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AIR QUALITY MODELING OF GEOTHERMAL POWER PLANTS IN COMPLEX TERRAIN

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ABSTRACT

Commercial energy development at the Geysers KGRA, California--the world's largest producing geothermal field--is confronted with increasingly more stringent air quality impact assessment requirements for not only regulated pollutants (e.g., hydrogen sulfide and primary particulates) but also unregulated species including benzene, ammonia, arsenic, $Radon^{222}$, boron, and mercury. An integrated program of ambient aerometric monitoring, tracer diffusion experiments, cooling tower plume rise studies, and numerical air quality simulation modeling was conducted for this mountainous region to provide estimates of potential short term (i.e., $\sim$ 1 hour) impacts attributable to development of the Geysers steam resource. A series of atmospheric tracer diffusion experiments, focusing on aerodynamic downwash, nocturnal drainage, fumigation, and limited vertical mixing were conducted to provide a basis for air quality model performance evaluation. Upper air meteorological measurements and cooling tower plume rise studies were performed to develop data useful in evaluating windfield and plume rise submodels.

INTRODUCTION

Commercial energy development at the Geysers KGRA, California--the world's largest producing geothermal field--is confronted with increasingly more stringent air quality impact assessment requirements for not only regulated pollutants (e.g., hydrogen sulfide and primary particulates) but also unregulated species including benzene, ammonia, arsenic, $Radon^{222}$, boron, and mercury. Notwithstanding ongoing abatement research and pilot-scale testing, malodorous H_2S emissions continue to promote violations of the California 1-hour ambient standard. In support of permit applications by state and municipal agencies, an integrated program of ambient aerometric monitoring, complex terrain tracer diffusion experiments, cooling tower plume rise studies, and numerical air quality simulation modeling was conducted to provide estimates of short-term impacts attributable to further development of the Geysers steam resource. Details of the historical data analyses, field experiments, and numerical modeling are discussed by Tesche et al. (1980) and Knuth et al. (1979).

COMPLEX TERRAIN TRACER DIFFUSION EXPERIMENTS

A series of atmospheric tracer experiments were designed and carried out at the proposed California Department of Water Resources' South Geysers site and at the Sacramento Municipal Utility Districts' SMUDGEO#1 site. Objectives of the tracer tests were to provide direct source-receptor relationships for estimating future H_2S impacts via scale-up of cooling tower emissions, and to provide data sufficient for air quality model performance evaluation. Criteria for the performance of the tests were based upon a detailed statistical analysis of historical aerometric data collected at the Geysers from 1976-1980. Dual tracers, SF_6 and Freon, were released under adverse limited mixing, fumigation, downwash, and nocturnal drainage conditions. Tracer sampling, at the ground and aloft, continued for 12 hours at more than two dozen downwind locations. Aircraft sampling of existing cooling tower plumes near the release sites was also performed to establish the proper tracer release height and to provide data for plume rise model verification.

MODEL PERFORMANCE EVALUATION STUDIES

Due to the complex topography (1400 m terrain relief) and moderate source-receptor distances (i.e., 5-10 km), the SAI Hybrid Model, employing both semi-Lagrangian and Eulerian concepts, was developed and applied to the geothermal field. The model simulates the sequential downwind transport and turbulent diffusion of point source emissions puffs until they attain a size commensurate with a specified Eulerian grid; at this point the Eulerian concept is invoked to characterize further transport and dispersion. Rise of buoyancy-generating moist cooling tower plumes is simulated numerically. Transport fields are computed by a diagnostic wind field model which relies, in part, on the high resolution terrain data available from the National Cartographic Information Center. The basic modeling approach consists of two parts, simulation of the flow-field and simulation of plume rise and dispersion. This dual approach received broad acceptance at a recent EPA-sponsored Workshop on Atmospheric Dispersion Models in Complex Terrain (EPA, 1979). The hybrid model is composed of the following sub-models:

> An Eulerian, grid-based dispersion model [the SAI Airshed Model (Reynolds et al., 1979)]
> A three-dimensional, mass-consistent wind model [the SAI Complex Terrain Wind Model [Yocke and Liu (1978)]
> A numerical cooling tower plume rise model [Winiarski-Frick (1978)]
> A Langrangian, sub-grid-scale Gaussian puff model.

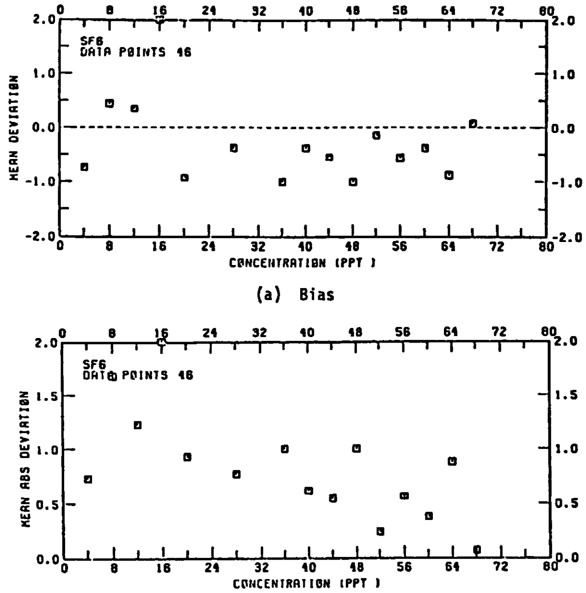
This modeling methodology was selected over the Gaussian approach because it provides a more realistic treatment of the relevant physical processes occurring in complex terrain.

Two numerical cooling tower plume rise models--Hanna (1976) and Winiarski and Frick (1978)--were evaluated using the results of 23 plume rise experiments performed at the Geysers. Examination of model predictions and observations revealed that the average errors associated with the Winiarski and Frick model vary between 22 and 27 percent. For the Hanna model, errors range between 30 and 36 percent. The average errors exhibit an overall tendency toward underestimation.

Policastro et al. (1977) reported that the Hanna and the Winiarski and Frick model's predictions of visibile plume height were within a factor of 2 of the observed values in at least 50 percent of the cases they studied. From results obtained in application to the Geysers cooling towers, we found that the Hanna model is within a factor of 2 of the observed values 48 percent of the time, and the Winiarski and Frick model is within a factor of 2 of the observed values 57 percent of the time. These results, consistent with the findings of Policastro et al., are encouraging, particularly in light of the fact that a far more detailed cooling tower data base was available to the Argonne group in their model verification work.

The Hybrid Model was evaluated using data sets from five tracer experiments and one historical Geysers H_2S eipsode. The tests were carried out under adverse limited mixing, drainage, downwash, and fumigation conditions. Model evaluation using the tracer data was intended to examine model performance in simulating single point source plumes. The historical H_2S episode was simulated to determine the model's capability of predicting the dispersion of emissions from 22 nearby geothermal power plants, leading to cumulative H_2S concentration levels.

Several measures of model performance were investigated with the Hybrid Model, including accuracy of the peak concentration prediction, bias, gross error, overall accuracy and precision, and temporal and spatial correlation. In general, agreement between the peak predicted and observed concentrations was within a factor of 1.5 to 2.5. Figure 1 exemplifies estimates of model bias and error (signed and absolute normalized residuals) as a function of concentration level for one of the limited mixing simulations. For the NS-1 experiment, the model tends to underestimate, on the average, by 50 percent. Overall accuracy and precision may be defined as the mean and standard deviation of the distribution of residuals (the difference between predicted and observed equivalent H_2S concentrations). In general, the accuracy of model predictions is approximately 1-13 ppt depending upon which test is simulated. (There exists a slight tendency toward overestimation.) Further, the precision is approximately ± 12 to 27 ppt. (Typically, the range in peak observed tracer concentrations is 75-125 ppt.) In the simulation of the historical 28 July 1976 H_2S episode, the average overall error (i.e., the average normalized difference between maximum predicted and observed H_2S concentrations at the seven SRI stations) was 37 percent.



(a) Bias

(b) Gross Error

Figure 1. Bias and Error Estimates as a Function of SF_6 Tracer Concentration Level for the NS-1 Diffusion Experiment [Mean and absolute deviations (residuals) are normalized by the observed concentration level.]

CONCLUSIONS

Comparison of the peak prediction and observation at each monitor for the five tracer tests indicated agreement within a factor of 2 over 60 percent of the time. This is comparable with a 70 percent figure obtained in recent application of the model to the Harry Allen Generating Station in southern Nevada. The model's performance, discussed in the recent studies of Burton et al. (1980) and Tesche et al. (1980), has led to its recent acceptance for use in estimating future impacts of proposed new sources in the West by local, state, and regional air regulatory bodies.

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