Cumulative Air Quality Effects Assessment

Jeff N. Rumrill and Larry W. Canter

Federal agencies in the United States are required to consider the cumulative effects (CEs) of their activities combined with those of others. This requirement has placed a burden on the environmental impact assessment (EIA) process due to the technical complexities involved with cumulative effects assessment (CEA). This article presents a CEA methodology that reduces some of the inherent complexities by focusing on the cumulative influence to a single environmental resource, ambient air quality. An eight-step method is presented herein as a tool for the assessment of cumulative air quality effects. Procedures for accomplishment of the more difficult steps, such as the determination of what activities to include in the evaluation and how to determine the significance of a cumulative effect, are also included.

BACKGROUND

The National Environmental Policy Act (NEPA) (Public Law. 91-190), in the United States, mandates that federal agencies evaluate and document the environmental impacts of their actions in order to publicly disclose those impacts and, more importantly, to provide decision makers with high-quality information so that they can incorporate that information, and its significance, into the decision-making process. One of the requirements specified by the Council on Environmental Quality (CEQ) regulations is that federal agencies consider the cumulative effects (CEs) of their activities combined with the activities of others.[1] Analysis of such CEs within NEPA documents is a significant challenge to environmental professionals.[2] The challenge stems from the technical complexity of the cumulative effects assessment

***Jeff N. Rumrill**, Ph.D., is a major in the U.S. Air Force assigned as an environmental management instructor, Civil Engineer and Services School, Air Force Institute of Technology, Wright-Patterson AFB, Ohio. **Larry W. Canter**, Ph.D., is a professor at the University of Oklahoma, director of the Environmental and Ground Water Institute, and Sun Company Chair of Ground Water Hydrology. The views expressed in this article are those of the authors and do not reflect the official policy or position of the U.S. Air Force, Department of Defense, or the U.S. Government.*

(CEA) and confusion, or lack of agreement, on appropriate term definitions and scope of analysis.

The CEQ defines cumulative impacts (effects) as:

> . . . The impact on the environment which results from the incremental impact of the action when added to other past, present, and reasonably foreseeable future actions regardless of what agency (Federal or non-Federal) or person undertakes such actions. Cumulative impacts can result from individually minor but collectively significant actions taking place over a period of time (40 CFR Sect. 1508.7).[3]

Cumulative effects analysis is essential to the development of appropriate management strategies for the environmental consequences of human activities. Thus, the purpose of this type of analysis is to ensure that federal decisions incorporate the full range of consequences of actions.[4] This article describes an approach for such an analysis and is presented in five main parts. The first summarizes an overall eight-step assessment method for cumulative air quality effects. The focus on an individual resource (air quality) was selected to reduce the analysis to a manageable level for purposes of this illustration. Simultaneous evaluation of every cumulative effect resulting from an activity can be overwhelming. Of all the possible resources to evaluate, air quality was selected due to the relatively consistent air quality analysis approach taken in individual activity impact assessments, as well as the high profile of air quality effects resulting from U.S. Air Force activities (for which this method was originally intended).

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The remaining sections relate to the accomplishment of four specific steps within the overall method where previously existing guidance was unavailable. These include a procedure for determining reasonably foreseeable future actions (RFFAs), quantification models suited to air quality CEA, a conceptual approach for CE significance determination, and opportunities for CE mitigation.

This method for the analysis of cumulative air quality effects results from research consisting of (1) a review of recent environmental impact statements (EISs) and environmental assessments (EAs) to identify and evaluate the techniques used to assess cumulative and air quality impacts (focused on a review of 27 EISs and EAs completed by the U.S. Air Force); (2) a review and analysis of approximately 40 federal and state court cases heard in the United States where rulings were made relevant to the legal interpretation of what actions are defined as RFFAs; (3) a review of air quality impact quantification methods and selection of methods that are best suited to CEA; (4) the development of a conceptual approach for significance determination for cumulative air quality effects and associated opportunities for mitigation; and (5) method testing to demonstrate how the environmental planner can use the developed procedures to assess effects with varying degrees of accuracy and levels of detail depending on information availability and concern about air quality in the study area. The details relative to this research can be found in Rumrill's work.[5]

THE CUMULATIVE AIR QUALITY EFFECTS ASSESSMENT METHOD

Exhibit 1 presents eight steps in the cumulative air quality effects assessment (CAQEA) method. The CEA process can be accomplished either as an integral part of the environmental impact assessment (EIA) process applied to a specific project, or it can be accomplished as a separate study for a general area and time frame and incorporated by reference into individual project assessments. Regardless of which approach is taken, the eight steps presented in Exhibit 1 are applicable.

Exhibit 1. Steps in the CAQEA Method

Step	Comments
1. Select definition of CE to be applied to the analysis.	CEQ definition is recommended.
2. Determine spatial and temporal boundaries.	Consider physical airshed and political regions (spatial) and forecasting capability limitations (temporal).
3. Determine past, present, and reasonably foreseeable future actions (RFFAs) to be included in the analysis.	See section of this paper addressing RFFAs.
4. Determine background ambient air pollutant concentrations and obtain applicable standards.	Regional air quality monitoring station data is recommended. Standards can include ambient air quality standards and emission standards.
5. Develop quantitative and qualitative emission data estimates for the actions determined in Step 3.	Develop an emission inventory for the project and other actions in the spatial and temporal boundaries.
6. Determine quantitative and qualitative change to background air quality (determined in Step 4) resulting from evaluated actions.	Emissions inventories and quantitative air quality modeling can be useful. See section of this paper summarizing three types of models.
7. Evaluate the CE significance in context with the air quality impacts of the action originally generating the NEPA requirement and incorporate that significance into the assessment.	Necessary to properly determine impact significance. See section of this paper which describes a scoring method for CE significance determination.
8. Include mitigation opportunities for CEs when discussing specific action impact mitigation.	Additional mitigation opportunities/options are available when other activities are considered. See section of this paper that highlights these opportunities.

The steps of the CAQEA method begin with the selection of a definition of cumulative effects to apply throughout the analysis. There are several definitions available and while each may be valid, the uniform employment of a single definition reduces the likelihood of inconsistencies in a specific CEA study.

Step 2, the determination of spatial and temporal boundaries, must include consideration of practical limitations such as time, funding, political influence, and the predictive capabilities of the models employed. A reasonable beginning to boundary selection is the spatial and temporal range of the predicted effects of the proposal originating the requirement of the CEA. In this case, the boundaries could be based on the anticipated dispersion area for the emitted pollutants over a time period where those effects could be reasonably monitored or modeled. These boundaries can then be adjusted based on the additional, reasonably foreseeable, or connected actions that are addressed with the original proposal, as well as other factors related to information availability and the increasing uncertainty of predictions associated with considerations further into the future.

In Step 3, the activities to evaluate are selected. The selection of the activities to evaluate firmly defines the context and extent, and thus influences the contextual significance, of the analysis. The importance of this step indicates that it deserves noteworthy attention. Accordingly, a procedure is included herein specifically for the delineation of appropriate future activities to include in a CEA.

Step 2, the determination of spatial and temporal boundaries, must include consideration of practical limitations such as time, funding, political influence, and the predictive capabilities of the models employed.

Step 4, the determination of background ambient pollutant concentrations and related regulatory standards, establishes the baseline conditions against which the subsequent CEs are to be evaluated. This information should be obtained for each pollutant addressed in the evaluation.

The fifth step requires the development of an air emission inventory, relative to the pollutants of concern, for the identified activities within the temporal and spatial boundaries. This information can be obtained from such sources as emission inventory reports and state emission summary reports, and/or developed independently from available emission estimating procedures.

In Step 6, the assessor must determine the quantitative and qualitative change to the air quality resulting from the cumulative influence of the evaluated activities. This can be done either through direct comparison of the preexisting and resultant emission levels or through modeling techniques used to approximate changes to ambient concentrations. Regardless of which method is used, the assessor should include a discussion of the uncertainty in each of the predictive methods employed so as not to lend undue weight to the value of the forecasted results.

The seventh step is the determination of the cumulative significance resulting from the evaluated future proposal(s) within the context of the spatial and temporal time frame of the analysis and the associated activities. Effects intensity ratings and a scoring matrix for combining various legal, political, and health considerations associated with effects significance are included herein. This provides the basis for a standardized significance determination system with results that can be incorporated into multiple future environmental analysis studies.

Finally, Step 8 addresses opportunities for cumulative effects mitigation. The intent of this step is to expand mitigation options beyond consideration of only the original proposal to encompass multiple future activities. This approach promotes improved cost effectiveness in the expenditure of limited mitigation resources.

ADDRESSING THE FUTURE (STEP 3 OF CAQEA)

Step 3 of the CAQEA method involves the selection of past, present, and RFFAs to include in the analysis. The influence of past and present activities can be adequately approximated through observation of the current ambient pollutant concentrations. Adequate discussion of the future is, however, more complex.

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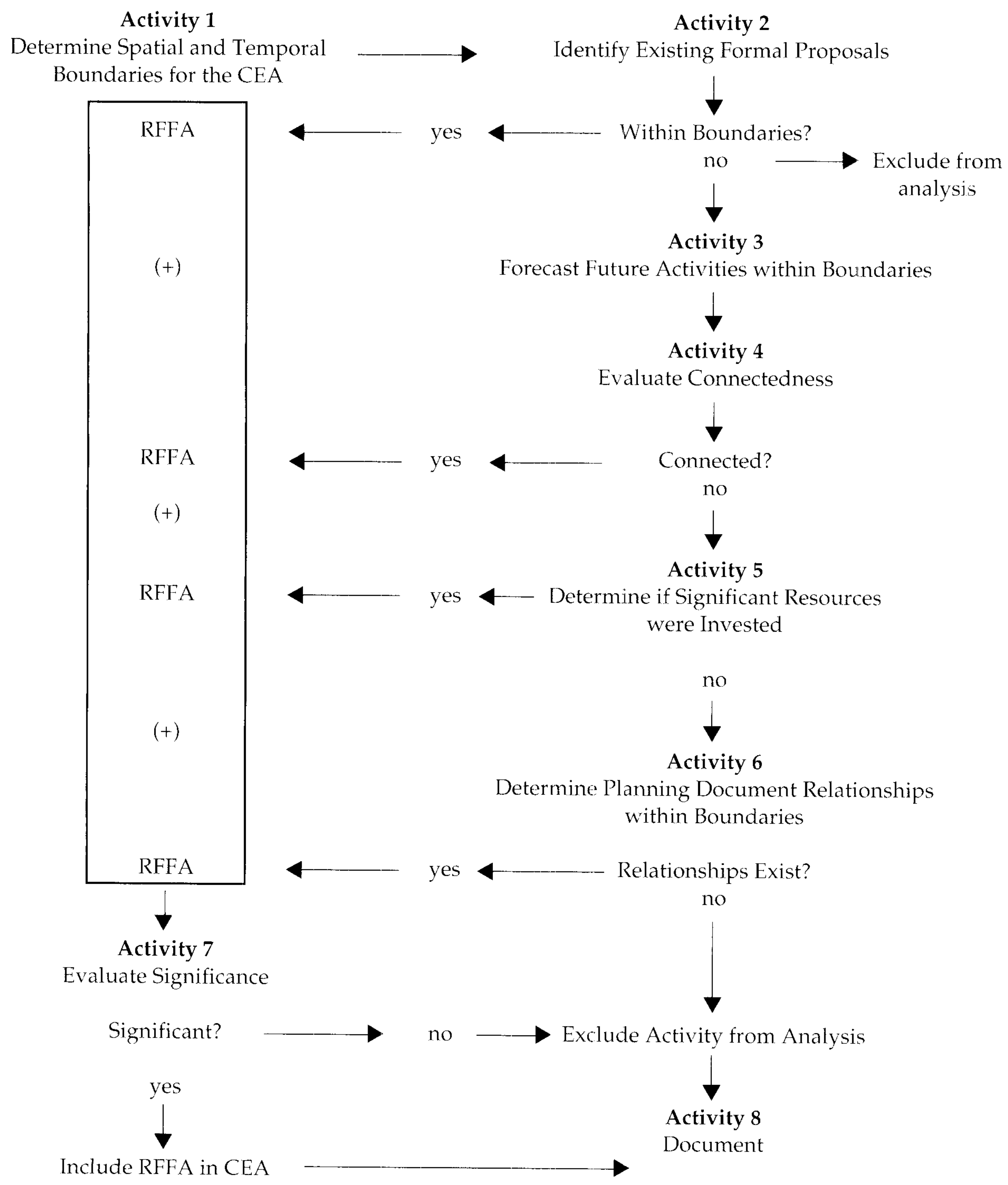
According to the CEQ, adequate consideration of CEs must involve an analysis of the proposed action in view of past, present, and RFFAs. One key difficulty in this analysis is the determination of what activities should be considered as RFFAs. For over two decades, the answer to the question—when does a contemplated action become "reasonably foreseeable?"—has been argued in the U.S. courts. In fact, over 40 court cases have involved CEs, and many of them hinged on the determination of RFFAs.

A review of the court cases addressing the issue of RFFA determination provided insight into the nature of the problem and offered the opportunity to develop improved procedures to avoid future litigation. In *Considering Cumulative Effects Under the National Environmental Policy Act*, the CEQ presents a discussion of some of the issues to consider when identifying future actions. The recommendations made include a review of pertinent planning documents and "reasonable forecasting." Additionally, guidance is provided to allow for exclusion of proposals that (1) are outside the temporal and spatial boundaries, (2) will not affect the resources that are the subject of the analysis, or (3) could be considered arbitrary.[6] This document does not, however, provide a pragmatic framework or procedure for the identification of RFFAs. Rather, it states that analysts should develop their own guidelines and that the assumptions or basis used to forecast future activities should be discussed in the assessment.[7]

Based on the issues addressed in the reviewed cases—and with the precondition that when the courts contradict, a conservative approach dictates that an action should be included—evaluation of future activities with respect to the eight activities shown in **Exhibit 2** should minimize court challenges on the basis of failure to include future actions in a CEA. Brief comments on each of these eight activities are as follows:[8]

Activity 1—Determine reasonable temporal and spatial boundaries with respect to the availability of information, the realm of influence or control exerted by the subject agency, and the nature of the

Exhibit 2. Eight-Activity RFFA Decision Flowchart



environmental impacts of the original project. This activity coincides with Step 2 in the CAQEA method.

Activity 2—Within those boundaries, if the agency has additional formal proposals, approved or pending approval, relating to the accomplishment of any agency goal or objective, include them as RFFAs.

Activity 3—Conduct forecasting to determine possible, plausible, conceivable, and probable future activities both internal and external to the subject agency that fall within the temporal and spatial boundaries established in Activity 1. This is not intended to encompass every speculative possibility. Evidence to support the likelihood of each forecasted activity should be included in the analysis. For example, a forecasted housing development informal proposal could be supported by population growth projections and existing dwelling unit occupancy statistics that demonstrate the need for the development. Other supporting evidence could be provided through a discussion of any linkages to formal proposals identified in Activity 2.

Activity 4—Evaluate the list from Activity 3 to determine possible connectedness to the original proposal. Consider (a) geographic relationships, (b) common resources or environmental media impacted, and (c) causal links or catalytic effects between the original and forecasted activities. If connections can be determined, consider those activities as RFFAs.

Conduct forecasting to determine possible, plausible, conceivable, and probable future activities both internal and external to the subject agency that fall within the temporal and spatial boundaries established in Activity 1.

Activity 5—Again evaluating the list of proposals from Activity 3, determine if "significant amounts" of effort, resources, time, and/or money have been invested into planning the future activities. If so, consider the activities as RFFAs.

Activity 6—Within the area of concern (spatial boundary), determine the existence of any planning documents, such as city or regional development plans, historic preservation plans, district plans, or environmental use plans, that relate future activities and the original proposal through a common goal or objective. If such relationships can be determined, consider the related future activities as RFFAs.

Activity 7—Evaluate the significance of each activity thus far categorized as reasonably foreseeable. Include consideration of (a) whether or not obtaining useful information, or relevant prediction models, related to the environmental impacts of the activity is possible at this point in time; and (b) whether or not the information obtained will have any influence on the original project alternative evaluation and selection. This determination is not intended to evaluate the significance of the project effects on the environment. It is a scoping exercise to ensure that the RFFA list is limited to only those activities with measurable effects on the resource or media of concern relevant to the scale of the analysis. If

RFFAs are determined to be "insignificant" or impossible to evaluate at this time, exclude them from the list. The remaining RFFAs should be included in the CEA for the original project.

Activity 8—Document the evaluation of RFFAs and include that documentation in the final impact study report, probably as an appendix.

The order of the activities is intended to demonstrate a logical flow for the decision-making process. This does not mean, for example, that Activity 1 must be completed prior to exerting effort toward Activity 2. Nor is it intended to imply that, once completed, the results of an activity cannot be revised. The importance resides in the inclusion of each issue for RFFA determination regardless of the order of activity completion or number of iterations.

Following these eight activities through the decision process illustrated in Exhibit 2 will ensure that most, if not all, relevant projects are included. It will demonstrate to the decision makers, regulators, and if necessary, the courts that a concerted effort was made to comply with the spirit of the legislation and CEQ regulations and provide the pertinent information needed to make responsible decisions with respect to the protection of the environment.

The first requirement of air quality effects quantification is the procurement, or development, of a comprehensive emissions inventory.

APPROPRIATE QUANTIFICATION MODELS (STEP 6 OF CAQEA)

Step 6 of the CAQEA method requires that the assessor determine the cumulative quantitative and qualitative changes to the air quality within the defined temporal and spatial boundaries. This section establishes the air quality quantification needs as related to CEA and then presents the modeling tools which meet those needs.

The first requirement of air quality effects quantification is the procurement, or development, of a comprehensive emissions inventory. This includes the emissions from mobile, as well as stationary, sources and should include the construction, operation, and possibly even demolition phases of the existing and future activities within the defined boundaries. Evaluation of the changes in specific pollutant emission levels over time provides valuable quantitative information. The influence of specific activities can be represented as a change to the total annual tonnage of an emitted pollutant, as well as a percentage increase over the previous or existing levels. This type of analysis may be sufficient to determine the cumulative change; however, where existing ambient concentration data are available, air quality modeling can provide additional, contextual; information about current and future conditions.

Air quality modeling provides a scientific means of relating source emissions and the atmospheric processes discovered through meteorological observation to provide estimates of resultant ambient air quality.[4] Modeling is often required as part of construction and operation permit processes to demonstrate that ambient air quality standards will be attained. With regard to future activities, modeling is about the only method available for determining air quality effects.[10] However, because numerous models are available, selection of appropriate models for specified conditions is necessary.[11]

Qualitative comparison selections can be made based on the identification of decision criteria (or desirable attributes) and display of the candidate methods (e.g., model classes) in conjunction with those criteria (or attributes). Once this evaluation has been conducted for each candidate method, the "best choice" can be identified based on the comparison results and sound professional judgment.[12]

Inclusion of RFFAs in the analysis introduces the requirement to forecast anticipated, but not guaranteed, future effects. Defining CEA to include these future planned activities infers the uncertainty, and possible limitations, of the data available on the anticipated air quality effects. Thus, the following six decision criteria (or desirable attributes) for the qualitative comparison approach for model selection were developed in part based on these inherent uncertainties:[13]

Through a qualitative comparison approach, the six decision criteria (or desirable attributes) were applied to over 20 model types, or classifications commonly available for use in air quality analysis.

1. The model employed should be simple to use and not resource intensive.
2. The model should provide acceptably accurate results without extensive, detailed input data.
3. The model should allow consideration of the relation of activity emissions to established emission and/or ambient air quality standards.
4. The model should be usable for forecasting future air quality concentrations and/or activity emission levels.
5. The model should be applicable to both local and regional air quality and/or emission level calculations.
6. The model should focus on the prediction and assessment of long-term (annual) average effects rather than short-term (hourly) worst-case effects.

Through a qualitative comparison approach, the six decision criteria (or desirable attributes) were applied to over 20 model types, or classifications commonly available for use in air quality analysis.[14] The results of the qualitative comparison indicated that three model types fully meet the six criteria for application to CEA. They are simple area source, rollback, and box. The multibox model type is only restricted from this list due to its complexity in calculation and resource, or data, requirements. Given the appropriate situation, it too could be applied within the CAQEA method.

Simple Area Source Models

Simple area source models are useful for screening level analyses of atmospheric pollutant concentrations in urban areas. Primarily, this type of evaluation is based on emission source strength patterns within the area (spatial boundaries) and average wind speed and direction.

Gifford and Hanna presented a simple area source equation in 1973 given by:

$$C = \frac{c_i Q}{U}$$

where

C = annual average air pollution concentration;
Q = source strength per unit area;
U = annual average wind speed; and
c_i = parameter weakly dependent on city size.

One expression for calculating c_i is:

$$c_i = \sqrt{2/\pi}\; X^{1-b}[a(1-b)]^{-1}$$

where

X = distance from receptor to the upwind edge of the area source; and
a,b = constants defined by the vertical atmospheric diffusion length $\sigma_z = aX^b$.[15]

Rollback models relate air quality forecasting to historical ambient air quality data and emission growth trends.

Rollback Models

Rollback models relate air quality forecasting to historical ambient air quality data and emission growth trends. This type of model has been used in air quality management as an estimation method for determining emissions reductions required to comply with ambient air quality standards. The simple form of the model estimates future pollutant concentrations using the equation :

$$C_i = B + kE_i$$

where

C_i = projected concentration;
B = background concentration;
E_i = future emissions estimate;
k = a proportionality factor that incorporates meteorology, source distribution, and other source-receptor variances.

One expression for calculating k, based on present emissions and observed maximum pollutant concentrations, is given as:

$$k = \frac{C_p - B}{E_p}$$

where

C_p = maximum pollutant concentration; and

E_p = present emissions.[16]

While the method is titled "rollback," the temporal direction in which the model is applied is irrelevant. The model can be used to project future emissions based on present ambient concentrations or to determine historical emission growth rates based on present ambient concentrations and known past ambient concentrations. This method does, however, require greater knowledge about the subject area (spatial boundaries) than the simple area source models. Accurate data relative to the "maximum pollutant concentration" is necessary to ensure that the appropriate projections can be determined for future scenarios.

Box models share attributes with simple area source and rollback models in that the format of the equations allow ease of information assimilation.

Box Models

The simple form of the box model is mathematically expressed by the equation:

$$C = \frac{Qt}{xyz}$$

where

C = average concentration of pollutant (< 20 μm diameter if modeling particulates), μg/m^3;
Q = emission rate of pollutant (< 20 μm diameter if modeling particulates) from emission source, μg/sec;
t = time period for which uniform mixing assumption is valid, sec;
x = downwind dimension of box, m;
y = crosswind dimension of box, m; and
z = vertical dimension of box, m.

The dimensions of the box are determined based on average wind speed and terrain for x; average wind speed, source configuration, and terrain for y; and limiting inversion height and terrain for z. Box models can be used for single and multiple point, line, and area sources or combinations of these source types.[17]

Box models share attributes with simple area source and rollback models in that the format of the equations allow ease of information assimilation. All three model classes employ generalizations of complex meteorological and emission source conditions to minimize errors in application resulting from numerous varying, or even inaccurate, estimations of complex conditions. An additional attractive feature of the box model is the ease of presenting the results spatially. Since the model directly incorporates the dimensions of the evaluated area, decision makers are provided with insight as to the predicted effects relative to specific geographic boundaries or landmarks. The box model also provides the opportunity to address effects over arbitrarily defined regions or those based on meteorological influence on the emitted pollutants.

The multibox model expands the concept of the box model by dividing the evaluated volume of air, or airshed, into two-dimensional or three-dimensional arrays of boxes. Individual box properties—such as inversion height, wind speed, and volume—can vary between boxes. The modeled pollutants travel between adjacent boxes through advective forces only. No diffusion across box boundaries is permitted in this method. Multibox models have the advantage over single box models in that time variation of inversion heights can be incorporated, and the multiple box dimensions can be selected to conform to local topography. The negative aspects of the multibox model include failure to address vertical diffusion, and excessive calculation requirements. However, modifications have been incorporated into the multibox model for specific applications to include vertical pollutant concentration distribution.[18]

Once the CEs have been estimated, Step 7 requires the assessor to evaluate the significance of those predicted effects.

Additional Observations

The applicability of multimedia transport and fate model structures and prepackaged software, as well as the treatment of uncertainty in the application of models, was also considered. The results can be summarized into five concluding points as to the applicability of existing classes of air quality models to air quality CE quantification:

1. There are existing models that can be applied or adapted to air quality CEA. They include the simple area source, rollback, and box models. There are no currently available physical models suitable to air quality CEA.
2. Most available software applications are too specific or too detailed to be of use in air quality CEA since the input data estimations may be too difficult or even impossible to obtain or may result in fluctuations to model uncertainty. This severely limits the comparative study value of the predicted CEs.
3. In accordance with the USEPA requirements for approval of air quality models, and to lend credibility to the predicted results, any air quality CE quantification model should be validated or calibrated in accordance with the USEPA guidelines.[19]
4. Discussion of the CE quantification model uncertainty or error factor within the study report will provide the decision maker with a sense of the validity of the predicted results.
5. And, once developed, appropriate CE quantification models can be integrated into a multimedia CEA executive protocol similar to that of the multimedia pollutant transport and fate modeling techniques.[20]

SIGNIFICANCE DETERMINATION FOR AIR QUALITY CEs (STEP 7 OF CAQEA)

Once the CEs have been estimated, Step 7 requires the assessor to evaluate the significance of those predicted effects. Determination of cumulative effects significance differs from that of project-level impact significance. In a CEA, multiple activities must be considered. The timing and location of these proposals can influence the spatial and temporal boundaries considered, and the resultant significance determinations. Whereas a project-level assessment considers the environmental consequences of a single action on its local surroundings, a CEA needs to address the long-term significance of the original proposal and other proposals connected either by proponent agency planning, geographic proximity, or affected resource. A CEA addresses not only the ability of

Exhibit 3. Significance Determination Factors in the CAQEA Method

Pollutant Emissions
- % change in total area emission level of a pollutant
- timing, duration, and rate of emission level change*
- comparison of emission rates to emission permit or rule limitations* (% of sources not meeting requirements)

Ambient Air Quality Standards
- change in ambient concentration*
- timing, duration, and rate of ambient concentration change*
- violation of standards* (federal, state, local)
- influence on air pollution episodes
- influence on current area classification (attainment/nonattainment, maintenance area, prevention of significant deterioration (PSD) area)

Public Perception
- level of concern expressed by public over air quality issues*

Secondary/Indirect/Synergistic Effects
- influence on photochemical pollution level (PPL) potential
- influence on VOC/NO_x ratio
- influence on stratospheric ozone
- influence on global warming
- spatial (transboundary) transport of pollutants (national, global)
- influence on SO_2 & NO_x contribution to acid deposition potential

Human Health
- level of carcinogenic effect
- level of noncarcinogenic effect

Mitigation
- timing/focus of mitigation efforts vs. timing/focus of effects

*Similar to factors typically addressed in project-level EIA.

Note: Sensitive receptors are not listed as a category for inclusion; however, they are addressed. A regional-level analysis will typically always have some mix of sensitive receptors (e.g., children, hospital patients, elderly, specific crops, terrestrial vegetation, valued structures or monuments, etc.) that could be affected. Direct consideration of sensitive receptors should be accomplished at the individual project assessment level where local plume concentrations and dimensions can be evaluated. At this level of analysis, consideration of sensitive receptors is included within the considerations of ambient air quality standards and secondary/indirect/synergistic effects.

the environment to assimilate the impacts of the original proposal, but also its influence on development sustainability.

Significance Determination Factors

Since there was no available method for addressing the significance of cumulative air quality effects, relevant air quality issues were considered, along with the assistance of a group of eight environmental professionals with experience in air quality and CEA issues, in the development of a list of factors for application to a systematic significance determination procedure. The result is a list of 18 factors (see Exhibit 3) determined to be appropriate for consideration in air quality cumulative effect significance determinations.[21]

The factors were categorized into six functional groups; however, some issues overlap multiple categories. For example, the combination of sulfur dioxide and suspended particulate matter can result in a synergistic adverse health effect. Therefore, it could theoretically fall under two categories: secondary/indirect/synergistic effects, and health effects. Professional judgment must dictate where it is applied for each assessment.

The factors were categorized into six functional groups; however, some issues overlap multiple categories.

As indicated in Exhibit 3, only 6 of the 18 factors determined to be of relevance in a cumulative assessment of air quality are typically addressed in project-level assessments. Project specific assessments will typically address the change in emission level, but only based on the contribution of a single proposal. Comparison to permit rules or limitations is also common; however, the study area trends toward compliance may not be addressed. Under the ambient concentration category, it is common to find discussions relating the proposal contributions to ambient levels and comparisons to standards. Also, project-level impact studies usually include public concern relative to air quality issues. The remaining issues presented as being important to a cumulative analysis are unique to the holistic evaluation goals of a human community, regional, or larger-level analysis.

Significance Scoring Procedure

Once the factors in Exhibit 3 have been reviewed as to their relevance for a specific CEA study, the next step is to actually apply them to the available air quality cumulative effects data. Importance weights should be assigned to each factor corresponding to an expert opinion-derived level of importance (e.g., high importance = 3, medium importance = 2, low importance = 1). Air quality effects resulting from the combination of all activities in the study area should then be rated as to the intensity of their influence on each factor. Note that some factors may need to be rated for individual pollutants or spatial boundary conditions (e.g., local, regional, national, etc.) to complete the analysis. Recommendations corresponding to three levels of impact intensity for the 18 factors are presented in **Exhibit 4**.

Next, the intensity rating for each factor is multiplied by the assigned importance weight. The result is a "weighted effect" for that individual

Exhibit 4. Impact Intensity Rating Recommendations

Cumulative Impact Intensity

Factor	High (3)	Moderate (2)	Low (1)
Pollutant Emissions			
- % change in emission level	10% or greater increase	5–9% increase	< 5% increase
- timing, duration, and rate of change	occurs early in study period, > 5 years duration, high rate of increase	occurs midway through study period, 1–5 years duration, moderate rate of increase	occurs late in study period, < 1 year duration, slow rate of increase
- comparison to emission limitations (% noncompliance)	10% or greater	5–9%	< 5%
Ambient Air Quality Standards			
- change in ambient concentration	> 5% increase	1–5% increase	< 1% increase
- timing, duration, and rate of change	occurs early in study period, > 5 years duration, high rate of increase	occurs midway through study period, 1–5 years duration, moderate rate of increase	occurs late in study period, < 1 year duration, slow rate of increase
- violation of standards	cause new violation	impairs plans to mitigate existing violation	small contribution to existing violation
- influence on air pollution episodes	new occurrence where none observed before or large increase in existing number of episodes	moderate increase in existing episode frequency or required level of response	small increase in existing episode frequency or required level of response
- influence on current area classification	exceeds classification based limits	classification based limits reached	limits future development
Public Perception			
- level of public concern	high level of concern	some concern	little concern
Secondary/Indirect/Synergistic Effects			
- influence on PPL potential	10% or greater increase in precursor emissions	5–9% increase in precursor emissions	< 5% increase in precursor emissions
- influence on VOC/NO_x ratio	10% or greater increase to limiting pollutant or change of limiting pollutant	5–9% increase to limiting pollutant	< 5% increase to limiting pollutant
- influence on stratospheric ozone	large increase in ODC emissions	moderate increase in ODC emissions	small increase in ODC emissions
- influence on global warming	large increase in precursor emissions	moderate increase in precursor emissions	small increase in precursor emissions
- spatial (transboundary) transport	large contribution to downwind area concentration	moderate contribution to downwind area concentration	small contribution to downwind area concentration
- influence on acid deposition potential	large increase in precursor emissions	moderate increase in precursor emissions	small increase in precursor emissions
Human Health			
- level of carcinogenic effect	known human carcinogen	probable human carcinogen	possible human carcinogen
- level of noncarcinogenic effect (dose response relationships, comparison to thresholds, synergisms, etc.)	Air Toxics - concentration above MAAC (or TLV/1000) Others - high likelihood of adverse effect	Air Toxics -concentration at MAAC (or TLV/1000) Others - moderate likelihood of adverse effect	Air Toxics - measurable conc. below MAAC (or TLV/1000) Others - low but identifiable possibility of adverse effect
Mitigation			
- timing/focus of mitigation vs. timing/focus of effects	allows for long-term (>5 years) continuance of mitigable effect	allows for continuance of mitigable effect for 1–5 years	allows for continuance of mitigable effect for less than one year

ODC = Ozone Depleting Chemical, MAAC = Maximum Allowable Ambient Concentration, TLV = Threshold Limit Value factor. Once all "weighted effects" are determined, they are added to yield a single score. The possible range of scores for a single pollutant is from 0 to 3 times the sum of the importance weights. Based on this range, the significance of the corresponding cumulative air quality effect can be ascertained. The available range of values could be divided into the following groupings:

0–33 percent of the range maximum (low significance or nonsignificant);
34–66 percent of the range maximum (moderate significance); and
67–100 percent of the range maximum (high significance).

Scientific uncertainty is associated with multiple activities in the CEA process.

Assessments resulting in low "weighted effect" scores (0 to 33 percent) can easily be termed as nonsignificant. Where a score is determined to be in the high range (67 to 100 percent), the assessment should clearly state that a significant adverse effect is predicted. However, where assessments result in moderate range scores (34 to 66 percent), professional judgment must be used in applying specific labels. Combined consideration of the cumulative effect with the direct effects related to the proposal originally generating the requirement for the NEPA process may sway the decision. Additionally, the level of uncertainty in the predictive techniques should be considered in determining the score's interpretation.

Beneficial effects are rated in the scoring matrix in combination with the "no effect" condition (intensity rating = 0) to eliminate the potential for a beneficial effect to mathematically "cancel" an adverse effect. Beneficial effects should, however, be considered as a complementary issue. Also, severely adverse effects may be muted by the limitations of the scoring system. To ensure that the contributions of beneficial and severely adverse effects are not masked by the analysis matrix, a short discussion of these effects should be included along with the composite quantitative rating. If several composite ratings are developed due to multiple boundary conditions, or several pollutant analyses, each should be presented and discussed.

Scientific uncertainty is associated with multiple activities in the CEA process. When assessing air quality effects, uncertainty can be found in the estimation techniques used to determine source emission strength, and models for predicting dispersion characteristics and ambient concentrations. Potential error related to source emission estimates stems from the prediction of the actual future activity. Actual conditions can, and typically do, vary from the average data. Inherent assumptions in the dispersion models introduce error as mistakes can appear in input data. Model validation or calibration techniques can be employed to minimize this source of uncertainty. Therefore, the recommended format for handling uncertainty in the CAQEA method is the preparation of an uncertainty report (the report can be included as an appendix in the impact study document). Once the uncertainties from all predictive techniques are combined, relative uncertainties can be determined and decisions regarding additional studies or activity modifications can then be made.

AIR QUALITY EFFECTS MITIGATION (STEP 8 OF CAQEA)

The final step of the CAQEA method (Step 8) offers the opportunity to consider mitigation options beyond the original proposed action. Mitigation measures for reducing air pollutant emissions from specific activities are commonly available. When considering activities cumulatively, within the defined spatial and temporal boundaries, additional mitigation opportunities may arise. For example, evaluation of mitigation options for a group of activities affecting the same environmental resource, such as air quality, allows the assessor to select which activities would provide the greatest emission reductions at the lowest cost. To illustrate, it may be advantageous to defer mitigation for a project planned for year two, and later include additional mitigation measures on a project scheduled for year five. Of course, some pollution control equipment may be legally required for a project regardless of other opportunities.

However, this enhanced mitigation opportunity or flexibility should not be used unconditionally. Once it is determined that some type of cumulatively significant adverse air quality effect exists as a result of the area activities, the following considerations or requirements can be applied: (1) perform a systematic analysis of the pollutant contributions; (2) conduct a legal review of the proposed activities; (3) identify available mitigation or pollution prevention measures; (4) determine the cost of each mitigation or pollution prevention measure; and (5) select mitigation option(s) and develop a financing and implementation plan.[22]

The systematic analysis refers to an evaluation of the activities that contributed to the significant effect. For example, assume it is determined that the carbon monoxide (CO) levels are significantly increased over the study period. All activities determined to contribute CO emissions during the study period would be identified and grouped by agency or private-sector development. This could include past and present activities, as well as future proposals within the established temporal boundaries. The resulting lists would provide the percentage contribution, as well as the timing of pollutant emissions for each agency or sector. Possible groups to include are federal, state, and local governments; private industry; nongovernmental organizations; and private citizens. While the NEPA process is only required for major federal agency actions, the cumulative nature of the effect requires the contextual consideration of nonfederal agency contributions.

The systematic analysis refers to an evaluation of the activities that contributed to the significant effect.

In the legal review, each activity should be evaluated to ensure that any and all legal requirements for emission limitations have been or will be met. These requirements can vary based on geographical location and the attainment status for each pollutant evaluated. If any agency, or activity, is not in compliance with legal standards, modifications to the appropriate projects must be made. Once all activities and activity proposals are in compliance with the applicable legal requirements, the significance determination and mitigation option review can be resumed.

The technical and procedural mitigation and pollution prevention opportunities are identified next. Options can include pollution control equipment, process or procedure changes, emissions trading, rescheduling of activities (to avoid short-term significant effects), or elimination of activities from the plan. Multiple options may be developed for each evaluated activity.

Determination of the cost of each mitigation, or pollution prevention option is then required. The intent is to determine the most cost effective options from those identified and provide economic justification for their incorporation into the area activity plans. This can be accomplished through an incremental cost analysis.[23] Incremental cost is the increase in cost when the output of the system is increased by one unit. It is an investigation into how the cost of additional output increases as the level of output increases. However, attaching a monetary value to some benefits of mitigation (e.g., improved air quality, public piece of mind, etc.) is subjective if at all achievable. Other considerations, such as the timing of the mitigation relative to the timing of the onset of the activity, can reduce the mitigative value. However, incremental cost analysis can provide an essential framework for efficient planning.

Once the costs and benefits of each mitigation measure have been identified, the most cost-effective option or option group can be selected for implementation.

Once the costs and benefits of each mitigation measure have been identified, the most cost-effective option or option group can be selected for implementation. It is possible that the most cost effective option will require mitigation for activities other than those of the agency primarily responsible for the significant adverse effect. Financing options may be needed to ensure that each agency or development sector pays for its fair share. Finance capital can be obtained through emission fees, construction and operation permits, or sales and property tax increases. Obviously, the success of this entire process is dependent on cooperation between the agencies and development activities involved. The alternative to cooperation, however, is to allow the effects to go unmitigated. This can lower the quality of life in the area and possibly bring the area to a point where further development is constrained.

SUMMARY AND CONCLUSIONS

The CEA process, as well as the entire EIA process, is reduced in effectiveness unless the gathered and derived information can be used in decision making. A key component in the information development is the determination of the importance of the predicted effects in context with surrounding activities. To accomplish this, it is vital to provide decision makers with significance determinations for the environmental effects resulting from the total human influence on the study area. One component of this total influence is the cumulative effect to air quality.

EIA professionals have struggled with concepts and procedures related to cumulative effects for over a decade. Multiple methods and ad hoc approaches have been applied to various proposal evaluations but none have met with widespread acceptance. Generally, this is due to the complexity of the approach and severe limitations in the range of application. By focusing this analysis to the effects on an environmental medium, air quality, rather than project type or affected ecosystem, the resulting CAQEA method can be useful for a broad range of applications.

Projections of activity proposals and their effects become increasingly more uncertain as the future time boundary is extended. Firm commitments to development activities far into the future are rare. Estimating the emissions from these uncertain future proposals can lead to inaccuracies in predicted emission levels and ambient concentrations. However, failure to include these more speculative possibilities can lead to the erroneous conclusion that emission levels will decline in the future. Regardless of the approach taken, it is important to be aware of the probability that far reaching future plans will likely be modified as the time frame draws closer. Therefore, it is vital to update the CEA study for a given geographical area on a periodic basis. Without this updated information, the value of the predicted data becomes increasingly limited as time progresses from the initial study.

The holistic method described herein can be used to evaluate all major development activities in context with the daily influences of modern society.

This article presents the development and application of one possible method for cumulative air quality effects assessment. The holistic method described herein can be used to evaluate all major development activities in context with the daily influences of modern society. Such an evaluation provides insight into the air quality sustainability of the area at current and predicted future activity levels. Assessors should not restrict themselves to following the exact order of the CAQEA method steps. The step sequences are intended to guide the assessor's thought processes, not dictate the specific chronology of the step applications. Further, it can be useful to revisit steps as new information becomes available. Additionally, a case study demonstrated the utility of the CAQEA method and associated procedures in a practical context that focused on the assumptions, information requirements, and necessary calculations and significance determinations.[24]

Finally, EIA can be a lengthy, resource-intensive process even without the added burden of CEA. The CAQEA method maximizes the utility of limited evaluation resources since the results of a single analysis can be incorporated into multiple future EAs and EISs in the study area. ❖

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