United States
Environmental Protection
Agency

Atmospheric Sciences Research
Laboratory
Research Triangle Park NC 27711

Research and Development

EPA/600/S3-85/064 Nov. 1985

Project Summary

Green River Air Quality Model Development: VALMET—A Valley Air Pollution Model

C. D. Whiteman and K. J. Allwine

Pacific Northwest Laboratory has developed an air quality model for application in valleys as part of the U.S. Environmental Protection Agency (EPA) Green River Ambient Model Assessment program. The purpose of the program is to provide air quality assessment tools applicable in the Green River Oil Shale Formation region of western Colorado, eastern Utah, and southern Wyoming. This region has the potential for large-scale growth because vast energy resources, especially oil shale, are located in the region.

Following a thorough analysis of meteorological data obtained from deep valleys of western Colorado, a modular air pollution model has been developed to simulate the transport and diffusion of pollutants released from an elevated point source in a well-defined mountain valley during the nighttime and morning transition periods. This initial version of the model, named VALMET, operates on a valley cross section at an arbitrary distance down-valley from a continuous point source. The model has been constructed to include parameterizations of the major physical processes that act to disperse pollution during these time periods.

This Project Summary was developed by EPA's Atmospheric Sciences Research Laboratory, Research Triangle Park, NC, to announce key findings of the research project that is fully documented in a separate report of the same title (see Project Report ordering information at back).

Introduction

This report documents an air quality model that was developed to predict concentrations of nonreactive pollutants arising from elevated continuous point sources that emit pollutants within well-defined deep mountain valleys. The model, termed VALMET, is intended to simulate the effects on pollutant transport and diffusion of various meteorological processes that are thought to result in worst-case pollutant concentrations. The model is run for situations when pollutants are carried in locally developed circulations within a valley when these circulations are "decoupled" from prevailing circulations above the valley. The primary physical processes included in the model follow:

Nocturnal Simulation:

- transport by down-valley drainage flows,
- plume channeling within the valley,
- enhanced horizontal and vertical diffusion due to topography,
- plume reflections off valley floor and sidewalls,
- pollutant diffusion out the top of the valley, and
- dilution of the plume due to clean air inflow from tributaries.

Post-Sunrise Simulation During Temperature Inversion Breakup Period:

- convective boundary layer growth,
- plume subsidence in the valley inversion,
- fumigation into growing convective boundary layers, and

- transport and diffusion in upslope flows over the sidewalls.

Overview

The model, while including a variety of meteorological processes, is highly parameterized so that it is simple in concept and easy to run. It is composed of 13 modules, or subroutines, arranged in such a way that an improved understanding of individual valley meteorological phenomena can be easily incorporated in future versions of the model. The modules within the model can be replaced by data if they are available. Thus, the model can be used in one of two modes. It can be used in a "screening" mode to calculate pollutant concentrations within a valley when little site-specific data are available, or it can be "calibrated" with site-specific data so that it can be used as a site-specific model.

The two-dimensional model was developed primarily to predict pollutant concentrations on the valley floor and sidewalls on a valley cross section an arbitrary distance down-valley from a pollutant source during the post-sunrise temperature inversion breakup period. It is necessary, however, to know the air pollution concentration within the valley cross section at sunrise, as an initial condition for the post-sunrise simulation. The model is therefore comprised of two parts—a nighttime part to predict concentrations on the valley cross section at sunrise, and the daytime part which predicts concentraions on the valley floor and sidewalls during the post-sunrise temperature inversion breakup period. The temperature inversion breakup period has been identified by previous investigators as a period when diurnal fumigations can produce high pollutant concentrations in valleys.

The nighttime simulation, which is applied during the steady-state period after valley temperature inversions and drainage wind systems have become established, uses a modified valley-following Gaussian plume algorithm to calculate air pollution concentrations for points on the valley floor and sidewalls. A plume rise formulation is used to simulate the initial rise of a pollutant plume at the stack due to momentum and buoyancy of the effluent. Pasquill-Gifford diffusion coefficients are modified to account for enhanced nocturnal diffusion caused by rough terrain. The Gaussian plume is also modified to allow for dilution of the plume during its down-valley transport caused by clean air flowing into the plume from valley tributaries or by converging downslope drainage flows. An integral constraint on pollutant mass is applied to ensure that pollutant mass is conserved during the plume's transport down the valley and within any valley cross section down-valley from the emission source, except for pollution diffusion out the top of the valley.

The daytime simulation uses numerical techniques that simulate the fumigation of the nocturnal plume onto the valley floor and sidewalls as a convective boundary layer grows upwards from the heated valley surfaces and as subsiding motions occur over the valley center after sunrise. The rate of growth of convective boundary layers and subsidence within the valley temperature inversion are simulated using the bulk thermodynamic model of Whiteman and McKee. This model is driven by sensible heat flux, estimated as a fraction of the solar radiation using a highly parameterized surface energy budget. The effects of such factors as snow cover, soil moisture, cloud cover, or surface albedo are not explicitly included in the model but can be incorporated into the model in the future through an expanded energy budget module. The shape of the topographic cross section of the valley is explicitly included in the model through the valley floor width and sidewall inclination angles at the valley cross section of interest. The retarding effect on temperature inversion breakup and pollution dispersion due to warm air advection above the inversion is also included in the model. Fumigated pollutants are transported from the valley cross section in upslope flows that develop within the convective boundary layers over the slopes. Pollutants are diffused through model grid elements during this transport up the slopes in the growing convective boundary layer. Pollutant concentrations decay exponentially within individual grid elements high on the sidewall as they are dropped from the simulation as the inversion top subsides below them.

The output from the nighttime simulation includes the steady-state pollutant concentration at valley floor and sidewall grid elements on the valley cross section of interest. The fraction of plume mass that has diffused out the top of the valley during the plume's travel is also an output of the model. Since an analytical formula describes the concentrations within a valley cross section, cross valley and vertical profiles of pollutant concentration can be calculated and plotted. The plume centerline concentration is an output of the model.

The primary output of the daytime simulation is the maximum 1- and 3-h average pollutant concentrations in each of the model grid elements on the valley floor and sidewalls. The time-varying 5-min average concentrations for each of the grid elements between sunrise and the time of inversion destruction is also an output of the model. In addition to these primary outputs, intermediate model outputs come from individual modules in the program. The local standard time of sunrise, the duration of the daylight period, and the solar flux on a horizontal surface at solar noon come from the solar module. The convective boundary layer height and inversion top height as a function of time come from the temperature inversion breakup module.

Twenty-seven input parameters are necessary to drive the model. These input parameters include the date, site location, topographic characteristics of the valley cross section, temperature inversion characteristics at sunrise, emission and stack characteristics, down-valley wind speed(s), atmospheric stability, grid element length, and sensible heat flux parameters. If known, the rate of warm air advection above the valley can be input. The necessary model inputs can be obtained from topographic maps, engineering information on the pollutant source, and one or more seasonal meteorological data collection campaigns in the valley of interest using tethered balloon data collection systems and/or doppler acoustic sounders.

Conclusions and Recommendations

The model shows promise for use as a planning tool and eventually as a regulatory tool. Further development, testing, and tracer evaluation of the model will be necessary before sufficient confidence can be gained to justify the model's use in a regulatory setting. The priorities for further development and testing are provided in the report. Testing of the model's sensitivity to input parameters and an initial evaluation of the model with tracer experiment data are high priority tasks. These tests will, no doubt, result in future modifications to the initial version of the model.

The authors stress that the model's ultimate utility in addressing and providing solutions to potential air pollution problems in mountain valleys will depend on the further evaluation of the model. To have confidence in model predictions, it is necessary to test the model against actual air pollution data. Several parameters in the model (A_o, k, σ_y, and σ_z) are, at present, poorly understood for mountain valleys due to a dearth of experimental data, and theoretical research should be focused on the need for information on both turbulent diffusion and valley energy budget studies. The use of full physics models may help in providing some of the answers necessary to improve the present model.

C. David Whiteman and K. Jerry Allwine are with Battelle, Pacific Northwest Laboratory, Richland, WA 99532.
***Alan H. Huber** is the EPA Project Officer (see below).*

The complete report, entitled "Green River Air Quality Model Development VALMET—A Valley Air Pollution Model," (Order No. PB 86-104 106/AS; Cost: $16.95, subject to change) will be available only from:

National Technical Information Service
5285 Port Royal Road
Springfield, VA 22161
Telephone: 703-487-4650

The EPA Project Officer can be contacted at:

Atmospheric Sciences Research Laboratory
U.S. Environmental Protection Agency
Research Triangle Park, NC 27711

United States
Environmental Protection
Agency

Center for Environmental Research
Information
Cincinnati OH 45268