Power Plant Research Program, State of Maryland, 1986-1990

Testimony, Senate Governmental Affairs Committee, House Marine Fisheries Committee, House Committee on Science, Space, and Technology

Member of U.S. Department of Energy Environmental Costing Task Force

Member of the New York State Managing Board for the Environmental Costing Study

B.2 Nino Künzli

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<u>Education</u>:

College or University	University of Basel, M.D., B.S., 1986
Medical School	University of Basel, 1976-1982
Advanced Degrees	University of California, Berkeley, M.P.H., 1993 University of California, Berkeley, Ph.D., 1996
Internships	Rotating Internships (University of Basel Program) with Internal Medicine and Surgery, Regional Hospital Davos; Gynecology and Obstetrics, Cantonal Hospital Münsterlingen; Neurology, Klinikum Steglitz, Berlin, West Germany; Ophthalmology, Clinica del Università die Siena, Italy, 1982
Residencies	General Practitioner Residencies with different physicians in Switzerland and Berlin (Germany), 1984 Regional Hospital Davos, Internal Medicine, 1985-1986 University Hospital Basel, Gynecology / Obstetrics 1986-1987 Resident, St. Clara Hospital, Basel, General and Abdominal Surgery 1987-1989 Preventive Medicine Research residency at the Institute of Social and Preventive Medicine, University of Basel, 1989-1992
Fellowships	Swiss National Science Research Fellowship, 1992-1995 Swiss National Science Advanced Researcher Fellowship PROSPER, 1997-2002
Honors and Awards	– Outstanding Graduate Student Instructor Award, School of Public Health, University of California, Berkeley, 1993/1994

	– Warren Winkelstein Epidemiology Best Thesis Award, School of Public Health, University of California, Berkeley, 1996
	– Annual Award of the Swiss Society for Internal Medicine 2001
Licensure	Swiss MD license
Board Certification	Swiss Specialization Title, FMH, in Social and Preventive Medicine; 1995

Professional Background:

Academic Appointments

Institute for Social and Preventive Medicine, University Basel; Research Assistant, Epidemiology; Adjunct to Swiss National Research Program 26, NFP26 Human Health and Environment, Basel

Scientific Coordinator of the Central Epidemiology Unit, Swiss Study on Air Pollution and Lung Diseases in Adults, SAPALDIA 1989-1992

Scientific Advisor, Swiss Lung Association, Department for Lung Diseases, 1996

Senior Researcher and Member of Board of Directors, Institute for Social and Preventive Medicine, University Basel, 1995-2002

Lecturer appointment, ETH Zurich; Environmental Epidemiology (Env Health Science Masters), 1996-2002

Assistant Professor (PD), University of Basel, Institute for Social and Preventive Medicine, 2001-2002

Associate Professor, Department of Preventive Medicine, University of Southern California, Los Angeles, CA, 2002-

Specific Administrative Responsibilities

Member of the Board of Directors, Institute for Social and Preventive Medicine, University of Basel, 1996-

President of the Faculty and Member of the Board of Directors, Swiss Master of Public Health Program, Universities of Basel, Bern, Zurich, 2000-2002

Head of Master of Public Health Epidemiology/Biostatistics Sub-Committee, Universities of Basel, Bern, Zurich, 1999-2000

Head of Master of Public Health Financial Commission, Universities of Basel, Bern, Zurich, 2000-2002

Member of the Preventive Medicine Curricular Committee, University of Basel, 1999-20002

Other Employment or Activity

Expert Advisory Committee, Austrian Particle and Health Program, 1999-2002

Member of the National Research Committee, National Academy of Sciences, Estimating Public Health Benefits of Proposed Air Pollution Regulation, 2001-2002

Expert Committee Swiss National Environmental Health Action Plan, NEHAP, (mandate by Swiss Lung Association), 1996-98

Member of the Swiss Federal Working Group on the Revision of the Swiss Medical Exam, Public Health, 1998

Expert Advisory Committee on Nuclear Energy and Sustainability of the Swiss Academies of Science, CASS, 1998-2001

Federal Advisory Board for Climate Change of the Swiss Government, 1998-2002

External Review Board of the WHO Project "Systematic Review of Health Aspects of Air Quality in Europe," 2002-2003

Review Board on Air Pollution Health Impact, New Zealand Research Council, 2002

U.S. EPA Scientific Advisory Board, Advisory Council on Clean Air Compliance Analysis. Health and Ecological Effects Subcommittee (May 2003 – present)

Research Activities:

Major Areas of Research Interest

Environmental determinants of diseases, with major focus on air pollution and health

Research in Progress

Long-term effects of air pollution and its disease burden on society

Research Grants in Past Five Years

Principal Investigator

1. Assessment of long-term health effects and population risk of ambient air pollution — $765,000
   Swiss National Science Foundation Advanced Research Fellowship
   1997-2002
   Co-Investigators: personal fellowship grant

2. Air Pollution, Exposure and Health in the European Community Respiratory Health Survey (ECRHS) City of Basel — $213,000
   Swiss Federal Office for Education and Science
   2000-2003
   Co-Investigators: Ackermann-Liebrich U, Leuenberger Ph, Brutsche M, Perruchoud A, Probst N, Schindler Ch, Burney P and ECRHS Research Team

3. Air Pollution in the European Community Respiratory Health Survey Centers — $500,000
   Swiss Federal Office for Education and Science
   2000-2004
   Co-Investigators: Ackermann-Liebrich U Basel, Burney P London, and ECRHS Research Team (Burney P is the Principal Investigator of the European wide Health Cohort Study)

4. Air Pollution Exposure Distribution Across Urban European Populations, The EXPOLIS Study — $208,000
   Swiss Federal Office for Education and Science (+ European Community)

and ETH Contributions
1996-2000
Co-Investigators: Jantunen Matti (PI of the European wide EXPOLIS Study; NK is PI of the Basel Centre); Katsouyanni Klea, Sram Radim, Zmirou Denis, Lebret Erik, Saarela Kristina, Maroni Marco.

5. Chemical Elements on European PM2.5: The Elemental Analyses Study of EXPOLIS — $154,000
Swiss National Science Foundation
1998-2001
Co-Investigators: Stern W, Basel; Jantunen Matti Helsinki; Katsouyanni Klea Athens, Sram Radim, Praha; Zmirou Denis, Grenoble; Lebret Erik; Bilthoven; Saarela Kristina, Helsinki; Maroni Marco, Milano; Ackermann-Liebrich Ursula, Basel; Braun-Fahrländer Charlotte, Basel.

6. SAPALDIA Cohort Followup Preparation Study with Basel Center Health Assessment — $313,000
Swiss National Science Foundation
2001-2004
Co-Investigators: Leuenberger Ph, Lausanne (Principal Inv of the full SAPALDIA Study I and II); Akcermann-Liebrich Ursula, Basel, Schindler Chrisitan, Basel, and SAPALDIA Team Switzerland

7. Trinational Public Health Impact Assessment of Traffic related Air Pollution — $35,000
Swiss Federal Agency of the Environment, Transport, Energy and Communication and WHO
1998-1999
Co-Investigators: Sommer H, Switzerland; Seethaler Rita, Switzerland, Filliger P Switzerland; Medina Silvia, Paris; Studnicka M, Vienna; and European Team.

8. Monetarization of the Public Health Impact of Traffic related Air Pollution in Switzerland — $36,000
Swiss Federal Agency of the Environment, Transport, Energy and Communication
1996-1997
Co-Investigators: Sommer H, Switzerland; Filliger P Switzerland; Kaiser Reinhard and Team.

PM2.5 and other pollutants in the SAPALDIA and SCARPOL Cities — $62,000
Swiss Agency for the Environment
1998-2001
Co-Investigators: NK (SAPALDIA) was Co-Principal with Braun-Fahrländer Charlotte (SCARPOL) and SAPALDIA and SCARPOL Team

The EXPOLIS Index Study on Indoor Pollutants and Personal Exposure — $280,000
The European Chemical Industry Council –CECFIC
2002-2004
Co-Investigators: Jantunen Matti, Oglesby Lucy, and EXPOLIS Group

9. Comparison of air quality, customer preferences and economic differences — $17,000

in a smoking and non-smoking Restaurant
Zurich Lung Association
2002
Co-Investigator: Brändli Otto

10. Cat ownership and sensitization to cat allergen in the European Community Respiratory Health Survey — $33,000
Swiss Academy of Medical Sciences
1998-1999
Co-Investigators: Roost Hp, Burney Peter, London, and ECRHS Team

11. Comparison of Spirometry Devices for a Multicenter Cohort Study (SAPALDIA) — $33,000
Basel Lung Association; Zurich Lung Association
1999-2000
Co-Investigators: Ackermann-Liebrich U, Leuenberger Ph, and SAPALDIA Group

12. Impact of Air Pollution on Health in the South Tyrolia county, Italy — $14,000
Tyrol Agency of the Environment
2001
Co-Investigators: none
Association of different long-term metrics of ozone exposure in Switzerland — $10,000
Swiss Agency for the Environment
1998
Co-Investigators: none

The EXPOLIS Index Study on Indoor Pollutants and Personal Exposure — $280,000
The European Chemical Industry Council – CECFIC
2002-2004
Co-Investigators: Jantunen Matti, Oglesby Lucy and EXPOLIS Group

13. Oxidative Properties of Los Angeles Particulates, The OPLAP Pilot Study. — $25,000
Southern California Environmental Health Sciences Center (SCEHSC) of NIEHS
May 2003-July 2004
Co-Investigators: Avol E, Borm P, Cho A, Frank K, Froines J, Nel A, Sioutas C.

Co-Investigator

1. DNA Module of European Community Respiratory Health Survey Basel Center and SAPALDIA Basel — $95,000
Freie Akademische Gesellschaft (Free Academic Society, Basel)
1998
Principal Investigator: Probst Hensch Nicole, and SAPALDIA Basel Team

2. The Swiss Study on Air Pollution and Lung Diseases in Adults, SAPALDIA, Mortality Follow-up — $300,000
Swiss National Science Foundation
1996-2001
Principal Investigator: Leuenberger Ph., Lausanne; and SAPALDIA Group

3. The Swiss Study on Air Pollution and Lung Diseases in Adults, SAPALDIA Cohort Study — $ 95,000
Swiss National Science Foundation, and others

1998
Principal Investigator: Leuenberger Ph., Lausanne; and SAPALDIA Group

4. The Basel Risk Assessment Study BRISKA $66,000
   Humans – Environment – Society Foundation Basel
   1998
   Principal Investigator: Braun-Fahrländer Ch; Co-investigators: Theis G, Stern WB and BRISKA Team

5. University of California Berkeley Ozone Study Subcontract: $22,000
   U.S. NIH
   1999-2003 (total grant: 1,174,000)
   Principal Investigator: Tager Ira B; Co-investigators: Balmes J, Lurman F, Holland N and Team

BIBLIOGRAPHY

PEER REVIEW

*indicates student first author

1. Braun-Fahrländer CH, **Künzli N**, Domenighetti GF, Carell CF, Ackermann-Liebrich U. Acute effects of ambient ozone on respiratory function of Swiss schoolchildren after a 10-minute heavy exercise. Pediatr Pulmono 1994; 17:169-77.
2. Leuenberger P, Schwartz J, Ackermann-Liebrich U, **Künzli N**, SAPALDIA Team. Passive smoking exposure in adults and chronic respiratory symptoms (SAPALDIA Study). Am J Respir Crit Care Med 1994; 150:1222-28 (with editorial + letter to the authors).
3. **Künzli N**, Ackermann-Liebrich U, Keller R, Perruchoud AP, Schindler CH, SAPALDIA Team. Variability of FVC and FEV1 due to technician, team, device and subject in an eight center study; three quality control studies in SAPALDIA. Eur Respir J 1995; 8:371-76.
4. **Künzli N**, Lurman F, Ngo L, Balmes J, Tager I. Reliability of life-time residential history assessment as an element of cumulative ambient ozone exposure estimates. J Exp Analys Environ Epidemiol 1996; 6(3):289-310.
5. Brändli O, Schindler CH, **Künzli N**, Keller R, Perruchoud AP, and SAPALDIA Team. Lung function in healthy never smoking adults. Thorax 1996; 51:277-83.
6. Jurvelin J, De Bortoli M, Cavallo D, Knoeppel H, **Künzli N**, Laine-Ylijoki J, Oglesby L, Saarela K, Jantunen M. Methodology and quality assurance of VOC measurements in the EXPOLIS study advances. Occup Med Rehab 1997; 3(3):27-32.
7. Ackermann-Liebrich U, Leuenberger PH, Schwartz J et al, **Künzli N**, and SAPALDIA Team. Lung function and long-term exposure to air pollutants in Switzerland. Am J Respir Crit Care Med 1997; 155(1):122-29.
8. **Künzli N**, Kaiser R, Rapp R, Sommer H, Wanner H, Ackermann-Liebrich U. Luftverschmutzung in der Schweiz - Quantifizierung gesundheitlicher effekte unter verwendung epidemiologischer Daten. [Air pollution in Switzerland. Quantifying of health effects using epidemiologic data] Schweiz Med Wochenschr 1997; 127:1361-70.

9. **Künzli N**, Braun-Fahrländer C, Rapp R, Ackermann-Liebrich U. Luftverschmutzung und epidemiologie - kausalitätskriterien der umweltepidemiologie. [Air pollution and health – causal criteria in environmental epidemiology] Schweiz Med Wochenschr 1997; 127:1334-44.

10. Martin B, Ackermann-Liebrich U, Leuenberger P, **Künzli N**, Zemp E, and SAPALDIA Team. SAPALDIA - Methods and participation in the cross-sectional part of the Swiss study on air pollution and lung disease in adults. Soz Präventivmed 1997; 42(2):67-84.

11. **Künzli N**, Lurman F, Segal M, Ngo L, Balmes J, Tager I, Association between life-time ambient ozone exposure and pulmonary function in college freshmen - Results of a Pilot Study. Environ Res 1997; 72(1):8-23.

12. **Künzli N**, Kelly T, Balmes J, Tager IB. Reproducibility of retrospective long-term assessment of outdoor time-activity patterns as an individual determinant of long-term ambient ozone exposure. Int J Epidemiol 1997; 26(6):1258-72.

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29. Oglesby L,* **Künzli N**, Monn C, Schindler C, Ackermann-Liebrich U, Leuenberger PH and SAPALDIA Team. Validity of annoyance scores to estimate long-term air pollution exposure in epidemiological studies. Am J Epidemiol 2000; 152:75-83.

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32. Junker M, Kasper M, Röösli M, Camenzind M, **Künzli N**, Monn C, Theis G, Braun-Fahrländer C. Airborne particle number profiles, particle mass distributions and particle-bound PAH concentrations within the city environment of Basel: an assessment as part of the BRISKA project. Atmos Environ 2000; 34:3171-81.

33. Oglesby L,* Rotko T, Krütli P, Boudet C, Kruize H, Jantunen MJ, and **Künzli N**. Personal exposure assessment studies may suffer from exposure relevant selection bias. J Expo Anal Environ Epidemiol 2000; 10:251-66.

34. Röösli M,* Braun-Fahrländer C, **Künzli N**, Oglesby L, Theis G, Camenzind M, Mathys P, Staehelin J. Spatial variability of different fractions of particulate matter within an urban environment and between urban and rural sites. J Air Waste Manage Assoc 2000; 50:1115-24.

35. Oglesby L,* **Künzli N**, Röösli M, Braun-Fahrländer C, Mathys P, Stern W, Jantunen M, Kousa A. Validity of ambient levels of fine particles as surrogate for personal exposure to outdoor air pollution. J Air Waste Manage Assoc 2000; 50:1251-61.

36. Rotko T, Oglesby L, **Künzli N**, Jantunen MJ. Population sampling in European air pollution exposure study, EXPOLIS: comparisons between cities and representatives of the samples. J Expo Anal Environ Epidemiol 2000; 10(4):355-64.

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51. Götschi Th,* Oglesby L, Mathys P, Monn Ch, Manalis N, Koistinen K, Jantunen M, Hänninen O, Polanska L, **Künzli N**. Comparison of Black Smoke and $PM_{2.5}$ Levels in Indoor and Outdoor Environments of Four European Cities. Environ Sci Technol, 2002; 36(6):67-73.
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Editorial positions

Editor in Chief:

Journal of Stochastic Environmental Research & Risk Assessment

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Advances in Water Resources
Environmental and Ecological Statistics

Research Activities

- Multi-disciplinary integration theories in uncertain environments (coupled human and natural systems, conceptual blending and knowledge synthesis techniques)
- Theoretical and computational modelling of natural systems
- Environmental health and human exposure assessment
- Modern geostatistics and spatiotemporal statistics
- Fluid dynamics
- Flow and transport processes in subsurface systems
- Advanced stochastic PDE techniques (diagrammatic, space transformation, and differential geometry techniques)
- Natural hierarchy of scales and upscaling analysis
- Stochastic logic and random field theory
- Atmospheric pollution monitoring and control
- Medical geography
- Spatiotemporal epidemiology
- Toxicokinetics models
- Decision analysis and risk assessment

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