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**Environmental Sciences Division
Annual Progress Report
for Period Ending September 30, 1982**

Environmental Sciences Division
Publication No. 2090

OPERATED BY
UNION CARBIDE CORPORATION
FOR THE UNITED STATES
DEPARTMENT OF ENERGY

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**ENVIRONMENTAL SCIENCES DIVISION
ANNUAL PROGRESS REPORT
for Period Ending September 30, 1962**

S. I. Auerbach, Director
D. E. Reichle, Associate Director

Environmental Sciences Division Publication No. 2090

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ABSTRACT

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Advanced Fossil Energy Program research activities related to coal conversion technologies were reduced during the past year. A study was completed to identify (1) vegetation potentially at risk from the additive atmospheric contributions of advanced technologies and (2) sites to be used to verify findings of field research studies. Aquatic research produced initial models of transport, fate (total and constituent), and effects of released coal liquid products. Completion of a program statement related to nonnuclear solid wastes led to expanded research in this area.

In the Toxic Substances Program, research for EPA concerning the development of multispecies test protocols was completed for soil microorganisms and for legume-*Rhizobium* symbiosis. Model validation research was initiated on a suite of radiological assessment models, and new applications of nondestructive gamma-ray spectroscopy were developed.

The Environmental Impacts Program continued the cooperative effort with the ORNL Energy Division in preparing environmental impact statements and assessments for energy-related projects (alcohol fuels, uranium fuel cycle, geothermal, and fusion). New methods for environmental risk analysis were developed and applied to an indirect coal liquefaction technology. Environmental technical assistance this year focused on the preparation of guidelines for compliance with 12 environmental laws or regulations and environmental issues associated with waste disposal. Studies were completed on (1) monitoring dissolved oxygen concentrations below hydroelectric dams and (2) hydroacoustic biomass estimation techniques applicable to power-plant monitoring programs.

Our management role continued for the DOE Short-Rotation Woody Crops Program and as did our research role in support of both short-rotation and whole-tree harvesting systems. Production research consisted of 3) contracted research projects across the United States addressing species selection and genetic improvement, stand establishment and management strategies, and economic evaluations of current systems. Environmental studies addressed resource utilization by selected tree species and changes in nutrient cycling and long-term productivity as a function of forest harvesting practice.

In the Low-Level Waste Research and Development Program, site characterization for a new solid low-level radioactive waste disposal area began while the performance of three older burial sites is being determined. Corrective measures included full-scale surface-water diversion at Solid-Waste Storage Area 4 as well as demonstration of in situ grouting, chemical treatment to suppress radionuclide migration, and passive ground-water suppression.

During FY 1982 the Low-Level Waste Management Program at ORNL drafted technology program plans; developed priority-ranked FY 1982, 1983, and 1984 budgets to support these plans; and provided technical guidance for the implementation of these plans at participating DOE sites.

Waste Isolation Program activities included identifying potential nuclear waste repository sites in the crystalline Southern Appalachians on the basis of geologic, environmental, and socioeconomic criteria. Future detailed work will reduce the number of sites considered.

Staff of the Global Carbon Cycle Program prepared a carbon density map for major world ecosystem complexes, implemented a method for delineating the world's major climatic life zones

according to the Holdridge Life-Zone System, and published a companion global synthesis of soil-carbon density organized according to the Holdridge classification. Significant advances were made in the development and calibration of two-dimensional ocean models for global carbon-cycle models, and sensitivity/uncertainty analysis techniques were successfully applied to a global carbon model developed by ORNL staff. Direct assistance by personnel from the Global Carbon Cycle Program was provided to the Division of Carbon Dioxide Research in the development, management, and research for the DOE Carbon Cycle Research Program.

Stream and reservoir ecosystem studies continued to be a major emphasis in the Aquatic Ecology Section. Other activities included research on the distribution, density, and abundance of Legionnaires' disease in power-plant cooling systems; study of the effects of multiple stresses on fish populations; analysis of the status of the Maryland striped bass population; and two symposia organized by section staff for the 1982 Annual Meeting of the American Fisheries Society.

Briefly summarized in the Earth Sciences Section are the nonnuclear solid-waste activities and the atmosphere-biosphere interactions studies, which represent growing areas of concern. Studies on organic-rich shales, slates, and schists in regard to heavy-metal distribution were initiated; at the same time, final reports of pollution distribution in the Hudson-Raritan estuary and of a training course on mathematical modeling are included.

The Environmental Resources Section performed research and analysis in three areas: modeling, environmetrics, and regional analysis. The modeling group completed theoretical studies on a range of population and food-web problems. The environmetrics group worked on statistical analysis of toxicological data and cooperated in the establishment of the Carbon Dioxide Information Center. Regional analyses were completed on the Tennessee-Tombigbee Corridor and on potential conflicts of energy facilities and critical natural areas.

Terrestrial Section research was organized around three basic areas (ecosystem studies, physiological studies, and environmental analyses), with a major emphasis on evaluating the ecological effects of air pollution on agricultural and natural systems. Specific research areas highlighted this year include bioclimatology, concerned with reconstruction of past climatic changes to evaluate future climate changes as well as impacts of pollution stress; forest ecology, emphasizing expanding succession modeling capabilities and evaluating impacts of management practices on forest systems; and air pollution studies, concentrating on interactive effects among acid precipitation, gaseous pollutants, and trace elements.

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PART I. ENVIRONMENTAL SCIENCES DIVISION PROGRAMS

1. ADVANCED FOSSIL ENERGY PROGRAM

C. W. Gehrs

C. P. Allen	J. M. Giddings	B. M. Ross-Todd
D. A. Backus ¹	J. C. Goyert	W. K. Roy
L. W. Barnthouse	S. E. Herbes	G. S. Saylor ²
S. M. Bartell	L. A. Hook ³	W. J. Selvidge
A. S. Bradshaw ²	G. A. Kazlow	P. J. Singley
F. S. Brinkley	J. R. Krummel	J. M. Skelly ⁵
M. G. Browman	D. S. Marshall	G. R. Southworth
D. K. Brown	J. F. McCarthy	A. J. Stewart ⁴
R. M. Cushman	R. K. McConathy	R. H. Strand
K. L. Daniels	S. B. McLaughlin	R. F. Strayer
E. C. Davis	E. R. Merchant ¹	G. W. Suter
D. F. Dickerson	J. D. Newbold	G. E. Taylor
N. T. Edwards	E. G. O'Neill	R. R. Turner
J. L. Fair	R. V. O'Neill	D. S. Vaughan
M. P. Farrell	D. T. Polovino	B. T. Walton
C. W. Francis	C. D. Powers	D. K. Whitmore
P. J. Franco	R. A. Reinert ⁴	G. T. Yeh

Atmospheric and Terrestrial Effects

S. B. McLaughlin

Research activities to determine potential effects on terrestrial systems from atmospheric effluents associated with synthetic fuels proceeded in three areas during 1982. These include (1) controlled exposures designed to examine either the direct effects of gaseous emissions on vegetation or the interactive effects of these pollutants in combination with regional-scale pollutants such as ozone (O_3); (2) comparative uptake and translocation potential of two polynuclear aromatic hydrocarbons (PAH), benzo[a]pyrene (SP) and benzo[a]anthracene (BA), in plants; and (3) regional-scale studies to determine potential air quality changes in an area of western Kentucky in which multiple siting of coal combustion and coal conversion plants is anticipated. Collectively, this work provides a data base for identifying both potentially problematic compounds and atmospheric pollution regimes associated with synfuels operations and multifacility siting. The following subsections detail progress in each research area.

¹The University of Indiana.

²The University of Tennessee, Knoxville.

³Predoctoral student, Oak Ridge Associated Universities, Oak Ridge.

⁴North Carolina State University, Raleigh.

⁵Virginia Polytechnic Institute and State University.

⁶Postdoctoral student, Oak Ridge Associated Universities, Oak Ridge.

Effects of Gaseous Pollutants (G. E. Taylor, W. J. Selvidge, and S. B. McLaughlin)

The atmospheric chemistry of the eastern United States is characterized by recurring episodes of elevated O_3 levels as a consequence of frequent air stagnation events. Thus, sulfur gas emissions from advanced coal processes sited in the East will occur simultaneously with existing background O_3 concentrations. Because the impact on vegetation of pollutant gases in combination may differ markedly from that predicted from single-gas exposures, the effect on agricultural crops and forests of emissions from advanced coal processes in concert with O_3 is being studied. Research is in progress with each of the major sulfur-containing gases such as sulfur dioxide (SO_2), hydrogen sulfide (H_2S), and carbonyl sulfide (COS); the results with SO_2 , the major sulfur emission, are complete. In the gas fumigation facility, Bush Blue Lake Beans (*Phaseolus vulgaris*) were exposed to increasing levels of SO_2 (0.10 to 0.50 $\mu L/L$) either singly or in combination with low levels of O_3 (0.10 $\mu L/L$). This scenario was selected to mimic ground-level air quality proximal to a commercial-scale conversion facility during a summertime air stagnation event. The climatic conditions during exposure, including air temperature (30 to 33°C) and relative humidity (60 to 70%), were representative of a cropland environment in mid-July. The rate of photosynthesis in each treatment (control, SO_2 alone, O_3 alone, and $SO_2 + O_3$) was monitored continuously as an indicator of plant response. The data were analyzed using least-squares linear regression techniques.

Among all exposure treatments, including control plants, net photosynthesis measured as CO_2 ranged from 21 to 35 millimoles $m^{-2} h^{-1}$. In the absence of air pollution stress, the initial photosynthetic rate (time = 0) was the minimum, and thereafter photosynthesis increased 12 to 18% [Fig. 1.1(a)]. After 7.5 h of exposure to SO_2 , O_3 , and $SO_2 + O_3$, photosynthesis was 83, 62, and 70%, respectively, of control rates [Fig. 1.1(b)] and each regression coefficient was statistically different from zero. Using the regression coefficients (i.e., slope) to compare treatment effects on photosynthesis, the $SO_2 + O_3$ combination was nearly twice as toxic as the same SO_2 dose alone. However, the most inhibitory treatment was constant exposure to O_3 at 0.10 $\mu L/L$, actually demonstrating that interactive effect of $SO_2 + O_3$ on photosynthesis was actually antagonistic. The results indicate that the impact of sulfur gas emissions from coal conversion facilities should be evaluated within the context of a region's existing air quality, particularly with regard to elevated levels of O_3 .

A major category of atmospheric emissions from coal conversion technologies is low-molecular-weight hydrocarbon gases. Initial screening techniques have identified three compounds (i.e., butane, ethylene, and ethane) that have chemical properties generally associated with phytotoxicity. Over a range of concentrations and exposure times, only ethylene showed any effect on photosynthesis in corn (*Zea mays*) and beans (*Phaseolus vulgaris*). Further studies of ethylene effects on plant productivity at chronic levels are warranted.

Uptake and Fate of PAH (N. T. Edwards and B. M. Riss-Todd)

Short-term (four-day) uptake experiments in which soybeans are grown in a nutrient solution tagged with ^{14}C -labelled BA and BaP are in progress. Counts of ^{14}C activity in roots and stems collected at 48- and 96-h intervals after PAH inoculation of the nutrient solution indicated that BA is more readily translocated to the upper parts of the plant (stems and leaves) than BaP.

At the end of the 48-h exposure, 1.2% of the BA and 0.007% of the BaP originally added to the nutrient solution had been translocated to the stems and leaves. At the end of the 96-h exposure, 2.6% of the BA and 0.126% of the BaP had been translocated to the stems and leaves.

Fig. 1.1. Net photosynthesis in unexposed *Phaseolus vulgaris* (a) and in plants exposed to increasing SO₂ levels, SO₂ plus a constant 0.10 μl/l O₃ concentration, and O₃ alone (b). Data are presented in absolute units in unexposed plants and linear regression (as a percentage of controls) in plants exposed to air pollutants.

The amount of BA and BaP remaining in solution after 48 h was only 0.03% and 0.05% of the original amount added, respectively. Most of the remaining BA and BaP was associated with the roots (adsorbed plus absorbed). These results will be verified by extraction and identification of the compounds (BA and BaP) by thin layer chromatography.

These experiments with BA and BaP, combined with earlier results from studies with anthracene, provide additional evidence of the relationship between structure and activity of PAH compounds. In the experiments with ¹⁴C-anthracene using identical concentrations and methods, 7.7% of the anthracene had been translocated to the stems and leaves after 96 h. Thus, it appears that low-molecular-weight PAH compounds such as anthracene (mol wt = 178) are more readily assimilated and translocated by plants than high-molecular-weight PAH compounds such as BA (mol wt = 228) and BaP (mol wt = 252).

Longer-term, chronic exposure experiments are under way in which the roots of bean plants are exposed to PAH during the plant's full life cycle. Plants chronically exposed to anthracene were harvested and the tissues are being stored until an improved extraction technique can be perfected.

Long-term exposure experiments with BA and BaP are in progress. Because one significant mode of PAH exposure will be via deposition of fly ash on which PAH has been adsorbed, a subcontract with the University of North Carolina Chemistry Department has been initiated to obtain fly ash that is vapor-phase coated with ^{14}C -anthracene. The fly ash will then be incorporated into soil for use in plant uptake and microbial degradation studies.

An extensive review of the literature on PAH in the terrestrial environment is complete. A review paper emphasizing plant uptake and PAH contamination of terrestrial vegetation was written and is being reviewed for possible publication.

A Regional Analysis of Field Siting and Landscape Vegetation "At-Risk": an Exploration in the Western Kentucky Region (J. R. Krummel and R. V. O'Neill)

A regional approach was used for locating field research sites to assess the impact from new coal-burning electricity-generating and proposed coal conversion facilities along the Ohio and Green rivers in western Kentucky. Because data are available on SO_2 and because SO_2 is released from both coal conversion and coal combustion facilities, it was selected as a model contaminant. The analysis of SO_2 levels included both current ambient air quality and the projected dispersion pattern from the new facilities.

Background air quality levels were obtained from continuous monitoring stations in the study region. Eight new facilities were modeled as eight emission points in the RAM(FR) and RAMSTO dispersion models (Witten et al. 1982). The specific location and extent of the landscape vegetation types in the study region were obtained from USGS land use/land cover maps. The study region was divided into 1600 grid locations (receptors on the landscape) and the probability of exceeding 3-h average SO_2 levels of 210 and 262 $\mu\text{g}/\text{m}^3$ was calculated for each grid location. Landscape vegetation and percent contribution from each new facility were determined at the grid locations found to exceed these 3-h average levels.

Given the higher background levels and the transport distance of SO_2 , only grid locations along the western section of the Ohio River Valley were found to have a reasonable probability (0.37 to 1.00) of exceeding the 3-h average SO_2 levels of 210 or 262 $\mu\text{g}/\text{m}^3$ during the growing season. The combined contribution of the eight facilities to a given grid location was a function of meteorological conditions, the siting pattern, stack heights, and emission levels. As a result, the field sites recommended by this approach were quite different from what one would expect from a site-by-site analysis. Agricultural crops occurred in 79% of those grid locations that had a reasonable probability of exceeding the two concentrations of SO_2 . However, forested and nonforested wetlands, while covering less than 2% of the regional landscape, appeared in 37% of those grid locations. Thus, this approach identified a vegetation type that would have been ignored in a site-by-site approach.

The siting of multiple pollution sources and receptors in a region provides an effective means of evaluating SO_2 deposition patterns with respect to vegetation patterns. In this way, vegetation types "at risk" are easier to locate and field research is sited such that the probability of detecting potential vegetation effects is increased. This is especially important if unique vegetation types are identified by this procedure. In addition, this regional approach provides a tool to examine multifacility siting patterns to determine cumulative impacts on the environment.

Transport, Fate, and Effects of Complex Organics: Oil Spills

J. M. Giddings

Research is under way to define the problems associated with releases of coal liquefaction products and other complex organic materials to the environment. The research program combines standard laboratory bioassays, specialized studies of transport and effect, microcosm and field experiments, and mathematical modeling. The objectives are

- to determine pathways and measure rates of transport, transformation, and partitioning of synthetic oils in the environment, as influenced by physical/chemical characteristics of the oils and conditions during the spill;
- to determine the effects of acute and chronic exposure to synthetic oils, oil fractions, and residues on organisms and ecosystems; and
- to evaluate strategies for reducing the environmental hazards of coal liquid spills.

Transport Model for Synthetic Oil Spills in Rivers (S. E. Herber, G. T. Yeh, and G. R. Southworth)

The synthetic Oil Pollution TRANsport model (SOPTRAN) is a one-dimensional model developed to describe the fate of coal liquid spills in rivers. We used SOPTRAN to simulate a spill of 300 m³ of a crude coal liquefaction product into the lower Ohio River. Petroleum spills of this size occur about twice yearly as a result of barge accidents in the Ohio-Kentucky-Illinois region. The model predicted that the oil would spread across the river in about 12 h and would spread to a slick 3 km long within 72 h. Times required for 90% depletion of phenol, C₇-phenols, and C₈-phenols from the slick would be 5, 10, and 30 h, respectively. According to the model, a zone of dissolved phenolics would travel downstream under the spreading oil slick, with concentrations of the different phenolics changing as they dissolve at different rates from the oil and disperse into the water. The maximum concentration of total phenolics was predicted to be 0.9 mg/L. Although phenols dissolve relatively rapidly, the maximum aqueous concentration of the slowly dissolving C₈-phenols was predicted to occur 30 km downstream. Sensitivity studies confirmed that predicted aqueous phenolics concentrations are essentially proportional to the oil volume spilled. Variations in evaporation rates have little effect on the level of waterborne phenolics; the most important variables are the rate of slick spreading and the intensity of water turbulence.

Effect of Naturally Occurring Organic Matter on Bioaccumulation of PAH by Aquatic Organisms (J. F. McCarthy and P. J. Singley)

Hydrophobic organic compounds, such as those found in synthetic oils, sorb to naturally occurring dissolved and particulate organic matter in aquatic ecosystems. Sorption was found to have an effect on the bioaccumulation of PAH by *Daphnia magna*. In the absence of particulate organic matter, the animals bioconcentrated BaP from the water by 8000-fold and anthracene by 500-fold. The presence of organic particles (yeast cells) reduced the uptake of PAH in proportion to the amount of PAH sorbed to the particles. Analysis by multicompartment models demonstrated that the rate of PAH uptake by ingestion of yeast cells laden with sorbed chemical was only 10% of the rate of uptake of dissolved chemical. Sorption of the PAH to dissolved organics (humic acids) reduced the bioaccumulation by 97%. These results indicate that accumulation of hydrophobic

contaminants in aqueous systems is dependent primarily on the amount of chemical remaining in free solution. To the extent that the presence of sorptive particulate or dissolved organic matter removes PAH from solution, bioaccumulation is reduced.

The uptake, depuration, and metabolism of naphthalene (NPH) and BaP by bluegill sunfish were also examined. NPH was bioconcentrated 500-fold; rates of uptake and depuration were independent of the concentration of NPH in the water. NPH was metabolized relatively slowly by fish, and metabolites were not retained in the animal. BaP was taken up rapidly but was also rapidly metabolized to water-soluble conjugates, and to phenol, diol, and quinone derivatives of BaP, all of which accumulated in the animal. Because of the rapid biotransformation, bioaccumulation of BaP by the fish was much lower than would be expected from its hydrophobic nature.

Analysis of an Aquatic Transport Model for Polycyclic Aromatic Hydrocarbons (S. M. Bartell)

Statistical regressions that relate transport processes to chemical characteristics of PAHs were used to estimate parameters in a model that forecasts the fate of anthracene in a pond ecosystem. Results of 200 Monte Carlo simulations, wherein 29 model parameters were chosen at random from distributions defined by the regression models, indicated that different degrees of precision are associated with predicted concentrations for different pond components. Similarity between the mean Monte Carlo and deterministic simulations demonstrated that the model does not systematically overestimate or underestimate concentrations when parameters are varied randomly. During 60-d simulations, the rank order of parameters that correlate with prediction uncertainty changes. These findings will be used to design sampling schedules in verification experiments.

The chemical descriptors used to estimate transport parameters for anthracene lie near the mean values of regression models. The fates of NPH and BaP were simulated to examine model behavior for compounds whose descriptors represent extreme values and whose uncertainties are therefore greater. The predicted concentrations of these PAHs in water, sediments, and zooplankton agreed qualitatively with published observations in similar aquatic systems. Analysis of the Monte Carlo simulations identified parameters associated with desorption from sediments and uptake by zooplankton as key contributors to uncertainty in predictions of the fate of NPH and BaP.

Acute Toxicity of Water-Soluble Fractions of Coal-Derived Oils (J. M. Giddings, P. J. Franco, A. J. Stewart, and J. L. Fair)

Acute toxicity screening tests with water-soluble fractions (WSFs) of natural and synthetic oils from a variety of sources indicated that coal liquid WSFs are considerably more toxic than WSFs from petroleum. Phenol and its alkylated derivatives make up most of the WSFs of coal liquids; anilines and small amounts of monoaromatic and diaromatic hydrocarbons are also present. We examined the relationship between the toxicity and chemical composition of WSFs. Coal liquid WSFs are acutely toxic to aquatic organisms (algae, zooplankton, insects, snails, and fish) at total phenol concentrations ranging from 1 to 100 mg/L. Toxicity depends to a great extent on the number of alkyl substituents on phenolic compounds in the WSFs; a WSF consisting mainly of trimethyl and tetramethyl phenols is five to ten times more toxic to *Daphnia magna*, for example, than a WSF containing mostly phenol and methyl phenols. Factors that influence the proportions of phenolic compounds in synthetic oils or WSFs, such as the distillation range of the oil, refining, oil-water contact time, and microbial degradation, will therefore influence toxicity correspondingly.

Few of the constituents of coal liquid WSFs have ever been tested for acute toxicity to aquatic organisms. We measured the toxicities of a series of individual phenols, anilines, and aromatic hydrocarbons to the green alga *Selenastrum capricornutum*, the crustacean *Daphnia magna*, and the midge *Chironomus tentans*. We combined the toxicity data with chemical analyses of WSFs to calculate overall WSF toxicity, assuming that the toxicities of the compounds in the mixtures were simply additive. For WSFs of light oils from coal liquefaction, 19 out of 22 predictions (spanning more than two orders of magnitude) were within a factor of three of the observed toxicities. The calculations tended to underestimate the toxicity of WSFs of heavy coal liquids, and further studies with these products are in progress. We can now couple the output of oil transport models such as SOPTRAN (p. 5) with toxicity calculations to predict the acute toxicity of WSFs of light coal liquids from the basic physical and chemical properties of the oils.

Effects of Coal-Derived Oils and Their Components on Aquatic Insects (P. J. Franco, D. A. Backhus, K. L. Daniels, and G. A. Kazlow)

The acute toxicity of a WSF of a coal-derived oil and two of its components, aniline and phenol, to larvae of four chironomid species was determined in 48-h bioassays. Three species (*Clinotanytus pingui*, *Einfeldia natchitochae*, and *Tanypus neopunctipennis*) were collected from natural populations; the fourth (*Chironomus tentans*) was reared in laboratory culture. LC50 values for the WSF ranged from 1.1% for *E. natchitochae* to 2.0% for *C. pingui*; for aniline, from 287 mg/L for *T. neopunctipennis* to 442 mg/L for *E. natchitochae*; and for phenol, from 73 mg/L for *T. neopunctipennis* to 187 mg/L for *C. tentans*. Comparisons based on a sensitivity analysis revealed that the closer the taxonomic relationship between species, the more similar the response to a given toxicant, regardless of whether the test populations were from nature or culture.

In addition to the toxicity of the water-soluble fraction of synthetic fuels, less soluble components of the oils, including PAHs and primary aromatic amines, may pose a hazard to aquatic ecosystems. We developed a procedure to assess the effects of oil-contaminated sediments on mortality, burrowing behavior, and bioaccumulation in the benthic larvae of *C. tentans*. In bioassays with whole oils and weathered oil residues, measureable amounts of organic contaminants were found in the larvae at exposure levels that had no effect on mortality or burrowing behavior.

Photolytic Changes in Water-Soluble Components of Coal Liquids (S. E. Herbes and C. P. Allen)

Toxicities of oxidants and other water-soluble transformation products of coal liquids produced by the action of sunlight were tested using 48-h *Daphnia magna* bioassays. Coal- and petroleum-derived oils were layered onto water in a closed, stirred tank and were irradiated through the Pyrex cover for ten days by an ultraviolet lamp. Oxidant concentrations and toxicity of the water underlying the oils increased with length of irradiation. Toxicities of water underlying crude H-Coal and SRC-II liquids increased less than 50% relative to nonirradiated controls. Aqueous extracts of a hydrotreated SRC-II product and a petroleum-derived diesel fuel were less toxic than the crude coal liquids, but they increased in toxicity more than threefold after irradiation. When photooxidants were reduced by addition of sodium thiosulfate, toxicity decreased. These results demonstrate that sunlight can cause changes in the water-soluble constituents of coal liquids, which may increase their acute toxicity, although to a lesser extent than for the petroleum crude and refined oils tested.

Experimental Product Releases in Microcosms and Ponds (J. M. Giddings, R. M. Cushman, P. J. Franco, S. E. Herbes, J. D. Newbold, G. R. Southworth, A. J. Stewart, L. A. Hook, C. P. Allen, J. L. Fair, and W. K. Roy)

In 1982, we completed a pair of experimental product releases in microcosms and ponds, complementing the set of experiments done the previous year. Whereas the 1981 experiments were one-time releases of crude coal liquid, this year we simulated chronic low-level releases such as might occur during loading or storage of oil. Oil was added daily or weekly for eight weeks to sixteen 50-L pond microcosms at eight different input rates. Concentrations of dissolved phenols were monitored by high-performance liquid chromatography and gas chromatography. Phenol concentrations increased steadily for the first two weeks of the study. Thereafter, microbial degradation reduced the concentrations of some phenols and slowed the rate of increase on others. Phenol degradation rates in the microcosms receiving the highest dose exceeded those in the microcosms receiving the lower dose despite the limitation of low dissolved oxygen. Total dissolved phenol concentrations in the microcosms were closely correlated with oil addition rates, ranging from about 20 mg/L at the highest dose to less than 10 μ g/L at the lowest dose.

Zooplankton abundance and ecosystem metabolism were altered in microcosms treated with as little as 1 μ L of oil per liter of water per day, in which phenol concentrations were less than 10 μ g/L. At oiling rates that resulted in 0.1 mg of total dissolved phenols per liter or more, a decline in the production:respiration ratio caused decreases in dissolved oxygen and pH and increases in total alkalinity and ammonium; the highest oiling rates caused the microcosms to become anaerobic. Dissolved phenols disappeared quickly when the oiling stopped, and conditions in most of the oiled microcosms returned to near control levels. Time to recovery was a function of oiling rate. Overall, dissolved oil concentrations near the *D. magna* 48-h LC50 produced severe damage in the microcosms; concentrations near the *D. magna* 28-d No Observable Effects Concentration caused ecologically significant changes in ecosystem metabolism and zooplankton communities.

In the pond experiment, the same liquefaction product was added daily for eight weeks at six input rates that bracketed the response threshold seen in the microcosms. Most of the same effects occurred in the ponds as in the microcosms at similar input rates, supporting the conclusion that the laboratory systems accurately simulate the larger, more natural ecosystems.

The ponds were stocked with mosquito fish (*Gambusia affinis*) before the oil treatments started. The fish were eliminated at the two highest dose rates, and their growth and reproduction were impaired at the third highest dose rate. Preliminary inspections of zooplankton samples showed that the larger cladocerans were most abundant at the third highest dose rate; at lower dose rates, the larger zooplankters may have been selectively removed by the fish, and at higher dose rates they were eliminated by the oil.

At the three lowest dose rates, insect emergence peaked midway through the study, whereas at the three highest doses, emergence declined monotonically after the oil additions began. Emergence was eliminated at the two highest doses. The short-term response of emergence, coupled with its ease of measurement compared to sediment sampling for benthic populations, suggests that emergence may be a useful indicator of the toxic effects of coal liquids.

To complement earlier work on the sensitivity of pond insect diversity, abundance, and biomass to contamination from coal liquids, structural deformities were counted in larval midge *Chironomus decorus* collected during the 1981 pond experiment. Aberrant mouthparts had been reported in chironomids from a number of polluted North American and European waters; in conjunction with

Advanced Fossil Energy Program (AFEP) research demonstrating the insect teratogenicity of some coal liquids, these deformities appeared to be a reasonable endpoint for aquatic studies. A low, dose-related frequency of mouthpart deformities was found in *C. decorus*. However, significant effects on species diversity, abundance, and biomass occurred at doses below that at which mouthpart aberrations were observed.

Terrestrial Invertebrate Toxicology (B. T. Walton, E. G. O'Neill, and E. R. Merchant)

Terrestrial insect studies have focused on a comparison of the acute, chronic, and developmental effects of coal liquids with those of petroleum products to several insect species. H-Coal products from the Catlettsburg, Kentucky, pilot plant were found to be of greater acute and chronic toxicity than petroleum crude oil to the milkweed bug *Oncopeltus fasciatus*. The 24-h LD50 of light and heavy fuel oils were 11.5 ± 3.6 mg/g and 22.7 ± 1.0 mg/g, respectively, whereas the 24-h LD50 for crude petroleum was >80 mg/g. The heavy fuel oil caused a dose-dependent delay in the adult molt, but the other two oils did not affect molting. Experiments are in progress to evaluate the effects of chronic sublethal exposure to these fuels on fertility and fecundity of the insects.

Soil collected six months after an SRC-II fuel oil spill was highly embryotoxic and teratogenic to cricket (*Acheta domesticus*) eggs. No eggs hatched of those oviposited in sand containing 0.8 wt % or more of contaminated soil mixed with oviposition sand. The LC50 was 0.099% (95% confidence limits of 0.053 to 0.18%), equivalent to 37 μ g of oil per gram of sand. Addition of fresh SRC-II fuel oil to the sand produced an LC50 of 66 μ g of oil per gram of sand (95% confidence limits of 57 to 76 μ g/g). Soil from the spill site was significantly more teratogenic than sand treated with the fresh oil. These findings suggest that chemical changes in oil after a spill enhance embryotoxicity and teratogenicity to soil-dwelling organisms.

The cricket egg bioassay has been modified for more precise dosing, better control of time of dosing, and lower requirements for eggs and test sample. Chemicals are applied topically to each egg using a Hamilton syringe attached to a power-driven micrometer. Typically, a test chemical is applied in 0.05 μ L dimethyl sulfoxide 16 to 24 h after oviposition. When incubated at 31°C, eggs can be scored for multiple eyespots on day 7 and nymphal emergence recorded beginning on day 10. Because the assay is simple, inexpensive, short term, and objective, it could be useful as an in vivo screen in an hierarchical approach to teratogen detection. Further investigation of cricket embryo responses to known teratogens is needed to establish the predictive value of the assay.

Solid Wastes

C. W. Francis

The quantity of solid wastes generated by the nation's energy-producing technologies will increase significantly over the next 20 years. The major factors that will contribute to this increase are (1) the need to become independent of imported oil, requiring development of liquid and gaseous fuels from coal and oil shales, and (2) the implementation of air and water pollution control regulations, resulting in a larger fraction of the residuals ending up in the form of solid wastes.

Solid wastes from advanced fossil energy technologies, such as coal conversion and the extraction of oil from oil shales, contain toxic heavy metals as well as mutagenic and carcinogenic

organic compounds. For many of the wastes (namely, the ash from coal conversion and retorted shale from oil shale processing technologies), the major environmental problem is not the acute toxicity or carcinogenicity of the wastes but rather the generation of solid-waste leachates from these wastes. Leachates from many of these wastes, predominantly those that contain reduced forms of sulfur, become acidic with age. The acidic character of the leachate enhances its capacity to leach toxic contaminants (e.g., Cu, Zn, Pb, Cd, Ni, and others) such that long-term release may overtax natural attenuation or dispersal mechanisms and result in accumulation of harmful quantities of these contaminants in surface waters and ground waters as well as other sensitive areas of the environment.

Microbial Sulfur Oxidation in Energy-Related Soil Wastes (R. F. Strayer and D. K. Whitmore)

Iron- and sulfur-oxidizing bacteria have been isolated repeatedly from acid mine drainage. These bacteria have been shown to accelerate the rate of oxidation of pyrite and other iron sulfide minerals, but their role in the dissolution of residuals from coal gasification is relatively unknown. Chemical characterization of a variety of coal gasifier ashes and slags has indicated the presence of significant quantities (0.3 to 4.0%) of sulfur (Francis et al. 1981). Environmental Sciences Division (ESD) research has indicated that sulfur in these wastes is subject to microbial oxidation. Experiments included both column and batch leaching of gasifier ash/slags; the column experiments were used to simulate disposal in a landfill, whereas the batch experiments were used to determine if the oxidative processes were chemical, microbial, or both.

Continuous application of distilled water to a column containing high-sulfur (4%) gasifier slag produced leachates having high sulfate levels (8000 to 1000 mg/L) and low pH values (3.5 to 4.5). At the termination of the experiment, an enumeration technique indicated that the waste contained 1.3×10^7 sulfur-oxidizing bacteria per gram. Samples of waste taken aseptically from the column produced sulfate under both abiotic and biotic conditions when incubated in a mineral nutrient culture. Both microbial and chemical sulfate production were greatly stimulated by the addition of thiosulfate to the waste suspensions, indicating that the form of the reduced sulfur in the gasifier ash/slag may be limiting the rate of sulfur oxidation. Ash and slags from five different gasification processes were used to assess the rates of microbial and chemical sulfur oxidation. Sulfate production was measured in sterile (autoclaved) vs nonsterile suspensions of these wastes in a nutrient solution. These experiments indicated that chemical sulfur oxidation as sulfate (2 to $27 \mu\text{g g}^{-1} \text{d}^{-1}$) and microbial sulfur oxidation (3.1 to $114 \mu\text{g g}^{-1} \text{d}^{-1}$) could occur in four of the five gasifier ash/slags tested. The relationships between the sulfur oxidation rate and either sulfur content or particle size of the waste were not immediately evident. Further leaching tests in columns simulating disposal conditions over a ten-week period revealed that two of the ash/slags released significantly more sulfate than did the three other wastes. Leachates from these wastes were highly acidic (pH values less than 3.5) and contained high concentrations of soluble iron (concentrations in excess of 3 to 6 mg/L) relative to the leachates from the other wastes (less than 0.2 mg/L). Analysis for toxic heavy metals (e.g., Cd, Pb, Zn, As, and Ni) are under way.

Leaching Characteristics of Raw and Retorted Eastern Oil Shale (C. W. Francis and F. S. Brinkley)

One potential source of oil is the Devonian shales that cover much of the eastern United States. Recovery of oil from such shale deposits could have environmental impacts that make development of such a technology questionable. One major environmental concern is the impact of

solid-waste leachates on the quality of surface waters and ground waters in the vicinity where the wastes are disposed of. Many of the shales contain on the order of 4 to 7% sulfur and, unlike the western shales, do not contain significant quantities of carbonate minerals to neutralize the sulfuric acid formed when the sulfur oxidizes. The acidic characteristics of the solid-waste leachates are a concern in two respects: (1) they enhance the leaching of toxic elements from the wastes and (2) they reduce the ability of the surrounding soils and geologic material to attenuate hydrologic transport of the leached toxic contaminants.

Two shales from Kentucky, the New Albany and Sunbury, were selected to assess the quality of solid-waste leachate before and after retorting by the HYTORT® process. Samples of the shale (raw and spent) were furnished by the Institute of Gas Technology (IGT) of Chicago, Illinois. The shales, sieved to 10- to 20-mesh size, were continuously leached (1.5 kg in a 10-cm-diam glass column) using distilled water over a 72-h interval (equivalent to approximately 15 pore volumes). Aliquots of leachate (150 to 200 mL) were collected over the leaching interval and characterized. After standing for one week, the remaining interstitial water was displaced from the column and analyzed (Table 1.1). These data imply that solid-waste leachate from some of the shales will severely affect surface water and ground water. For example, the leachates are highly acidic and contain high concentrations of toxic constituents (As, B, Cu, Ni, Zn, and Mo) relative to those measured in leachates from raw mined shales and soils from Colorado (Bates et al. 1981).

Table 1.1. Solid-waste leachate characteristics as mg/L of raw and spent eastern oil shales

Leachate characteristics	New Albany		Sunbury	
	Raw	Spent	Raw	Spent
Major constituents				
SO ₄ ²⁻	1700	1800	3000	1700
Na	3.1	25	1.6	82
Ca	510	500	140	400
K	15	33	a	130
Mg	180	60	64	68
Secondary constituents				
Al	a	2.3	1.5	0.14
Fe	a	17	940	26
Mn	10	6.2	7.1	3.3
Toxic constituents				
As	a	0.23	2.5	a
B	0.37	3.6	0.16	2.4
Cu	<0.01	0.13	33	0.07
Cd	<0.01	0.01	10	0.21
Ni	1.4	1.4	31	0.85
Pb	a	a	0.28	0.05
Zn	0.62	1.9	400	12
Mo	0.07	0.04	3.5	1.2
Other constituents				
U	a	a	1.5	0.14
pH	6.9	5.1	2.6	3.5
EC ^b	2400	2300	5400	2600

^aBelow detection.

^bAs micro-Siemens per centimeter.

Comparative Studies of Solid Wastes from Coal Gasification and Combustion (R. R. Turner)

Comparisons among solid wastes from coal gasification and conventional combustion were extended this year to include wastes from Illinois No. 6 and Kentucky No. 9 coals. Along with other high-sulfur eastern coals, these coals are prime candidates for large-scale gasification in the future. Previous research (Francis et al. 1982; Skarlos 1982) has demonstrated that certain gasification slags produced from these high-sulfur coals will yield acidic, high-sulfate leachates because of oxidation of reduced sulfur forms (chiefly pyrrhotite) in the waste. Column leaching experiments conducted during the past year using combustion wastes (fly ash, bottom ash, slag) from these coals have also yielded acidic, high-sulfate leachates. As shown in Fig. 1.2, bottom ash from Kentucky No. 9 coal yielded an acidic (pH = 4.6) leachate having sulfate concentrations (~1000 mg/L) in excess of the secondary drinking water standard (250 mg/L). Boiler slag from the same coal yielded much lower sulfate concentrations in the leachate, but the leachate was still somewhat acidic (pH = 5.8). In contrast, boiler fly ash (not shown in Fig. 1.2) yielded high-sulfate concentrations (~1000 mg/L), but the leachate was alkaline (pH = 9.9). X-ray diffraction analysis of the boiler bottom ash indicated the presence of pyrite (FeS_2), which was probably derived from the coal pulverizers (as reject) and not from the furnace. Such pulverizer reject

Fig. 1.2. Sulfate concentrations and pH of column leachates from solid wastes from coal gasification (entrained slags and fluidized ash) and combustion (boiler bottom ash and slag). All wastes produced from Kentucky No. 9 coal. Dashed line is drinking water standard (DWS) for sulfate. Data for gasification wastes from Francis et al. 1982.

(termed "tramp iron") is commonly disposed of along with combustion bottom ash. The alkaline fly-ash leachate results from hydrolysis of alkali and alkaline-earth oxides produced during the combustion process. Sulfate in fly-ash leachate is derived from soluble sulfates and is governed by the solubility of sulfates rather than by oxidation of reduced sulfur forms. These results suggest that acidic and/or high-sulfate leachates are not limited to coal gasification solid wastes.

Synfuel Wastewater Sludges

Edward C. Davis Della S. Marshall

The quantity of solid wastes produced by commercial-scale coal conversion facilities will be substantial, probably exceeding 7000 Mg of dry residue per day for a typical facility having a coal feed rate of 20,000 Mg/d (DOE 1980). Most of this solid waste will consist of gasification ash/slag and coal cleaning refuse, similar to coal combustion solid wastes in that it contains the bulk of the noncombustible inorganic fraction of the converted feed coal. In addition to this large quantity of inorganic waste material, smaller quantities of organic-laden wastewater sludges having no counterpart in the coal combustion industry will be generated and will require disposal. Work conducted during this reporting period has focused on these smaller-volume waste sludges, in particular, their behavior, degradation, and potential environmental effects in the disposal environment.

Chemical characterization of three synfuel primary sludges (SRC-I sump sludge, SRC-II centrifuge sludge, and H-Coal API oil effluent) and an API separator sludge from an oil refinery in the southwestern United States was completed and supports an initial hypothesis that the wastes are unique in elemental composition and must be treated as such from both a regulatory and an environmental perspective. Except for Mg, Se, and Zn, the concentrations of elements in the refinery sample fall within the range of concentrations observed in the three synfuel samples. Carbon appears to be the dominant element, occurring at levels as high as 61% in the H-Coal waste (see Table 1.2).

To simulate a land-treatment disposal scenario, the four sludge samples were mixed with a silt-loam soil using an application rate of 440 Mg/ha (195 tons/acre to a depth of 6 in.). After mixing, the samples were incubated in 5-cm-diam by 20-cm-height glass columns for a 245-d period. During this incubation time, CO₂ being generated by the waste/soil mixture was continuously monitored to determine organic matter degradation rates. In addition, leachate from two simulated 6.3-cm rainfall events was collected and analyzed.

The evolution of CO₂ resulting from sludge biodegradation was found to be described by a first-order exponential model. Rates and extent of CO₂ evolution were compared, and the H-Coal material was found to be the most biodegradable, approximately 100 mg of C being evolved for each gram of sludge applied to the soil. The SRC-I sample was least biodegradable, yielding only 3 mg of carbon per gram of sludge applied. Relatively high pH (8.6 to 9.2) and sludge toxicity are thought to be responsible for the stability toward biodegradation of this particular sample.

Given the sludge application rates used, the oil refinery waste was observed to degrade the fastest, requiring only 96 d for 90% of the estimated maximum amount of CO₂ to be evolved. Projections indicate that one year after disposal, three types of wastes (SRC-II, H-Coal, and oil refinery) will have completed greater than 95% biodegradation, whereas the SRC-I waste will be only 63% degraded.

Table 1.2. Comparison of the chemical characteristics of three synfuel wastewater sludges with that of a conventional separatory sludge oil refinery American Petroleum Institute (API)

Parameter	Sample			
	SRC-I	SRC-II	H-Coal	Oil refinery
pH ^a	13.1	6.4	6.3	7.8
Total solids, ^b %	14.4	27.9	4.0	11.7
Volatile solids, ^c %	26.4	67	85	84
Al, %	2.78	3.99	0.59	0.95
C, %	26.4	54	61	60
Ca, %	7.1	0.21	0.57	0.65
Fe, %	2.14	2.19	0.87	1.16
K, %	0.22	0.11	0.14	0.23
S, %	0.73	3.46	^d	2.11
As, ppm	51	10.2	1.82	10.1
Ba, ppm	91.4	56.6	≤12	≤860
Cd, ppm	4.2	2.77		
Cr, ppm	49	103	79	50
Cu, ppm	126	178	4	≤1700
Mg, ppm	24,600	1,030	850	≤200
Mn, ppm	875	53.0	78.6	237
Na, ppm	82,200	1,910	1,410	6,670
Se, ppm	4.15	1.94	10.1	31.9
Zn, ppm	283	402	201	918

^apH of 1:1 (deionized water to sample) mixture.

^bResidue remaining after heating to 100°C for 1 h.

^cPercentage of dry total solids lost after heating to 500°C for 30 min.

^dNot determined.

With few exceptions, concentrations of measured contaminants in the leachate were observed to decrease between simulated rainfall events 1 and 2. Certain contaminants, including sulfate, Cd, Cr, Pb, and Se, were found to exceed drinking water standards, indicating that the water quality of receiving streams should be of concern. The lowest water quality was observed in leachate from the SRC-I waste, which had a pH of 9.1 and an average total organic carbon (TOC) of 1500 mg/L. Visual inspection of this leachate identified a separate oil phase that was easily leached from the sludge-soil columns.

In summary, laboratory-scale experimentation indicates that land application of organic-laden wastewater sludge produced in the synthetic fuels industry will not only facilitate degradation of organic matter but also will mobilize potential environmental contaminants. Microbial degradation of organics, as measured by carbon dioxide evolution, has been shown to be essentially complete at the end of one year's time for the 440-Mg/ha sludge application rate used. The major environmental problem will probably be contamination of surface water by leachate having high levels of TOC and inorganics of concern to human health. Current work in this area is concentrating on the mobilization of these organics and their relevant environmental effects.

H-Coal Data Management

R. H. Strand M. P. Farrell D. T. Polouino

A coal liquefaction process assessment (H-Coal) was begun in 1980 to evaluate potential environmental and health effects. Efforts this past year have focused on process monitoring and sampling and subsequent examination of the products and effluents for possible occupational exposure and environmental impact. The data management component of the H-Coal assessment has successfully implemented a sampling design and a Project Results and Tracking System (PRTS) to organize and evaluate the numerous samples needed for the assessment. The computerized tools used in this assessment were those previously developed for an assessment of a gasifier. The restructuring of existing computer software resulted in substantial financial savings in executing the H-Coal assessment. This open-ended data management approach has facilitated the incorporation of specific sampling periods and concomitant process measurements and the selection of appropriate parameters to assess health and environmental effects of the H-Coal process.

Environmental Risk Analyses

L. W. Barnthouse G. W. Suter

Efforts in this area centered on (1) completion of documentation on the five techniques we are developing for doing environmental risk analyses (ERA) and (2) conducting ERA for Indirect Coal Liquefaction. Techniques that made possible the translation of tests on one species of fish to another and estimation of aquatic ecosystem response were evaluated. A description of the result of this effort is found in the section on the Environmental Impacts Program.

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2. TOXIC SUBSTANCES PROGRAM

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Introduction

Research in ecotoxicology is under way for the U.S. Environmental Protection Agency (EPA) Office of Toxic Substances, and several test protocols recommended for development are now under experimental evaluation. The Organization for Economic Cooperation and Development (OECD) single-species test protocols are also being evaluated before their incorporation into EPA's chemical assessment scheme. A multimedia modeling project is expanding the Oak Ridge National Laboratory (ORNL) Unified Transport Model to include toxic substances (organics). This model, UTM-TOX, will assist EPA in evaluating chemical dispersion and potentials as part of a chemical assessment. Also, an evaluation of water quality models for EPA was undertaken this past year.

Research for the U.S. Department of Energy (DOE) on radionuclides in the environment is one of the major concerns of the Toxic Substances Program. This past year was devoted, in part, to initiating a radionuclide assessment model validation program; continuing Pu, Am, Cm, and U work on Pond 3513; and completing our terrestrial Tc work. Because of the increased applications of high-resolution gamma spectroscopy to ²¹⁰Pb detection, an expansion of research relating to natural radionuclides has occurred.

Evaluation of OECD Protocols for Testing of Toxic Chemicals with Aquatic Biota

B. G. Blaylock J. F. McCarthy M. L. Frank

The Toxic Substances Control Act (TSCA) requires EPA to approve any chemical before it is marketed. The decision is based on various types of information regarding human, terrestrial, and aquatic environments. Consequently, EPA undertook the task of evaluating protocols in the OECD

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³Computer Sciences Division, UCC-ND.

guidelines to determine whether the tests could provide some information required under TSCA. The Environmental Sciences Division assisted EPA by evaluating the following aquatic tests.

1. **Fish Acute Toxicity Test.** This protocol was evaluated in fathead minnows and bluegill sunfish for a readily soluble inorganic chemical, copper chloride, and for a hydrophobic organic compound, acridine. The toxicity was evaluated under static, semistatic, and flow-through exposure regimes. The 96-h LC50 for copper was from 1.0 to 1.8 mg Cu²⁺ L⁻¹, while for acridine, the LC50 was from 2.0 to 3.1 mg L⁻¹. The range of LC50s indicates the results of experiments with different exposure regimes and shows that similar toxicity estimates are produced regardless of the method of exposure.

2. **Flow-through Fish Test.** The bioaccumulation of organic contaminants of differing hydrophobicities was evaluated using the bluegill sunfish. Two chemicals were evaluated in detail: naphthalene, a relatively water-soluble PAH, and a very hydrophobic insecticide, 2,2'-bis(4-chlorophenyl)-1,1'-dichloroethylene (DDE). The rates of uptake and depuration and total bioaccumulation in fish were determined under flow-through exposure conditions at two concentrations of each chemical. The steady-state bioaccumulation of naphthalene was 300 times the concentration in water, and DDE bioaccumulated 100,000-fold. The estimated bioaccumulation factor was independent of the amount of chemical in the water. These results are in agreement with the literature and consistent with the general observation that more hydrophobic chemicals have greater potential for bioaccumulation. This observation was found to be invalid, however, in assessing the bioaccumulation of chemicals which are rapidly metabolized and/or detoxified by fish. The bioaccumulation of BaP, a PAH with a hydrophobicity comparable to DDE, was found to be several orders of magnitude less than that of DDE because of the rapid biotransformation and excretion of the PAH by fish.

3. ***Daphnia* Acute Immobilization Test.** The OECD guidelines for the *D. magna* immobilization and reproduction tests, respectively, were evaluated by conducting these tests with three chemicals representing either a water-soluble or less water-soluble chemical. Cupric chloride was the water-soluble chemical, and acridine and di-*n*-butyl phthalate represented the less water-soluble chemicals. The 24-h immobilization test provided data necessary for determining the range of chemical concentrations to use in the reproduction test and also data concerning acute toxicity. The 24-h LC50 for *D. magna* was 0.075 mg L⁻¹ for Cu²⁺, between 2.5 and 10 mg L⁻¹ for acridine, and between 3.0 and 7.5 mg L⁻¹ for di-*n*-butyl phthalate. Significant effects on reproduction were observed at 0.03 mg L⁻¹ for Cu²⁺, 1.25 mg L⁻¹ for acridine, and 1.8 mg L⁻¹ for di-*n*-butyl phthalate. Results obtained in these tests on acute toxicity and reproduction are consistent with similar results found in the literature.

Some of the procedures in the guidelines were evaluated to determine their influence on test results. Extending the test from three to six broods did not produce additional significant information on reproduction in the cupric chloride test. Individually culturing the *D. magna* provided information on female sterility and more precise information on the number of broods per female; however, group culturing provided the data necessary for determining the effect of a chemical on reproduction. Statistical analysis of either the number of young produced per female per brood or the total number of young produced per female for three broods gave similar results.

4. **Alga Growth Inhibition Test.** The OECD guidelines were evaluated by conducting tests with two species of green algae and three chemicals. The chemicals tested were cupric chloride, acridine, and paradichlorobenzene. These chemicals represented the following classes of chemicals: water soluble, less water soluble, and volatile, respectively. Exponential growth rates were obtained in the

control cultures, and growth inhibition was obtained in the treated cultures. Growth inhibition data were used to calculate the following 96-h EC50s for *Selenastrum capricornutum*: Cu^{2+} , -0.4 mg L^{-1} ; acridine, -0.8 mg L^{-1} ; and paradichlorobenzene, -6.0 mg L^{-1} . A growth inhibition test with capric chloride was conducted with another species of green algae, *Chlorella vulgaris*. The 96-h EC50 was 0.2 mg L^{-1} , thus indicating that this species was more sensitive to Cu toxicity than was *S. capricornutum*; however, both species were suitable for conducting the inhibition test. The EC50s determined in these tests are within the range of similar values cited in the literature that were obtained by using other protocols.

An evaluation of counting methods for determining cell number or biomass in algae cultures indicated that fluorometric measurements of intact cells or fluorometric measurements of extracted chlorophyll *a* gave reproducible results in the shortest time under the test conditions employed and for the species used in the test. Microscopic counts of algae cells gave reproducible results but were time consuming. The Coulter counter model used in these tests did not provide satisfactory results under the test conditions.

Although some minor improvements of the various protocols are suggested based on our test results, the OECD protocols are valuable guidelines for evaluating the toxicity and bioaccumulation potential of new chemicals. The greatest value of the protocols is in standardizing exposure conditions and the treatment of and reporting on results of the tests. Such standardization should improve the quality of the toxicity estimates and permit the variations in reported results of tests conducted in different laboratories to be more readily resolved.

Multispecies Protocol Development for EPA

C. T. Garten, Jr. G. W. Suter

Test Protocol for Chemical Toxicity to *Rhizobium*-Legume Symbioses

Toxicity testing has classically involved testing a single chemical on a single species of plant or animal, and only recently have multispecies tests been developed. For example, we developed a suggested protocol for testing chemical toxicity on two multispecies associations involving the *Rhizobium*-legume symbiosis for N fixation. The test protocol uses bush beans (*Phaseolus vulgaris*) or clover (*Trifolium repens*), along with their respective *Rhizobium* symbiont, grown under greenhouse conditions in sand irrigated with a nutrient solution containing the test chemical. In order to evaluate the system and several exposure protocols, three chemicals were chosen for testing that would selectively attack (1) the host legume (2,4-dichlorophenoxyacetic acid), (2) the bacteria (streptomycin sulfate), and (3) both the host legume and bacteria (copper sulfate). Published data from testing the effects of pesticides on *Rhizobium*-legume symbioses indicated that a chronic or subchronic exposure protocol would be inexpensive, rapid, and sensitive to chemical effects. A chronic exposure test (i.e., one where the chemical was present in the nutrient solution over the entire life of the plant) proved to be more sensitive than other exposure protocols tested. The chronic test was more likely to detect toxicity because of the chemical effects on the process of *Rhizobium* infection and nodule establishment and on early plant growth.

Clover and beans had disadvantageous properties as host legumes for the chronic exposure protocol. Clover grew very well without nitrogen in nutrient solution and was a more sensitive test plant for detection of chemical toxicity than were bush beans. However, if the clover seed is irrigated too frequently with the nutrient solution, the seed is subject to attack by mold, which reduces

the final yield. Washing clover seed with ethanol before planting the seed in sand seems to lessen the susceptibility of the seed to fungal attack. Our studies indicated that bush beans would not grow to healthy mature legumes when irrigated with an N-free nutrient solution. Supplemental NO_3^- at a level of approximately 100 ppm in the nutrient solution promoted plant growth, but it did not inhibit nodulation or N fixation. Of all the response variables examined, bean and clover biomasses were the most sensitive indicators of chemical toxicity. Therefore, all plants must be tested at the same age to allow comparisons of results with different chemicals. Beans and clover were ready to test about four weeks after their germination. Although measures of nodulation were sensitive to chemical treatments in tests using beans, they were not sensitive in tests using clover. Measurements of N fixation by the C_2H_2 -reduction assay and whole-plant N by Kjeldahl analysis were expensive, time consuming, and no more sensitive than were simple measurements of plant growth and nodulation performance in detecting chemical toxicity. An absolute difference between treatment means of 25-50% was statistically detectable with a reasonable number of replicate pots per treatment.

Soil Microbial Processes

The purpose of this study was to examine the utility of a test for the effects of chemicals on soil processes. The test system, which was proposed by an EPA-sponsored workshop, is the simplest system which could realistically represent the energy and nutrient dynamics of soils. The system consists of 50 g of sieved fresh soil amended with ground alfalfa. Carbon dioxide efflux is measured as an indication of community metabolism and decomposition rates; NO_3 and NH_3 concentrations are measured to reveal effects on the nitrogen cycle.

Five chemicals (Cd, Cu, phenol, streptomycin, and hexachlorobenzene) were chosen to represent a range of potential test chemicals. At high concentrations, Cd, Cu, and phenol reduced CO_2 efflux, while low concentrations of those chemicals and all effective concentrations of streptomycin and hexachlorobenzene increased CO_2 efflux. All of the chemicals tested tended to increase NH_3 concentrations and decrease NO_3 concentrations.

Alfalfa-amended soil was found to be more sensitive to the effects of chemicals than was unamended soil. Soil amended with nutrient broth was also found to be sensitive, but some responses were qualitatively different from those of both alfalfa-amended and unamended soil.

The results obtained with this test system are generally consistent with responses observed in other laboratory tests and with observed effects on soil and litter in heavy-metal-contaminated areas. A variation of about two orders of magnitude appears to exist in the concentrations of metals to which different soils respond, and there is also considerable variation in the direction of response. Results with hexachlorobenzene also suggest that the lowest effective concentration of a chemical can vary by more than three orders of magnitude, depending on the way the chemical is applied.

Natural soil can be considered a basic terrestrial microcosm. The numerous biotic and physical components of soil contribute most of the diversity in even highly complex terrestrial microcosms. This diversity confounds mechanistic interpretation of the results of soil tests. A chemical may decrease CO_2 efflux by general toxicity or increase it by (1) being degraded to CO_2 ; (2) killing sensitive organisms, which are then degraded by resistant microbes; (3) generally promoting biotic metabolism; or (4) releasing CO_2 from carbonates. Similarly, a toxic chemical may simultaneously inhibit both mineralization and uptake of nitrogen, thus resulting in little change in the size of inorganic nitrogen pools. Finally, the sorptive properties of soil can greatly reduce the effective concentration of a test chemical.

In general, the effect of this physical and biotic diversity is to decrease the sensitivity and increase the realism of this test relative to those tests which contain one or a few species growing in solution media. This increased realism compensates for the high variability of test systems using natural soils.

Evaluation of Water Quality Models

C. C. Coutant J. E. Breck

The EPA wants to use water quality models to assist in the Wasteload Allocation (WLA) and National Pollutant Discharge Elimination System (NPDES) permitting processes in order to help meet water quality criteria for the priority toxic pollutants. Many computer models have been developed and used for different types of water quality analyses, but not all of these models are appropriate for modeling organic chemicals or metals discharged into receiving waters. Water quality models developed for conventional pollutants, such as suspended solids, biological oxygen demand, and high water temperature, can treat only chemical pollutants as conservative substances. However, this may be an unnecessarily restrictive approach for organics and metals because several processes may significantly reduce their concentrations in the receiving water. Thus, this study is being done to identify, describe, and evaluate computer models appropriate for organic chemicals and metals in order to aid water quality analysts in choosing models most appropriate for the particular problem being addressed.

When scientists consider organic and metal pollutants, several additional processes that are not included in models developed for conventional pollutants must be considered: volatilization, direct photolysis, hydrolysis, oxidation, biodegradation, absorption/desorption, speciation, complexation, and precipitation. These processes may reduce the threat to biota, and their incorporation into models aids scientists in making decisions about the allowable effluent discharge rates.

Models with a much greater level of temporal and spatial resolution include the Channel Transport (CHNTRN) (Yeh 1982) and Hydrologic Simulation Program—Fortran (HSPF) (Johanson et al. 1980). In these models, the processes mentioned previously are treated separately, and several processes are functions of temperature and pH. Both models require detailed hydrodynamic flow data, which may be supplied by a separate hydrodynamic model. Sediment transport, deposition, and scouring are simulated for several particle sizes. Interactions with sediment (including transport of sediment-sorbed chemicals) can be very important in determining the concentration of a chemical in the water column for chemicals that sorb strongly to sediment particles. Correct modeling of sediment may be very important in estimating chemical concentrations in the water. These models require a great deal more input data than does the Simplified Lake Stream Analyses (SLSA) model. The greater resolution of these models is useful when pollutant loadings vary greatly in time (e.g., analyses of effluent discharges of chemical manufacturing plants which produce chemicals in batch processes).

When an effluent is of unknown composition, models cannot be used. In these cases, the effluent, which is often a complex mixture, must be tested directly. Consequently, as another part of this study, we are identifying, describing, and evaluating bioassay methods for evaluating complex effluents. Because an important goal of the water quality legislation is to restore and maintain the biological integrity of the nation's waters, methods at several levels of biological organization are being considered.

Several models that can be used for organic pollutants have been identified. Among these are CHNTRN, CMRA, EXAMS, FETRA, FOAM, HSPF, PEST, RIVMOD, SERATRA, SLSA, TOXIC, TOXWASP, UTMD-TOX, WASP, and WASTOX. These models differ in several ways: (1) the water bodies modeled (stream, lake, or estuary), (2) the type of mathematical solution (dynamic or steady state), (3) the processes included, (4) the data and time required to apply the model and obtain a solution, (5) the temporal and spatial scale considered, (6) the types of biota included, and (7) the extent of error analysis and verification needed.

A good example of a model which was developed specifically as a simple tool for steady-state partitioning is SLSA (DiToro et al. 1981), which contains simplified descriptions of the basic processes influencing chemical fate in streams and unstratified lakes. For example, chemical loss processes are represented by a single first-order rate constant, which is the sum of loss rate constants for processes such as volatilization, oxidation, and photolysis. For certain idealized conditions, an analytical solution is given for the steady-state chemical concentration as a continuous function of distance downstream. Relatively few input data are required. Such a model would be useful where preliminary evaluations of pollutant concentrations in the receiving water are required, more detailed input data are lacking, or resources for evaluation of the problem are very limited.

Experimental Model Validation

E. A. Bondietti C. T. Garten F. O. Hoffman

The assessment of the environmental impact of toxic substances relies on the use of mathematical models to predict the transport, fate, and consequences of these substances in aquatic and terrestrial ecosystems, including exposure pathways of importance to human populations. However, decisions based on model predictions are subject to contention when the amount of uncertainty associated with these predictions is unknown. Improvement of the reliability of models used for decision making requires knowledge of the uncertainties in model predictions. The best method for determining these uncertainties involves field testing of the models and their data bases against independent sets of observations. This process is referred to as "model validation."

In addition to determining the accuracy associated with the predictions of specific environmental assessment models, validation research within the Toxic Substances Program has several other objectives:

1. determination of the appropriate experimental designs for testing models, submodels, and parameters under field conditions in order to explain sources of model misprediction and/or compensating error;
2. identification of the degree to which parameter and model bias and system variability contribute to predictive uncertainty;
3. definition of the practical level of irreducible uncertainty associated with either the generic or site-specific application of models under both conditions of prolonged and acute exposure; and
4. recommendation of procedures for improving the accuracy of current assessment models.

A preliminary attempt at model validation is depicted in Fig. 2.1, in which concentrations of particulate aerosols on the surfaces of herbaceous pasture vegetation (resulting from a unit rate of continuous deposition) are predicted by six internationally recognized radiological assessment models. These predictions are compared to two sets of observations obtained by using cosmogenic ^7Be as a natural tracer of regionally dispersed small particulate matter ($\sim 0.3\text{-}\mu\text{m}$ -diam particle

Fig. 2.1. Predictions from six models of the concentration of tropospheric particulate radionuclides on the surfaces of herbaceous pasture vegetation are compared with two sets of observations that used cosmogenic ^7Be as a natural tracer for regionally dispersed, submicron aerosols. All values are normalized for a unit rate of continuous deposition per square meter of ground area.

size). One set of observations represents data collected at a specific location (0800 area of the Oak Ridge National Environmental Research Park), while the other set comprises data from the multiple environmental monitoring stations in the near vicinity and general region surrounding ORNL (Auxier 1981).

The two sets of observations are represented by estimates of the geometric mean and 95% range. It is evident that the predictions of three of these six models (NRPB, IAEA, and AIRDOS/EPA) are comparable to the geometric means of both sets of observations. All six model predictions are encompassed by the 95% range of observed values associated with monitoring data; however, three models (BIOPATH, ABG, and NRC) are not encompassed by the 95% range for the 0800 site. For this preliminary attempt at model validation, the extent of natural variability, represented by the 95% range of observations for multiple monitoring locations, is about an order of magnitude, whereas at a specific site, it is only a factor of 3.

Air-to-Vegetation Transfer

The air-to-vegetation transfer function of the various models considers wet and/or dry flux, vegetation interception, and effective weathering half-life. For steady-state air concentrations, it is not possible to validate either the plant interception or the effective half-life parameters because the observed vegetation concentrations are a net function of both processes. For an accident case (i.e., a pulse release), validation of both parameters is obviously possible. One might ask why experiments cannot be designed to evaluate these parameters under steady-state conditions. The answer is, of

course, that they can—although such experiments defeat the purpose of validation, which is to see how adequately past experimentation has been interpreted for decision-making applications and to assess variability. Thus, such experimentation is model improvement, not model testing.

Beryllium-7 and Radiolabel Isotopes as Models

Cosmogenic ^7Be ($t^{1/2} = 53.3$ d) is distributed in the earth's lower atmosphere quite uniformly, especially at a given latitude. A spring maximum-fall minimum cycle exists which shows a factor-of-3 range in airborne concentrations; this range results from the winter-spring intrusion of stratospheric air (with higher ^7Be levels). Both ^{210}Pb and ^7Be reside on accumulation-size aerosols (~ 0.3 μm diam), while ^{214}Pb (26.8 min) and ^{212}Pb (10.6 h) isotopes may, on the average, be associated with smaller aerosols because of the isotopes' short half-lives relative to tropospheric coagulation processes. It is not clear if ^{210}Pb or ^7Be is the better atmospheric radionuclide model. Lead has the advantage of being produced from ^{222}Rn (exhaled at ground level) but the disadvantages of nonuniform distribution (coastal vs inland) and tedious measurement, especially for vegetation interception studies. Beryllium-7 is uniformly distributed and monitored, thus making long-term ambient ground-level air concentration data available at various continental locations. When normal natural variation is considered, the washout ratios of ^7Be and ^{210}Pb are similar, except for a short period in the spring when the stratospheric ^7Be source affects the in-cloud scavenged air mass more than it does the ground-level air mass and ^7Be may underestimate dry deposition in high inversion frequency regions. Beryllium-7 is very easily measured with high-resolution gamma detectors. The short-lived ^{212}Pb and ^{214}Pb isotopes have only limited uses. Lead-212 is mixed in the boundary layer fairly uniformly under most conditions of atmospheric turbulence and thus should provide a model for dry deposition in humid environments.

Like all surrogates, these tracers of natural aerosols are not ideal. We will use them, however, as "real world" radioactive aerosols representative of regional plume dispersion.

Deposition to vegetation. Table 2.1 presents a comparison of ^7Be levels in vegetation sampled under two distinct climatic regimes—dry summer (California) and wet summer (Tennessee). The same ambient annual air concentrations, 0.09 pCi m^{-3} , are found in Livermore, California, and Oak Ridge, Tennessee (Auyong et al. 1982; Auxier 1981). The expected consistency of air concentrations makes the comparisons and interpretations of the two climatic regimes relatively easy.

Dry deposition of the accumulation-mode aerosol (mean diameter = 0.3 μm) appears to contaminate vegetation about only 10% as effectively as does wet deposition, with the exception of the pines and the beans sampled in Santa Barbara County. However, the results of the pine studies are difficult to interpret. The specific surface area of the pines is about a factor of 3 lower than that of the broadleaves; this finding is consistent with the observed differences in ^7Be concentrations (rain derived) under Tennessee conditions. Thus, the California pine values could represent a combination of much higher dry deposition capture and memory of spring rains. The Santa Barbara bean results are significant. Being situated 8 km from the coast, the pole bean leaves received almost continuous nightly fog and daily wind exposures. In contrast, the lima beans (56 km farther inland) grew under no fog (and low dew) and low wind conditions. The pole beans, which received no rain, have elevated levels of ^7Be , probably because the fog increased the deposition rate, or fixation rate, of atmospheric ^7Be to the leaves, as well as specific leaf area ($\text{cm}^2 \text{g}^{-1}$) differences.

Deposition velocities (pasture). The data in Table 2.1 can be used to calculate the following total vegetation deposition velocities for fescue, assuming 0.09 - pCi m^{-3} air concentrations and a

Table 2.1. Measured values of cosmogenic ^7Be associated with vegetation sampled Aug. 26 to Sept. 3, 1982, in two different climatic regimes: dry summer (California) and wet summer (Tennessee)^a

Locations and plants sampled	^7Be concentration (d.y weight)	
	pCi/g ($\pm$ SD) ^b	pCi/m ² ($\pm$ SD)
California		
San Mateo County (38°N)		
Monterey pine (<i>P. radiata</i>)	0.97 (0.07)	
Livermore (39°N)		
Leaves		
Bush bean (<i>P. vulgaris</i>)	0.67 (0.09)	
Fescue (<i>Festuca</i> sp.)	0.55 (0.05)	211 (31)
Corn (<i>Z. mays</i>)	0.54 (0.12)	
Bigleaf maple (<i>A. macrophyllum</i>)	0.40 (0.07)	
Monterey pine (<i>P. radiata</i>)	1.9 (0.2)	
Whole plants		
Dallis grass (<i>Paspalum</i> sp.)	<0.05	
Dry annual grasses (<i>Bromus</i> , <i>Avena</i> , et al.) ^c	0.99 (0.09)	
Santa Barbara County (35°N)		
Leaves		
Pole bean (<i>P. vulgaris</i>)	1.8 (0.2)	
Lima bean (<i>P. vulgaris</i>)	0.48 (0.06)	
Fescue (<i>Festuca</i> sp.)	0.67 (0.1)	568 (85)
Tennessee (36°N)		
Leaves		
Pole beans (<i>P. vulgaris</i>)	4.4 (0.4)	
Sycamore (<i>P. occidentalis</i>)	4.3 (0.4)	
Fescue (<i>Festuca</i> sp.)	5.9 (0.4)	1610 (110)
Corn (<i>Z. mays</i>)	7.2 (0.3)	
Loblolly pine (<i>P. taeda</i>)	2.1 (0.1)	
Shortleaf pine (<i>P. echinata</i>)	1.2 (0.1)	
Whole plants		
Dallis grass (<i>Paspalum</i> sp.)	2.5 (0.3)	
Barnyard grass (<i>E. crusgalli</i>)	3.3 (0.2)	
Old field vegetation	3.9 (0.1)	3190 (110)

^aHistorical monitoring data indicate very similar annual ^7Be concentrations in air between ORNL and Lawrence Livermore Laboratory (LLL), 0.09 pCi m^{-3} .

^bSD = standard deviation.

^cCalifornia annual grasses germinate in the fall and mature in April-May.

14-d effective half-life: for Livermore, 0.13 cm s^{-1} ; for Santa Barbara County, 0.36 cm s^{-1} ; and for Tennessee, 1.0 cm s^{-1} . The dry values (0.13 and 0.36 cm s^{-1}) are quite consistent with the 0.2 cm s^{-1} value often calculated (Krey and Toonkel 1977) or inferred (Malakhov and Pudovkina 1970) for fallout.

Deposition velocities (leaf surfaces). Table 2.2 presents ^7Be , ^{212}Pb , and ^{214}Pb data for dry deposition to leaf surfaces. The values are quite similar if all the uncertainties (not shown) are considered. The fescue ^{212}Pb value may be high because of its proximity to the soil (nighttime air stagnation problems). The values are not different from the literature where wind tunnel studies have dominated.

Table 2.2. Selected concentrations and dry deposition velocities (V_d) for leaf surfaces using ^7Be , ^{212}Pb , and ^{214}Pb as aerosol tracers

Sample	pCi g ⁻¹			Specific area (cm ² g ⁻¹)	t ^{1/2}	V _d (cm s ⁻¹) ^a		
	⁷ Be	²¹² Pb	²¹⁴ Pb			⁷ Be	²¹² Pb	²¹⁴ Pb
California								
Fescue	0.61			211	14 d	0.02		
Bean (lima)	0.48			375	14 d	0.008		
Bigleaf maple	0.40			331	14 d	0.008		
Pine	0.13			72	14 d	0.13		
Tennessee								
Fescue		5.2		211	10.6 h		0.05	
Sycamore		0.95		331	10.6 h		0.006	
			1.23	331	0.477 h			0.003
Pine		0.9		72	10.6 h		0.02	

^a $V_d = (0.693) (t^{1/2})^{-1} (\text{pCi cm}^{-2}) (\text{pCi cm}^{-3})^{-1}$; air concentrations (pCi m^{-3}): ^7Be , 0.09; ^{212}Pb , 9.44; and ^{214}Pb , 636.

Summary. We feel that the ^7Be -labeled natural aerosol provides a useful tool to validate radionuclide assessment models. The other nuclides (^{210}Pb , ^{214}Pb , and ^{212}Pb) offer additional tools for validation studies as well as more mechanistic approaches (Russel et al. 1981). Most intriguing is the use of ^7Be to look at regional-scale deposition processes, especially under low summer rainfall conditions. Lead-210, even with the limitations of a poor air-monitoring record, resuspension, root uptake, and long half-life, is equally valuable for studying certain deposition trends. Also, ^{212}Pb and ^{214}Pb offer exciting possibilities for dry deposition evaluation in humid climates, particularly for species-specific measurements.

Soil/Vegetation-to-Milk Transfer

In preparation for validating the soil-milk and vegetation-milk predictions of various radiological assessment models, we maintained a goat doe-kid pair on the contaminated floodplain site from mid-April through July 1982. Using the Regulatory Guide methodology of the U.S. Nuclear Regulatory Commission (NRC) (NRC 1977), we compared the observed concentrations of ^{137}Cs and ^{90}Sr in goat milk to the predicted concentrations and the dry matter intake, intake-to-milk transfer, and soil-to-plant transfer parameters recommended by the NRC as default values. The goats were maintained on small fescue plots previously used for a garden. The soil in these plots was previously mixed mechanically to ensure uniformity. The single-animal results indicated the following: the NRC methodology overpredicted ^{137}Cs in milk by a factor of 67, with the intake-to-milk prediction high by a factor of 10 and the soil-to-plant prediction high by a factor of 6.7 (i.e., a factor of 67 total). The ^{90}Sr prediction, however, was low by a factor of 21, almost entirely because of a misprediction in the soil-to-plant transfer. Because only one animal was studied, it is premature to call the previous results a validation. During the coming year, we will examine ten animals for variabilities (e.g., variabilities in transfer).

We have, however, reached several procedural conclusions. First, the dry matter intake term (i.e., contaminated pasture) of the models is almost impossible to validate without extensive experimentation because all dairy animals are fed protein supplements. Second, the amount of pasture vs grain to be fed to the animals is uncertain since there is not a standard ratio worldwide. We will

use either a standard amount for all animals, such as a university farm extension circular might recommend, or an amount based on the respective animal body weight.

Vegetation-milk. This pathway will be used to simulate accidental releases. Iodine-131 and ^{131}C will be applied by spraying a field once, and the animals will then be allowed to graze. Half-lives on vegetation and in milk will be measured and compared to the model predictions, as will be the magnitude of the radionuclide in milk as a function of vegetation level. Variability of measurements among the herd will also be examined.

Soil-milk. For a site contaminated with long-lived fission products, we will examine the soil-to-milk prediction and its variability. This is the only practical study currently possible since the animals will be in a semiforested environment for which we do not have as good an estimate of vegetation species consumption as we do regarding animals in open pasture.

Radionuclide Distributions in Coastal Areas

N. H. Cutshall I. L. Larsen C. R. Olsen

The objective of this study is to use the distribution of natural and anthropogenic radionuclides to determine the rate, pattern, and extent of contaminant transport and accumulation in estuarine and coastal areas. This research has involved cooperative efforts with other coastal zone scientists. In particular, we have been working with M. Nichols, R. Huggett, and R. Diaz (Virginia Institute of Marine Sciences) in examining the processes which affect the fate of synthetic organic chemicals and radionuclides in the James and Elizabeth estuaries (Cutshall et al. 1981). In addition, we recently cooperated with T. Church and R. Biggs (University of Delaware) in obtaining samples from Delaware Bay to examine the fate of contaminants released from the Salem reactor site and from the Chambers Works radioactive burial sites. We have also continued our studies on the Amazon shelf with K. Turkian (Yale University) and D. Demaster and C. Nittrouer (North Carolina State University), in Cape Lookout Bight and adjacent coastal waters with L. Benninger (University of North Carolina), in the New York Bight with M. Bothner (U.S. Geological Survey), and in the Hudson-Raritan estuary with H. J. Simpson and R. Bopp (Lamont-Doherty Geological Observatory). We are participating in all of these cooperative studies by measuring ^{137}Cs , ^{134}Cs , ^{60}Co , ^7Be , ^{234}Th , ^{226}Ra , ^{228}Ra , and ^{210}Pb in water, suspended matter, and sediment samples. We have developed techniques for measuring ^{210}Pb , ^7Be , and ^{234}Th by nondestructive gamma-ray spectrometry (Larsen and Cutshall 1981; Cutshall et al., in press) which enhance the number and rapidity of analyses, reduce the cost, and preserve samples for other analyses such as polychlorinated biphenyls (PCBs), Kepone, or plutonium, which require sample digestion.

Lead-210 is one of the naturally occurring radionuclides most frequently measured by geochemists and geologists, who use it for dating sedimentary and environmental processes that have occurred over the past 100 years. Analyses of ^{210}Pb are difficult and time consuming because they involve sample leaching, radiochemical purification and counting. Previous attempts at direct sample analysis by gamma-ray spectrometry have been imprecise because self-absorption of the 46.5-keV ^{210}Pb gamma ray is highly dependent on sample composition.

Our new instrumental procedure determines the attenuation coefficient on each sample by measuring the transmission of ^{210}Pb gamma rays from a solid source. Then a correction factor, $F = (\ln T/T - 1)$, is calculated, where T is the transmitted ^{210}Pb source count rate divided by the count rate without a sample present. When F is then multiplied by the sample ^{210}Pb gamma emission rate and by an efficiency factor, the result yields the ^{210}Pb content of the sample.

The method has been applied to several standardized materials and to samples previously analyzed by radiochemical methods. The accuracy of our gamma-ray ^{210}Pb results for standard reference materials and for agreement for radiochemically analyzed samples is excellent. The number of samples for which the cost of gamma-ray instruments equals the cost of radiochemical processing is estimated at 300.

Beryllium-7 (53.3-d half-life) is another natural radionuclide which has been measured nondestructively by gamma-ray spectrometry in our laboratory. The distribution of ^7Be in coastal zones has been used to calculate the length of time chemically reactive contaminants remain in the water column before they are removed by settling particles and to trace the redistribution (accumulation patterns and mixing) of sediments in coastal waters (Olsen et al. 1982). Beryllium-7 activities (concentrations) in coastal water samples are fairly constant, ranging from 3.7 to 11.1 mBq/L. Concentrations of ^7Be on suspended matter ranged over an order of magnitude, with the highest levels occurring in areas of little or no deposition and the lowest activities (0.037 Bq/g) associated with suspended particles collected in the turbidity zone of the James River estuary. Variations in ^7Be concentrations in suspended matter appear to reflect the length of time that a particle remains in the water column. Half-removal times for ^7Be ranged from 4 to 8 d in the James and from 20 to 60 d in near-shore marine waters during June–July 1981.

The anthropogenic radionuclides (^{137}Cs , ^{134}Cs , and ^{60}Co) have been used to trace contaminant transport, calculate contaminant accumulation rates, estimate the extent of contamination associated with reactor releases, and develop contaminant budgets (Cutshall et al. 1981; Olsen et al. 1981). Future efforts will focus on the erosional input, dynamics, and accumulation patterns of ^{137}Cs in Chesapeake Bay. In addition, we are discussing the possibility of a study in conjunction with R. Mclean (State of Maryland, Power Plant Siting Committee) on the kinetics of radiocesium sorption-desorption and the effects of Fe-Mn and organic cycling on the fate of ^{60}Co , ^{54}Mn , and ^{65}Zn in Chesapeake Bay.

ORNL Pond 3513 Research

T. R. Trabalka E. A. Bondietti

Pond 3513 Description

For several years, the ORNL staff has studied the distribution and behavior of a varied assemblage of actinides in the water, sediment, and biota in a system which appears to provide the opportunity to examine near-equilibrium conditions. The system is Pond 3513, the former final low-level radioactive waste settling basin for ORNL. The ultimate objective of this research is the development of additional predictive capability on the biogeochemical behavior of actinides which are important radiological constituents of wastes from nuclear fuel cycles (isotopes of U, Pu, Am, and Cm). The surface sediments in ORNL Pond 3513 are a relatively thick (>20 cm, except in areas of scour), homogeneous mixture of materials which were used or produced in the lime-soda clay waste treatment process.

Primary Features of Solution Behavior

Concentrations of ^{238}U and $^{239,240}\text{Pu}$ (Fig. 2.2) in pond water filtered through a 0.22- μm membrane varied significantly, with time, over the observation period of March 1977 to June 1982.

Fig. 22. Behavior of soluble Pu and U in Pond 3513 located at the Oak Ridge National Laboratory. The water concentrations (Bq/m^3) represent the period March 1977 through June 1982. The cyclic behavior reflects a late summer maximum.

About 75% of the Pu, especially during the maximum, is apparently Pu(V) (Bondietti and Trabaika 1979). Except for the low U and Pu concentrations noted after the first few months (summer) of data collection (caused by a massive algal bloom) and the Pu spike occurring at about the 24th month (December) (caused by an accidental discharge from misdirected waste transfer), an annual cycle appears to exist for both U and Pu. The two actinides peak in summer and decline in winter. The hypothesis for this effect is that the pH increase noted during the summer because of photosynthetic degassing of CO_2 causes increased complexing of U(VI) and Pu(V) or Pu(VI). This increase could be due to either carbonate or hydroxyl ions. An alternative explanation would be that a shift of the oxidation state equilibria in favor of the higher Pu and U valences results because of higher pHs.

Oxidation/Reduction Kinetics of Pu and Np in Pond 3513

In April 1982, an experiment was started in Pond 3513 to evaluate the rate at which sediment-bound Pu, when subjected to reducing (in sediment) conditions, would oxidize to the more soluble Pu(V) state after exposure to the atmosphere. Large plastic tanks (127 cm high and 71 cm diam) were embedded into the pond sediment enclosing about 500 L of pond water 1 m in depth. Two enclosures served as test systems where O_2 was excluded by sealing alone or by sealing after glucose was added. Both indigenous Pu and added ^{237}Np were studied. The results indicated that

solution-phase Pu(V) and Np(V) could be reduced to Pu(III + IV) and Np(IV) by adding glucose and thus forcing the systems anaerobic. When the system was re-aerated, Np(V) immediately reappeared in the overlying water to about 25% of its original solution concentration. However, Pu(V) did not reappear as fast; in fact, in the two covered tanks, the response of Pu to aeration was a factor of 3 increase in soluble Pu(V) after about three months. These concentrations were still about a factor of 5 lower than the bulk pond (but comparable to the control enclosure). Although more data need to be examined, evidence exists, as expected, for slower reoxidation of Pu than Np. The annual cycle depicted in Fig. 2.2 could therefore be due to a redox cycle driven by pH, decay processes in the sediment, and temperature (oxidation kinetics). The shallow nature of Pond 3513 (1 m) makes processes occurring in the sediment extremely important. More work will be needed, however, to elucidate the redox cycle, if indeed it actually exists.

Field and Greenhouse Experiments on the Fate of Technetium in Plants and Soil

C. T. Garten, Jr. F. O. Hoffman

The behavior of ^{95m}Tc in plants and a Captina silt loam soil following a single application of the pertechnetate form of the radionuclide to bare soil was compared under field and greenhouse conditions. Over a period of six months, the net uptake of ^{95m}Tc by plants from undisturbed, intact soil in the greenhouse was approximately a factor of 10 greater than in the field. This difference was probably caused by new root growth in the excavated soil and less meteorological weathering of contamination from the foliage under greenhouse conditions. Sieving the soil through a 2-mm mesh screen prior to potting and then planting new grass increased plant uptake of ^{95m}Tc by approximately a factor of 20 compared to grass in the field. Uptake by new grass was increased even more by decreasing the pot size. The differences between experimental conditions did not correlate with differences in the extractability of ^{95m}Tc from soil using 0.01 M CaCl_2 ; the differences were more likely related to physiological differences between young and old grass roots and the greater root mass per unit soil volume in smaller pots. Under each set of experimental conditions (field or greenhouse), most of the ^{95m}Tc applied to soil remained in the top 4 cm of the profile during the six months of the study. The relative extractability of ^{95m}Tc from soil using 0.01 M CaCl_2 decreased, over time, as did concentrations in the vegetation. Based on extraction of soil using CaCl_2 and NaOCl , an oxidant, the pertechnetate applied to soil appeared to be chemically reduced, over time, to a less soluble and, therefore, less bioavailable form.

Modeling of ^{95}Nb and ^{95m}Tc in Freshwater Ecosystems

B. G. Playlock M. L. Frank

Studies were conducted on Nb and Tc, two radionuclides for which little information was available for freshwater ecosystems. Radionuclide cycling studies were conducted by making acute or chronic (30 d) releases of ^{95m}Tc or ^{95}Nb to small experimental freshwater ponds. Uptake and elimination rates were determined for the aquatic biota, and the distribution of the isotope was measured in the abiotic compartments of the system. Three-compartment (ambient water, gastrointestinal tract, and tissue for each organism) linear models were constructed of the ^{95m}Tc movement in the pond ecosystem from data obtained from an acute release. The model was used to predict the body

burden of an aquatic organism to steady chronic input into the water. The procedure involves using data from the acute release for the estimation of transfer coefficients of the model by means of the Marquart nonlinear least-squares technique and then examining the consequences of a steady input to the model. A similar mathematical model was constructed for ^{95}Nb from data obtained from an acute release. Verification of the model with data from a ^{95}Nb chronic release study indicated that some additional refinement of the model is needed. Error analysis, which can play an important role in the development of ecological models, was used to evaluate the different models. Results suggest that organisms with a relatively long biological half-life for a radioisotope can be adequately represented by a single compartment in the model. Organisms with a relatively short half-life for a radioisotope may require a model with two or more compartments plus a food source compartment. Additional information is needed on food source compartments for further model development.

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3. ENVIRONMENTAL IMPACTS PROGRAM

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Introduction

Environmental Impacts Program (EIP) activities during this reporting period included (1) ecological input for environmental impact statements and assessments, (2) analysis of regional environmental information, (3) environmental risk analysis, (4) technical assistance in the development of guidelines for compliance with environmental legislation, (5) field research addressing methods for evaluating instream flow needs of aquatic biota, and (6) analysis of environmental issues related to nuclear waste. These activities continue to span a broad range of energy technologies including nuclear, geothermal, hydroelectric, synfuels, and biomass. Major program sponsors during this reporting period included DOE (Office of Alcohol Fuels, Office of Environmental Compliance, Division of Geothermal and Hydropower Technology, and Office of Nuclear Waste Isolation), NRC (Office of Nuclear Material Safety and Safeguards and Office of Nuclear Regulatory Research), and EPA (Office of Research and Development).

Highlights of six EIP projects are presented below.

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Environmental Risk Analysis

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Environmental risk analysis may be defined as the process of identifying and quantifying probabilities of adverse changes in the environment resulting from human activities. Since mid 1981, ESD has been developing and demonstrating methods for environmental risk analysis for the EPA. During FY 1982, the major activities of the project were the preparation of a report describing five techniques for environmental risk analysis (Barnthouse et al. 1982) and the use of these techniques to analyze risks associated with atmospheric and aqueous effluents from a hypothetical indirect coal liquefaction plant. Additional activities included development of a surface-water transport/transformation model and adaptation of methods for assessing bioaccumulation in terrestrial and aquatic food chains.

Five methods of risk analysis have been investigated to date. First, the quotient method involves direct comparison of estimated environmental concentrations to standard toxicological benchmarks (e.g., LC50s). In the second, the analysis of extrapolation error, expected effects of contaminants on organisms in the field are estimated, with appropriate error bounds, from observed effects on laboratory test organisms. Third, the fault tree analysis can be used to elucidate causal linkages between pollutants and endpoints. Fourth, the analytic hierarchy method uses expert opinion to rank the relative environmental risks of different stresses. Fifth, the ecosystem uncertainty analysis uses Monte Carlo simulation and ecosystem models to extrapolate estimates of risks to populations and ecosystems from laboratory toxicological data.

Preliminary Environmental Risk Analysis of Indirect Coal Liquefaction Technology

Indirect coal liquefaction technology was used as an example to test the usefulness of the five methods (Barnthouse et al., in review). The source terms employed were derived from a characterization of the process and waste streams of a hypothetical Lurgi/Fischer-Tropsch indirect coal liquefaction plant. The waste stream characterizations were transformed into aquatic and atmospheric source terms, expressed in terms of Risk Analysis Units (RAUs). RAUs are groupings of chemicals with similar properties for the purpose of risk analysis. Aquatic source terms were developed for 17 RAUs; atmospheric source terms were developed for 25 RAUs.

The environmental scenario employed in the risk analysis was a "reference environment" with meteorological, hydrological, and biological characteristics representative of the Central Appalachian Coal Basin. Estimates of the concentrations of 17 RAUs in the surface waters of the reference site were computed using a simple steady-state model developed for this project (Barnthouse et al., in review). Estimates of ground-level concentrations of 25 RAUs and deposition rates for 19 RAUs contained in atmospheric effluents were calculated using a Gaussian-plume model modified to incorporate photochemical transformation processes.

Evaluation of Risks

The endpoints for aquatic risk analysis were (1) reductions in abundance and production of commercial or game-fish populations and (2) development of algal populations that detract from

water use. Because of the availability of a comparatively large data base, all five of the risk analysis methods were used to address potential risks of the RAUs to fish populations. Only one method was used to address the risk of producing algal blooms.

Two methods, the quotient method (QM) and the analytic hierarchy method (AHM), were used to obtain independent rankings of the RAUs with respect to their hazard to fish populations. In the QM, estimated environmental concentrations were simply compared to toxicological benchmarks such as LC50s, EC50s, and MATs. In the AHM, expert opinion was used to evaluate the relative hazards of the RAUs, taking into account both the direct effects of contaminants on fish and indirect effects associated with contaminated effects on invertebrates.

The potentially most hazardous RAUs, according to both analyses, are monoaromatics and diaromatics, phenolics, Hg, and Cd. These four were analyzed in more detail using two quantitative risk analysis methods: analysis of extrapolation error (AEE) and ecosystem uncertainty analysis (EUA). In AEE, statistical relationships between the sensitivities of the various taxa of fish to contaminants (Fig. 3.1) and between acute and chronic effects concentrations were used to estimate,

Fig. 3.1. Natural logarithms of LC50s for *Micropterus* plotted against *Lepomis* (genera of the same family: Centrarchidae). The solid line represents the linearized least-squares regression of *Micropterus* LC50 on *Lepomis* LC50. Data from Johnson and Finley (1980).

with appropriate error bounds, chronic effects thresholds for the four RAUs for the nine fish species present in the reference river. These sensitivities (in the form of probability distributions) were compared to the calculated environmental concentrations. The highest risks of exceeding threshold were obtained for phenolics (5 to 46%) and for monoaromatics and diaromatics (8 to 18%). Risk estimates for Cd were highly variable (most values were low), but a few were as high as those for monoaromatics and diaromatics. All risk estimates for Hg were negligible.

In EUA, an aquatic ecosystem model was used to compute risk estimates that explicitly incorporate biological phenomena, such as competition and predation, that can magnify or offset the direct effects of contaminants on organisms. Using Monte Carlo simulation, estimates of errors in toxicological response parameters were propagated through the model to obtain estimates of the probability of observing predefined adverse effects [e.g., a 25% reduction in game-fish abundance or a fourfold increase in production of blue-green algae (Fig. 3.2)]. In this analysis, Cd had the

Fig. 3.2. Probability of increase in blue-green biomass or reduction in game fish biomass in relation to exposure concentration of phenol.

greatest effects on game fish. Monoaromatics and diaromatics were a distant second, followed by Hg and phenolics. The risk of a fourfold increase in production of blue-green algae was less than 10% for all four contaminants examined.

Both AEE and EUA ranked the four RAUs examined differently than did QM. Both predicted potentially significant risks to fish populations at environmental concentrations that might appear negligibly low according to QM. The reasons for the differences between the results obtained from AEE and from EUA cannot be readily explained and will be the subject of further research.

The endpoints for terrestrial analysis were (1) reductions in timber production, (2) reductions in agricultural production, and (3) reductions in wildlife populations. Risks to timber and agriculture were addressed using QM and AHM. Because of the limited availability of phytotoxicity data, risks to these endpoints could not be addressed separately using QM. Estimated ground-level concentrations and deposition rates for most of the RAUs examined were several orders of magnitude lower than published thresholds for acute and chronic effects on vegetation. Sulfur oxides (SO_x), nitrogen oxides (NO_x), and hydrocarbon (HC) gases were ranked as the most hazardous gaseous RAUs. Cadmium was identified as the most hazardous RAU with respect to deposition. The results obtained from AHM were similar in that SO_x and NO_x were identified as the potentially most hazardous gaseous RAUs. However, the experts ranked HC gases lower than would be expected on the basis of phytotoxicity data alone. In addition, they judged Cd to be a greater hazard to forests than to crops.

Risks to wildlife were addressed by using QM to examine the effects of inhalation of gases and vapors. All of the quotients were smaller than 10^{-2} , indicating relatively little risk that any of the RAUs would have serious respiratory effects on wildlife.

All of the results, for both aquatic and terrestrial endpoints, are subject to several important caveats. First, there is some conservatism built into both the source terms and the exposure analyses. Effluent from the biological treatment plant was assumed to be discharged directly into the reference river, although in reality such a plant design is unlikely. Unknown contaminant removal coefficients (e.g., photolysis) in both the aquatic and the terrestrial exposure analyses were assumed to be zero. Also, a number of potentially significant sources of risk could not be addressed. Many of these were identified by using fault tree analysis (FTA) to trace causal pathways between contaminant releases and adverse effects of contaminants on fish and bird populations. The unanalyzed pathways included sublethal behavioral and physiological effects, habitat alteration, and bioaccumulation. Finally, the quantitative risk estimate produced by AEE and EUA have components related to (1) the intrinsic hazard of the contaminants, (2) the inherent variability of the environment and of the sensitivities of organisms to contaminants, and (3) our uncertainty about (1) and (2). At the current state of methodology development, we cannot separate the relative contributions of these three factors to the risk estimates. Consequently, it is more reasonable to interpret a risk estimate of 40% not as indicating that there is a 40% chance of a significant effect, but that we are only 60% certain that there won't be an effect.

Evaluation of Methods

All of the methods were evaluated based on the results of this study. The QM appears useful without modification as a screening tool. It can be used to identify contaminants requiring more detailed study. The AHM, although providing interesting results, was difficult to use in this application because of the large number of contaminants being analyzed. Future use of this method

should involve either reducing the number of contaminants ranked or combining the RAUs into higher-order groupings.

The usefulness of FTA appears to be primarily as an organizational tool. It can be used to identify causal pathways leading from contaminant release to adverse effects and to identify the information needed to evaluate the risks associated with those pathways. However, it is not currently possible to perform quantitative analyses of ecological fault trees.

The most promising methods for quantitative environmental risk analysis appear to be AEE and EUA. Further development of both methods is needed. Currently, AEE can predict the risk that there will be a measureable effect on organisms exposed to a contaminant but cannot predict the magnitude of the effect. It is both desirable and feasible to extend the method to bridge the gap between organisms and a population. EUA can be improved by employing advanced techniques for estimating toxicological parameters. The use of an alternative ecosystem model more appropriate for synfuel assessments is desirable.

Long-Term Stabilization of Uranium Mill Tailings

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The primary hazard associated with uranium mill tailings is exposure to a radioactive gas, ^{222}Rn , the concentration of which has been correlated with the occurrence of lung cancer. Previous studies on radon attenuation conclude that the placement of earthen cover materials over the tailings is the most effective technique for reducing radioactive emissions and dispersal of tailings in a manner that would eliminate the need for long-term site surveillance and maintenance. The success of such a plan, however, is dependent on long-term protection of these cover materials from erosion. Uranium milling operations to date have been restricted almost entirely to the arid or semiarid regions of the western United States. The geographic location of the mill sites has a dominant influence on how tailings can be most effectively stabilized.

Literature regarding the physical and biological processes of surface stabilization, including how these processes are influenced by variations in environmental characteristics present at existing and potential uranium mill sites, was reviewed. This background information was used to develop guidance on how to evaluate a specific stabilization plan with respect to minimizing erosion, disturbance, and dispersion of uranium mill tailings by natural forces over the long term.

Denudation and mass wasting are the primary physical processes affecting surface stabilization. These processes are controlled by several factors such as the size, density, and moisture content of soil particles and aggregates, surface roughness, vegetation, slope angle, slope length, and climatic variables. Surface erosion is the most important disrupting force during the initial stages of stabilizing a reclaimed area. Engineered designs can be maintained over relatively short time periods (<200 years), but it appears that geomorphic processes are the most important considerations for design of stable landforms for the tens of thousands of years required for isolation of uranium mill tailings. Because of the great uncertainty about many of the factors controlling denudation and mass failure mechanisms acting over long periods, design criteria should be simple and should reflect our current understanding of the dynamics of natural landscapes. Geomorphic evidence indicates that soil covers are not likely to persist over the long term on slopes greater than about 3 to 5°. Therefore, for slopes greater than 3 to 5°, rock covers should be used to minimize erosion to the extent practicable.

In some cases, erosion of tailings covers may also be reduced by revegetation. Erosion reduction by vegetation is directly related to the amount of plant material, living and dead, both above and below the ground. Although a diverse plant community, including many fibrous-rooted species, provides greater erosion control than a simple community, the amount of cover provided by the plants is of key importance in reducing erosion. The maximum possible cover that can be expected from revegetation can be estimated by surveying existing undisturbed natural vegetation around the site. It is unlikely that any greater cover can be sustained than what appears in these natural communities. Revegetation of many of the tailings sites located in desert ecosystems (precipitation <25 cm annually) will probably offer little protection from erosion because natural cover in such communities generally averages between 16 and 24%. The highest erosion rates in the United States occur in regions having annual average precipitation of between 20 and 40 cm. Approximately 83% of all existing mills and 58% of all counties with uranium resources fall into this high-erosion category. Communities such as grasslands, shrub steppes, and woodlands support considerably more cover than do deserts. However, even where vegetation is relatively dense, a large amount of local variation may exist as a result of microclimatic conditions. Hence, site-specific surveys are necessary to determine the applicability of vegetation for erosion control. Although vegetation may effectively reduce erosion, it should be used with caution because plant communities can and do change over the geologic time scale associated with isolation of tailings. Fossil evidence indicates what the vegetation communities were like in the past, but this knowledge does not imply that their composition can be accurately predicted for the future.

Site-specific tailings cover designs cannot be recommended without onsite data. The environmental conditions at each mill site form a set of constraints that limits the success of cover strategies (e.g., revegetation) and defines the destabilizing forces to which the site will be subjected. Because each site has its own characteristics, a heuristic approach for evaluating plans for stabilization is proposed. This approach consists of an iterative examination of specified design variables for possible improvements in achieving performance objectives. A series of questions was developed, the answers to which should serve as the basis either for plan approval or revision of individual design aspects.

The science of controlling soil loss through engineering and revegetation practices is based on a limited amount of field data, much of which is only indirectly applicable to the problem of long-term isolation of uranium mill tailings. A few quantitative tools, such as the Universal Soil Loss Equation, are available for planning erosion protection, but their use when extrapolating thousands of years into the future cannot be verified. Further, concern over stabilization of tailings in western arid lands is of recent interest and much remains to be learned. Despite these shortcomings, sufficient information is available to eliminate totally inadequate proposals; to distinguish relative, incremental benefits resulting from changes in specific designs; and to evaluate the need for different design strategies among sites. Until more field experience is acquired, evaluation of stabilization plans should be based on these types of relative determinations.

Dissolved Oxygen Concentrations Below Hydroelectric Dams

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Staff members in the EIP have assisted the DOE Small-Scale Hydroelectric Development Program in recent years by evaluating potential environmental issues that might constrain the develop-

ment of small-scale hydroelectric (SSH) facilities. One of these issues is the degradation of water quality in water discharged from SSH dams.

Water quality problems in the discharges from hydroelectric reservoirs can occur as a result of seasonal warming and the consequent thermal stratification of impounded waters. During the summer, this natural process can divide the reservoir into distinct vertical strata, [i.e., a warm, well-mixed upper layer (epilimnion) overlying a cooler, relatively stagnant lower layer (hypolimnion)]. Dissolved oxygen progressively declines in the hypolimnion as a result of plant and animal respiration, bacteria! decomposition of organic matter, and chemical oxidation until either anaerobic conditions predominate or reoxygenation occurs with the fall overturn. Chemically reducing conditions brought about by lowered dissolved oxygen concentrations can also result in the buildup of hydrogen sulfide and ammonia and increase the solubility of Fe, Mn, and some heavy metals. Degraded hypolimnetic water, when discharged from hydroelectric facilities, may have adverse effects on both tailwater biota (inability to support a balanced aquatic community) and other water use (taste and odor problems, decreased waste assimilative capacity).

Although thermal stratification is a common phenomenon in temperate regions, not all lakes and reservoirs stratify. Conditions that are conducive to stratification (e.g., great depth, low surface area: volume ratio, and flushing rate) are not characteristic of many SSH sites. The purpose of this study (Cada et al. 1982) was to determine whether water quality degradation, as exemplified by low dissolved oxygen concentrations in reservoir tailwaters, is likely to be a significant issue affecting SSH development in the United States.

The approach was to pair operating hydroelectric sites of all sizes (listed in the U.S. Army Corps of Engineers National Hydropower Study data base) with dissolved oxygen measurements from nearby downstream U.S. Geological Survey (USGS) water quality stations (acquired from the WATSTORE data base). The USGS data were used to calculate probabilities of noncompliance (PNC), that is, the probabilities that dissolved oxygen concentrations in the discharged waters of operating hydroelectric dams will drop below 5.0 mg/L. The 5.0-mg/L value was adopted from EPA water quality criteria as that concentration necessary to maintain good aesthetic quality of the water and to support a "well-rounded population" of fish.

The Small Hydropower Development Program of the DOE defined SSH facilities as those facilities having maximum generation capacities of 30 MW. As a result, facilities used in this analysis were characterized as either small-scale (≤ 30 MW) or large-scale (> 30 MW) dams. Also, because thermal stratification and resultant oxygen depletion are seasonal phenomena, two probabilities were calculated for each site—one for the summer months (July, August, September, and October) and another for the remaining (winter) months.

Although a large number of dams were included in the data base, surprisingly few could be identified with USGS water quality stations sufficiently close or with enough dissolved oxygen measurements to be useful. A total of 65 small-scale and 74 large-scale sites was selected. Because of the low numbers of usable sites in many states, much of the analysis was conducted on a regional basis. During the winter months (November through June), all regions had low mean PNCs (i.e., generally less than 0.05), regardless of the generating capacity category. Most regions had higher mean PNCs in summer than in winter, and summer PNCs were greater for large-scale than for small-scale sites. Among regions, the highest mean summer PNCs for SSH sites were found in the Great Basin, the Southeast, and the Ohio Valley (0.373, 0.131, and 0.111, respectively).

To obtain a more comprehensive picture of the effects of season and capacity on potential dissolved oxygen problems, cumulative probability distributions of PNC were developed for selected

regions (Fig. 3.3). These figures can be used to estimate the probability of observing a PNC greater than or equal to a particular value by determining the cumulative probability value (ordinate) that is associated with the desired PNC (abscissa) and subtracting that value from unity. For example, the probability of encountering a $PNC \geq 0.1$ at a southeastern large-scale dam in the summer (Fig. 3.3) is 0.68 ($1.0 - 0.32$). On the other hand, the probability of observing that same PNC value at small-scale sites in the summer is much lower ($1.0 - 0.74 = 0.26$). The probabilities of encountering PNCs ≥ 0.1 in the Southeast during the winter are even smaller.

Fig. 3.3. Cumulative probability functions of the probabilities of noncompliance (PNCs) for hydroelectric sites in the Southeast.

Our study indicates that low dissolved oxygen concentrations in the tailwaters below hydroelectric dams are primarily a problem of large-scale (>30 MW) facilities. It should be noted that PNCs are not a function of electrical capacity per se, but rather appear to be dependent upon factors related to capacity, such as reservoir depth. Although discharges from some SSH dams have violated the 5-mg/L dissolved oxygen criterion, the probability of violating this limit is relatively

low at the majority of existing sites, particularly in the northern and Pacific Coast regions. Although other water quality factors (e.g., heavy metals, and toxic materials) may be important concerns at particular sites, our analysis indicates that potential dissolved oxygen problems (as defined by violations of the 5-mg/L criterion) are unlikely to hinder the development of small-scale hydropower in the United States.

Alcohol Fuels Environmental Project

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ORNL has served as the environmental, health, and safety compliance support for the Office of Alcohol Fuels since the creation of the office. In the first phase of our work, completed last fiscal year, we produced two generic assessment documents (Elmore et al. 1982; Watson et al. 1982). The second phase has consisted of the preparation of ten project-specific environmental assessments in support of the loan guarantee program. The ten conditional loan guarantees included projects in a variety of settings, with different capacities, feedstocks, and processes (Table 3.1).

All plants producing their own process heat will emit more than 90 Mg/year of one or more criteria pollutants to the air. Because alcohol fuel plants are designated "major sources" by the EPA, each will be required to undergo full review under the Prevention of Significant Deterioration (PSD) regulations. Final emission rates will be established during that review. Worst-case assessments based on use of the full PSD Class II increment at the respective sites indicated that no plant would violate the primary National Ambient Air Quality Standards.

Production of fermentation alcohol uses large quantities of water. The ratio of wastewater to product averaged 4.4:1 for the ten plants. Although the concentrations of biochemical oxygen demand (BOD) and total suspended solids (TSS) are quite high in process wastewater, dilution with boiler and cooling-tower blowdowns reduced concentrations in the total wastewater stream to <300 mg/L. Attainment of the standard 30-mg/L discharge limit was then economically feasible. One plant, however, was proposed for a site where low flows in the receiving water body and the presence of an endangered anadromous fish indicated a discharge limit of 10 mg/L BOD. This limit is technically possible to achieve but economically infeasible and will result in either the plant's not being built or the selection of an alternative site.

Only one other proposed plant site was found to have potential for significant environmental impact. The site is located on the Tennessee River where there is sufficient flow to accommodate treated discharges, and it was determined that construction of an outfall line from the wastewater treatment plant would affect both archaeological resources along the river bank and a population of endangered mussels within the river. The design was changed to release effluents to the local municipal system following pretreatment to reduce BOD.

In summary, ten proposed fuel alcohol plants were evaluated, eight of which lacked significant potential for environmental degradation. Of the remaining two, significant impacts at one could be

Table 3.1. Summary descriptions of projects receiving conditional loan guarantees from the U.S. Department of Energy

Location	Setting	Annual capacity (liters $\times 10^6$)	Feedstock	Process heat	Wastewater disposal	Dehydration	Denaturation
Garden City, Kans.	Rural	58.3	Corn ^a	Manure/corn stover	Evaporation	Benzene	Gasoline
Lane, S.C.	Rural	75.7	Corn ^a	Coal	Onsite treatment	Benzene	Gasoline
Miley, S.C.	Rural	79.5	Corn ^a	Wood	On-land spray	Diethyl ether	Gasoline
Keokuk, Iowa	Rural	79.5	Corn ^a	Coal	Onsite treatment	Gasoline	Gasoline
Mankato, Minn.	Small town	75.7	Corn ^a	Purchased steam	Municipal ^b	Benzene	Gasoline
Auburn, Maine	Rural	94.6	Corn ^a	Coal	Municipal ^c	Cyclohexane	Gasoline
Jasper, Tenn.	Rural	94.6	Corn ^d	Coal	Municipal ^b	Diethyl ether	Gasoline
New Iberia, La.	Rural	132.0	Molasses	Dried stillage and bagasse	Onsite treatment	Diethyl ether	Gasoline
South Bend, Ind.	Urban	189.0	Corn ^a	Coal	Municipal ^c	Benzene	Gasoline
E. Baton Rouge, La.	Industrial	454.0	Corn ^d	Purchased steam	Onsite treatment	Benzene	Gasoline

^aDry milled.^bFollowing pretreatment to reduce BOD.^cWithout pretreatment.^dWet milled.

mitigated at an acceptable cost but could not at the other. The environmental constraints are seen as failures in the site selection rather than as technological problems.

Environmental Compliance Activities (G. F. Cada, C. T. Hunsaker, D. B. Hunsaker, Jr., P. J. Muiholland, C. D. Powers, R. M. Reed, M. J. Sale, M. S. Salk, F. E. Sharples, L. L. Sigal, E. D. Smith, and J. W. Webb)

Because DOE projects must generally comply with federal, state, and local environmental laws and regulations, DOE project managers responsible for the construction and operation of such projects must be thoroughly familiar with all applicable requirements for environmental permits and approvals. During FY 1982, the EIP staff, with some assistance from the Energy Division, developed twelve guidance manuals for the DOE Office of Environmental Compliance (OEC) to assist DOE project managers in ensuring project compliance with respect to many of the major federal environmental laws and regulations. Staff from EIP reviewed each law and its implementing regulations to determine the information needed, the approach to be used in data collection, and the analyses that should be performed. Federal and state regulatory agencies were contacted to determine the latest applicable requirements and interpretations and to discuss the views of these agencies on current enforcement philosophies. In addition, pertinent published reports and guidance manuals were reviewed. Using all this information, the authors prepared manuals that contain (1) a brief overview of the law and its relevant regulations, (2) an outline of the procedural steps that must be followed to comply with the law, and (3) guidance on the data that should be collected and how the data should be used to ensure compliance.

The twelve manuals developed during FY 1982 deal with the following laws or regulations: (1) the Endangered Species Act (ESA), (2) the Underground Injection Control Program, established by the Safe Drinking Water Act, (3) the National Pollutant Discharge Elimination System of the Clean Water Act (CWA), (4) Army Corps of Engineers (COE) permits for dredging and filling activities required by the CWA and the Rivers and Harbors Act (RHA), (5) the Fish and Wildlife Coordination Act (FWCA), (6) the Prevention of Significant Deterioration (PSD) Program of the Clean Air Act, (7) nonattainment area requirements of the Clean Air Act, (8) Executive Orders on floodplains and wetlands, (9) the National Historic Preservation Act (10) the Toxic Substances Control Act, (11) the Marine Protection, Research and Sanctuaries Act, and (12) the Coastal Zone Management Act. Three of these manuals are described below.

Endangered Species Act. Section 7 of the ESA of 1973, as amended, requires a federal agency such as DOE to ensure that none of its actions jeopardizes the continued existence of endangered or threatened species or results in the destruction or adverse modification of designated critical habitat. DOE is required to consult with the U.S. Fish and Wildlife Service (FWS) and/or the National Marine Fisheries Service (NMFS) on proposed activities that could affect federally listed or proposed listed species or habitat. If these agencies advise DOE that an endangered or threatened species or critical habitat may be affected, DOE must prepare a biological assessment of the effects of the proposed action. Information in the biological assessment is used by the FWS and NMFS as a basis for evaluating the effects of the proposed action on species and habitats of concern.

The ESA could cause significant delays in DOE project schedules. Early consultation with the FWS and NMFS and development of information on the possible presence of endangered or threatened species are essential to avoiding such delays. The guidance manual clearly defines the types of information and analyses that are needed for compliance with the Act.

Corps of Engineers permits on dredging and filling activities. The COE issues permits for dredging and filling activities under authorities contained in the RHA and the CWA of 1977. Sections 9 and 10 of the RHA authorize the COE to issue permits for erecting dams and structures or undertaking work (including dredging) in or affecting navigable waters. Although the original purpose of these sections was to facilitate navigation, the COE currently includes environmental concerns in its review of permit applications.

Under Sect. 404 of the CWA, the COE is authorized to issue permits for the discharge of dredged or fill materials into all waters of the United States. The principal concern under this section is environmental protection. Although specific procedures and requirements for information may vary, the review of permit applications follows general EPA guidelines. These guidelines require consideration of potential impacts on physical, chemical, and biological characteristics of the aquatic ecosystem, special aquatic sites, and human use. Early planning meetings involving affected government agencies, organizations, and individuals play a critical role in the permitting process by identifying the level of existing information available and the types of new information needed for permit review. The DOE guidance manual presents general approaches for collecting, analyzing, and presenting information that addresses appropriate environmental issues, including project effects on substrate, suspended particulates, turbidity, water quality, current patterns, water circulation, water level fluctuations, salinity gradients, aquatic and terrestrial biota, threatened and endangered species, special aquatic sites, and human use.

Fish and Wildlife Coordination Act. The FWCA requires that consideration be given to the conservation of fish and wildlife resources during the planning and development of any DOE (or other federally supported) project that directly or indirectly affects water resources. DOE must cooperate with state and federal wildlife agencies early in project planning in evaluating project effects on fish and wildlife. To accomplish this objective, DOE should provide wildlife agencies (i.e., FWS, NMFS, and state agencies) with project information, including descriptions of (1) the project site and facilities, (2) construction activities, and (3) potentially affected wildlife resources. In addition, engineering measures intended for environmental protection or mitigation should be included. The federal and state wildlife agencies use this information to prepare an FWCA report that contains assessments of site-specific project impacts, measures necessary to minimize harm, and recommended project alternatives. DOE uses the FWCA report to decide which of the wildlife conservation recommendations can be justifiably incorporated into the project plans. The DOE guidance manual discusses these procedures, describes the types of information that should be provided by DOE, briefly discusses habitat evaluation techniques that can be used, and outlines the FWS mitigation policy.

Environmental Issues Associated with Nuclear Waste Disposal

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Geologic Isolation of High-Level Radioactive Waste

To assist DOE in evaluating the adequacy of environmental documents associated with high-level radioactive waste repositories, EIP has conducted a review of publicly available documents on selected environmental issues. Current plans for such repositories call for wastes to be incorporated

into leach-resistant solids, packaged in metal containers, and placed 300 to 1200 m underground in mined chambers. Potential sites for a first repository are located in six states and represent three rock types (salt, volcanic tuff, and basalt).

A primary environmental consideration in designing and siting a repository is the long-term effectiveness in preventing releases of radioactive material into the environment. Published risk analyses of hypothetical modes of failure in the waste isolation system point to ground-water release and transport as the most important potential threat. Until additional information on the geologic, hydrologic, chemical, and mechanical characteristics of possible sites has been obtained and engineered components of the repository are well defined, predictions of the long-term radiological impact of a high-level waste repository will remain tentative. Preliminary systems analyses, however, based on likely repository designs and settings, indicate that radiological releases will be extremely small. Key considerations for establishing general confidence in predictions of repository performance will be the ability (1) to predict long-term behavior of engineered components (e.g., waste form, canisters, and backfill) under stresses imposed by waste disposal; (2) to characterize the physical setting of the repository; and (3) to test the validity of models used. During operation, handling and transportation of radioactive wastes will result in radiation exposures to waste-management workers and the general public. Although published analyses have concluded that routine transportation exposures and accident risks would be extremely small, the transport of radioactive wastes to the repository is expected to be a controversial issue.

Nonradiological environmental impacts of repository construction and operation of large-scale preliminary test activities (e.g., exploratory shafts for detailed site characterization and facilities for testing and evaluating engineering concepts) will include

1. impacts associated with land surface disturbance (e.g., habitat destruction, fugitive dust emissions, increased sedimentation),
2. socioeconomic and community effects from an influx of up to 1600 workers,
3. impacts from surface stockpiling and disposing of rock mined during repository construction,
4. use restrictions on at least 4000 ha of land, and
5. effects of wastewater disposal and temporary ground-water drawdown if dewatering is required during shaft construction.

Long-term resource commitments include loss of materials buried in the repository, permanent restriction of land access above the repository, and denial of any subsurface resources located above or below the repository.

A review was made of available information on sensitive features or conditions in the six areas currently being considered for repository sites. Although more specific environmental information is needed to determine the likelihood of potential impacts, several important concerns have been identified. Repository water requirements are not large relative to the demands of many industries or the capabilities of most community water supply systems, but several of the possible repository sites are in arid or semiarid regions where water supplies may already be limited. Information compiled from the U.S. Water Resources Council and other sources suggests that water availability will be a critical concern in locating a repository in the Paradox Basin of southeastern Utah or in the Palo Duro Basin on the Texas panhandle because limited water supplies already seriously constrain development in both areas. Onsite water needs for a Nevada Test Site repository might be met by "mining" ground water beneath the test site, but increased community water demands are

likely to exacerbate a strained supply situation off the site. Although supplies in the other candidate areas appear to be adequate on a regional basis, some localized supply problems were found in all three areas.

Other location-specific issues that could arise include conflicts with national parks and other specially designated lands in the Paradox Basin, conflicts with known or potential mineral resources in the Paradox Basin and near the two possible salt dome repository sites in Mississippi and Louisiana, and the possible need to relocate a small community near Richton Dome in Mississippi. Archaeological sites, occurrences of endangered species, or other sensitive local features are present in the vicinity of all possible repository locations. Site-specific studies will be required to identify which of these issues are pertinent.

Uranium Mill Tailings Remedial Action Projects

Under the Uranium Mill Tailings Radiation Control Act of 1978 (UMTRCA), DOE is responsible for implementing remedial actions to mitigate radiation hazards at inactive uranium processing facilities. To provide background for reviewing environmental documents on the 20 or more expected Uranium Mill Tailings Remedial Action Program (UMTRAP) projects, EIP reviewed the state of the art in predicting impacts from these activities and prepared a report that identifies and evaluates mathematical models, empirical prediction techniques, and other methods that could be used to make quantitative evaluations of certain potential radiological and nonradiological impacts of existing tailings piles and possible remedial actions. Methodologies reviewed were those for predicting radon gas emissions from tailings piles, airborne release of tailings particles, atmospheric transport of radionuclides, release of tailings radionuclides and nonradioactive inorganic contaminants to ground water and streams, contaminant transport in ground water and streams, radiologic doses and resultant health effects from environmental or occupational exposure to tailings radionuclides, and effects of nonradioactive tailings constituents in water supplies.

For each of these areas, the report (1) includes a brief background discussion on the nature of the phenomena to be predicted, (2) outlines methods that could be used for predictions, (3) discusses their major strengths and weaknesses, and (4) identifies critical input variables. Examples are given of published computer programs that incorporate the various quantitative methodologies, and the methods used in several computer programs that are likely to be used in UMTRAP assessments are identified.

Hydroacoustic Biomass Estimation Techniques

This study examined the use of hydroacoustic biomass estimation techniques as possible assessment tools for power-plant aquatic monitoring programs. The purpose was to provide sufficient background material so that a fisheries biologist who has little experience with such systems can appreciate the operation, application, advantages, and disadvantages of these techniques related to power-plant aquatic monitoring programs.

The analysis covered seven topics:

1. sound in water (addressing basic hydroacoustic principles),
2. hydroacoustic systems (describing the components of a hydroacoustic survey system, selection of equipment, and its operation),
3. case studies (use of hydroacoustics for general aquatic surveys in a variety of habitats),

4. applicability to power-plant monitoring (reviewing use of hydroacoustics at power-plant sites and general recommendations),
5. glossary of technical terms,
6. user survey results, and
7. indexed bibliography.

Sound waves are defined as spreading disturbances in a compressible medium that move in all directions from a source. In water, sound waves travel at approximately 1500 m/s. When sound waves encounter a change in density (fish, bottom, or air bubbles), they are reflected in all directions, and some energy is reflected back toward the source. The time it takes for the original sound pulse to return as an echo allows estimation of the distance to the target. The intensity of the returning echo is proportional to the target size, target acoustic properties, target orientation, and position within the acoustic beam. It is these properties of sound that allow its use as a biomass estimation technique.

A complete hydroacoustic system for shipboard use in biomass estimation (Fig. 3.4) would consist of

1. a transmitter and receiver for creating and receiving the electronic signals, usually located in the same piece of equipment and then called a transceiver;

Fig. 3.4. Schematic of a typical hydroacoustic system. The transmitter generates the electronic signal, which is converted into the acoustic signal by the transducer mounted in the water (hull-mounted or towed). The transmitted acoustic pulse is reflected off a target (fish) and returns to the transducer. The transducer converts this acoustic energy to an electronic signal, which is amplified and filtered by the receiver. The electronic echo signal can be displayed (1) as a trace on a paper-chart recorder, where displacement of the trace downward from the baseline is proportional to the depth of the target, and (2) visually on an oscilloscope. The range of the target (R) is equal to the velocity of sound in water (c) times the time for the echo to return (t) divided by 2

2. a transducer to create and receive the acoustic signals, either hull-mounted or towed from the vessel in a body;
3. display device(s), such as paper chart recorder, oscilloscope, or cathode-ray tube; and
4. some method of either recording the received signals for future analysis, such as reel-to-reel or cassette tape recorders, or a method for simultaneous analysis of the signal, such as a computerized fish counter, echo integrator, or onboard digital computer.

Echo counters can be used when the density of fish is relatively low. They yield biomass estimates the number of fish per 10,000 m³. When fish densities are great, echo integrators must be used because of overlapping echoes. Echo integrators yield biomass estimates in kilograms of fish per 10,000 m³.

Processing of hydroacoustic data can occur in real-time onboard ship or the signals can be recorded on tape and analyzed on the shore. Hydroacoustic systems can be relatively simple or complex, depending primarily on the operating environment and survey objectives.

Although the technique of using hydroacoustic methods to quantify biomass is only about 12 years old, the literature reflects its successful application in a variety of environments from open-ocean surveys to monitoring power-plant intake embayments and targets of interest varying from 500-kg fish to 2-mm zooplankton. This study describes a useful, flexible, aquatic survey technique that can be profitably applied to power-plant monitoring programs. The results of a hydroacoustic user survey (distributed to over 140 institutions worldwide) reflect the usefulness of this technique under appropriate conditions. Survey respondents were almost unanimous in their belief that the use of hydroacoustics enhanced the quality of their biomass surveys and justified the extra equipment expense. The user survey also identifies shortcomings of the technique and future research areas.

The greatest asset of hydroacoustics is its speed and accuracy as a biomass estimation technique. The greatest shortcomings of hydroacoustics are that species identification capability is lacking and that fishery biologists perhaps are not familiar with the technique.

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4. BIOMASS

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Introduction

The current efforts of ESD in the field of biomass focus on the production of woody biomass for energy and on the environmental consequences of the intensive production and harvesting of that biomass. ESD manages two research programs, the Short-Rotation Woody Crops Program (SRWCP) and the Environmental Effects of Whole-Tree Harvesting Program, for the Biomass Energy Technology Division of the U.S. DOE. Management of these programs includes subcontract procurement, program synthesis, and in-house research efforts in support of the SRWCP and the Whole-Tree Harvesting Program. These research efforts include nutrient studies of intensive forest management and economic analyses of biomass production. In addition, ESD performs related research for the DOE's Division of Carbon Dioxide Research and its Office of Basic Energy Research.

The biomass program is divided into three major activities, the SRWCP, biomass environmental studies, and the Environmental Effects of Whole-Tree Harvesting Program. The SRWCP is designed to improve the productivities and economic efficiencies of systems for short-rotation, intensive silviculture. ESD provides overall field management for the SRWCP, which in 1982 included subcontracted research at 30 institutions across the United States. Most of the subcontracted research consists of long-term field studies testing species and management techniques for use in intensive silviculture. Research in support of the SRWCP in ESD concentrates on regional research and economic assessments and nutrient utilization studies.

Biomass environmental studies combine nutrient conservation studies in support of the SRWCP and basic research on the physiological processes affecting biomass production. All studies are being performed at ORNL on an experimental plantation established during the winter of 1980 to 1981 and are designed to provide insight into the mechanisms and pathways of nutrient movement and water availability.

The SRWCP, the biomass environmental studies, and the Environmental Effects of Whole-Tree Harvesting project are discussed separately in this section. In each case, a brief description of the project is followed by a review of progress during the year and a discussion of significant results. In presenting the SRWCP, the results of subcontracted research are mentioned, but the discussion concentrates on the supporting economic analyses at ORNL.

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The Environmental Effects of Whole-Tree Harvesting Program is examining the effects of forest harvesting, including residue removal, on nutrient processes in forest systems. ESD coordinates the research of five participating institutions at nine sites in the major forest regions of the United States and performs complementary studies at an ORNL site. The general research plan at all sites includes measuring the erosion and nutrient loss on watersheds harvested with and without whole-tree removal, quantifying the changes in nutrient supply associated with residue removal, and assessing these changes in terms of subsequent biomass productivity. The report on the Environmental Effects of Whole-Tree Harvesting Program compares results from five different experimental sites, one at ORNL, to highlight their similarities and differences.

Short-Rotation Woody Crops Program

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Overview

The SRWCP is an integrated program of research on short-rotation, intensive culture (SRIC) of hardwood trees and shrubs managed by the ESD for DOE's Biomass Energy Technology Division. In 1982, the SRWCP consisted of research projects at 30 institutions across the United States and supporting research and management activities in ESD. Locations of the projects and the names of the participating institutions are shown in Fig. 4.1.

ORNL-DWG 81-1000502 ESD

Fig. 4.1. Location of contractor research sites for projects in the Short-Rotation Woody Crops Program.

SRIC systems use selected fast-growing trees and shrubs, fertilizers, weed control, and other agronomic techniques to maximize rates of biomass production. The SRIC concept includes harvests as often as every three to ten years followed by regrowth from the existing stumps. The purpose of SRIC is to increase the amount of wood that can be grown per unit of land. The purpose of the SRWCP is to make SRIC possible at prices that allow it to compete with other sources of fuel. Conceptually, SRIC appears promising. But major questions remain about biological productivity rates and the costs, risks, and profits of short-rotation systems from site to site and region to region.

SRWCP research focuses on four major elements: (1) selection and improvement of promising species, (2) stand establishment and management strategies, (3) economic evaluation, and (4) management and program synthesis. Each of these elements has an objective and a set of activities that contribute to reaching the overall objective of the SRWCP. Reaching high productivity levels at competitive prices requires research to define the potential productivity of woody species under intensive culture as well as experimentation to improve the productivity and increase the economic efficiency of SRIC systems.

The following specific objectives have been established for the major research areas in the SRWCP.

1. Species selection research—to improve the productivity of SRIC through genetic studies that test, select, and develop species and strains of trees and shrubs for use in intensively managed systems.
2. Stand management research—to improve productivity and decrease the costs of SRIC by developing efficient techniques for stand establishment and management.
3. Economic studies—to decrease the price of SRIC-derived woody biomass by integrating economic considerations into system design and research planning.
4. Management and program synthesis—to ensure the purposeful development of the SRWCP as a whole and integrate information from all SRWCP research projects in a smooth and timely manner.

Achievement of these objectives will be measured by defining SRIC systems suitable for a range of available sites across the country and establishing their baseline costs and biological productivities.

The current status of research in the SRWCP is presented in the sections that follow. The three major areas of subcontracted research are discussed first. The objectives of each are listed, and conclusions from recent studies are presented briefly. Next, current research at ORNL is described in which recent economic analyses of SRIC are discussed at some length.

Subcontracted Research

Species selection. The species screening and genetic-selection studies are designed to improve the productivity of SRIC by identifying superior species, strains, and hybrids of trees and shrubs for intensively managed systems. The goals of the four major stages of this work are listed below.

1. Identify the best woody species for SRIC systems in each major region of the United States that appear to have potential for supporting SRIC.
2. Define the genetic diversity within promising species to identify the possibilities for further improvement.
3. Select strains within species or hybridize species for traits valuable in short-rotation systems.
4. Test the selected species, strains, and hybrids for production under intensive management on a range of sites.

The goal of identifying the best woody species for SRIC systems has been essentially achieved in the South, the lake states, the Pacific Northwest, the Northeast, and subtropical regions. Species screening is still in its initial stages in Alaska and the semiarid Southwest. At least three promising species have been identified for each region to take advantage of the variation in soil type and nutrient status of lands available for SRIC systems.

The other three goals represent more advanced genetic-selection research and are being pursued, often simultaneously, at several locations. A recently completed study by Dr. Samuel Land at Mississippi State University demonstrates the type of information on genetic diversity and seed source-site quality interaction that the SRWCP hopes to obtain in its genetic-selection studies.

The Mississippi State study included a sycamore progeny test containing ten families planted on one site in Mississippi in 1974 and a larger test containing 160 families from 16 seed sources in the Mid-South planted in 1975 and 1976 at four sites in Mississippi. SRWCP support, which began after the tests were planted, allowed the collection of data on early biomass production and disease incidence. One hundred ninety-two trees at each site were destructively subsampled for biomass determinations during the sixth growing season (1980 and 1981).

Resistance to a lethal complex of canker diseases was strongly controlled by geographic seed origin and by mother-tree family within seed source. Seed-source differences in biomass yields per hectare were significant, as were site-source interactions. Generally, sources from south of the planting site and near the Mississippi River were better than sources from north of the site. There was little site interaction with the superior sources from southwestern Mississippi and southeastern Louisiana, so that seed from this area could be used throughout the Mid-South.

Mother-tree families within seed sources differed significantly in biomass yields per hectare. Many of the top families came from the best three seed sources in southwestern Mississippi and southeastern Louisiana, but not all families from a good source were equally good. Furthermore, site-family interactions were highly significant. Genetic gains from selection of the top eight unrelated mother trees would be 17% for good performers over all sites (an additional 2.0 Mg ha^{-1} at age five for stem-plus-limb dry weight) or 22% for site-specific varieties [2.45 Mg ha^{-1} (dry wt)]. Because of added costs from maintaining site-specific improvement programs, however, it is recommended that only the superior families for average performance over all sites be used now.

Stand management. The goal of stand management research is to improve the productivity and decrease the costs of SRIC by developing efficient techniques for establishing and maintaining SRIC systems. A majority of the SRWCP projects are concentrating on stand management problems, and most of the species selection projects also address some aspects of stand management. The large variety of regions and sites being used for stand management research ensures that a good data base will be available for assessing and improving the economic efficiencies of SRIC.

The specific goals of the SRWCP stand management research, listed below, will lead to information needed to evaluate SRIC as a biological and economic concept.

1. Develop procedures for the mass propagation of planting material with a high degree of genetic control.
2. Improve techniques for ensuring high survival and rapid early growth of newly planted seedlings and cuttings.
3. Identify the most efficient means for controlling competing vegetation in SRIC.
4. Develop the most cost-effective systems for using fertilizers in SRIC.
5. Determine the costs and benefits of using irrigation in SRIC.

6. Determine the relationships among species, spacing, rotation length, and production in SRIC.
7. Identify the major pests and diseases in SRIC systems, and develop ways to control them.

The productivity rates achieved to date in over 350 different tests of SRIC are presented in Fig. 4.2. These rates are the results of the first SRIC studies in the United States and in many cases do not include rates of coppice regrowth because the stands are not yet old enough. The productivity rates (dry wt) in Fig. 4.2 average $6 \text{ Mg ha}^{-1} \text{ year}^{-1}$.

Fig. 4.2. Productivity rates estimated from short-rotation intensive culture from sites located in the United States.

These rates are low compared with some predictions for SRIC, but they do not mean the predictions are misleading. By learning from mistakes and taking advantage of successes, the average productivity rates in ongoing studies are improving. For instance, the average production estimate (dry wt) for research that preceded the SRWCP was $5.5 \text{ Mg ha}^{-1} \text{ year}^{-1}$ ($n = 126$ observations). The current average value of $6 \text{ Mg ha}^{-1} \text{ year}^{-1}$ (dry wt) is based on data from a wide variety of sites in which generally unimproved stock and a wide variety of spacings, ages, fertilizer levels, and weed control regimes are used. Although the improvement is not great, it does show that progress is being made. Research to date has provided much information on how weed control, fertilization, and careful timing can optimize production.

During the first few growing seasons, chemical or mechanical weed control appears mandatory in SRIC and can improve productivity by as much as 100% over plots receiving only preplanting weed control. Fertilizers are also mandatory for achieving high productivity levels. A summary of SRWCP results suggest that application of fertilizer can result in more than doubled productivity over the first four or five years.

Improvements in productivity can also be made through careful spacing of crops and timing of harvests. Experimental results suggest that spacing of 2 m or more between trees and harvests

around eight years apart yield the most biomass. Harvests of coppice regrowth (stump sprouts) are expected to yield 30% more biomass per year of growth than the first harvest, but data are so limited that generalizations are probably very inaccurate. Because information on coppice growth is important for evaluating SRIC, coppice regrowth cycles are currently the focus of much attention in current SRWCP research.

Economic studies. The major objective of the economic studies in the SRWCP is to increase the cost efficiencies of SRIC systems by integrating economic considerations into system design and research planning. Specific goals for this subject area are listed below.

1. Identify and define the expenses associated with SRIC.
2. Determine the relative economic importance of the different components of SRIC systems.
3. Define the range of variation for major components of SRIC.
4. Determine the site-specific revenue requirements for selected short-rotation woody biomass production systems.

This research area, originally called "harvest, collection, transportation, and storage of biomass," includes studies that are not in themselves economic analyses, but are producing information needed to evaluate the economics of SRIC. Subcontracted research is supplemented by the ORNL economic analyses described later.

Existing cost studies underscore the limits of our current ability to make forecasts about SRIC. Estimates for some of the most important factors are quite tentative, and almost no information about their variability is available. Land costs and product values can be estimated for specific situations with a degree of certainty, but they change across the country and become more uncertain when projected into the future. Harvesting costs, though important, remain uncertain because short-rotation harvesting systems have been proposed but none has been fully developed. Most importantly, the SRIC productivity rates are still variable, and we have very little information about coppice growth rates. However, coppice regrowth is essential to the SRIC concept and must be considered in calculating SRIC costs. Under such conditions, the general trends revealed by sensitivity analyses on economic models are more valuable than the calculated cost figures.

Table 4.1, derived from a Mittelhauser Corporation preliminary study for the SRWCP, shows the results of a typical sensitivity analysis. Doubling management and equipment costs has little

Table 4.1. Results of sensitivity analysis showing the impact on price of changing individual components of a proposed SRIC system

Change from base case	Price impact (% change)
Doubling management costs	+3.5
Doubling equipment investment	+2.5
Adding irrigation system	+38.0
Changing land price from \$815 ha ⁻¹ to \$2500 ha ⁻¹	+25.4
to \$250 ha ⁻¹	-7.8
Increasing yield by 20%	-9.2
Decreasing yield by 20%	+13.7

effect on the final price of the biomass product, assuming all other items remain unchanged. Irrigation, on the other hand, is prohibitively expensive and requires that the price be raised 38% to cover costs. Even if irrigation increased productivity by 20%, the price of biomass would have to be raised. However, if productivity could be increased by 20% by doubling management costs, the price of the biomass could be reduced by roughly 5%.

ORNL Research: Regional Resource and Economic Evaluation

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As field manager for the SRWCP, ORNL must determine the most economically attractive SRIC system and decide the most productive directions for future research. Even within the United States, possible applications of SRIC include intensively managed systems in moist temperate zones, systems with relatively low levels of management in arid and semiarid regions, and high-productivity applications in tropical and semitropical areas. In a world gradually substituting renewable energy resources for fossil fuels, many different SRIC systems may eventually become competitive. However, in the near term it is important to understand how costs are influenced by economic and environmental conditions so that limited research funds can be directed to the most promising opportunities. SRIC management regimes in industrialized vs developing countries will probably take very different forms. However, in most important respects, the central issues are the same. First, if a variety of geographic regions are available, how do the economics of SRIC change from one to the next? Second, within a given region, which species and management approaches offer the potential for the lowest cost? Third, in which areas do the current uncertainties about the economic and biological characteristics of SRIC systems lead to the greatest financial risks?

At this early stage in development, little is known about the comparative economics of the wide variety of production systems that fall under the short-rotation classification. About a dozen evaluations of specific systems have appeared in the technical literature, but differences in their objectives and assessment methodologies make direct comparisons of results impossible. ORNL's objectives require such direct comparisons, both among different systems designed for different regions and among different values for important variables within individual systems.

To meet the programmatic needs of the SRWCP, the ESD staff has worked with economists from ORNL's Energy Division to develop a computerized cost-accounting system called FIRSTCUT. FIRSTCUT is designed to facilitate the systematic investigation of a wide range of potential SRIC applications. It uses a simulation approach that allows the consideration of a range of management practices within a unified analysis. The model structure is specifically designed to expedite sensitivity analyses and permits the detailed examination of the effects of changes in individual parameters.

FIRSTCUT includes few internally specified economic, biological, or managerial assumptions. This provides maximum flexibility but requires the user to specify a large number of such relationships and to ensure that they are internally consistent. Thus, formulating a "base case" (i.e., a description of a specific SRIC system) involves considerable effort. However, once the base case has been specified, individual parameters within it can be changed easily to facilitate sensitivity analyses on conditions about which considerable uncertainty exists.

The results of a series of sensitivity analyses on two base cases are presented here. Although both cases represent SRIC systems being investigated for use in the United States, they have very different biological and financial characteristics. They were selected to demonstrate the range of

systems FIRSTCUT is capable of handling, and the way in which it can be used in evaluating and comparing SRIC alternatives.

One case was constructed from experimental data on mesquite (*Prosopis* spp.) developed by Dr. Peter Felker at Texas A&I University. The other was based on experiments with hybrid poplar (*Populus* hybrid) production in central Pennsylvania under the direction of Drs. Paul Blankenhorn, Todd Bowersox, and Charles Strauss at the Pennsylvania State University. In the mesquite case, costs for land rental, equipment-rental rates, interest rates, and the current value of wood [\$40 Mg^{-1} (dry wt)] were based on conditions in southeastern Texas. The mesquite production functions, however, were based primarily on experimental results from the Imperial Valley of southern California. Uncertainty about actual production levels in southeastern Texas was a major reason for examining a mesquite base case.

Two production functions were used in the mesquite analyses. The higher produces a mean annual growth rate of 16 Mg ha^{-1} (dry wt) in the third year, declining slightly thereafter. Productivity under the second function peaks at mean annual increment of 6 Mg ha^{-1} (dry wt) in the fourth through seventh years. Management costs per hectare are the same for both production functions. All land and equipment are leased.

The second base case depicts a capital and equipment intensive-management approach in which hybrid poplar (NE388) is grown under very close spacing conditions (0.5 m^2 per tree). Practically all land and equipment are acquired through outright purchase. The costs used reflect local conditions in central Pennsylvania. Wood is valued at \$35 Mg^{-1} (dry wt). Two production functions were tested, using identical input costs. The higher function reaches a mean annual productivity in the third- through fifth-year period of approximately 12 Mg ha^{-1} (dry wt). By the tenth year, mean annual productivity drops to about 8 Mg ha^{-1} (dry wt). In the lower function, mean annual productivity peaks at 8 Mg ha^{-1} (dry wt) in the fourth and fifth years and declines to about 6 Mg ha^{-1} (dry wt) by the tenth year. The hybrid-poplar base case represents one of the most intensive approaches possible in forestry without using irrigation.

Evaluations of the two base cases, each with two different productivity levels, can be used to examine system design and identify further avenues of research. For example, Figs. 4.3(a and b) show the relationship between the real cost of money and its effect on the cost of producing biomass. The response of discounted average cost (levelized cost) to changes in the real interest rate on borrowed funds is not linear. At the higher levels of productivity tested, both the poplar and mesquite examples are relatively insensitive to real interest rate because both systems achieve a positive cash flow relatively quickly. The mesquite example is even less sensitive to interest rates than the poplar example at the higher productivity level because of its extensive use of leasing rather than outright purchasing of equipment. Only when real interest rates climb above 10% (corresponding to perhaps an 18 to 20% nominal interest rate) do average costs become very sensitive to changes in the real interest rate. When biomass production falls to the level presumed in the low productivity curves, the plantations are less solvent and, hence, are more sensitive to changes in the interest rate.

Additional analyses of the two cases show the effect on average costs of changes in the cutting cycles under conditions of high and low productivity. In very short rotations (e.g., one to two years), average costs for both systems are relatively high. Costs decline rapidly as rotation age is increased. A minimum average cost is reached with rotation ages between three and eight years for both species and both levels of productivity. Optimal rotation age in the poplar case is about four to five years under conditions of high productivity and about six years under conditions of low productivity.

Fig. 4.3. Sensitivity to high real interest rates of (a) capital-intensive short-rotation biomass production systems and (b) labor-intensive systems.

For mesquite, optimal ages are three to eight years, assuming high productivity, and eight or nine, assuming low productivity.

These results suggest several conditions that can be evaluated only through further testing of SRIC at other locations under diverse management systems. The poplar cases, in which average costs rise quickly after dropping to their minimum, indicate that capital-intensive management systems will have a tight time window for optimum rotation age, especially if productivity rates do not measure up to expectations.

The optimum rotation age for mesquite shifted to eight years at lower productivity rates, a much longer period than is optimum for poplar. It appears that when capital costs are high, returns on investments must come in quickly, even if this means that productivity rates fail to meet expectations; in systems with low capital requirements, the timing of returns is not so critical. The shorter period for optimizing returns in more intensively managed systems may have important ramifications for system design and risk management, though these have not yet been evaluated.

Biomass Environments' Studies

D. W. Johnson	N. T. Edwards
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R. F. Walker	L. M. Stubbs

Maximization of woody biomass production on nutrient-poor sites using environmentally acceptable management practices is the primary emphasis of field studies sponsored at ORNL by the Biomass Energy Technology Division and the Office of Basic Energy Research, both of DOE. A plantation was established on the northern border of the Oak Ridge Reservation during the winter of 1980 to 1981 to evaluate the environmental effects of intensive forest management. Before this, the vegetation on the site consisted of secondary hardwood-pine scrub forest resulting from agricultural abandonment. After the removal of all salvageable timber and pulpwood, the slash was windrowed and the site was prepared for planting by bogging. Loblolly pine (*Pinus taeda*), yellow poplar (*Liriodendron tulipifera*), and sweetgum (*Liquidambar styraciflua*) seedlings were machine-planted during February and March of 1981 (approximately 5 ha per species). The experimental design (Fig. 4.4) used in this study provides for a determination of the differences in the survival and growth (including causal physiological processes and soil-plant interrelationships) of these species under various combinations of cultural treatments. One-half of the seedlings of each species bore a mycorrhizal infection induced through the use of vegetative inocula in the nursery; the loblolly pine were infected by the ectomycorrhizal symbiont *Pisolithus tinctorius*, the yellow poplar by the endomycorrhizal symbionts *Glomus fasciculatus* and *G. mosseae*, and the sweetgum by *G. mosseae* alone. The control seedlings of each species were infected by fungal symbionts endemic to the nursery in which each species was grown. The plantings of each host species and mycorrhizal treatment were divided into nine plots of equal size. A fourth species, black locust (*Robinia pseudoacacia*), was planted in a similar manner but included only seedlings infected with naturally occurring mycorrhizal symbionts.

In March 1982, three plots of each host species-mycorrhizal treatment combination received a single application of urea at the rate of 100 kg ha⁻¹. Three additional plots of each species-treatment combination received four applications of urea at the rate of 25 kg ha⁻¹ per application at equal intervals during 1982. The remaining three plots of each species-treatment combination received no fertilizer. These fertilization regimes will be continued yearly for the remainder of this study.

The plots of all species and treatments were disked in May 1982 as a weed-control measure. The aboveground biomass of the naturally invading herbaceous ground-cover species was determined for each plot in August 1982. Seedling height and stem diameter were measured biweekly from March through May 1982; additional measurements were made in July and August.

Fig. 4.4. Schematic diagram of the Oak Ridge short-rotation forest biomass plantation.

Randomly selected seedlings of each species-treatment combination were harvested in March, May, and August 1982; separated categorically into leaves, stems, and root systems; dried and weighed; and prepared for chemical analysis. These samples will be analyzed for total N, P, K, Ca, and Mg. Soil samples were collected monthly from March through October 1982 in each of the yellow poplar plots and analyzed for NO_3 and NH_4 . A total of five water samples was collected in 1982 from each of the lysimeters installed in the center of the plots in 1981 and was analyzed for NO_3 , NH_4 , P, and Ca. Collectively, these chemical analyses of plant tissue, soil, and water samples will provide insight into the mechanisms and pathways of nutrient movement and availability under the intensive management practices required for the optimization of biomass production on marginal lands.

In addition to continuing the investigations initiated in 1981 and 1982, additional experiments in the remaining years of this study will address the plant physiological and soil-plant nutrient processes that will be considered in the near-term utilization of marginal land for intensive silviculture. These experiments will consider interactions between processes by which plants acquire and use resources and the biological and physical processes by which nutrients are transformed and cycled within the soil-plant system (Fig. 4.5). The studies will consider the rate and seasonal kinetics of net assimilation; energy allocation during the seasonal growth, storage, and mobilization cycle; growth partitioning; and soil-plant-water relationships. This study will produce significant information needed to balance the enhanced short-term production of woody biomass with the sustained productive capacity of the site.

Fig. 4.5. Processes being examined in studies of resource allocation in an intensively managed biomass plantation.

Environmental Effects of Whole-Tree Harvesting Program

D. C. West	D. W. Johnson	D. E. Todd
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Overview

The Biomass Energy Technology Division and the Carbon Dioxide Research Division of DOE are supporting research on the environmental effects of whole-tree harvesting. This research involves site analysis of residue removal and whole-tree utilization for several forest types on ten U.S. sites (Table 4.2). All sites have been dedicated to intensive forestry research for some time, and the effects of whole-tree harvesting are built on a foundation of baseline data. The overall program plan

Table 4.2. Sites and forest types included in the Whole-Tree Harvesting Research Program

Research group	Site location	Forest type
Oak Ridge National Laboratory	Oak Ridge National Environmental Research Park, Tenn.	Mixed upland hardwoods
Southeastern Forest Experiment Station	Coweeta Hydrologic Station, N.C. Holt Walton Experimental Forest, Ga.	Mixed upland hardwoods Slash pine
Northeastern Forest Experiment Station	Mt. Success, N.H. Chesuncook Lake, Maine Cockaponset State Forest, Conn. Hubbard Brook, N.H.	Northern hardwoods Spruce-fir Central hardwoods Northern hardwoods
Clemson University	Clemson, S.C.	Loblolly pine
University of Washington	Charles Pack Forest, Wash.	Douglas fir
University of Florida	Bradford Forest, Fla.	Slash pine

is designed to (1) measure the erosion and nutrient loss from traditionally cut watersheds with and without whole-tree removal and, thereby, quantify the effects residue removal can be expected to have on water quality; (2) quantify the changes in nutrient supply associated with residue removal; (3) assess what these changes mean in terms of subsequent (e.g., in five to ten years) biomass productivity of the areas following the different techniques of harvesting; and (4) identify whether mitigation techniques can minimize adverse effects of aboveground vegetation removal in hardwood stands. Nutrient studies include measurement of N, K, P, Mg, Ca, and C. The sites for study were selected from geographic regions and locales that are the most heavily forested and harvested areas in the United States. From these areas, specific sites were picked primarily because of the large data bases existing for these forests.

The ultimate goal of this project is to provide information to the timber industry and watershed managers that will assist them in making environmentally sound decisions regarding timber harvest. In those areas of the United States where whole-tree harvesting and residue removal are possible, results from this project can be used to ascertain both short- and long-term consequences of a given harvesting practice. In addition, results from this research can be used to narrow the set of possible negative effects resulting from forest harvesting for a particular region of the United States. Consequently, decisions can be made to ensure long-term forest productivity regarding critical element removal and replacement, practical intensity of harvest, and mitigative harvesting techniques.

Nutrient Depletion Estimates

Because of the difficulties in comparing sites subjected to widely diverging harvesting techniques, data have been standardized in the following manner. Two methods or intensities of harvest have generally been used: one is usually a form of commercial harvest in which primarily the bole is used, and the other is a more complete biomass-removal harvest. Depending on the characteristics of the vegetation on the site and harvesting techniques, the complete harvest consists of removing only the overstory trees with bole, branches, and sometimes foliage or the harvest may include understory, ground cover, and litter in the removed material. Because all sites removed at

least understory and overstory branches in their residue-removal treatment, we chose this level of harvest as a standard for comparison. Foliage was included in residue-removal totals only for conifers.

By combining total nutrient pools in vegetation, litter, and soils (Table 4.3) with net changes in nutrients via losses and input, estimates of nutrient depletion for each rotation using differing harvesting intensities can be made (Table 4.4). Total-pool values include total soil, litter, and all aboveground vegetation. They do not include below-ground roots or stumps because these data are not available. In depletion rate calculations, values for roots and stumps were assumed to be constant. Although it is not possible to determine what portion of the total-soil pool of any nutrient will become available during a single rotation, total-soil measurements provide an upper limit to the soil nutrients potentially available.

By looking at system losses and inputs, regardless of harvesting intensity, it is apparent that K and Ca are the two elements being depleted naturally from most sites. However, total K in soils from most sites is high, thus providing a large reserve. In addition, K and Ca in rock may offset naturally occurring losses of these elements as these materials weather and become part of the soil pool. On the other hand, P pools, which are much lower at most sites, increase as a result of input from rainfall and negligible losses at most sites.

Depletion rates vary widely from site to site for different harvest intensities and for different nutrients. For the five sites for which data are currently available, two show as high as 30% depletion rates of Ca for a single rotation using whole-tree harvesting. Both of these sites, Oak Ridge and Coweeta, are in similar vegetation, mixed upland hardwoods (Table 4.4). The Coweeta site shows almost as great a depletion rate with sawlog harvest. Calcium is also being depleted at the Mt. Success, New Hampshire, northern hardwood site but at a much lower rate (4 to 5%). Timber harvest is apparently less of a drain on P and K than on Ca. Because of relatively high rates of input of N (even without considering N fixation), low loss rates, and moderate amounts removed in harvest, N shows low-to-high (1 to 27%) rates of increase, depending on the site and harvest intensity.

Table 4.3. Nutrient concentrations in selected ecosystem components before harvest at 13 forest sites

Stand age (years)	Aboveground woody component (≥ 5 cm dbh) ¹											
	Total nutrients (kg/ha)						Soil nutrients (kg/ha) ²					
	Biomass (Mg/ha)						Litter biomass (Mg/ha)					
	N	P	K	Ca	Mg		N	P	K	Ca	Mg	
	Douglas fir, high fertility						Douglas fir, low fertility					
55	318	728	95	326		578	18	214	21	26		0.6
55	165	325	56	141		125	14	147	19	27		2.2
55	147	345	47	174		1,275	15	127	20	30		12.0
55	120	178	25	143		1,356	14	130	17	22		8.0
60	210						80					
80	168						40	760				
40	115	316	20	135	358	40	74	1,738	36	30	486	23
70	178	277	41	216	544	6,800	21	120	17	18	185	7.0
						(117)						
70	165	363	25	160	1,084	3,080	16	150 ³	11 ³	24 ³	203 ³	3.6
						(31)						
40	132	150	13	63	334	3,656	26	192	14	19	113	1.6
30	112	162	14	51	167	39	34	277	10	9	96	5.6
						(121)						

¹Includes foliage for Douglas fir, spruce fir, and loblolly and slash pines (does not include small understory, but does include branches).

²Numbers in parentheses are amounts extractable. Extractable values include litter at Mt. Success.

³Includes shrubs, herbs, foliage, and other aboveground components not included in aboveground woody components.

⁴Woody litter not yet included.

Table 4.4. Estimates of nutrient depletion rates as a function of harvesting practice
 Rotation = 70 years at Coweeta and Oak Ridge; 40 years at Clemson and
 Mt. Success; and 30 years at Bradford Forest

Site	N			P			K			Ca		
	Total* pool (kg/ha)	Change ^a by end of one rotation (%)		Total pool	Change by end of one rotation (%)		Total pool	Change by end of one rotation (%)		Total pool	Change by end of one rotation (%)	
		Commercial harvest	Whole-tree harvest		Commercial harvest	Whole-tree harvest		Commercial harvest	Whole-tree harvest		Commercial harvest	Whole-tree harvest
Mt. Success, N.H.	7,996	0.5	-0.8	2,257		-0.7	10,244		-1.3	15,736	-3.0	-3.9
Coweeta, N.C.	7,307	6.4	3.6				124,317	-0.3	-0.4	3,288	-15.8	-27.0
Oak Ridge, Tenn.	3,652	4.5	-1.1	1,370	0	-1.1	21,999	-2.0	-2.4	2,680	-55.5	-80.5
Clemson, S.C.	2,018	24.4	20.1									
Bradford Forest, Fla.	4,156	-2.4	-2.3	532	-5.8	-6.0						

*Estimated soil total plus aboveground.

^aTotal pool (either commercial harvest or whole-tree harvest removals) + (input vs losses for duration of one rotation).

^cSystem changes via ground-water leaching as estimated from lysimeter collections not included.

5. LOW-LEVEL WASTE RESEARCH AND DEVELOPMENT PROGRAM

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Introduction

That Low-Level Waste Research and Development Program integrates work directed toward waste-management activities at ORNL with generic LLW studies and demonstration projects conducted for the DOE LLWMP. Site-specific ORNL work involves solid-waste disposal area studies of three ORNL burial grounds; vegetation management studies for burial grounds; monitoring and corrective measures analyses for inactive, intermediate-level liquid radioactive waste sites; and waste-management-related studies of local and regional geology. Generic tasks are focused on improving SLB methods and instituting corrective measures for older sites; primary emphasis is on disposal in environments with >750 mm of annual precipitation.

Site-Specific Low-Level Waste Studies

D. D. Huff

The primary purpose of the site-specific LLW studies is to provide environmental research and development support to solve LLW management problems at ORNL. The major objectives of the work are to

1. identify environmental factors that affect waste-disposal operations at ORNL,
2. determine the potential impact of waste disposal operations on environmental safety and regulatory compliance, and
3. determine and recommend procedures to ensure that environmental safety and regulatory goals are met.

The following descriptions summarize activities directed toward meeting the objectives described above.

¹Montana State University, Bozeman.

²East Tennessee State University, Johnson City.

³Information Division.

⁴Tennessee Technological University, Cookeville.

Solid Waste Storage Area 4 Studies (D. E. Huff and N. D. Farrow)

The primary purpose for solid waste storage area (SWSA) 4 investigations is to supply information needed to satisfy the objectives of upgrading and achieving long-term stabilization of the burial ground. Because SWSA 4 is the most important contributor of ^{90}Sr to White Oak Creek (Stueber et al. 1981a), it has been the focus of detailed studies of the distribution of ^{90}Sr as well as mechanisms for the hydrologic transport of ^{90}Sr from disposal trenches (Huff et al. 1982). These studies have resulted in plans for a surface-water diversion to capture uncontaminated runoff from the upslope portions of the SWSA 4 watershed and divert the runoff to other basins. Construction is expected to be completed in 1984. Meanwhile, more detailed characterization of the nature and extent of radionuclide contamination susceptible to transport by ground-water runoff from within SWSA 4 has proceeded. A 30- $\times$ 30-m grid system was extended into the region of most active ^{90}Sr transport and is being used to accurately determine the spatial distribution of radionuclide distribution there. A surface contamination survey on 5- $\times$ 5-m centers revealed patterns that suggest releases from several individual sources rather than from a general broad-area source from which contaminated ground water might be expected to be discharged over an extended area. Soil samples were collected using a percussion-driven coring device and were then subjected to gamma-scintillation analysis, which showed the presence of both ^{137}Cs and ^{60}Co . Cesium-137 contamination is present primarily at the ground surface, whereas ^{60}Co shows highest concentrations at from 0.3 to 0.5 m below ground. The nature of the three-dimensional distribution pattern strongly suggests that the spread of contamination results from the "bathtub" effect within several individual trenches in low-lying areas. These trenches, which were constructed perpendicular to contour lines, collect water and overflow to the ground surface at the downslope end rather than releasing contaminated water to the surrounding soils for subsequent ground-water transport. This shortened pathway is expected to be reduced to a minor role by the diversion of upslope runoff when the diversion construction is completed in 1984. However, evaluation studies continue, and the need for additional stabilizing measures will be determined only after the surface-runoff diversion project is completed.

Solid Waste Storage Area 3 Studies (J. Switek and K. O. Hasson)

Stueber et al. (1981b) noted that SWSA 3 appeared to supply small quantities of ^{90}Sr not only to the Northwest Tributary (NWT) of White Oak Creek but also to Raccoon Creek, which lies outside the White Oak Creek watershed. The inferred transport pathway was by way of a solution cavity labyrinth that parallels the geologic strike. To better define the nature of this solution network and allow the development and demonstration of corrective measures to be used in SLB grounds sited in carbonate (limestone or dolomite) terrain, further characterization using dye tracer tests, water chemistry analyses, and geologic studies were pursued.

Dye tracer experiments have confirmed that SWSA 3 is the source of ^{90}Sr to seeps on Raccoon Creek and the NWT. The relative intensity of dye reaching the NWT and the Raccoon Creek seeps (Fig. 5.1) indicates that a spring on the NWT is the major recipient of radionuclides migrating from SWSA 3. This spring should be an excellent monitoring point for assessing the effectiveness of any remedial actions implemented at SWSA 3. Breakthrough of tracers to both Raccoon Creek and NWT reveals that the ground-water drainage divide is approximately 100 m farther east than previously believed, and it now appears that under appropriate conditions, the entire southwestern portion of SWSA 3 may contribute ^{90}Sr to the Raccoon Creek drainage.

Reconnaissance-level geological investigations around SWSA 3 suggest that the southwestern end of the area is underlain by fault gouge clay that marks the thrust-faulted contact between limestones of the Chickamauga group and the older, overlying Rome formation (Fig. 5.1). Stratigraphic cross sections prepared from logs of SWSA 3 wells drilled in 1949-1950 do not show significant deformation of Chickamauga rocks related to this thrusting event. The contact between the clays of the fault gouge and outcropping limestone on the eastern side of SWSA 3 appears to be a major ground-water flow zone that feeds water directly into the middle of the burial ground from a small

Fig. 5.1. Map of the SWSA 3 area, ORNL, showing contaminated seeps and the approximate location of the Rome-Chickamauga fault clay deposit.

catchment area on Haw Ridge. The area at the base of this catchment, which is just outside the fence, is an old landfill having one trench about 100 m long (not shown). The disturbed ground probably increases the amount of water storage in this area, thus allowing releases of water to the burial ground over a prolonged period of time. It may be possible to install a grout curtain or french drain between this fill area and SWSA 3 to direct water away from the buried wastes. Alternatively, a drain could be installed at the top and a bentonite cap placed over the landfill itself. Future studies will involve drilling a well into the area and conducting a dye tracer test to establish the hydrologic connection between this area and the NWT. Seismic surveys will be run to determine more nearly accurately the position of the clay-limestone contact.

Solid Waste Storage Area 7 Site Characterization (C. S. Haase, D. D. Huff, C. D. Farmer, and E. R. Rothschild)

Within about ten years, new disposal facilities for solid LLW will be required at ORNL. The SWSA 7 is intended to receive higher-activity LLW, and characterization of this proposed site has

begun. Ground-water levels in the proposed SWSA 7 were monitored in 11 wells throughout the year. Seven of the original wells were redrilled to 30 m, and four of these were finished with multiple screens to permit study of deeper levels of ground-water flow. In September, three additional 30-m wells having multiple screens were installed. Thus, by September 30, 1982, ground-water monitoring was conducted using a total of 14 wells, 4 of which are 10 m deep and 10 of which are 30 m deep. In addition, a rain gauge was installed to measure precipitation at the site.

Making use of the observed minimum depth to ground-water level from CY 1981 (measured from land surface) and land-surface slope data, a preliminary map illustrating the potential usable land areas for conventional SLB practices was constructed (Fig. 5.2). The cross-hatched regions (Fig. 5.2) represent potentially usable areas where the depth of ground water is >5 m and the slope is 25% or less. The size of the region is about 10 ha; this value is very dependent on the minimum acceptable depth to ground-water value assumed in construction of the map. If a value of 2 or 3 m for this parameter is acceptable, the usable area will increase significantly, perhaps by a factor of 2 or 3. The appropriate value for this parameter and the value of the maximum acceptable surface

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Fig. 5.2. Map showing the general area encompassed by proposed SWSA 7. Regions enclosed within the solid lines in the center of the figure are potentially usable portions that have a depth to ground water >5 m. Within these regions the cross-hatched portions are areas where the slope of the land surface is $<25\%$.

slope will be determined by the disposal technology to be employed at SWSA 7. The extent of the potentially usable region illustrated in Fig. 5.2 must therefore be considered as tentative at this stage of engineering and design for SWSA 7.

To provide accurate measurement of surface-water discharge from SWSA 7 over a wide range in flow rate and at the same time to cause minimal ponding of water upstream, a critical-flow flume with a complex cross section was designed, fabricated, and installed on the primary stream that drains the proposed disposal area. The design parameters were finalized using an interactive computer program (Replogle 1975) together with field-determined estimates of downstream channel capacity. Because the flume represents an experiment in the performance of low head-loss measuring structures, it was fabricated from plywood to minimize costs and was installed on a concrete foundation that allows for changes in design if they become necessary.

Early indications are that the flume performs well enough to measure flow within $\pm 3\%$ at very low flow rates. Evaluation of the design will continue and be the basis for more nearly permanent structures in future years.

Intermediate-Level Liquid Waste Pits and Trenches (C. R. Olsen, S. Y. Lee, and P. D. Lowry)

From 1951 to 1966, seepage pits and trenches were used for the disposal of intermediate-level liquid wastes (ILWs) at ORNL. These waste pits and trenches were excavated in soil derived from the weathered Conasauga group and backfilled with crushed limestone. Waste liquids (adjusted to a pH of ~ 12 with NaOH) were allowed to percolate through the weathered rock (pH ~ 5), and radionuclide migration was retarded by reactions with the fill and soil. Over 1×10^6 Ci of fission products ($\sim 75\%$ ^{137}Cs and $\sim 25\%$ ^{90}Sr) including some activation products, actinides, and transuranics were disposed of in this manner before the implementation of deep-well hydrofracture.

Ground-water samples were collected on a monthly basis from ~ 35 wells in the vicinity of these formerly used ILW pits and trenches and routinely analyzed for pH, ^3H , ^{90}Sr , ^{137}Cs , and ^{60}Co . Selected samples have also been analyzed for other radionuclides (including ^{99}Tc , ^{233}U , and transuranics) and water chemical characteristics (ΣCO_2 , Eh, PO_4 , Fe, Mn, etc.). Data concerning the chemical properties of the water were used to help identify the geochemical factors and complexes that may influence nuclide solubility. Once in solution, nuclide migration from these waste-disposal sites is controlled primarily by local hydrological flow patterns, which are governed to a great extent by the local geological features, such as folds, faults, and zones of accelerated weathering.

Concentrations of ^3H , ^{60}Co , ^{233}U , ^{238}Pu , and ^{99}Tc in the ground waters around the ILW pits and trenches may range as high as 12,000, 1700, 41, 0.06, and 3200 Bq/L, respectively. The distribution of ^3H was used to delineate contaminated flow paths. Complexation of ^{60}Co with a soluble chelating agent (EDTA) was the reported cause for the high mobility of ^{60}Co . Experiments to positively identify the chemical speciation of mobile ^{60}Co are in progress. The mobile ^{233}U species is a low molecular weight anionic complex—probably a carbonate complex; the possibility of it being a phosphate complex was not ruled out, however. Between 20 and 50% of the dissolved (<0.45 m) ^{238}Pu in the ground waters is in an oxidized (V, VI) state. It is suspected that the ^{238}Pu contamination in these ground waters actually reflects the movement of its parent ^{242}Cm at the original time of disposal rather than during the subsequent migration of ^{238}Pu . The high concentrations of long-lived ^{99}Tc (210,000-year half-life) in the ground waters probably reflects its mobility as a negatively

charged pertechnetate ion, TcO_4^- , which is stable in slightly oxidizing aqueous solutions. Currently, levels of ^{90}Sr contamination in these ground waters are relatively low (<1 Bq/L) as a result of retardation by reactions of the alkaline waste with Ca-Mg carbonates in the soil or crushed limestone fill.

A detailed characterization of the geochemical, hydrological, and geological factors governing radionuclide migration is currently being undertaken at ILW trench 7. This site was chosen because of the occurrence of ^{60}Co and ^{233}U in a surface seep in a valley ~ 50 m east of the trench. Ground-water ^{60}Co and ^{233}U concentrations undergo a seasonal variation at this site, the highest activities occurring in the springtime. The seasonal rise in nuclide activity is correlated with a rise in the ground-water level and a concurrent increase in ground-water pH. This phenomenon suggests that during the spring, the water table may rise to saturate the alkaline fill in the trench or contaminated soils near the trench and, thus, promote nuclide migration.

Two suspected migration pathways of contaminated water from the trench to the nearby seep were identified on the basis of nuclide concentrations, inflections in the ground-water table, ground-water compositions, field seismic surveys, and local geologic structures. Both pathways appear to be associated with fault zones that strike parallel to a line drawn from the trench to the seep area. A series of wells drilled parallel to the trench and across these fault zones (open circles in Fig. 5.3) indicated an inflection in the ground-water table with a sharp rise occurring north of well T7-23. Seismic refraction results were too complex for unequivocal interpretation but definitely indicated structural discontinuities at wells T7-21 and T7-23. Along with this series of wells, a geologic cross section was exposed parallel to the trench by widening the banks of an already existing access road. This exposure delineated a fault zone at well T7-21, a large anticlinal fold at well T7-23, and another fault zone at well T7-25 (Fig. 5.4).

Ground-water analyses indicated that the greatest contamination occurred in wells drilled through the fault zones and that little or no contamination occurred in the ground waters capped by the limestone fold (Table 5.1). Well T7-21, which is not shown in Fig. 5.3, is a 15-m well that penetrates a fault zone ~ 8 m south of well T7-22. This fault zone is delineated by a surface topographic gully, along which several shallow 9-m wells (T7-4, T7-9, and T7-10 in Fig. 5.3) were drilled over a decade ago. These shallow wells did not penetrate deeply enough to tap the contaminated flow path indicated by gamma-ray borehole logs and by a comparison of the nuclide data for wells T7-21 and T7-10 in Table 5.1. Although ^{60}Co and ^{99}Tc concentrations in the ground waters of well T7-21 are high, the alkalinity, pH, and ^{233}U concentrations are relatively low, suggesting that this pathway is not currently transporting contamination from the trench itself but rather is a relict pathway that was active during past disposal operations.

The high alkalinity and pH of the ground waters in wells T7-24 and T7-25 along a fault zone at the north end of the trench (Figs. 5.3 and 5.4) in addition to the high ^{60}Co , ^{99}Tc , and ^{233}U concentrations (Table 5.1) indicate that this pathway is currently transporting contamination from the north end of ILW trench 7 to the seep areas in response to the spring rise in the ground-water level. A new series of wells and soil borings are currently being drilled at the north end of the trench to evaluate the (1) this mechanism and pathway for nuclide mobilization and transport and (2) the remedial effectiveness of using a french drain, ground-water interceptor to retard nuclide migration along this pathway

Fig. 5.3. Areal map illustrating the location of previous wells (closed circles) and new wells (open circles) in the vicinity of ILW Trench 7.

Solid Waste Storage Area Vegetation Management (F. G. Taylor, Jr., and P. D. Parr)

The use of vegetative covers other than grass or a change in maintenance of the current grass cover may be advantageous for both short- and long-term management of former solid LLW disposal sites. The "ideal" vegetation cover would require low or no maintenance, have a high water demand and a shallow root profile, cause negligible radionuclide uptake, and be capable of successful competition with invading successional species.

Plant species having potential use as ground cover on the LLW disposal areas were identified through review of the literature. Vegetation types evaluated included successional grass stages, successional thicket stages, shallow-rooted lawn grass species, drought-tolerant lawn grass species, prairie grass species, herbaceous horticultural species, forbs and weeds, low shrub species, tall shrub species, and trees. No single species or vegetation type emerged as fulfilling all requirements for the ideal cover.

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Fig. 5.4. Cross-sectional photo and map illustrating the geological structures that strike between ILW Trench 7 and a nearby contaminated scarp. Several wells (for which radionuclide data are presented in Table 5.1) are located in relation to the geologic structures.

Table 5.1. Contamination levels in wells near ILW trench^a

Well No.	pH	³ H (Bq/L)	⁹⁰ Sr (Bq/L)	⁹⁹ Tc (Bq/L)	⁶⁰ Co (Bq/L)	²³³ U (Bq/L)
T7-10	6.5	4,000 ± 700	0.4 ± 0.2		89 ± 3	0.2 ± 0.1
T7-21	6.9	29,000 ± 1,000	<0.1	3,200 ± 100	2,680 ± 67	1.6 ± 0.2
T7-22	7.3	10,000 ± 1,000	<0.1		1,090 ± 41	0.3 ± 0.1
T7-23	7.1	10,000 ± 1,000	0.9 ± 0.3		<4	<0.1
T7-24	7.3	6,700 ± 1,000	<0.1	400 ± 10	2,180 ± 11	2.3 ± 0.3
T7-25	8.9	5,600 ± 1,000	1.6 ± 0.4		1,820 ± 30	15.0 ± 2.0

^aThe samples were collected on Apr. 23, 1982, except for those for ⁹⁹Tc which were collected July 19, 1982.

Based on the literature review, natural succession stages may show promise as ideal cover, although the stabilizing of particular stages may require some maintenance. Broomsedge fields, for example, do not require fertilization, have a sufficiently shallow root profile, and are relatively stable if mowed annually. Thicket or vine stages (e.g., honey-suckle, kudzu, and sumac) may resist invading deep-rooted species. A grass cover (as presently maintained on the disposal areas) requires greater labor intensive care (mowing and fertilization) but can provide the least risk of root mining as long as deep-rooted, drought-resistant species are avoided. A dense thicket of ornamental shrubs (e.g., sumac, spiraea, forsythia, and jasmine) can be obtained if shrubs are pruned back occasion-

ally. Of the herbaceous ornamental species, yellow root, groundcover, bamboo, and lilyturf or a combination of these with periwinkle, bugleweed, and English ivy, can be effective. Ornamental shrubs and herbs will also require some maintenance (periodic weeding, pruning, and pest control).

Some possibilities may exist for low-maintenance arboreal vegetation. For example, preliminary work with simulation models indicates that plantations of certain early successional species may provide suitable vegetation cover but may require infrequent, labor-intensive manipulation. Species such as red maple or white ash may have proper rooting characteristics; sprout readily when harvested; and be able to regenerate and maintain, through coppicing (stump sprouting) on a 20-year cycle, leaf areas suitable for relatively high evapotranspiration. Current work with the modeling effort also indicates highly variable growth under different moisture and nutrient regimes.

The long-term objective of the research is to demonstrate that improved vegetative covers are available and to provide a sound basis for recommending the type of cover best suited for a particular disposal area. Proposed cover types will be evaluated locally through a series of demonstration plots and extrapolated regionally through modeling efforts utilizing forest types and variable environmental conditions typical of the Southeast.

Melton Valley Geology (C. S. Haase, K. O. Hasson, E. C. Walls, and C. D. Farmer)

Research this past year focused on the regional stratigraphic character of the Conasauga group throughout eastern Tennessee and on the refinement of the general stratigraphic and petrologic understanding of the Conasauga group at the Oak Ridge locality. The purpose of this subtask is to characterize the sedimentology, stratigraphy, and petrology of the Conasauga group so that its role as a host formation for the hydraulic fracturing and the SLB operations at ORNL can be better evaluated.

Regional stratigraphic studies were based on an extensive compilation of data from published and unpublished sources. Lithofacies and isopach maps in conjunction with stratigraphic cross sections of the Conasauga group and its constituent formations in eastern Tennessee were prepared as both present-day and palinspastic bases (Hasson and Haase 1982).

Examination of the present-day base isopach and lithofacies maps resulted in the identification of spatial and temporal patterns of lithofacies distribution that are generally consistent with those outlined by Rodgers (1953). Such patterns suggest that the Conasauga group was deposited on a passive continental margin in a shallow marine-shelf setting. Examination of the data plotted on a restored palinspastic base, which removes the effects of postdepositional thrust faulting, demonstrates that the prethrusting isopach and lithofacies patterns are not consistent with the simple, shallow marine-shelf depositional setting. Instead, the data suggest the following features for the regional depositional setting for the Conasauga group:

1. Depositional settings ranged from dominantly marine to locally peritidal. Sedimentation occurred on a northeast-southwest-trending continental shelf (300 to 500 km wide) that contained an intrashelf basin (100 to 200 km wide) that closed to the southwest and opened to the northeast along an axis approximately parallel to the trend of the shelf margin.
2. The eastern margin of this intrashelf basin consists of shaly limestones and dolostones that become dominantly dolostones east of the basin margin.
3. Intrashelf basin sediments consist mainly of shales, siltstones, and shaly limestones.

4. The western margin of the basin consists mostly of siltstones, shales, and calcareous shales that become dominantly clastic-rich westward of the basin.

These conclusions about the Conasauga group depositional setting and lithofacies distribution patterns for eastern Tennessee agree well with the shelf-intrashelf basin-carbonate ramp shelf margin model proposed for the Nolichucky shale and upper Conasauga group equivalents in southwestern Virginia by Markello and Read (1981, 1982). The results of this study provide information about the southern extent of the intrashelf basin described by Markello and Read (1981, 1982) and about the nature of the Conasauga group depositional setting south of the area studied by them. Results of this regional stratigraphic study indicate that the Conasauga group that occurs at the Oak Ridge locality was deposited on the Western edge of the intrashelf basin but to the east of the western basin margin. The abundance of clastic-rich material and the complexly interfingering nature of clastic-rich and carbonate-rich lithologies within the Conasauga group at the Oak Ridge locality are consistent with such a depositional setting.

To date, local stratigraphic investigations of the Conasauga group in the White Oak Mountain and Copper Creek thrust blocks (Haase and Vaughan 1981) were based on limited outcrop data and widely scattered diamond-drill cores. To provide a complete reference stratigraphic section of the Conasauga group for the Copper Creek thrust block (Melton Valley), a deep borehole drilling project was begun in August 1982. The goal of this project is to obtain a continuous rock core of the Conasauga group and the underlying Rome formation. The rock core will allow an unambiguous correlation of numerous fragmentary rock cores of Conasauga group material obtained previously throughout the DOE Oak Ridge Reservation. It will also provide stratigraphically well-characterized samples for use in well-logging studies planned for FY 1983. As of October 26, 1982, the deep borehole was drilled to a depth of 730 m (~2400 ft); the total depth of the borehole will be approximately 900 m (~2900 ft).

Generic Low-Level Waste Studies

B. P. Spalding

Projects addressing the generic aspects of radioactive solid-waste disposal include the evaluation and demonstration of improved burial procedures for future and existing disposal sites and the development and demonstration of corrective measures and strategies for site stabilization and closure. The *Code of Federal Regulations* (10 CFR Pt. 61) requires all future commercial disposal sites to be managed to meet a performance objective of no offsite ground-water contamination that would result in a radiological dose above certain regulatory limits. To meet this requirement, certain sites may require engineered barriers, such as lined or grouted trenches, as improvements to the current practice of dump and fill. Thus, a significant effort is underway to demonstrate and evaluate grouting and lining techniques. Even using good site planning and advanced burial techniques, the proposed regulations also require contingency plans for corrective actions should site performance be compromised by ground-water contamination. Thus, techniques for ground-water contamination management, particularly for the more mobile radionuclides contained in the waste, need to be developed and demonstrated before generic recommendations for them can be advocated. Techniques under evaluation include a passive ground-water diversion system, remedial trench grouting, and chemical (caustic soda and soda ash) treatment of trenches and ground-water seeps. The final phase in the management of a waste-disposal site is its stabilization and closure. After

closure, a site is abandoned to the processes of geological weathering and vegetational succession, through which period the site must still meet certain performance objectives. Possible strategies to minimize these processes from compromising site performance need to be identified so that the consequences of various strategies for site stabilization and closure can be predicted.

Corrective Measures (B. P. Spalding, M. G. Browman, E. C. Davis, L. K. Hyder, D. S. Marshall, and I. L. Munro)

The dominant disposal method for most solid LLW has been and will continue to be SLB. Usually SLB trenches perform well in retaining radionuclides and preventing their migration to uncontrolled areas. Occasionally, trenches leak radionuclides to the extent that corrective measures seem warranted. Problems with SLB that could precipitate situations requiring corrective action include the (1) infiltration of surface runoff into burial trenches, (2) ground-water intrusion, (3) trench subsidence, (4) soil erosion, (5) trench intrusion by plants and animals, and (6) radionuclide migration. A hypothetical trench having all of these problems is depicted in Fig. 5.5. The seasonal

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Fig. 5.5. Problems encountered in the shallow land burial of low-level waste to be addressed by corrective-measures technology.

fluctuation of the water table leads to periods when the buried waste is bathed by ground water. Additional inundation is facilitated by direct infiltration of precipitation and the catching of any surface runoff resulting from partial subsidence of the trench backfill. The points of rapid trench subsidence or cover collapse can effectively function as drains for surface runoff, thus leading to an accumulation of water that results in a perched water table within the trench. Obviously, the control and diversion of surface runoff can alleviate many of these inundation problems. Sealing the trench cover with bentonite or plastic sheeting was advocated to relieve the situation of direct

infiltration of precipitation (Duguid 1976). However, trenches like the one depicted in Fig. 5.5 are often situated in areas where the water table is maintained by lateral ground-water recharge rather than, or in addition to, direct infiltration precipitation. Passive ground-water interception and diversion drains provide a means to relieve such situations.

Such engineered drainage alterations, however, can become economically prohibitive for large regions containing many trenches, particularly when only one or a few trenches are the source of the problem. In these situations, hydrologic isolation of individual trenches can be better addressed by waste grouting. The injection of grout throughout the void space of a burial trench, which upon grout set becomes impermeable to water, can effectively isolate buried waste from further ground-water intrusion. In addition, because trench void spaces become filled, subsidence can also be effectively controlled.

Mobility of radionuclides in LLW is the source of their potential hazard. One radionuclide, ^{90}Sr , is particularly troublesome for SLB not only in a generic hazard evaluation because of its high radiotoxicity and its high mobility in soil but also at specific sites such as the waste-disposal areas of ORNL (Duguid 1975). Fixation or immobilization of ^{90}Sr in soil in and around a burial trench was pursued both in laboratory and field studies using caustic soda and soda ash chemical treatment. Such chemical techniques would be most applicable to situations where either ground-water diversion or grouting would be expensive and would also be applicable to ground-water seep contamination where an immediate abatement of radionuclide concentrations would be required. Treatment at a source trench may require a considerable interval before effects are observed at a distant contaminated seep.

The ORNL task for corrective measures technology is divided into four demonstration subtasks: passive ground-water diversion drainage, trench-grouting, trench chemical treatment, and ground-water seep treatment.

The passive-drain demonstration subtask addresses the situation in which ground-water intrusion of a group of trenches is maintained by lateral recharge rather than by direct infiltration of precipitation. By constructing a drain to intercept and divert ground water between the area to be protected and its recharge area, the ground-water recharge can be eliminated. To demonstrate this technology, a subsection of SWSA 6 at ORNL, which contains 49 burial trenches, was selected for construction of a french drain (Fig. 5.6). The suite of 49 trenches to be protected by the drain, was surface sealed with a soil-bentonite mixture in November 1976; seasonally, standing water still exists in many of the trenches (Arora et al. 1981). Whether the bentonite seal is working in this area cannot be determined from observations of the water table alone; in addition to any infiltration of precipitation allowed by a poorly performing seal, the water table in this area is maintained by lateral ground-water recharge from areas not under the seal. Interestingly, based on the surface topographic contours and water-table elevation data in the area (Webster et al. 1980), a traditional hydrologic analysis would indicate that the recharge area is the shaded area in Fig. 5.6. However, because it lies along the line of joint fractures (Sledz and Huff 1981) that function as preferred ground-water flow paths, the area immediately east of these 49 trenches is probably more important as a recharge zone. Additional experimental determinations of the ground-water velocities and directions along the line of the proposed drain are being collected. Regardless of the relative contributions of these two possible recharge areas, the 49-trench area will be protected by the surrounding drain. Test borings along the proposed drain have been completed, and no hard rock was encountered within the 7.6-m maximum depth of the drain. Construction will begin in the near future, and in the preconstruction interval, water-table elevations will continue to be monitored to add to the existing five-year record of the area (Webster et al. 1980).

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Fig. 5.6. Location of proposed french drain for ground-water diversion demonstration SWSA 6 at ORNL.

The trench-grouting demonstration addresses the situation in which a particular trench, rather than a group of trenches, is functioning as a source of radionuclide contamination of ground water and, therefore, compromising the performance of a site. By injecting a low-viscosity and nonparticulate grout into the void space of a problem trench, the buried waste can be hydrologically isolated (after the grout sets to its impermeable state). Two basic problems confront the potential user of grout as a corrective measure for solid LLW disposal. First, of the many types and formulations of grout currently available (Herndon and Lenahan 1976), a selection must be made using criteria including a low viscosity (similar to that of water); a set time controllable from minutes to days; an inherently low permeability after grout has set; durability to resist the physiochemical and microbial stresses in its applied environment; low toxic hazard; and, of course, low cost. Any grout selection will, of necessity, represent a compromise among these criteria. Based

on existing data (Herndon and Lenahan 1976), five grout formulations were selected for laboratory testing; the fundamental property for this laboratory evaluation was the ability of the grout to reduce the hydraulic conductivity of several soil and waste types. Both 10% polyacrylamide and 15% sodium silicate performed well and were selected for field demonstration.

The second problem to be faced is how to achieve a distribution of the grout within the target trench. Because both the polyacrylamide and sodium silicate grout formulations are low viscosity and nonparticulate, they would flow within trench voids as easily as would intruding ground water. Therefore, grout injection could be effected with a minimum number of injection wells. Because the hydraulic conductivity of a trench's waste/backfill is much greater than the surrounding unperturbed soil formation, trenches can be easily filled with fluids. To test this critical assumption, three disposal trenches were constructed in the suspect waste landfill area of SWSA 6. The trenches were then filled with suspect solid waste and backfilled with soil—as SLB is currently practiced at ORNL. A grid of nine wells was positioned in each trench, and each trench was surrounded by four additional wells within the unperturbed formation. By measuring the hydraulic conductivity of the material surrounding each of these wells through constant-head, pump-in tests, grouting effectiveness can be determined by comparing measurements before and after grouting, respectively. The grid of wells, in addition to measuring the conductivities of the waste/backfill and the soil formation, provides a means to determine the areal extent of grout penetration.

Both silicate and polyacrylamide grouts were readily injected into the trenches and were observed in all monitoring wells. The hydraulic conductivities of all wells were dramatically reduced; more than 80% became effectively impermeable. Continuing the monitoring of the permeability of each of the grouted trenches will establish the longevity of their respective effectiveness.

Chemical treatment of trenches addresses the problem of specific radionuclide leaching from waste. Strontium-90, for example, is probably the most compromising radionuclide to the performance of an SLB site. Laboratory studies that employ both test-tube batch and soil columns indicate that ^{90}Sr can be fixed and immobilized in the $\text{Ca}(^{90}\text{Sr})\text{CO}_3$ form and that this can be achieved in situ in soil by the addition of soda ash and/or caustic soda (Spaulding 1981). A number of concerns remained about the applicability of this technique to acidic soils, which are inherently low in available Ca from which CaCO_3 would form following the addition of soda ash. Several acidic soils were treated with soda ash and supplemental Ca and Ba to supply adequate amounts of alkaline earths to effect a precipitation of CaCO_3 or BaCO_3 , respectively. Soil columns were treated with ^{85}Sr and chemicals as described previously (Spaulding, 1981) and eluted with dilute CaCl_2 . Supplemental Ca or Ba effected a greater fixation of ^{85}Sr than did soda ash alone. Thus, a two-step system for the chemical fixation of radiosttrontium in strongly acidic soils seems quite feasible and considerably broadens the range of soils to which the technique is applicable.

The field demonstration of the trench treatment with caustic soda and soda ash reported last year (Spaulding and Huff 1981) has continued in its monitoring phases. Since then, little change in the trends of the reported observations occurred. Hydrologic characterization of the trench environs using some water pump-in tests was attempted. The resulting hydrologic characteristics will be used to evaluate the chemical behavior of this trench, through time, and to formulate a model of the trench environs from which conclusions about trench performance beyond the period of experimental observation can be based.

Ground-water seep treatment addresses the situation in which a ground-water seep is discharging radioactivity into surface water. Such a situation may require an immediate corrective

action, depending on the level of radioactivity involved. Source treatments, like the three techniques discussed above, could not result in an immediate response at a seep discharge because the contamination plume, which leads to the seep, could take several years to flush. Thus, even interim techniques to address such situations have considerable merit. A seep on the periphery of SWSA 5 was selected for a field demonstration, and a weir, stage-height recorder, and automatic water sampler were installed at the site. After about a year of pretreatment monitoring, 360 kg of soda ash was buried among seven locations immediately upslope from the seep, and the response of ^{90}Sr and seep water quality were observed. Following soda-ash burial, the pH and electrical conductivity of the seep water increased markedly, whereas the hardness and ^{90}Sr levels decreased. An in situ softening of the seep water, with the coprecipitation of ^{90}Sr on calcite, was brought about by this treatment. Average water quality parameters are listed in Table 5.2 for the periods 0–300 d before

Table 5.2 Average chemical characteristics of seep water before and after soda ash treatment of a ground-water seep

Characteristic	Units	Period		
		0–300 d before	0–90 d after	91–310 d after
^{90}Sr	Bq/mL	7.37a ^e	1.36b	5.34c
Hardness	mg CaCO_3/L	390d	83e	390f
Conductivity	$\mu\text{S}/\text{cm}$	638g	9000h	662g
pH	$-\log [\text{H}^+]$	7.4i	9.5j	7.6i
Number of samples		63	9.3	106

^eLetters indicate statistical significance. Means followed by the same letter are not significantly different at the 5% level.

and 0–90 and 91–310 d after soda-ash burial. An average 80% reduction in ^{90}Sr concentration was maintained for the 90-d period following soda-ash burial. This reduction was followed by a slow recovery over the next year to near pretreatment levels. Thus, the technique has merit as an interim corrective measure that could be repeated as often as necessary, and more permanent corrective measures could be carried out concurrently at the source. This measure is only temporary because of the depletion of the soda ash via dissolution, neutralization, and calcite precipitation in the ground-water flow path. Because the incoming ^{90}Sr in ground water was not stopped through a source treatment, once the soda ash was depleted, no mechanism existed for continued radiostrontium fixation.

Shallow Land Burial Technology Development (N. D. Vaughan, W. J. Boegly, J. D. Newbold, G. T. Yeh, and O. M. Sealand)

The purpose of this task is to adapt, develop, and demonstrate technical procedures that support the SLB of LLW. The Engineered Test Facility (ETF) is a five-year field demonstration project of improved SLB procedures. To date, the ETF site characterization and waste emplacement have been completed, and the monitoring phases have begun. The ETF is located within the Copper Creek thrust block of the Valley and Ridge province of eastern Tennessee and is

underlain by strata of the Middle to Late Cambrian Conasauga group. The Maryville Limestone formation, which is composed of ribbon-bedded and interclastic limestones and dark grey shales and mudstones, comprises the bedrock immediately beneath the site. The bedrock and residuum structure are characterized by anticlinal folds having numerous joints and fractures, some of which are filled with calcite. Seismic and electrical resistivity methods were useful in characterizing the thickness of residuum and the presence of structural features. Soils are illitic and range from podzolic to lithosols to alluvial in the vicinity of the ETF, but the original soil solum was removed in 1975 when the mixed hardwood forest was cleared and the site was planted in grasses. The remaining residuum consists of acidic soil aggregate (pH 4.4 to 5.6) and extensively weathered siltstone and sandstone that exhibit the original rock structure. The mean annual precipitation at the site is 1500 mm, although during the initial study period (October 1, 1980, to September 30, 1981) the annual total was 939 mm. Runoff was estimated to be about 50% of the total precipitation, based on observations at two Parshall flumes installed at the site. Storm runoff is quite responsive to rainfall, and the lag time between peak rainfall and runoff is less than 15 min during winter storms. Water quality of surface runoff is as expected for a mixed carbonate and siliceous terrain except that some tritium migration occurs from an adjacent disposal area in the flume to the east of the study area. Tracer studies of the ground-water system, together with pump tests, have shown the important influence of fractures and joints on ground-water movement at the site. To date, the results suggest that ground-water flow has two distinct components: one associated with fracture flow, and the other, with intergranular flow (Vaughan et al., in press).

Waste emplacement consisted of selection of the type of waste, identification of specific liner and grout treatments, and actual emplacement. Compacted and baled LLW was chosen because of the quantity of waste needed for the triplicate demonstration-sized ($\sim 27\text{m}^3$) trenches for each treatment (control, grout, and liner). These trenches were constructed in a Latin-square array within the space enclosed by the characterization wells. The bales were dumped rather than stacked into the trenches to simulate the voids normally found in LLW disposal trenches.

A 1.1-mm reinforced Hypalon material was selected as the liner and was placed into the trenches before the bales were and was then sealed shut after the trench was full. The grout, composed of 0.45 kg bentonite and 2.75 kg type I cement for every 3.78 L of slurry, was introduced after the waste was emplaced. These treatments are anticipated to retard water movement into the trenches, thus reducing subsequent radionuclide migration from the trenches and reducing trench subsidence. For monitoring purposes, a unique chemical tracer was placed in each trench at the time of treatment. Twenty-four monitoring wells were drilled; each trench was surrounded by at least 4 wells. Samples are taken from the monitoring and characterization wells on a biweekly schedule to be analyzed for chemical or radionuclide contamination. Results indicate that tracer breakthrough has not occurred in the first four months after closures.

An automated data acquisition system has been developed for monitoring ground-water levels at the ETF site. The system employs a battery-operated data logging instrument that digitizes potentiometer output from water-level monitors in the 15 ETF wells and records the digitized data on cassette tape at about 14-min intervals. At one-to-two-week intervals, the cassette is removed from the logger, and its contents are transferred onto a disk file on ORNL's PDP-10 computer. The raw data are preprocessed on the PDP-10 to convert from reverse octal to decimal millivolts. An interactive program prompts the user for the date, time, and calibration information associated with a given tape and creates a raw data file for transfer to, and permanent storage on, the IBM Mass Storage Subsystem. A Statistical Analysis System (SAS) program that runs on the IBM 3033

converts the raw millivolt data to water-level elevations, associates these elevations with appropriate date-time information, and performs several checks for consistency of calibration and timing. The new data are added to a data base (stored as an SAS data set) that contains all previously collected data in a form readily accessible for plotting and further data analysis, including model validation.

Numerous models using finite-difference and finite-element approaches for simulating the water flow and contaminant transport in either saturated-unsaturated porous media or in completely saturated aquifers were reported in the literature (Appel and Bredehoeft 1976; Bachmat et al. 1980). However, none of the computational codes were designed to simultaneously handle the transient sources/sinks; Dirichlet (prescribed head or concentration), Neumann (prescribed gradient of head or concentration), or Cauchy (prescribed flux of water or contaminant) boundary values; and variable boundary conditions (also confining leaky aquifers in the case of a completely saturated system). In real-world problems, such as occur in disposal sites, recharge/pumping is more likely to be distributed over the region of interest and to be time dependent. The boundary values, with rare exception, vary both with time and along a Dirichlet boundary. The prescribed gradients are both temporally and spatially distributed over the Neumann surfaces. The total fluxes vary with time and along Cauchy surfaces. Furthermore, in many occasions, the boundary conditions cannot be predetermined but change with the passage of time and field conditions. For prototype applications, a computational model must have the capability to deal with these aspects efficiently and simultaneously. Four computer codes, FEWA (Yeh and Huff 1982a), FEMA (Yeh and Huff 1982b), FEMWATER-1 (Yeh 1982a), and FEMWASTE-1 (Yeh 1982b) were developed and implemented to achieve these objectives in the past year. Both FEWA and FEMA are intended for application to completely saturated aquifers over horizontal areas. This pair of models can be applied to large-scale as well as small-area problems. On the other hand, FEMWATER-1 and FEMWASTE-1 are intended for applications to combined saturated-unsaturated porous media on a vertical cross-sectional area, and they are more applicable to problems on a scale of hundreds of meters. They can be applied to larger-scale problems, although computer storage requirements and central processing unit (CPU) time will be large. These four computer codes were developed and modified based on FEMWATER (Yeh and Ward 1980) and FEMWASTE (Yeh and Ward 1981). The modifications will consider (1) space- and time-dependent sources/sinks representing recharges and pumping; (2) highly transient boundary values on Dirichlet segments; (3) time-dependent, distributed gradients over Neumann boundaries; (4) highly time-dependent total fluxes on Cauchy boundaries; (5) addition of off-diagonal hydraulic conductivity to the water-flow equation; (6) options of underrelaxation and overrelaxation techniques in iteration solutions; and (7) automatic resetting of time-step size when boundary conditions or sources/sinks change abruptly. In addition, the input structure is completely reformulated so that practitioners can use them easily. Modifications 1 through 4 make the model applicable to realistic situations when internal sources/sinks and boundary conditions are changing with time either gradually or abruptly and are distributed over space. Modification 5 enables the application of these models to cases of geologic media consisting of several formations; each is nonhomogeneous and anisotropic. Modification 6 extends model applications to wider-ranged parameters when they make the numerical solution fluctuate or converge too slowly. Modification 7 makes the schedule of time-step size easy upon change of conditions. In addition, because point-wise iterative computation is built in to FEWA and FEMA as an alternative to the direct solution, this makes FEWA and FEMA applicable to large-scale problems.

Soil Erosion Measurement (N. H. Cutshall, I. L. Larsen, G. A. Nielsen, and O. Arnalds)

Postclosure soil erosion may affect SLB sites by reducing the integrity of trench covers, thereby allowing infiltration into the trench and, in extreme cases, exposing the waste. Agricultural erosion work has previously led to development of the "universal soil-loss equation", which estimates erosion rates based on such variables as precipitation, land surface slope, and soil erodibility. Direct field measurements of erosion were made to confirm the validity of the universal soil-loss equation for relatively flat midwestern terrain. The current work will determine if the validation can be generalized to a wider set of terrains. It is conducted in cooperation with G. A. Nielsen and O. Arnalds at Montana State University.

Direct analysis of soil movement in the field is slow and expensive. Therefore, indirect tracer methods have been developed to allow more rapid estimation of erosion and deposition. Cesium-137 was used as a soil tracer in erosion studies by Rogowski and Tamura (1965). Their techniques were adapted to ^{137}Cs from fallout experience from atmospheric weapons tests and were refined and applied by McHenry (1968), Ritchie and McHenry (1977) and coworkers, and by Brown et al. (1981a, 1981b). These techniques will be used in a variety of terrains in Montana, ranging from prairie farmland to high alpine, and the results will then be compared to estimates from the universal soil-loss equation. A preliminary investigation was completed, and ^{137}Cs in fallout appears to be a promising indicator of soil movement in Montana. In particular, two sets of samples were analyzed. The first set was selected from a wind-eroded field that had been plowed just before the occurrence of a major historical windstorm. Plow-layer samples taken from the field itself were depleted in ^{137}Cs , thus reflecting the loss of soil that had occurred. Cesium-137 inventories in paired samples taken to the windward and leeward sides of windbreaks and fence rows downwind from the eroded field also showed the effects of soil movement. Windward inventories are 1.5 to 2 times the leeward inventories, showing the accumulation of soil that occurred.

The other set of samples were taken in a small watershed. Vertical profiles from four sites were determined (Table 5.3). A regular gradient in ^{137}Cs inventories is apparent. In the upper and lower

Table 5.3. Distribution of ^{137}Cs (pCi/g) in soil profiles of a Montana watershed

Site	Slope	Segment thickness (cm)	^{137}Cs in profile segments		
			Upper	Center	Lower
Upper slope	5-7%	15	0.17	0.08	Not sampled
Lower slope	1-3%	15	0.59	0.13	Not sampled
Grass near pond	flat	13	0.84	0.48	0.07
Pond, center	flat	13	0.72	0.65	0.53

slope areas, which are subject to erosion, ^{137}Cs inventories are markedly lower than they are in the pond at the bottom of the watershed. Thus, it appears that the results are qualitatively consistent with expectation. About 200 samples are now being analyzed for ^{137}Cs , and the results will be used to make quantitative estimates of soil removal and deposition.

Vegetation Studies in Humid Site Stabilization and Closure (F. G. Taylor and D. C. West)

Long-term stabilization and minimization of maintenance requirements are desirable components of closure for SLB sites. State-of-the-art protocols that use grass as cover to inhibit invasion of undesirable species are labor intensive and not suitable for the long term. A more desirable vegetative cover would use phases other than pioneer stages (grasses) and would persist for many years with only periodic maintenance. Considering the diverse floristic composition of the humid eastern United States, no single taxon is likely to provide an ideal cover. Succession models can identify potential cover types (grasslands, thickets, and forests) that can be manipulated (maintained) to prolong dominance.

Preliminary work with simulation models indicates that plantations of certain early successional arboreal species may provide suitable vegetation cover and require only infrequent, labor-intensive manipulation. Species such as red maple or white ash have proper rooting characteristics; sprout readily when harvested; can regenerate and maintain growth, through coppicing (stump sprouting) on a 20-year cycle; and provide high leaf areas suitable for relatively high evapotranspiration. Results from current work indicate highly variable growth under different moisture and nutrient regimes. The use of solely successional models, however, oversimplifies the temporal characteristics of a cover. Addition of moisture and nutrient subroutines in model studies, superimposed upon manipulative practices, will provide design criteria in cover recommendations throughout the southeast.

From an initial selection process, red maple and white ash were chosen for plot studies to begin next year. Efforts will be combined with site-specific research to evaluate the ability of each species to cover an area, interact with invading (competing) species, and persist without intense maintenance.

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6. DEPARTMENT OF ENERGY LOW-LEVEL WASTE MANAGEMENT PROGRAM

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Introduction

In early FY 1979, ORNL was assigned the associate lead-contractor role in the DOE Low-Level Waste Management Program (LLWMP). This role is carried out by the Program Manager at DOE's Idaho Operations Office, the lead contractor, (EG&G Idaho) at the Idaho National Engineering Laboratory (INEL); and DOE's Oak Ridge Operation Office (ORO).

The overall objective of the LLWMP is to develop and promote environmentally sound techniques for safely and efficiently managing the disposal of all types of low-level wastes (LLW). Such activities as energy production, manufacturing, and the use of radioisotopes in medical and research activities produce LLW. Specific program technology objectives include the development of waste treatment and packaging technology; development of improved shallow-land burial (SLB) technology; establishment of corrective measures for stabilizing and improving performance of existing burial grounds; identification and evaluation of alternative methods for storage and disposal of LLW that provide greater confinement than SLB; and development of guidelines or standards for waste characterization, disposal, and monitoring.

ORNL in its role as associate lead contractor of the DOE LLWMP has responsibility for the management of program-funded technology development activities. In this role, with general guidance provided by DOE and the lead contractor (EG&G Idaho), the ORNL program office is charged with the responsibility to (1) develop program plans for the major technology areas, (2) recommend allocations for the program resources, (3) review the technology development tasks to ensure that program objectives are being met, and (4) assist the lead contractor in coordinating the DOE program with other ongoing U.S. and foreign waste-technology programs. Although the ORNL office generally assists the lead laboratory in management of the total program, our emphasis is on management of R&D for development of basic technology and on assessing concepts for alternative systems of processing and disposal of LLW.

Technical progress for each of the tasks performed by this program office for FY 1982 follows.

Low-Level Waste Management

Technical Planning

Details for the technology-development portions of the LLW Management Five-Year Program Plan were developed in conjunction with EG&G Idaho. The detailed overall program plan for FY 1982 was actually issued by EG&G Idaho. Three reviews were prepared by this office in support of program planning and control.

¹Energy Division, ORNL

²Operations Division, ORNL

- Revision of Position Paper: "Evaluation of the Need for Greater Confinement than Shallow Land Burial of Low-Level Wastes" (L. J. Mezga)
- Final Report: "Review of Liquid Waste Treatment Processes Developed by the DOE LLWMP," ORNL/NFW 82/7 (J. E. Vath)
- Final Report: "Verification and Validation Protocols for Low-Level Waste Disposal Site Performance Models" (M. S. Moran)

To insure that program outputs are of consistently high quality and delivered on schedule, the following program guidance was developed for technology-development tasks:

1. Guidance for the Preparation of Experimental Test Plans,
2. Technical Guidance for the Preparation of FY 1983 Current Year Work Plans, and
3. Technical Guidance for the Preparation of FY 1984 Field Task Proposals/Agreements (FTP/A).

Resource Allocation

The major effort during FY 1982 focused on developing and setting priorities for the FY 1982, FY 1983, and FY 1984 budgets. These activities included: (1) preparation of FTP/A and budget call technical guidance, (2) evaluation and revision of FY 1982, FY 1983, and FY 1984 budgets, (3) evaluation and revision of the FY 1982, FY 1983, and FY 1984 Current Year Work Plans, and (4) setting priorities for the FY 1982, FY 1983, and FY 1984 budgets. These were iterative processes based on changes in the proposed budgets for these years and were made more complex because of the problems associated with operating under a continuing resolution.

Program Review

Program review activities during FY 1982 included: (1) conducting site visits to existing contractor facilities, (2) briefing DOE headquarters and field offices, and (3) conducting the third and fourth Annual Information Meetings. Site visits were conducted to review and discuss current fiscal year activities and to develop the elements of the Current Year Work Plan for the coming fiscal year. The LLWMP staff provided guidance to the various contractors relative to program goals and technical needs, anticipated funding levels, and program organization during these visits. The information gained during this exchange was used in evaluating and setting priorities for the FY 1982, FY 1983, and FY 1984 budgets.

Information exchange and program coordination within the LLWMP occurred during the third and fourth Annual Information Meetings held in New Orleans, Louisiana, on November 4-6, 1981 and Denver, Colorado, on August 31 and September 1-2, 1982. Proceedings were published from the third annual meeting (Large 1981) and the fourth annual meeting (Large, in press). During these meetings, the various contractors reported on the status of projects funded during the current fiscal years (FY 1981 and FY 1982). A series of workshops were held during the third annual meeting to obtain input from the contractors regarding research needs and program approach. The fourth annual meeting consisted almost entirely of small-group, technical sessions to maximize information exchange and discussion among the participants. The audience for this meeting was expanded to include representatives of NKC, EPA, USGS, several states, and private consultants and facility operators. Contractors from all four federal agencies presented reports on their work, allowing for better coordination and understanding of the federal program.

Coordination With Other Waste-Technology Programs

Information exchange and program coordination with other DOE and federal waste programs continued. In addition to the major effort on coordination with other federal waste programs that occurred at the third and fourth Annual DOE LLWMP Program Participants' Meetings, the LLWMP office of ORNL participated in an interagency meeting on the application of models to LLW disposal held in Germantown, Maryland, June 15, 1982. This meeting brought together representatives from DOE, EPA, USGS, and NRC.

Coordination with other defense waste programs was maintained through participation in the Headquarters Field Coordination Meeting. In addition, a memorandum of agreement was developed between the LLW Management and TRU programs of DOE that identified areas of programmatic interaction related to greater confinement disposal. To that end, TRU program representatives participated in the Fourth Annual Participants Meeting.

Corrective Measures Handbook

This task consists of two closely related projects: (1) the development of criteria for implementing measures to correct the performance of LLW disposal sites and (2) the documentation of experience in applying corrective measures.

Corrective Measures Criteria

Draft Corrective Measures Criteria were prepared and submitted to EG&G Idaho in July, 1982 (two months ahead of schedule) for use as part of DOE Order 5820. This completed ORNL's effort on the criteria. The Corrective Measures Criteria provide standards for addressing problems encountered with the SLB of LLW by identifying threshold levels that require corrective measures to improve disposal-site performance. In developing the criteria, an initial working draft was prepared and a review committee was formed with representation from the DOE, the states, and the commercial sector. The committee recommendations were used as foundation principles for developing the criteria.

The Draft Corrective Measures Criteria provide for correction of conditions that could jeopardize performance objectives of a site. Conditions covered in the criteria are: (1) wind and water erosion, ponding or flooding, (2) accumulation of water in trenches, (3) plant or animal intrusion, and (4) chemical or biological reactions.

Corrective Measures Handbook

The Corrective Measures Handbook describes the experience of SLB site operators with the implementation of corrective measures to eliminate conditions that result or could result in the site's failure to meet its stated performance objectives. The report provides operators with documentation of previous efforts to correct conditions common to several SLB disposal sites. As such, the report is a state-of-the-art document and will be the reference point for the final Corrective Measures Handbook.

The report is based on a literature review and on visits to six DOE and five commercial disposal sites. Experience indicates that the most effective corrective actions are based on an understanding of the site conditions that caused the problems. Accordingly, the report is organized by

cumulative factors (i.e., conditions that have resulted in problems). These factors include: (1) unstable trench cover, (2) permeable trench cover, (3) subsidence, (4) groundwater entering trenches, (5) intrusion by deep-rooted plants, (6) intrusion by burrowing animals, and (7) chemical and physical conditions in the trench. In discussion of each, the condition is briefly introduced, followed by an itemization of actions to correct it.

A peer-review committee representing both DOE and commercial disposal facility operators reviewed the report, and their recommendations were incorporated. The current practices corrective measures report titled "Previous Experience and Related Research and Development in Applying Corrective Measures at the Major Low-Level Radioactive Waste Disposal Sites" (Rose et al. 1982) was completed in September, 1982, as scheduled.

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7. WASTE ISOLATION PROGRAM

S. H. Stow

The Waste Isolation Program, which is funded through the Office of Nuclear Waste Isolation (ONWI) at Battelle-Columbus represents a diverse effort heavily oriented toward basic research at ORNL. Activities span seven ORNL divisions and range from studies of the geochemistry of salt recrystallization to socioeconomic analysis for waste siting. The program is managed through ESD.

The program emphasis of ONWI calls for identification during the late 1980s of one repository site suitable for permanent waste disposal that will be safe and environmentally acceptable; it is possible that the site will be in a salt formation. A granitic site might also be considered in the future. Thus, research emphasis has been oriented toward these two rock types. Many of the activities in the program at ORNL are germane to the ONWI plans, especially those activities dealing with salt. Salt-related research has included study of: brine migration through salt deposits, the long-term stability of pillars in a salt mine, the corrosive effects of brines on various canister metals, theoretical work on the flooding of a salt repository, and on sensitivity and uncertainty analyses of repository siting in salt deposits.

In the ESD, the major emphasis has been on regional environmental characterization of the southern Appalachians for possible repository siting. Regional characterizations are useful in site selection when a large geographic area is to be analyzed and uniform, objective criteria are to be applied. Relevant information summarized at a level of resolution appropriate for the size of the region was processed using predetermined screening criteria. Environmental and socioeconomic criteria, in conjunction with geologic criteria, were used as inputs for selection of a site. Environmental and socioeconomic data that were analyzed include demography, mineral resources, water availability and quality, land use, the nature of terrestrial and aquatic systems, and climate. Criteria for selecting sites have been established by DOE and were applied to the environmental and socioeconomic data. Through the application of these screening criteria, evaluation matrices were produced that rated both environmental factors and geologic characteristics. This process ranked the potential sites and reduced their number by half. This method provides an objective and uniform means of selecting potential sites on which to locate a permanent high-level waste repository.

During FY 1983, our involvement with siting in the southern Appalachians will increase. We will continue the regional environmental studies as well as initiating studies of granitic rock bodies in the Blue Ridge Province for possible repositories.

8. GLOBAL CARBON CYCLE PROGRAM

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Introduction

The principal purpose of this program is to develop a quantitative basis for understanding the global biogeochemical cycle of carbon and implementing simulation models to describe its dynamic behavior. Another objective of this research is to further the scientific methodology for assessing the response of the global cycle, particularly changes in atmospheric CO₂ concentration, to further releases of CO₂ by fossil-fuel combustion. Research is being supported both by DOE and the National Science Foundation (NSF). Mathematical models of the carbon cycle are being developed and updated with refinements in basic understanding and improved estimates of key parameters. Sensitivity and error analyses provide a basis for selecting aspects of models that require refinement. Basic data sets underlying carbon-cycle models are refined and augmented where indicated. Particular attention in this program is given to improving our understanding the terrestrial component of the cycle. In this regard, the impacts of land-use change and climate on the global carbon cycle are also major areas of concern.

Another objective of the Global Carbon Cycle Program is to provide assistance to the Division of Carbon Dioxide Research in development, management, and research activities for the DOE carbon-cycle research program. In carrying out this task, the program is responsible for monitoring research progress of DOE contracts and ORNL subcontracts in the Carbon Cycle Research Program, identifying research needs to support global carbon-cycle model development and the recommending of methods for fulfilling these needs. The ORNL staff executes and administers subcontracts to universities for new or continuing research supporting this effort, concentrating on model development and terrestrial biospheric data acquisition. This involves the preparation and updating of multiyear technical plans for DOE. The ORNL staff prepares technical and topical reports to update research progress, to provide responses to specific questions, and to resolve technical issues. A major activity under way in this area involves the coordination of efforts and integration of contributions from DOE contractors and the international CO₂ research community for a 1984 State-of-the-Art Report for DOE on the global carbon cycle.

The development of the ORNL Global Carbon Cycle Program has led to a significant expansion in the number of intramural and extramural collaborators in the ORNL research programs, and, in addition, in extramural subcontracts for the DOE program. A listing of relevant institutional affiliations and principal investigators' names is provided in Table 8.1.

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²Chemistry Division.

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⁴Computer Sciences Division.

Table 8.1. Extramural subcontractors and collaborators in the Global Carbon Cycle Program

Brown University	Webb
Duke University	Richards, Schlesinger
Goddard Institute for Space Studies	Fung
Institute of Tropical Forestry	Lugo
Lamont-Doherty Geological Observatory	Broecker, Li
Marine Biological Laboratory	Houghton
Oak Ridge Associated Universities—Institute for Energy Analysis	Rotty, Clark, Marland, Edmonds, Reilly
Tropical Science Center	Holdridge, Tosi
University of Arizona	Long
University of California-Berkeley	Zinke
University of Florida	Ewel
University of Illinois	Brown
University of New Hampshire	Moore
University of Oklahoma	Mulholland
University of Washington	Stuiver

Program Research Activities

Mapping Carbon Storage and Flux for Terrestrial Ecosystems (J. S. Olson)

Locating major ecosystems in the world is a classic problem of biogeography that takes on special significance in relation to global carbon cycling and, ultimately, the impacts of climate change. A map of natural ecosystems emerged as one kind of synthesis for the International Biological Program (Olson 1970). This map had to be updated to current conditions so that pools and fluxes of global and regional carbon budgets could be estimated. A preliminary world map in the format of printer symbols, published from the data base on ecosystem locations, is described elsewhere (Auerbach et al. 1982). Using this map, a flux (<5 Pg C/year) of nonfossil organic matter burned to CO_2 or charcoal was estimated (Olson 1981a). A black and white computer-drawn map appeared in an overview article (Olson 1981b) designed to help resolve an apparent conflict in theories about CO_2 : that the biosphere is a significant source of CO_2 (including that contributed by burning fossil fuels) and that part of the excess CO_2 from fossil fuels is being accumulated by additional organic matter in land or water. Identifying the major ecosystems that might be functioning as sources and sinks for carbon would help to clarify this controversy and lead to a unified understanding of biogeochemical geography.

After review and incorporation of additional information from several German institutes in November 1981, color-separate plates were generated by computer. Color printing from those plates was then used to construct a map of Major World Ecosystem Complexes (Olson and Watts 1982a). This map was used in a book on carbon/climate research (Clark 1982) as a concise characterization of contrasting vegetation types. A data base (Olson and Watts 1982b) contains 1981 estimates of means, uncertainties, and local variations in carbon per unit area in the mapped ecosystem types. A more detailed report characterizes the (1) methodology, (2) landscape complexes actually mapped, (3) area estimates inferred from mapping and other sources, and (4) carbon in various parts of the biosphere (Olson et al., in press).

Olson (1982) emphasized that the various contributors on the biospheric carbon balance sheet must ultimately be resolved by carbon-cycling research. The article attempts to distinguish natural

burning from accelerated burning (and related oxidation) of wood products, burning during land clearing, and other processes of relatively rapid decay of debris. In the summer of 1982, we collaborated with John Richards, a historian from Duke University, to document when and where the land conversion to farming occurred in the period 1860 to 1978. Locations of abandoned cropland (chiefly in the temperate zone, where higher yields can be produced on less area than before) were also determined and translated into changes in area and regrowth of live carbon in this analysis. Another regional analysis (Chan 1982) quantified both the CO₂ release and the possible reaccumulation of carbon in Southeast Asia and confirmed that net shifts of CO₂ are considerably less than either sources (0.18 to 0.21 Pg of C per year) or sinks (0.13 to 0.19 Pg of C per year) in Malaysia, a rain forest country that we observed to undergo very rapid land-use changes. Summarizing our observations, worldwide, the clearing of wild or modified vegetation for new farmland released more net CO₂ than was stored in plants by the invasion of new forests, brush, or grassland. Carbon estimates were derived from the maps, inventories, and flux terms mentioned herein and in earlier reports (Auerbach et al. 1980, 1981). Tabulations indicate that the agricultural clearing portion of the total nonfossil carbon is at least 0.4 Pg of C per year. Several other biotic exchange terms (e.g., forest harvesting) are still imperfectly quantified.

Comparisons with revised calculations of fossil-fuel sources of CO₂ (Clark 1982) indicate that, in recent decades, net biospheric C is probably smaller than fossil C. However, clearing for cropland alone apparently generated more CO₂ than did fossil fuels in the 19th century. The soil pool and fluxes, shifting agriculture, and inadequately quantified terms such as cropland clearing add significantly to the overall net shifts of CO₂ between the atmosphere and biosphere. Because these net shifts comprise a fairly small difference between large opposing processes of nature (photosynthesis removing CO₂ from air; respiration as well as fires returning most of it), significant changes are possible within a relatively few years. How such shifts are reflected in models of the global cycle, therefore, will influence the models' ability to track past changes in world pools and to predict possible shifts in the future.

Life-Zone Mapping (W. R. Emanuel, W. M. Post, and H. H. Shugart)

The world distribution of terrestrial ecosystems and their functional characteristics are closely correlated with climate, and climate-based systems for classifying life zones provide useful schemes for organizing data and models to study the role of terrestrial ecosystems in the global carbon cycle. Furthermore, to incorporate the effects of climate change induced by using atmospheric CO₂ levels into analyses of the global carbon cycle, climate-based classification systems need to be exploited. A number of climate classification systems have been proposed (Köppen 1931; Holdridge 1947; Thornthwaite 1947). Because of its ecological basis (the nomenclature implies an association between climate and vegetation), the Holdridge Life-Zone System (Holdridge 1947) is particularly well suited to terrestrial carbon studies.

We have implemented a scheme for delineating the world's major climatic life zones according to Holdridge's system. Using climate data from the instrumental record, a life-zone classification is assigned to each 0.5°-latitude × 0.5°-longitude cell on the earth's land surface, based on annual precipitation and biotemperature (annual mean temperature discounted for values below 0°C) values. Precipitation and temperature are interpolated to this uniform grid from the irregularly spaced meteorological stations by a triangle-based method.

Two data bases of globally distributed temperature and precipitation records have been used. *The World Weather Records* (Weather Bureau 1959), comprised of approximately 2500 stations,

and The Climate Atlas assembled by Walter and Lieth (1960), comprised of approximately 7500 stations. The Walter and Lieth data are as dense as any world-scale data set of which we are aware and have the additional benefit of having been assembled for purposes similar to our own; however, the World Weather Record data are probably more reliable. We compared life-zone maps derived from each of these data sets and found no major discrepancies. We, therefore, adopted the Walter and Lieth data.

Interpolation to the uniform grid of $0.5^\circ \times 0.5^\circ$ cells was accomplished using a triangle-based method developed by Renka (1982a,b,c) in conjunction with this project. A difficult aspect of interpolation in two dimensions using arbitrarily spaced data is the determination of the data points to (1) interpolate at a particular point from the standpoint of proximity and (2) ensure a reasonable distribution about the point. Triangle-based methods, in which a set of triangles are derived that have data points as their vertices, provide an effective approach to this aspect of the problem. If the triangulation is derived with interior angles as large as possible (i.e., long narrow triangles are avoided), the nodes at the vertices containing the interpolation point are the primary points used to determine an interpolated value. Adjacent triangles are also considered if curvilinear interpolation is used. Implemented on the sphere, this approach is well suited to life-zone mapping.

Holdridge life-zone maps constructed thus far are in good agreement with those derived from field mapping of vegetation zones and other theoretical maps of vegetation distribution (Küchler 1978). Although the spatial variability in the underlying climatic data is quite large, the temperature and precipitation intervals that define life zones are sufficiently wide to yield meaningful maps. Altitudinal effects are apparent in our life-zone maps, and although it is not possible to determine the details of complex altitudinal gradients, major high-altitude zones are delineated. Further testing and refinement are under way; however, this life-zone map, derived solely from meteorological records, now provides a description of climatic zones and the associated distribution of terrestrial ecosystems before human disturbance and land management.

Global Soil-Carbon Pool (W. M. Post)

A soil-carbon data base was established initially as a collection of soil-nutrient data from various projects at the University of California that examined forest and soil fertility. The initial data included more than 500 wildland soils from California (California Soil-Vegetation Survey, no date); several independent studies in California (Stangenberger 1968, 1979; Zinke, no date); and other primary data from profiles collected in tropical regions (Zinke et al. 1978; Zinke 1974), Iran (Zinke 1976), and the Mediterranean (Zinke 1965). Although these data were from a wide range of climate and vegetation types, it was recognized that this data set was not completely representative of the global soil-carbon pool. In particular, it did not include profiles from tundra, grasslands, deciduous forest, or very dry tropical regions. To fill these gaps we turned to the literature for published soil-profile data.

Organizing the soil-profile data on the basis of climate, according to the Holdridge life-zone classification system, we observed a strong relationship between climate and soil-carbon density (Post et al. 1982). The contours of soil-carbon density displayed in Fig. 8.1 reflect the balance of carbon input and loss imposed by climate. Soil-carbon density increases from left to right because of greater production of organic matter with higher annual precipitation. This effect is clearest in the tropics where temperature does not limit productivity. The effect of temperature is greater than that of precipitation, so that soil-carbon density increases on Fig. 8.1 with decreasing

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Fig. 8.1. Contours of soil carbon density plotted on Holdridge schematic for world life zones. Dashed lines indicate probable extrapolation of contour lines in climatically extreme life zones from which data were not available.

biotemperature for any particular annual precipitation. Organic matter production decreases with temperature, but low temperatures limit the decomposition of organic matter in soil.

The combined influence of temperature and precipitation is clarified by the third axis of the Holdridge diagram (Fig. 8.1), the ratio of potential evapotranspiration (PET) to annual precipitation. When this ratio is 1.0, rainfall exceeds potential evapotranspiration and vice versa. All the life zones bordering the unit PET:precipitation line have soil-carbon densities of around 10 kg m^{-2} , except in the warm temperate and subtropical belts. In these regions, a strong seasonality limits production but decomposition conditions are favorable for most of the year. These conditions introduce an area of low soil-carbon density in the life zones of this part of the diagram. Perpendicular to this line, soil-carbon density uniformly increases as the PET:precipitation ratio decreases, indicating not only increased vegetative productivity with humidity but possible inhibition of organic decomposition in waterlogged soils of the superhumid life zones. Conversely, as the ratio increases, soil-carbon density decreases.

Our analysis (Post et al. 1982) of 2700 profiles organized on a climate basis according to the Holdridge life-zone classification system can be used to estimate the global soil-carbon pool. Using an interpretation of recent estimates of the areal extent of major ecosystems (Olson et al., in press), which correspond well with climatic life zones, the global soil-carbon pool is estimated to be approximately $1400 \times 10^{15} \text{ g}$.

Assuming that the only uncertainty in this estimate is a result of the variation in soil-carbon density between profiles within each life zone, we can estimate the standard deviation of this estimate of the global pool. First, we note the frequency distribution of profile carbon density within a

life zone may be fitted to a Weibull distribution. Using Monte Carlo computer techniques, we generated 100 random samples from each life zone, computed the mean, and used it to compute a global total, weighted by area of each life-zone group. This was repeated 1000 times to calculate the standard deviation of the global total. The standard deviation, calculated in this way, is 200×10^{15} g.

The relatively large amount of variation in the soil measurements reported here is a result of variation in soil-forming factors not considered in the analysis. We have taken into account the influences of human disturbance and climate but not the effects of topography, parent material, nutrient status, or vegetative productivity. These latter factors have a large residual effect on soil-carbon density and are the focus of ongoing research.

Terrestrial Flux Estimates from the Tree-Ring-Based ^{13}C Record (T.-H. Peng)

Changes of the carbon isotope record ($^{13}\text{C}/^{12}\text{C}$) of tree rings have been used to estimate both historical values of atmospheric CO_2 and amounts of CO_2 emanating mainly from biospheric and fossil sources. Biochemical reactions fractionate carbon isotopes, resulting in lower $^{13}\text{C}/^{12}\text{C}$ ratios in biospheric and fossil samples than in the atmosphere. The range of $\delta^{13}\text{C}$ (relative variation in the $^{13}\text{C}/^{12}\text{C}$ ratio from the Pee-Dee Belemnite standard) is similar for carbon derived from most modern biospheric and fossil materials. Release of carbon from these materials through oxidation or combustion causes ^{13}C of the atmosphere to become slightly more negative, and it is assumed that a time series of atmospheric ^{13}C change is recorded in tree rings.

The Freyer and Belacy (1981) tree-ring data base represents average $\delta^{13}\text{C}$ of a large number of trees from different European sites. We assumed that the tree-ring-based $^{13}\text{C}/^{12}\text{C}$ record constructed by Freyer and Belacy is representative of the fossil-fuel and forest-soil-induced $^{13}\text{C}/^{12}\text{C}$ change for atmospheric CO_2 . The uptake of CO_2 by the ocean was estimated by a modified box-diffusion model in which the major features of ocean dynamics (e.g., the upwelling, deep-water formation in the polar regions, and biological fixation of carbon in the surface ocean and subsequent respiration at various depths) were incorporated. Vertical eddy diffusivity in the main thermocline was reevaluated for the model using the tritium data obtained during the GEOSECS program. We then computed the contribution of the combustion of coal, oil, and natural gas to this observed $^{13}\text{C}/^{12}\text{C}$ change. A large residual remained after the tree-ring-based record was corrected for the contribution of fossil-fuel CO_2 . A deconvolution was performed on this residual to determine the history and magnitude of the forest-soil reservoir changes over the past 150 years (Fig. 8.2). Several important conclusions were reached.

1. The magnitude of the integrated CO_2 input from these sources was about 1.6 times that from fossil fuels.
2. The forest-soil contribution reached a broad maximum centered at about 1900.
3. Over the two-decade period covered by the Mauna Loa atmospheric CO_2 record, the input from forests and soils was about 30% of that from fossil fuels.
4. The $^{13}\text{C}/^{12}\text{C}$ trend over the last 20 years was dominated by the input of fossil-fuel CO_2 .
5. The forest-soil release did not contribute significantly to the secular increase in atmospheric CO_2 observed over the last 20 years.
6. The pre-1850 atmospheric pCO_2 values must have been in the range of 245 to 260×10^{-6} atmospheres if forest-soil CO_2 release histories derived from the deconvolution of tree-ring ^{13}C data or from the latest reconstruction of land-use data (Houghton et al., in press) are accurate.

Fig. 8.2. Forest and soil input time history based on the deconvolution of Freyer's tree-ring-based atmospheric $^{13}\text{C}/^{12}\text{C}$ curve. Shown for comparison are fossil-fuel CO_2 input time history and the sum of these two contributions. As can be seen, the integrated forest-soil contribution exceeds the fossil-fuel contribution by a factor of 1.6.

This analysis presents a history of CO_2 release from the terrestrial biosphere in which annual biospheric release exceeded fossil CO_2 emission until about the year 1950. Since then, fossil emissions have been the dominating source of increased atmospheric CO_2 . The pre-1850 atmospheric pCO_2 estimate of 245 to 260×10^{-6} atm is at the lower range of other estimates of preanthropogenic CO_2 . Despite progress represented by the Freyer data and the analysis reported herein, neither the isotopic approach nor other applicable methods are currently reliable enough to provide a firm estimate of the magnitude of the forest-soil contribution to the buildup of atmospheric CO_2 . Aspects of the problem that still need to be investigated include: (1) identification and elimination of "noise" sources in the potentially powerful, tree-ring $^{13}\text{C}/^{12}\text{C}$ record; (2) full exploitation of CO_2 partial-pressure estimates from ice-core data and from archived solar spectra data; (3) examination of the possibility that the biomass in the world's unaffected forests and soils has shown a recent increase as a result of anthropogenic CO_2 , nitrogen, and phosphorus fertilization; and (4) investigation of the effect of outcropping isopycnal horizons on ocean uptake of excess CO_2 , possibly requiring use of 2-D ocean models.

Calibration of a Two-Dimensional Ocean Model (W. R. Emanuel and G. G. Kilough)

Currently, most models of the global carbon cycle incorporate submodels for the oceans that are one-dimensional in the sense that they represent the distribution of carbon as a function only of depth; a limited number of tracers have been considered in calibrating these models (Bolin et al.

1981). Such models are limited in a number of respects. In calibrating globally averaged, depth-dependent models on the basis of the distribution of natural radiocarbon, Killough and Emanuel (1981) found that a substantial adjustment of the profiles is required to accommodate variation with latitude and between oceans. Nonuniformity of carbon uptake by the oceans at different latitudes is well documented (Broecker et al. 1979), and these differences are important in calibrating and testing models of carbon turnover in the oceans. We have, therefore, undertaken implementation of a model of carbon turnover in the oceans that represents the Atlantic, Pacific, Indian, and Antarctic oceans separately and, within each major ocean, treats variation of quantities with depth and latitude (Fig. 8.3).

Fig. 8.3. Schematic presentation of a conceptual detailed 2-D model of carbon circulation in the world ocean.

Initial attention is directed to the Atlantic Ocean. In a preliminary calibration, seven latitude zones were considered along with thirteen depth layers. A hypsographic curve for the Atlantic was used to scale 10° -latitude zones so that cross-sectional area at each depth could be estimated. Each interior box exchanges water with its neighbors. The purpose of the calibration exercise is to determine nonnegative fluxes such that the simulated distributions of tracers agree with observed values as closely as possible, and constraints such as mass balance are satisfied. Three tracers were considered: temperature, salinity, and tritium produced by nuclear weapons tests. The first two were assumed to be in steady state, whereas tritium must be considered to be a transient tracer. Our treatment of temperature considers internal transport of heat only by advection and assumes that heat crosses the boundary of the ocean only at the surface. Rather than simulating explicitly the variation of precipitation minus evaporation with latitude as a mechanism for redistributing salinity, we chose to introduce net sources of salt to surface boxes. The historical source of tritium in the

model and its dependence on latitude are based on the time-series data of Weiss and Roether (1980).

Estimation of model parameters such that the differences between simulated and observed tracer distributions are as small as possible can be posed as a constrained nonlinear optimization problem. In the case of temperature and salinity, the steady-state distributions are given by algebraic equations, but for tritium, a system of ordinary differential equations forced by the appropriate source terms must be solved to the contemporary year in which data for the distribution of this transient tracer are available. To date, we have considered data on these tracers collected by the GEOSECS program.

Initial results from this three-tracer calibration exercise for the Atlantic Ocean are promising, but not totally satisfactory. Convergence of optimization schemes tested thus far has not been pronounced; however, reasonable simulated distributions of the tracers have been derived. Assuming parameter values calibrated against temperature, salinity, and tritium, the corresponding distributions of ^{14}C and surface CO_2 concentration have not been in agreement with measured levels, perhaps implying the need for additional constraints or consideration of ^{14}C in calibration.

Global Carbon-Cycle Modeling for Atmospheric CO_2 Projections (W. R. Emanuel and G. G. Killough)

Currently, it is difficult to discriminate among models of the global carbon cycle that are applicable to projecting future atmospheric CO_2 concentrations for different fossil-fuel use scenarios. Given the available data for calibration and testing, a large number of alternative models can be derived that appear satisfactory. In our comparison of one-dimensional models of carbon turnover in the ocean (Killough and Emanuel 1981), five alternative models, differing in structure (Fig. 8.4) but consistently calibrated against the same profiles for distribution of total inorganic carbon and natural radiocarbon, demonstrated substantial differences in the net uptake of excess fossil-fuel carbon from the atmosphere. Of the estimated 134×10^{15} g of fossil carbon produced in the period 1860 to 1975, the models estimate a net uptake range of 24×10^{15} to 66×10^{15} g of C by the ocean. Three of these models are structurally similar to formulations that have been widely used to project atmospheric CO_2 concentration: 1b—Bacastow and Keeling (1973) two-box model with 260-m surface layer, 3a—Björkström (1979) advective/diffusive model, and 3b—Oeschger et al. (1975) box-diffusion model. Any of these three models reasonably can be used to estimate future CO_2 levels.

The box-diffusion model (Oeschger et al. 1975) and variations have been analyzed extensively. Although these models are relatively simple (treating a spatially averaged ocean and emphasizing diffusive transport of carbon from surface waters to deep layers), they do a reasonable job of fitting available data (Bacastow and Björkström 1981; Brøecker et al. 1979) and provide a useful benchmark for comparison with other formulations. Although a number of models of the atmosphere-ocean carbon system (Björkström 1979; Hoffert et al. 1981; Enting and Pearman 1982) have recently been proposed, their responses to fossil-fuel release do not deviate from that of the basic box-diffusion model as much as might be expected.

On the historical period of interest in evaluating the consequences of fossil-fuel use, the role of terrestrial ecosystems in the global carbon cycle has been influenced predominantly by land-use change and other disturbances that have reduced terrestrial carbon storage by as much as 300×10^{15} g of C over preagricultural conditions (Woodwell et al. 1978; Olson et al. 1978). The magnitude and timing of historical fluxes to the atmosphere from the terrestrial component of the carbon

Fig. 8.4. Structures of the five compartment models of carbon exchange in the oceans.

cycle remain uncertain, but several hypothesized reconstructions based on available data are now complete (Houghton et al. 1982; Peng et al. 1982). If the input of fossil fuels to the atmosphere continues to increase at any rate near the various scenarios proposed thus far, the cumulative future release of carbon from terrestrial ecosystems will be small by comparison (Perry 1982). However, global carbon-cycle models should include a terrestrial component that permits analysis of the influence on atmospheric CO_2 concentrations of terrestrial fluxes specified either as a net exchange with the atmosphere or as a gross change in terrestrial standing crop per unit time. The terrestrial component of models should also provide sufficient range in turnover times so that transit time and age characteristics of the model are reasonable.

As a benchmark for projecting atmospheric CO₂ concentration, we have combined a diffusive ocean model with a recently proposed terrestrial model (Emanuel et al. 1982) that we believe is a minimum formulation for addressing questions about the influence of terrestrial ecosystems on changes in atmospheric CO₂.

The ocean model is model 3b in Killough and Emanuel (1981). Like Oeschger and co-workers, we calibrate the ocean model against the measured distribution of natural radiocarbon; however, in our model the transfer coefficients for carbon fluxes between adjacent layers are calculated independently to agree with the ¹⁴C and total-carbon profiles. Effectively, diffusivity is allowed to vary with depth. We structure the layers in our model against the general hypsographic data so that the model ocean is conical rather than cylindrical as considered by Oeschger. Generally, these two differences cause our model to have a greater propensity for taking up excess carbon from the atmosphere than the original box-diffusion model.

A five-compartment model, which includes a concise treatment of the releases of carbon and shifts in carbon storage as a result of forest clearing, is used for the terrestrial component of the cycle. This terrestrial model was designed as a reasonable counterpart to globally averaged models of carbon turnover in the oceans and provides a consistent means of analyzing the implications of either historical or future forest clearing.

Details of model formulation and calibration are provided in Killough and Emanuel (1981) for the ocean component of the model and Emanuel et al. (1982) for the terrestrial component.

Uncertainties and Global Carbon Models (R. H. Gardner)

Knowledge of model uncertainties allows a quantitative assessment of the gain in precision that may be achieved by improving the data base and/or the model formulation. These issues were examined by analyzing a World Carbon Model assembled from the diffusive ocean model documented by Killough and Emanuel (1981) and the terrestrial model proposed by Emanuel et al. (1982). Initial levels of uncertainty were introduced into the model by specifying reasonable limits for the initial conditions of the atmosphere, terrestrial biota, and parameters describing fluxes of carbon between components of the biota and atmosphere and between the atmosphere and ocean surface. Sets of random and independent values were then selected (Gardner et al. 1981; Iman et al. 1981) and simulations from year 1800 to 1980 were performed. The predicted atmospheric level of carbon from 1958 to 1980 of each simulation was compared with yearly average values of measured CO₂ at Mauna Loa (Keeling et al. 1982). This process was repeated 500 times for each case considered, and the results were analyzed to determine which components and processes were contributing most to the uncertainties associated with predictions of contemporary levels of atmospheric CO₂.

Uncertainties associated with model predictions are most sensitive to the estimates of initial level of carbon in the atmosphere and the parameter describing temperature relationships in the partial pressure equations (these equations determine the rates of CO₂ exchange across the sea surface-atmosphere boundary). Simulations in which all parameters and states remain at nominal values produce little error when compared with the Mauna Loa record, if no contemporary flux (from 1910 to present) of carbon resulting from forest clearing is allowed. However, when parameters are varied within their prespecified limits, the standard deviation associated with the predicted atmospheric CO₂ is equal to 36 ppm. If uncertainties for the initial atmospheric CO₂ level and gas exchange/temperature relationship are reduced, then the variance of predicted carbon in the atmosphere can be reduced by 76%.

If recent forest clearing has resulted in a net increase in carbon in the atmosphere, then errors in predicted atmospheric carbon increase dramatically. Nominal values of all parameters do not result in small prediction errors. Further, these errors in prediction have two distinct components: those contributing to constant errors with time and those contributing to increasing errors with time (i.e., predicting a different rate of increase of CO_2). Sets of simulations with randomly varied parameters show that the two parameters described above are no longer the only sensitive ones, but others involved in biotic fluxes at ocean surface-atmosphere interactions become important.

These results are significant because they indicate both the time and the scenario dependence of uncertainties associated with predicting atmospheric levels of CO_2 . The scenario dependence of errors is particularly important for predicting future trends because the scenarios themselves have associated uncertainties that must be considered, both in terms of fossil-fuel carbon emissions and forest-clearing sources. Two other issues need to be investigated further before final causes of uncertainty can be determined: first, how do results from one model compare with other models of the global carbon cycle and, second, what can be inferred from experiments, measurements, and model improvements. The capability exists to examine these issues, resolve some of the uncertainties, and estimate realistic confidence intervals for future predictions of atmospheric concentration of CO_2 .

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PART II. ENVIRONMENTAL SCIENCES DIVISION SECTIONS

9. AQUATIC ECOLOGY SECTION

W. Van Winkle

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Introduction

The Aquatic Ecology Section is involved in basic and applied research that focuses on environmental problems and on gaining a better understanding of the structure and function of aquatic ecosystems. In addition to interacting with the programs and other sections of the Environmental Sciences Division (ESD), the Aquatic Ecology Section interacts with several other Oak Ridge National Laboratory (ORNL) divisions (e.g., Analytical Chemistry, Energy, Health and Safety Research, and Information), with the Union Carbide Corporation Nuclear Division (UCC-ND) Computer Sciences Division, and with several outside research organizations in the Southeast [e.g., Tennessee Valley Authority (TVA), The University of Tennessee, Tennessee Technological University, and the National Reservoir Research Program of the U.S. Fish and Wildlife Service (FWS)]. Research in the section for FY 1982 was funded by the National Science Foundation (NSF) (27%),

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Department of Energy (DOE) (23%), Electric Power Research Institute (EPRI) (23%), Nuclear Regulatory Commission (NRC) (17%), Environmental Protection Agency (EPA) (4%), FWS (3%), TVA (2%), and the Army Corps of Engineers (1%).

Streams, rivers, and reservoirs are the predominant aquatic ecosystems throughout the southern United States, and stream and reservoir ecosystem studies continue to be a major emphasis in the section. We will describe several lines of ecosystem-oriented research on streams and river-reservoir systems that were emphasized during the past year. The first three summaries describe investigations in progress on materials cycling and transport in low-order streams. The next two report our progress in developing a conceptual basis for examining man-made impoundments (i.e., reservoirs) as ecological systems and investigating the determinants of biological productivity and ecosystem structure in individual reservoirs and reservoir series. Finally, we will summarize some proposed initiatives in stream and reservoir research that focus on an issue of international concern, the ecological effects of acidic deposition.

During this past year, our DOE project on development of guidelines for monitoring focused on the use of growth of predatory fish as an integrative index for detecting changes in aquatic ecosystems. The results for largemouth bass suggest that the ratio of liver weight to total fish weight is the single best variable for predicting monthly growth; this finding is, in turn, useful in evaluating the effects of perturbations and alternative management practices.

Studies in the EPRI and NRC projects on Legionnaires' Disease Bacteria (LDB) in power-plant cooling systems have led to (1) finding that LDB are a normal component of natural aquatic systems, (2) isolating a new species of LDB, and (3) concluding that LDB densities are a poor predictor of LDB infectivity in guinea pigs.

Our continuing analysis and modeling of fish populations included preparing a set of reports on the effects of multiple stress and analyzing the status of the Maryland striped bass population. The reports for the FWS included (1) a literature review of field observations, experimental studies, and theory concerning the cumulative effects of multiple stress, (2) an evaluation of existing population models for quantifying effects of multiple stress, and (3) an identification of research needs. The analysis of Maryland striped bass indicated that estimates of first-year survival declined significantly from 1969 to 1981 and averaged less than that needed for replacement for the last ten years.

The staff in the Aquatic Ecology Section organized two symposia for the 1982 Annual Meeting of the American Fisheries Society: Striped Bass: Environmental Risks in Fresh and Salt Water and Advancing the Science of Assessment: Technical Lessons from the Hudson River Power Plant Case.

Material Spiraling in Stream Ecosystems

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During the past year, a central focus of the NSF-funded project on Material Spiraling in Stream Ecosystems was on seasonal patterns of phosphorus cycling in a small woodland stream. In addition, work on the role of various biotic and abiotic mechanisms and pathways in controlling the uptake, turnover, and transport of phosphorus in streams has continued. Because physical conditions (i.e., discharge and velocity) and energy inputs to streams vary seasonally, the rates, mechanisms,

and pathways of nutrient cycling may also undergo seasonal changes. We chose to study the seasonal patterns of phosphorus cycling because litter decomposition and primary production in our study stream were shown to be phosphorus limited. The effect of storms on phosphorus transport and the role of microbes associated with decomposing detritus in controlling phosphorus uptake were also examined.

Seasonal Patterns of Phosphorus Spiraling in a Woodland Stream

To determine whether regular seasonal variations in phosphorus spiraling occur in natural streams, we have performed four 1-h releases of $H_2(^{32}P)O_4$ and tritiated water (a hydrologic tracer) to Walker Branch during different seasons. Our first release was conducted about two weeks after peak leaf fall in November 1981. Additional releases were made during winter (January 1982), during spring before canopy leaf-out (April 1982), and in summer (August 1982). During each release, uptake of ^{32}P from the water relative to 3H was measured. Turnover of ^{32}P in aufwuchs, fine particulate organic matter (FPOM), coarse particulate organic matter (CPOM), and seston and uptake of released ^{32}P by CPOM were measured following the release.

Physical, chemical, and biological conditions in Walker Branch varied with the season. Among the greatest variations were (1) abundance of CPOM, which was greatest in November following leaf fall; (2) aufwuchs biomass, which was also highest in November; (3) base streamflow and water velocity, which were greatest in April; and (4) soluble reactive P (SRP) concentration, which was lowest in August. Although the levels of light reaching the stream were not measured, they were probably greatest in April, just before canopy leaf-out.

The spiraling length of P (uptake length + turnover length) increased from a minimum of 24 m in November to a maximum of 93 m in summer. In all seasons, uptake length (distance traveled by a P atom dissolved in the water before uptake onto particles) was the dominant component of spiraling length. Turnover length (distance traveled by a P atom associated with particulates before release back to the water) was relatively constant and never comprised more than 10% of the total spiraling length. The uptake length of P (and consequently total spiraling length) was found to be inversely related to CPOM abundance (Fig. 9.1). Despite seasonal variation in the abundance of CPOM, FPOM, and aufwuchs, the relative importance of these substrates in total stream uptake of ^{32}P was relatively constant. The uptake of ^{32}P by CPOM was greatest, accounting for 55–60% of total ^{32}P uptake during all seasons, and the uptake of ^{32}P by FPOM accounted for about 35–40% of total uptake. Aufwuchs accounted for 5–10% of the total uptake.

Rates of P turnover were most rapid in aufwuchs and least rapid in FPOM. Turnover rates were generally highest in summer when water temperatures were highest. Low turnover rates of ^{32}P associated with CPOM in November (when water temperatures were still relatively high) may have resulted from the rapid reuptake of P within dense accumulations of leaves on the streambed. The turnover of P in aufwuchs appeared to have at least three different components, based on measured differences in rate constants. Although our data did not indicate multiple components of P turnover in CPOM and FPOM, previous studies indicated a fast turnover component dominating over periods of about 1 d.

Data collected during the past year and previous years indicate the general pattern of variation in uptake length of P with season in Walker Branch. The utilization of available P is greatest and the uptake length (and presumably total spiraling length) is shortest following autumn leaf fall. High streamflows generated by winter storms scour the lower portions of the streambed, thus moving leaves and other organic debris into dense packs and onto more elevated portions of the stream

Fig. 9.1. Relationship between the uptake length of $\text{PO}_4\text{-P}$ and the standing stock of coarse particulate organic matter (CPOM) in Walker Branch. The date beside each data point is the month and year when the estimates of P uptake length and CPOM standing stock were made.

channel and bank. This rearrangement effectively reduces the abundance of CPOM in the wetted streambed at base flow. High streamflows during winter may also remove FPOM from streambed areas subject to scour, thus depositing FPOM in more elevated regions or behind debris dams. As the abundance of CPOM and FPOM declines in late autumn or winter, uptake length increases markedly. Although CPOM and FPOM abundance may increase somewhat during spring as a result of new inputs or gradual redistribution of streambed material back into the lower portions of the streambed, uptake length shows no corresponding decrease. This lack of response in uptake length may result from the lower quality (i.e., less microbial biomass) of allochthonous CPOM in the spring; much of the CPOM is in the final stages of decomposition at this time. The uptake length P during summer is longest and most variable, primarily because of the low abundance and generally low quality of CPOM.

Effect of Storms on Phosphorus Transport

We sampled transport of ^{32}P -labeled particulates throughout several storms as part of our analysis of seasonal patterns of P spiraling in Walker Branch. Our primary objective was to estimate the contribution of storms to long-term average spiraling lengths. We hypothesized that spiraling lengths would be considerably longer than those calculated for base-flow conditions because of brief periods of very long particulate turnover lengths associated with storm transport.

Results from the largest storm sampled, which began on January 20, 1982, illustrate some of the general findings that have emerged from preliminary analysis of the data. As was observed in studies by several others, peak concentrations of seston [as ash-free dry mass (AFDM)] occurred before peak discharge. Seston concentration was significantly related to the rate of increase in discharge ($r^2 = 0.43$; $P = 0.0001$), but was not related to discharge itself ($r^2 = 0.00$). The relationship between seston concentration and rate of increase in discharge was also found in other streams, although in Walker Branch this relationship was significant in only about half of the storms sampled. Other factors, particularly the durations of the storms and the intervals between storms, may need to be considered to develop a better explanation of seston concentration.

Concentrations of ^{32}P in the seston [disintegrations per minute (DPM) per milligram AFDM] (DPM/mg AFDM) during the storm were about 15–50% of those just before the storm, thus indicating that there is a temporary increase in P transport associated with FPOM on the stream bottom during storms. These results thus tend to support our hypothesis that storms temporarily increase the turnover length of P in streams by increasing the transport velocity of FPOM. Lowest ^{32}P concentrations occurred early in the storm when the discharge was increasing rapidly and seston concentrations in the water were highest. This storm-related depression of ^{32}P concentrations was typical of the majority of storms sampled and suggests that the source of storm-transported seston differs from that of base-flow seston.

Microbial Conditioning of Particulate Detritus and Its Effects on Phosphorus Uptake and Metabolism

To document the microbial succession or conditioning of CPOM in streams and its effect on phosphorus uptake by CPOM, we incubated three species of autumn-shed leaves in laboratory stream channels and made periodic measurements of various metabolic processes and $^{32}\text{PO}_4$ uptake. Dogwood (*Cornus florida*), red maple (*Acer rubrum*), and white oak (*Quercus alba*) leaves were incubated in cobble-filled laboratory streams supplied with ground water at 15°C and covered over with opaque plastic to eliminate algal growth. Our measurements reported below were performed as a pilot study. A more comprehensive examination of the effects of CPOM conditioning on P cycling in streams began in November of 1982.

Rates of P uptake by CPOM increased with time to a maximum after about 22 d in the stream channel, declined rapidly thereafter to a value roughly one-third the maximum value, and then remained relatively constant through 44 d (Fig. 9.2a). All three leaf species followed this pattern, and all reached maximum P uptake at about the same time. Rates of oxygen consumption by CPOM also followed this pattern, and, again, the leaves of all three species exhibited peak rates on day 22 of the study (Fig. 9.2b). Dehydrogenase activity [based on rates of reduction of p-iodonitrotetrazolium violet (INT) and adenosine triphosphate (ATP) values of CPOM], however, exhibited somewhat different patterns (Fig. 9.2c and Fig. 9.2d). Throughout the study, these measurements generally continued to increase for leaves of each species.

Our results indicate that although microbial biomass on CPOM, as indicated by ATP levels, continued to increase with time during much of the study, metabolic activity and rates of phosphorus uptake peaked after about 20 d and then declined. Although the measurements of INT reduction should have measured electron transport activity and thus served as an index of metabolic activity, the temporal pattern in INT reduction we observed was different from that of respiration measured with the Gilson respirometer. This result indicated that these two methods were not

Fig. 9.2. Temporal patterns of (a) biotic uptake of $\text{PO}_4\text{-P}$ from water; (b) microbial respiration rate; (c) dehydrogenase activity as measured by INT reduction; and (d) ATP content of decomposing dogwood, red maple, and white oak leaves as a function of time after being placed in an artificial stream.

measuring the same metabolic process. Also, we did not observe different microbial colonization rates for different species as was reported by others.

Our results imply that P utilization and, hence, spiraling length in streams may follow a predictable pattern after input of autumn-shed leaves. As the microflora develops on CPOM, the spiraling length of P should decrease, reaching a minimum about 20 d after peak autumn leaf fall. Thereafter, if new inputs of leaves are not great, spiraling length should increase. Consequently, in addition to the quantity of CPOM, the level of CPOM conditioning (i.e., its quality) should influence stream P utilization and spiraling length.

Reservoir Studies

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Because reservoirs were rarely studied holistically, our understanding of reservoirs as ecological systems is poor. The adherence to the prevalent notion of "reservoir individuality" (i.e., that individual reservoirs behave differently from all others) provides little opportunity for constructing an

integrated basis for understanding reservoir ecosystem structure and function. The primary objectives of our DOE Office of Health and Environmental Research (OHER) reservoir studies are to (1) develop a conceptual basis for examining man-made impoundments as ecological systems and, thereby, for predicting their responses to environmental perturbations and (2) provide a sound scientific foundation applicable to effective impact prediction, benefit/risk assessment, multiple-use management, and decision making regarding energy technologies and river-reservoir systems.

Development of a Conceptual Basis for Reservoir Ecosystem Research

Conceptually, reservoirs occupy an intermediate position between riverine and lacustrine systems in regard to organic carbon sources, modes of nutrient supply and recycling, spatial structure, and morphologic and hydrodynamic characteristics. Because man-made impoundments combine numerous features of river and lake environments, reservoirs can be viewed as "river-lake hybrids," and, thereby, an initial basis for the investigation of reservoirs as ecosystems may be derived from existing ecological and limnological knowledge of rivers and natural lakes.

For example, our consideration of the factors which influence phytoplankton productivity within the context of a river-lake hybrid analogy provided (1) an initial basis for interpreting the spatial, temporal, and intersystem heterogeneity in algal production and biomass in reservoirs and (2) a framework for developing research questions and hypotheses (Fig. 9.3). For questions concerning reservoir productivity; organic matter processing; sedimentation processes; nutrient transport and retention; and, perhaps, contaminant transport and accumulation, hypotheses derived from the river-lake hybrid paradigm appear to be appropriate for examining impoundments. Certainly, interpretation of ecological and limnological data from the perspective of such a conceptual framework should advance our understanding of reservoir ecosystems more efficiently than would merely documenting the differences between the behaviors of individual reservoirs, rivers, and lakes.

Determinants of Biological Productivity in Reservoirs and Reservoir Series

Understanding the determinants of biological productivity is critical for defining ecosystem structure and function. Although considerable effort was invested in attempting to predict fishery yields of and water quality for reservoirs, little effort was given to studying the ecological processes and interactions which determine the productivity of reservoir ecosystems and their responses to environmental perturbations. Therefore, gaining an ecological understanding of reservoir productivity is the central objective of several ongoing investigations we initiated during the past year. Here we describe two of these studies: the first, an evaluation of organic carbon sources for reservoir food webs based on our synthesis of available reservoir productivity data; the second, a field investigation of phytoplankton productivity and environmental factors influencing productivity in a headwater to mainstream reservoir series.

The organic matter base of reservoir foodwebs. Reservoirs receive inputs of organic matter from both autochthonous (internal) and allochthonous (external) sources. Although it is commonly assumed that fluvial inputs of allochthonous organic matter to man-made impoundments significantly supplement the organic-matter base of reservoir food webs, the actual extent of the incorporation of allochthonous organic matter into food webs and its subsequent contribution to fish production is unknown. We employed a trophic-dynamics analysis to examine the probable relationships of phytoplankton production, other autochthonous primary producers, and allochthonous

Fig. 9.3. Hypothesized longitudinal gradients in environmental factors affecting phytoplankton production and organic matter supply in the riverine, transition, and lacustrine zones of an idealized reservoir.

organic matter to the organic-carbon supply necessary to support the annual fish community production in 16 southeastern and midwestern U.S. reservoirs. In brief, the results of our analysis suggest that autochthonous primary production can often account for the organic-carbon supply required for reservoir fish production and that the common assumption that allochthonous organic matter is of major significance to reservoir food webs may be erroneous. Because numerous assumptions involving both methodological and ecological uncertainties were required for this analysis, our conclusions must be considered preliminary. However, our synthesis will serve to identify (1) the limitations of the existing data and (2) the needs for improved estimates of reservoir fish and primary production and for budgets of reservoir organic matter coupled with assessments of the biological availability of the various organic matter pools. Additionally, our analysis should stimulate further hypotheses, questions, and discussions addressing the structure and function of reservoir ecosystems.

Productivity patterns in a headwater to mainstream reservoir series. Dam construction associated with water and power development projects converted (and continues to convert) major river systems throughout the world into a regulated series of man-made impoundments. However, little is known of (1) limnological gradients that occur within a series of reservoirs or (2) the ecological influences of upstream impoundments on reservoirs located downstream. We are examining patterns in phytoplankton productivity and environmental factors controlling productivity in a three-reservoir series (Norris, Melton Hill, and Watts Bar reservoirs) located in the upper Tennessee River valley. Our initial results indicate that (1) distinct longitudinal zonation of environmental conditions and relative productivity occurs within each reservoir and (2) major differences exist among reservoirs within a headwater-to-mainstream series in light and nutrient availability and in vertical mixing regimes with consequent effects on phytoplankton distribution and productivity. During the summer and fall of 1982, phosphorus was the nutrient most limiting phytoplankton growth in these reservoirs. Although variable, the relative degree of nutrient deficiency increased downlake within reservoirs and decreased downstream along the headwater to mainstream reservoir series. Based on preliminary data, patterns in primary productivity within and among reservoirs appear to be related to morphologic and hydrologic changes associated with transitions between riverine and lacustrine environments and should be interpretable within the context of the river-lake hybrid paradigm previously discussed.

Research Proposals Addressing Acidification Effects in Headwater Streams and Reservoirs

Research that integrates and interrelates the chemical and biotic effects of headwater stream acidification was not previously undertaken. Such research, however, is essential in the overall assessment of the consequences of acidic deposition on sensitive forested watersheds and their associated aquatic resources. Work under consideration for funding by the EPRI will first characterize longitudinal and temporal patterns in water and sediment chemistry (with emphasis on aluminum) in two streams in the Adirondack region of New York and in two streams in the Great Smoky Mountains of North Carolina and Tennessee. Both regions are considered to be sensitive to acidic deposition. Concurrently, relationships between gradients in stream-water chemistry and selected biotic variables, including detritus decomposition, microbial biomass and activity, macroinvertebrate density and growth rates, fish density and growth, gonad maturation, and physiological indicators of stress, will be determined. Subsequently, experimental studies will be conducted to verify inferred cause-and-effect relationships, which may be confounded by other variables not related to stream acidification. This research will permit testing of the general hypothesis that the biotic responses to stream acidification are most pronounced in the headwaters and decrease downstream in response to chemical gradients that expand longitudinally during episodic inputs (e.g., storm flow and snowmelt) of acid and aluminum from the watershed.

In the absence of natural lakes, Southern Appalachian headwater storage impoundments are potentially sensitive indicators of regional acid deposition and watershed acidification impacts. However, it is difficult to predict *a priori* (1) their susceptibility to acidification, (2) the degree of buffering which may occur within reservoir basins, or (3) the extent to which the presence of an impoundment may alter the impact of episodic acid runoff events on downstream aquatic systems. In a research proposal which has been approved for funding by DOE/OHER, we proposed to examine selected Southern Appalachian headwater impoundments and associated streams to (1) deter-

mine the present and potential sensitivity of these systems to increases in acid deposition in the southeastern United States and (2) improve our general understanding of the processes controlling acidification of aquatic ecosystems. We intend to use the unusual features of headwater storage impoundments (e.g., their river-lake nature, seasonal manipulation of volume and flushing rate, and hypolimnetic outflow) relative to natural lakes to further our understanding of acidification processes and effects and resistance to acidification in other types of aquatic systems.

Development of Guidelines for Monitoring

S. M. Adams

Previous work performed under this DOE/OHER project (FY 1978-1980) involved evaluating statutory requirements for ecological monitoring, evaluating the usefulness of existing ecological data bases for incorporation into site-specific assessments, and developing conceptual strategies for measuring and assessing ecological effects over the life of an energy production facility. These efforts demonstrated the need to (1) identify functional ecosystem parameters that are relatively easy to measure and that reflect ecosystem history or health and (2) utilize conceptual monitoring strategies along with site-specific baseline data to develop a monitoring program at a reference energy production facility.

During the past year, we investigated the possibility of using predator fish growth as an integrative index to detect aquatic ecosystem changes. Fish growth can reflect the overall condition of an ecosystem because growth integrates the effects of many ecosystem variables such as water quality, temperature, and food availability. Current approaches for measuring fish growth are usually costly and labor intensive. In addition, because growth measurements are commonly taken at infrequent intervals (e.g., months or longer), they are probably incapable of revealing short-term (one month or less) ecosystem changes.

An index for predator health is being developed by predicting growth for both male and female largemouth bass based on various predator condition indices and the temperature of the aquatic system under study. Growth predictions based on these simple and easily measured indices are then validated against field measurements of growth to determine the applicability of the predictions. Condition indices such as condition factors, liver-somatic and viscera-somatic ratios, and caloric densities are entered into multiregression equations to determine the best combination of factors that predict monthly growth.

Preliminary data show that the liver-somatic index (liver weight/total fish weight) is the single best variable for predicting monthly growth in both sexes. For male bass, the best three-variable regression model ($r^2 = 0.93$) that predicts growth for a particular month includes the following variables: (1) liver-somatic index during that month, (2) standard metabolism the previous month, and (3) the liver-somatic index the previous month. For female bass, the reservoir temperatures for the previous month and the liver-somatic index for the previous two months are included in the best three-variable model ($r^2 = 0.96$).

These results suggest that this relatively simple and rapid method to predict monthly growth of predators in the field can aid the environmental manager or regulator in evaluating the effects of perturbations and management practices on the growth and health of important fish species.

Legionnaires' Disease Bacteria in Power-Plant Cooling Systems

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Legionnaires' Disease Bacteria (*Legionella*) are a component of the normal aquatic biota that, when aerosolized, can be pathogenic to man. Studies on the source of infection of various outbreaks of *Legionella* at times implicated cooling towers used in air-conditioning systems. Surveys have established that the organisms are ubiquitous, occurring in natural waters as well as in cooling-tower systems of all sizes and configurations. The EPRI judged it desirable to support a study of the distribution, abundance, and infectivity of *Legionella* in power-plant cooling systems as a step toward the possible development of control technologies. This subsection presents the results from the first of two phases of this project.

Water samples were collected during each of the four seasons at various locations within each of nine power plants and from ambient waters at each site. Measurements of temperature, dissolved oxygen, pH, conductivity, alkalinity, phosphate, nitrate, ammonia, and inorganic and total dissolved carbon were obtained for each sample. In addition, the samples were concentrated 500-fold by centrifugation and processed using direct fluorescent-antibody staining to determine the density of *Legionella*. Viability, defined as possession of a functional electron-transport apparatus, was estimated using a tetrazolium dye. Infectivity of selected samples was also determined by intraperitoneal inoculation of guinea pigs and subsequent isolation of the bacterium on agar. Data were entered into a computer data base and analyzed statistically.

Legionella were detected in nearly all samples, whether from ambient (source) water or from plant-exposed water. In addition, infectious *Legionella* were found fairly frequently in both ambient and plant-exposed water. The Knoxville serotype of *L. pneumophila* was the most prevalent subgroup, followed by the Los Angeles serotype of *L. pneumophila* and the newly discovered species, *L. oakridgensis*.

Cell densities of *Legionella* were significantly greater during the cold period (winter and spring) in ambient waters supplying the closed-cycle plants in our study than were those in ambient waters supplying the once-through plants. The reason for this difference is not understood, but latitudinal differences and the types of water bodies associated with the use of closed-cycle cooling may be relevant. During the cold period, cell concentrations were significantly ($P < 0.05$) reduced at closed-cycle plants in the plant-exposed water compared to those concentrations in the ambient water. The densities during the warm seasons (summer and fall) were significantly lower than were the densities during the winter and spring, and no power-plant effect on densities could be demonstrated.

The viability of *Legionella* was greater during the cold months than the warm months and was greater at once-through sites than at closed-cycle sites. Although these are statistically significant comparisons, only 20% of the variance in the viability data is explained by period, operating mode, and location of sample (ambient vs plant exposed). No power-plant effect on viability could be demonstrated. On the whole, viability as an isolated variable is not particularly informative.

The density of viable *Legionella* cells was calculated as the product of the total cell density and the proportion of viable cells. As was true for total cell densities, the density of viable cells was significantly greater in the cold period in ambient waters at the closed-cycle sites than that at the once-through sites, and viable cell densities were significantly reduced during the cold period in plant-exposed water from closed-cycle plants.

Infectious *Legionella* were isolated from ambient waters in all seasons except spring and from plant-exposed water during all seasons. Seasonal differences were apparent; fall had the greatest and spring the least infectivity, but the differences did not prove to be significant at the 0.05 probability level. Infectious *Legionella* were significantly more likely to be found ($P < 0.01$) in samples from the plant-exposed water of closed-cycle plants than in samples from once-through plants or in ambient samples. In addition, the property of infectivity seemed to be associated more with some power plants and less with others. Contrary to expectation, infectivity could not be related to *Legionella* density, viability, or combinations of those two characteristics. Analyses indicated a number of physical and chemical variables that may be related to *Legionella* abundance, viability, and infectivity, but cause-effect relationships cannot be established from the current data.

A new species *L. oakridgensis*, was initially isolated from two of the sites and was since found to have widespread distribution. The clinical importance of this species is undetermined. Two other organisms apparently causing illness in guinea pigs may also be a new species. The personnel at the Center for Disease Control (CDC) have been unable to classify one of these microbes as belonging to any known genus.

The results indicate that the current practice of using densities of *Legionella* greater than $10^5/L$ as the sole "trigger" for instituting attempted control measures may warrant reexamination because densities alone are a very poor predictor of water sample infectivity. The factors influencing the infectivity of *Legionella* should be studied in more controlled settings to enable cause-effect relationships to be established. Phase II of the continuing EPRI project was modified somewhat from the original plan to focus on identifying such cause-effect relationships. The results will contribute toward developing control technologies for this pathogen.

Effects of Multiple Stress on Fish Populations

D. S. Vaughan	P. Kanciruk
J. E. Breck	R. M. Yoshiyama
D. L. DeAngelis	

Fish populations in nature are subjected to a variety of man-induced stresses such as fishing, thermal and chemical pollution, and mortality at power-plant intakes. The effects of each new stress on the health of a population are determined in part by the level of preexisting stress. It is possible for the cumulative effects of many stresses to cause the collapse of a population even when the effects of each individual stress appear insignificant. It is important that fish and wildlife biologists who review permits, environmental impact statements, and siting proposals for power plants be able to evaluate the combined effects of all stresses, both new and preexisting.

This problem was addressed by the Eastern Energy and Land Use Team of the FWS as a series of three tasks: (1) a synthesis of the literature concerning field observations, experimental studies, and theory dealing with the cumulative effects of multiple stress; (2) an analysis and critical review of existing population models applicable to the quantification of the effects of multiple stress on populations; and (3) an identification of research needs based upon the results of the first two tasks.

The completion of task 1 resulted in the (1) documentation of the need to consider multiple stress in fisheries management by reviewing field observations on the effects of multiple stress on fish populations in river, lake, estuarine, and coastal ecosystems; (2) evaluation of the literature on laboratory characterization of the effects of simple and complex multiple stresses and the definition

of the complex nature of these interactions; and (3) evaluation of the existing theoretical and empirical methods of categorizing and quantifying these interactions. This review provides the informational basis for completion of the remaining two tasks. Although the analysis of the effects of single stresses was useful in impact assessment, the development of a method to predict the effects of multiple stress on a population offers the advantage of more realistically addressing potential population responses to man's activities than do single-stress studies.

Both traditional fisheries-management approaches to modeling and nontraditional approaches were addressed in task 2, including (1) surplus production models, (2) yield and yield-per-recruit models, (3) stock-recruitment models, (4) Leslie matrix models modified to incorporate growth, and (5) bioenergetics models. For each modeling approach, the kinds of data required to implement the basic model and ways that the effects of stress (single or multiple) might be incorporated into the model structure were described. The assumptions, dynamics, estimation problems, advantages, and usefulness of the various modeling approaches were compared. The choice of modeling approach depends, in part, on data availability. Data are required for obtaining parameters in the basic model and incorporating the effects of stress on important population parameters. Simpler, less data-intensive models are useful for screening a large number of fish populations that may be at risk. Additional research can then be directed toward implementing more complex, data-intensive models for the reduced number of fish populations that are at risk. These approaches (both simple and complex) should be used for comparing stressed-to-unstressed fish populations rather than attempting to accurately predict future population levels.

Our recommendations for future laboratory and field research are concerned with (1) correcting inadequacies prevalent in earlier laboratory and field studies, (2) emphasizing usage of multispecies and microcosm studies as an intermediate step between laboratory and field work, and (3) taking advantage of *de facto* field experiments undergoing known stresses. We recommend further development of theory to (1) incorporate the influence of physical-chemical and biological factors on toxicity, (2) describe sublethal effects of stress on growth and reproduction, (3) relate toxic effects (lethal and sublethal) to internal toxicant concentrations rather than to ambient toxicant concentrations, and (4) understand the effects of fluctuating toxicant concentration and multiple exposure on fish and fish populations. Although we emphasized a combined bioenergetics and Leslie matrix approach for comparing population-level predictions under alternative stress hypotheses, other, simpler modeling approaches should be considered for both screening and comparative purposes. Furthermore, specific situations may not require the level of complexity inherent in the bioenergetics-Leslie matrix approach, or the necessary data may not be available. If so, several simpler models might be implemented as part of an initial investigation.

Analysis of the Status of Maryland Striped Bass

S. W. Christensen

In cooperation with Dr. C. Phillip Goodyear of FWS and Dr. Joel E. Cohen of The Rockefeller University, an analysis of some population-level data on Chesapeake Bay striped bass was undertaken as part of our EPA project on long-term impacts of anthropogenic stresses on fish populations and communities. To determine whether statistical support exists for the widely held notion that this population is in difficulty, first-year survival rates of Maryland bass were derived from data on year-class strength. Survival, rather than year-class strength, was chosen for examina-

tion to account for the possible influence of stock size on recruitment and to allow comparison of annual first-year survival with that required for replacement. Estimates of first-year survival of Maryland striped bass declined significantly from 1969 to 1981, and averaged less than that needed for replacement for the last ten years. Treatment of the individual spawning grounds separately indicated that survival in the Nanticoke and Potomac rivers averaged below replacement for the last ten years and declined in the Choptank River and Upper Bay, where it was below replacement for each of the last seven years.

Interpretation of these results depends on assumptions about changes in adult survival and fecundity through time. Through simulation studies we found that an annual decline in adult survival (due to fishing) of about 0.018 times the assumed initial survivals would produce the observed correlations. Alternatively, analogous decreases in adult fecundity could also account for the correlations. Whatever the cause, continuing declines in first-year survival or in adult survival or fecundity would eliminate the Maryland striped bass stock and the fishery it supports. Conversely, an increase in adult survival, which is achieved perhaps through a reduction of fishing mortality, could probably offset the effect of the unknown factor or factors responsible for the apparent decline in first-year survival.

Symposia

Striped Bass: Environmental Risks in Fresh and Salt Water (C. C. Coutant)

Hypotheses for environmental risks to striped bass (*Morone saxatilis*) were explored in a symposium organized by C. C. Coutant of ESD for the 112th Annual Meeting of the American Fisheries Society. Nineteen invited speakers and five panelists combined the experiences with coastal stocks and freshwater introductions to propose and evaluate environmental requirements of this highly valued sport and commercial fish species.

The declining status of striped bass populations in coastal waters and the mixed success of striped bass introductions to freshwater reservoirs were discussed in three opening papers. With these problems in mind, three hypotheses for environmental risks were presented in speculative syntheses, and each was followed by a set of "evidence" papers from field or laboratory research. The first hypothesis—an environmental "squeeze" of adults between high surface temperatures and low hypolimnetic dissolved oxygen levels under conditions of increasing eutrophication—was proposed by C. C. Coutant based on ORNL research on temperature selection in freshwater quarry lakes and Cherokee and Watts Bar reservoirs. The second hypothesis—interaction between toxicant stresses and overfishing—was formulated in a quantitative manner using population modeling by a team that included S. W. Christensen of ESD. A third hypothesis—climate control of optimal living space and food—integrated field research on juvenile survival and growth in different years in the Chesapeake Bay, Hudson River and San Francisco Bay systems. A concluding panel critiqued the hypotheses and the research results presented in evidence papers to determine management implications for restoring declining coastal stocks and to establish rational criteria for inland waters suitable for stocking. The extensive interest in the symposium encouraged us to publish the papers in the near future.

Hudson River Power Plant Case Symposium (L. W. Barnhouse, E. W. Christensen, D. S. Vaughan, and W. Van Winkle)

The Hudson River Power Plant Case is a historic, precedent-setting case for utilities, governmental agencies, and society in general. A symposium entitled *Advancing the Science of Assessment: Technical Lessons from the Hudson River Power Plant Case* was held at the 112th Annual Meeting of the American Fisheries Society on Hilton Head Island, South Carolina. The symposium was organized by Douglas S. Vaughan of ESD and Ronald J. Klauda of Johns Hopkins University and was funded by EPRI and DOE. The objectives of this symposium were the (1) integration and summarization of the major technical issues, (2) discussion of the varied scientific interpretations of the data and analyses presented during the adjudicatory hearings, (3) discussion of the technical rationale for the mitigation measures spelled out in the 1980 settlement agreement that ended over a decade of litigation, and (4) the development of recommendations specific to a long-term monitoring plan for the Hudson River but that are generally applicable to other aquatic impact assessment studies.

Ten papers, four by ESD staff members, were presented in this half-day symposium that will serve as the nucleus for a proposed monograph to be published by the American Fisheries Society. Topics presented in the symposium included: (1) an introduction and perspective on the Hudson River Power Plant case, (2) advances in the field and in analytical methods for estimating entrainment mortality factors, (3) comparison of methods for estimating entrainment and impingement conditional mortality rates, (4) relative stock composition of the Atlantic Coast striped bass population, (5) application of stock-recruitment theory to the assessment of power-plant impacts, (6) an analysis of the validity of the utilities' stock-recruitment curve-fitting exercise, (7) population biology in the courtroom, (8) mitigative measures required by the Hudson River Power Plant case settlement, (9) management implications of the mortality of young striped bass at Hudson River power plants, and (10) biological monitoring after the Hudson River settlement agreement. The proposed monograph will present an introduction, an overview of the study area, discussions on entrainment and impingement impacts, the negotiated settlement and beyond, and a summary and synthesis.

10. EARTH SCIENCES

Tsuneco Tamura

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Introduction

The major goal of the Earth Sciences Section (ESS) is to develop a geosciences program that will provide the information necessary for the understanding and effective utilization of our geophysical environment. The major emphasis continues to be in waste management; contributions of the staff are reflected in the waste programs of the Division. In addition, other programs and projects provide valuable contributions and could, themselves, become major areas of emphasis as the importance of the geoscience to technology increases.

One of the growing areas is in the nonnuclear solid-waste technology. Most of the progress in this effort is reported in Sect. 1, Advanced Fossil Energy Program; next year, plans call for the integration of reporting in this area within ESS. Note also that the waste isolation program is reported separately; this program is developing a new emphasis in gathering information on geologic formations in the Southeast.

The interactions and effects of acid precipitation on the biotic community are of growing environmental concern. Development of atmospheric sampling methodologies at ORNL over the past few years is beginning to receive greater attention, and expanding programs in atmospheric research are utilizing these methods. Although only the technical aspects are summarized in this report, it is not the only product of this work; the groundwork of greater collaboration and cooperation with other sites in the United States has been laid during the year.

This section presents summaries of several activities that may develop into more definitive projects or are of sufficient technical merit to be included as part of this report.

Nonnuclear Solid-Waste Technology

C. W. Francis

Concern mounts in developing solutions to the problems of disposing of hazardous wastes. Disposal of some energy-related wastes will have serious long-term health and environmental effects. Most of the work on solid wastes is reported in Sect. 1, Advanced Fossil Energy Program; findings are reported on microbial sulfur oxidation of wastes, leaching characteristics of raw and retorted eastern oil shale, differences in coal gasification wastes as compared with combustion wastes, and characteristics of different synfuel wastewater sludges. Our report details efforts in developing a laboratory-extraction protocol for the EPA. In addition, an evaluation of grouting as a potential method to reduce migration of undesirable ions is presented.

Toxicity of Solid-Waste Leachates (C. W. Francis, D. K. Brown, R. W. Regan, J. W. Gooch, Jr., and S. J. Anderson)

The objective of this research is to develop a second-generation, laboratory-extraction protocol for the EPA to test the mobility of inorganic and organic toxic constituents of industrial wastes placed with municipal wastes in a landfill. This newly developed laboratory-extraction protocol is intended to replace the current extraction toxicity test (EPA 1980). The desirable characteristics of such an extraction test include (1) its ability to simulate leaching in a landfill containing municipal (95%) and industrial wastes (5%); (2) its compatibility with biological toxicity tests (mutagenic, aquatic, and terrestrial); and (3) its relative low cost in terms of time, equipment, and personnel.

To evaluate the leaching characteristics of municipal-waste leachate (MWL), each of two large-scale lysimeters (1.8 m in diam and 3.6 m in height) was packed with approximately 1.5 Mg

of municipal refuse. Leachate was generated by flowing 26 L of water per day to each lysimeter. The resulting MWL was used to leach four samples of industrial wastes, both in field and in laboratory experiments.

The four industrial-waste samples selected were (1) a mixture of petroleum-refining ash and API separator sludge, (2) ethylenedichloride still bottoms mixed with sawdust, (3) paint sludge mixed with sawdust, and (4) an electroplating sludge. In the field lysimeter experiments, municipal-waste leachate was pumped to glass columns (38.7 cm diam by 30.5 cm high) containing 3.6 and 0.9 kg of the industrial wastes. Flow, for as long as 79 d, was maintained until the volume of leachate reached a 20:1 liquid-to-solid ratio. The purpose is to measure the leaching characteristic of MWL on the industrial wastes. Preliminary data from the lysimeter experiment indicate that potential contaminants are leached from the various wastes differently (Fig. 10.1).

The intent of the laboratory work is to simulate the leaching characteristics of MWL. To simulate these characteristics in the laboratory, two extraction procedures (an upflow column and a batch rotary extractor) and four extraction media are being tested [0.1 M acetate buffer (pH 5); CO₂-saturated, deionized distilled water; deionized distilled water; and a synthetic MWL]. The concentrations of inorganic and organic constituents found in waste leachate from the large-scale lysimeter experiments are being compared to those observed in the laboratory. These data are being examined and evaluated to develop a laboratory-extraction protocol that will assess the potential toxicity of a variety of industrial wastes placed in a landfill with municipal wastes.

Fig. 10.1. The leaching of an electroplating waste by a municipal-waste leachate.

Grouting Research for Application to Wastes (W. J. Boegly, Jr., B. P. Spalding, T. Tamura, I. L. Munro, and L. K. Hyder)

In situ stabilization of wastes, such as solid low-level waste (LLW) and uranium mill tailings by using grouts can be effective in correcting many situations in which waste migration is occurring. Uranium mill tailings emanate radon from the ground surface and, like solid LLW, also produce radionuclides and hazardous-ion leachates that migrate through ground water. The strategy of grouting entails the filling of void space in the waste and its surrounding backfill or tailings with a fluid whose properties allow it to flow into small pores. After a controllable set time, the fluid changes to solid and the hydraulic conductivity of the resulting volume falls to near that of the impermeable grout itself. Successful grouting does not necessarily require that all void space be filled. Partial grouting to form an in situ liner can be a very cost-effective technique. If the floor, walls or sides, and top of a trench or mill-tailings pile are made impermeable with grout, the hydrologic isolation of the waste could be achieved with minimum costs in terms of grout.

As a means to evaluate grouts for such applications, the hydraulic conductivity of 2.5-cm-diam by 10-cm-long columns of soil, rock, or tailings was measured before and after application of grout. The lower hydraulic conductivity limit of the technique (Klute 1965) used was 2.6×10^{-7} cm/s. In addition, each grout formulation was tested on a column of quartz sand that functioned as an inert, or at least minimally reactive, material for inhibiting grout set. Samples of uranium mill tailings were obtained from three sites: Shiprock, New Mexico; Salt Lake City, Utah; and Durango, Colorado; their chemical characteristics have been described elsewhere (Williams et al. 1981). Soil samples, used for backfilling burial trenches of LLW, were collected from ORNL solid-waste storage areas and were characterized as described previously (Luxmoore et al. 1981).

The specific grout formulations are given in Table 10.1, along with the results of the hydraulic conductivity determinations. In general, polyacrylamide yielded the best reductions, approaching the

Table 10.1. Hydraulic conductivities (cm/s) of grouted materials

Grout	Uranium mill tailings			Quartz sand	ORNL backfill soil
	Shiprock	Salt Lake City	Durango		
None	5.5×10^{-3}	3.8×10^{-3}	4.1×10^{-3}	3.9×10^{-2}	5.2×10^{-2}
Polyacrylamide (10%)	5.4×10^{-5}	$\leq 2.6 \times 10^{-7}$	$\leq 2.6 \times 10^{-7}$	$\leq 2.6 \times 10^{-7}$	$\leq 2.6 \times 10^{-7}$
Bentonite (5%) ^a	$\leq 2.6 \times 10^{-7}$	$\leq 2.6 \times 10^{-7}$	$\leq 2.6 \times 10^{-7}$	$\leq 2.6 \times 10^{-7}$	<i>b</i>
Resorcinol formaldehyde (10%)	1.1×10^{-3}	8.7×10^{-4}	$\leq 2.6 \times 10^{-7}$	$\leq 2.6 \times 10^{-7}$	<i>b</i>
Urea formaldehyde (20%)	3.4×10^{-3}	1.4×10^{-3}	2.5×10^{-3}	2.6×10^{-2}	<i>b</i>
Sodium silicate (15%)	1.4×10^{-6}	7.0×10^{-7}	5.2×10^{-4}	2.6×10^{-4}	1.2×10^{-5} ^c

^aIn all cases, bentonite failed to infiltrate the soil columns, and the reported low conductivities are the result of surface plugging.

^bNot determined.

^cIn this case, 3% sodium silicate was used instead of 15%.

detection limit in most cases. Some inhibition of acrylamide polymerization was noted with the Shiprock tailings sample. Although the 5% bentonite slurry yielded apparent low water permeabilities, these were achieved by surface plugging of the test columns rather than grouting of the matrix; therefore, its potential for in situ grouting of either soil or mill tailings is quite low because it cannot penetrate these materials. In general, sodium silicate, offered the next best reduction in hydraulic conductivity and was compatible with all materials. The resorcinol-formaldehyde grout failed to perform well for two tailings samples; notably, the acidic condition of these samples probably inhibited the base-catalyzed polymerization of this grout. Urea-formaldehyde grout performed poorly in all cases; it appears to be quite undesirable for this use.

The work at ORNL on LLW has progressed from the laboratory to field demonstration. Both polyacrylamide and sodium silicate will be used to grout 15 m³ trenches previously filled with solid LLW and backfilled with soil. A network of wells within each trench will monitor the distribution of grout within the trench with respect to a single central injection well. Evaluation will be performed by the observed reductions in hydraulic conductivities in the sections of the trench surrounding the monitoring wells. It is hoped that grouting will prove to be effective as a corrective action to hydrologically isolate radioactive wastes from the environment.

Atmosphere-Biosphere Interactions

S. E. Lindberg

The complexity of the atmospheric chemistry of anthropogenic emissions is well known and extends to their interactions at the earth's surface. Quantification of wet and dry atmospheric deposition of gases and particles is necessary for prediction of the fate and effects of emissions from energy technologies. Although forest vegetation is the initial point of contact between the atmosphere and the ground for roughly 50% of the eastern United States, no widely accepted sampling strategies exist for routine measurement of the dry deposition to such canopies or of the interactions with forest vegetation. Micrometeorological methods are applicable in specialized studies of gas and submicrometer particle-flux measurements, but field data suggest that large particles may transport a significant mass of some pollutants. Inert ("surrogate") surfaces have proved successful for estimating flux of large particles and, combined with meteorological methods, may yield a measurement of total dry deposition. However, surrogate-surface data must be compared with vegetation studies to obtain accurate calibration because of the difficulty in simulating plant surfaces.

In addition to studies involving sampling strategies, a summary of results of water-soluble and acid-leachable concentrations of several trace metals are presented. The Walker Branch Watershed on our reservation is rapidly becoming recognized as a valuable facility for atmosphere-biosphere studies.

Atmosphere Deposition Interactions with Forest Canopy (S. E. Lindberg and G. M. Lovett)

Walker Branch Watershed, Tennessee, is the site of several completed and ongoing research projects addressing the wet and dry deposition of atmospheric substances (Lindberg and Harriss 1981a; Johnson et al. 1982; Lindberg and Lovett 1982; Lindberg et al. 1982; Hicks and McMullan 1982). In March, 1980, Walker Branch became the first site in Tennessee for monitoring of weekly precipitation chemistry in the National Atmospheric Deposition Program, and in January, 1981, it

became the first southeastern U.S. site in the MAP3S-RAINE event rain-chemistry network. Currently, both DOE and EPRI fund research projects at Walker Branch dealing with deposition/forest-canopy interactions of acids, plant macronutrients, and trace elements in the atmosphere. In addition, collaborative projects with the TVA and the National Oceanographic and Atmospheric Administration (NOAA) Atmospheric Turbulence and Diffusion Laboratory that involve comparison of deposition rates to different Southeastern watersheds and watershed-scale calibration studies of atmospheric particle deposition, respectively, are either under way or planned.

In an effort to evaluate the applicability of methods developed at Walker Branch for measuring dry deposition, numerous comparison experiments are planned or are currently under way at diverse locations. In conjunction with the Department of Civil Engineering at Carnegie-Mellon University and several other institutions, dry deposition to a grassy field in Illinois has been estimated using micrometeorological, air concentration, and several surrogate-surface methods in a study funded by EPA (Dolske and Gatz 1982). With the cooperation of other atmospheric researchers, artificial deposition surfaces used at Walker Branch are also being tested in New Hampshire (Dartmouth College), Scotland (Macaulay Institute for Soil Research, The Institute of Ecology), and England (University of Nottingham). In addition, studies of continuous variations in aerosol size distributions in the forest canopy are planned with the National Aeronautics and Space Administration (NASA) Langley Research Laboratory, whereas experiments on the chemistry and deposition of trace organics in the forest atmosphere are being pursued with colleagues at Brookhaven National Laboratory. Together these projects constitute an active research program aimed at developing the best techniques for measuring both wet and dry deposition to forest canopies and applying these techniques to a variety of forested ecosystems.

Water- and Acid-Soluble Trace Metals in Atmospheric Particles (S. E. Lindberg and J. M. Coe)

The water solubility of atmospheric particles is an infrequently studied but important parameter influencing (1) nucleation efficiency, (2) atmospheric residence time, (3) physical growth of suspended particles, and (4) the efficiency of particle capture, retention, and uptake by biologically active surfaces. A particle-associated element of relatively high solubility residing on a vegetation surface can be dissolved by precipitation, dew, intercepted fog, or by reaction with leaf exudates. Particle solubilities and soluble-element concentrations have been reported in the literature to a limited extent for major aerosol constituents, such as SO_4^{2-} , NH_4^+ , and Cl^- , and for the total atmospheric particle mass, but not for many trace constituents. Published studies of trace-metal solubility in atmospheric particles generally consider only the total aerosol mass and provide limited information on the variability of solubility with particle size (Hodge et al. 1978). We present here a summary of results of a study of water-soluble and acid-leachable concentrations of Cd, Mn, Pb, and Zn in suspended particles collected at a forested site in the southeastern United States and fractionated into four particle size classes.

Samples of total suspended particles were collected using membrane filters mounted on towers above the forest canopy at the Walker Branch Experimental Watershed. Size-fractionated aerosols were collected using eight-stage Andersen cascade impactors having backup filters. Laboratory extractions were used to determine the distilled water solubility and dilute-acid (0.1 N HNO_3) leachability of metals in aerosols. Details on sample collection and analysis have been published (Lindberg and Harriss 1981b).

The data on concentration and solubility of trace metals in atmospheric particles collected at this forested site in the Tennessee Valley may be summarized as follows:

1. Element concentrations and size distributions do not reflect a significant influence of local coal-fired power plants, being more similar to values measured at rural than in urban/industrialized areas.
2. As regional air stagnation increases, the concentrations of Cd, Pb, and Zn increase, whereas that of Mn decreases.
3. Size distributions and concentrations and their relationships to various meteorologic parameters suggest a soil source for Mn, combustion sources for Pb and Zn, and both fine-particle-combustion and coarse-particle-dispersion sources for Cd.
4. Substantial proportions of the quantity of metals extractable from atmospheric particles by HNO_3 at pH 1 are soluble in distilled water alone (pH 5.6). For the total aerosol, relative solubilities (ratio of water soluble to water plus pH 1, HNO_3 leachable) range from 48 to 98% with mean values in the following order: Zn (89%) > Mn (83%) > Cd (81%) > Pb (74%).
5. Relative solubility is a reasonable measure of water solubility for Cd and Mn, but is a factor of two to three overestimate of water solubility for Pb and Zn, based on concentrated acid digestions of one sample set.
6. In general, relative solubility increases with decreasing particle size and with the frequency of atmospheric water-vapor saturation during a sampling period.
7. The relationship between solubility and particle size may be related to the increased surface-area-to-volume ratio for fine particles, characteristic surface association of these metals, and the increased free H^+ , organic carbon, and strong-acid anion concentrations in the fine-particle fraction.

Outreach Activities

Other activities undertaken by staff members are unfocused efforts, seeking greater applicability, or out of the mainstream of ORNL activity. An example of unfocused efforts is represented by the initial study of shales, slates, and schists that represent a basic approach to understanding the geochemistry of metals occurring in organic-rich rocks. A report on a training seminar has been published and training course manuals (Yeh 1982a, 1982b) have been issued, representing a growing realization of greater applicability and the importance of information transfer. A report on the Hudson-Raritan estuary is being completed that represents the final evaluation of the different pollutants in the bottom sediments of the estuary; a summary of this report is included in this section under Sedimentation and Contaminant Distribution in the Hudson-Raritan Estuary. This activity completes efforts started elsewhere but extended and completed at ORNL.

Petrology and Geochemistry of Metals in Organic- and Graphite-Rich Shales, Slates, and Schists (C. S. Haase and S. H. Stow)

The objective of this research is to study some aspects of the geochemistry of heavy metals (U, Cu, Mo, Ti, V, etc.) in organic- and graphite-rich shales, slates, and schists. The major goal of the research this year was to attempt to delineate the mechanisms by which heavy metals are housed within organic-rich rocks that have experienced only diagenetic recrystallization. A question to be

answered was whether or not heavy metals had formed discrete, very small (10 to 30 nm diam), mineral phases that were dispersed throughout the organic-rich matrix. Furthermore, the application of high-resolution transmission and scanning electron microscope (TEM and SEM) techniques in searching samples for the heavy metal-bearing phases was to be evaluated. Samples were first studied by standard optical and x-ray diffraction methods. Bulk chemical analyses of selected samples were obtained by multi-element inductively coupled plasma (ICP) techniques. Data from these various analytical methods permitted samples having extreme heavy-metal enrichment and promising large-scale (10 to 200- μ m range) textural features to be identified and selected for detailed TEM/SEM study of very small-scale textures (10 to 100-nm range). We hoped that such high-resolution examination would confirm or refute the existence of discrete heavy-metal-bearing phases.

Sample suites were collected during fieldwork in east-central Tennessee (Chattanooga Shale), in the Talladega Slate Belt and vicinity of Alabama (Erin Slate and Ashland-Wedowee Group), and in the Marquette District of Michigan (Michigamme Formation). From these suites, 216 samples (36 of Chattanooga Shale, 47 of Erin Slate, 73 of Ashland-Wedowee Group, and 60 from the Marquette District) were selected to be analyzed by the Analytical Chemistry Division. The samples were analyzed for total C and S by Leco procedures, for U by neutron activation techniques, and for Ag, As, B, Ba, Ca, Co, Cr, Cu, Fe, Mg, Mn, Mo, N, P, Pb, Sb, Se, T, and V by ICP techniques. The samples analyzed were, in some cases, selected after preliminary optical microscopic study indicated petrogenetically significant mineral assemblages and reaction textures, especially in cases that involved heavy-metal-bearing minerals. In other cases, samples were selected to try to delineate regional trends in heavy-metal content and geochemistry.

The results of optical microscopic and SEM/TEM study conducted to date on Chattanooga Shale samples indicate that the most common heavy-metal sulfide mineral is pyrite (FeS_2). It occurs in two different habits, framboids and euhedral grains. The framboids typically are in clusters and stringers and are associated with exinite-rich kerogen that fluoresces in UV light. The euhedral grains are distributed randomly, occasionally forming coalesced stringers, and are distributed throughout nonfluorescing vitranite-rich kerogen. The framboidal pyrite is frequently associated with other metal sulfides [sphalerite, ZnS , and chalcopyrite (FeCuS_2)] in complex intergrown recrystallized patches and stringers, whereas the euhedral pyrites are rarely associated with other metal sulfides.

High-resolution TEM observations have identified 10- to 30-nm pyrite grains dispersed throughout the nonfluorescing kerogen matrix. Compositionally, these sulfides are pure FeS_2 . Small (10- to 20-nm) Ti-rich minerals have also been found dispersed in the matrix. These TEM results suggest two things: first, that heavy metals, at least Fe and Ti, are housed in very small, heavy-metal-bearing phases dispersed throughout the organic matrix in shales like Chattanooga Shale and, second, as indicated by microanalysis of the amorphous kerogen matrix, that no heavy metals occur randomly within such kerogen. Therefore, the metals detected in the bulk analysis occur either in discrete phases not yet identified, as a result of the already-mentioned heterogeneous heavy-metal distribution, or in phases such as pyrite or sphalerite as lattice substituents.

Research planned for FY 1983 involves continuation of the TEM study of the Chattanooga Shale samples to more completely document how heavy metals are housed. Because of textural and compositional heterogeneity, a large number of samples must be examined by TEM techniques to accurately define the mode of occurrence for the heavy metals of interest. In addition to the TEM work, petrologic characterization of the sample suites from Alabama and Michigan will continue.

Mathematical Modeling Seminar (G. T. Yeh)

Two reports (Yeh 1982a; 1982b) were prepared that covered the training seminar for the NRC staff on the applications of ground-water flow and transport models to LLW management. Following the classroom presentation, queries often made regarding the adaptation of numerical models concerned: (1) size of spatial discretization, (2) size of time step, (3) computation of number of time steps when variable time-step size is used, (4) specification of dispersion parameters, and (5) determination of hydraulic properties.

The selection of spatial discretization size is usually dictated by the accuracy requirement for numerical computation. There is no way to compute the maximum grid size, given an accuracy specification. Normally, one would apply the numerical model to simplified one-dimensional cases that have analytical solutions available. Using the system parameters, one then would try different grid sizes until the numerical simulations agree with analytical solutions within the accuracy specification. This trial and error technique would yield the maximum grid size one can use.

Selection of the time-step size depends on the grid size, the flow velocity, and dispersion coefficient. As a rule of thumb, one should choose a time-step size small enough to require more than two time steps for the waste particle to travel, or disperse, through one grid. Once time-step size is determined, the number of time steps is computed by summing geometrical series with the length of real-time simulation desired.

The specification of dispersion parameters depends on the type of porous media. These parameters must be obtained from field measurements or column experiments. When obtained from column studies, these parameters are generally made two orders of magnitude larger for the longitudinal dispersivity and one order larger for the transverse dispersivity. Other hydraulic properties, such as bulk density, effective porosity, saturated hydraulic conductivity, and the compressibility of the media, are readily obtained from laboratory measurements. When unsaturated porous media are encountered, a retention curve and relative hydraulic conductivity must be obtained. These often involve in-field measurements using a tensiometer and a neutron probe (Luxmoore et al. 1981) or laboratory determinations (Black et al. 1965).

Since the issuance of the two training course reports (Yeh 1982a; 1982b), several universities have adopted them as an integral part of the teaching materials in courses on ground-water flow and contaminant transport, for example, the University of Nevada at Reno (personal communication, T. J. Burbey, Desert Research Institute, UNR, 1982). At the University of Maryland, research has been conducted to compare experimental data with several model predictions. Researchers concluded that the models depicted in the training manuals yield the least error in mass balance; however, all models predict peak concentrations that lag about 10 cm behind observations from experiments (personal communication, Robert Powell, University of Maryland, 1982).

Sedimentation and Contaminant Distribution in the Hudson-Raritan Estuary (C. R. Olsen, I. L. Larsen, N. H. Cutshall, and R. F. Bopp)

Existing data on the distribution of sediments and sediment-associated contaminants in the Hudson-Raritan estuary have been reviewed. In addition, the distribution of geochemical tracers have been used to (1) identify patterns of particle and contaminant transport and accumulation, (2) determine a first-order budget for fine-particle accumulation, and (3) estimate sediment fluxes from riverborne, marine, sewage, and in situ productivity sources in the Hudson-Raritan estuary.

The sediment surface in most areas of the Hudson-Raritan estuary (particularly, wide shallow areas, such as Raritan Bay) is currently in a state of equilibrium with the current, wave, and freshwater flow regimes. In these areas, the sediment surface has apparently obtained an equilibrium depth above which net particle and contaminant deposition is negligible, despite an excess supply of both. Net sedimentation rates in these areas are 1 to 3 mm/year and appear to reflect the rate of sea-level rise or land subsidence.

Small localized areas out of equilibrium with the wave, current, and flow regimes (i.e., dredged-channel areas) may serve as fine-particle and reactive-pollutant traps, collecting material that has been added to, resuspended from, or dispersed over considerably larger areas. Rates of sedimentation in dredged areas of Newark Bay and Raritan Bay and in the inner harbor area of New York are one to two orders of magnitude greater than rates in nearby "equilibrium" areas.

About $1.5 \pm 0.5 \times 10^6$ Mg of fine-grained particles accumulate annually in the Hudson-Raritan estuary. About 70% ($1.1 \pm 0.3 \times 10^6$ Mg/year) may be derived from riverborne sources, ~10% ($0.17 \pm 0.1 \times 10^6$ Mg/year) from sewage solids and in situ productivity, and ~20% ($0.35 \pm 0.35 \times 10^6$ Mg/year) from marine sources. Sediment input by shore erosion is negligible. Although the total sewage and in situ productivity input is $\sim 0.4 \times 10^6$ Mg/year (of which ~70% is organic matter), only about 20% of the organic matter accumulates in the sediments; the rest is oxidized or transported out of the estuary.

Recently deposited estuary sediments, containing ^{137}Cs , (1) have higher trace-metal concentrations by about an order of magnitude, (2) contain plutonium and (3) are severely contaminated with PCBs, organochlorine pesticides, and petroleum hydrocarbons relative to older sediments containing no ^{137}Cs . About 0.17×10^6 Mg of sewage solids, 3.8 Mg of PCBs, 525 Mg of zinc, and 370 Mg of copper are annually accumulating with fine-grained particles in the Hudson-Raritan estuary. About 70% of the total zinc and ~90% of the total copper burden in the estuary sediments is derived from anthropogenic sources. Dredge-spoil disposal is the primary mechanism by which chemically reactive contaminants are transported from the estuary to the shelf.

Data supporting these results and interpretations have been assembled in a draft report that has been submitted to the Office of Marine Pollution Assessment of NOAA to be published as a Technical Memorandum.

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11. ENVIRONMENTAL RESOURCES

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Introduction

The Environmental Resources Section performs research and analysis in three areas: modeling and systems analysis, environmetrics, and regional studies, including the work done on the Oak Ridge National Environmental Research Park (NERP). The staff members are assigned either to projects within the Section or to those elsewhere in the ESD where their expertise is needed.

The modeling and systems analysis group worked on studies ranging from stochastic simulation of chaotic population models to the eradication of disease in epidemiological models. The group continued its interest in trophic relationships with a study of coevolution in a unique marine predator-prey system and a study of stability in evolving food webs.

The environmetrics group continued its emphasis on applied statistics, data management and computer science, and the integration of these tools into environmental research. Efforts during the year focused on statistical analysis of toxicological data and on studies of LDB. Collaborative efforts continue on the development of the Carbon Dioxide Information Center (CDIC) and on application of the Geoecology Data Base.

Regional assessments have been completed on the Tennessee-Tombigbee Corridor and on potential conflicts between proposed energy facilities and critical natural areas. Using radio-transmitter equipment, the NERP staff has completed an intensive study of bobcat activity.

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Modeling and Systems Analysis

Chaotic Models as Reasonable Representations of Ecological Systems (R. H. Gardner, R. V. O'Neill, and D. E. Weller)

Much interest was shown in the dynamics of simple models whose predictions can be chaotic, that is, not tending toward an equilibrium point or limit cycle. Speculations about the ecological importance of chaotic behavior include the following: (1) populations may vary in an unpredictable manner so that long-term predictions are impossible, (2) small changes in initial populations or growth rates can yield divergent predictions, and (3) chaotic behavior may explain relative abundances of rare species. If these speculations are true, they have far-reaching consequences for ecological research and modeling.

Evaluation of these results requires that model formulation, parameter values, and method of simulation be ecologically sound. The following observations seem relevant: (1) values for the growth rate (r) must be biologically reasonable, (2) parameter values of ecological models always contain uncertainty, and (3) extinction is an ecological reality when predicted values are close to zero. The most thoroughly studied chaotic models are single-difference equations describing density-dependent population growth. To analyze results, the solution for each time (t) was placed in one of 100 frequency intervals from 0.0 to the maximum observed value. The relative frequency (c) was calculated by dividing the number in each interval by the expected value. The frequency (c) in each interval approaches 0 if the time series approaches an equilibrium or cycles with period 10 or less. As the time series approaches "white noise," c approaches 100.

Figure 11.1 shows isopleths of c for values of r (abscissa) and $r\%$ (ordinate), using an initial condition of 0.01 for all simulations. At $r = 1.5$, the system is periodic (even at $r\% = 100$). At $r = 3.5$, the system appears regular because of the high probability of extinction. At intermediate values of r [Eq. (2.5)], the situation is more complex. As this range, $r\%$ increases to 20; unpredictability increases dramatically because the randomly chosen values of r cover a wide range of behavior including stable cycles of various periods and chaotic behavior. It is obvious that the uncertainty in r (i.e., $r\%$) is as important in determining the regularity of the system as is the mean value and that model solutions are never completely unpredictable.

The results point out several ecologically relevant aspects of behaviors of the model. Among these are: (1) the predictions are always bounded when r remains within biologically reasonable limits; (2) the mean population remains predictable for all values of r ; and (3) even when the time sequence seems erratic, the frequency distribution of observed population values is not. These results are robust under different criteria of extinction and variability of the initial conditions and are in contradistinction to conclusions drawn from purely deterministic studies of chaotic models.

Gastropod-Bivalve Coevolution (D. L. DeAngelis and W. M. Post)

Coevolution occurs between two or among more species that are coupled biotically. A strong interaction between a predator and prey species, for example, may alter both predation and defense mechanisms over evolutionary time, thus resulting in a so-called "coevolutionary arms race." In systems-theoretical terms, coevolution is a case of positive feedback.

J. A. Kitchell of the University of Wisconsin has outlined the unique advantages of naticid gastropod predator-prey systems for testing aspects of coevolution theory. These marine gastropods are predators on other mollusks (both gastropods and bivalves), which they attack by drilling

Fig. 11.1. Isopleths of c , the index of unpredictability, for values of r and r_g (r is the coefficient of the discrete logistic model and was uniformly varied over the interval $r \pm r_g$).

through the shells of their prey. The advantage of this system for analysis is that a record of attacks, whether successful or not, is left on the fossil shells of the prey. Predator size can thus be estimated from the size of the boreholes. A testable hypothesis is that because the success of the drilling attack by the predator is related to its size with respect to prey size, a coevolutionary race in sizes could have occurred during the Cenozoic period.

In collaboration with Professor Kitchell, we are developing a set of increasingly complex models of naticid predator-prey interactions aimed at elucidating possible coevolutionary mechanisms. The first model is restricted to one predator species, *Polinices duplicatus*, and one prey species, the bivalve *Mercenaria mercenaria*. The model simulates the energetics of the predator and prey and the mortality of the prey caused by drilling attacks. The respiration energy losses of both species, success probability of attacks, prey energy value to the predator, size selection of prey by predators, and prey reproductive potential can all be related to sizes of the individual. Hence, measures of fitness can also be related to size.

To determine in which direction the modeled coevolution of predator size and prey size would go under a variety of initial conditions, several simulation runs were made. Combinations of seven

initial adult prey sizes and seven predator sizes were tested. The results for a given set of these combinations are shown in Fig. 11.2, in which the starting points of the predator and prey lengths are denoted. Two attractors are evident in this figure. One occurs at a predator length of zero and attracts trajectories for predator lengths that started too small. The other occurs at a predator size of about 45 to 55 mm and an adult prey size of roughly 50 to 70 mm. Because the model is a discrete-time-step model, considerable fluctuation occurs in the neighborhood of this second attractor.

The results show that the mutual interaction of the predator and prey species results in movement toward equilibrium values of size that are different from the values in the absence of the interaction. These results will be compared to the fossil record, which shows increasing sizes in naticid gastropods and their prey throughout parts of the Cenozoic period.

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Fig. 11.2. Trajectories of prey length and predator length through time predicted by gastropod-bivalve co-evolution model. The X's denote 16 different hypothetical initial values of the lengths.

Community Assembly and Food-Web Stability (W. M. Post)

Recently, much interest exists in the relationship between the ecological organization of natural communities of organisms and their stability to perturbation, either natural or human induced. Progress was made in understanding some very general properties of food-web structure by considering the observed structure as a factor in stabilizing interactions between predators and prey. Using fixed population parameters and patterns of interactions, novel food-web properties were predicted and later confirmed by analysis of real webs.

A study was conducted to determine how stability properties change as food webs develop. Ecological processes of colonization and extinction were incorporated in a computer program to simulate how a food web develops through time. The results showed that population parameters and patterns of interactions change as the food web undergoes a successional process. In particular, the stability properties of these food webs change with succession. Questions regarding three types of stability were asked.

1. Do food webs become more resistant to invasion of new species with succession?
2. Will a colonist cause more or fewer species losses from the food web as time progresses?
3. How quickly will the densities of the species return to equilibrium following perturbation, and how will this return time change with succession?

Simulations using different ranges of population parameters, species pool sizes, and probabilities of interaction showed the following general results.

1. The difficulty of colonization increases approximately linearly with time; older food webs are harder to colonize than younger ones. This occurs even after the number of species in the food web has reached equilibrium.
2. Successful colonists do not cause serious extinctions more commonly early or late in successional time.
3. The resilience, or species density return time, of food webs decreases with succession.

The changes in the different food-web stabilities are a result of changes in parameters of the successful colonists, but such changes cannot be detected from any simple combinations of parameters. Such parameter changes may also be difficult to observe in nature. Before applying these results to more general ecological communities, we must examine the effect of biological details that are missing from the computer model. For example, neither direct (interference) competitive and mutualistic interspecies interactions nor feedbacks between the environment and organisms that result from the accumulation of soil organic matter and nutrients are included.

Strategies for Eradicating Infectious Diseases (C. C. Travis)

In the seventeenth and eighteenth centuries, smallpox was the most devastating disease in the western world; it killed 40-50% of infected individuals. Despite repeated attempts at mass vaccination, smallpox remained endemic in most parts of Asia, Africa, and South America until as late as 1950. Classical models of epidemics predicted that populations with sufficiently high levels of natural or artificial immunity would be resistant to attack by disease. However, this prediction was not borne out by the smallpox mass-vaccination campaign. By 1967, it was evident that mass vaccination alone would not eradicate smallpox.

Classical models are based on the assumption of randomly mixing populations. However, random mixing serves only as an adequate approximation in small, closed populations. Typical real-life situations are heterogeneous with respect to geographic, cultural, and socioeconomic factors. These factors may result in pockets of susceptible subpopulations in spite of a high overall level of population immunity. Epidemics in large populations can then result from the spread of an infection from one semiisolated group to another.

We developed a model that accounted for subpopulations and predict the failure of the mass vaccination strategy for smallpox and the success of a strategy introduced in 1967. This strategy consisted of diligent surveillance followed by prompt intervention through patient isolation and vaccination of actual or potential contacts. The goal of the model was to gain insight into why the application of mass vaccination by itself had failed in eradication, whereas the second strategy was successful.

Environmetrics

Environmetrics is a branch of environmental sciences that uses the tools of applied statistics, data management, and computer science for organizing research. The primary goal of environmetrics is to integrate appropriate methods from each of these fundamental subject areas into environmental research.

Toxicology and Regression Analysis (D. S. Vaughan)

Least-squares regressions provide a powerful analytic tool for comparing acute toxicity data from two taxa when the errors have constant variance and the independent variable is known to be without error. Various transformations can then be used to obtain approximately constant variance. A method (sometimes referred to as major-axis regression) is available for use when the independent variable is subject to error. This method minimizes the orthogonal distance of the regression line from the observed points, whereas the least-squares method minimizes the vertical distance of the regression line from the observed points. The major-axis regression method is appropriate when obtaining estimates of future observations from future measurements of the independent variable. However, it is more appropriate to use the least-squares method when estimating true values of the dependent variable from future measurements of the independent variable.

In environmental risk analysis, it is often necessary to extrapolate between acute toxicities for two different taxa. Two distinct components to the total error arise from this extrapolation: (1) a variance resulting from individual genetic differences among the test organisms, variations in test conditions, measurement errors, etc. (inherent variance) and (2) the variance associated with a prediction of the dependent variable (Y), given an observed value of the independent variable [X (extrapolation variance)]. Without replication of toxicity tests for each combination of taxa and chemical, it is necessary to assume a known ratio (such as 1) between the inherent variance of X and Y to obtain an estimate of this inherent variance. This assumption was tested on acute toxicity data for fish by pair-wise comparisons of 95% confidence intervals. The average ratios at different taxonomic levels were found to be very close to 1.

Carbon Dioxide Information Center (J. A. Watts)

The CDIC, which is sponsored by the Carbon Dioxide Research Division of DOE's Office of Basic Energy Sciences, was established this year. The CDIC is a collaborative effort of the Environ-

mental Sciences, Engineering Physics, Information, and Computer Sciences divisions and is administered by the Information Division. The CDIC supports the national carbon dioxide-climate research effort by providing a focal point for the compilation and distribution of CO₂-related information under systematic quality control. The information analysis center is organized into three components: (1) operations and networking, (2) bibliographic information, and (3) evaluation of numeric data.

The operations and networking segments are an interface between the user/contributor community and the large number of established national and international data centers containing data relevant to the CO₂-climate issues. The CDIC provides documentation on content, accessibility, format, and applicability of the data housed in these centers to the CO₂ research community.

The bibliographic information system contains over 3000 citations and is currently used to support CDIC internal programs and request/response activities.

A major activity of the CDIC is to provide a clearinghouse for evaluated information. Numerical and statistical techniques are applied to numeric data sets to develop a peer-reviewed documented reference data set with which others can be compared. Such a reference data set will contain quantitative estimates of the uncertainty in the data and traceability to the primary sources of the information. Emphasis is currently on the Carbon Cycle and Climate and First Detection programs; the Vegetation Effects and Indirect Effects programs are to be added later. An Inventory of Numeric Data for Carbon Dioxide Research, which contains descriptions of numeric data organized according to broad categories identified as needed or being collected in the DOE-sponsored projects, was prepared. Specific data bases were identified, and the inventory serves as a tool for acquisition of numeric data based on priorities defined by the CO₂ program needs. These data and a preliminary, evaluated data base will serve the CO₂ program in the preparation of state-of-the-art assessment reports in 1984.

Statistical Methods to Investigate Legionnaires' Disease Bacterium in Power Plants (J. A. Solomn)

Studies to elucidate the relationship between the bacterial causative agent of Legionnaire's Disease and the power-plant environment were sponsored by the Electric Power Research Institute (EPRI). A research data management system was established containing estimates of the organism's density, viability, and infectivity and associated measurements of environmental parameters for nine power plants during each of four seasons. Analysis of variance was then used to investigate differences in cell density and viability among the seasons and between the two major operating modes and to detect any influence of passage through power plants. Contingency table analysis was used to study the effect of these factors on infectivity as measured by the ability of the bacterium to cause illness in guinea pigs.

Using a linear modeling approach, we investigated possible causal relationships between the measured environmental parameters and cell density/viability. Certain categorical variables (e.g., season, plant, operating mode, and sampling site) were included in the model to remove extraneous variance. The use of step-wise regression analysis permitted a selection of the most efficient model from a multitude of possible combinations.

Potential causal relationships between these environmental variables and infectivity required a different statistical approach because infectivity is a binary variable having possible values of "infectious" and "noninfectious." Here, a logistic relationship was assumed, and again step-wise regression analysis was used to select the best model. Because the results of these analyses indicated that multicollinearity was a considerable problem in these data, significant changes were made in the design of the second phase of this project.

Geocology Data Base (R. J. Olson)

The Geocology Data Base is an integrated collection of environmental data files covering terrain and soils, water resources, forestry, vegetation, agriculture, land use, wildlife, air quality, climate, natural areas, and endangered species. The county-level data provide resources for regional or national studies of environmental impact assessment and planning related to energy development. The dynamic system is updated and expanded according to research needs and availability of new data. New data files include atmospheric deposition, air emissions, and water quality. Documented files are distributed to other national laboratories and other agencies.

The annual Integrated Data User Workshop provides an opportunity for users of integrated systems and producers of component data sets to exchange information and ideas. ORNL was one of several key agencies in organizing the workshop. The 1982 workshop attracted over 200 participants, and a better awareness of the available data resources resulted. Communications and data-exchange activities of this group are facilitated by a published contact network of over 300 individuals.

Regional Ecological Analysis**Tennessee-Tombigbee Corridor Study (R. J. Olson and M. K. Nungesser)**

Regional environmental characterizations provide a means for site selection over a broad geographic area by using standardized data and applying uniform selection criteria. Collection and presentation of these data are significant efforts in terms of staff time, data analysis, and technical support. The Tennessee-Tombigbee Corridor Study was one such significant effort. The corridor, which is defined by the U.S. Army Corps of Engineers as the Tennessee-Tombigbee Waterway, consists of 51 counties. Its northern boundary is the junction of the Tennessee and Ohio rivers in western Kentucky, and the corridor extends south to the mouth of the Tombigbee River at Mobile, Alabama. Environmental data were collected and presented in ten reports and a summary based on planning district and watershed boundaries for these 51 counties. Resources discussed include (1) land use, (2) water quality, (3) air quality, (4) physiography and mineral resources, (5) natural areas and recreation sites, (6) free-flowing streams, (7) endangered and threatened species, and (8) historic and archeological sites. The reports presented detailed analyses of these resources (based on available information) and discussed relevant environmental legislation. In addition, useful agency contacts and literature were listed for each report.

Information in these reports will be used in studies by the Corps of Engineers to define environmental management alternatives. Using environmental data in conjunction with information on water, human resources, and economics, local planners and developers can apply screening criteria to identify preferred sites based on local priorities and requirements of the business, industry, or development. Through this process, they can attract and site new businesses while they preserve and enhance natural amenities.

Conflicts Between Proposed Energy Facilities and Critical Natural Areas (R. J. Olson)

In 1981, 549 energy facilities in various construction or planning stages in the United States were projected to come on line in the next two decades. Developing these facilities requires compliance with environmental legislation such as the Clean Air Act and, when federal money is involved, the National Environmental Policy Act (NEPA). The Environmental Impact Statement associated

with NEPA requires, among other considerations, an inventory of local or nearby critical natural areas that may be affected. Similarly, the Clean Air Act specifies that large national parks or wilderness areas near new facilities are to be treated as "Class I" air quality areas. Within such areas, allowable air emissions are restricted to maintain acceptable air quality.

The "critical natural areas" include parks, wilderness areas, research natural areas, ecological preserves, and other types of areas that are managed or legally protected to preserve natural features. Such areas are owned and managed by a variety of federal, state, local, and private groups. Information on the location and characteristics of natural areas is difficult to find and entails searching many sources. Consequently, within ESD, an inventory of critical natural areas is being compiled that readily provides information for use in assessing potential conflicts with the development of energy-related facilities. The inventory can be used in preliminary site selection and in site-specific impact analysis. Both the inventories of natural areas and of power plants used in this analysis are in the ESD Geoecology Data Base.

The inventories of natural areas were created by contacting individual agencies to obtain the agencies' most recent inventory data. The Nature Conservancy (TNC) provided computer files describing TNC-owned areas and environmental scientific research areas (Fig. 11.3). Currently, the inventory contains information on most federally owned natural areas, state lands, and selected private areas. Federal areas include national parks, forests, grasslands, fish and wildlife refuges, and wilderness tracts. Although this collection of files represents the largest computerized, integrated data base of natural areas, the inventory is still not complete and requires continual updating.

Assessing potential conflicts involved the following three-step process (1) identification of those counties with planned generating facilities that also contain natural areas, (2) comparison of types of facilities and natural areas within a county, and (3) site-specific evaluation of potential conflicts. This analysis addressed the first two steps and provided summary information to facilitate the last step. Although counties are convenient and useful spatial units, the results can be influenced by the location of features within counties; that is, facilities and natural areas within a county may be located such that no conflicts occur or that a natural area within an adjacent county may, in fact, be affected by facilities in another county. These items need to be considered in the site-specific evaluation.

Using the inventory, 76 of the 259 counties targeted for siting of facilities have no natural areas, whereas 128 of the counties have five or more areas, that is, areas greater than 400 ha. A list of area names, size, and ownership was produced for each county selected as a facility site; this list can be used in the site-specific analysis. In addition, the various types of natural areas and power plants were individually mapped at the national scale. Most of the proposed energy facilities were already extensively planned, including the preparation of an environmental impact statement, or are already under construction. Therefore, this analysis serves primarily to illustrate the use of the inventory. However, as new facilities are proposed, the data resources within the Geoecology Data Base and the methods described here can play a key role in selecting sites to minimize conflicts with existing natural areas or other environmental concerns.

Oak Ridge National Environmental Research Park (J. T. Kitchings and J. D. Story)

Little information exists on the bobcat (*Lynx rufus rufus*) in the deciduous forests in the Ridge and Valley Province of the southern Appalachian Mountains. Although the bobcat is widespread throughout this area, it is not as abundant as in some areas of the United States. Studies of this

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Fig. 11.3. Environmental scientific research areas represented by circles plotted proportional to the size of the area. Source: The Nature Conservancy 1981 data base.

animal's behavior in the wild are also hampered by its secretive nature. In the spring of 1978, a radio-transmitter study aimed at acquiring data on the home range, spatial distribution, and behavior of bobcats was begun on the DOE's Oak Ridge NERP. Interest in the bobcat on the NERP stemmed concomitantly from a desire to characterize its habits in the Ridge and Valley Province and to monitor the long-term effects of anthropogenic activities.

From February 1978 through May 1981, 15 bobcats were captured a total of 82 times. Trap nights numbered 3696, with overall trap success at 2.5%. Success in capturing bobcats increased over the three-year period. In 1978, only two bobcats were captured during 933 trap nights (0.02%); in 1979, captures increased to 27 during 1182 trap nights (2.3%); in 1980, 29 captures occurred during 1155 trap nights (5.6%). The number of individuals by sex and age are adult females, 3; adult males, 2; juvenile females, 6; juvenile males, 4. At the time of capture, all animals were healthy, and the animals were radio-located afterwards throughout the study, except for periods when transmitters failed or antennas were damaged.

The average home range size for adult males in our study was 7677 ha ($n = 2$), whereas the adult females ranged over an average area of 2590.8 ha ($n = 3$). The data presented here support previous studies in which larger mean home ranges for males were reported than for females. In this study, the home ranges for adult males were three times larger than for adult females. The same pattern was noted for juvenile animals—males averaged 15,861.5 ha (range = 10,625.8–22,873.7), whereas females averaged 5630.5 ha (range = 629.5–23,953.3). A comparison of the usage of the home range by both juvenile and adult males and females emphasizes the greater mobility of the males. Females tended to frequent the same locations within their home range more regularly than did males.

During the study, we noted a great deal of interaction between animals and considerable overlap in home range usage, probably because of the preponderance of young animals in our population. The home ranges calculated for our bobcats are larger than those reported for bobcats in other portions of the southeast. Marshall and Jenkins (1966) reported an average home range for two adult females of 460 ha, for one juvenile male of 350 ha, and for a juvenile female of 245 ha. Hall and Newsom (1976) used the modified minimum method to estimate home ranges for females and males of 97 ha and 494 ha, respectively, in bottomland forest in Louisiana. Buie et al. (1979) found three adult female home ranges of 1035 ha and three adult male home ranges of 2077 ha during the winter at the Savannah River Plant near Aiken, South Carolina. In Idaho, Bailey (1974) calculated average adult female home ranges to be 1930 ha and those of adult males to be 4210 ha. Griffith et al. (1980) studied two subadult bobcats in Georgia, and their activity areas covered 1266 ha and 535 ha, respectively; both of these areas were considerably smaller than the ranges of any of our bobcats.

Three times during the overall study period, the two adult females exhibited restricted movement in the middle-to-late spring periods, and all three times we captured juvenile bobcats the following winter that we presumed to be the young of the two females. These young bobcats tended to stay within their mother's ranges until the spring of the following year when these juveniles began to disperse into unoccupied areas.

The beginning of dispersal for these young bobcats coincided with the next breeding of their mother. In fact, complete dispersal coincided with parturition. Griffith et al. (1980) and Crowe (1975) also noted that dispersal tends to be correlated with the breeding activities of adults and that the adult females' intolerance toward their previous offspring is related to parturition.

Our best current estimate of parturition dates is March, April, May, and sometimes into June. This estimate is based on direct observation of females with small kittens and on the periods of restricted movement by the adult females. It follows that breeding probably occurs in the period of December through March. Crowe (1975) estimated that young bobcats become sexually mature at two years of age. Likewise, Fritts and Sealander (1978) estimate sexual activity begins from 1.5 to 2.0 years of age. The movement of a young male in the winter of 1979-1980 into the area of an adult female was possibly for breeding, and if so, the age of this animal (1.5 years) is in agreement with those ages of sexually active males reported previously. We did not see the long-distance dispersion patterns of young bobcats suggested by Bailey (1974), but this lack of a pattern could result from the relatively small population and the availability of suitable unoccupied habitat in the vicinity of existing adult territories in our study area.

The data we have collected on the weights of the bobcats in the wild indicate a seasonal fluctuation in adult males; the heaviest weights were recorded in winter and early spring. The average for the two males was 10.2 kg. The adult females were considerably lighter (7.0 kg) and did not show the same pattern as the males. Juvenile females tended to weigh approximately 4.5 kg after their first year, and the one who reached two years of age weighed 5.1, 5.0, and 5.0 kg, respectively, after the first 6 to 8 months, but they did not increase significantly during the next 6 months (5.2-kg average).

Human activity did not appear to adversely affect the normal routines of bobcats in this study. One animal was captured in a building on the ORNL site, one female consistently used a materials storage area as a daily resting site, and one juvenile female was observed on numerous occasions chasing young ducks around a pond in the middle of the ORNL facility. Timber-harvesting operations usually caused the bobcats to avoid these areas, but the operations did not result in a shift of the bobcats' home range.

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12. TERRESTRIAL ECOLOGY

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Introduction

The Terrestrial Ecology Section is involved in basic and applied environmental research to support energy technology development and in gaining a better understanding of the structure and function of terrestrial ecosystems. The Section is organized around three basic areas of research (ecosystem studies, physiological studies, and environmental analyses); a major emphasis is on evaluating the ecological effects of air pollution on agricultural and natural systems. Staff members are assigned to major division programs and other research divisions at ORNL, and we make use of other division staff members in terrestrial activities. Our basic research program is designed to ensure continued development of expertise in disciplinary areas of terrestrial ecology. We are currently interacting with a number of outside institutions including TVA, a number of universities, sister national laboratories, and the National Park Service (NPS) within the Department of the Interior. Research is supported by DOE (44%), NSF (30%), EPRI (14%), and EPA (12%). Activities also include subcontracting approximately 15% of our total research budget to universities. In the following paragraphs, we highlight recent activities in bioclimatology, forest ecology, and atmospheric pollution effects studies.

Research activities in bioclimatology continue to address reconstruction of past climatic changes through pollen analysis and tree-ring studies as a means of providing a sufficient data base from which to evaluate future climate changes and air pollution stress on forest and agricultural systems in the eastern United States. Current projects include (1) evaluation of potential changes in crop production regions as a function of atmospheric CO₂-level-induced climatic warming and (2)

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utilization of tree rings from sensitive forest species in evaluating the impacts of increased air pollutant levels, especially acid precipitation, ozone, and trace elements.

Forest ecology studies are concerned primarily with expanding succession modeling capabilities and evaluating the impacts of management practices in terms of carbon metabolism and nutrient cycling. Forest-succession modeling currently is concerned with incorporating the fundamentals of nutrient cycling and water relations into our existing models. This added information will assist in comparing forest stands in different regions and in extending our modeling capabilities to include simulation of tropical forest growth and development. Experimental studies have been concerned with changes in the oxidation rate of soil carbon as a function of different harvesting techniques. These studies are designed to provide data input into our global carbon-cycling program.

Air pollution studies continue as a major activity of the terrestrial section with emphasis on oxides of sulfur, ozone, trace elements, and acidic precipitation. Because of our ongoing activities, we are currently assisting the NPS in evaluating several air pollution issues in the Acadia, Buffalo Creek, and Great Smoky Mountains national parks. We have also completed a field exclusion facility during the past year that will be used to evaluate the effects of controlled levels of acidic precipitation by selectively omitting wet and dry components of atmospheric deposition. These studies will complement ongoing activities in which the effects of simulated gaseous and particulate pollutant levels on agricultural and forest species are studied in laboratory environments.

Effects of Changing Climate on Crop Production Regions

T. J. Blasing

The ability to project biological responses to climatic change is partially dependent on the way in which the climatic change is described. Average annual temperature for the Northern Hemisphere, for example, is of little use in projecting the corresponding heat and moisture stresses on Iowa corn. Although climatologists need to summarize their work in terms of interest to other climatologists, there is also a recognized need to summarize their observed data and model output such that it will be most useful to researchers who project effects of climatic change on such things as agriculture and human health. Generation of such relevant climatic summaries can be facilitated if the users of the climatic summaries can first specify their needs. Research this year is designed to identify, characterize, and define ways of analyzing climatic data and model output to reduce or more explicitly characterize uncertainties in projections of agricultural response to CO₂-induced climatic warming. The focus has been on changes in geographical patterns of crop production, exemplified by the North American corn belt.

Climatic parameters were restricted to those for which extensive and accessible data bases are available and those for which projections can be made from climate models. These constraints appreciably limit the objectives of CO₂-effects assessment, but they are necessary because (1) climatic variability must be objectively calibrated with effects and (2) climate projections beyond the range of measured climatic variability must be modeled.

Under these constraints, heat characteristics can be expressed as growing degree days (defined as the mean daily temperature minus 10°C) accumulated for all days of the year that the mean daily temperature exceeds that value. Moisture is represented as annual or seasonal precipitation values. However, the geographical distribution of precipitation is summarized only in general terms (e.g., averaged over a selected latitude band) in the output of current climate models. Heat and

moisture characteristics most favorable for corn were obtained by plotting degree-day and precipitation data for regions within the corn-belt region of the United States. These data are approximately bounded by the straight lines shown in Fig. 12.1. Those lines do not mark limits to growth of corn, but rather the perceived desirability of a corn crop vs other crops in terms of producing an acceptable and steady income (i.e., where corn is grown as the major crop rather than where corn *can* be grown but is not the major crop). This relative profitability is strongly influenced by climate in some regions and by soil and topography in others. The lines in Fig. 12.1 have been extended to include regions that are not in the Corn Belt (e.g., western Tennessee) but where corn is known to do well if soil and topographical conditions permit.

Fig. 12.1. Heat and moisture characteristics of the North American corn belt. Dots outside the lines correspond to central Wisconsin (dairy), central North Dakota (spring wheat), and west-central Kansas (winter wheat).

Regions with climatic characteristics favorable for corn production can be identified for any projected climate. The more geographically and seasonally specific the climatic projection, the more readily this identification can be made. Therefore, general-circulation models that incorporate realistic geography are most appropriate. Because of limitations of models and climatic data bases, plus current limits in knowledge of direct and indirect biological effects of CO₂ changes, this approach ignores (1) any improvements that may occur in agricultural technology or practice, (2) any increases in water-use efficiency or photosynthesis in plants as a result of CO₂ enrichment (may affect both crops and weeds), and (3) changes in the soil on which the crop is to be grown, which can only be specified after geographic (climatic) limitations have been specified. Changes in consumer preferences, economic conditions, etc., are also not considered.

Implementation of this exercise for a doubling of atmospheric CO_2 , including various modifications to account for supply and importance of summer precipitation, indicates a shift of the Corn Belt to Minnesota, Wisconsin, and barely into Canada; most of Iowa is still included. The inclusion of Illinois, Indiana, and Ohio is less certain. Different assumptions about the timing and importance of summer precipitation produce different conclusions about the relative profitability of growing corn in those states. The assumptions made are all consistent with the output of general-circulation models of climate, which is open to a variety of interpretations.

FORAST—A Regional Study of Forest Growth Responses to Air Pollution Stress

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D. C. West T. J. Blasing
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During the past year, a large collaborative project has been initiated to systematically evaluate forest growth trends and their relationship to air pollution stress in the eastern United States. Principal focus is on the past 50 years of growth, during which regional-scale pollution from acid rain and ozone has increased throughout much of the eastern region. The project entitled FORAST (Forest Responses to Anthropogenic Stress) is sponsored principally by EPA with interagency support by the U.S. Park Service, the USGS, and the State of Ohio. The experimental protocol involves collection and analysis of increment cores from approximately 500 trees at each of 12 research sites. The 12 study sites are shown in Figure 12.2. Overall responsibility for coordination

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Fig. 12.2. The FORAST study involves increment core collection and analysis of growth trends of more than 6000 trees distributed over areas in the eastern United States currently receiving a range of inputs of atmospheric pollutants.

of this effort lies with ORNL and principal responsibility for quality assurance of tree-ring measurement protocol is shared with the Tree Ring Laboratory (USGS) at Reston, Virginia.

The research plan is designed to provide a common format for collecting increment cores from trees on soils of variable quality (acidity, depth, and nutrient exchange capacity) within regions having different current and past histories of exposure to air pollution. At each research site, 15 co-dominant trees (≥ 50 years old) from each of 6 species are being cored in each of 6 forest stands to provide historical growth data. The species list includes some individuals common to as many sites as possible (white oak, white pine, red oak, pitch pine, shortleaf pine, and black cherry) and others that are economically or ecologically significant within each region.

The six stands at each station have been grouped into three pairs, each pair being comprised of one stand located on soil currently considered to have a high potential for acid-rain-mediated effects and the alternate stand being on more calcareous, highly buffered, and nutrient-rich soils. Additional data on stand biomass, stem density, and soil chemistry are being collected to aid in analyzing stand and site quality influences. Analysis of growth trends will depend heavily on statistical programs developed at ORNL and at the University of Arizona Tree Ring Laboratory. These analyses allow isolation of the influences of climate, mean monthly temperature and rainfall, and stand competition based on variations in the ring-width series of individual trees. The occurrence and magnitude of residual variability are then examined in relationship to a variety of direct and indirect indices of past and present air pollution stress.

In its initial two-year study interval, the project goals are to provide a sound basis for determining (1) if there has been a systematic pattern of declining growth of several representative species of eastern forest trees, (2) when it began to occur in different regions, (3) its areal extent, (4) its dependency on soil-nutrient availability, and (5) the degree to which its temporal and spatial characteristics are related to regional levels and changes in air pollution stress. Such information is seen as extremely critical to providing a systematic, experimental basis for designing a variety of second-phase studies aimed at establishing more substantive relationships between the level and nature of observed changes (if and where they occur), tree physiology, soil chemistry, and system-level responses to air pollution stress.

Multielement Analysis of Tree Rings

C. F. Baes III S. B. McLaughlin

Heavy reliance on fossil-fuel combustion for energy since the turn of the century has contributed to significant releases of fly ash and combustion products to the atmosphere. Documentation of pollutant effects on natural ecological systems cannot be effectively accomplished without reference to a historic record of exposure. Because widespread monitoring of atmospheric pollutant deposition has occurred only recently, natural biological monitors or indicators having the potential of reconstructing of long-term pollutant chronologies are needed to reconstruct historic data. Tree rings may prove useful in this regard. If the chemical composition of xylem is indicative of pollutant exposures during the year in which it was formed, xylem rings could serve as natural chronometers of anthropogenic pollution. Work is currently under way to examine concentration profiles of trace elements in tree rings to determine if tree-ring analysis can be used to construct an historical record of exposure or to quantify indirect effects of atmospheric deposition such as increased or decreased availability of nutrients or toxic elements.

In a preliminary survey at Walker Branch Watershed, shortleaf pine, American beech, yellow poplar, red oak, white oak, chestnut oak, bitternut hickory, and pignut hickory were sampled using a 4-mm-increment corer. Ring sections representing the pre-Oak Ridge era (before 1942) pre-Kingston steam plant (KSP) era (1942 to 1954), KSP short stack era (1955 to 1977), and KSP tall stack era (after 1977) were analyzed by inductively coupled plasma-emission spectroscopy. The resulting concentrations on a parts per million dry weight basis for 31 elements were compared among the tree species. Each species was scored to determine whether patterns found for each element were strong, weak, or nonexistent (great to no difference among sections of different ages). On the basis of this screening, red oak and shortleaf pine were selected as the most promising natural monitors of the nearby fly-ash sources—Kingston, Y-12, and Bull Run steam plants.

In a second study, three trees each of red oak and shortleaf pine were sampled near (~ 2.4 km) and far (~ 16 km) downwind of the TVA Kingston coal-fired steam plant. Xylem rings were cut into four-year sections back to 1942 and into ten- or eleven-year sections back to 1921 and analyzed as before. It was found that concentration profiles are replicable, element specific, and tree-species specific. Profiles found for Al, Cr, Cu, Mn, Ti, and Zn may be correlated with stack emissions or may reflect acid-rain mobilization of materials already available from the soil because concentrations generally increase in the late 1950s to early 1960s. However, because of the number and diversity of fly-ash sources in the Oak Ridge area and uncertainty about the role of metabolic processes in determination of concentration profiles, interpretation of the results is still speculative. Nevertheless, the results [e.g., Cu and Zn in shortleaf pine (Fig. 12.3)], indicate a threefold to

Fig. 12.3. Concentrations of copper and zinc in shortleaf pine xylem tissue at 2.4 and 16 km downwind of the TVA Kingston coal-fired steam plant. Values shown are the mean and standard error for three replicates.

fivefold increase in exposure or availability of these elements from 1960 to 1980. No such increase was observed in ring sections from a red spruce tree sampled in the Great Smoky Mountains National Park. Concentrations of these elements are relatively constant from 1890 to the present, except for an increase of about 1.5- to 2-fold during the period 1920 to 1930. These dates correspond to a period of extensive clearing and burning of the Smoky Mountain site, indicating the potential of red spruce tree rings to incorporate historical anthropogenic impacts.

Analysis of the red spruce core showed concentrations of Al, B, Ba, Cd, K, Mg, Mn, P, Sr, and Zn in cambial-zone tissue to be more than an order of magnitude greater than concentrations in the most recent xylem. Notably, Zn concentrations in the most recent xylem tissue of shortleaf pine from the Oak Ridge area are approaching some of the highest values measured in wood. The implication here is that if the same ratio of cambium to recent xylem concentrations holds for Oak Ridge area trees, then cambium concentrations of heavy metals, especially Zn, may far exceed concentrations known to be toxic when found in the foliage of agricultural plants. Work is currently under way to examine cambial-zone and xylem metal concentrations in shortleaf pine growing in acid-sensitive and acid-resistant (alkaline) soils at sites having significantly different levels of dry deposition from fossil-fuel combustion. This study will not only examine the potential of shortleaf pine as a deposition indicator, but also assess the effects of substrate (pH, nutrient availability, etc.) on heavy-metal accumulations.

Forest Succession

D. C. West D. W. Johnson H. H. Shugart

Forest dynamics research continued; a major effort has been toward incorporating additional system-level variables into the stand growth simulators and expanding the modeling capabilities into tropical forest systems. A computer-simulation model of the interaction between successional dynamics and long-term nutrient retention has been constructed for the purpose of comparing the retention characteristics of two southern Appalachian forest stands. Descriptions of mechanisms of competition for light, water, and nutrients included in the model were tested by comparing the 12-year average diameter increment of trees in four stands from different slope positions in the Walker Branch Watershed with model predictions. With only competition for light controlling growth in the model, predictions of diameter increment for lower-slope tulip poplar, mid-slope chestnut oak, upper-slope oak-hickory, and ridge-top pine stands were 0.36, 0.35, 0.33, and 0.39 cm/year, respectively. Including water limitation, predicted rates decreased to 0.32, 0.27, 0.27, and 0.26 cm/year. Addition of nutrient limitations caused rates to decrease to 0.29, 0.20, 0.22, and 0.20 cm/year, respectively, which compare favorably to field measurements of 0.27, 0.19, 0.23, and 0.18 cm/year.

In an assessment of long-term nutrient-retention characteristics in the dry mid-slope forest of the Walker Branch Watershed in the Ridge and Valley Province of eastern Tennessee, losses of Ca from the soil pool during 500 years of simulation were large. In contrast, simulation of the dry mid-slope forest of the Hannah Branch Watershed in the Great Smoky Mountains National Park showed large losses of N and an increase of soil Ca. The differences in species dominance or community structure that developed during the succession of each forest were insufficient to produce the differences between the two forests. The greater cycling rate of the more productive Hannah Branch Watershed stand did not account for the differences. The differences were the result of the accumulated effects of short-term imbalances between uptake and mineralization rates

rather than the result of a chronic characteristic of the nutrient cycles. The balance of mineralization and uptake is dependent on site-specific characteristics varying through time. When tree uptake is similar to mineralization release, nutrients will be tightly held in the system. Losses are the result of releases from the litter layer in excess of quantities taken up by trees. Losses increase when tree uptake is limited by environmental conditions. The large Ca losses in the simulated Walker Branch Watershed could have been caused by low N supplies limiting growth and uptake, whereas the Hannah Branch Watershed N losses could have been caused by Ca limitation. Many mechanisms, such as translocation alteration, tissue concentration alteration, and nitrogen-fixation relationships, were shown to be capable of enhancing the ability of trees to efficiently capture available nutrients and reduce nutrient loss. This study demonstrated the importance of spatial variability from plot to plot as well as the importance of temporal dynamics in assessing the causes of nutrient losses from an entire landscape.

Recently initiated research in the tropics will focus on the long-term effects of human disturbances in the tierra firme forest in San Carlos de Rio Negro Territorio Federal Amazonas, Venezuela. The interpretation of data will be directed toward a better understanding of the nature of forest vegetation recovery after the impact produced by the cut and burn of small areas (i.e., 0.5 to 2.0 ha) followed agricultural use for two or three years. The main emphases of this study are: (1) to describe and analyze biomass, forest structure, and nutrient data from abandoned slash and burn agriculture sites of different ages and mature forest; (2) to predict the time of recovery after human disturbance, determine possible patterns of succession, and estimate changes in biomass, structure, species, composition, carbon content in soils, and nutrients in biomass and soils; and (3) to predict (a) the dynamics of the forest after human disturbance and (b) vegetation changes based upon soil moisture content. These results will be used to formulate a better understanding of how the tierra firme forest of San Carlos de Rio Negro recovers after slash and burn agriculture.

Effects of Forest Management on Soil-Carbon Dynamics

N. T. Edwards B. M. Ross-Todd

The effect of two harvest intensities on soil-carbon dynamics was determined for the first year following harvest of a mixed deciduous forest in Tennessee. Harvest procedures were clear-cutting in which sawlogs were removed (RL) and clear-cutting in which all above-stump woody material (RR) was removed. Trees ranged in age from 50 to 150 years. Soil types are primarily Fullerton and Bodine.

By the end of the first growing season following harvest, herbaceous species, woody seedlings, and stump sprouts appeared to cover the entire harvested area. The stump sprouts and some of the annual herbaceous flora were about 1.5 to 2.0 m in height. Woody seedlings (mostly *Liriodendron tulipifera*) were numerous and were about 30 cm in height. Only a small proportion (<20% by visual observation) of the surface area of woody branches and logs left on the RL watersheds was in direct contact with the leaf litter and soil and, therefore, could be considered as "standing dead" in terms of its interaction with soil decomposers. Mineral soil was exposed in many areas of the RR watersheds throughout the year following harvest even though the litter layer was not intentionally removed. There was no visual evidence of erosion of soil or detritus from any of the watersheds. However, very small areas (>10 m²) within the RR watersheds showed evidence of some soil movement.

There were no significant differences in soil-carbon pools between treated and control watersheds before harvest or at 5 and 17 months after harvest. Total carbon (pre- and post-harvest averages) to a depth of 45 cm was 3426 g/m² in the control watershed, 3318 g/m² in the RR watersheds, and 3168 g/m² in the RL watersheds. Essentially all of the soil carbon was in an organic form. Inorganic carbon averaged only 0.11% at the 0 to 15 cm depth and decreased to 0.04% at 15 to 30 cm and 30 to 45 cm depths.

Annual carbon lost from the forest floor surface to the atmosphere totaled 492, 483, and 529 g/m² in the RR, RL, and control watersheds, respectively. These totals are not significantly different. However, the seasonal patterns of CO₂ efflux did change following harvest. During the winter following harvest, CO₂ efflux from the RR watersheds was significantly ($P > 0.05$) greater than CO₂ efflux from the control watershed. Rates were also greater in the RL vs control watersheds during the winter months, but the differences were small and not statistically significant. These differences were apparently caused by disturbance during harvest because temperatures were somewhat warmer in the control than the harvested watersheds. Carbon dioxide efflux was significantly ($P > 0.05$) greater in the control than the RR watersheds May through August. Control rates were also greater than RL rates during this period, but differences were significant only in June and August. The greater CO₂ efflux rates in the RL vs RR watersheds during the summer months reflect a much dryer and thinner litter layer in the RR watersheds. The greater rates of CO₂ efflux in the control vs the harvested watersheds during the growing season apparently resulted from live-root respiration.

Mineral soil respiration was greater in the harvested vs control watersheds because of elevated soil moisture and temperature in the harvested watersheds during the growing season. Differences in mineral-soil respiration rates between RR and RL watersheds partly resulted from slightly higher soil temperatures in the more exposed RR watersheds, especially near the surface where microbial activity is greatest. However, RR mineral-soil respiration rates were greater than the RL soil even when incubated at the same temperature.

Turnover time of mineral-soil carbon calculated from carbon pools and losses during the first year following harvest is 135 years for the control watershed, 96 years for watersheds in which residue was not removed, and 80 years for watersheds in which residue was removed. The increased mineral-soil respiration rates resulting from harvest were not reflected in the total CO₂ efflux measurements because mineral-soil respiration amounted to only 4.7% of the total in the control watershed and only 8.5 and 6.8% of the total in RR and RL watersheds, respectively.

Air Pollution Studies for the National Park Service

F. G. Taylor	L. L. Sigal	S. B. McLaughlin
R. R. Turner	R. J. Olson	S. G. Hildebrand

Based on ORNL expertise in research on air pollution effects, the NPS entered into an interagency agreement with the ESD to determine the extent to which long-range atmospheric transport and deposition of gaseous and particulate pollutants and acid precipitation affect mandatory Class I prevention of significant deterioration (PSD) areas. The assistance to the NPS consists of six tasks; four are specific to the Great Smoky Mountains National Park, an International Biosphere Reserve, and two are generic (regional) in scope. Some tasks are designed to obtain detailed field data on specific pollutants previously identified and suspected of causing impacts in the Park, whereas others use new disciplines (dendroecology) to determine the influences

of air pollutants and sensitive parameter analyses to rank Class I areas potentially vulnerable to atmospheric pollutants.

Fluoride is of interest in the Park because foliar concentrations determined in a relatively pristine area (Cades Cove) were reported to exceed concentrations in an area having known emission sources. To ascertain whether the park is being affected by F, concentrations are being determined along an elevation gradient (cover, mid-mountain, mountain top) during two seasons (mid-growing season, post-growing season). Analyses of foliage and soils will identify the manner of contamination (atmospheric vs soil uptake) and assist the NPS in assessing the potential risk to park flora from this pollutant.

Similarly, Pb has previously been identified as significantly higher in forest litter than in soils or vegetation of the Park. This suggests that lead from long-range transport and deposition is possibly accumulating to toxic levels in a critical ecosystem component. To determine whether Pb constitutes a direct threat, we are quantifying concentrations spatially (elevation, windward/leeward, slope) among foliage of several tree species and soils from remote areas of the park.

As a long-range indicator of air quality, lichen species are being inventoried within the park to visually assess the vitality of existing species by comparison with historical collections in herbaria and evaluated from presence-absence data to determine if subtle effects are evident from chronic, low-level stresses. Based on species richness and abundance, a system of permanent sampling sites will be proposed to the NPS.

Using dendroecological techniques developed at ORNL, we are assessing the influence of anthropogenic air pollutants on forest growth in several national parks including Acadia, Buffalo Creek, and the Great Smoky Mountains. Cores of several species are being collected and analyzed to determine relative influence of climate, age, and stand competition on tree growth. Unexplained residuals are being evaluated relative to past air quality records for evidence of pollution stress.

Areas within the park system differ in their sensitivity to air pollutants because of differences in ecological, physical, and climatic factors. To assist the NPS in identifying sensitive Class I areas, an index system is being developed for 48 NPS Class I areas. The overall approach utilizes parameter selection (vegetation, soils, endangered species, etc.), ranking areas for each parameter, combining ranks into an overall index, and comparing these to current and projected atmospheric pollutant loadings. Sulfur dioxide and ozone are the pollutants of primary concern, although other pollutants are considered where information and monitoring data are available. The rank index will identify sensitive areas that are currently at risk to impacts from atmospheric pollutants.

As a Federal Land Manager, the NPS is responsible to protect air-quality-related values (i.e., flora and fauna) in mandatory Class I areas against "adverse impacts." The discharge of that responsibility requires a thorough knowledge of "adverse impacts." Unfortunately, the task becomes difficult in that acceptable definitions, based on empirical data and methodologies, are not available. We are assisting the NPS in the definition of adverse impacts by identifying and describing methods of measurements used by ecologists in recognizing adverse atmospheric pollutant effects or responses.

Effects of Simulated Acid Rain on Soybeans

R. J. Norby R. J. Luxmoore

Reliable documentation of the responses of crop plants to acid rain is a critical component needed for assessment of the overall impacts of acid deposition. The best approach for determining

the effects of ambient levels of acid rain on agricultural productivity is to evaluate the responses of crop plants grown in the field with standard agronomic practices. Such research has been undertaken at ORNL in an EPRI-sponsored project. Identification of mechanisms of plant responses that may be useful for predictive or diagnostic purposes is difficult in the field, so greenhouse/controlled environment studies of simulated acid-rain effects on soybeans were undertaken as a complementary task. By integrating field and greenhouse studies in a single research effort, we can address the question of whether greenhouse experiments that use simulated acid rain adequately predict the responses of plants to acid rain in the field.

It is important to separate the effects and understand the interactions of acid rain and gaseous air pollutants on crop plants. Pollutant stress can affect plant physiological processes such as photosynthesis and carbon allocation and could affect responses of plants to acid rain by altering compensatory growth mechanisms. Stress-induced changes in photosynthesis or other metabolic processes do not necessarily translate into changes in plant productivity. Our approach has thus been to determine how short-term physiological changes integrate into whole-plant response to acid rain and gaseous air pollutants. Methods of classical growth analysis are especially suited to this task.

Soybeans [*Glycine max* (L.) Merr. CV Davis] were grown in a greenhouse in soil from the acid-rain research field site. Plants were exposed periodically over eight weeks to simulated rain of pH 2.6, 3.4, 4.2, or 5.6 on greenhouse rain simulators. One-half of the plants were also exposed to 0.2 ppm SO₂ + 0.1 ppm O₃ in continuously stirred, tank-reactor fumigation chambers for a total of 18 hours over a two-week period prior to harvest. Leaf area and dry weights of leaves, stems, and roots were measured at harvest. From these data several growth functions were calculated. Relative growth rate (RGR) is the rate of increase in dry matter per unit dry matter present. Leaf area ratio (LAR) is the ratio of photosynthetic area to respiring mass. Unit leaf rate (ULR), an approximate measure of photosynthetic efficiency, is the rate of increase in dry matter per unit leaf area. At any instant, these growth functions have the following relationship: $RGR = LAR \times ULR$.

Simulated rain solutions adhered in large droplets primarily to young, unexpanded leaves and along margins and large veins of older leaves. The most acidic (pH 2.6) rain induced severe marginal necrosis, resulting in curling and crinkling of leaves as they continued to expand. Vegetative growth of the soybean plants, especially root growth, was inhibited by the pH 2.6 rain. Simulated rain of higher pH, however, had no effect on growth, and there were no significant effects of the air pollution treatment on responses to acid rain. Growth analysis demonstrated that the reduction in growth caused by the pH 2.6 rain was not a result of an effect on photosynthetic efficiency (ULR) but could be explained by a reduction in the relative amount of photosynthetic area (LAR). LAR was reduced because of the acid-rain-induced deformation of leaves, not because of an alteration in allocation of dry matter to leaves.

There have been reports of individual rain events having a pH as low or lower than 2.6, but it is very unlikely that soybeans in the field would receive repeated exposures to rain of such high acidity. In a second experiment, we concentrated on exposures to simulated rain of pH ≥ 3.4 . Water use of the plants was monitored closely, and nitrogen-fixing root nodules were counted at harvest. The results of this second experiment confirmed the lack of effect of simulated rain of pH ≥ 3.4 on vegetative growth of soybeans. Cumulative water use, a measure that integrated aspects of root size, leaf area, and whole-plant physiology, was remarkably similar among plants treated with different rain simulants. Initiation of nodules was inhibited by the SO₂/O₃ treatment, suggesting a possible

disruption of carbon allocation to root systems, but there was no effect of the rain treatment on nodulation, in accordance with the lack of effect of rain pH on ULR.

The results of these experiments may be useful in identifying key mechanisms to be observed in field evaluations of soybean response to acid rain. Vegetative growth was affected by acid rain only when the pH was sufficiently low to induce physical damage to leaves and loss of photosynthetic area; physiological processes such as photosynthesis apparently were not affected. Assessment of crop losses in the field resulting from acid rain would be much easier if only visible foliar damage need be evaluated. Physical characteristics of leaves that affect aggregation of raindrops, damage to cells, and continued leaf expansion may be the critical factors in determining sensitivity of plants to acid rain.

Within-Canopy Measurement of Gas Exchange: Development of a Chamberless Technique

R. K. McConathy S. B. McLaughlin

Interest in air pollution effects on the environment has led to a widespread attempt to develop methods that will define the physiological bases of plant responses to air pollutants. A major limitation of physiological studies aimed at detecting a response threshold has been the necessity of developing measurement systems that do not disturb normal physiological processes. In addition to visual damage, pollutants can cause a more subtle chronic, nonvisual damage by affecting plant physiological processes that result in reduced growth and plant vigor. Detecting the threshold pollutant concentrations that cause these subtle effects requires the use of special measurement techniques. Measuring plant physiological processes, such as photosynthesis, by gas-exchange methods requires that the plant be enclosed in a chamber that alters the plant's environment and removes it from natural atmospheric variations. We have developed a sampling scheme that does not require the use of plant chambers.

Plant response to air pollutants can be measured by obtaining simultaneous leaf flux measurements of both the pollutants and other gases, such as CO_2 and H_2O , that are indicative of plant physiological status. Changes in photosynthesis and transpiration can then be correlated with concentrations and fluxes of pollutant gases to determine thresholds for physiological response. Our method involves differential measurement of gas concentrations at the leaf-air interface and in the incoming airstream. This *relative* measure of gas-exchange activity compares the *relative* plant behavior in polluted vs nonpolluted atmospheres.

Small Teflon tubes (OD—2 mm, ID—1.5 mm) are attached to the lower leaf surface within the plant canopy to sample the air immediately adjacent to the leaf. Gas concentrations in this air layer change because of photosynthesis, transpiration, and adsorption or absorption of pollutant gases by the leaf. Ten tubes are placed in the canopy, and the individual air streams are combined in a manifold (Fig. 12.4) before differential analysis using an air sample from outside the canopy. When used with open-top field chambers, up to 12 manifold samples are collected with a timer-controlled solenoid system to sequentially switch samples. Each sample is simultaneously measured CO_2 , H_2O , SO_2 , and NO_2 , and the resulting values are collected by a data-logger system.

The system has been tested both in the greenhouse and in the field. In the greenhouse, one manifold was used in a soybean [*Glycine max* (C. V. Davis)] canopy where photosynthetic activity was monitored. The photosynthesis data showed good sensitivity to changing radiation level (below light saturation), noise levels that could be handled by a data-logger, and easily measured responses

ORNL-PHOTO 4082-82

Fig. 12.4. Inside an open-top chamber, Teflon sample lines attached to the undersurface of bean leaves feed to a common manifold where the sample streams are mixed.

even with disturbance by wind movement across the canopy (100 to 400 cm sec^{-1}). Changes in relative photosynthetic rate occurred within approximately one minute of significant changes in radiation levels.

Field measurements on tulip poplar (*Liriodendron tulipifera* L.) in open-top chambers (charcoal-filtered and nonfiltered) and open plots were obtained to test the usefulness of the system for field applications. One day's data is illustrated in Fig. 12.5. Variability in the data was highest for the open plot where extremes in wind velocity were greater than inside the open-top chambers. Measurements of CO_2 at the leaf surface showed the transition from respiration at night to photosynthetic uptake in daylight, which corresponded well to changing ambient light levels. During the day, filtered-chamber CO_2 differential was higher than in the unfiltered chamber, possibly showing depressed photosynthesis by ambient air pollution. Ozone levels collected by the manifold/tube system were lower than ambient reference values, indicating an ozone gradient produced by ozone uptake at the lower leaf surface. The ozone level in the filtered chamber was about two-thirds that of the nonfiltered chamber.

This technique will provide a much-improved basis for measuring gas exchange of vegetation under a variety of field and laboratory conditions. Because it requires no expensive photosynthetic

Fig. 12.5. Tulip poplar seedling data for September 18, 1982. Seedlings were growing in open-top chambers (charcoal-filtered and nonfiltered) or in the open (no chamber). Air samples were collected by teflon tubes attached to the lower leaf surface, and a reference sample was collected adjacent to the plots.

chamber, the technique will make measurements of gas exchange easier, less expensive, and more realistic. The preliminary testing showed the system provides usable measurements under rigorous field conditions. The technique is being used to obtain simultaneous measurement of photosynthesis, transpiration, and pollutant uptake for plants growing in open-top field chambers.

Acidic Deposition Effects on Agricultural Crops: Interactions Between Gaseous Pollutants and Acid Rain in the Field

D. S. Shriner	S. B. McLaughlin
J. W. Johnston	R. K. McConathy

During the 1982 growing season, development of a field facility for studying the effects of acid precipitation on crops was completed for research sponsored by EPRI on the ORNL Reservation. The primary objective of studies conducted with this facility is to evaluate the impact, in terms of economic crop-yield, of acid precipitation alone and in combination with gaseous pollutants of significance in the region.

The development of this facility represents the first major attempt to separate the relative importance of wet deposition (as acid rain) from dry deposition (as gases) of pollutants in the response of crop vegetation to ambient pollution levels. The methodology combines aspects of gaseous pollutant exclusion established as a part of EPA's National Crop Loss Assessment Program with simultaneous rainfall exclusion and simulation techniques. In so doing, crop growth and yield can be compared across a range of wet and dry pollutant-deposition rates, and the main and interactive pollutant effects can be determined.

Gaseous pollutant exclusion is accomplished through the use of 3-m-diam open-topped chambers. By forcing either ambient (polluted) air or charcoal-filtered air through the bottom of these chambers and out the open top, the vegetation canopy can be selectively exposed to "clean" air. Such exposure serves as a base from which to estimate growth and yield changes. A weakness of previous applications of this method has been its inability to account for microclimatic differences between chamber-grown and open-field-grown vegetation response. Through the use of automated sampling systems, the relationships among chamber-induced variations in light, temperature, and humidity and plant physiological response and pollutant dose will be determined.

A system of rainfall exclusion covers has been superimposed upon the open-top chambers to provide exclusion of ambient ($\sim$ pH 4.2) rainfall (Fig. 12.6). Beneath these covers, rainfall ranging

ORNL-PHOTO 4034-82

Fig. 12.6. Aerial view of field facility for study of the interactive effects of wet and dry deposition of pollutants on crop vegetation. Note cylindrical open-top chambers and square rainfall exclusion covers.

from pH 3 to pH 5.6 is simulated to develop a dose-response to hydrogen, sulfate, and nitrate concentrations typical of "acid rain." The field experiment, therefore, includes twelve treatment combinations of gaseous pollutants and acidic precipitation in a completely randomized block design using three replicate blocks.

Crops grown for this experiment currently include winter wheat and soybean. The crops are managed under standard agricultural practice, and economic yield and quality are parameters of primary interest. Results from these experiments will provide quantitative estimates of the relative importance of wet vs dry deposition of pollutants to the net response of crop vegetation to air pollution burdens in the field.

PART III. EXTRAMURAL ACTIVITIES

13. EDUCATIONAL ACTIVITIES

Environmental Sciences Division (ESD) Seminar Program

During the past year, the seminar committee offered a diverse program of guest lectures to inform ESD staff and other interested members of the local scientific community about topics of general interest in environmental sciences (Table 13.1). The seminar series relies largely on suggestions from ESD staff members concerning the selection of outstanding speakers, an arrangement that was very successful in the past year.

Table 13.1. Environmental Sciences Division invited speakers:
October 1, 1981–September 30, 1982

Date	Speaker	Title
11/2/81	Dr. Chris Cronan University of Maine Orono	Black box biogeochemistry: internal processing of acid rain in forested watersheds
11/17/81	Dr. Ellis Cowling North Carolina State University Raleigh	Management of acid rain in North America
12/18/81	Dr. James Grace University of Arkansas Fayetteville	Niche differentiation and competitive displacement in cattails (<i>Typha</i>)
2/2/82	Dr. Christine Stevens Harwell Laboratory Harwell, England	A programmatic approach to waste disposal
3/18/82	Dr. Robert Ulanowicz University of Maryland Colomons	Pattern development in naturally organizing systems
3/29/82	Dr. Eshel Aresler Ministry of Agriculture Israel	Modeling of water flow and solute transport in unsaturated heterogeneous soil
4/20/82	Dr. John Newton U.S. Geological Survey Tuscaloosa, Alabama	The role of water in natural and man-related subsidence in carbonate terrains
4/26/82	Dr. William Bowers Cornell University Geneva, New York	Biorational strategies for insect control
4/27/82	Dr. Wallace Broecker Lamont-Doherty Geological Observatory Palisades, New York	Preanthropogenic CO ₂ and ocean chemistry
4/29/82	Dr. William Reiners Dartmouth College Hanover, New Hampshire	Chemical control of nitrification in subalpine hemlock forests

Table 13.1 (continued)

Date	Speaker	Title
5/3/82	Dr. Larry Paulson University of Nevada Las Vegas	Lake Mead-Lake Powell interactions: effects of an upstream impoundment on the biological productivity of a reservoir downstream
5/28/82	Dr. J. B. Dixon Texas A&M University College Station	Mineralogical aspects of acid sulfate weathering
6/17/82	Dr. Anders Björkström University of Stockholm Sweden	Modeling the uptake of fossil fuel CO ₂ by the world oceans
6/23/82	Dr. Jennifer Kitchell University of Wisconsin Madison	Coevolution in a predator-prey system
6/24/82	Dr. John Ryan Savannah River Laboratory Aiken, South Carolina	Chemical factors in radionuclide migration from shallow land burial sites
7/13/82	Dr. Barry C. Batzing State University of New York Cortland	Studies on the natural occurrence of Legionnaire's Disease Bacteria
7/14/82	Dr. Karl K. Turekian Yale University New Haven, Connecticut	In situ determinations of retardation factors in aquifers using natural radionuclides
7/15/82	Dr. John L. Gallagher University of Delaware Lewes	The role of halophytes in natural and managed ecosystems
8/4/82	Dr. Timothy Allen University of Wisconsin Madison	Hierarchy theory: an approach to diversity, stability, and connectedness

Graduate Education Program

The ESD provides opportunities for graduate and postdoctoral research consistent with the mission of ORNL. During this reporting period, 16 graduate students were supported through a contract with The University of Tennessee Graduate Program in Ecology and one each through contracts with Indiana University; Miami University, Oxford, Ohio; and the University of Oklahoma. Each supported student receives stipends administered by the student's respective university, and his or her research is guided by selected ESD staff members, one of whom serves on the respective student's university academic guidance committee. In addition, research done by students not requiring ESD support was accommodated on a more limited basis.

During this past year, periodic meetings were held involving all the graduate students and the ESD's graduate education coordinator. The purpose of the meetings was to explain ESD programs to new students and to provide a forum for comments and suggestions relating to the graduate program.

Undergraduate Education Program

Several programs for undergraduate student participation in ESD research and assessment projects provide a continuing opportunity for interaction between students and staff. A summary of these programs is provided in Table 13.2.

**Table 13.2. Number of students in
ESD under-graduate programs,
October 1, 1981-September 30, 1982**

Program	Number
Oak Ridge Associated Universities	4
Southern College and University Union	1
Emory University	3
Great Lakes College Association	4
Ferrum College	1
University of Wisconsin-Stevens Point	4

Students involved in these programs are assigned to individual ESD advisors who guide the students through an experiment or project associated with one of the ESD programs. Each student is required to document results in a report and present a seminar to the ESD staff. These experiences in research participation are designed to expose the student to the research process in a large laboratory. The greatest benefits to students are frequently an expanded outlook on career opportunities in research and an understanding of practical approaches to research problems.

14. ENVIRONMENTAL SCIENCES DIVISION RESEARCH AND DEVELOPMENT SUBCONTRACTS AND INTERAGENCY AGREEMENTS

Title of subcontract/interagency agreement	Subcontractor	Division technical contact
Assist with the determination of differences in nitrogen uptake of fungus-infected and noninfected tree species	A & L Agricultural Laboratory, Inc.	D. C. West
Wood for energy in the Taiga—evaluation of potential species and their growth rates	Alaska, University of	J. H. Cushman
Preparation of a Manual of Engineering Practice for the manual series of the American Society of Civil Engineers	American Society of Civil Engineers	C. C. Coutant
Verification of predator scales to determine their age and monthly growth	Aquatic Consultants, Inc.	G. F. Cada
Assist in the development of a national operational plan for acid precipitation effects research	Argonne National Laboratory	D. S. Shriner
Evaluation of woody plant species for biomass production potential in the semiarid southeastern United States	Arizona, University of	R. I. Van Hook
Research to determine accurately the ^{13}C : ^{12}C isotopic ratio in atmospheric CO_2 over the past 150 years by analyzing the corresponding isotopic record in tree rings by removal of climatic interferences	Arizona, University of	J. R. Trabalka
Research to determine the nature, character, and extent of understory vegetation within uneven-aged pine and pine-hardwood southern forests and the effects of periodic harvests of such understory vegetation on site quality	Arkansas, University of	J. W. Ranney
Provide engineering process descriptions for conventional full alcohol plants in the size range of 15 to 150 million gal/year for use in assessing the environmental, health, and safety issues of such plants	Battelle Columbus Laboratories	J. F. McBrayer
Evaluation and technical review of the Alternate Fuels Programmatic Environmental Impact Statement	Battelle Memorial Institute	R. M. Reed
Assist in developing a national operational plan for acid precipitation effects research	Battelle Pacific Northwest Laboratories	D. S. Shriner
Fuels and chemicals from Woody Biomass Program	Bioenergy Development Corporation	R. I. Van Hook
Evaluation of the availability of land for silvicultural energy farms in the western lake states	Biosystems Corporation	R. I. Van Hook
Assist in developing a national operational plan for acid precipitation effects research	Brookhaven National Laboratory	D. S. Shriner

**14. ENVIRONMENTAL SCIENCES DIVISION RESEARCH AND DEVELOPMENT
SUBCONTRACTS AND INTERAGENCY AGREEMENTS**

Title of subcontract/interagency agreement	Subcontractor	Division technical contact
Assistance in developing the preliminary relationships between remote sensing-derived surface classes and stored organic carbon in the soil	California, University of	R. I. Van Hook
Production of woody biofuels from mesquite	Ceasar Kleberg Wildlife Research Institute	R. I. Van Hook
Assist in the study to make a broad comparison of acid rain vs natural acid production and harvesting on forest nutrient status	Clemson University	D. W. Johnson
Ecosystem effects of whole-tree harvesting	Clemson University	D. C. West
Involvement with the National Atmospheric Deposition Program that requires sample analysis by a central analytical laboratory for comparability of data on atmospheric deposition on a national scale	Colorado State University	S. E. Lindberg
Toxicological and chemical characterization of the water-soluble fraction of three oils will be studied. Tests to be short-term lethality studies with chemical characterization and fractionation determined by initial biological responses	Colorado State University	C. W. Gehrs
Analyze chlorinated hydrocarbons (PCBs, DDT, DDE, DDD, and chlordane) in samples selected from Hudson River and Raritan Bay sediment	Columbia University	C. R. Olsen
Development of mathematical models of carbon turnover in the world oceans, which requires a major effort in data evaluation and compilation	Columbia University	W. R. Emanuel
Assist in the development of a regional effects of air pollution on forest dynamics	Cornell University	S. B. McLaughlin
Complete a literature survey and experimental work designed to define the role of carbonate formation in arid-zone soils in the global carbon cycle	Duke University	J. R. Trabalka
Provide technical and analytical assistance to the U.S. Department of Energy's (DOE's) Short-Rotation Woody Crops Program	J. E. Dunwoody	J. H. Cushman
Supply materials, perform research, and consult and advise on various aspects of the Legionnaire's Disease Bacterium project	Ecological Microbes Unlimited	S. W. Christensen
Assist in preparing a document on Standardization of Remedial Action Activities Related to the Uranium Mill Tailings Remedial Action Plan	Evaluation Research Corporation	L. D. Eyman
Assist in preparing a handbook on shallow land burial for the DOE Low-Level Waste Management Program (LLWMP), which is to assist in locating and operating new facilities, and, as such, represents a "how-to-do-it" document	Evaluation Research Corporation	W. J. Boegly, Jr.
Prepare a report on Remedial Actions in Shallow Land Burial Sites	Evaluation Research Corporation	N. H. Cutshall

14. ENVIRONMENTAL SCIENCES DIVISION RESEARCH AND DEVELOPMENT SUBCONTRACTS AND INTERAGENCY AGREEMENTS

Title of subcontract/interagency agreement	Subcontractor	Division technical contact
To prepare a revised draft Corrective Measures Handbook based on the current draft Corrective Measures Manual	Evaluation Research Corporation	R. B. Fitts
Provide support for planning, conduct, and documentation of the Third Annual Information Meeting of the DOE LLWMP	Evaluation Research Corporation	R. B. Fitts
Provide technical services to the Environmental Sciences Division (ESD) on the conduct of the DOE Low-Level Waste Management Annual Information Meeting	Evaluation Research Corporation	L.E. Stratton
Revise the draft document titled "Experience in Applying Remedial Action of Shallow Land Burial Facilities"	Evaluation Research Corporation	L. E. Stratton
Ecosystem effects of whole-tree harvesting: Florida Coastal Plain Flatwoods	Florida, University of	D. C. West
Energy and chemicals from woody species in Florida	Florida, University of	R. I. Van Hook
Provide input to the project on the role of managed forests in the global carbon cycle and to include collection and assembly of basic data and development and testing of mathematical models for carbon cycling in managed forests	Florida, University of	R. I. Van Hook
Assist in designing monitoring strategy for waste disposal sites at Oak Ridge and demonstrate advanced technology applications for the DOE LLWMP	Geo Centers	N. H. Cutshall
Studies to increase the biomass production of short-rotation coppice forest	Georgia Research Institute, University of	J. H. Cushman
Material spiraling in stream ecosystems: feasibility of manipulating natural streams using pesticides	Georgia, University of	W. Van Winkle
Obtain chemical analyses for soil and plant tissue samples	Georgia, University of	D. C. West
Provide the existing hydrologic records for the Whitehall Watershed to be reduced to computer input format for an eight-year period of record	Georgia, University of	D. D. Huff
Prepare a set of technology-specific environmental guidance documents for synfuels	Georgia Institute of Technology	R. M. Reed
Assistance to the Environmental Impacts Program in preparing two guidance documents being submitted to DOE	Gilbert Associates	R. M. Reed
To develop a recommended soil bedrock sampling program for solid waste storage areas	Henningson, Durham, and Richardson, Inc.	R. B. Fitts

**14. ENVIRONMENTAL SCIENCES DIVISION RESEARCH AND DEVELOPMENT
SUBCONTRACTS AND INTERAGENCY AGREEMENTS**

Title of subcontract/interagency agreement	Subcontractor	Division technical contact
Cultural and management practices for the Chinese tallow tree as a biomass fuel source	Houston, University of	R. I. Van Hook
Provide access to the CDC Cyber 175 computer at the University of Illinois and the Habitat Simulation System	Illinois, University of	M. J. Sale
Species spacing and management alternatives for short-rotation woody biomass production	Illinois, University of	R. I. Van Hook
Cooperation between Indiana University School of Public and Environmental Affairs and Oak Ridge National Laboratory (ORNL) on environmental sciences research and education programs	Indiana University	S. G. Hildebrand
Studies on the mobility of organic molecules in ground water	Indiana University	N. H. Cutshall
Program integration for the DOE Ecological Program in coal synthetic fuels	International Research and Technology Corp.	C. W. Gehrs
Furnish the necessary labor and materials and install the necessary equipment to perform drilling services to ORNL	Joy Machinery Company	C. S. Haase
Determination of the best species and management techniques for short-rotation production of fuel wood in the Great Plains	Kansas State University	J. W. Ranney
Aquatic toxicity tests on organic contaminants originating from coal conversion	Kentucky, University of	R. E. Millemann
Assemble and evaluate oceanographic data in support of ocean model development	Lamont-Doherty Geological Observatory, Columbia University	W. R. Emanuel
Research designed to identify and quantify principal sources and sinks of atmospheric CO ₂ on a global scale	Lamont-Doherty Geological Observatory, Columbia University	J. R. Trabaika
Sedimentation and contaminant distribution in the Hudson-Raritan estuary	Lamont-Doherty Geological Observatory, Columbia University	N. H. Cutshall
Computer-based data base in support of biomass programs as part of the larger DOE/Advanced Conservation Technology (ACT) Information System at Lawrence Livermore National Laboratory	Lawrence Livermore National Laboratory	R. I. Van Hook
Consistent description and energy balance studies for specific biomass conversion technologies	Los Alamos National Laboratory	J. H. Cushman
Description of the status and well-being of the Ohio River fish community to provide a background against the impacts of site-specific projects that can be assessed by regulatory agencies	Louisville, University of	S. M. Adams
Computer analysis of biomass harvesting model	Methtech, Inc.	R. I. Van Hook
Internship program	Miami University	S. I. Auerbach

**14. ENVIRONMENTAL SCIENCES DIVISION RESEARCH AND DEVELOPMENT
SUBCONTRACTS AND INTERAGENCY AGREEMENTS**

Title of subcontract/interagency agreement	Subcontractor	Division technical contact
A comprehensive range-wide collection of tag older seed sources	Michigan State University	R. I. Van Hook
Tree species and management strategies for biomass production in the Great Lakes states	Michigan State University	R. I. Van Hook
Application of sugar maple and black locust to the biomass/energy plantation concept	Michigan Technological University	R. I. Van Hook
Air quality monitoring and studies relative to coal gasification plant and biomedical effects	Minnesota, University of	G. W. Suter
Use of wetlands for production of woody plants for fuels and petrochemical substitutes	Minnesota, University of	R. I. Van Hook
Economic methodology for the determination of woody biomass product prices	Mittlehauser Corporation	R. I. Van Hook
Review experience to date of construction and operation of farm-scale anaerobic digesters for methane production and prepare a manual to guide the agricultural industry in developing on-farm systems	Mittlehauser Corporation	J. F. McBrayer
Quantify genetic variation in biomass yields and disease resistance for sycamore and identify superior seed sources and parent trees	Mississippi Agricultural and Forestry Station	R. I. Van Hook
Collaborative research on Legionnaire's Disease Bacterium in power-plant cooling waters	New York, State of	C. W. Christensen
Species selection and silvicultural systems for producing fuels from woody biomass in the southeastern United States	North Carolina State University	R. I. Van Hook
The influence of NO ₂ , SO ₂ , and O ₃ combined at three concentrations on the growth of several plant species	North Carolina State University	D. S. Shriner
Analyze the relationships between airborne fraction mathematical models of the global carbon cycle and measurements of atmospheric CO ₂ concentration	Oklahoma, University of	J. R. Trabalka
Provide program component descriptors for specific research objectives determined through national laboratory joint planning meetings	Pacific Northwest Laboratory	D. S. Shriner
Evaluation of woody biomass production on a commercial-scale basis	Packaging Corporation of America	R. I. Van Hook
Evaluate responses of acid deposition in natural systems	Pennsylvania State University	S. B. McLaughlin
Evaluate effects of municipal wastewater irrigation on biomass production in hybrid-poplar energy plantation	Pennsylvania State University	J. H. Cushman
Evaluation, on paper, of the economic efficiency of wood-energy plantations and delineation of needed further research to evaluate properly and accurately wood-energy plantations	Pennsylvania State University	J. W. Ranney

**14. ENVIRONMENTAL SCIENCES DIVISION RESEARCH AND DEVELOPMENT
SUBCONTRACTS AND INTERAGENCY AGREEMENTS**

Title of subcontract/interagency agreement	Subcontractor	Division technical contact
Legionnaire's Disease Bacterium in power-plant cooling waters	Savannah River Laboratory	S. W. Christensen
Collect, validate, and analyze data on woody biomass plant growth models in use in the United States	Science Applications, Inc.	J. H. Cushman
Perform a survey and preliminary assessment of modeling and monitoring techniques associated with radionuclide containment/release from the burial of low-level waste	Science Applications, Inc.	R. S. Lowrie
Provide control of incoming analysis (status of sample analysis and detection of errors) as well as available access to existing data and associated statistical analysis	Science Applications, Inc.	C. W. Francis
Provide word-processing and editorial support for preparation proceedings	Science Applications, Inc.	J. F. McBrayer
Site-specific environmental data acquisition and review for small hydroelectric demonstration sites	Science Applications, Inc.	S. G. Hildebrand
Terrestrial and aquatic ecology support for Fossil Energy Environmental Project	Science Applications, Inc.	S. G. Hildebrand
The role of terrestrial ecosystems in the global carbon cycle and the effects of climate change on carbon amounts and distribution	Southern Illinois University	R. I. Van Hook
A cooperative venture between ORNL's ESD and The University of Tennessee Graduate Program in Ecology	Tennessee, The University of	R. E. Millemann
A cooperative venture between ORNL's ESD and The University of Tennessee Graduate Program in Geological Sciences	Tennessee, The University of	T. Tamura
Assess the presence of wood rot fungi among timbers of the Oak Ridge Gaseous Diffusion Plant Cooling Towers	Tennessee, The University of	F. G. Taylor
Automated biomonitoring applications to remote water-quality stations and satellite data retrieval	Tennessee, The University of	W. Van Winkle
Field collection of data and sediments from lakes and ponds in Tennessee adjacent to Kentucky	Tennessee, The University of	A. M. Solomon
Impact of coal-conversion and shale contaminants on the microbial activity of aquatic sediments	Tennessee, The University of	C. W. Gehrs
Model morphological characteristics of impoundments using surface area and slopes of reservoir bottom configurations as variables	Tennessee, The University of	S. G. Hildebrand
Survey of cooling towers within the Oak Ridge Operations for presence of the Legionnaire's Disease Bacterium	Tennessee, The University of	R. L. Tyndall

**14. ENVIRONMENTAL SCIENCES DIVISION RESEARCH AND DEVELOPMENT
SUBCONTRACTS AND INTERAGENCY AGREEMENTS**

Title of subcontract/interagency agreement	Subcontractor	Division technical contact
Extending systems analysis in ecology	Texas, University of	R. I. Van Hook
Identify and evaluate rangeland shrubs for biomass production	Utah State University	J. H. Cushman
Environmental consequences of the disposal of coal-conversion solid waste	Vanderbilt University	W. J. Boegly
Evaluation of wastewater treatment models for their suitability for use by the U.S. Environmental Protection Agency (EPA) in assessing the fate of organic chemicals in the environment and their risks to human and nonhuman populations	Vanderbilt University	C. C. Coutant
Production of biomass on abandoned farmlands in the Northeast	Vermont, University of	R. I. Van Hook
Analysis of the impact of air pollutants emitted from a coal degasifier on native and planted forest vegetation	Virginia Polytechnic Institute and State University	D. S. Shriner
Conduct a series of experiments to determine the density and fall velocity of particulate organic matter from stream ecosystems and the effects of increased discharge on POM erosion and transport	Virginia Polytechnic Institute and State University	J. W. Elwood
Materials spiraling in stream ecosystems: effects of physical, chemical, and biological factors on organic matter spiraling	Virginia Polytechnic Institute and State University	R. I. Van Hook
Modeling area biomass dynamics of terrestrial forest ecosystems at the subcontinental scale	Virginia Polytechnic Institute and State University	R. I. Van Hook
Environmental research for small hydroelectric technology	Washington, University of	S. G. Hildebrand
Evaluation of the effect of atmospheric sulfur deposition on the nutrient status of soil and plants from two forested ecosystems in western Washington	Washington, University of	D. W. Johnson
Impact of whole-tree harvesting and residue removal on productivity and nutrient loss from selective soils of the Pacific Northwest	Washington, University of	D. C. West
Review of existing data on three heavy metals (zinc, cadmium, and mercury) in New York Bight and development of a comprehensive picture of their transport and cycling among waters and sediments of the Bight	Wesleyan University	N. H. Cutshall
Supply 12 pregnant goats	Winrock International	E. A. Bondietti
Develop new theoretical tools in ecology	Wisconsin, University of	R. V. O'Neill
Evaluate responses of acid deposition in natural systems	Yale University	S. B. McLaughlin

PART IV. PUBLICATIONS, PRESENTATIONS, THESES, AND PROFESSIONAL ACTIVITIES

1. PUBLICATIONS

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Presentations

Adams, S. M.

"Predator-prey dynamics in southeastern reservoirs," Annual Meeting of the Great Plains Limnological Society, Ames, Iowa, October 1981.

"Energy partitioning in largemouth bass under conditions of fluctuating prey availability," Annual Meeting, American Fisheries Society, Hilton Head Island, South Carolina, September 1982.

Auerbach, S. I.

"Overview of North/South American radioecology research programs," International Union of Radioecologists Workshop, Brussels, Belgium, March 1982.

Barnthouse, L. W., D. L. DeAngelis, R. H. Gardner, R. V. O'Neill, C. D. Powers, G. W. Suter II, and D. S. Vaughan

"Assessing environmental risks of synthetic fuels technologies," 2d Annual Meeting of the Society for Environmental Toxicology and Chemistry, Arlington, Virginia, November 1981.

Barnthouse, L. W.

"Population biology in the courtroom," Annual Meeting, American Fisheries Society, Hilton Head Island, South Carolina, September 1982.

"Integrative field testing," Advanced Fossil Energy Program Review, November 1981.

Bartell, S. M., R. H. Gardner, R. V. O'Neill, and J. M. Giddings

"Simulation of fate and effects of synthetic fuel toxicants in experimental ponds," Second Annual Meeting of The Society of Environmental Toxicology and Chemistry, Arlington, Virginia, November 1981.

Bartell, S. M., R. V. O'Neill, and R. H. Gardner

"Aquatic ecosystem models for risk assessment," Third International Conference on State-of-the-Art in Ecological Modeling, Colorado State University, Fort Collins, Colorado, May 1982.

Blasing, T. J.

"Statistics and climate," Workshop on Forest Responses to Anthropogenic Stress (FORAST), Blacksburg, Virginia, March 1982.

"Dendrochronology," Environmental Protection Agency Meeting on Reconstructing Pollution Histories, Washington, D.C., April 1982.

"Climatic change and agriculture," Workshop on Indirect Carbon Dioxide Effects, Richland, Washington, August 1982.

Blasing, T. J., and D. N. DuVick

"Statistical procedures in exploratory dendroclimatological studies," Annual Meeting of the American Institute of Biological Sciences, State College, Pennsylvania, August 1982.

"Dendroclimatology in the corn belt," Annual Meeting of the American Institute of Biological Sciences, State College, Pennsylvania, August 1982.

Blaylock, B. G.

"Radionuclide cycling in aquatic ecosystems," Swedish Powers Industries Organizations (CDL), Stockholm, Sweden, June 1982.

"Radionuclide cycling of ^{95}Nb in aquatic systems," Studsvik Energiteknik, AB, Nykoping, Sweden, June 1982.

Breck, J. E.

"Physiological pharmacokinetic models for bioaccumulation of contaminants in fish, with an example of PCBs in rainbow trout," Second Annual Meeting of the Society of Environmental Toxicology and Chemistry, Arlington, Virginia, November 1981.

"Suboptimal foraging strategies for a patchy environment: A comparison of capture rate maximization and risk minimization," Meeting of the Animal Behavior Society, Dallas, Texas, December 1981.

Breck, J. E., and S. M. Adams

"Influence of stochastic variation in daily ration on predator growth: application of a bioenergetics model," 112th Annual Meeting, American Fisheries Society, Hilton Head Island, South Carolina, September 1982.

Christensen, S. W., J. A. Solomon, R. L. Tyndall, S. B. Gough, and C. B. Fliermans

"Legionnaires' disease bacterium in power plant cooling systems: Phase II research plan," Electric Power Research Institute, Legionnaires' Disease Project Advisory Committee, Atlanta, Georgia, March 1982.

Christensen, S. W., C. P. Goodyear, and B. L. Kirk

"An analysis of the validity of the utilities' stock-recruitment curve-fitting exercise," 112th Annual Meeting, American Fisheries Society, Hilton Head Island, South Carolina, September 1982.

Christensen, S. W., and C. P. Goodyear

"Are Maryland striped bass declining because of fishing?" 112th Annual Meeting, American Fisheries Society, Hilton Head Island, South Carolina, September 1982.

Contant, C. C.

"The thermal niche of striped bass," Seminar, Tennessee Technological University, Cookeville, Tennessee, November 1981.

"Environmental problems related to energy," Seminar, Oak Ridge High School, Oak Ridge, Tennessee, 1981.

"Thermal niche analysis for estimating toxicant exposure of fishes," (paper) Annual Meeting, Society for Environmental Toxicology and Chemistry, Washington, D.C., November 1981.

"Energy and ecology," Seminar, Greenville High School, Greenville, Tennessee, April 1982.

"Stream ecology," 1-day course for elementary school students, Tremont Environmental Education Center, Great Smoky Mountains National Park, Tennessee, June 1982.

"Remote biotelemetry applications in fisheries research," Seminar, Tech Aqua Biological Station, Smithville, Tennessee, July 1982.

"Striped bass, temperature and eutrophication: A speculative hypothesis for environmental risk," Symposium paper, Annual Meeting, American Fisheries Society, Hilton Head Island, South Carolina, September 1982.

Cushman, R. M., and D. K. Brown

"Composition and toxicity of solid waste leachates from industrial coal gasifiers," Fourth Miami International Conference on Alternative Energy Sources, Miami Beach, Florida, December 1981.

Cutshall, N. H.

"Humid site stabilization and closure," DOE Low Level Waste Annual Information Meeting, New Orleans, Louisiana, November 1982.

"Radionuclides in sediments as markers for environmental pollutants," ORAU Traveling Lecture, University of North Carolina, Chapel Hill, February 1982.

"ORNL low level waste program," DOE Low Level Waste Review Committee Meeting, Orlando, Florida, March 1982.

"Shallow land burial technology—humid," DOE Low Level Waste Program Information Meeting, Denver, Colorado, September 1982.

"Geological and hydrological aspects of low level radioactive waste site management," International Conference on Radioactive Waste Management, Winnipeg, Canada, September 1982.

"Problems in shallow land burial in humid environments," DOE Low Level Waste Review Committee Meeting, Minneapolis, Minnesota, September 1982.

Davis, E. C.

"Environment and solid wastes, characterization treatment and disposal," Department of Civil and Environmental Engineering, Vanderbilt University, Nashville, Tennessee, November 1981.

Davis, E. C., D. M. DeMarini, C. W. Gehrs, and J. L. Epler

"Biohazards of coal conversion residuals," ASCE Annual Meeting, Las Vegas, Nevada, April 1982.

Davis, E. C., M. R. Helton, and D. S. Marshall

"Land treatment of synfuel organic sludges," AIChE Annual Meeting, Cleveland, Ohio, August 1982.

Eddlemon, G. K.

"Ecological hazards assessment of indirect coal liquefaction," Second Annual Meeting of the Society of Environmental Toxicology and Chemistry, Arlington, Virginia, November 1981.

Eddlemon, G. K., and L. L. Sigal

"Ecological hazard assessment of H-coal liquefaction," 16th Annual Conference on Trace Substances in Environmental Health, University of Missouri, Columbia, Missouri, May-June 1982.

Edwards, N. T.

"First year soil carbon dynamics in an oak-hickory forest following harvest with and without residue removal," Annual Meeting of the American Institute of Biological Sciences, State College, Pennsylvania, August 1982.

Elwood, J. W., J. D. Newbold, P. J. Mulholland, and C. L. Hom

"Controlling influence of grazers on phosphorus spiraling in stream ecosystems," Annual Meeting, North American Benthological Society, Ann Arbor, Michigan, May 1982.

Elwood, J. W.

"Nutrient spiraling—a conceptual approach for analyzing nutrient and carbon dynamics in lotic ecosystems," Tennessee Tech. University Biological Station, Invited Seminar, August 1982.

Emanuel, W. R.

"Introducing terrestrial sources in global carbon cycle simulations," Marine Biological Laboratory, Woods Hole, Massachusetts, May 1982.

"Discussion of review of carbon cycle research by C. D. Keeling," CO₂ Research Conference, Berkeley Springs, West Virginia, September 1982.

"Global carbon cycle modeling," Contractors Review, DOE Carbon Cycle Research Program, Gaithersburg, Maryland, December 1982.

Farrell, M. P.

"Computer graphics in environmental research," Seventh Annual SAS Users Group International Conference, San Francisco, California, February 1982.

"Environmental data management and analysis: An environmetrics approach," Symposium on Energy and Environmental Processes in Terrestrial Systems, U.S. Department of Energy, Washington, D.C., March 1982.

"Research data management for the Oak Ridge National Environmental Research Park and Oak Ridge Natural Resources," Workshop on Data Management at Biological Field Stations, W. K. Kellogg Biological Station, May 1982.

"Environmetrics," Baruch Institute for Marine Biology and Coastal Research, University of South Carolina, Columbia, September 1982.

"Computer graphics in applied statistics," Statistical Applications Seminar, Oak Ridge National Laboratory, June 1982.

Francis, C. W.

"Toxicity of leachates," Hazardous Waste Monitoring Research Program Technical Review, U.S. Environmental Protection Agency, Environmental Monitoring System Laboratory, Las Vegas, Nevada, April 1982.

"Synthetic fuels solid waste research," DOE/OHER Research Division Workshop, Airlie House, Virginia, January 1982.

Gardner, R. H.

"Parameter uncertainty analysis of the World Carbon Model," CO₂ Research Conference: Carbon Dioxide, Science and Consensus, Coolfont Conference Center, Berkeley Springs, West Virginia, September 1982.

Gardner, R. H., W. G. Cale, and R. V. O'Neill

"Aggregation problems in field ecology," Annual meetings of AIBS, Pennsylvania State University, University Park, August 1982.

Garten, C. T., Jr.

"Actinides in the environment," DOE Review of Research on Environmental Radioactivity, Harpers Ferry, Virginia, November 1981.

Giddings, J. M.

"Assessing the effects of contaminants on the structure and function of aquatic ecosystems," 4th ORNL Life Sciences Symposium: Environment and Solid Wastes, Gatlinburg, Tennessee, October 1981.

"Summary of Oak Ridge National Laboratory's aquatic toxicity research on coal liquefaction," Columbia National Fisheries Research Laboratory, Columbia, Missouri, May 1982.

Giddings, J. M., R. M. Cushman, P. J. Franco, J. C. Goyert, S. E. Herbes, R. E. Millemann, J. D. Newbold, G. R. Southworth, and A. J. Stewart

"Assessing the hazards of synthetic oil spills using results of laboratory, microcosm, and field experiments," 2d Annual Meeting, Society of Environmental Toxicology and Chemistry, Arlington, Virginia, November 1981.

Haase, C. S.

"Petrology and diagenesis of the Pumpkin Valley Shale in the vicinity of Oak Ridge, Tennessee," Geological Society of America, Northeastern-Southeastern Section Annual Meeting, Washington, D.C., March 1982.

Hildebrand, S. G.

"Environmental constraints to hydroelectric development: Challenge to developers and regulators," Annual meeting of the American Society of Civil Engineers, St. Louis, Missouri, October 1981.

"Water research opportunities in the 1980s: An analysis of selected topics," Oak Ridge National Laboratory Senior Planning Group, August 1982.

Huff, D. D.

Technical Course B-400, "The water cycle and environmental transport," Organized and presented 10 of the 12 sessions, including two field sessions. January through March 1982.

"Subsurface flow in fractures, joints, and macropores and its relevance to shallow land disposal," Program Review Committee of the National Low-Level Waste Management Program, Minneapolis, Minnesota, September 1982.

"Hydrologic factors and ^{90}Sr transport at a low-level waste disposal site," Symposium on Hydrologic and Geologic Factors in Waste Disposal, Waste Management '82, Tucson, Arizona, March 1982.

"Variable source areas in forested system hydrologic transport studies," DOE/OHER Terrestrial Ecology Meeting, Gaithersburg, Maryland, March 1982.

"Hydrologic study and evaluation of Ish Creek Watershed (West Chestnut Ridge proposed central disposal site)," LLW Site Characterization Subcommittee, August 1982.

Johnson, D. W.

"Effects of acid rain on forest nutrient status," testimony to U.S. Senate Committee on Environment and Public Works, Washington, D.C., May 1982.

"Effects of harvesting schedules on nutrient depletion from forests," IUFRO Symposium on Forest Site and Continuous Productivity, Seattle, Washington, August 1982.

"A comparative evaluation of the effects of acid precipitation, natural acid production, and harvesting on cation removal from forests," EPA Acidic Deposition Ecological Effects Research Peer Review, Raleigh, North Carolina, February 1982.

Johnson, D. W., D. C. West, D. E. Todd, and L. K. Mann

"Effects of residue removed on the N, P, K, and Ca budgets of a mixed deciduous forest," Soil Science Society of America, 1981 Annual Meeting, Atlanta, Georgia, November-December 1981.

Kimmel, B. L.

"The organic matter base of reservoir foodwebs," Department of Microbiology, University of Tennessee, Knoxville, October 1981.

"Man-made impoundments as aquatic ecosystems," Biology Department, Davidson College, Davidson, North Carolina, April 1982.

"Reservoir research at Oak Ridge National Laboratory," Tech Aqua Field Station, Tennessee Tech. University, Cookeville, Tennessee, June 1982.

Kimmel, B. L., S. M. Bartell, and A. W. Groeger

"Reservoirs as river-lake hybrids: A conceptual basis for reservoir ecology?," Annual Meeting, Great Plains Limnology Association, Iowa State University, Ames, Iowa, October 1981.

Kitchings, J. T.

"Oak Ridge National Environmental Research Park," Junior Women's General Federated Club, Kingston, Tennessee, October 1981.

"Research on the Oak Ridge National Environmental Research Park," Toxicology Information Response Center Seminar, Oak Ridge National Laboratory, December 1981.

"Oak Ridge's National Environmental Research Park," Special Interest Group of Energy and Environment Information of the American Society of Information Science, Oak Ridge National Laboratory, June 1982.

"Oak Ridge NERP," Symposium on a Decade of National Environmental Research Parks: Long-term Ecological Studies in the Southeast, Aiken, South Carolina, September 1982.

Kroodma, R. L.

"Effects of power-line corridors on the density and diversity of bird communities in forested areas," Third Symposium on Environmental Concerns in Rights-of-way Management, San Diego, California, February 1982.

Krummel, J. R., and M. I. Dyer

"Consumers in agriculture: A landscape perspective," 33rd Annual Meeting, American Institute of Biological Sciences, College Station, Pennsylvania, August 1982.

Lee, S. Y.

"Bench-scale tests of removing uranium from drinking water," Soil Science Society of America 1981 Annual Meeting, Atlanta, Georgia, November 1981.

"Distribution coefficients of trace elements in relation to soil properties," 1982 Meeting of Regional Soil Mineralogy Research Committee, Knoxville, Tennessee, May 1981.

Lindberg, S. E.

"Interactions between airborne heavy metals and acid precipitation," invited paper at the 75th Annual Meeting of the Air Pollution Control Association, New Orleans, Louisiana, June 1982.

Loar, J. M.

"Environmental impact statements for nuclear power plants," ORAU Workshop on Nuclear Power and the Energy Crisis, Oak Ridge, Tennessee, October 1981.

"Environmental issues related to small-scale hydropower development: An overview," U.S. Army Corps of Engineers Conference on Environmental Impacts of Small-Scale/Low-Head Hydropower Development, St. Louis, Missouri, March 1982.

"Impacts of hydropower development on downstream fish passage," American Fisheries Society Northeast Coldwater Workshop on Hydropower Development and Fisheries Impacts and Opportunities, Cornell University, Ithaca, New York, June 1982.

Lovett, G. M., and S. E. Lindberg

"The effects of a deciduous forest canopy on element inputs from wet and dry deposition," Annual Meeting of the American Institute of Biological Sciences, State College, Philadelphia, August 1982.

Luxmoore, R. J.

"In situ hydraulic characteristics of two forest soils," American Society of Agronomy Annual Meetings, Atlanta, Georgia, December 1981.

"Coupled processes in whole plants," Energy and Environmental Processes in Terrestrial Ecosystems Workshop, Gaithersburg, Maryland, March 1982.

"Heterogeneity of soil physical properties and effects on evapotranspiration," S-124 Regional Technical Committee Meeting, Auburn, Alabama, March 1982.

"Water, carbon, and chemical dynamics of whole plants," Invited Seminar, Botany Department, The University of Tennessee, Knoxville, Tennessee, June 1982.

"Soil heterogeneity and catchment water budgets," Hydrology Seminar Series, Department of Environmental Science, University of Virginia, Charlottesville, Virginia, September 1982.

Luxmoore, R. J., and R. H. Sedgley

"Seasonal dynamics of SPAC resistances in winter wheat," Evapotranspiration workshop, Bunbury, Western Australia, May 1982.

Luxmoore, R. J., and M. L. Sharma

"Evapotranspiration and soil heterogeneity," Evapotranspiration Workshop, Bunbury, Western Australia, May 1982.

McBrayer, J. F.

"Environmental consequences of biomass energy production," Solar R&D Panel, Energy Research Advisory Board, U.S. Department of Energy, Albuquerque, New Mexico, July 1982.

McCarthy, J. F.

"Routes of uptake of benzo(a)pyrene by *Daphnia magna*," Sixth International Symposium on Polynuclear Aromatic Hydrocarbons, Battelle-Columbus Laboratory, Columbus, Ohio, October 1981.

"Routes of uptake of polynuclear aromatic hydrocarbons by *Daphnia magna*," Annual Meeting of the American Society of Zoologists, Dallas, Texas, December 1981.

McLaughlin, S. B.

"Forest responses to anthropogenic stress," USEPA Acid Deposition Effects Program Review, Raleigh, North Carolina, February 1982.

"Effects of gaseous pollutants on acid rain on growth processes of natural terrestrial vegetation," USEPA Acid Deposition Effects Program Review, Raleigh, North Carolina, February 1982.

"Effects of acid rain on natural terrestrial systems—program overview," USEPA Acid Deposition Effects Program Review, Raleigh, North Carolina, February 1982.

"Environmental impacts of chemicals—real or perceived," UCC-ND/GAT Environmental Protection Seminar, Gatlinburg, Tennessee, April 1982.

"Analysis of forest growth responses to air pollution stress in the Great Smoky Mountains, Buffalo River, and Acadia National Parks," Annual Meeting on Scientific Research in the National Parks—Uplands Section, Tremont, Tennessee, June 1982.

"Effects of advanced fossil energy technologies on terrestrial vegetation," DOE Review, Arlie House, Washington, D.C., January 1982.

"Allocation of energy by forest trees," Cornell University, Ithaca, New York, May 1982.

"Effects of air pollution on terrestrial vegetation," DOE Workshop on Energy and Environmental Processes in Terrestrial Systems, Gaithersburg, Maryland, March 1982.

McLaughlin, S. B., and R. K. McConathy

"Within-canopy measurement of gas exchange: Development and potential applications of a chamberless technique," XIIth Air Pollution Workshop, Riverside, California, May 1982.

Moran, M. S.

"Overview of DOE LLW disposal technology activities," Fourth Annual DOE LLWMP Participants' Information Meeting, Denver, Colorado, August 1982.

"Greater confinement disposal," Fourth Annual DOE LLWMP Participants' Information Meeting, Denver, Colorado, September 1982.

Mulholland, P. J.

"Organic carbon cycles in riverine wetland systems," Workshop on Tropical Wetlands in the Global Carbon Cycle, The Institute of Ecology, Indianapolis, Indiana, June 1982.

Mulholland, P. J., J. D. Newbold, J. W. Elwood, and J. R. Webster

"Phosphorus spiraling in a woodland stream: Seasonal variations," American Society of Limnology and Oceanography, Raleigh, North Carolina, June 1982.

Newbold, J. D., J. W. Elwood, J. R. Webster, and J. B. Wallace

"Effects of insect removal on phosphorus spiraling in a small woodland stream," Ecological Society of America Annual Meeting, Pennsylvania State University, University Park, August, 1982.

Newbold, J. D., C. L. Hom, J. W. Elwood, P. J. Mulholland, and P. T. Singley

"Influence of grazers on primary production rates in stream ecosystems," Ecological Society of America Annual Meeting, Pennsylvania State University, University Park, August 1982.

Norby, R. J., and T. T. Kozlowski

"Flooding-induced changes in resistance to SO_2 stress in birch," Annual Meeting, American Society of Plant Physiologists, Urbana, Illinois, June 1982.

O'Neill, E. G., and B. T. Walton

"Developmental morphology of chemically induced supernumerary eyes in the house cricket, *Acheta domesticus* (L.)," Annual Meeting of the Southeastern Branch, Entomological Society of America, Mobile, Alabama, January 1982.

O'Neill, R. V.

"The role of modeling in the DOE mission," OHER Meeting, Washington, D.C., April 1982.

"Error analysis," OHER Meeting, Washington, D.C., April 1982.

Olsen, C. R.

"Radionuclides and sedimentation in the Hudson Estuary," Oak Ridge National Laboratory, Geosciences Seminar Series, October 1981.

"Radionuclides as tracers for the fate of contaminants in coastal systems," Distinguished Lecturer Series, Old Dominion University, Norfolk, Virginia, April 1982.

Olsen, C. R., I. L. Larsen, and N. H. Cutshall

"Current status of coastal research in the James River Estuary," Virginia Institute of Marine Science, Gloucester Point, Virginia, April 1982.

Olson, J. S.

"The role of the biosphere in the carbon cycle," Environmental Consequences of Energy Development: Global CO₂, Session in Third International Conference on Energy Use Management, West Berlin, October 1981; also SCOPE Carbon Center of the International Council of Scientific Unions, University of Hamburg and Max Planck Institute, Hamburg, November 1981.

"Tropical forests and carbon cycling," Man and Biosphere Working Group Conference at World Forestry Institute, Bundesforschungsanstalt für Forst- und Holzwirtschaft, Hamburg and Aumühle, November 1981.

"Mapping and modeling world ecosystem complexes," University of Osnabrück, Germany, November 1981.

"Policy implications of global CO₂ for coal," Gesamtverband des Deutschen Steinkohlenbergbaus, Essen, Germany, November 1981.

"Mapping world plant formations," Botanisches Institute, University of Göttingen, Göttingen, Germany, November 1981.

"Human alterations of the biosphere," Technische Hochschule Kassel, Kassel, Germany, November 1981.

"Biospheric sources and sinks for atmospheric CO₂," Laboratory Director's Program Planning Committee, Oak Ridge National Laboratory, December 1981.

"Computer-generated map and data base for vegetation and carbon," DOE Contractors' Meeting for CO₂/Climate Program, Gaithersburg, Maryland, December 1981.

"Ecosystem models and CO₂ cycling," University of Florida, Gainesville, December 1981.

"Global carbon cycles and climate," Conference on the Biotic Contributions to the Global Carbon Cycle, Woods Hole, Massachusetts, February 1981.

"Carbon dioxide releases before and during clearing vegetation for crop land," Institute for Energy Analysis, Oak Ridge Associated Universities, Oak Ridge, Tennessee, June 1982.

"Working assumptions for estimating carbon dioxide releases from clearing African vegetation," Woods Hole, Massachusetts, September 1982.

"Computer-assisted maps of major global carbon storage and of major landscape impact," DOE Contractors' Meeting for Carbon Dioxide and Climate Program, Coolfont Conference Center, Berkeley, West Virginia, September 1982.

Olson, R. J.

"Geocology Data Base: County-level environmental data for the conterminous United States," 1981 Integrated Data Users Workshop, Reston, Virginia, October 1981.

Olson, R. J., and M. K. Nungesser

Overview of geographic data bases and display systems, 1982 SUGI, San Francisco, California, February 1982.

Parr, P. D.

"Germination and growth effects of hexavalent chromium in Orocol TL on *Phaseolus vulgaris*," 1982 UCC-ND and GAT Environmental Protection Seminar, Gatlinburg, Tennessee, April 1982.

"Effect of Orocol TL on germination and growth of bush beans," Association of Southeastern Biologists, Plant Ecology Section, Richmond, Kentucky, April 1982.

"Rare plants on the Oak Ridge Reservation," The University of Tennessee Plant Ecology Class, Oak Ridge National Laboratory, October 1981 and May 1982.

Peng, T.-H.

"Accumulation rates on calcite in the world oceans as determined by the radiocarbon dating," 11th International Radiocarbon Conference, University of Washington, Seattle, Washington, June 1982.

Peng, T.-H., W. S. Broecker, and G. Mathieu

"Oxygen supersaturation in surface water," American Geophysical Union Fall Meeting at San Francisco, California, December 1981.

Post, W. M.

"Positive feedback and the evolution of mutualism," Population Biology Group, University of Sussex, Falmer, England, December 1981.

"Succession and food web stability," Biology Department, University of York, York, England, December 1981.

Post, W. M., D. L. DeAngelis, and C. C. Travis

"Characteristics of mutualistic interactions in many-species communities," AAAS Annual Meeting, Washington, D.C., January 1982.

Ranney, J. W.

"Future directions for the Short Rotation Woody Crops Program," Annual Technical Meeting of the Short Rotation Woody Crops Program, Athens, Georgia, August 1982.

"Status and new developments in the production of wood for energy," an energy seminar, Increasing Use of Biomass for Energy and Chemicals, The Aspen Institute for Humanistic Studies, Aspen, Colorado, July 1982.

Testimony to the House Subcommittee on Energy Development and Applications, field hearings, renewable energy in the eighties: needs for further research, development, and demonstration, Knoxville, Tennessee, May 1982.

"The potential for short rotation intensive culture of woody species for energy in the U.S.," invited seminar, Center for Environmental Resources, University of Florida, Gainesville, Florida, August 1982.

"The status of short-rotation intensive culture research," Fourth Meeting of the Southern Forest Biomass Working Group, Alexandria, Louisiana, June 1982.

Ranney, J. W., and J. H. Cushman

"Short rotation growth of hardwoods for energy applications across the United States—Field results and economics." Institute of Gas Technology, Lake Buena Vista, Florida, January 1982.

"Short-rotation woody crops as a source of energy," Ninth Energy Technology Conference, Washington, D.C., February 1982.

Ranney, J. W., J. H. Cushman, and J. L. Trimble

"Future prospects of short-rotation woody crops," Industrial Wood Energy Forum 82, Washington, D.C., March 1982.

Reed, R. M., L. D. Voorhees, and P. J. Mulholland

"Overview—Using peat for energy. Potential environmental constraints," Symposium on Peat as an Energy Alternative II, Arlington, Virginia, December 1981.

Reichle, D. E.

"DOE state-of-the-art report for the global carbon cycle," DOE Technical Conference, Berkeley Springs, West Virginia, September 1982.

"The global carbon cycle," Edison Electric Institute, New Orleans, Louisiana, May 1982.

"The global carbon cycle," ORNL Summer Seminar Series, Oak Ridge, Tennessee, July 1982.

"Temperate forest ecosystems—Scientific contributions from the IBP," Class: Ecosystems of the World, The University of Tennessee, Knoxville, Tennessee, November 1981.

Richter, D. D.

"Effects of acid precipitation on base cation leaching in two deciduous forests in eastern Tennessee," Eighth Annual Conference of Biological Research in Smoky Mountains National Park, Tremont, Tennessee, June 1982.

"Effects of municipal sewage sludge-cake on nitrogen and phosphorus distributions in a pine plantation," Fifth Annual Madison Conference on Waste Management, Madison, Wisconsin, September 1982.

"Prescribed fire: Effects on nutrients in southern pine forests," 73rd Annual Meeting, Soil Science Society of America, Atlanta, Georgia, November 1981.

Sale, M. J.

"Assessing the impacts of regulated flows at hydropower projects," Hydropower Development and Fisheries, Impacts and Opportunities, New York Chapter of the American Fisheries Society and New York State Department of Environmental Conservation, Ithaca, New York, June 1982.

Sale, M. J., J. M. Loar, D. K. Cox, and G. F. Cada

"Instream flow research at Oak Ridge National Laboratory," Annual Scientific Research Meeting, Uplands Field Research Laboratory, Great Smoky Mountains National Park, Gatlinburg, Tennessee, June 1982.

Sale M. J., S. F. Railsback, and E. E. Herricks

"Frequency analysis of aquatic habitat," Symposium on the Acquisition and Utilization of Aquatic Habitat Inventory Information, Western Division of the American Fisheries Society, Portland, Oregon, October 1981.

Shriner, D. S.

"Acid rain, an environmental issue," Tennessee Conservation Education Association, Knoxville, November 1981.

"Acid rain—Gaseous pollutant interactions," EPA Project Review, Raleigh, North Carolina, February 1982.

"Monthly status reports to interagency task force on acid precipitation," Washington, D.C., April–July 1982.

"Acid rain—Gaseous pollutant interaction field study," National Air Pollution Effects Workshop, Riverside, California, April 1982.

Shugart, H. H.

"Forest Dynamics," DOE Workshop on Energy and Environmental Processes in Terrestrial Systems, DOE Headquarters, Gaithersburg, Maryland, March 1982.

"Systems ecology," Short course, Illinois Natural History Survey, March 1982.

"Forest succession models," to the Botany Department, Arizona State University, Tempe, Arizona, March 1982.

"Computer models of ecological succession," University of Hawaii, Honolulu, Hawaii, April 1982.

"Succession models," CSIRO Division of Land-Use Research, Canberra, A.C.T., Australia, April 1982.

"Computer models of forest succession," Davis Laboratory, CSIRO, Townsville, Australia, April–August 1982.

"Forest dynamics models," University of Malaya, Kuala Lumpur, Malaya, August–September 1982.

Sigal, L. L.

"Comparison of acid rain and gaseous pollutant effect on the lichen *Umbilicaria mammulata*," XIV Air Pollution Workshop, University of California, Riverside, California, April 1982.

"Photosynthesis of lichen species in relation to gaseous pollutants and acid rain," AIBS meetings, Pennsylvania State University, University Park, Pennsylvania, August 1982.

"Acid rain and gaseous pollutant effects on lichens," 8th Annual Scientific Research Meetings, The Uplands Areas of the Southeast Region, National Park Service, Tremont, Tennessee, June 1982.

Solomon, A. M.

"Plant community response to decreased seasonality during full-glacial time," Seventh Biennial Conference, American Quaternary Association, Seattle, Washington, June 1982.

"Effects of vertical temperature gradient on the atmospheric transport of pine pollen from isolated sources," Second International Aerobiology Conference, Seattle, Washington, August 1982.

"Legionnaires' disease bacterium in power plant cooling systems. Phase I interim report: Statistical summary," EPRI Advisory Committee Meeting, Atlanta, Georgia, March 1982.

Solomon, A. M., and T. J. Blasing

"Modern analogues for Holocene climatic regimes in the desert southwest: A hot, dry Altithermal?" Annual Meeting, Ecological Society of America, State College, Pennsylvania, August 1982.

Southworth, G. R., S. E. Herbes, P. J. Franco, and J. M. Giddings

"Persistence of phenols in aquatic microcosms receiving chronic synthetic fuel inputs," Gordon Conference, Environmental Sciences: Water, New Hampton, New Hampshire, June 1982

Spalding, B. P.

"Remedial action technology for humid sites," DOE-LLWMP Third Annual Information Meeting, New Orleans, Louisiana, November 1981.

"Research efforts on environmental transport of hazardous materials at Oak Ridge National Laboratory," American Nuclear Society Meeting, Los Angeles, California, June 1982.

"Corrective measures technology for humid sites," DOE-LLWMP Fourth Annual Information Meeting, Denver, Colorado, September 1982.

Stov, S. H.

"Geology and geochemistry of the pyriton massive sulfide deposit, Alabama Piedmont," ORAU Traveling Lecture Series, University of Alabama at Birmingham, Birmingham, February 1982, and Florida State University, Tallahassee, April 1982.

"Geology of mafic rocks of the Talladega Belt, Alabama Piedmont," Geoscience Seminar Series, The University of Tennessee, Knoxville, November 1981.

Stow, S. H., M. J. Neilson, L. J. Schwarz, and J. L. Harris

"Geochemistry of mafic-ultramafic bodies, Dadeville Complex, Tallapoosa County, Alabama," Southeastern Section Geological Society of America Annual Meeting, Washington, D.C., March 1982.

Stratton, L. E.

"Corrective measures technology development for shallow land burial of low-level radioactive waste," DOE Headquarters Staff in Idaho Falls, Idaho, May 1982, and Germantown, Maryland, June 1982.

Suter, G. W., II

"Methods for environmental risk assessment," Invited seminar, U.S. Environmental Protection Agency, Duluth Environmental Research Laboratory, Duluth, Minnesota, October 1981.

"Multispecies tests for environmental toxicology," Annual Meeting, Society of Environmental Toxicology and Chemistry, Arlington, Virginia, November 1981.

"The uses of uncertainty in environmental risk analysis," AAAS Symposium, Quantification of Risk: Reducing the Uncertainties, Santa Barbara, California, June 1982.

Tamura, T.

"In-situ linear and cover applications of grouts in uranium mill tailings remedial action," presented to DOE/UMTRAP representatives at Colorado State University, Fort Collins, April 1982.

Tamura, T., and S. Y. Lee

"Physical-chemical characteristics of Pu-contaminated soils of the Nevada Test Site: Summary and relevance," presented to the Nevada Applied Ecology Group program review at Las Vegas, Nevada, July 1982.

Taylor, F. G.

"Fluoride survey of vegetation in the Great Smoky Mountains National Park," Eighth Annual Science Research Meeting for the Uplands Area of the Southeast Region. National Park Service, Tremont, Tennessee, June 1982.

Taylor, G. E., Jr.

"The significance of the developing energy technologies of coal conversion to plant productivity," Annual Meeting, American Society for Horticultural Science, Ames, Iowa, August 1982.

Taylor, G. E., Jr., and S. B. McLaughlin

"Leaf conductance to SO_2 and O_3 in *Phaseolus vulgaris*," Poster Session, XIV Air Pollution Workshop, University of California, Riverside, California, April 1982.

Taylor, G. E., Jr., D. T. Tingey, and S. B. McLaughlin

"Leaf resistance to sulfur dioxide flux in *Geranium carolinianum* and *Phaseolus vulgaris*," Annual Meeting, American Society of Plant Physiologists, Champaign-Urbana, Illinois, June 1982.

Tolbert, V. R.

"A preliminary assessment of environmental impacts of obtaining oil from Chattanooga Shale," 1981 Eastern Oil Shale Symposium, Lexington, Kentucky, November 1981.

"Can benthic communities recover from surface mining disturbance?" North American Benthological Society, Ann Arbor, Michigan, May 1982.

Trabalka, J. R., and C. T. Garten, Jr.

"Development of predictive models for xenobiotic bioaccumulation in terrestrial ecosystems," Annual Meeting, Society for Environmental Toxicology and Chemistry, Arlington, Virginia, November 1981.

Turner, R. R.

"Survey of lead in vegetation and soils of the Great Smoky Mountains National Park," National Park Service, Animal Science Meeting, Southeastern Region, Townsend, Tennessee, June 1982.

Turner, R. R., P. D. Lowry, and C. W. Francis

"Gasification versus combustion of coal: Are the solid wastes similar?" American Institute of Chemical Engineers National Meeting, Cleveland, Ohio, August 1982.

Tyndall, R. L.

"Association of Legionnaires' disease bacterium with cooling towers," Annual Meeting of the American Association of Industrial Hygiene, Cincinnati, Ohio, May 1982.

"Association of *Legionella pneumophila* with thermally altered water," Department of Microbiology, The University of Tennessee, Knoxville, Tennessee, June 1982.

Tyndall, R. L., and S. Findlay

"Concentration, serotypic profiles and infectivity of Legionnaires' disease bacteria populations in cooling towers," Meetings of the Cooling Tower Institute, Houston, Texas, February 1982.

Tyndall, R. L., G. Kuhl, and J. Bechthold

"Chlorination as an effective treatment for controlling *Naegleria fowleri* in cooling waters of an electric power plant," Fourth Conference on Water Chlorination, Pacific Grove, California, October 1981.

Van Winkle, W.

"The frustrating quest to understand variations in year-class strength of fish populations," Invited presentation for the Third Midwest Conference on Population Biology, Bloomington, Indiana, March 1982.

Van Winkle, W., and K. D. Kumar

"Relative contributions of Chesapeake and Hudson River striped bass stocks to the Atlantic Coast Population vary substantially among year classes," Presentation for the Symposium on Advancing the Science of Assessment: Technical Lessons from the Hudson River Power Plant Case, Annual Meeting of the American Fisheries Society, Hilton Head Island, South Carolina, September 1982.

Vaughan, D. S., and R. J. Klauda

"An introduction and perspective on the Hudson River power plant case," Annual Meeting, the American Fisheries Society, Hilton Head Island, South Carolina, September 1982.

Vaughan, D. S., R. M. Yoshiyama, J. E. Breck, and D. L. DeAngelis

"Modeling approaches for assessing the effects of stress on fish populations," Fish Health Workshop, Geneva Park, Ontario, Canada, November 1981.

Voorhees, L. D.

"The role of chemicals in management of roadside vegetation," The Third Symposium on Environmental Concerns in Rights-of-way Management, San Diego, California, February 1982.

"NEPA and nuclear power plants," ORAU Training Seminar Series, Oak Ridge Associated Universities, Oak Ridge, Tennessee, April 1982.

"NEPA and nuclear power plants," ORAU Training Seminar Series, Oak Ridge Associated Universities, Oak Ridge, Tennessee, June 1982.

"NEPA and nuclear power plants," ORAU Training Seminar Series, Oak Ridge Associated Universities, Oak Ridge, Tennessee, September 1982.

Walker, R. F., D. C. West, and S. B. McLaughlin

"*Pisolithus tinctorius* ectomycorrhizae reduce moisture stress of Virginia Pine on a southern Appalachian coal spoil," Seventh North American Forest Biology Workshop, University of Kentucky, Lexington, Kentucky, July 1982.

Walton, B. T.

"Chemical teratogenesis in insects," Sigma Xi Invitational Banquet Address, University of Kentucky, Lexington, April 1982.

"Effects of energy-related organic pollutants on insect populations," U.S. Department of Energy Symposium on Energy and Environmental Processes in Terrestrial Systems, Gaithersburg, Maryland, March 1982.

"Environmental effects of synthetic fuels: Predictions from insect studies," Tennessee Entomological Society Annual Meeting, Nashville, Tennessee, October 1981.

"Insect teratogens: A potential environmental hazard?" Grambling State University, Grambling, Louisiana, March 1982.

"Use of the cricket embryo *Acheta domesticus* as an invertebrate teratology model," Symposium on Innovating Models in Teratogenicity, American Society of Pharmacology and Experimental Therapeutics/Society of Toxicology, Louisville, Kentucky, August 1982.

Walton, B. T., C.-h. Ho, and M. V. Buchanan

"Insect embryotoxicity and teratogenicity of chemically fractionated petroleum, shale oil, and a coal liquid," IUPAC Fifth International Congress of Pesticide Chemistry, Kyoto, Japan, September 1982.

Walton, B. T., J. B. Nardi, and E. G. O'Neill

"Influence of developmental age on teratogen susceptibility in the crickets *Gryllus rubens* Scudder and *Acheta domesticus* (L.)," Entomological Society of America Annual Meeting, San Diego, California, December 1981.

Watts, J. A.

"Numeric data management aspects of carbon dioxide research," Presented to the Department of Energy Carbon Dioxide Research Division Director and Program Managers, Washington, D.C., November 1981.

"Overview of the Carbon Dioxide Information Center Numeric Data Inventory," Presented at the Carbon Cycle Workshop, CO₂ Research Conference, Berkeley Springs, West Virginia, September 1982.

Wright, L. L.

"Distribution and abundance of the mayfly *Hexagenia bilineata* in the vicinity of a power plant," North American Benthological Society Thirtieth Annual Meeting, Ann Arbor, Michigan, May 1982.

Theses

Boerner, A. J. 1982. The Effects of Acute Ionizing Radiation on *Daphnia magna*. M.S. The University of Tennessee, Knoxville.

Doyle, T. W. 1981. FORICO: Gap dynamics model of the lower montane rain forest in Puerto Rico. M.S. The University of Tennessee, Knoxville.

Smith, T. M. 1981. Variation in territory size of the ovenbird (*Seiurus aurocapillus*): The role of habitat structure. Ph.D. The University of Tennessee, Knoxville.

Walker, R. F. 1982. The growth, nutrient absorption, and moisture status of selected woody species in coal mine spoil in response to an induced infection by the ectomycorrhizal fungus *Pisolithus tinctorius*. Ph.D. The University of Tennessee, Knoxville.

Weinstein, D. A. 1982. The long-term nutrient retention properties of forest ecosystems: A simulation investigation. Ph.D. The University of Tennessee, Knoxville.

Professional Activities**ADAMS, S. M.**

Chairman: Awards committee, American Fisheries Society, 1981-1982; annual meeting of the evaluation committee, American Fisheries Society, 1981-1982.

Participant: NRC workshop on environmental assessment, December 1981; EPA/NOAA workshop on meaningful measures of marine pollution effects, April 1982.

Advisor: Jim Elser, M.S., The University of Tennessee, Knoxville; Tim Higgins, ORAU science semester, Ferrum College, Ferrum, Virginia.

Reviewer: *Transactions American Fisheries Society*; *Environment International*, *Environmental Management*; proposals, EPA.

Other: Editorial board, *Transactions American Fisheries Society*, 1982-1984.

AUERBACH, S. I.

- Member:** Commission on Physical Sciences, Mathematics, and Resources of the National Research Council.
- Participant:** Subcommittee to select the recipient of the Ecological Society of America Distinguished Service Citation for 1981-1982.
- Other:** President, Administration Council, Union of International Radioecologists; Editor: *Environment International*, *Environmental and Experimental Botany*.

BARNTHOUSE, L. W.

- Member:** Funding Panel, Hudson River Foundation for Science and Environmental Research.
- Participant:** Workshop, The ecological basis for environmental impact assessment in Canada, Brandon, Manitoba, October 14-16, 1981; NYU Law School Conference on the Hudson River Power Plant Settlement, New York, New York, December 10, 1981; Third Annual Contractor Meeting, DOE Health and Environmental Risk Analysis Program, Alexandria, Virginia, February 16-18, 1982; EPA Level II Exposure Assessment Workshop, Atlanta, Georgia, April 27-28, 1982; Hudson River Foundation Panel Conference, Palisades, New York, May 25-26, 1982; EPA Environmental Risk Analysis Project User Group Review, Washington, D.C., November 3-4, 1981; EPA Environmental Risk Analysis Project Peer Review, Knoxville, Tennessee, November 18-19, 1982; EPA Environmental Risk Analysis Project User Group Review, Washington, D.C., September 23, 1982.
- Advisor:** Leslie Hook, Ph.D., Southern Illinois University, Carbondale; Gavin Thompson, M.S., Indiana University, Bloomington.
- Ad hoc reviewer:** *American Naturalist*; *Risk Analysis*; EPRI, Cornell University Ecosystem Research Center.

BARTELL, S. M.

- Chairman:** Computer Advisory Committee, Environmental Sciences Division.
- Advisor:** Graduate committee member: Alan Groeger, Ph.D., Department of Zoology, University of Oklahoma.
- Ad hoc reviewer:** National Science Foundation NATO Postdoctoral Review Panel; U.S. EPA, Competitive Research Grants Review Panel.

BLASING, T. J.

- Member:** ESD Computer Advisory Committee.
- Participant:** Workshop on Forest Responses to Anthropogenic Stress (FORAST), Blacksburg, Virginia, March 1982; U.S. Environmental Protection Agency Meeting on the Reconstruction of Pollution Histories, Washington, D.C., April 1982; Annual Meeting of the American Institute of Biological Sciences, State College, Pennsylvania, August 1982; Workshop on Indirect Carbon Dioxide Effects, Richland, Washington, August 1982.

Faculty: Adjunct Assistant Professor, Geography Department, The University of Tennessee, Knoxville.

Ad hoc reviewer: *Science; Journal of Applied Meteorology*; proposals, NSF, DOE.

BLAYLOCK, B. G.

Chairman: Group Session, Workshop on Environmental Assessment, U.S. NRC, Gaithersburg, Maryland, December 15-18, 1981.

Member: Research Committee, Water Pollution Control Federation; Subcommittee on Toxic Substances, Water Pollution Control Federation; Panel on Radioactivity in Aquatic Environments, National Research Board of Canada; Task Group 2 of Scientific Committee 64 of the National Council on Radiation Protection and Measurements; Task Group 6 of Scientific Committee 64 of the National Council on Radiation Protection and Measurements; International Scientific Group to Evaluate Swedish Projects Concerning Impacts of Large Cooling Water Dischargers, CDL, Centrala Driftledningen, Sweden.

Faculty: Adjunct Professor, The University of Tennessee, Knoxville.

Advisor: Alex J. Boerner, M.S., Institute of Radiation Biology, The University of Tennessee, Knoxville.

DOEGLY, W. J., Jr.

Member: Committee on Utilities, Transportation Research Board, National Academy of Sciences. National Academy of Engineering; Committee on Dual Distribution Systems, American Water Works Association; Working Commission W-62 (NAS/NRC) on Water Supply and Drainage in Buildings; Committee D34 on Waste Disposal, ASTM.

Faculty: Associate Professor, The University of Tennessee, Knoxville.

Ad hoc reviewer: Proposals, EPRI, DOE.

Other: Energy Conservation Coordinator, ESD, ORNL.

BRECK, J. E.

Participant: Annual Meeting of the Society of Environmental Toxicology and Chemistry, Arlington, Virginia, November 1981; Annual Meeting of the Animal Behavior Society, Dallas, Texas, December 1981; EPA Level II Exposure Assessment Workshop, Atlanta, Georgia, April 27-29, 1982; Annual Meeting of the American Fisheries Society, Hilton Head Island, South Carolina, September 1982; Oral Technical Presentation, ORNL in-hours course, January 1982; IBM Job Control Language I, Spring 1982.

Ad hoc reviewer: *Canadian Journal of Fisheries and Aquatic Sciences*.

CADA, G. F.

Advisor: Margaret Kenna, B.A., St. Joseph's College, Brooklyn, New York.

Ad hoc reviewer: *Transactions of the American Fisheries Society*.

CHRISTENSEN, S. W.

Participant: EPRI, Legionnaires' Disease Bacterium Project Advisory Committee Meetings, November 1981 and March 1982; EPRI, Workshop on Compensation in Fish Populations, February 1982 (discussion leader).

- Consultant:** Salem Technical Advisory Group (EPA, Region II); California Department of Fish and Game.
- Ad hoc reviewer:** *Canadian Journal of Fisheries and Aquatic Sciences.*
- COUTANT, C. C.**
- Chairman:** ASTM Task Group E47.06 on Modeling Transport and Fate of Chemicals; peer review panel for EPA toxic materials models; program committee, American Fisheries Society (1982-1983); ESD Scientific Achievement Award Committee; Environmental Quality Advisory Board, City of Oak Ridge; Striped Bass Symposium, AFS annual meeting.
- Member:** ORNL Wigner Fellowship Selection Committee; ORNL General Energy Conservation Committee; ORNL World's Fair Committee; Utah State University review team for fisheries research program; American Fisheries Society review group on water quality effects of dam discharges; ORNL review panel for the Biomedical Graduate School; ORNL Long-range Planning Committee; Ecological Society of America Program Committee.
- Faculty:** Adjunct faculty at The University of Tennessee, Knoxville, and Tennessee Technological University, Cookeville.
- Advisor:** Undergraduate research participant Paul Vandermeer, University of Wisconsin, Stevens Point; Terry Cheek, M.S., Tennessee Technological University.
- Ad hoc reviewer:** *Environmental Science and Technology; Freshwater Invertebrate Biology; Transactions of the American Fisheries Society; Water Resources Bulletin; Second International Symposium on Regulated Streams; AFS Fisheries Techniques Manual; EPA Hudson River report; Tetra-Tech report on models for screening chemicals; proposals, Maryland Sea Grant Program and National Science Foundation.*
- Other:** Secretary/treasurer, East Tennessee Chapter, American Fisheries Society; Editor, *Underwater Telemetry Newsletter*; Vice Chairman, Applied Ecology Section, Ecological Society of America; reviewer for tenure and promotion.
- CUSHMAN, J. H.**
- Participant:** Short Rotation Woody Crops Program Contractors' Workshop, Athens, Georgia, August 1982.
- Ad hoc reviewer:** Proposals, DOE.
- CUSHMAN, R. M.**
- Member:** Ad Hoc Subcommittee for Tennessee Synfuels Associates Review, Environmental Quality Advisory Board, City of Oak Ridge.
- Participant:** Fourth Miami International Conference on Alternative Energy Sources, Miami Beach, Florida, December 1981; course on Statistical Methods in Toxicology, The University of Tennessee, Knoxville, March-June 1982.
- CUTSHALL, N. H.**
- Member:** Committee for ORNL Radioactive Waste Long Range Plan; Low Level Waste Site Characterization Subcommittee of UCCND Waste Disposal Steering Committee; ORNL Geosciences Committee; Hazardous Waste Task Force.

Consultant: Research Review Group, U.S. Nuclear Regulatory Commission, Review of Hydrology/Geochemistry Programs.

Ad hoc reviewer: *Estuarine and Coastal Marine Science, Science, Environment International*; Third International Ocean Dumping Symposium; DOE, NOAA.

DAVIS, E. C.

Participant: ASCE Annual Meeting, Las Vegas, Nevada, April 1982; ORNL Life Sciences Symposium, Environment and Solid Wastes, Characterization Treatment and Disposal, Gatlinburg, Tennessee, October 1981; American Institute of Chemical Engineers Annual Meeting, Cleveland, Ohio, August 1982.

DeANGELES, D. L.

Faculty: Adjunct Professor, The University of Tennessee, Knoxville.

Advisor: Patrick J. Cocke, M.S., The University of Tennessee, Knoxville.

Ad hoc reviewer: *American Naturalist, Ecology, Journal of Theoretical Biology, Mathematical Biosciences*, NSF.

DYER, M. I.

Ad hoc reviewer: Long-Term Ecological Reserve Program for Oregon State University.

EDDLEMON, G. K.

Participant: 16th Annual Conference on Trace Substances in Environmental Health, University of Missouri, Columbia, Missouri, May 31-June 3, 1982; Second Annual Meeting of the Society of Environmental Toxicology and Chemistry, Arlington, Virginia, November 1981; preparation of EAs for Minnesota Alcohol Producers Loan Guarantee Application and New Energy Corporation of Indiana Loan Guarantee Application; review of NRC Rules and Regulations Related to the Disposal of High Level Radioactive Waste in Geologic Repositories; review of NRC Rules and Regulations Pertaining to Demonstration Liquid-Metal Fast Breeder Reactors.

EDWARDS, N. T.

Advisor: Holly Hattemer, B.S., Ohio Wesleyan University, Delaware, Ohio.

Ad hoc reviewer: Proposal, NSF.

ELMORE, J. L.

Participant: Preparation of EIS for Conoco Sand Rock Uranium Mine and Mill (Campbell Co., Wyoming) and EAs for fuel alcohol plants (Agrifuels Refining Corporation, New Iberia, Louisiana; U.S. Ethanol Corporation, East Baton Rouge Parish, Louisiana; Gulf Coast Resources, Inc., Keokuk, Iowa; and Tennol, Inc., Marion Co., Tennessee).

Other: Sampling and analysis of zooplankton populations in Advanced Fossil Energy Program's experimental ponds. Tours of Advanced Fossil Energy Program's experimental ponds. Ish Creek Hydrology Project (construction of weirs, sampling, and report writing)

ELWOOD, J. W.**Member:**

Executive Committee, North American Benthological Society.

Participant:

Workshop on Research on Lotic Ecosystems, Crystal Lake, Montana, February 26-28, 1982; North American Benthological Society, Annual Meeting, Ann Arbor, Michigan, May 18-31, 1982.

Faculty:

Adjunct Assistant Professor, graduate program in ecology, The University of Tennessee, Knoxville.

Advisor:

Carol L. Hom, M.S., The University of Tennessee, Knoxville; Richard E. Perkins, Ph.D., The University of Tennessee, Knoxville.

Consultant:

EPRI, Palo Alto, California.

Ad hoc reviewer:*Ecology, Ecological Monographs, Canadian Journal of Fisheries and Aquatic Science, American Midland Naturalist, National Science Foundation, EPRI.***EMANUEL, W. R.****Member:**

ESD Graduate Student Selection Committee.

Ad hoc reviewer:*Tellus*; proposals, DOE, NSF.**FARRELL, M. P.****Participant:**

Seventh Annual SAS Users Group International Conference, San Francisco, California, February 1982; Symposium on Energy and Environmental Processes in Terrestrial Systems, U.S. Department of Energy, Washington, D.C., March 1982; Workshop on data management at biological field stations, U. K. Kellogg Biological Station, National Science Foundation, May 1982; First Annual Review Meeting on Acid Precipitation, Interagency Task Force on Acid Precipitation, Fredrick, Maryland, September 1982; Decade of National Environmental Research Parks, Department of Energy, Savannah River Ecology Laboratory, Aiken, South Carolina, September 1982.

Faculty:

Adjunct Professor of Zoology, Miami University, Oxford, Ohio.

Advisor:

Danney Lee, M.S., The University of Tennessee, Knoxville; H. N. Polovino, M.S., Miami University, Oxford, Ohio.

Ad hoc reviewer:*Transactions of American Fisheries Society, Environmental International, Life Sciences, Ecology, EPA, NSF.***FRANCIS, C. W.****Chairman:**

Cochairman, Fourth ORNL Life Sciences Symposium, Environment and Solid Wastes: Characterization, Treatment, and Disposal, Gatlinburg, Tennessee, October 4-8, 1981; Environmental Control Technology Workshop for Coal Gasification, Palo Alto, California, July 28-30, 1982.

FRANCO, P. J.**Advisor:**

Sherry Denise Moore, undergraduate, Eastern Kentucky University, Richmond, Kentucky.

GARDNER, R. H.**Member:**

Committee for workshop on Propagation of Uncertainties Models, Oak Ridge, October 7-9, 1982.

Participant: EPA Workshop on Determining the Field Applicability on Environmental Assessment Methods, Airlie House, Virginia, March 15-19; 33rd Annual AIBS Meeting, Pennsylvania State University, August 8-12; Workshop on Propagation of Uncertainties: Models, Oak Ridge, October 7-9, 1982; CO₂ Research Conference: Carbon Dioxide, Science and Consensus, Coolfont Conference Center, Berkeley, September 1982.

Advisor: D. E. Weller, Ph.D., The University of Tennessee, Knoxville; Y. I. Jager, M.S., The University of Tennessee, Knoxville.

Ad hoc reviewer: *Ecology, American Naturalist, Science, Environmental Management*; proposals, DOE, NSF.

GARTEN, C. T., Jr.

Advisor: Dwight Errickson, B.S., Emory University, Atlanta, Georgia.

Ad hoc reviewer: *Journal of Environmental Quality*; proposal, DOE.

Other: Section Editor, *Nuclear Safety*.

GIDDINGS, J. M.

Advisor: Lisa Huberty, B.S., Lawrence University, Appleton, Wisconsin; Leslie Hook, Ph.D., Southern Illinois University, Carbondale, Illinois.

Reviewer: *Archives of Environmental Contamination and Toxicology*; FDA; proposals, NSF.

Other: Ph.D. recruiter, Cornell University, Ithaca, New York.

HAASE, C. S.

Participant: Annual Meeting of the Geological Society of America, Cincinnati, Ohio, November 1981; Annual Meeting on the Combined Northeastern-Southeastern Sections of the Geological Society of America, Washington, D.C., March 1982.

Faculty: Adjunct Assistant Professor, The University of Tennessee, Knoxville.

Ad hoc reviewer: Proposals, Research Corporation.

HILDEBRAND, S. G.

Chairman: ORNL Water Research Committee; American Nuclear Society Special Session: Hydropower, A New Outlook.

Member: Acidic Deposition Assessment Committee of the National Laboratory Consortium; Assessment and Policy Analysis Task Group of the Interagency Task Force on Acidic Deposition.

Participant: American Society of Civil Engineers Convention and Exposition, October 26-30, 1981, St. Louis, Missouri; Industrial Research Institute Management Study Group, November 30-December 2, 1981, West Palm Beach, Florida; ORNL in-house course, Marketing Strategy for R&D Organizations.

Faculty: Faculty Associate, The University of Tennessee, Knoxville.

Ad hoc reviewer: *Ohio Journal of Science*; NSF.

HUFF, D. D.

Participant: DOE/OHER Terrestrial Ecology Meeting, Gaithersburg, Maryland, March 1982; Waste Management '82, Tucson, Arizona, March 1982.

Faculty: Adjunct Associate Professor, The University of Tennessee, Knoxville.
Ad hoc reviewer: *Water Resources Research*; NSF.

HUNSAKER, C. T.

Participant: Clean Water—New Directions for the 80's, May 20–21, 1982, Arlington, Virginia; Waste Impact on Water and Symposium on Unified River Basin Management—Stage II, October 4–8, 1981, Atlanta, Georgia. Preparation of Environmental Assessment for New England Ethanol Products—Loan Guarantee Application, Androscoggin County, Maine, February 1982.

JOHNSON, D. W.

Chairman: Workshop on Predicting Soil and Water Acidification to be held June 1983 (second in a series begun in Uppsala, Sweden, June 1982). Cochairman of IUFRO Working Party S.1-02-01 "Fertilization."
Advisor: Ecosystem Advisory Committee for Research through the Organization for Tropical Studies at La Selva, Costa Rica.
Other: Coeditor and contributor to U.S. EPA Critical Assessment Document. Contributor, Office of Technology Assessment Document, *The Regional Implications of Transported Air Pollutants*. Contributor, U.S./Canada Memorandum of Intent, Phase II Document.
Consultant: National Council of the Pulp and Paper Industry for Air and Stream Improvement, Inc.
Ad hoc reviewer: *Journal of Environmental Quality*, *Soil Science Society of America Journal*; NSF, IEA, EPA.

KIMMEL, B. L.

Participant: Southern Blue Ridge Province Acid Precipitation Research Task Force Meetings (Gainesville, Georgia, November 1981; Asheville, North Carolina, March 1982; Chattanooga, Tennessee, September 1982); National Energy Laboratories Atmospheric Deposition Effects Program (ADEP) Workshop, Oak Ridge, Tennessee, December 1981; Perspectives on Reservoir Ecosystems Workshop Vicksburg, Mississippi, June 1982; Tennessee Valley Authority Workshop on Dissolved Oxygen and Associated Water Quality Processes, Chattanooga, Tennessee, August 1982.
Faculty: Adjunct Assistant Professor, Department of Zoology, University of Oklahoma, Norman.
Advisor: DOE-ORAU Laboratory Graduate Research Participant, A. W. Groeger, Ph.D., University of Oklahoma, Norman; J. J. Elser, M.S., The University of Tennessee, Knoxville; M. A. Mueller, M.S., The University of Tennessee, Knoxville.
Ad hoc reviewer: *Ecological Monographs*, *Transactions of the American Microscopical Society*, *The Southwestern Naturalist*; proposals, NSF, DOE-GHER.

KITCHINGS, J. T.**Participant:**

A Decade of National Environmental Research Parks: Long-term Ecological Studies in the Southeast, Aiken, South Carolina, September 1982; Diversity Delphi Study, Integrated Case Studies in Natural Resource Analysis, School of Forestry and Environmental Studies, Duke University, March 1982.

Ad hoc reviewer:

Journal of Mammology; proposals: NSF, DOE.

KROODSMA, R. L.**Participant:**

Third Symposium on Environmental Concerns in Rights-of-way Management, San Diego, California, February 1982; preparation of Environmental Impact Appraisals, Westinghouse Electric Corporation, Waltz Mill Site and Combustion Engineering, Inc., Nuclear Fuel Fabrication Plant; Draft Environmental Analysis of the Operation of the Oak Ridge National Laboratory; DEIS, Teton-Nedco Project; ORNL-5911, *Preparation of Environmental Analyses for Synfuel and Unconventional Gas Technologies*.

Advisor:

Secondary advisor, Steven Seagle, Ph.D., The University of Tennessee, Knoxville; Kevin Kritz, B.S., University of Wisconsin-Stevens Point.

Ad hoc reviewer:

Condor.

KRUMMEL, J. R.**Participant:**

Symposium on Agroecosystems at 33rd Annual Meeting of American Institute of Biological Sciences, College Station, Pennsylvania, August 1982.

Ad hoc reviewer:

Science; National Academy of Sciences.

Other:

Secretary/treasurer, Society of Human Ecology.

LEE, S. Y.**Participant:**

Annual Meeting of the Soil Science Society of America, Atlanta, Georgia, November 1981; Annual Meeting of Clay Minerals Society, Urbana-Champaign, Illinois, October 1981; Southeastern Regional Clay Committee, Knoxville, Tennessee, May 1981.

Ad hoc reviewer:

Journal of Environmental Quality, *Soil Science of America Journal*, *Health Physics Journal*.

LINDBERG, S. E.**Chairman:**

Vice-chairman, Committee on Data Management and Interpretation, National Atmospheric Deposition Program.

Member:

Conference Organizing Committee, International Conference on Heavy Metals in the Environment; MAP3S/RAINE Program, Network for Precipitation Chemistry; DOE Program Review Team, Illinois State Water Survey, Atmospheric Chemistry Department; Committee on Dry Deposition Methodology, National Atmospheric Deposition Program.

Participant:

Workshop, Atmospheric Deposition Effects Plan, Oak Ridge, December 1981; EPRI Survey, Determining Health Effects of Inhalable Fly Ash, April 1982; DOE Review of NOAA Atmospheric Turbulence and

Diffusion Laboratory, Oak Ridge, April 1982; EPA Dry Deposition Methodology Intercomparison Study, Champaign, Illinois, June 1982; Session on Impacts of Airborne Heavy Metals, 75th Annual Meeting Air Pollution Control Association, New Orleans, Louisiana, June 1982; EPRI Integrated Lake Watershed Study Workshop on Modelling Basin Input and Canopy Processes, Lafayette, California, August 1982.

Ad hoc reviewer: *Environmental Science and Technology; Science; Metals in the Hydrologic Cycle*, Springer-Verlag; NSF, DOE, ACS.

LOAR, J. M.

Chairman: Work Group on Aquatic Habitats, Oak Ridge Reservation Resource Management Plan Committee.

Participant: U.S. Army Corps of Engineers Workshop on Environmental Impacts of Small-Scale/Low-Head Hydropower Development, St. Louis, Missouri, March 1981; Working Group Chairman, American Fisheries Society Coldwater Workshop on Hydropower Development and Fisheries Impacts and Opportunities, Cornell University, Ithaca, June 1982.

Ad hoc reviewer: Proposals, DOE.

LUXMOOR, R. J.

Member: S-124 Regional Technical Committee on Soil Water Research.

Participant: Workshop on Methods and Techniques of Extrapolation of Controlled Environment Research with High CO₂ Levels to Field Application, Atlanta, Georgia, January 1982; International Conference on Rising Atmospheric Carbon Dioxide and Plant Productivity, Athens, Georgia, May 1982.

Faculty: Member of the Plant Physiology and Genetics Programs, Life Sciences Graduate Program, The University of Tennessee, Knoxville.

Advisor: Mary H. Ward, M.S., The University of Tennessee, Knoxville.

Ad hoc reviewer: *Agronomy Journal, Journal of Environmental Quality, Soil Science Society of America Journal, Water Resources Research, American Society of Agronomy*; book chapter; EPA report.

MCCRAY, J. F.

Member: Environmental Quality Advisory Board, City of Oak Ridge, Tennessee.

Participant: The University of Tennessee/ORNL workshop: The engineer/scientist as a manager, Oak Ridge, Tennessee, May 17-20, 1982; ORNL workshop: Interpersonal Effectiveness, ORNL, October 1981. Project manager, Alcohol Fuels Environmental Project. Preparation of Agrifuels Refining Corporation Loan Guarantee EA; Circle Energy Corporation Loan Guarantee EA; New England Ethanol Corporation Loan Guarantee EA; Eastern Ethanol Corporation Loan Guarantee EA; Energy Conversion Corporation Loan Guarantee EA; Gulf Coast Resources Loan Guarantee EA; Minnesota Alcohol Producers Loan Guarantee EA; New Energy Corporation of Indiana Loan Guarantee EA; Tennol, Inc., Loan Guarantee EA; U.S. Ethanol Corporation Loan Guarantee EA; Generic

Environmental Assessment Report for Conventional Fuel Alcohol Plants;
Draft Shallow Land Burial Handbook.

Ad hoc reviewer: *Pedobiologia, Journal of Arid Environments, Ecology, Canadian Journal of Zoology, Environmental Science and Technology*; proposals, NSF.

McCARTHY, J. F.

Chairman: Session Chairman, Comparative Physiology and Biochemistry, American Society of Zoologists, Dallas, Texas, December 27-30, 1981.

Member: Panel of aquatic experts for risk assessment evaluation by the analytical hierarchy method.

McLAUGHLIN, S. B.

Member: TE-2 Agricultural Effects Committee of National Air Pollution Control Association.

Other: Program coordinator, EPA program on Effects of Acid Deposition on Natural Terrestrial Systems.

Advisor: Roger Walker, postdoctoral research; Tom Doyle, Ph.D., University of Tennessee, Knoxville; Paul Oleksa, visiting professor, Kalamazoo College, Kalamazoo, Michigan.

Ad hoc reviewer: *Horticultural Science, Science, Journal of Environmental Quality*; U.S. Forest Service, U.S. Park Service, EPA.

MILLEMANN, R. E.

Chairman: Education Committee, Environmental Sciences Division.

Participant: Preparation of Guidance Manual for Department of Energy Compliance with the Toxic Substances Control Act.

Faculty: Adjunct Professor, The University of Tennessee, Knoxville.

Ad hoc reviewer: *Environmental Technology Letters*.

MORAN, MARY S.

Participant: Fourth Annual DOE LLWMP Participants' Information Meeting, Denver, Colorado, August-September 1982. Preparation of: LLWMP Position Paper, Verification and Validation Protocols for Low-Level Waste Disposal Site Performance Models.

Ad hoc reviewer: Proposals, DOE LLWMP.

Other: National Water Well Association's resident scientific expert, ground water pollution, state of Tennessee.

MULHOLLAND, P. J.

Chairman: Session chairperson, Riverine Processes, American Society of Limnology and Oceanography Annual Meeting, Raleigh, North Carolina, June 1982.

Participant: Workshop on Tropical Wetlands in the Global Carbon Cycle, The Institute of Ecology, Indianapolis, Indiana, June 1982.

Ad hoc reviewer: *Canadian Journal of Fisheries and Aquatic Science Ecology*, Water Resources Research; proposals, NSF; reports, U.S. Fish and Wildlife Service.

NEWBOLD, J. D.

Ad hoc reviewer: *Ecology*, proposals, NSF.

NORBY, R. J.

Participant: Planning workshop, Atmospheric Deposition Effects Program, Oak Ridge, Tennessee, December, 1981; Annual Meeting of the American Society of Plant Physiologists, Urbana, Illinois, June, 1982; Rapporteur, CO₂ Research Conference: Carbon Dioxide, Science, and Consensus, Berkeley Springs, West Virginia, September 1982.

Ad hoc reviewer: *New Phytologist*; U.S. Forest Service.

NUNGESSER, M. K.

Member: Environmental Quality Subcommittee, Tennessee-Tombigbee Corridor Study, U.S. Army Corps of Engineers, Nashville and Mobile Districts; Environmental Quality Subcommittee Task Force, Tennessee-Tombigbee Corridor Study, U.S. Army Corps of Engineers, Nashville and Mobile Districts.

Participant: Chairman, Moderator, and Judge, Graphics Sessions, 1982 SAS (Statistical Analysis Systems) Users Group International Conference, San Francisco, California, February 14-17, 1982; Cochairman and Judge, Geographic Data Bases and Display Session, 1982 SAS Users Group International Conference, San Francisco, California, February 14-17, 1982; Integrated Data Users Workshop, Reston, Virginia, October 14-15, 1982.

Advisor: Darla J. Juhl, B.S., Kearney State College, Kearney, Nebraska.

Ad hoc reviewer: DOE; proposals, TVA.

OLSEN, C. R.

Participant: NOAA Workshop on Pollutant Transport by Particles in the Marine Environment, January 19-21, 1982, Norfolk, Virginia; EPA Review Committee on Metal Modeling Projects, December 7-9, 1981, Athens, Georgia; DOE Workshop on Plutonium and Cesium Transport by Rivers, October 18-20, 1982, Hickory Knobb, South Carolina.

Advisor: Thesis committee, James Todd, Ph.D., Old Dominion University, Norfolk.

Ad hoc reviewer: *Environment International*, *Canadian Journal of Earth Sciences*.

OLSON, J. S.

Cochairman: Cochairman and organizer, Environmental Consequences of Energy Development: Global CO₂, for Third International Conference on Energy Use Management, October 1981.

Member: International Union of Forest Research Organization (IUFRO) Research Group S 1.01.06: Tropical and Subtropical Forest Ecosystems.

Participant: U.S. DOE Carbon Cycle and Climate Program Reviews: December 14-16, 1981, Gaithersburg, Maryland; September 1982, Berkeley Springs, West Virginia; Conference on the Biotic Contributions to the Global Carbon Cycle, Woods Hole, Massachusetts, February 1982.

- Faculty:** Professor, Botany Department and Ecology Graduate Program, The University of Tennessee, Knoxville.
- Advisor:** Richard Busing, M.S., The University of Tennessee, Knoxville.
- Ad hoc reviewer:** *Ecology, Science, Climate Change.*
- Other:** Editorial Board, Ecological Studies, Springer-Verlag, Inc.
- OLSON, R. J.**
- Member:** Planning Committee, 1982 Integrated Data Users Workshop.
- Participant:** 1981 Integrated Data Users Workshop, Reston, Virginia, October 1981.
- O'NEILL, E. G.**
- Participant:** Annual Meeting, Southeastern Branch of the Entomological Society of America, Mobile, Alabama, January 1982; Introduction to Radionuclides Course, Oak Ridge Associated Universities, Oak Ridge, Tennessee, August 5-20, 1982.
- O'NEILL, R. V.**
- Member:** National Academy of Sciences Committee on Planetary Science.
- Faculty:** Adjunct Associate Professor, The University of Tennessee, Knoxville; Visiting Scientist, Ecosystem Research Center, Cornell University, Ithaca, New York.
- Ad hoc reviewer:** *Ecology*, proposals, NSF.
- PARR, P. D.**
- Member:** Resources Management Plan Committee, Endangered and Threatened Plant Species Section.
- Participant:** Eighth Annual Scientific Research Meeting for the Uplands Area of the Southeast Region, National Park Service, Tremont, Tennessee, June 1982; 1982 UCC-ND and GAT Environmental Protection Seminar, Gatlinburg, Tennessee, April 1982; 43rd Annual Meeting of the Association of Southeastern Biologists, Richmond, Kentucky, April 1982; ORNL in-house course, Water Cycle and Environmental Transport, Winter 1982; ESD Short Course on Regression Diagnostics and Robust Regression, Summer 1982.
- PENG, T.-H.**
- Participant:** Workshops on TTO preliminary results and plan for follow-ups, March 15-19, 1982, Woods Hole Oceanographic Institution, Woods Hole, Massachusetts; Geophysical Fluid-Dynamics: Symposium on Chemical and Biological Tracers in Fluids; July 26-29, 1982, Woods Hole Oceanographic Institution, Woods Hole, Massachusetts; Research Conference on Carbon Dioxide, Science and Consensus, September 19-23, 1982, Coolfont Conference Center, Berkeley Springs, West Virginia.
- Ad hoc reviewer:** *Journal of Geophysical Research, Geophysical Research Letter*, proposals, NSF, DOE.

POST, W. M.

Ad hoc reviewer: *American Naturalist, Journal of Theoretical Biology*, NSF, DOE, American Philosophical Foundation.

REED, R. M.

Participant: Session Chairman, Environmental Effects and Land Reclamation, Institute of Gas Technology Symposium on Peat as an Energy Alternative II, Arlington, Virginia, December 1981; Habitat Evaluation Procedures Short Course, U.S. Fish and Wildlife Service, Atlanta, Georgia, November 1981; Health Physics Short Course, Oak Ridge Associated University, September 1982.

Witness: Ontario Municipal Board hearing into Amendment No. 12 (Conservation Lands Amendment) to the Regional Official Plan, Ottawa, Ontario, May 1982.

Other: Professional Certification as Senior Ecologist by the Ecological Society of America, July 1982.

REICHLE, D. E.

Member: National Board of Governors, The Nature Conservancy; Environment Project Advisor Group, Gas Research Institute; Advisor Panel for Ecosystem Studies, NSF; Air Quality Task Group, Committee on Environmental Conservation, National Petroleum Council; Admissions Committee, Graduate Program in Ecology, The University of Tennessee.

Participant: Program management team, Carbon Cycle Research, Carbon Dioxide Effects Division, DOE; ORNL: Site Development and Design Review Committee; Environmental Protection GPP Review Group.

Faculty: Adjunct Professor, Graduate Program in Ecology, The University of Tennessee, Knoxville.

Advisor: Christopher Craft, M.S., The University of Tennessee, Knoxville; Steven W. Seagle, Ph.D., The University of Tennessee, Knoxville.

Ad hoc reviewer: *Ecology, Science, BioScience*, Cambridge University Press, Springer-Verlag, Academic Press; proposals, DOE, NSF, USGS, USDA.

Other: Editorial Board, *Pedobiologia*; Series Editor, Advance Texts in the Life Sciences, Springer-Verlag.

RICHTER, D. D.

Member: Secretary, Southern Forest Environment Research Council, 1982-1983.

Participant: Fifth Annual Madison Conference on Waste Management, Madison, Wisconsin, September 1982; Water—A Resource in Demand, Southern Forest Environment Research Council, Texas A&M University, College Station, August 1982.

Ad hoc reviewer: *American Journal of Botany; Environmental International*; proposals, NSF, U.S.-Israel BSF.

SALE, M. J.

Member: ESD/ORNL Computer Advisory Committee; Comprehensive Environmental Studies for the Tennessee-Tombigbee Waterway, U.S. Army Corps of Engineers.

Participant: Invited speaker, Hydropower Development and Fisheries Impacts and Opportunities, New York Chapter of the American Fisheries Society and the New York State Department of Environmental Conservation, Ithaca, New York, June 1982; lecturer, The Water Cycle and Environmental Transport, ORNL Technical Continuous Education Course B-400; Scheduling Reservoir Releases for Optimal Power Generation, Special Energy Management Course, The University of Tennessee, Knoxville, June 1982.

Ad hoc reviewer: *Water Resources Research.*

Other: Technical support to the Division of Geothermal and Hydropower Technologies, Office of Renewable Energy, DOE, for proposal review, contract monitoring, and development of long-range research needs.

SHRINER, D. S.

Member: Technical Council, TE-2 Agricultural Effects Committee, Air Pollution Control Association; Scientific Advisory Board, National Atmospheric Deposition Program; technical advisor, NAS/NRC Committee on Atmosphere and the Biosphere, Sulfur Oxides Subcommittee and Pollution Effects on Plants Committee, American Phytopathological Society.

Participant: Annual Meeting, Air Pollution Workshop, April 1982, Riverside, California; EPA Project Review, Raleigh, North Carolina, February 1982; Formal Review of the Long-Range Operating Plan of the ITFAP, September 1982.

Faculty: Adjunct Professor, Department of Plant Pathology and Physiology, Virginia Polytechnic Institute and State University.

Advisor: Matthew Mahoney, Ph.D., Virginia Polytechnic Institute and State University, Blacksburg; Virginia C. I. Klarer, M.S., North Carolina State University, Raleigh.

Ad hoc reviewer: *Science, Journal of the Air Pollution Control Association, Journal of Environmental Quality, Environmental and Experimental Botany*; EPA; proposals. NSF, DOE, EPRI, EPA.

SHUGGART, H. H.

Member: UNESCO Expert Panel on Systems Ecology.

Faculty: Part-time full professor, Ecology Program/Department of Botany, University of Tennessee.

Advisor: Daryl Moorhead, Ph.D.; Juan Saldarriaga, Ph.D.; John Schutt, Ph.D.; Tom Doyle, Ph.D.; Don Weller, Ph.D.; Steve Seagle, Ph.D.; A. Hansen, Ph.D., The University of Tennessee, Knoxville.

Ad hoc reviewer: *Ecology, American Naturalist, Australian Journal of Ecology.*

Other: Associate Editor, *Ecology and Ecological Monographs.*

SIGAL, L. L.

Participant: Fifth Annual Environmental Impact Statement Conference, Atlanta, Georgia, October 1981; National Program for Acid Deposition, Task I Workshop, Brookhaven National Laboratory, Long Island, New York,

January 1982; Environmental Regulations Course, Arlington, Virginia, January 1982; XIV Air Pollution Workshop, University of California, Riverside, California, April 1982; 8th Annual Scientific Research Meetings, The Uplands Areas of the Southeast Region, National Park Service, Tremont, Tennessee, June 1982; Annual Meeting American Institute of Biological Sciences, University Park, Pennsylvania, August 1982. Preparation of Draft of Coal Use Handbook for Army Installation Heating Plants, Department of Army, Fort Belvoir, Virginia, and Environmental Resources of the Tennessee-Tombigbee Corridor, Reports 1-10, U.S. Army Corps of Engineers, Nashville, Tennessee.

Ad hoc reviewer:

Canadian Journal of Botany, Environmental International.

Other:

Editor, *Tennessee Native Plant Society Newsletter*.

SMITH, E. D.

Participant:

Atomic Industrial Forum's Fuel Cycle Conference '82, New York, New York. March 22-24, 1982; preparation of: Guidance Manual for DOE Compliance with the Underground Injection Control Program, Review of Quantitative Methods for Evaluating UMTRAP Environmental Impacts, and Review of Recent Developments and Potential Environmental Issues in Geologic Isolation of High-Level Radioactive Waste.

SOLOMON, A. M.

Participant:

Seventh Biennial Meeting, American Quaternary Association, Seattle, Washington, June 1982; Second International Aerobiology Conference, Seattle, Washington, August 1982; Annual Meeting, American Institute for Biological Sciences, Ecological Society of America, Botanical Society of America, State College, Pennsylvania, August 1982.

Ad hoc reviewer:

Palynology, proposal, John Simon Guggenheim Memorial Foundation.

Other:

Editor, *Newsletter of the American Quaternary Association*; Secretary, Paleocology Section, Ecological Society of America, 1980-1982; member, Education Committee, Ecological Society of America, 1982-1983; member, Murray F. Buell Award Committee, Ecological Society of America, 1979-1983.

SOLOMON, J. A.

Participant:

EPRI Advisory Committee Meetings, Legionnaires' Disease Project, Atlanta, Georgia, November 1981 and March 1982; American Institute of Biological Sciences Annual Meeting, Pennsylvania State University, State College, Pennsylvania, August 1982; American Society for Microbiology 82nd Annual Meeting, Atlanta, Georgia, March 1982; Electron Microscopy Society of America Annual Meeting, Washington, D.C., August 1982.

SOUTHWORTH, G. R.

- Member:** American Chemical Society; Society for Environmental Toxicology and Chemistry.
- Participant:** Gordon Conference, Environmental Sciences: Water, New Hampton, New Hampshire, June 1982.
- Ad hoc reviewer:** *Environmental Science and Technology*; proposals, NSF.

SPALDING, B. P.

- Ad hoc reviewer:** *Journal of Environmental Quality, Soil Science Society of America Journal*; proposals, NSF.

STOW, S. H.

- Chairman:** ORNL Geosciences Committee.
- Member:** Fellow, Geological Society of America; Alabama Geological Society; Georgia Geological Society; Geochemical Society; International Geologic Correlation Program on Volcanic Rocks; American Geophysical Union; Society of Economic Geologists.
- Participant:** National Geological Society of America Meeting, Cincinnati; Southeastern Geological Society of America Meeting, Washington, D.C.; ONWI Annual Information Meeting, Columbus, Ohio; Life Sciences Seminar on Hazardous Waste, Gatlinburg, Tennessee; UCC-ND Management Program Course.
- Faculty:** Part-time professor, The University of Tennessee; Adjunct Professor, The University of Alabama.
- Advisor:** L. Long, M.S.; D. Whittington, M.S.; L. Bundschu, M.S.; M. Steltenpohl, M.S., The University of Alabama, Tuscaloosa; A. Strange, M.S.; K. Fronabarger, Ph.D., The University of Tennessee, Knoxville.
- Ad hoc reviewer:** *Geochimica et Cosmochimica Acta*; NSF.
- Other:** Secretary-treasurer, Southeastern Section of the Geological Society of America; Member of Student Support Committee, Southeastern Section Geological Society of America; Member of Hydrology Committee, City of Farragut, Tennessee; Member of UCC-ND Central Waste Disposal Committee.

STRATTON, L. E.

- Chairman:** Corrective Measures Criteria Review Committee for the Shallow Land Disposal of Low-Level Radioactive Waste, DOE.
- Member:** Scientific Committee 41 on Radiation Resulting from Nuclear Power Generation, National Council on Radiation Protection and Measurements.
- Participant:** Technical secretary of the Third Annual Information Meeting of the DOE Low-Level Waste Management Program New Orleans, Louisiana, November 4-6, 1981; Technical secretary of the Fourth Annual Information Meeting of the DOE Low-Level Waste Management Program, Denver, Colorado, August 31-September 2, 1982.

SUTER, G. W., II

- Ad hoc reviewer:** *Environmental Management*.

TAMURA, T.

- Member:** EPRI Solid Waste Advisory Committee; UMTRAP/DOE Liners Task Group; Executive Committee, Environmental Division/ANS; NAEG Site Cleanup Committee.
- Participant:** OHER/DOE Workshop on Solid Waste Leaching Modeling, Germantown, Maryland, June 1982.
- Faculty:** Adjunct Professor, Graduate Program in Geology, The University of Tennessee, Knoxville.
- Ad hoc reviewer:** American Society of Agronomy; *Health Physics*; *Journal of Environmental Quality*.

TAYLOR, F. G.

- Chairman:** Oak Ridge DOE Reservation Resource Management Plan Committee.
- Participant:** Eighth Annual Science Research Meetings for the Uplands Area of the Southeast Region, National Park Service, Tremont, Tennessee, June 24-25, 1982; International Fluoride Symposium, Utah State University, Logan, Utah, May 24-27, 1982.
- Advisor:** Rick Young, ORAU Undergraduate Participant, B.S., University of Wisconsin, Stevens Point, Wisconsin.
- Other:** Traveling Lecture Program, DOE, 1981-1982; Recording Secretary, Tennessee Native Plant Society, 1982.

TAYLOR, G. E.

- Chairman:** XIV Air Pollution Workshop, University of California, Riverside, California, April 1982.
- Member:** Executive Steering Committee, Air Pollution Workshop; Natural Sources Task Group, Interagency Task Force on Acid Precipitation.
- Participant:** Session Chairman, Annual Meeting, Air Pollution Workshop, Riverside, California, April 1982; Annual Meeting, American Society of Plant Physiologists, Champaign-Urbana, Illinois, June 1982; Annual Meeting, American Society for Horticultural Science, August 1982; Introduction to Radionuclides, Training Program, Oak Ridge Associated Universities, Oak Ridge, Tennessee, August 1982.
- Advisor:** Eloise B. Carter, Ph.D., Emory University, Atlanta, Georgia.
- Ad hoc reviewer:** *New Phytologist*, *Journal American Society for Horticultural Science*, *Environment International*, *USEPA Ecological Research Series*; proposals, EPA, USFWS, DOA, DOE.

TOLBERT, V. R.

- Member:** RAMP (Rural Abandoned Mines Program, State Implementation Committee); North American Benthological Society, Special Committee on Membership 1982.
- Participant:** Preparation of U.S. Nuclear Regulatory Commission, 1982, Combustion Engineering, Inc., License Renewal, Draft Environmental Impact Statement; U.S. Nuclear Regulatory Commission, 1982, General Atomic Co., License Renewal, Draft Environmental Impact Statement; U.S.

Nuclear Regulatory Commission, 1982, Westinghouse Advanced Reactors Division, License Renewal, Draft Environmental Impact Statement; Staff Position Paper on Need for Water Quality/Sediment Monitoring for Edgemont Mill Tailings Decommissioning, prepared for U.S. Nuclear Regulatory Commission; U.S. Nuclear Regulatory Commission—Final EIS Edgemont Uranium Mill Tailings Decommissioning, June 1982; U.S. Nuclear Regulatory Commission, Babcock & Wilcox Commercial Nuclear Plant, License Renewal, August 1982.

Advisor:

Abby Goldsmith, B.S., Biology, Emory University, Atlanta, Georgia.

Ad hoc reviewer:

Environmental Entomology.

TRABALKA, J. R.**Member:**

ORNL Seed Money Proposal Review Committee; ORNL Professional Education Resource Committee for Life Sciences.

Participant:

Annual Meeting of the Society for Environmental Toxicology and Chemistry, Arlington, Virginia, November 1981; DOE-sponsored CO₂ Research Conference, Carbon Dioxide, Science, and Consensus, Coolfont, West Virginia, September 1982.

Ad hoc reviewer:

DOE, ORAU.

TURNER, R. R.**Chairman:**

ESD Seminar Committee.

Member:

ESD Hazardous Chemical Safety Committee.

Participant:

4th Annual Life Sciences Symposium, Environment and Solid Waste: Characterization, Treatment, and Disposal, Gatlinburg, Tennessee, October 4-8 1981; AIChE Symposium, Solid Waste Disposal from Coal Conversion Plants, Cleveland, Ohio, August 31, 1982.

Ad hoc reviewer:

Environment International, Journal of Environmental Quality; Mississippi River Research Consortium, National Park Service Uplands Field Research Laboratory, EPRI, NSF.

TYNDALL, R. L.**Participant:**

Discussion leader, Workshop on Industrial Microbial Pathogens sponsored by Society of Cosmetic Chemists, New York City, December 1981.

Faculty:

Research Associate Professor, Zoology Department, The University of Tennessee, Knoxville.

Advisor:

Audrey Nicholson, Ph.D., Zoology Department, The University of Tennessee, Knoxville.

Consultant:

Northern States Power, Minneapolis, Minnesota Salt River Project, Phoenix, Arizona.

VAN WINKLE, W.**Member:**

Committee on Professionalism, American Fisheries Society.

Participant:

Hudson River Conference, Natural Resources Defense Council, New York University Law School, New York, December 1981; DOE/OHER Meeting on Freshwater Systems and National Environmental Research

Parks, Germantown, Maryland, January 1982; U.S. Environmental Protection Agency Acidic Deposition Ecological Effects Research Peer Review Workshop, Raleigh, North Carolina, February 1982; Project Advisory Committee Meeting, Legionnaires' Disease Bacterium in Power Plant Cooling Systems, EPRI, Atlanta, Georgia, March 1982; Workshop on Southern Appalachian Acid Precipitation Research Plan, Asheville, North Carolina, March 1982; and Eighth Annual Scientific Research Meeting, Great Smoky Mountains National Park, June 1982.

Faculty: Adjunct Professor, Graduate Program in Ecology, The University of Tennessee, Knoxville.

Ad hoc reviewer: *Canadian Journal of Fisheries and Aquatic Sciences, Fishery Bulletin, Science, Transactions of the American Fisheries Society, Estuarine Research Foundation.*

VAUGHAN, D. S.

Participant: Fish Health Workshop, Geneva Park, Ontario, Canada, November 1981; 112th Annual Meeting of the American Fisheries Society, Hilton Head Island, South Carolina, September 1982. Preparation of proposal on Advancing the Science of Assessment: Technical Lessons from the Hudson River Power Plant Case, EPRI.

Ad hoc reviewer: *Fisheries Bulletin, Journal of Great Lakes Research, Transactions of the American Fisheries Society*, proposals, Sea Grant (NOAA).

Other: Co-covonor of symposium, Advancing the Science of Assessment: Technical Lessons from the Hudson River Power Plant Case, 112th Annual Meeting of the American Fisheries Society, Hilton Head Island, South Carolina, September 1982.

VOORHEES, L. D.

Member: Committee on Roadside Maintenance, Transportation Research Board for the National Research Council.

Participant: Project Management Seminar, ORNL Management Resource Development Program, July 13-15, 1982; Introduction to Health Physics, Oak Ridge Associated Universities, Oak Ridge, Tennessee, September 8-17, 1982. Preparation of FES related to the decommissioning of the Edgemont uranium mill, South Dakota; DEIA related to General Atomic fuel fabrication facility, California; DEIA related to Babcock and Wilcox commercial fuel fabrication facility, Virginia; draft report for NRC, Guidance for Disposal of Uranium Mill Tailings: Long-term. Stabilization of Earthen Cover Materials.

Ad hoc reviewer: Board on Agricultural Renewable Resources for the National Research Council.

Other: Technical advice to Office of Environmental Compliance, DOE, related to interagency review of NEPA-related documents.

WALTON, B. T.

Member: Committee on Systematic Resources, Entomological Society of America, 1982-1985.

Participant: Tennessee Entomological Society Annual Meeting, Nashville, Tennessee, October 1981; U.S. Department of Energy Symposium on Energy and Environmental Processes in Terrestrial Systems, Gaithersburg, Maryland, March 1982; Entomological Society of America Annual Meeting, San Diego, California, November 1981; Joint Meeting of the American Society of Pharmacology and Experimental Therapeutics and the Society of Toxicology, Louisville, Kentucky, August 1982; IUPAC Fifth International Congress of Pesticide Chemistry, Kyoto, Japan, September 1982.

Advisor: J. E. McCachern, B.S., Emory University, Atlanta, Georgia; E. R. Merchant, M.S., The University of Tennessee, Knoxville.

Ad hoc reviewer: *Toxicology, Annals of the Entomological Society of America, Environmental Entomology, Journal of Economic Entomology, Environment International, Bulletin of the Entomological Society of America*; proposals, NSF.

Other: Program Chairperson, Fourth Annual Meeting of the Society of Environmental Toxicology and Chemistry.

WATTS, J. A.

Participant: Color Computer Graphics Workshop, ORNL in-house course, March 3-April 7, 1982; Career Planning Workshop, UCC-ND Career Planning Program, June 22-August 6, 1982, ORNL; Fourth Conference on Ocean-Atmosphere Interactions, June 8-10, 1982, San Diego, California; Numeric Data Workshop, June 16, 1982, sponsored by Information Division, ORNL; Solar-Terrestrial Influences on Weather and Climate International Symposium, August 1-6, 1982, Boulder, Colorado; CO₂ Indirect Effects Program Review and Planning Meeting, August 17-19, 1982, Battelle Pacific Northwest Laboratory, Richland, Washington; CO₂ Research Conference, September 19-23, 1982, Coolfont Conference Center, Berkeley Springs, West Virginia; Climate and First Detection Workshop, CO₂ Research Conference, September 23, 1982, Coolfont Conference Center, Berkeley Springs, West Virginia.

WEBB, J. W.

Participant: Preparation of EAS, Energy Conversion Corporation, Alcohol Fuels Loan Guarantee Program; EA, Minnesota Alcohol Producers, Alcohol Fuels Loan Guarantee Program; New Energy Corporation, Alcohol Fuels Loan Guarantee Program; and Eastern Ethanol Ltd., Alcohol Fuels Loan Guarantee Program. Preparation of Draft Guidance Manual for DOE Compliance with Floodplains and Wetlands Regulations; Draft Evaluation of Environmental Mitigation and Monitoring Commitments at Four Geopressure Design Wells; and Draft Guidance Manual for Disposal of Uranium Tailings.

Advisor: Christopher Craft, M.S., The University of Tennessee, Knoxville.
Ad hoc reviewer: *Annals of the Entomological Society of American, Environmental Entomology, Ecology*; proposals, NSF.

WEST, D. C.
Faculty: Adjunct Professor, The University of Tennessee, Knoxville.

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American Institute of Fishery Research Biologists.

C. C. COUTANT

Union Carbide Corporation Community Service Award.

DAVID K. COX

Certified as a Fisheries Scientist by the American Fisheries Society.

K. L. DANIELS, J. C. GOYERT, R. H. STRAND, AND M. P. FARRELL

Award for best paper of Biometrics/Applied Statistics Session of the Seventh Annual SAS Users Group, International Conference: A general linear models approach for comparing the response of several species in acute toxicity tests.

J. F. McBRAYER

Certified as a Senior Ecologist by the Ecological Society of America, July 1982.

GEORGE E. TAYLOR

Research award for published manuscript, Ozone flux in *Glycine max* (L.) Merr.: Sites of regulation and relationship to leaf injury, *Oecologia* 53:179-186. Award from Environmental Protection Agency's Corvallis Environmental Research Laboratory, Corvallis, Oregon.

D. S. VAUGHAN

Certified as a Fisheries Scientist by the American Fisheries Society, December 1981; member, Sigma Xi, Oak Ridge Chapter, October 1981.

B. T. WALTON

Diplomate of the American Board of Toxicology (certified in general toxicology).

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