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Project Summary

Utilization of Municipal Wastewater and Sludge on Land: Proceedings of the 1983 Workshop

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A workshop on *Utilization of Municipal Wastewater and Sludge on Land* was held in Denver, Colorado from February 23 through 25, 1983. Researchers and practitioners of land treatment, totaling 203 in number and from the United States and other countries were invited to attend and evaluate advances in the land treatment technology during the past decade. Thirty-seven percent of the participants in the Denver conference were from colleges, universities, and agricultural experiment stations; thirty-one percent were from federal agencies; sixteen percent were from state and local governments and sixteen percent were from consulting firms. A similar conference had been held in Champaign, Illinois during 1973.

Following the presentation of position papers on institutional constraints, hydrologic and nutrient management, pathogens, metals, organics, engineering and economics and public health aspects, six separate workshop sessions were convened with approximately 30 people participating in each. Using the position papers as a starting point, the sessions defined the significant developments in land treatment since 1973 as well as the critical future research needs. Key findings of each workshop session are discussed in the "Highlights" Section of this proceeding.

This Project Summary was developed by EPA's Office of Environmental Engineering and Technology, Washington, DC, to announce key findings of the workshop that is fully documented in a separate report of the same title (see Project Report ordering information at back).

Introduction and Background

Objectives of the workshop were to (1) define the present knowledge on land application of municipal sludges and effluents; (2) reassess the research needs identified ten years ago in light of current knowledge; and (3) formulate recommendations for future research and development.

Position papers were used as a basis for comment and discussion in the following workshop sessions: Engineering Systems; Political and Institutional Constraints; Management Considerations in Sludge Use; Management Considerations in Effluent Use; Public Health and Risk Assessments: Pathogens; and Public Health and Risk Assessment: Organics and Inorganics. Each workshop session determined for its respective topic the significant developments in land treatment of municipal wastewater and land application of municipal sludge since 1973 as well as the state of the art and critical future research needs.

The 1973 conference held in Champaign, Illinois based upon an agenda for critical research associated with the recycling of municipal sludges and effluent on land stimulated extensive federal, state, municipal, and private agency research. The data base established from this on going research enabled the promulaerosols is treated by means of deposition velocities during daytime and is assumed to be zero during nighttime.

Chemistry and Aerosols

The concentrations of chemical species are governed by nine reactions. Near the source, the thermal oxidation of NO leads to NO_2 formation. Further downwind, the concentrations of NO, NO_2, and O_3 are maintained at photo-stationary state through three reactions: NO_2 photolysis, reaction of O atoms with O_2, and reaction of NO with O_3 to form NO_2. Oxidation of SO_2 and NO_2 by OH radicals leads to sulfuric acid and nitric acid formation, respectively. Sulfuric acid is assumed to condense on existing aerosols as sulfate. Nitric acid is assumed to remain in the gas phase. The OH radical concentrations are calculated from the O_3 photolytic rate and H_2O vapor concentration.

The aerosol population is represented by six aerosol modes, each having a lognormal distribution of mass. These modes are treated separately and include fine, coarse, and carbonaceous aerosols in the background and sulfate, carbonaceous, and primary aerosols in the plume.

Atmospheric Optics

The visual effects of the plume are calculated from the atmospheric radiance field, and scattering and absorption characteristics of the plume aerosols and NO_2. Light is absorbed in the plume by NO_2 and carbonaceous aerosols. Light scattering by sulfate, carbonaceous, and primary aerosols in the plume is calculated according to Mie theory. The atmospheric radiance field is calculated by taking into account Rayleigh and background aerosol scattering. An anisotropic multiple-scattered radiance field is calculated.

The atmospheric radiance, $I_{obj}(\Omega)$, seen by an observer at a distance R from an object and in direction Ω, is represented by the following radiative transfer equation:

$$I_{obj}(\Omega) = I_o(\Omega)e^{-\tau R} + F_s \int_0^{\tau R} \frac{\omega(\tau')}{4\pi} e^{-\tau_z/\mu_s} P(\Omega_s \rightarrow \Omega, \tau')e^{-\tau'}d\tau' + \int_0^{\tau R} \frac{\omega(\tau')}{4\pi} \int_{\Omega' = 4\pi} I(\Omega', \tau')P(\Omega' \rightarrow \Omega, \tau')d\Omega' e^{-\tau'} d\tau' \qquad (1)$$

where $I_o(\Omega)$ is the radiance leaving the object; $I(\Omega', \tau')$ is the radiance in direction Ω' and at optical depth τ'; τR is the optical depth between the observer and the object;

$$\tau R = \int_0^R b_{ext}\, ds; \; b_{ext}$$

is the extinction coefficient of aerosols and NO_2; F_s is the solar flux; ω is the single-scattering albedo (ratio of scattering coefficient to extinction coefficient); τ_z is the total vertical atmospheric optical depth at height z; μ_s is the cosine of the solar zenith angle; and P is the scattering distribution, or phase function. The first term represents the light that travels directly from the object to the observer, the second term is integrated along the line of sight and represents the light that has been scattered once from the sunlight's angle of incidence into the line of sight (single-scattering term), and the third term represents the light that has been scattered at least once before being scattered into the line of sight (multiple-scattering term).

The atmospheric radiance calculations are performed at 39 wavelengths ranging from 350 to 730 nm for the plume and the background. The visual-effect parameters that are subsequently calculated include the plume contrast at 550 nm, the blue/red ratio of the plume reduction in the visual range, and the color-change-perception parameter.

Geometry of Plume, Observer, and Sun

For performing as many as four different types of optics calculations at selected points along the plume trajectory, PLUVUE has two modes: plume-based and observer-based calculations. The calculations for plume transport, diffusion, and chemistry are identical for calculations in both modes. The major difference between the two types of calculations is the orientation of the position of the viewer to the source and the plume.

Plume-based calculations are repeated for several combinations of plume-observer-sun geometries. Because of the repetitions, these plume-based calculations are more expensive and produce more printed output than the observer-based calculations, which are only performed for the specific line-of-sight orientations corresponding to the given observer position, the portions of the plume being observed, and the specific position of the sun relative to these lines of sight.

There are four types of optics calculations: (1) horizontal views through the plume with a sky viewing background; (2) nonhorizontal views through the plume with a sky viewing background; (3) horizontal views through the plume with white, gray, and black viewing backgrounds; and (4) horizontal views along the axis of the plume with a sky viewing background.

Model Evaluation

PLUVUE and PLUVUE II have been evaluated with the VISTTA data base. PLUVUE was evaluated with the 1979 VISTTA data base, which was collected in the vicinity of the Navajo power plant near Page, Arizona. This power plant emits small amounts of particles, and secondary aerosol formation in the plume is slow. Thus, the visual effects of the Navajo power plant plume are primarily due to NO_2 light absorption. Since light absorption by NO_2 chemistry and turbulent diffusion are treated in the same manner in PLUVUE II as in PLUVUE, the model evaluation with the 1979 VISTTA case studies was not repeated for PLUVUE II. PLUVUE II was evaluated for particle-laden plumes with the 1981 VISTTA data base, which was collected in the vicinity of the Kincaid power plant near Springfield, Illinois; the Labadie power plant near St. Louis, Missouri; and the Magma copper smelter near San Manuel, Arizona.

The overall evaluation of PLUVUE with the 1979 VISTTA data base was performed for three different types of background conditions:

- Clear-sky background (20 case studies using data from July 13, December 7, and December 15, 1979).
- Dark-mountain background (2 case studies using data from June 28, 1979).
- Hazy-sky background (5 case studies using data from December 4, 1979).

Simulations were carried out on the basis of emission, meteorological, and background air quality data — the inputs listed in the 1979 VISTTA data base.

Evaluation of the dispersion and chemistry modules was conducted from case studies in which the aircraft flew through the approximate plume from December 7, 1979, for which there was good alignment between the telephotometer sight path and the aircraft flight path. Thus, the aircraft measurements could be used as direct inputs to the optics modules.

Results of the PLUVUE evaluation with the 1979 VISTTA data base indicate the following conclusions for the conditions considered:

- PLUVUE tends to overpredict the plume visual effects; the average absolute relative errors in plume contrast are 69, 83, 69, and 154% at 405, 450, 550, and 630 nm, respectively. The larger error at 630 nm is due to the fact that both observed plume contrasts are small in the red light range and are therefore difficult to predict accurately.
- The PLUVUE dispersion module appears to contain the primary source of uncertainty in model predictions; plume dispersion is generally underestimated by the module.
- Predictions of the PLUVUE chemistry module show reasonable agreement

with measurements of the NO_2/NO_x ratio, considering the uncertainties introduced by the dispersion module, because of the dependence of plume chemistry on plume dispersion.

- The PLUVUE optics module compares satisfactorily with the case studies. Average absolute relative errors in plume contrast are 47, 45, 39, and 164% at 405, 450, 550, and 630 nm, respectively. The evaluation of the PLUVUE optics module shows that the plume visual effects were overestimated in 9 out of 10 case studies. Correlation coefficients between observations and predictions are 0.70, 0.84, 0.77, and 0.21 at 405, 450, 550, and 630 nm, respectively. Thus, the PLUVUE optics module performance is quite satisfactory in the blue and green light ranges for which plume visual effects are important.

The 1981 VISTTA data base presents nine case studies of particulate plumes, including three case studies from the Kincaid power plant in Illinois, two case studies from the Labadie power plant in Missouri, and four case studies from the San Manuel copper smelter in Arizona. The 1981 VISTTA data base was used to evaluate PLUVUE II under conditions in which scattering of light by particles is important.

Model simulations were conducted to evaluate the overall plume visibility model PLUVUE II as well as the optics module. The following conclusions can be drawn from the evaluation of PLUVUE II with the 1981 VISTTA data base:

- PLUVUE II tends to overpredict plume visual effects; the average absolute relative errors in plume contrast are 134, 134, 153, and 79% at 405, 450, 550, and 630 nm, respectively. These results show that it is more difficult to predict the visual effects of particle-laden plumes than those of NO_2-laden plumes, since better model performance was obtained for the NO_2-laden plumes of the 1979 VISTTA data base.
- The PLUVUE dispersion module overestimates plume dispersion by a factor of 1.5 to 2.
- The PLUVUE II optics module tends to overpredict plume visual effects; the average absolute relative errors in plume contrast are 140, 78, 72, and 111% at 405, 450, 550, 630 nm, respectively. The optics module appears to underpredict forward scattering of light by aerosols; i.e., it predicts a darker plume than is observed for scattering angles less than 90°.

Input Data

The input data needed to run PLUVUE II are contained in one file of 80-byte, card-image records. These data include the following parameters:

- Wind speed aloft or at the 7-m level.
- Stability category.
- Lapse rate.
- Height of the planetary boundary layer (mixing depth).
- Relative humidity.
- SO_2, NO_x, and particulate emissions rates.
- Flue gas flow rate, exit velocity, and exit temperature.
- Flue gas oxygen content.
- Ambient air temperature at stack height.
- Ambient background NO_x, NO_2, O_3, and SO_2 concentrations.
- Properties (including density, mass median radius, and geometric standard deviation) of background and emitted aerosols in accumulation (0.1-1.0 μm), coarse (1.0-10.0 μm), and carbonaceous aerosol size modes.
- Coarse mode background aerosol concentration.
- Background visual range or background sulfate and nitrate concentration.
- Deposition velocities for SO_2, NO_x, coarse model aerosol, and accumulation mode aerosol.
- UTM coordinates of the source location.
- Elevation of the source location.
- UTM coordinates and elevation of the observer location for an observer-based analysis.
- UTM zone for the site and observer locations.
- Time, day, month, year, and time zone for the time and date of the simulation.
- For an observer-based run, terrain elevation at the points along the plume trajectory at which the analysis will be performed.
- For an observer-based run with white, gray, and black viewing backgrounds, the distances from the observer to the terrain that will be observed behind the plume.
- For an observer-based run, the wind direction.

The input data file also has numerous switches or flags to allow the user to select the particular subset of the complete model that meets his or her needs.

Output Data

A PLUVUE II run will write results on three files: the print files on logical file unit 6, the observer-based perceptibility data for plotting on logical file unit 7, and the plume-based plot data on logical file unit 8. If a PLUVUE II run is for either observer-based or plume-based calculations, an observer-based or a plume-based plot file will be created. The principal PLUVUE II run output is the print file written on logical unit 6. The file size depends on the number and type of calculations invoked by the input file. All runs contain data tables for the emission source, meteorology, ambient air quality, and background radiative transfer, and tables of calculated values for plume visual effects and pollutant concentrations.