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**ENVIRONMENTAL
SCIENCES
DIVISION**

ANNUAL PROGRESS REPORT
Period Ending September 30, 1978

Environmental Sciences Division Publication No. 1280

OAK RIDGE NATIONAL LABORATORY
OPERATED BY UNION CARBIDE CORPORATION · FOR THE DEPARTMENT OF ENERGY

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ENVIRONMENTAL SCIENCES DIVISION

ANNUAL PROGRESS REPORT

For Period Ending September 30, 1978

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Environmental Sciences Division Publication No. 1280

Date Published: April 1979

NOTICE
This document contains information of a preliminary nature. It is subject to revision or correction and therefore does not represent a final report.

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Oak Ridge, Tennessee 37830
operated by
UNION CARBIDE CORPORATION
for the
DEPARTMENT OF ENERGY

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ENVIRONMENTAL SCIENCES LABORATORY COMPLEX, UPDATED

The new Environmental Sciences Laboratory (ESL) complex has now been occupied for approximately one year. Occupancy and landscaping have served to increase pride in the new facility.

Features of the building are conservation of energy and time, efficiency of services and personnel interaction, and economy of scale and support facilities. Slope, drainage, and soils in the 250-ft "Environmental Panorama" at the back of the building provide characteristic regional plant habitats: moist mountain coves, cool mountain slopes, high mountains, dry mountain slopes, dry uplands, moist uplands, and bottom lands. These unique recreations of native vegetation associations establish the environmental character of the laboratory's research function.

The ESL, constructed with many safety features in mind, is designed to resist the forces caused by earthquake motions. Seismic activities corresponding to the intensity of VII of the Modified Mercalli Intensity Scale are not expected to create any special risk or safety hazard in the complex. The building was built to withstand a maximum wind speed of approximately 100 mph. Because the probability of winds much in excess of 100 mph in a time span of 100 years has been estimated at 0.327, the risk from tornadoes is low. Flooding is not considered to be a safety hazard because of the location and elevation of the ESL.

Provisions for the storage and use of tracer quantities of radioisotopes in laboratories in the ESL follow procedures and practices for radiation protection given in the ORNL Health Physics Manual. The Radiation Control Officer, representing the Division Director, has the responsibility of assuring compliance with administrative control procedures to ensure safe handling, use, and storage of radioactive materials. Also, strict control procedures in the storage and use of the small amounts of carcinogenic materials involved in division research ensure a low potential hazard.

The ESL complex is designed to minimize the likelihood of occurrences of fires and consequences of fires, should they occur; Type-II fire resistive construction provides, in most cases, fire resistance for no less than four hours. The complex is equipped with a wet pipe sprinkler system, designed to conform to specifications in NFPA Pamphlet No. 13 for ordinary hazard occupancy. The fire alarms can be activated manually or by the sprinkler water flow rate monitors and are provided with emergency power.

The electrical system for the ESL complex is designed for a nonhazardous facility meeting the applicable specifications of the National Electric Safety Code and other federal and local guidelines. An emergency generator, driven by a diesel engine with a 48-hour fuel tank and automatic starting capability, is available in the event of a loss of the normal power supply. Emergency lighting, exit signs, critical laboratory equipment including life-support systems, monitoring devices, and the fume hood ventilation system are provided with emergency power.

In addition, to these special features, the building contains many points of interest to visitors as well as to personnel from other divisions at the Laboratory and from the other plants. The following pictures show the facilities as the employees and visitors see them today.

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Conference Center Lobby

Library

Word Processing Center

Computer Center

Earth Sciences Research Laboratory

Muffle Furnace and Oven Room

Analytical Chemistry Laboratory

Radiation Counting Laboratory

Controlled Environment and Animal Building (CEAB)

CEAB Coal Laboratory

CEAB Growth Chamber Room

CEAB Toxic Materials
Exposure Laboratory

CEAB Greenhouse

ENVIRONMENTAL SCIENCES DIVISION AWARDS AND HONORS

W. J. BOEGLY, Jr.

Communication Competition Award of Achievement in the category of technical reports. Presented by the East Tennessee Chapter of the Society for Technical Communication in the 1978 STC Technical Publications Competition.

E. G. STRUXNESS

Honorary Doctor of Science Degree, presented by the Regents and Faculty of Luther College, Decorah, Iowa, October 1977.

LINDA J. SVOBODA

Best Student Paper: "Analysis of Nonlinear Matrix Equations for Fish Population Dynamics, presented at the Society for Industrial and Applied Mathematics, Southeastern Atlantic Section, Clemson, South Carolina, April 1978. The paper was based on a Master's degree thesis done under the direction of D. L. DeAngelis.

WEBSTER VAN WINKLE

Communication Competition Award of Excellence in the category of conference proceedings. Presented by the East Tennessee Chapter of the Society for Technical Communication in the 1978 STC Technical Publications Competition.

PART II. ENVIRONMENTAL SCIENCES DIVISION PROGRAMS

1. ENVIRONMENTAL IMPACTS PROGRAM¹

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Introduction

The Environmental Impacts Program (EIP) is responsible for environmental impact statement (EIS) preparation and related activities in the Environmental Sciences Division. This impact statement work is a cooperative effort with the ORNL Energy Division, in which the EIP deals with terrestrial and aquatic ecology and land and water use. In this effort the Program assists the Department of Energy (DOE) and the Nuclear Regulatory Commission (NRC) in accomplishing their environmental responsibilities under the National Environmental Policy Act.

The EIP was formally established in May 1974. During its first two years, the Program was involved primarily in the preparation of EISs dealing with proposed nuclear power plants for the U. S. Nuclear Regulatory Commission (then the Regulatory Division of the U. S. Atomic Energy Commission). Since then the Program has become involved with NEPA-related environmental impact assessments in the areas of uranium mining, milling, fuel fabrication, geothermal energy development, demonstration coal conversion

¹Previously Ecological Analyses and Applications Program.

²Dual capacity.

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facilities, enhanced oil recovery pilot projects, and DOE's proposed conversion-to-coal regulations. During the last three years NRC nuclear power plant statements continued to be the primary effort, with geothermal, uranium fuel cycle, and coal conversion efforts being other major activities.

Impact assessments for nuclear power plants (NRC Division of Site Safety and Environmental Analysis) have included both special research studies and NEPA-required EISs. During this reporting period, nearly all effort was on site-specific EISs for both construction and operation permits. While the ecological impacts of entrainment, impingement, forest clearing, etc., are addressed in all EISs for nuclear plants, usually requiring challenging assessments, several proposed plants presented unusually challenging assessments. Some of these are presented below.

Early EIP work related to the uranium fuel cycle involved assessment of expansion of enrichment capacity at the Portsmouth Gaseous Diffusion Plant (DOE), and assessment of uranium mines (both open-pit and in-situ), fuel fabrication facilities, and fuel reprocessing facilities (NRC Division of Fuel Cycle and Material Safety). During this reporting period, staff assessed two in-situ (solution) uranium mines and two open-pit mines with associated mills, and initiated assessment of two uranium mills. Major issues assessed were surface disturbance and siltation of aquatic habitats (open-pit mines), leaching of mill tailings from retention ponds and below-grade tailings pits (mills), and ground-water contamination by leaching solutions (solution mines).

The geothermal assessment activity (DOE Division of Geothermal Energy) centered on nine geothermal projects, including issues on cultural resources, raptor populations, resource ownership, and religious beliefs. For the first time, EIP staff will prepare EISs (in contrast to Environmental Impact Assessments) on a few geothermal projects. Most geothermal projects are located in the western states, where challenging assessment problems are posed by short water supplies, salinization of rivers and lakes, emission of toxic gases and airborne particulates, and endangered or threatened species.

In the coal conversion area, activity was minimal, and primarily involved occasional technical assistance to contractors in developing monitoring programs for proposed demonstration plants. During the next year, EIS preparation will greatly increase activity in this project.

A new activity for the EIP this year is the ecological monitoring development project (DOE Division of Ecological Research). Its purpose is to develop state-of-the-art assessment of ecological effects associated with energy technologies. Work is in progress on three documents: an inventory of existing ecological data on the United States, a summary of state and federal statutory requirements for ecological effects monitoring, and a development of conceptual strategies for the monitoring and assessment of ecological effects in site-specific situations.

In another new activity, EIP staff assessed ten enhanced oil recovery pilot projects (DOE Office of Energy Technology and DOE Environmental Program). These included thermal, chemical injection, and carbon dioxide injection techniques used to extract oil left by conventional techniques, which extract generally only a third of the oil in the formation.

Finally, EIP staff for the first time participated in preparation of an EIS on proposed legislation, the Power Plant and Industrial Fuel Use Act (DOE Economic Regulatory Administration). The EIS dealt with the regional impacts of enacting this legislation, which would require major natural gas and petroleum fuel-burning facilities to convert to coal or other alternative fuels.

Assessment of Nuclear Power Plants

The preparation of environmental impact statements (EIS) for power reactors (NRC Division of Site Safety and Environmental Analysis) continues to constitute a major portion of EIP activities. The EIP is responsible for assessing impacts of plant siting, construction, and operation on terrestrial and aquatic species, communities, and

ecosystems. In addition, EIP is responsible for assessment of land-use impacts. License applications from 13 states were under review during the reporting period (Table 1.1). A comparison with licensing reviews presented in last year's annual report

Table 1.1. Summary of activities of Environmental Impacts Program staff on nuclear power generating stations for the U.S. Nuclear Regulatory Commission - October 1977 through September, 1978.

Plant	Application	Location	Licensing phase ^a				
			Environmental report review	Preliminary draft EIS ^b	Draft EIS ^b	Final EIS ^b	ASLB ^c hearings
Atkins Creek	Construction permit	Texas		X	X	X	
Atlantic Generating Station	Construction permit	New Jersey				X	
Blue Hills	Early site review	Texas				X	
Comanche Peak	Operating license	Texas	X				
Erbe	Construction permit	Ohio			X	X	
Fort Calhoun	Construction permit	Nebraska				X	
Grand Gulf	Operating license	Mississippi	X				
Greene County	Construction permit	New York				X	X
Winstage	Construction permit	Connecticut					X
New England	Construction permit	Rhode Island		X	X		
Offshore Power Systems	Supplement	Florida				X	X
Perkins	Supplement	North Carolina				X	X
San Onofre	Operating license	California		X			
Shoreham	Operating license	New York				X	X
South Texas	Operating license	Texas	X				
Sundesert	Construction permit	California		X	X	X	
Tyrone	Construction permit	Wisconsin					X
Virgil Summer	Operating license	South Carolina		X			

^a"X" indicates EIP staff activity in licensing phase (not necessarily completion of the stage).

^bEIS = Environmental Impact Statement.

^cASLB = Atomic Safety and Licensing Board, written testimony and/or hearings.

(Auerbach et al. 1978) reveals that nine of last year's reviews were inactive this year, and that only three additional reviews (for operating license applications) were

activated this year. In addition, supplemental activity (an alternate site analysis) occurred on the Perkins review. The fact that no new reviews were initiated for construction permit applications reflects the much reduced rate at which new nuclear plants are being proposed.

The following selected examples of assessments accomplished during this reporting period illustrate EIP activities in the NRC licensing process.

Evaluation of Ichthyoplankton Entrainment at Riverine Sites

The withdrawal of cooling water during operation of an electrical generating facility may result in high levels of mortality to those organisms (primarily plankton) small enough to pass through the 1-cm mesh of the intake screens. Subsequent entrainment in the condenser cooling system of the plant exposes these organisms to thermal, chemical, and mechanical stresses which may result in levels of mortality approaching 100% at plants with closed-cycle cooling systems. The calculation and evaluation of entrainment losses at proposed power plants focuses primarily on one group of plankton, ichthyoplankton (fish eggs and larvae). A methodology was developed to assess the losses of ichthyoplankton that might occur due to entrainment at the proposed Fort Calhoun Station Unit 2, located on the Missouri River north of Omaha, Nebraska (Fort Calhoun FES, March 1978). This methodology was then modified and used to assess the potential for entrainment at the proposed Greene County Nuclear Power Plant, which would be located on the upper (freshwater) portion of the Hudson River estuary in New York (Greene County PFES, September 1978).

Three levels of entrainment assessment (Methods I, II, III) are possible at riverine sites, the choice depending on the extent of biological and hydrological information available. With the most simplistic method of estimating entrainment losses (Method I), the organisms are assumed to have a uniform distribution in the cooling water source (e.g., the river). Thus, the number entrained is directly proportional to the percentage of the river flow that is withdrawn for cooling purposes. Although this assumption may be valid for other groups of plankton (e.g., phytoplankton), ichthyoplankton are not likely to be uniformly distributed in the water column, either horizontally or vertically, due to increased motility or swimming ability as larval development progresses and differences between the specific gravity of eggs or early larvae and water.

To assess ichthyoplankton entrainment using Method II, data on the vertical and horizontal distribution of ichthyoplankton in the river are required. With these data, an estimate of the number entrained (n) can be obtained by making various assumptions about the zone of withdrawal (that region of the river from which the cooling water is withdrawn during plant operation). In addition, data on the distribution of ichthyoplankton densities across the river can be used to obtain an estimate of the number of ichthyoplankton passing the plant (N) during a particular time period. Numerical integration techniques can then be applied to derive an estimate of the total number of organisms that passed the plant during the spawning and nursery season (or that period during which the ichthyoplankton are vulnerable to entrainment). With this value and an estimate of the number entrained (n) during that period, the proportion of the ichthyoplankton passing the plant that could be entrained ($P = n/N$) can be calculated. This procedure, however, does not account for the differences in current velocities that may exist either across the river or with depth. The number of ichthyoplankton passing the plant per unit time is dependent upon both their abundance and the rate at which they are transported. Assuming a uniform distribution of velocities may result in errors in the estimate of N if the distribution of ichthyoplankton is nonuniform.

Since data were available on river velocities at both the Fort Calhoun and Greene County sites, this information was used in the calculation of N (Method III). As in Method II, n was based on measured ichthyoplankton densities in the zone of withdrawal and a constant intake volume. Using information on the location of the ichthyoplankton sampling stations, river morphometry, and the velocity regime in the river, a cross-section of the river at the cooling water intake site was divided into x sections. The density of ichthyoplankton in each section had been determined empirically, and estimates of the proportion of the river flow in each section could be derived from data on total river flows and the area and velocity for each section. Thus, a more accurate

estimate of the proportion entrained (P) was obtained with this procedure than with Method II, because the total number of organisms passing the plant calculated by Method III considers spatial differences in current velocities. In the Hudson River case, for example, velocities were highest in the shipping channel near the west shore, while ichthyoplankton densities were greatest in a mid-river shoal area. Since the region of the river with the greatest proportion of the flow did not coincide with the region exhibiting the highest abundance of ichthyoplankton, the estimates of N calculated in cases II and III would differ. Similarly, velocities and ichthyoplankton densities in the Missouri River were not uniform either vertically or horizontally.

The methodology used in the entrainment assessment for both of these power plants is applicable to most riverine plants, regardless of the design of the cooling system [i.e., either open-cycle (once-through cooling) or closed-cycle cooling]. It is also applicable to estuarine plants, such as Greene County, if the volume of cooling water required is a very small fraction of the tidal flow. However, for estuarine plants, use of this methodology should be limited to facilities with closed-cycle cooling. Assessments involving once-through power plants located on estuaries may require the use of more complex transport models, such as those that were used to evaluate the impacts on the striped bass population from operation of several once-through plants located on the lower Hudson River (Barnthouse et al. 1977).

The assessments conducted on the Fort Calhoun and Greene County plants demonstrated the importance of acquiring data not only on the horizontal and vertical distribution of ichthyoplankton but also on the velocity regime in the river. With this information, reliable estimates can be obtained of the proportion of ichthyoplankton entrained so that sound judgments regarding the magnitude of entrainment impacts can be reached.

Allens Creek Pathogenic Amoeba Literature Review

As part of EIS preparation for the proposed Allens Creek cooling reservoir, the possible effect on public health from artificial heating of the reservoir was investigated. The cooling reservoir is located near Houston, Texas, and would be used by the public for recreational purposes. The study was predicated on recent reports of deaths (one in Texas) from primary amoebic meningoencephalitis (PAME) associated with swimming in naturally or artificially heated fresh waters and from a growing concern from epidemiologists for the rate of these occurrences in the United States. The study consisted of a thorough literature search and personal interviews with recognized authorities in the field of amoebic diseases, with the aim to determine the ecology of free-living pathogenic strains of amoeba and to evaluate their potential for occurrence in the proposed cooling reservoir. The results of the study show that the basic ecology of these organisms is poorly understood. Although the range of these organisms was found to be cosmopolitan, there is no understanding of the environmental factors which select for pathogenic versus nonpathogenic strains or which may trigger pathogenicity in previously benign strains. There is some correlation of the occurrence of pathogenic amoeba with artificially heated water bodies, but existing environmental information does not permit prediction of either the occurrence or the virulence of clearly pathogenic strains. The study concluded, for the Allens Creek site, that there is no justification to interfere with the construction of the proposed generating station based on this public health question. However, further research is needed on the general problem. Consequently, the knowledge gained from this effort was used to foster a grant from the Electric Power Research Institute and from the Nuclear Regulatory Commission to investigate aspects of the ecology and epidemiology of free-living pathogenic amoebic strains which may be associated with power plant operation.

San Onofre Kelp Assessment

The San Onofre Nuclear Generating Station (SONGS), Units 2 and 3, is currently under construction on the Pacific Coast, approximately midway between San Diego and Los Angeles. Because of its proximity to kelp beds, an assessment was initiated to determine the potential impact on these communities from operation of the facility.

The temperature tolerance of kelp is probably a reflection of a combination of factors, including physiological responses, susceptibility to disease, and susceptibility to grazing. It has been rather well established that temperatures above 18 to 20°C (64-68°F) cause tissue deterioration, and the degree of degradation is directly related to the duration of the exposure to these temperatures (Dawson 1966).

Increased surface temperatures caused by SONGS operation would have the effect of extending the period of canopy absence. During the hottest time of the year, the closest bed will experience an average 24-hr surface temperature increase of 1.4°C (2.6°F); the range of temperature increase will be 0.6 to 2.2°C (1-4°F). Although daily natural temperature variations of 1°C (2°F) are not uncommon in the area, they are not continuous through time and thus do not affect the bed as severely as the more continuous SONGS discharges would. Accurate prediction of the degree to which canopy disappearance would be prolonged is not feasible. Regeneration would be quicker in years with naturally cooler ocean temperatures, assuming the regenerative tissues remained unaffected (see below).

The greatest threat of SONGS to the long-term survival of the San Onofre kelp bed is the possibility of injury to the basal tissues from which the canopy is regenerated each year as the waters cool. Estimates for bottom temperatures within the bed at the end of July indicate that temperatures could reach 23 to 25°C (73-77°F), with a 24-hr mean of 24°C (75°F) due to operation of SONGS. Such temperatures would represent a 1 to 1.5°C (2-3°F) increase above ambient conditions encountered during the hottest portion of the year (conditions which are likely to persist for up to one week). The natural ambient temperatures would in and of themselves be detrimental to the kelp, although exposure to them for up to a week would not likely cause permanent injury to the entire bed, because the mean exposure temperature does not quite exceed the recognized threshold temperature for rapid degradation (24°C) (Phillips 1974). Moreover, deeper portions of the bed would be slightly cooler and would thus have a greater probability of surviving and maintaining a viable population. However, adding 1 to 1.5°C (2-3°F) to these ambient temperatures could place the bottom tissues in a critical temperature environment, subjecting most of the plants to temperatures greater than their short-term tolerance. It would also prolong the period of time in which the plants would experience temperatures greater than 20°C (68°F); this would cause them to be more susceptible to grazing pressure, diseases, etc. (Dawson 1966) and could lead to their eventual demise. Since ambient bottom temperatures in the region from August to early September may typically range up to 19°C (66°F), a several-week period could exist in which temperatures exceed 19°C.

Thus it appears that the thermal discharges from SONGS 1, 2, and 3 may result in the destruction of at least a portion of the San Onofre kelp bed during the summer months. Under average conditions, the effect may not be detectable or it may be manifested in a noticeably earlier decline of the canopy. However, under extreme worst-case conditions (e.g., several days with high ambient temperatures and slack currents, and with all three units operating continuously), destruction of the basal regenerative tissues might result. Although recolonization of the area from outside sources could occur during the cooler months, the community, if destroyed frequently, could never achieve a stable-state characteristic of other kelp beds in the area (Wilson et al. 1977). Furthermore, constant temperature increases coupled with added turbidity (also likely from operation of the facility) would be inimical to interim reestablishment because these factors tend to increase the effects of grazing (Neushal 1977). However, the perennial occurrence of extreme worst-case conditions seems highly unlikely and the long-term thermal impacts from normal station operation are not likely to be severe.

To ensure the integrity of the kelp bed, an extensive monitoring program has been proposed by EIP staff. This will include frequent preoperational and operational determinations of areal coverage, stand density, the physiological "health" of the kelp tissue, water temperature, and sediment deposition. Mitigation will be necessary if kelp deterioration is noted which can be attributed to operation of the facility. Potential mitigative action might include a modification of the diffuser configuration or placement of the discharge ports farther offshore.

Comanche Peak Chlorine Minimization Study

As a means of controlling circulating water system and condenser tube biofouling during the initial operation of its Comanche Peak Generating Station, the Texas Utilities Generating Company has proposed chlorinating the cooling water system to achieve a maximum concentration of 0.5 ppm total residual chlorine at the discharge. This is in excess of the 0.1 ppm maximum concentration specified in the NRC construction permits granted for the Comanche Peak Station and, as a result, the applicant has applied for amendment of these permits to allow them to begin operation at the higher levels. Further, the applicant has proposed to conduct a chlorine minimization study during initial operation to determine the minimum practicable level of chlorination necessary to maintain efficient operation of the plant.

In support of its request, the applicant provided to the NRC a prediction of environmental impacts of the proposed chlorine minimization study on the effluent-receiving water body, Squaw Creek Reservoir. Dissipation of total residual chlorine in the discharge plume was simulated by means of a hydrodynamic model. The effects of the resultant chlorine concentration-exposure time histories on plume-entrained aquatic biota were evaluated using the techniques of Mattice and Zittel (1976) and Mattice (1977). ORNL staff assisted in the evaluation of the model, in the application of the Mattice and Zittel techniques, and in the evaluation of the applicant's prediction of no effect on aquatic biota in Squaw Creek Reservoir.

Personnel from the ORNL Energy Division simulated total residual chlorine concentrations in the discharge plume, utilizing assumptions regarding dilution and reaction rates different from those of the applicant. Output from this independent model was used by the EIP staff to calculate the time-weighted chlorine concentrations needed for use of the Mattice-Zittel technique. Figure 1.1 is a representation of the predicted

Fig. 1.1. Chlorine concentration-exposure time curves for organisms entrained into the plume at three points downstream from the Comanche Peak discharge outfall. Threshold line and numbered points taken from Mattice and Zittel (1976).

biological effects of the proposed chlorination schedule under worst case conditions (1 unit operation - summer). It shows the chlorine concentration-exposure curves time for aquatic organisms entrained into the chlorine plume at various distances from the circulating water discharge structure. An organism whose concentration-exposure time curve crosses the acute mortality threshold line (e.g., when entrained at or within 1100 m of the discharge) will be killed by the cumulative chlorine dose. On the other hand, organisms entrained farther away from the discharge (at or beyond 1340 m, Fig. 1.1) will survive their exposure to total residual chlorine in the plume. Because biological data are not yet available from this newly created reservoir, it was assumed that productivity per unit of surface area in the region to be impacted by the chlorine plume was similar to that in the remainder of Squaw Creek Reservoir (i.e. the impacted region is not unusually productive or unique). The staff estimated that the portion affected by potentially lethal total residual chlorine concentrations would account for approximately 5% of the surface area of the entire reservoir. This part of the reservoir would be within the security area of the plant and would be restricted from public use. Potential loss of production in this area should not have a significant impact on total reservoir productivity. Therefore, the predicted impact was considered acceptable.

Erie Woodlots

A commonly recurring problem of transmission line impact assessment involves collection of biological data from land areas which are legally inaccessible. Utility companies in most states cannot gain access to proposed transmission line corridors until options to purchase the rights-of-way are obtained. However, the options normally cannot be obtained until environmental assessments have been completed. This set of circumstances effectively eliminates the use of onsite biological data from impact statements for transmission lines.

This problem was particularly acute at the Erie Nuclear Plant proposed by Ohio Edison Company in northern Ohio. Transmission lines were to cross 158 km (98 miles) of farmland and forests. Trees were to be removed permanently from the 46-m-wide (150-ft-wide) right-of-way where forest land was crossed. One hundred and sixty years of clear cutting, selective logging, and grazing left north central Ohio with very few forested areas, most of which are composed of young forest trees in disturbed stands. Any forest land that contained reproductively mature hardwoods, undisturbed forest stands, or virgin forest was, therefore, relatively unique in the region. In addition, mature hardwood forests are the habitat required by most of the local plant species that are proposed for federal listing as endangered or threatened.

Ohio Edison Company originally provided complete aerial photography of the proposed routes. The ORNL staff used these photos to analyze the size and density of some 140 forest stands through which the preferred and alternate transmission corridors were to cross. Of this group, 96 woodlots were determined to be potentially mature, closed forests which could be significantly altered by planned construction. Ohio Edison representatives agreed to inspect the woodlots by helicopter at and near tree-top level. Each woodlot would be evaluated against criteria developed by the ORNL staff to distinguish the woodlots which were too young or too disturbed to support either mature hardwood communities or associated rare plant species. The criteria were: the woodlot is so young that all forest trees are under 15 m tall; is so intensively harvested that the canopy covers less than half of the woodlot area; is so disturbed that at least 20% of the canopy consists of trees at least 6 m shorter than the tallest woodlot trees; and/or is so heavily grazed that grassland occurs in place of shrubs below the forest canopy. Of the 96 woodlots evaluated, 81 were eliminated as potentially mature and undisturbed forest stands, and 89 were eliminated as potential habitat for rare plant species. After analysis of these results, ORNL staff confirmed the Ohio Edison evaluation by inspecting about half the woodlots from the air and several woodlots from the ground where public access was available.

In the near future, Ohio Edison will collect biological survey data in the woodlots which were not eliminated from consideration after application of the maturity and disturbance criteria. The surveys will occur after purchase options are obtained, and before construction begins in the seven woodlots identified along approved (preferred)

transmission line routes. Analyses will be submitted that evaluate the costs and benefits of rerouting lines around either rare species populations, or mature, undisturbed woodlots that may be discovered during ground surveys.

The use of objective criteria during detailed aerial inspection of otherwise inaccessible land proved to be a valuable approach. It provided a sound basis for circumscribing the locally important ecological impact problems. It also allowed efficient resolution of conflicts resulting from data bases which were inadequate for NEPA and CEQ impact assessment.

Impact Assessments of Uranium Fuel Cycle Projects

Environmental Impacts Program ecologists have conducted several assessments of uranium fuel cycle operations (NRC Division of Fuel Cycle and Material Safety) during this reporting period (Table 1.2). The South Powder River Basin Mine and Mill in Converse County, Wyoming, and the Pitch Uranium Mine and Mill in the Gunnison National Forest, Colorado, both involved open-pit mines and adjacent mills. The Shooting Canyon and White Mesa projects in Utah involved uranium mills and associated ore-buying stations. The Irrigary Uranium Mine Project in Johnson County, Wyoming, and the Highland Uranium Mine in Converse County, Wyoming, utilize solution mining in which both mining and the equivalent of milling occur during a single underground process within the ore body.

Table 1.2. Nuclear fuel cycle projects actively reviewed by EIP staff in FY 1974

Facility	Location	Fuel cycle component	Activity completed
Babcock and Wilcox	Apollo, Pennsylvania	UF ₆ -- UO ₂ fuel fabrication	Environmental impact appraisal
Exxon Corporation Highland Operation	Converse County, Wyoming	In-situ uranium mine	Final environmental impact statement
Wyoming Minerals Corporation, Irrigary Project	Johnson County, Wyoming	In-situ uranium mine	Final environmental impact statement
Homestake Mining Company, Pitch Project	Gunnison National Forest, Colorado	Open-pit uranium mine, uranium mill	Draft environmental impact statement
Plateau Resources and Energy Fuels Nuclear	San Juan and Wayne Counties, Utah	Ore buying stations	Preliminary draft impact appraisals
Shooting Canyon Mill, Plateau Resources	Garfield County, Utah	Uranium mill	Initiation of ecological analyses
White Mesa Uranium Project Energy Fuels Nuclear	San Juan County, Utah	Uranium mill	Initiation of ecological analyses
Kerr McGee Nuclear South Powder River Basin	Converse County, Wyoming	Open pit uranium mine and mill	Preliminary draft environmental impact statement

The ecological impacts of open pit uranium mining differ little from those associated with surface mining for other minerals. Offsite aquatic communities may be impacted by silt originating from disturbed soils. Onsite habitats of endangered or rare plant and animal species, natural biotic communities, humic soils, and the pre-existing terrain are replaced with surrogates.

The ratio of mineral to ore is usually very small (only 0.2% uranium), which often results in milling operations being located at or near the mine site to avoid high transportation costs. After milling, the crushed rock (usually more than 99.8% of the ore) and the spent chemicals which remain after uranium extraction are dumped as slurries into tailings ponds.

The tailings contain approximately 85% of the radioactivity originally present in the ore, along with unreacted process chemicals, heavy metals brought into solution along with the uranium, and traces of organic solvents. Potential release of the radiological and particularly the nonradiological contaminants into ground and surface waters can impact biota and humans outside the project boundaries. At the Pitch Mill, approximately 600 tons per day of tailings will be dumped behind a retention dam across a small watershed. Such impoundments are subject to seepage and to failure of retention dams, which decrease the safety of this disposal method. At the South Powder River Basin Mill, a "below grade" tailings pond (a mined-out open pit) was proposed to handle 2500 tons of slurry each day. Such open pits often interrupt shallow aquifers, and may result in more ground-water contamination than conventional surface tailings impoundments.

Solution mining of uranium is feasible within sandstone/shale formations where the ore-body itself is a confined aquifer. Wells are drilled into the ore-body aquifer and an alkaline leach solution (either ammonium carbonate/bicarbonate or sodium carbonate/bicarbonate) with an oxidizing agent is injected into the aquifer to dissolve uranium. The "pregnant" leach is then pumped to the surface and the dissolved uranium is recovered by ion exchange and precipitation with ammonia. Compared to conventional mining, solution mining results in minimal surface disturbance. There is no necessity for disposal of large amounts of tailings. Impacts on air quality from radon gas from the mine and tailings and from fugitive dust from mining and ore handling are avoided.

The major environmental issue in solution mining is potential ground-water contamination. Such contamination may occur as a result of loss of leach solution from a poorly confined aquifer or rapid movement of the leach solution within the aquifer beyond the well field. Current operations in both Texas and Wyoming indicate that, subsequent to the completion of mining activities, removal of all leach solution and other contaminants from the aquifer may not be achieved. Remaining contaminants present a potential source for long-term ground-water effects. Of concern are both the leach solution itself and the heavy metals besides uranium which are mobilized by leaching. These may include molybdenum, vanadium, arsenic, and selenium. Analyses to date indicate considerable uncertainty in predicting ground-water impacts. As a result, the size of initial solution mining operations has been limited and extensive ground- and surface-water monitoring programs have been required with mitigating measures in the event of loss of leach solution.

Fossil Energy Environmental Project

The ORNL Fossil Energy Environmental Project (FEEP) assists DOE (Division of Fossil Fuel Processing) in evaluation of the environmental impacts of coal conversion facilities for which DOE provides funding. Six demonstration plants (Table 1.3) are planned, representing a variety of processes and products which are intended to serve as substitutes for coal, oil, and natural gas.

The FEEP provided generic guidance to subcontractors through two FEEP publications (Salk et al. 1978 and Salk and DeCicco 1978). In technical assistance activities, staff reviewed the environmental information presented by the industrial partners and visited the proposed sites for two gasification demonstration plants (low/medium Btu). Subsequently, EIP staff recommended modifications to the environmental programs and identified additional data needs so that site-specific concerns and generic impacts of these developing technologies can be adequately assessed. In addition to potential impacts of process-related effluents and wastes, siting criteria (e.g., avoidance of floodplains, wetlands, and prime farmlands) are of particular relevance to environmental analyses and were considered by the staff. Ultimately, ORNL will prepare the environmental impact statements (EISs) for the high- and low/medium-Btu gasification facilities. In addition, ORNL will prepare independent analyses for the solvent-refined coal (SRC-I and SRC-II) EISs, which are to be written for DOE by the environmental subcontractors.

Table 1.3. Coal conversion demonstration projects.

Project	Process	Site location	Industrial partner	Final environmental impact statement date
High-Btu gasification^a				
COGAS	COGAS	Perry County, Illinois	Illinois Coal Gasification Group	January 1980
CONOCO	Slagging Lurgi	Noble County, Ohio	Conoco Coal Development	February 1980
Low-medium-Btu gasification^b				
MSB & A	Orsat	Shelby County, Tennessee	Memphis Light, Gas & Water	June 1980
GRACE EBASCO	Texaco ammonia product	Henderson County, Kentucky	W. R. Grace-Ebasco Services	March 1980
Solvent refined coal				
SPC-1	Solid product	Daviess County, Kentucky	Southern Company Services	May 1980
SPC-11	Liquid product	Monongalia County, West Virginia	Gulf Mineral Resources	May 1980

^aDecember 1978 decision by DOE on which of the two high-Btu gasification projects will proceed.

^bJanuary 1980 decision by DOE on which of the two low-medium-Btu gasification projects will proceed.

In other activities, project staff completed final revisions to two FEEP documents, and presented two papers on coal conversion impacts. The pipeline assessment (Stinton 1978) examines the impacts of the construction and operation of hypothetical gasification facilities. It covers six different processes (CO₂ acceptor, Hygas, Bi-Gas, Synthane, COGAS, and Slagging Lurgi) sited in three different locations (Mason County, West Virginia; St. Clair County, Illinois; and Campbell County, Wyoming) representing a range of environmental settings. Operation impacts (especially of solid waste disposal, air emissions, and liquid effluents) and impacts of offsite development (mining) are judged to be of potential significance. Additional research and data needs are recommended. The other document (Braunstein 1978) addresses the issue of solid waste disposal in more detail. The complex interaction of wastes with the hydrologic, geologic, and morphologic characteristics of burial sites is described, and the potential for ground-water and surface-water contamination is discussed. The two papers presented were Roop et al. (1978) which summarizes assessment and monitoring approaches developed at ORNL, and Barnthouse et al. (1977) which categorizes 25 trace elements as being of high, variable, uncertain, or low concern. Determining factors include abundance in wastes, mobility in soil, and toxicity to aquatic organisms.

Geothermal

Environmental analysis and evaluation of DOE (Division of Geothermal Energy) geothermal exploration, demonstration and loan guarantee-supported projects continued vigorously in FY 1979. Environmental assessments (EA) of geothermal resource demonstration projects in Coso Hot Springs, Raft River, and Hawaii were continued into a second phase of each project. Important environmental issues were raised at each site. At Coso Hot Springs, potential interference of geothermal testing with important cultural resources was identified, evaluated, and resolved. At Raft River, impacts on raptor habitat were studied and evaluation methodologies developed. With regard to the Hawaii project, concerns of native Hawaiians relating to resource ownership as well as religious issues are unresolved.

An EA for the geothermal loan guarantee project at Westmorland in the Imperial Valley was completed and preparation plans for an impact statement concerning the South Brawley (loan guarantee) Project were submitted to and accepted by DOE. Plans for an EIS concerning the Baca Geothermal Project in New Mexico were also developed. These

will be the first EISs on geothermal projects, and procedures, guidelines, and scope developed this year will be extremely important to the development of the industry.

Geopressure projects on the Texas and Louisiana Gulf Coast were initiated. The EIP geothermal staff acted for the first time in an overview capacity, as a subcontractor actually evaluated and wrote the EA on the first DOE geopressure demonstration at Chocolate Bayou and an exploration project at La Fourche Bayou.

Several DOE-supported projects that would demonstrate the value of geothermal fluids for nonelectric, process heat use were evaluated by the staff with respect to potential environmental problems. An environmental assessment of a project in Marlin, Texas, was released in September. In this project a single well located beside a community hospital would supply geothermal fluids to the hospital's heating system to reduce dependence on natural gas. Disposal of the geothermal fluids, noise, and fugitive dust in the urban setting were systematically evaluated. Several nonelectric geothermal projects were reviewed and determined not to require an EA.

Enhanced Oil Recovery Assessments

During this reporting period the EIP essentially completed assessment activity pertaining to Enhanced Oil Recovery (EOR) (DOE Office of Energy Technology and DOE Environmental Programs). Ten individual pilot projects analyzed in the EOR effort are given in Table 1.4. Three general categories of EOR methods are currently being employed in the United States. These are: (1) thermal (i.e., in-situ combustion and steam injection), (2) chemical injection (e.g., micellar-polymer and alkaline flooding), and (3) carbon dioxide injection. All processes are intended to promote recovery of oil from conventionally depleted oil fields by minimizing capillary forces, reducing viscosity of the oil, overcoming gravity segregation, and increasing pressures and force in the reservoir, thereby moving oil to production wells.

Table 1.4. Enhanced oil recovery projects evaluated by EIP staff

Project	Location	Technique
Guyan Oil Co.	Griffiths field, West Virginia	CO ₂ flooding
Columbia Gas Transmission Corp.	Granny's Creek Field, West Virginia	CO ₂ flooding
Pennzoil Co.	Rock Creek Field, West Virginia	CO ₂ flooding
Shell Oil Co.	Weeks Island Field, Louisiana	CO ₂ flooding
Cities Service Inc.	E! Dorado Field, Kansas	Micellar-polymer flooding
Philips Petroleum Co.	Burbank Field, Oklahoma	Micellar-polymer flooding
Penn Grade Crude Oil Co.	Bradford Field, Pennsylvania	Micellar-polymer flooding
Gary Operating Co.	Bell Creek Field, Montana	Micellar-polymer flooding
Bartlesville Energy Research Ctr.	Nowata Field, Oklahoma	Micellar-polymer flooding
Cities Service Co.	Bellvue Field, Louisiana	Thermal

EOR projects are conducted in areas which have already been developed for oil production, and for use methods that are basically similar to conventional oil production methods. Acceptable methods for minimizing and controlling potential environmental problems are available, although not necessarily required by present regulations. Without proper planning and implementation of control measures at appropriate stages of

project development, several potential problem areas could result in significant environmental damage. These include land disturbance and associated erosion and sedimentation; accidental spills of oil, brines, and chemicals; deterioration of surface-water and ground-water systems; and excessive air emissions.

Sources of land disturbance resulting from EOR construction activities include preparation of well pads, laying of pipeline, and construction of roads, waste disposal pits, sediment ponds, and plant facilities (e.g., office, parking area, storage tanks). The need for drilling of new wells and road construction is often reduced, since existing roads and wells from previous oil operations are used whenever possible. Based on the commonly employed five-spot pattern (four injection wells plus one central production well), the amount of land disturbed by EOR development averages about 1.2 ha (3 acres) for every 4 ha (10 acres) of project area.

Surface disturbance and stream crossing by roads and pipelines may result in significant increases in stream sedimentation and turbidity with resultant detrimental effects on aquatic habitats and biota. Detrimental effects can be minimized if proper control measures are implemented. Other potential problems include seepage of pollutants from waste disposal pits and accidents such as ruptured pipelines and spills of oil, brine, or other chemicals used in EOR processes. The potential for accidental spills suggests a need for spill-prevention control and countermeasure plans for early detection and control of escaping pollutants.

Enhanced oil recovery techniques use a variety of chemicals, some of which could be toxic to biota and possibly carcinogenic to man if they were translocated in sufficient quantities to ground or surface waters. Ground waters may become contaminated as a result of (1) thermal processes which produce subsurface heat and pressure and may result in the release and increased solubility of potentially hazardous compounds contained in underground deposits, (2) use of carbon dioxide containing hydrogen sulfide, (3) seepage of chemicals and brines from waste disposal pits, (4) injection of brines and other waste chemicals back into oil-depleted reservoirs, and (5) long-term migration of chemicals by natural flow out of the reservoir into aquifers and even surface water. For ground waters to become contaminated there must be communication between the pollution source and the ground-water system, or between aquifers of different water qualities. Such communication and translocation of potentially hazardous substances can occur from broken well casings in both active and abandoned wells, and through underground drainage channels, fractures, and faults.

Our experience with EOR assessments to date indicates that ground-water quality and surface-water quality monitoring, spill prevention and control plans, proper plugging of abandoned wells, and erosion control measures should be integral components of EOR project development.

Monitoring Development

The basic purpose of the monitoring development project (DOE Division of Ecological Research), which was initiated this year, is to improve the monitoring and assessment of site-specific ecological effects associated with energy technologies. More specific objectives are (1) to evaluate current statutory requirements for ecological effects monitoring which DOE must satisfy, (2) to evaluate the current approaches used in determining ecological impacts in the field, and (3) to develop prototype monitoring programs to give increased scientific validity to the assessment of long-term ecological impacts. Three recently prepared draft documents inventory the existing ecological information on the United States, summarize statutory requirements for ecological effects monitoring, and develop conceptual strategies for the assessment of ecological effects in site-specific situations.

Inventory of Sources of Computerized Ecological Information

To avoid or minimize redundancy in DOE monitoring programs, an "Inventory of Sources of Computerized Ecological Information" was prepared which provides short summaries of existing data bases on the ecology of the United States and includes necessary

user information. Although the initial intention was to catalog the existing data bases according to geographical coverage, it was quickly realized from analysis of these data bases that comprehensive geographical coding of environmental information for the United States does not exist. Therefore, although this document is useful to anyone seeking this type of information, the current state of affairs dictates long searches through computer printouts and lengthy personal contacts with local regulatory or institutional personnel to acquire existing ecological data on specific geographical sites.

Statutory Requirements for Ecological Effects Monitoring

A draft document entitled, "Statutory Requirements for Ecological Effects Monitoring," reviews and discusses the a-priori needs of a monitoring and assessment program for statutory fulfillment. This work covers a large number of federal environmental protection laws, including detailed analysis of nine major laws. In addition, three representative states, California, Wyoming, and Maryland, were selected to be analyzed for their environmental protection laws relative to ecological effects monitoring and assessment.

Results of this study show that environmental monitoring required by statute is a complex moving target as adjudicatory proceedings, promulgation of new regulations, and the administration of statutes through regulatory proceedings are constantly providing fundamental changes in the interpretation of statutes or providing new statutes entirely. Further, no obligate list of monitoring parameters exists for site-specific implementation; rather, site-specific statutory requirements evolve as a process of inquiry and feedback between contractor and regulatory personnel at the federal, state, and local level. Most federal and state laws require only compliance monitoring at the end of the pipeline outfall or in the emission stack. Such regulations seek to reduce ecological impacts by controlling the sources of pollution without requiring field data for verification. This approach generally neglects consideration of antagonistic or synergistic interactions among effluent constituents or any accumulative effects in regions receiving numerous discharges. The National Environmental Policy Act (NEPA), on the other hand, explicitly requires field monitoring for impacts. Unfortunately, NEPA has frequently been interpreted to require only routine characterization of the receiving system structure, with no monitoring of ecosystem dynamics. Thus, long-term chronic impacts have been poorly addressed. Much work remains to be done to apply state-of-the-art ecology to the full intent of NEPA.

Conceptual Strategies for Ecological Effects Assessment

To aid in the fulfillment of the NEPA, a rough draft document dealing with conceptual strategies for site-specific ecological effects assessment has been prepared. The objective of this effort is to bring together conceptual approaches for prediction, monitoring, and assessment of ecological impacts from energy facility development. The document aims to increase the scientific validity of ecological effects assessment for both short and long-term impacts and to provide guidance for the development of prototype ecological effects monitoring and assessment programs which advance the state-of-the-art. Chapters include a general discussion of applied ecology relative to ecological impact assessment, terrestrial and aquatic ecology, estuarine ecosystems, hydrodynamics and atmospheric physics relative to pollutant dispersion and changes in physicochemical environment, the use of experimental enclosures for system studies and perturbation analysis, use of mathematical models as assessment and program development tools, statistical considerations relative to detection of ecological change in receiving systems, and a synthesis of pertinent ideas into a general program.

Fuel Use Act Environmental Impact Statement

The EIP contributed to the Fuel Use Act (FUA) EIS, the first legislative EIS written by the staff and a cooperative project with Argonne National Laboratory. It dealt with the regional impacts of enacting legislation that would require major natural gas- and petroleum fuel-burning facilities to convert to coal or other alternative fuels.

Projected 1985 and 1990 coal use attributable to the program represents a small proportion of all coal use (7% and 10% respectively) in the nation by that time. Projected increases in coal use due to FUA are 68% by 1990 in Demand Region VI (Texas, Louisiana, Arkansas, Oklahoma, and New Mexico), 41% in the Central West and Gulf Coast coal regions, and over 10% in Southern Appalachia, the Northern Great Plains, and the Southwest.

Increased coal usage could reverse currently improving air quality unless strict emission controls are employed. The predicted maximum regional increase in concentration of SO_2 due to the FUA is $2.5 \mu\text{g}/\text{m}^3$, compared to a present national average background concentration in excess of $20 \mu\text{g}/\text{m}^3$. Increased concentrations of SO_2 as a result of the FUA are predicted in 104 of the 235 Air Quality Control Regions (AQCRs) in 1985 and 141 in 1990. Increases in concentrations of particulates and other pollutants will be less than SO_2 increases.

The FUA will accelerate coal mining to the greatest degree west of the Mississippi and in central and southern Appalachia. In Appalachia, the major hazard posed to water quality and water use is sedimentation. In the West, major concerns are contamination of ground-water aquifers and increases in levels of dissolved solids.

The FUA will contribute slightly to acid precipitation. The Texas-Oklahoma-Kansas-Arkansas-Missouri area, is expected to experience moderately lowered pH of precipitation. However, surface waters are less sensitive to acid precipitation in this region due to hardness. Acid precipitation is expected to be minimal in the East Texas Gulf area, where surface waters are softer.

Land-use impacts of the proposed action will result primarily from surface mining activities and disposal of combustion wastes. An estimated 20,000 ha (49,200 acres) of land will be disturbed directly by surface mining and an equivalent amount may be disturbed indirectly for use as roads, rail lines, storage, processing equipment, etc. Over the life span of the converted boilers, a total of 133,000 ha (328,000 acres) of land may be disturbed by mining. Much of the land which will be disturbed is currently used as rangeland and cropland, although forest land will be affected in Appalachia. Coal mining of prime farmlands, especially in the West and Midwest, could have serious impacts on regional agriculture. Ash and scrubber sludge produced by the combustion of coal burned as a result of the FUA, result in an estimated 6550 ha (16,200 acres) of land by 1990 and 44,000 ha (108,000 acres) of land over the lifetime of the facilities required for disposal. Up to 70% of the wastes will be produced along the Gulf Coast of Texas.

On a national basis, the aquatic ecological impacts attributable to the FUA are expected to be minor in comparison to the impacts expected due to the general increase in coal use. However, the FUA may create local impacts, especially in central and southern Appalachia, the Northern Great Plains, and Texas. Coal combustion effects (as they relate to changes in water quality) probably will be most severe in southern Texas.

On a national basis, increased coal use as a result of the FUA is expected to result in 45 fatal and 1300 nonfatal injuries in 1985 and 82 fatal and 2500 nonfatal injuries in 1990 from extraction, cleaning, and transportation. This would result in approximately 4,000 fatalities over the lifetime of the plants. Excess deaths associated with the increased combustion of coal due to FUA. In 1990 as many as 100 and more than 2500 over may be the life of the converted plants (1.5% of excess deaths due to coal use in general).

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2. COOLING SYSTEMS PROGRAM

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Introduction

The Cooling Systems Program continued to examine the many sources of potential ecological effects of power plant cooling, including physical effects of entrainment, causes and fish community effects of impingement, proliferation of thermophilic human pathogens, and thermal aquaculture, as well as the effects of temperature on fish and benthic communities which was the origin of the program in 1970. The program's strategy has been to conduct aquatic ecological research and scholarship of high scientific quality in often-diverse topics needed to regulate and design the technologies of power station cooling.

The program is in a phase of intense data synthesis (primarily funded by the Department of Energy) as the nation faces a major reassessment of federal policy regarding the general need for closed-cycle cooling. Separate reviews for the Department of Energy (DOE), the International Atomic Energy Agency (IAEA), and the United Nations Educational, Scientific, and Cultural Organization (UNESCO), have detailed the environmental risks and opportunities of once-through cooling, advancements in understanding of cooling system effects in the past five years, and guidance for assessing environmental impacts of cooling systems. The influence of physical factors (e.g., temperature) on predator-prey relations in fishes was reviewed for a major symposium. Field research on

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benthic invertebrate populations at the Kingston Steam Plant studied for the past five years is being summarized. Models and simulation techniques have been developed to synthesize a broad scope of our laboratory and field data on thermal effects and ecological interactions.

Hypothesized risks to human health from pathogenic amoeba in power plant cooling water seem more probable as the result of screening studies conducted at representative sites nationwide for the Nuclear Regulatory Commission and the Electric Power Research Institute. Cooling lakes appear to have higher incidences of these pathogens than unheated lakes nearby, particularly in northern latitudes. Correlation of the "Legionnaires Disease" bacterium with cooling towers (air conditioning) has led to preparations for research on this organism in power station cooling towers.

Habitat selection studies for DOE of striped bass in Cherokee Reservoir over the past two summers have identified striking behavioral responses to temperature and isolation of fish in cool thermal refuges in this warm reservoir that is both heated by a thermal discharge and enriched by nutrients. The strong temperature selection behavior is causing a reassessment of the suitability of this species for stocking in warm water reservoirs, particularly power plant cooling lakes. Thermal refuges (warm) have been discovered to play a prominent role in survival of threadfin shad populations in Watts Bar Reservoir during winter when they are simultaneously subjected to cold stress and power plant impingement. This NRC-funded research is rapidly expanding to a community-level study as changes in shad are related to predator species.

Aquaculture research, although only funded internally, has yielded results that are important for energy conservation and protein production. Enthusiasm by staff and students for helping to solve these twin problems has yet to be matched by agency funds.

A major significance of cooling systems research in the future appears to lie in its relevance to energy conservation. Cooling towers, mandated by federal guidelines implementing the 1977 Water Pollution Control Act Amendments, carry a heavy penalty in energy consumption. Rational use of environmental criteria to determine when cooling towers are genuinely needed to protect aquatic systems holds the potential for very large energy savings for the country.

Corbicula Studies

The rapid expansion of the geographic distribution of Corbicula (the Asiatic clam) in the United States following its introduction in 1938 has resulted in increasing problems for raw water users. Studies of Corbicula biology can yield information important for control of fouling, regulation to prevent environmental impact, and understanding ecosystem functioning.

Field studies of filtration rate (FR) were carried out in the intake and discharge of the Kingston Steam Plant from 1976 to 1978. In the intake, FR was found to be a linear function of temperature. This relationship did not obtain in the discharge. For the period from April 1 through the highest recorded temperature, FR in the discharge increased to a maximum at 26 to 28°C, then declined. As temperatures dropped in September and October, however, FR was lower than at the same temperatures found in spring and early summer. Dissections in late September of clams used in some of the experimental runs during this period revealed that the inner demibranches of the gills contained large numbers of young clams with shells. It is likely that the presence of these young clams interferes with normal water flow through the gills, decreasing the measured FR. The FR of a standard clam ranged from 100 to 1800 ml/hr over the temperatures studied. Corbicula almost certainly play a major role in reducing downstream energy flow in reservoir and river ecosystems, transporting energy to the sediments for utilization by benthic organisms.

Introduction of Corbicula may also influence the dynamics of predator populations. We conducted laboratory studies of predation of crayfish, Cambarus bartonii, on adult Corbicula (> 24-mm SL). Predation rates averaged 1.5 clams/day or about 4.3% of crayfish body weight per day at a temperature of 20°C. Data indicate that this rate is

sufficient to supply the full energetic requirement of crayfish. This could have widespread impacts on ecosystem dynamics because of the role of crayfish in supporting top predators in aquatic environments.

Aspects of *Corbicula* growth are important for questions of control technology and potential for inclusion in polyculture systems designed for waste heat utilization systems. Shell lengths (SL) of marked (> 10 -mm initial SL) and unmarked (< 10 -mm initial SL) clams were measured at two sites differing by about 5°C in both 1976 and 1977 and at the lower temperature site in 1978. Shell lengths began to increase in April and growth generally continued through October. Increase in SL was an inverse linear function of initial SL. Comparison of these rates for a single site during the year indicated that temperature plays a major role in growth rate determination. Laboratory studies of growth at 15, 20, 25, and 30°C supported this conclusion. The field studies also suggest that the optimum growth temperature is in the mid- 20°C range. However, a decline in growth rate in spring, when other investigators found a peak in reproduction, indicates that intrinsic factors are also important. Variation of these factors over the wide range of geographical distribution of *Corbicula* probably accounts for some of the differences in growth and life cycle reported for this species.

Mayfly Studies

Mayflies (*Hexagenia* sp.) are one of the more abundant fish food resources in Watts Bar Reservoir in the vicinity of the Kingston Steam Plant. The steam plant modifies the aquatic habitat in the discharge area both by warming the water year-round and by attracting fish in winter. Comparative studies were initiated to determine the effect of these changes on mayfly populations.

Laboratory studies were conducted in 1978 to assess the effects of a broad temperature range on growth rates, emergence synchrony, and size at emergence. Initial studies were conducted at 15, 22.5, and 30°C on medium-sized nymphs (9-17 mm) collected from Watts Bar Reservoir in April 1978. Mean growth rates per day were 0.075, 0.147, and 0.124 mm at 15, 22.5 and 30°C , respectively. Nymphs at both 22.5 and 30°C emerged simultaneously, but the nymphs at 22.5°C were slightly larger. This difference in size is probably significant because fecundity is directly proportional to female size. At 15°C , only two nymphs emerged during the 12-week period. These data suggest that the optimum growth temperature is probably greater than 22.5 but less than 30°C . Follow-up studies were initiated with eggs collected in late July 1978 and held at temperatures between 10 and 35°C . Days to 50% hatching were approximately 9, 8, 10, 24, and 60 days at 35, 30, 25, 20, and 15°C respectively, while eggs held at 10°C had not hatched after 97 days. Nymphs hatched from eggs held at 15°C and above are being followed through emergence.

We conducted a laboratory study to test the hypothesis that nymph distribution was random with respect to substrate. *Hexagenia* nymphs left clay, gravel, and sandy clay and settled in adhesive mud or fine sandy mud. Substrate composition as indicated by median particle size is not sufficient to describe the preferred substrates. The time required to dig a burrow (penetrability or desirability) and the organic content both correlated well with substrate preferences. These data supported the trends in distribution of *Hexagenia* within coves suggested by the field data and indicated the necessity of factoring substrate type into intercove comparisons.

Temperature Selection by Striped Bass in Cherokee Reservoir

Summer habitat selection patterns were analyzed for 18 adult striped bass, *Morone saxatilis*, in Cherokee Reservoir monitored with externally attached temperature-sensing acoustic or radio transmitters from June through September 1977. Summer home ranges of most fish corresponded to cool, oxygenated spring or tributary effluents feeding shallow, submerged channels (less than 10 m deep) located in the lower reservoir. These inhabited areas or refuges differed from noninhabited areas by maintaining temperatures less than

or equal to 22°C and dissolved oxygen concentrations (DOC) greater than 5 mg/liter. Total water hardness, pH, and water transparency were not significantly different among refuges and noninhabited areas.

Movement of fish outside refuges occurred more frequently and for longer periods during June when the temperature-DOC regime was less severe. Fish experienced temperatures between 15 and 27°C, with mean temperatures of individuals ranging from 18.5 to 22.0°C. Several tagged fish migrated outside the refuges and selected the lowest available temperature, generally near 21°C, even though DOC at these temperatures were 3 mg/liter or less. Long-term survival of tagged and nontagged fish outside refuges was undetermined because no fish were tracked outside a refuge for more than 12 days without being lost. This study indicates that temperature strongly influences the behavior of striped bass and that this species' thermal preferendum is approximately 21°C.

Field studies were conducted again in 1978, beginning in March. Fish in the spring were initially found in the summertime refuges where water temperature was closer to the thermal preferendum than that in the cooler reservoir. The fish dispersed through the reservoir in late spring, but aggregated in the refuges through the summer until fall overturn. A thermal preferendum of 19 to 21°C was seen in 1978, based on preliminary review of temperature telemetry records.

To facilitate the continuing field work on fish temperature selection in bodies of water, a computer code has been developed that plots two-dimensional isotherms from temperature-versus-depth data. The program can also be used to plot dissolved oxygen isopleths.

Temperature Selection by Smallmouth Bass in Lambert Quarry

A single adult smallmouth bass, Micropterus dolomieu, was tagged with an ultrasonic, temperature-sensing transmitter and monitored in Lambert Quarry during May and early June 1978. The fish selected temperatures within 1°C of the maximum surface temperature through most of the period when temperatures ranged from 15.5 to 24.8°C. During a rapid rise in surface temperature between May 17 and 22, the selected temperatures rose more slowly, suggesting the influence of thermal acclimation on temperature preference. Brief excursions were observed throughout the month to temperatures as low as 11°C (bottom temperature = 6.5°C). The data are similar to those collected on other fish, both largemouth and smallmouth, in the same quarry lake. Attempts to determine temperature selection by striped bass juveniles, Morone saxatilis, in a laboratory shuttlebox apparatus were unsuccessful due to poor thermal responsiveness of the fish in the artificial environment.

Rates of Heat Exchange in Largemouth Bass

The body temperatures of four adult largemouth bass, Micropterus salmoides (1.2-1.8 kg), were monitored during sudden changes in water temperature. Values of the coefficient of heat exchange (k) ranged from 0.136 to 0.059. Differences in heating and cooling k values indicated that largemouth bass heat faster than they cool. A high correlation was found between the initial lag time before body heating began and the weight. Lag times for adult bass (mean = 43.6 sec) are within the time ranges of thermal excursions of fish in the field (generally < 1 min), suggesting a behavioral response that minimizes body temperature changes.

Conduction accounted for approximately 30% of the heat exchange in these fish and convection for 70%. High variability of half-time for complete body temperature change and k values for individual fish suggested that several physiological parameters affect rates of heat exchange in bass.

The full temperature-change response can best be simulated by a logistic model that incorporates lag phase, rapid rise phase, and asymptote to the final temperature. For deriving k values (useful for comparisons with previous research), Newton's Law of excess temperature applies with reasonable accuracy after about 5 min of temperature change.

Growth Efficiencies of Juvenile Striped Bass as a Function of Temperature and Ration

Growth efficiencies of juvenile striped bass, *Morone saxatilis*, were determined at constant temperatures (12 - 34.5°C) or fluctuating temperatures ($\pm 4^\circ\text{C}$ around means of 18, 24, and 30°C) and at each temperature regime for 100, 60, 30, and 0% of unrestricted food rations.

These laboratory experiments were done to identify optimum and zero growth temperatures and to test the effect of reduced rations on them. From these data, reasonable estimates of a maximum upper allowable temperature can be made. The data should help explain why striped bass, tagged with ultrasonic temperature sensors, selected temperatures between 18 - 22°C in the field rather than those between 23 - 26°C determined in the laboratory to be optimum for growth with unrestricted rations.

Both optimum growth for 100% ration and minimum maintenance ration occurred near 24°C. The upper allowable temperature estimated from a 24°C optimum and a 33.5°C zero growth temperature is 28.8°C. Reduced ration reduced growth rates and shifted the point of zero growth to lower temperatures, but did not markedly shift the optimum. The greatest energetic efficiency in fluctuating temperature regimes is found in a 12 - 22°C range, with a mean of 18°C, which is well below the optimum value of 24°C for constant temperatures.

Striped bass in the field without access to an abundant ration may be behaviorally adjusting their metabolic rate to match the available food supply by selecting cooler temperatures, or they may be responding to enhanced bioenergetic efficiency produced by cooler fluctuating temperature regimes.

A Model for Size Dispersion in Growth of Juvenile Fish

In previous studies of the growth rates of black bass, attention has been focused on obtaining average rates of growth. However, individual fish may vary markedly in their growth rates, leading to broad size distributions among even-aged fish. Size variations within a population of first-year fish can have significant effects on the population dynamics and the ultimate number of adult recruits, because these variations influence competitive and cannibalistic relationships within a species as well as predator-prey relationships among species. A partial differential equation model has been used to simulate the growth of fish in a smallmouth bass population. The model predicts that when the rate of increase of length is a constant, the variance of fish sizes about the mean should increase as the square of time if the individual fish have different growth rates. This observation is in agreement with observations on smallmouth bass during their first few weeks of life.

Pathogenic Amoebae in Cooling Waters

The human pathogen, *Naegleria fowleri*, is thought to be ubiquitous. Fatal encephalitis caused by these microorganisms is generally contracted by swimming in naturally or artificially heated waters such as shallow lakes, thermal springs, heated swimming pools, or in waters artificially heated by industrial plants. We and others have previously shown that naturally or artificially heated waters in the southern United States were more likely to harbor the pathogen than comparable cooler waters. In light of these observations, and the fact that the pathogenic *N. fowleri* grows preferentially at

higher temperatures relative to the nonpathogenic Naegleria, a study of northern power plant cooling lakes was undertaken. The purpose of this study was to determine if such cooling lakes will select for the growth of pathogenic N. fowleri in the northern United States relative to unheated control lakes. In addition to heated northern lakes, several western lakes receiving thermal effluents were also studied. Unlike the northern lakes, however, the thermal additions did not raise the temperature of these lakes above ambient. Additionally, test waters were analyzed for levels of nitrites, nitrates, sulfates, phosphorus, chlorine, and total organic carbon. Colony counts on millipore test plates determined levels of total aerobic bacteria and total coliform bacteria per milliliter of test water.

Results of these studies showed an outgrowth of thermophilic Naegleria from the northern cooling lakes compared with the control unheated lakes. Over half of the 91 test samples from northern cooling lakes yielded thermophilic Naegleria, whereas less than 10% of control samples were positive. The western cooling lakes yielded no thermophilic Naegleria. Chemical and bacterial analysis of test and control lakes did not reveal an obvious correlation between the presence of thermophilic Naegleria and these parameters. The fact that thermophilic Naegleria have been isolated from relatively small volumes of test water (i.e., 50 or 250 ml) indicated a rather high concentration of these organisms.

Of the 52 thermophilic Naegleria isolates from northern cooling lakes, ten were encephalitic for mice on intranasal inoculation. No pathogenic Naegleria were isolated from control lakes. All mice injected with these isolates died, or were sacrificed within ten days after inoculation with acute, clinical signs of encephalitis.

The data from our studies to date indicate that cooling lakes may inadvertently serve as habitats for growing and/or disseminating thermophilic human pathogens. These findings are highly significant, considering the pending construction of new power plants with closed-cycle cooling systems.

Impingement: Cause and Ecological Ramifications in a Southeastern Reservoir

The goals of this project were aimed at defining temperature-related change in behavior of threadfin shad, Dorosoma petenense, and gizzard shad, D. cepedianum, as these influence impingement, predator-prey dynamics, and population resiliency of threadfin in Watts Bar Reservoir, Tennessee. Impingement and fish movement were monitored during a TVA-ORNL cooperative impingement count, gill netting, and thermal survey program. Laboratory studies measuring mortality and behavioral changes in response to temperature difference were performed in the ORNL aquatic ecology laboratory.

Over 350,000 threadfin shad were impinged from September 28, 1977, to April 30, 1978 (compared to 240,000 in 1976-1977), indicating that these fish rebounded after extensive mass mortality during the winter of 1976-1977. The population structure was changed, however, in that over 99% of these impinged fish were young-of-the-year compared to about 85% the previous year. In addition to threadfin, over 300,000 of both gizzard shad and river herring, Alosa chrysochloris, were also impinged compared to almost none of these latter two species the year before.

Mechanisms responsible for Dorosoma impingement include a change in rheotaxis as well as temperature-related stress. In the laboratory, young-of-the-year gizzard shad demonstrated a change from negative to positive rheotaxis (upstream to downstream orientation) at decreasing temperatures between 12 and 8°C. This supports the hypothesis that a downstream movement, in response to seasonal drops in temperature, contributes to concentrations of fish in the vicinity of the intake structures. Hydraulic mapping in the intake lagoon of Kingston Steam Plant explains, in part, interscreen differences in the amount and size of fish impinged. The main hydraulic factors affecting impingement are thought to be the presence of large eddies that concentrate fish and segregate them according to swimming ability, thus by size and species.

Predator-prey relationships were investigated and condition factor of sauger was measured to quantify the effect of prey loss to this important segment of the aquatic community. Visceral fat stores of sauger changed little throughout the year in spite of prey fluctuations. Stomach content analysis of five predators revealed that prey switching is common, increasing food availability as prey species become scarce. Thus, a diversity of potential prey, as well as the ability of fluctuating prey populations to rebound, becomes important to the functioning of a stable system.

Mechanisms used by threadfin shad to maintain a population during potentially lethal cold stress are thought to include the use of thermal refuges in the winter and hybridization with gizzard shad, a cold-tolerant conspecific. An aerial thermal scan of Watts Bar Reservoir during January 1972 showed several potential warm water refuges. Threadfin-gizzard shad hybrids and young-of-the-year gizzard shad were found in these areas. Although threadfin were not found, we hypothesize that they overwinter in similar refuges in Watts Bar or upstream in Melton Hill Reservoir. Threadfin-gizzard shad hybrids were found to comprise over 10% of the threadfin population. Their possible fecundity as well as resistance to cold stress are currently being investigated.

Entrainment

Entrainment (the passage of small aquatic organisms through condenser cooling systems) is being examined, using a power plant cooling system simulator (a 2000-gpm scale model of a cooling system). This device allows detailed experimentation on the various physical stresses that are part of the entrainment process. The goal of the project is to define the factors which cause mortality during entrainment and to provide this information to regulatory agencies and industry so that cooling systems can be designed for minimum impact. During the past year, the cooling system simulator was completed, tested, and used in a series of experiments which examined mortality associated with pump passage.

Aquaculture

Aquaculture research at ORNL has been oriented around waste heat utilization and wastewater treatment. Using selected species of fish in a system which combines modern technology with ancient Chinese aquaculture techniques, a system has been developed which appears capable of producing approximately 23,000 kg/0.40 ha/year (50,000 lb acre/year) of high quality fish protein at very low cost.

3. ECOSYSTEM STUDIES PROGRAM

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Introduction

The Ecosystem Studies Program was initiated in February 1978 to provide a common focus for post-IBP (International Biological Program) activities and smaller ecosystem research-related projects supported by the National Science Foundation and the Department of Energy (DOE). Post-IBP studies include biome synthesis and process level research concerning photosynthate allocation, role of consumers, and land-water interactions. These activities were completed in June 1978, were included in the 1977 Annual Report, and will not be addressed in this report. Ecosystem Studies currently encompasses NSF-sponsored work in systems analysis, spiralling of nutrients in stream

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ecosystems, and global carbon inventory and cycling, and DOE-sponsored work in fuels from biomass. The program is designed to stimulate fresh thinking and approaches to ecosystem level concepts and relies heavily upon both individual creativity and group interaction to accomplish the tasks at hand. The program places strong emphasis on interaction and collaboration with outside institutions as evidenced by the number of universities and federal agencies involved in our efforts. Educational aspects of the program include support of undergraduate and pre- and post-doctoral candidates who are actively involved in one of our four major research areas

Research activities in the Extending Systems Analysis in Ecology Project were initiated on March 1, 1978, for a three-year period. The primary objectives of this project are (1) to explore areas of topical importance in ecology in which systems-ecological applications may aid in development of the field, (2) to determine solutions to certain problems that have emerged in the subdiscipline of systems ecology, and (3) to identify ecological applications of systems techniques from other sciences. Major areas of research effort include forest succession modeling, development of new error analysis techniques, and studies of spatial heterogeneity in terrestrial and aquatic ecosystems. Significant accomplishments in this project include the development and application of the stand growth simulator (FORET) to the forests of the southeastern United States, and in particular to the analysis of long-term environmental changes on these forests; development and application of a Monte Carlo method of sensitivity and error analysis of nonlinear systems (APIS) for evaluating propagation of error in these systems; application of m-matrices mathematical theory to unraveling the dynamics of mutualistic biological systems; determination of the basic structure of food webs in relation to their local stability properties; and finally, isolation of the water-use component of the evapotranspiration model (PROSPER) which has led to a stand-alone evapotranspiration simulator.

The Material Spiralling in Stream Ecosystems Project was initiated on May 1, 1978, for a three-year period, with the objective to test the hypothesis that the ability of a stream community to retain and reutilize materials such as nutrients and carbon is an important systems level process that alters stability properties of the total stream system. Experimental studies in this project are designed to utilize tracers in natural and artificial streams to determine spiralling indices and to experimentally manipulate stream systems to define their stability properties. The work is divided into three major areas: measurement of spiralling in stream systems, detailed investigations of spiralling mechanisms, and field manipulations of streams to test spiralling length-stability hypotheses. First-year work has concentrated on quantifying spiralling length of phosphorus in Walker Branch and testing the hypothesis that phosphorus limits detrital processing and primary production in this stream. An important observation of our initial experiments is that while phosphorus appears to be limiting in Walker Branch, measurements of nitrogen concentration during these experiments indicate that this nutrient may simultaneously be limiting decomposition and ultimately stream productivity.

Global carbon dioxide research in the Division is directed toward clarifying the role of the terrestrial biota in the carbon cycle and developing methods for assessing the effects of climate change that might be induced by increases in CO_2 . These increases are generally attributed to the transfer of CO_2 to the atmosphere in the combustion of fossil fuels. A portion of the CO_2 from fossil fuel combustion stays in the atmosphere, while the remainder is presumably transferred either to the biota through photosynthesis or to the oceans through chemical processes. The Global CO_2 Project, which was initiated on October 1, 1978, for a six-year period, is developing mathematical models of the global carbon cycle based on our newly developed inventories of carbon distribution in world ecosystems and incorporating ocean representations developed by other institutions. In particular, we are attempting to provide a model of the terrestrial biota which is disaggregated in space and incorporates environmental conditions such as temperature. In this disaggregated model the fluxes of carbon due to forest clearing will be represented explicitly. In addition, the variation in past climate is being investigated by analyzing tree-ring and pollen chronologies in concert with models for forest succession. The goal of these efforts is to understand the role of the terrestrial biota in the carbon cycle in sufficient detail to provide meaningful projections of the influence of man's activities on the global carbon cycle and ultimately, climate.

The Fuels from Woody Biomass Project was initiated on October 1, 1977, and is supported by the DOE Division of Distributed Solar Technology. The objective of this project is to provide technical assistance to the DOE Fuels From Biomass Program Office in developing economically and technically sound woody biomass for energy through support of 24 contractors in the areas of species screening, stand establishment, improved management strategies, and improved techniques of harvesting. Major accomplishments in the program during the past year include development and initiation of the 24 R&D contractors located in 22 states totalling \$3.2 million, and development of working relationships with the USDA-Forest Service, Tennessee Valley Authority, EPA-Office of Solid Waste, and the Solar Energy Research Institute. The program is designed to run for five years and the Environmental Sciences Division's role will be to continue to assist DOE in managing the 24 contractors; to continue developing and promoting interactions with other major agencies and offices concerning woody biomass; and to promote program outreach in the form of interactions with state energy offices, industry initiatives, and regional energy offices.

Systems Analysis

Work in the Systems Analysis Project is supported by the National Science Foundation and addresses questions arising in the application of systems theory to ecosystems and their component parts. The major objective of this project is to further our understanding of ecological phenomena through the application of systems techniques. To obtain this objective, our research activities are centered around forest succession modelling; development and evaluation of new error analysis techniques; and evaluation of spatial heterogeneity in community stability, vegetation distribution patterns, and soil moisture flow. These activities are conducted by division staff members as well as collaborators from several universities and other federal agencies.

Succession Modelling

Considerable progress has been made toward the development and use of the stand growth simulator FORET (Shugart and West 1977). In addition to FORET, which simulates the deciduous forest of east Tennessee, simulators for upland forests of southern Arkansas and floodplain forests of the Mississippi River have been developed. Work has been initiated on constructing additional simulators for the natural and plantation coniferous forests of the southcentral and southeastern coastal plain. Field work is now in progress for parameterization of a simulator for the Puerto Rican Tabonuco rain forest. Completion of these different stand models provides simulation capability for stand succession and growth of the major southeastern forest types.

The FORET model has been used to explore several types of spatial considerations in natural forest systems, including cyclic behavior of forests under natural and disturbed conditions, density-diameter distribution relationships, and biomass dynamics related to gradual climatic changes. Stand dynamics with regard to variation in the simulated plot size have been investigated. The contrasting effects of plot size on the importance of root and crown competition has provided a quantitative basis for identifying the size of a natural forest stand based on community-level dynamic (Shugart and West, in press). Examination of temperature gradients on the simulation behavior of a hypothetical American beech-yellow poplar stand has demonstrated the possibility of sharp transitions in forest types due to competitive effects.

Considerable effort has been spent gathering and incorporating species autecological characteristics into the stand-growth simulators (FORET, FORAR, and FORMIS). The list now includes approximately 100 eastern deciduous forest species with appropriate modeling capabilities for handling these large arrays. An objective is to make the modelling effort as transferable as possible within the various forest types of the southeastern United States for eventual use in studying long-term effects of fire, flood, climate change, pollution stress, and competition on the dynamics of the deciduous and coastal plain forests.

Spectral analysis techniques have been applied in the study of forest succession model output (Emanuel et al. 1978). The utility of spectral analysis for examining the changes in stand dynamics as a result of temperature fluctuations or pollution impacts has also been investigated. Such perturbations may cause only subtle changes in time series of total stand biomass; however, alteration of the cyclic response of a given species may be quite significant. Future plans call for the investigation of the role of species dominance, using spectral analysis.

Error Analysis of Nonlinear Systems

Error analysis methods have been systematically applied to a suite of ecosystem models to evaluate errors due to the natural variability of the system, bias in estimating true system behavior, and representation of system behavior with alternate mathematical expressions. The results show that small coefficients of variation on parameter values can result in coefficients of variation on model output that are as much as an order of magnitude larger. In these simulations, uncertainty in model output does not simply grow through time because of environmental constraints on system behavior (e.g., aquatic systems which freeze in winter and exceed optimal temperatures in the summer). These constraints result in time-specific contributions to model error and neither arbitrary selection of validation data nor selection of data at uniform time intervals is optimal.

Comparison of six models for the same two-species system (Gardner et al., submitted) was effected by partitioning the errors into component sums of squares. Models differed in their error propagation properties with more complex functions generating greater uncertainty on output. The contribution of a specific term in a model (e.g., various respiration terms or Q_{10} relationships, etc.) to overall error was dependent on its mathematical form (especially, the partial derivative of the term with respect to the parameter) and also its position in the model. No single model showed the smallest output uncertainty for all possible modeling objectives. These results indicate that the most useful data for testing a model should be gathered during periods of the year when the state variables are changing most rapidly.

Monte Carlo simulation of preliminary models is most useful in determining optimal sampling strategies for validation. The serious implications of error propagation provide strong motivation for continuing explorations so that systematic approaches to minimizing uncertainty can be devised. Alterations in model formulations which reduce errors must be considered as well as strategies for parameter measurement that will minimize uncertainty.

Natural variability may introduce a bias whose magnitude is a function of the mathematical form of the model, the degree of natural variability, and other parameters in the system (O'Neill, submitted). Although the errors due to this bias may sometimes be small, in other cases the error is quite significant and can distort conclusions drawn from model predications.

To analyze model error from sources other than parameter variability (e.g., errors due to model structure, model formulation, and interdependencies between parameters), a series of linear models with increasing number of connections between successive compartments were examined. When the turnover rates of all compartments are normalized and all the transfer coefficients are varied at 10% of their mean value, the relative errors of a given compartment are dependent on its location in the model. With no feedback loops, increasing connectances do not affect the first compartment (dependent only on the external forcings) nor the last compartment in the model. However, the mean rate of loss of material from the system is important to the variability of all compartments. The distinction between the first and last compartment diminishes when feedback loops are added. Feedback, however, becomes less important as the mean rate of loss from the system increases.

Closed systems which are time invariant are difficult to analyze because every component in a model eventually affects every other component. By simultaneously varying the parameters of model equations, a multivariate approach can be used to inspect the

interdependencies of parameter values and model structure (Garten et al., in press) and to evaluate the effects of alternate model formulations and assumptions. Results show that errors for these closed systems can rapidly amplify from 10 to 20% variability of the rate coefficients to as high as 250% variability of the final state of a given compartment. Because of the strong interdependencies in these models, a final judgment about their predictability cannot be made until problems of spatial aggregation, pools of material with long turnover times, and the inadequacy of critical information are solved.

Spatial Heterogeneity

Theoretical analyses of community stability have pursued three principal lines: (1) dynamics of mutualistic systems, (2) relationships between basic structure of food webs and their local stability properties, and (3) global stability of three-species Lotka-Volterra models. Work on the dynamics of mutualistic systems has employed the mathematical theory of m -matrices and the economic theory relevant to essentially positive matrices. We have developed simple conditions for the local stability of general community models and for the persistence of species within models of mutualistic and limited competition communities. This work has been extended to define conditions for global stability and to show that criteria for persistence and stability derived for mutualistic communities apply to spatially patchy systems. The criteria for stability are applicable to models of communities with predatory-prey interactions and competitive interactions of any pattern. Under specified conditions, the criteria assess the community stability more accurately than any other simple condition that is currently known.

In attempts to relate the basic structure of food webs to their local stability properties, we have shown that an increasing number of trophic levels in Lotka-Volterra food web models leads to a less resilient system. Furthermore, systems with species feeding on more than one trophic level are likely to be unstable. Compartmentalization also decreases the likelihood of stability. Increasing complexity tends to decrease stability with respect to species deletion.

We have derived mathematical conditions for the extinction and persistence of three competing species in Lotka-Volterra models. In systems where one of the three species is mutualistic with one of the two competitors, the presence of the mutualist can upset the global stability of an originally persistent system, driving one of the competitors to extinction.

Work on interactions between vegetation patterns and soil moisture dynamics has followed two directions: (1) water use by vegetation and (2) subsurface-flow simulation. We have isolated the water-use component of our soil-plant-atmosphere moisture dynamics model (PROSPER; Goldstein et al. 1974), and developed it into a stand-alone evapotranspiration simulator (Huff et al., in press). We have also developed the conceptual framework for linking it to a subsurface-flow module. In addition, simulation of the interaction between transpiration and moisture content of a marshy area has been used to quantify moisture dynamics of a freshwater marsh.

The subsurface-flow simulation models require four types of input: (1) precipitation data, (2) antecedent moisture condition, (3) basin morphology, and (4) soil-hydraulic characteristics. The first two input requirements have been assembled for Walker Branch Watershed on the Oak Ridge Reservation. The latter two data needs have required extensive field work. A topographic map of Walker Branch has been prepared and used to sub-divide the basin into individual modeling units (segments), which have been characterized in three dimensions. Hydraulic characteristics have been studied and adjusted for high stone content. The resulting data were then used in preliminary simulations with the Troendle-Hewlett variable source-area model and the Reeves-Duguid finite-element model (FEM) for saturated-unsaturated flow which has been applied to a vertical cross-section of the West Fork of Walker Branch Watershed. Extension to a one-month simulation of four rainfall events reveals that transient simulation by the FEM will be costly. Investigation to increase the efficiency is currently underway.

Material Spiralling in Stream Ecosystems

This NSF-supported project represents an integrated experimental-theoretical approach to nutrient and carbon dynamics in streams, based on the premise that streams are adapted to maximize the retention and reutilization of these materials as they are transported downstream. As materials move through a stream, they do not return to the point of origin but are displaced some distance downstream. Thus, the cycle is open and can be represented conceptually as a spiral. Spiralling length is used to indicate the downstream displacement distance associated with one passage of an element such as P or N through an ecosystem cycle. First-year work in stream spiralling has concentrated on quantifying the spiralling of P in Walker Branch and testing the hypothesis that P is limiting detrital processing and primary production in this stream.

Quantification of Spiralling in Walker Branch

To quantify spiralling of phosphorus in Walker Branch an experiment was initiated on July 5 with the simultaneous release over a 30-min period of approximately 8 mCi of ^{32}P (as $\text{K}_2\text{ }^{32}\text{PO}_4$) and 10 mCi of ^3H (as tritiated water) into a 120-m experimental reach of the west fork. Sampling for six weeks thereafter of water, FPOM, CPOM, aufwuchs, benthic invertebrates drift, and transport was carried out in order to obtain data to estimate transfer coefficients of P from which spiralling indices will be computed. A budget prepared for the first 3 hr indicated that 58% of the total ^{32}P input passed directly through the 120-m reach. Phosphorus-32 sampled in various ecosystem components accounted for another 55% of the input, yielding an error of approximately 14%.

Taking this margin of error into consideration, it is estimated that the coarse particulate organic matter (CPOM) accounted for 65 to 75% of the entire uptake of phosphorus from the water. Fine particulate organic matter (FPOM) and inorganic substrates each accounted for 10 to 13% of the uptake, while aufwuchs (the microbial community, including algae on rock substrates) accounted for 6 to 8%. The overestimate of the total ^{32}P uptake probably arises from overestimates of the standing crops of CPOM and FPOM that were directly exposed to the ^{32}P input.

The initial release data also allowed us to compute a preliminary estimate of spiralling length for phosphorus. For this purpose we employed the following simple model for phosphorus transport and uptake through the reach:

$$\frac{dC_i}{dt} = \frac{\lambda}{\Delta x} (C_{i-1} - C_i) - k C_i,$$

where C_i is the concentration of the isotope in stream segment i , λ is the downstream transport rate (m/hr), Δx is the segment length, and k is the rate of uptake of the isotope from the water (/hr). The biotic uptake length, U , defined as the distance P will travel in the abiotic compartment before being taken up into the biotic compartment, can be calculated as λ/k . From the tritium data, for which k is assumed to be 0, we arrived at a value for λ of 132 m/hr averaged over the 120-m reach, and from the ^{32}P data we obtained a value for k of 0.45/hr (corrected for uptake onto inorganic surfaces). The latter value was obtained by a simple trial and error fitting to the above model, but in spite of this relatively crude approach the resulting fit was good.

From these values of λ and k , $U = 295$ m. The other component of spiralling length, the biotic turnover length, T , defined as the distance P will travel in the biotic compartment before being released to the abiotic compartment, was then calculated from U according to

$$T = U (F_A/F_B),$$

in which F_A (0.078 g P/hr) and F_B (0.0054 g P/hr) are the downstream fluxes of stable phosphorus in the abiotic and biotic components, respectively. From these values, $T = 20$ m, and the spiralling length, $S = U + T = 315$ m. This length is the downstream displacement distance of phosphorus in Walker Branch associated with its passage through the stream ecosystem cycle (i.e., from biotic uptake of the inorganic PO_4-P in water to its remineralization back to inorganic PC_4-P).

These computations of spiralling indices are preliminary, being based on only a fraction of the data now available and on relatively crude estimation techniques. Refinement of these estimates, validation of the theoretical assumptions used in their calculation, and further elaboration of spiralling processes will be achieved through analysis of the entire data set. This work involves fitting the data from the stream release to a model of the form:

$$dx/dt = A x + f,$$

where x is the phosphorus pool in each component of each section of the stream, f is the forcing function (rate of release of the isotope), and A is a matrix of transfer coefficients. Our indices of spiralling are then algebraic combinations of coefficients, a_{ij} , taken from the matrix A .

The nonlinear least-squares problem implied in this effort is a difficult one. Success depends on fitting a few coefficients at a time and then setting these to constant values while additional coefficients are estimated. Therefore, we have begun by focusing on the results of the 3H data which permit us to estimate the hydrologic characteristics of the stream, without the complexities of phosphorus uptake and release rates. The tritium data permit calculation of flow rate, segment volume, water velocity, and transfer coefficients involved with water movement from segment to segment. The flow rate, which is estimated from the time integral of tritium passing each sampling station, shows six locations at which water is entering the stream. Several of these locations correspond to known springs and serve as a validation of the estimation procedure.

Global Carbon Dioxide

The NSF-supported Global Carbon Project, initiated October 1, 1978, was developed to determine whether forests and woodlands which comprise the bulk of terrestrial carbon storage are a net source or sink for atmospheric carbon dioxide, and to establish a means by which it is possible to predict how the carbon balance might be changed, especially by climatic shifts associated with credible changes in atmospheric carbon dioxide. Our six-year approach in addressing these two objectives includes a series of six subtasks. These are: evaluation of major geographic and geochemical carbon pools, determination of land-use shifts as these effect trends in carbon pools, utilization of this information in an overall terrestrial carbon submodel for global exchanges, evaluation of production and loss rates of carbon for the main classes of ecosystems that dominate the terrestrial environment, comparison of the climatic control of present geographic patterns to real climatic fluctuation in post-glacial times, and utilization of all this information for a beginning assessment of how the carbon cycle itself could be modified by future climatic changes which now seem likely to arise if atmospheric carbon dioxide increases substantially.

Simulations of Land-Use Patterns Affecting the Global Carbon Cycle

Increases in the concentration of carbon dioxide in the earth's atmosphere, which are projected to cause significant climate modification, are generally associated with the combustion of fossil fuels. It is becoming clearer, however, that an additional source of CO_2 to the atmosphere exists because of the clearing of forests, particularly in tropical zones. The CO_2 release from forest clearing may be balanced to some degree by accelerated regrowth, but significant land area continues to be converted to

agriculture or other nonforest use. Insufficient data make it difficult to assess the annual net transfer of carbon between the terrestrial biota and the atmosphere; yet, it is important to begin to account for fluxes due to forest clearing in mathematical models of the global carbon cycle.

A comprehensive diagrammatic representation with estimates of pool sizes and average flows for the global carbon cycle has been developed by Olson et al. (1978). Flows of carbon from woody material compartments to the atmosphere due to the immediate release of CO_2 from deforestation and from woody compartments to nonwoody compartments due to changes in land use have been added to this basic representation. In addition, a flow from rapid-turnover to slow-turnover woody compartments is incorporated to allow for testing of management strategies based on storing carbon in terrestrial pools. A mathematical model has been formulated, based on material balance relationships derived from this approach. In the model equations, the transfers of carbon associated with forest clearing have been incorporated by dynamic equations for changes in area of the terrestrial carbon pools. The mass of carbon transferred is calculated, based on estimates of density. Scenarios for forest clearing are evaluated by explicitly specifying change in area as a function of time.

The model has been tested by comparing solutions with measurements of atmospheric CO_2 concentration. Differences between calculated and measured values are small, but generally the calculated values are larger than the measured values. This may indicate that hypothesized fluxes for clearing were too large. The sensitivity of the model to changes in parameter values was tested with respect to (1) the initial concentration of CO_2 in the atmosphere, (2) the biotic growth factor, (3) the area concentration of terrestrial biomass, and (4) the flow of carbon into the deep ocean. In all cases, reasonable variations in the simulated concentration of atmospheric CO_2 were observed. The greatest sensitivity was noted for changes in the deep ocean flux of carbon.

With insights provided by the validation and sensitivity experiments in mind, a number of scenarios for fossil fuel utilization and forest clearing were used in conjunction with the model to predict future concentrations of atmospheric CO_2 . In the worse case a doubling of the assumed 1860 level of atmospheric CO_2 was calculated for year 2025. A conservative set of scenarios was tested corresponding to low fossil fuel use, high carbon storage, and high net primary production of forested ecosystems, which delayed the doubling until year 2290.

A Comparison of Three Carbon Models

If the accuracy and precision of global carbon models can be ascertained, uncertainty about long-range trends may be reduced and future planning will be more credible. By considering the carbon cycle as a closed system (i.e., including the entire biosphere) and the amounts of carbon in various pools or compartments as state variables, any variation in fluxes between the compartments result in perturbations in all state values. The nature and extent of variation in state values are not easily discerned because they depend on several factors, including the mean sizes of the compartments, intercompartment fluxes, and the model structure. We have used Monte Carlo simulations to gain insight into the effects of parameter variability, to place confidence intervals around state variables, and to examine the effects of model structure on predicted levels of carbon pools in three global carbon models.

The three models (Fig. 3.1) were formulated from compartment diagrams and parameter values excerpted from the literature. Model 1 is based on a compartment diagram and data presented by Bolin (1970) with the linear coefficients given by Gowdy et al. (1975). Model 2 is a synthesis of concepts and data estimates provided by participants in the 1972 Brookhaven symposium on the Global Carbon Cycle (Reiners 1973). Model 3 represents a highly aggregated structure typical of numerous models (e.g., Keeling and Bacastow 1977).

Although these models may not be adequate for prediction of the future states of carbon fluxes or pools, they provide an opportunity for comparing the effects of alternate formulations and parameter variation on model predictions. Where there is agreement between model simulations and other sources of information, then insight into

Fig. 3.1. The median, 97.5 and 2.5 percentile of atmospheric carbon dioxide predicted by 300 Monte Carlo simulations are shown for each model at 1, 5, 10, 20 and 30% parameter variation.

the effects of variation and parameter uncertainty on predictions and understanding of the carbon cycle may be gained. The important results of the Monte Carlo simulations are:

(1) With modest levels of parameter variability (5 to 10%), the three models show no significant difference in predicted mean atmospheric carbon, although Model 3 is

always the most conservative. The definition of compartments and the connections between them produce significant differences in the variances of model predictions and the correlations between state variables and parameters.

(2) Depending on the response times of the various components and levels of uncertainties in model parameters, predicted levels of atmospheric carbon dioxide can change by a factor of 2 without assuming an increase in the estimated mean rate coefficients (i.e., constant rates of fossil fuel combustion). The most sensitive parameters are ones which describe the ocean-atmosphere interaction and the ocean surface-biological productivity interaction.

(3) Certain high order interactions may provide feedback responses which could reduce carbon dioxide variability. Such interactions are suspected to exist between ocean mixing rates, net phytoplankton productivity, and long-term changes in terrestrial land-use patterns.

(4) The greatest potential long-term effect on the atmospheric level of carbon dioxide predicted by Models 1 and 2 are volcanic releases. However, actual observations indicate that volcanic activity may result in a net reduction in atmospheric CO₂ because dust screens out solar radiation and cools the ocean surface and increases its ability to absorb carbon dioxide (Keeling et al. 1976).

In order to adequately model the dynamics of the carbon cycle, the problems of spatial aggregation, long turnover times of carbon pools, inadequacy of critical information, and conflicting views and predictions must be reconciled. By simultaneously varying the parameters of model equations, it is possible to use a multivariate approach to quickly inspect the interdependencies of parameter values and model structure (sensitivity analysis), evaluate the effect of alternate model formulations and assumptions, and recommend future refinements.

Fuels From Woody Biomass

The objectives of this DOE-supported project are to provide the Distributed Solar Technology Division of DOE with technical assistance in managing 24 basic research and development contractors in 22 states dealing with various aspects of producing woody biomass for energy. The major emphases of the Woody Biomass Program include screening potential woody species for maximum growth, yield, and Btu content; investigation of new methods of stand establishment of silvicultural crops including irrigation, weed control, and fertilization; evaluating current silvicultural management practices and recommending new techniques or modification of existing systems; and developing new innovative methods of harvesting, transporting, and storing woody biomass grown for energy.

Depending on the particular contractor, research has now been in progress for three to eight months. Fifteen of the 25 contractors have been site-visited to discuss their research progress, to gain insight into future funding needs, and to clarify reporting procedures and format for renewal proposals. New research needs have also been identified. The first quarterly reports (September 30, 1978) have been received, summarized, and forwarded to the Distributed Solar Technology Division in Washington. Areas of research coordination among contractors are being identified and implemented. The first annual meeting of contractors in July was instrumental in contractor research coordination. The second quarterly reports are currently being received and progress by most contractors is satisfactory.

Species Selection

From an initially large list of tree and shrub species, over 76 are being examined in detail to determine their suitability for biomass production. A number of species are under examination at more than one location. Heading this list are species with high yield potential: sycamore (Platanus occidentalis), hybrid poplars (Populus spp.), black locust (Robinia pseudocacia) as a nitrogen fixer on poor sites, willow (Salix

spp.), sweetgum (*Liquidambar styraciflua*), red and sugar maple (*Acer rubrum* and *A. saccharum*), and *Eucalyptus* spp. The list goes on to include conifers and shrub species. Native species are being examined as candidates for both distributed and intensively cultivated biomass production, while exotics and hybrids are being evaluated strictly for energy farm stocking.

Stand Establishment

Considerable effort is being placed on species propagation by a few of the contractors. Of particular difficulty is the wide variation of growth within and among species. Such variation is believed to indicate that phenotypic selection (now occurring) can provide much improved stock for biomass production. Many species have never previously been considered for cultivation and management. Consequently, there is little information on their propagation and growing behavior. Considerable progress is occurring in piecing together this information from current field testing. Most researchers are utilizing sites which are considered "available" for biomass production (i.e., sites marginal for agricultural, pulpwood, and sawtimber production). The most critical problems encountered are weed control, pest control, determination of the most desirable establishment method to ensure propagule survival, and interactions of interplanted species. The spacing being tested ranges from 61 x 16 cm (2 x 2 ft) to about 3.7 x 3.7 m (12 x 12 ft) depending on region, species, and anticipated rotation length. Several researchers have broadened their work scope to include weed control research.

Silvicultural Treatment

As mentioned above, a wide range of tree spacings are being tested on a wide range of sites. Considerable work is being directed toward interplanting with species associated with nitrogen fixation (alder, black locust) and increasing overall biomass production on marginal sites. Rotation lengths being tested vary from 2 to about 15 years. These rotation lengths, of course, are related to method of species propagation (and harvesting), plant spacing, level of irrigation/fertilization, and biological growth characteristics for specific species. Thus, rotation lengths are based on long-term (30- to 40-year) economic gain. Initial results indicate that fertilization may increase growth of cuttings and seedlings by as much as 100% for selected species. Species selection may show equal or greater increases. Several ideas have been expressed in selecting different crown forms from a single species (or mix of species) which can eventually be interplanted to maximize site utilization and production of biomass. There are no direct indications of the magnitude of potential insect and disease problems associated with monoculture or limited multiculture plantings, species selection for biomass production alone, or for spacing and coppicing regimes with most of the species being examined.

Harvesting

Two lines of research deal with harvesting: (1) modelling of alternative harvesting techniques, equipment, and modes of transport to determine acceptable economic combinations; and (2) direct harvesting and measuring of biomass to determine the methods and equipment most desirable for use or improvement to economically recover woody biomass. Chipping and bailing before hauling are the two methods of biomass treatment receiving most attention. The major problem encountered is the anticipated size of biomass harvested for fuel (about 3 to 20 cm in diameter) which lies between traditional sizes of agricultural and woody crops that machinery has been designed to harvest.

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4. SYNTHETIC FUELS PROGRAM

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Introduction

Coal continues to occupy a prominent position in the nation's endeavor to attain energy independence. As such, development of methods for converting coal to more environmentally acceptable gaseous, liquid, and solid fuels continues. Emphasis has shifted, however, with major support directed at early construction and operation of several large-scale demonstration facilities for the coal conversion process types. Additionally, a program, referred to as the Gasifier-In-Industry Program, was initiated to demonstrate the feasibility of using state-of-the-art gasifiers for providing low Btu gas for industrial use.

Major goals of the program remain relatively unchanged. They include: (1) aiding the development of environmentally amenable coal conversion technologies; (2) developing a data base for assessing the effects of coal conversion technologies on biological communities; and (3) determining the form, source, and potential concentrations of trace contaminants in man from environmental releases of coal conversion-related products and effluents.

Attainment of the first goal continues to emphasize use of short-term environmental test systems, although initiation of data management will ultimately allow greater use

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of results of all our studies. As the Department of Energy (DOE) continues to require rapid response to questions of energy assessment related to coal conversion, we are having to make greater use of computers to manage and analyze our data quickly. Data management and program integration activities were initiated towards the end of the fiscal year, and initial efforts have focused on formatting, coding, and verifying the research data already in notebooks and file drawers. Several data sets on aquatic bioassays have been automated and where appropriate, merging and subsetting programs have been developed to allow comparisons of experimental results. Textual descriptions of each data set and standardization of units and variable nomenclatures have been performed. Work has begun to code and automate the seed germination studies data sets.

The data base needed to develop predictive capabilities for attaining the second and third goal arises from mechanistic studies in both effects and transport areas. These studies include those activities designed to elucidate how a particular material causes an effect, which particular compounds are problematic or nonproblematic, what the critical pathways of given materials to man and other organisms might be, and how much of a material might reach various organisms (including man).

The program continued to grow during this past year both in size and diversity of support base. The Division of Ecological Research within DOE continues to be the major source of funds, with additional research covered by the Division of Environmental Control Technology. The Environmental Protection Agency (EPA), through its Office of Solid Waste and Industrial Environmental Research Laboratory supports efforts evaluating potential hazards of solid waste.

In addition to new efforts in data management (described above), the program has initiated research in reproductive toxicology and an environmental assessment activity at a small gasification facility on the campus of the University of Minnesota-Duluth. This latter activity is part of an interdivisional effort of the Life Sciences Synthetic Fuels Program. Preparation of the plan and initiation of the activity impacted heavily upon programmatic research efforts in several areas.

The remainder of this section contains brief highlights of many of these activities.

Aquatic

Wastewater derived from synthetic fuel processes are chemically very complex, being comprised of hundreds of organic and inorganic chemicals. Our efforts during FY 1978 were aimed at attempting to understand some of the potential toxicological hazards that may result from releases of these wastewaters. Several approaches have been taken, including studies on whole effluents, their chemical fractions, and their individual chemical components.

Acute Toxicity of Coal Conversion Effluent Components

During FY 1978, tests were conducted to determine the acute toxicities of a large number of the individual chemicals present in synthetic fuels wastewaters. The basic acute toxicity test used has been the static acute toxicity test with *Daphnia magna* as the test organism. *D. magna* was chosen as the test organism because it is relatively sensitive to most toxic materials and is an easy animal with which to work.

The chemicals tested belong to four chemical classes: phenolics, azarenes, organic acids, and inorganic and organic salts. Their acute toxicities, calculated as 48-hr LC50s, are presented in Table 4.1. As a class, the phenolics and azarenes were the most toxic, while the salts, except for ammonium chloride, potassium thiocyanate, and cadmium chloride, were the least toxic.

Table 4.1. Acute toxicities of some chemicals in synthetic fuel wastewaters

Chemical	48-hr LC ₅₀ (mg/liter)
<u>Phenolics</u>	
Phenol	30.1
M-cresol	18.8
P-cresol	1.4
O-cresol	16.1
Trimethylphenol	0.3
2-naphthol	2.9
<u>Azaarenes</u>	
Quinoline	28.5
Isquinoline	4.1
2-methylquinoline	27.3
2,6-dimethylquinoline	34.1
Acridine	2.4
Trimethylpyridine	47.5
<u>Inorganic and organic salts</u>	
Sodium sulfate	2233.0 (SO ₄ ²⁻) ^a
Sodium nitrate	2006.0 (NO ₃ ⁻)
Sodium phosphate	2399.0 (PO ₄ ³⁻)
Potassium thiocyanate	57.4 (SCN ⁻)
Ferrous sulfate	21.0 (Fe ⁺²)
Ammonium chloride	25.4 (as NH ₄ ⁺)
Sodium acetate	3354 (C ₂ H ₃ O ₂ ⁻)
Cadmium chloride	0.02 (Cd)
<u>Organic acids</u>	
Acetic acid	192.2
Hexanoic acid	42.8

^aChemicals in parentheses refer to chemical form that was measured in the calculation of the LC₅₀.

Acute Toxicity of Aqueous Waste and Wastewater Components of the ORNL Bench-Scale Hydrocarbonization Process

Among the synthetic fuel technologies currently under development is the hydrocarbonization (HCZ) process of which there is an operating process development unit (PDU) at ORNL. Concomitantly, the Chemical Technology Division at ORNL has developed a fluidized-bed bio-reactor to treat the wastewater produced by the PDU.

Acidic, basic, and neutral organic fractions from untreated HCZ wastewater were screened for acute toxicity to *D. magna*. The neutral fraction had the greatest toxicity and the acidic fraction the least. A similar screening of an untreated solvent-refined coal (SRC) wastewater had previously produced somewhat different results. Although the neutral SRC fraction was also the most toxic, the basic SRC fraction was the least toxic.

A procedure was developed to evaluate the hazard of the acutely toxic chemical components of treated and untreated wastewater produced by the PDU. Static tests with *D. magna* were used together with chemical analyses of the effluent to determine: (1) the acute toxicity of the effluent, (2) the concentration of the major chemical components, (3) the acute toxicity of each of the major components, and (4) the acute toxicity of a synthetic effluent comprised of a mixture of the components at concentrations found in the original effluent. From these data, the contribution of each component to the

toxicity of the whole effluent was determined and the presence of interactions between the components was evaluated.

The 48-hr LC₅₀ of the untreated HCZ wastewater was determined to be 1060 μ l/liter. The major toxic components of the wastewater were phenol and cresol (Table 4.2), accounting for 91.3% of the toxicity of the wastewater. Ammonia contributed 8.8%. The treated wastewater was determined to be 1% as toxic (48-hr LC₅₀ = 116,000 μ l/liter) as the untreated wastewater. Its principal toxic component was ammonia (Table 4.2).

Table 4.2. The calculated contribution of each of the major components of the hydrocarbonization wastewater to the toxicity of the wastewater

Component	% of total effluent toxicity	
	Untreated effluent	Treated effluent
Phenol	18.0	0.4
O-cresol	22.5	<0.1
P-cresol	47.8	<0.1
M-cresol	3.0	<0.1
Ammonia	8.8	80.1
Sulfate	<0.1	0.7
Total nitrate	<0.1	<0.1
Total phosphate	0.1	1.7
Thiocyanate	<0.1	0.6
Unidentified	<0.1	16.5

The toxicities of the individual components of the untreated wastewater were found to be additive; however, the components of the treated wastewater demonstrated apparent less-than-additive toxicities (i.e., the actual toxicity of the wastewater was less than the predicted toxicity of the wastewater based on its chemical composition). This was determined to be a result of the influence of the pH of the solutions tested on the toxicity of ammonia. Ammonia is most toxic in its undissociated form and pH controls the dissociation of ammonia (i.e., the higher the pH the greater the proportion of ammonia in solution that will be undissociated). The pH of the treated HCZ wastewater had a pH of 7.3 as its 48-hr LC₅₀, while the pH of ammonia tested alone at its 48-hr LC₅₀ was 8.2. The lower pH of the wastewater would thus appear to explain the apparent lower toxicity of the ammonia present in the wastewater as compared to ammonia tested by itself. This would, in turn, explain the apparent less-than-additive toxicities of the components of the wastewater.

Terrestrial

Effects research directed at assessment of the potential hazard of synfuels technology development to terrestrial ecosystems has progressed in five distinct areas during the past year. One of these areas is a new effort in support of the DOE Gasifiers-in-Industry Program. A second new area involves the development and application of short-term bioassay tests for the assessment of the potential phytotoxic effects of solid waste leachates. A third new area is the development of an activity in reproductive toxicology in which an insect is used as the test system. In addition, program research projects in the areas of air pollution effects on vegetation and terrestrial food chains continued to develop.

Staff of the Synthetic Fuels Program participated in the development of the environmental portion of a comprehensive environmental, health, and safety plan for the University of Minnesota-Duluth gasifier-in-industry demonstration project. Following

development of the plan, two ambient air quality monitoring station sites were selected and monitoring instrumentation procured and installed in mobile field stations at the site. Each station will continuously monitor sulfur dioxide, hydrogen sulfide, total sulfur, nitrogen oxide, nitrogen dioxide, ozone, carbon monoxide, and total hydrocarbons. Periodic measurements will be taken of total suspended particulates, and volatile organic compounds. The stations are sited at locations estimated from atmospheric transport modeling to represent maximum ground-level concentrations of atmospheric effluents from the gasifier.

Program staff developed important modifications in seed germination bioassay test protocol which promise to improve test reproducibility and sensitivity, while at the same time reducing the amount of time previously required to set up and measure such a test by ten-fold. During the past year, approximately fifty extracts of hazardous or potentially hazardous solid waste materials have been utilized to evaluate the test system. Results to date suggest this modified test protocol may have widespread application for the screening evaluation of hazardous substances.

Program research has continued during the past year on the vegetation effects of potential gaseous emissions from synthetic fuels processing. Experiments have been completed to establish the response of a higher plant to three gaseous sulfur species potentially associated with coal conversion processes. Bush beans (*Phaseolus vulgaris* cultivars "Bush Blue Lake 274" and "Red Kidney") were exposed to equivalent doses of total sulfur as SO_2 , H_2S , or COS . The plants were compared for their relative sensitivity to each of the sulfur gases as determined by degree of tissue injury. Tissue injury data indicate the relative phytotoxicity of the sulfur gases decreases in the order $\text{SO}_2 > \text{H}_2\text{S} > \text{COS}$.

Terrestrial food chain research was concerned with the behavior of selected trace elements present in coal conversion effluents in one link of the terrestrial food chain during the past year. The specific link is that of grass to small mammals. Preliminary laboratory feeding studies have been completed with cotton rat and fescue tagged with ^{75}Se . As a result of three-week feeding studies, assimilation of Se from grass appears to be about 63%. The biological half-life of Se was determined to be approximately 10 days, with 75 to 85% of the elimination occurring through the urine. In similar experiments with Hg, assimilation appeared to be very low. At termination, the rats retained very little of the total amount of Hg eaten (0.3%) after 4 and 6 weeks elimination. The excreta accounted for 99% of the Hg recovered, with only kidney and liver, of the seven organs examined, having measurable Hg contents.

The newest program effort addresses the mechanisms whereby complex organic constituents of coal technology effluents affect reproductive systems and, hence, influence ecological systems.

Toxicity of PAH and Azaarenes

Understanding the effects of polycyclic aromatic hydrocarbons and azaarenes on insects is of considerable importance for predicting ecological consequences of these chemicals in the environment. Toxicity of the polycyclic aromatic hydrocarbons (PAH) to insects is being investigated with special attention to effects on reproduction. In initial studies, however, cricket (*Acheta domesticus*) mortality was used to compare the effectiveness of the G.I. tract and the integument as barriers to PAH entry.

Toxicity studies showed that PAHs are of low acute toxicity to crickets. Naphthalene, anthracene, benzo(a)anthracene, acridine, anthrone, pyrene, benzo(a)pyrene, and chrysene were noninsecticidal ($\text{LD}_{50} \leq 500 \mu\text{g compound/g of insect}$) in 24-hr toxicity tests with adult male and female crickets. However, when PAHs were mixed with food and fed to crickets over an 18-day period, mortality was observed. Mortality is shown in Table 4.3 as LT_{50} (the amount of time needed to kill 50% of the treated animals) for crickets feeding on 0.2% PAH food. Hempa (hexamethylphosphoramide) was included in the study because it will be used as a reference compound in experiments to determine effects of PAH on insect reproduction. Examination of dissected insects under long-wave ultraviolet light showed that organs of treated animals fluoresced, indicating that PAHs or metabolites were able to cross the gut wall.

Table 4.3. Toxicity of equivalent doses of chemicals to *Aedes triseriatus* (L.) after oral and topical administration

Compound	LT ₅₀ (days)	
	Oral	Topical
Acridine	9.25 ± 0.25	>18 (37.5%)
Benz[a]anthracene	10.45 ± 0.61	>18 (29.2%)
Pyrene	11.65 ± 0.29	>18 (26.1%)
Naphthalene	11.98 ± 0.41	>18 (25.0%)
Anthracene	>18 (39.1%) ^a	b
Benz[a]pyrene	>18 (31.8%)	b
Control	>18 (4.5%)	>18 (8.5%)
Hemp	8.33 ± 0.29	>18 (33.3%)

^aPercent mortality after 18 days is in parentheses for compounds with LT₅₀ >18 days.

^bCompounds could not be applied topically because solubility in acetone was too low.

To determine whether PAHs could cross the integument as well as the gut wall, PAHs were applied topically to insects every other day at a dose rate equivalent to the oral doses. The amount of a PAH eaten by the crickets was calculated from measurements of food consumption at 48-hr intervals over an 18-day period. Toxicity data in Table 4.3 show that PAHs were less toxic when applied topically.

Results of this study indicate that the cricket integument is a more effective barrier to PAH entry than the G.I. tract. In addition, this study suggests that environmental exposure through food will be more important than contact with contaminated substrates in determining toxicity of PAH to insects.

Aquatic Transport

Transport studies this year have focused in two areas: (1) accumulation of data at the coking plant field site on polycyclic aromatic hydrocarbon (PAH) transport and transformation, and (2) initiation of laboratory studies on azaarene (nitrogen-containing PAH) transport and transformation behavior. Additional research areas included sorptive partitioning of PAH and movement of a representative PAH compound (anthracene) through microcosms.

The Bethlehem Steel Corporation coke discharge at Bethlehem, Pennsylvania, was selected last year for PAH transport studies as being the most suitable analog for a commercial-scale coal conversion facility. Until late July 1978, the biologically treated effluent was discharged into Saucon Creek 1.5 km below the confluence with the Lehigh River. Since July 28, the effluent has bypassed the creek through an interceptor sewer and has been discharged directly into the Lehigh River. With the cooperation and active assistance of personnel from the Bethlehem Steel Division of Environmental Control and the Pennsylvania State Department of Environmental Resources, we intensively sampled Saucon Creek and the Lehigh River twice before the effluent diversion to assess PAH transport behavior in the stream-river system. One sampling since the diversion and two other planned samplings will elucidate rates of PAH flushing from the contaminated area.

Because azaarenes have been identified as potential mutagenic or carcinogenic hazards in coal conversion products, we have assigned the aquatic transport behavior of the azaarene class second in priority (next to PAH) of the various contaminant classes which may enter natural waters from coal conversion processes. Studies to date on

abiotic transformations have paralleled earlier work on the PAH class. With the completed synthesis of five ^{14}C -labeled azarene compounds by subcontractors this past year, we anticipate the accumulation of further transport data in the months ahead.

Aquatic Transport of PAH at the Bethlehem, Pennsylvania, Coking Plant Site

Intensive samplings of the river environment at the Pennsylvania coking plant site were undertaken on April 26-27 and July 19-20, 1978. A third sampling, considerably reduced in scale, was conducted on August 28 (one month after the effluent diversion) to assess rates of PAH flushing from the contaminated sediments. Seven sites on Saucon Creek and four on the Lehigh River (Fig. 4.1) were included in each study.

Fig. 4.1. Coking plant study area, Bethlehem, Pennsylvania. Black circles indicate sampling sites on the Lehigh River; distances from outfall (km) in parentheses. For clarity, sampling sites 1 through 7 on Saucon Creek are not shown.

During the April study, water samples were passed within 3 hr of collection through resin sorption columns (XAD-2; Rohm and Haas) to concentrate PAH. Samples from the July and August studies were sterilized by addition of 40 ml of chloroform to each bottle and shipped back to ORNL for PAH analysis. To provide an internal standard for effects of dilution and dispersion of the effluent plume during April and July studies, a constant concentration (160 g/liter) of LiCl dissolved in Saucon Creek water was metered by siphon into the effluent channel from a 210-liter drum. Sediment samples (200 g) were collected by scooping or dredging at the same locations.

Resin columns used in the April study were extracted sequentially with methanol, tetrahydrofuran, ether, and methylene chloride. Water samples from July and August studies were extracted with triplicate portions of methylene chloride. Sediment samples are extracted with acetone for 48 hr in a Soxhlet apparatus. Solvent extracts are reduced in volume under nitrogen and subjected to column chromatographic purification, and PAHs are identified and quantified by gas chromatography and GC-mass spectrometry.

Recoveries are determined by addition of ^{14}C -labeled PAH prior to sample extraction (Griest, in press). Concentrations of Li tracer were measured by atomic absorption spectrophotometry.

Only April (and several August) water samples have been analyzed for PAH content to date; sediments will be stored at -20°C until all water samples have been analyzed. Numerous PAHs were quantified in the April coke discharge (Table 4.4). Effluent levels of PAHs which are relatively water-soluble, such as fluoranthene and pyrene, were higher than those of less soluble species [e.g., benzo(a)pyrene and perylene]. On the basis of effluent flow, the coke plant discharges approximately 36 g of benzo(a)pyrene daily.

Table 4.4. Concentrations ($\mu\text{g/liter}$) of PAH on April 26, 1978, Bethlehem coke outfall water samples

	Mean and standard error of 5 replicates
Fluoranthene	18.3 (4.3)
Pyrene	14.4 (3.2)
Benzo[a]fluorene	1.4 (0.3)
Benzo[b]fluorene	1.3 (0.3)
Benzo[c]phenanthrene	0.67 (0.13)
Benzo[b]fluoranthene	5.4 (1.6)
Benzo[a]pyrene	2.7 (0.5)
Perylene	0.72 (0.24)
Dibenzanthracenes	1.4 (0.3)
Benzo[ghi]perylene	1.2 (0.1)

Gas chromatographic scans of April samples from all sites contained many peaks which were not attributable to the coke discharge, and which make quantification of a PAH mass balance unreliable. Because these peaks were absent from August samples (which were extracted directly), they appear to be due to disintegration of the column resin packing, rather than to the presence of additional PAH sources on Saucon Creek. Analysis of the July water sample suite (and samples anticipated to be collected in November 1978 and April 1979) should thus provide more valid data on PAH movement from a point source on a stream-river system.

Rates of PAH Photolysis at the Bethlehem, Pennsylvania, Coking Plant Site

Midday, midsummer photolysis rate constants were determined for aqueous solutions of naphthalene, phenanthrene, anthracene, benzo(a)anthracene, pyrene, and benzo(a)pyrene. Estimates of the rate of removal of these PAHs from the creek and river at the field site due to photodegradation were calculated as outlined previously (Southworth 1978). Input parameters were mean water depth, transparency to ultraviolet light, and adjusted photolysis rate constants.

Although incident sunlight at the time of the April sampling was reduced due to overcast skies, PAH photodegradation rates in April were substantial (Table 4.5). In July, photolysis was enhanced due to greater sunlight intensity and shallower water, but was offset somewhat by lower water transparency.

Photolysis is thus anticipated to be unimportant in moderating the transport behavior of naphthalene and phenanthrene, a significant factor in the behavior of anthracene, pyrene, and benzo(a)anthracene, and perhaps the dominant factor in the transport behavior of benzo(a)pyrene. Incorporation of these estimates into a predictive model and comparison with the observed persistence of PAHs in this system should enable evaluation of the reliability of predicting PAH transport from laboratory data.

Table 4.5. Predicted photodegradation of PAH in Saucon Creek-Lehigh River. Values represent the fraction of a PAH compound discharged to Saucon Creek at station 2 remaining undegraded when it reaches downstream stations.

Compound	April 1978		July 1978	
	Station 7	Station 10A ^a	Station 7	Station 10A ^a
Naphthalene	0.99	0.99	0.99	0.99
Phenanthrene	0.99	0.98	0.99	0.98
Anthracene	0.78	0.52	0.70	0.40
Pyrene	0.84	0.68	0.78	0.49
Benzo[a]anthracene	0.82	0.64	0.68	0.42
Benzo[a]pyrene	0.81	0.24	0.28	0.03

^aStation 10 was 5.0 km downstream from the mouth of Saucon Creek in April 1978. In July, Station 10 samples were taken 3.5 km downstream from the creek mouth to compensate for slower current velocity.

Microbial Transformations of Polycyclic Aromatic Hydrocarbons in Water and Sediment Samples

Sets of water and sediment samples from the coking plant environs have been collected on five dates during the past year (October 10, 1977; January 31, April 26, July 18, and August 29, 1978), and assayed for rates of microbial transformation of PAH by methods described in previous quarterly progress reports. Transformation fractions isolated included ¹⁴C₀, polar metabolites, and bound cellular ¹⁴C.

At all collection times, rates of transformation of ¹⁴C-labeled anthracene were consistently several-fold lower in sediment samples from an upstream control site than in samples collected below the effluent outfall. Rates of ¹⁴C-anthracene transformation in August 1978 samples, which were collected one month after the effluent diversion, still showed PAH-degradative activities essentially equal to samples collected in April and July. Transformation patterns of ¹⁴C-anthracene in water samples were similar to those in sediments. Breakdown rates of other ¹⁴C-labeled compounds in both water and sediment decreased in the order: naphthalene > anthracene > benzo(a)anthracene > benzo(a)pyrene > dibenzo(a,h)anthracene. Transformation rates of all compounds were 10- to 50-fold higher in sediment samples than in water; breakdown of ¹⁴C-benzo(a)pyrene, while measurable in sediments, was below the limit of detection (approximately 0.2% per 24 hr) in water samples. Breakdown rates of all compounds were considerably higher than those observed previously in a petroleum-contaminated stream, and may be related to the elevated degree of PAH contamination of the coking plant environment. Additional samplings are planned for November 1978 and January and April 1979 to permit evaluation of a complete year's data.

Persistence of Azaarenes in Aquatic Systems

Henry's Law constants were determined for quinoline, isoquinoline, acridine, and benzo(a)acridine at 25°C. All four compounds exhibited very low volatility from aqueous solution. Henry's Law constants ranged from a high of 9×10^{-5} (mass/volume) for isoquinoline to $< 1 \times 10^{-5}$ for acridine and benzo(a)acridine. Volatilization is thus unlikely to play a significant role in removing azaarenes from water.

Rates of photodegradation of aqueous solutions of azaarenes in summer sunlight were determined experimentally at pH 7 to 8. Photolysis rate constants of $< 0.006/\text{hr}$ were observed for phenanthridine, quinoline, and acridine. 5,6-benzoquinoline was rapidly degraded in sunlight ($K_p = 0.041/\text{hr}$). The photolysis rate constant for isoquinoline was $0.013/\text{hr}$. This wide variation in susceptibility to photodegradation indicates that sunlight will be a major factor in removing some azaarenes but relatively insignificant for others.

No spontaneous degradation of azaarenes [isoquinoline, quinoline, acridine, 5,6-benzoquinoline, phenanthridine, and benzo(a)acridine] was observed at pH 3, 7, and 10. Loss of these compounds due to oxidation/hydrolysis at 25°C is thus characterized by rate constants of < 0.001/hr.

As a group, azaarenes appear to be more persistent in aquatic systems than PAH with respect to abiotic degradation processes and volatilization. Further information on microbial degradability and sediment-water partitioning will clarify their anticipated behavior in aquatic ecosystems.

Bioaccumulation Pathways of Azaarenes: Comparison of Relative Uptake Rates

The role of various pathways of uptake in the bioaccumulation of acridine by fat-head minnows was investigated. Uptake rates from four pathways were calculated: (1) direct uptake from water, (2) uptake via interaction with contaminated sediments, (3) uptake via ingestion of contaminated zooplankton, and (4) uptake via ingestion of benthic invertebrates living in contaminated sediments.

Fathead minnows in 20-liter aquaria were exposed under flow-through conditions either to 0.1 µg/g aqueous acridine (in the absence of bottom sediments) or to sediments containing 100 µg/g acridine (dry wt basis). Both in the presence and absence of acridine-contaminated sediment, acridine was rapidly taken up by the fish, and apparent equilibrium conditions were attained within 24 hr at a bioconcentration factor (acridine concentration in fish/acridine concentration in water) of 125. Elimination kinetics were rapid, with an instantaneous elimination rate at equilibrium of 0.257/hr ($T_{1/2} = 2.7$ hr). The overall elimination curve indicates a two-stage process, with an initial rapid decrease (0.257/hr) followed by a slower (0.033/hr) release. In the initial elimination phase, much of the acridine was returned to the water without metabolic alteration. Tissue distribution studies indicated a somewhat uniform distribution of acridine within tissue systems, with only the eyes having dramatically higher acridine concentrations (~ 8x) than the fish as a whole. Muscle concentration was slightly more than half that of the whole fish. In similar studies, wet weight bioaccumulation factors of *Daphnia pulex* and *Chironomus tentans* were determined to be 30 (S.E. 2) and 51 (S.E. 5), respectively.

The overall accumulation of acridine by fish from all four pathways was described by the expression:

$$\frac{d[A]_{\text{fish}}}{dt} = C[A]_{H_2O} + D[A]_{\text{sed}} + E[A]_{\text{Daphnia}} + E[A]_{\text{Chiro}} - k_e[A]_{\text{fish}},$$

where:

- $[A]_{\text{fish}}$ = acridine concentration in fish (wet wt), (µg/g),
- $[A]_{H_2O}$ = acridine concentration in water, (µg/g),
- $[A]_{\text{sed}}$ = acridine concentration in sediment (µg/g dry sediment) in equilibrium with $[A]_{H_2O}$,
- $[A]_{\text{Daphnia}}$ = acridine concentration in *Daphnia pulex* (µg/g wet wt) in equilibrium with $[A]_{H_2O}$,
- $[A]_{\text{Chiro}}$ = acridine concentration in *Chironomus tentans* (µg/g wet wt) in equilibrium with $[A]_{\text{sed}}$ and $[A]_{H_2O}$,
- C = uptake constant from water (/hr),
- D = uptake constant from sediment (/hr),

- E = uptake constant from food (assumed to be 0.0021/hr, equivalent to a fish consuming 5% per day of its wet weight in food), and
- k_e = acridine elimination rate constant (/hr).

Calculated rates of acridine uptake via each pathway, and the fractional contribution to total uptake, are shown in Table 4.6. Under equilibrium conditions, essentially all the acridine body burden in the fish is due to direct uptake from the water.

Sorption of PAH to Suspended Particles in Natural Waters

Studies designed to characterize partitioning behavior of PAH between dissolved and particle-bound forms have been completed. To measure partitioning, individual ^{14}C -labeled PAHs are added to 15-ml water samples at levels below the solubility limit, and are held at a constant temperature for periods ranging from 15 sec to 24 hr (for kinetic studies) or for 3 hr (for determination of equilibrium partitioning constants). Particle-bound ^{14}C is measured by scintillation counting after filtration through pre-combusted glass fiber filters (particle cutoff 0.45 μ ; Reeve-Angel). Samples prefiltered through identical filters and treated similarly with ^{14}C -PAH serve as controls for sorption of dissolved PAH to filters.

Table 4.6. Calculated rates of uptake of acridine by fathead minnows (± 1 S.E.) at 22°C from water, sediment, and planktonic and benthic food organisms. Aqueous acridine concentration = 0.100 $\mu\text{g/g}$.

	Uptake rate ($\mu\text{g/g/hr}$)	Fraction of total uptake rate
Direct aqueous uptake $E[A]_{\text{aq}}$	1.43 $\pm$ 0.07	0.96
Uptake from sediment $E[A]_{\text{sed}}$	0.013 $\pm$ 0.019	0.01
Uptake from zooplankton $E[A]_{\text{zoopl}}$	0.006 $\pm$ 0.001	<0.01
Uptake from benthos $E[A]_{\text{benth}}$	0.011 $\pm$ 0.001	0.01

Data on partitioning behavior of ^{14}C -labeled naphthalene, anthracene, 9-methylanthracene, benzo(a)pyrene, and 7,12-dimethylbenzo(a)anthracene have been accumulated, using samples of municipal wastewater, treated coking effluent, and river water. Fractions of ^{14}C -PAH sorbed range from 0.1% (naphthalene) to 60 to 70% [benzo(a)anthracene and benzo(a)pyrene] in some samples; similarly, equilibrium partition coefficients range from 1.1×10^2 to 1.6×10^5 . Partition coefficients correlate far better with parachor (a normalized molar volume parameter) and with octanol-water partitioning coefficient than with the inverse of water solubility. Organic carbon content of particles seems to be related to sorption (as has been reported in soils and sediments), but particle size distribution appears to be equally significant. The importance of "large" ($> 3\text{-}\mu$) relative to "small" ($0.4\text{-}\mu$ - $3\text{-}\mu$) suspended particles in controlling sorption is not constant; 3-ring PAHs sorb to a greater extent onto "large" particles, while the pattern is reversed as PAH molecules increase in size. Trends of sorption as functions of temperature and particulate organic carbon content were not apparent.

Kinetics of the sorption process were examined by filtering aliquots within short time intervals after ^{14}C -PAH addition. Kinetics of desorption were investigated by aliquot removal at intervals following a dilution of wastewater samples containing

^{14}C -PAH with filtered water to reduce particle concentrations 15-fold. Both sorption and desorption appear to consist of two reversible processes: one rapid ($t_{1/2} < 15$ sec) and the second less rapid ($t_{1/2} \approx 5$ to 30 min).

Results suggest that 4- and 5-ring PAHs in a wastewater discharge containing a particle loading of 30 to 40 mg/liter (dry wt) would be present in roughly equal quantities of dissolved and particle-bound forms, and that desorption to the dissolved form would rapidly occur upon dilution of the effluent with less turbid natural water. Analyses of naturally occurring PAHs in coking effluent samples to confirm predictions are planned.

Transport and Fate of Anthracene in Pond Microcosms

Microcosms (laboratory model ecosystems) represent a level of experimental complexity between single-process transport studies and actual environmental events, and provide one means (mechanistic models are another) of integrating simultaneous processes. In this experiment, two 80-liter pond microcosms (containing water, sediment, and a macrophyte community from a natural pond) were treated with $0.5\text{-}\mu\text{g/liter}$ [$9\text{-}^{14}\text{C}$] anthracene to examine the long-term fate of this representative PAH in a typical aquatic environment.

The anthracene disappeared rapidly from the water. After 84 days, 17% of the anthracene added was recovered (unchanged) from the sediment. Approximately 40% was degraded to more polar compounds, apparently by photolysis. An additional 35% was unextractable from the sediment, possibly reflecting incorporation into bacterial cells; 7% was transformed into an unextractable form in the water.

Several of the degradation products persisted in the water or the sediment for the duration of the experiment. The most abundant degradation product was found in all microcosm components examined. One of the main products formed from anthracene in distilled water exposed to light was never found in the microcosms, implying that it was broken down further by the microcosm biota.

Anthracene was much less susceptible to degradation when sorbed to sediment than when dissolved in water. Since sorption occurs rapidly in shallow water, a significant fraction of the anthracene entering a pond or stream would accumulate in the sediment. This would probably be available for uptake by organisms interacting with the sediment.

Environmental Characterization of Solid Waste from a Lurgi Facility

Staff research has, during the past year, expanded the data base of physical and chemical characterization of Lurgi gasifier bottom ashes. Research initiated last year to characterize unquenched bottom ash from three U.S. coals gasified in an Lurgi gasifier in Westfield, Scotland, has been completed.

Additional physical/chemical data not presented in last year's annual report (Auerbach et al. 1978) include microscopic observations and x-ray diffraction data on the ash samples. Preliminary microscopic observation of the samples revealed the presence of a predominantly glassy matrix with scattered metallic inclusions. A small number of segregated metallic particles were also observed.

X-ray diffraction data on two density fractions also indicated an abundance of non-crystalline components. A small amount of quartz and some iron oxides (Fe_3O_4 , Fe_2O_3 , $\alpha\text{-Fe}_2\text{O}_3$) were observed in all three wastes. A small number of diffuse diffraction peaks were unidentified, but the total amount of crystalline materials was relatively low. Most of the metallic portion present in these wastes should sink in tetrabromoethane (TBE) during heavy-liquid separation (specific gravity > 2.9). Presence of a large "specific gravity > 2.9 " fraction combined with neutron activation analysis also indicated that a quantity of heavier metals like Fe were concentrated in this fraction.

Scanning electron microscopy and electron beam images of iron and sulfur in "specific gravity > 2.9" fractions for Rosebud, Illinois 5, and Illinois 6 wastes revealed that the chemical makeup of individual particles was highly variable and that Fe and S were widely distributed in this fraction in all the wastes.

Electron beam images of selected elements show that Fe, in addition to being widely distributed in the matrix, was found to be highly concentrated in certain ash particles. The particles also showed a high S concentration indicating the presence of an iron-sulfur compound. Presence of pyrrhotite mineral (FeS_2) has been observed in slagging Lurgi ash (Arora, unpublished data), although the presence of such a compound could not be detected by our x-ray diffraction data (perhaps because of its very low concentration).

Based on the integrated physical, chemical, and ecological testing which has been conducted on the Montana Rosebud, Illinois 5, and Illinois 6 ash samples from a Lurgi gasifier, the following conclusions have been made regarding the potential environmental hazard associated with disposal of the ash materials.

Although physical characteristics of the three waste materials studied were relatively constant and relatively independent of the feed coal type, the elemental composition of the wastes differed significantly as a function of the composition of the source Montana and Illinois coals. Moreover, the results suggest a potentially significant subsampling problem associated with such wastes because of the wide variation in pH and soluble salts in the various size fractions. Proper subsampling techniques become extremely important to allow correct interpretation of results under these circumstances. These experiments indicate that since toxicity is related to both solid waste and leachate characteristics, better estimates of replicability of results from different subsamples and precision of trace element analyses may be expected to be extremely important to the interpretation of future generations of tests of this type.

The ultimate significance of the acute toxicities determined here would be measured by several site-specific factors as well: (1) dilution to surface waters (very site-dependent), (2) the quality of the receiving water, and (3) soil attenuation.

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5. ACTINIDE ELEMENTS IN AQUATIC AND TERRESTRIAL ENVIRONMENTS

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Introduction

Department of Energy-funded research on the actinide elements involves aquatic and terrestrial food chain studies and environmental physicochemical investigations. These research areas are providing inputs into the evaluation of long-term biogeochemical fate of these elements. The primary interest in understanding fate is to provide an evaluation of accumulation by people upon exposure to terrestrial and/or aquatic environments contaminated with actinides, particularly Pu, Am, and Cm.

As the ESD's research efforts on transuranic elements have matured, comparative data sets on biogeochemical behavior have developed. One of these data sets represents the comparative plant uptake behavior of Pu, Am, Th, and U from soil contaminated with these elements as early as 1944. From those comparisons, we find that U is more available to plants than Th, Pu, and Am. Studies under greenhouse conditions demonstrate similar trends. In a study designed to compare the plant uptake of added transuranics (²³⁸Pu, ²⁴⁴Cm) with indigenous transuranics (²³⁹Pu, ²⁴¹Am), it was found that about two years were needed before freshly added isotopes showed similar uptake to isotopes present in soil for 35 years.

A second and major data set involves actinide behavior in Pond 3513. For the past two years, water quality data have been collected and elemental patterns established. While a complete interpretation of the behavior of the actinides in the pond still requires additional data, several important patterns appear. First, the U concentration in the soluble phase is similar to other natural, hard water systems with closed drainages. This indicates that the aqueous phase of the pond is at equilibrium with U in the sediment, although the exact nature of the factors controlling solution levels are unknown. While the soluble U concentrations averaged 1.9×10^{-4} mM, Pu, Am, and Cm concentrations were 10^6 to 10^8 lower. Plutonium concentrations averaged 9.5×10^{-11} mM, while Am and Cm concentrations were both about 3×10^{-12} mM.

The use of mass rather than radioactivity to express concentrations is important because it allows chemical comparisons. Thus the Am(III) and Cm(III) molar

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concentrations were almost identical while the Cm/Am radioactivity ratios were about 23/1. The average Pu concentration (9.5×10^{-11} M) was only a factor of four lower than the value predicted by water solubility. Somewhat surprisingly, Am and Cm mass levels were lower than Pu levels. These observations are invaluable points of perspective in evaluating the real-world chemistry of man-made elements since they allow testing of biogeochemical predictions.

In addition to the abiotic data set on Pond 3513, data sets for aquatic and terrestrial biota are being established. Small mammals trapped near the pond's shoreline and frogs from the pond showed that relative to sediment or shoreline soils, Am and Cm are enriched over Pu in internal tissues. The ongoing study of fish accumulations of actinides indicates that fish with direct contact with the sediment contain more actinides than fish physically isolated from the sediment but in contact with the pond water column.

The ultimate objective of the actinide program is an input into the evaluation of hazards to people from released radioactivity, particularly the man-made actinides. One use of the comparative metabolism data being obtained is to estimate dose to bone from chronic exposure to Pu-contaminated soil. In previous comparisons of Pu and Th in the White Oak Creek floodplain, the accumulation behavior by small mammals, relative to soil, was very similar (Auerbach et al. 1978). Consequently, if it is assumed that the lifetime accumulation of Pu from contaminated soil would be comparable to natural Th, appropriate dose calculations can be made. Thus, we applied the EPA-proposed soil Pu screening level of $0.2 \mu\text{Ci}/\text{m}^2$ (top 1 cm depth) to the results of literature evaluation which indicated that people accumulate, in 1 g of bone ash, 0.2% of the ^{232}Th in 1 g of "typical" soil. From this ratio, a maximum dose rate of 1.7 mrad/year (from Pu) would accrue in the skeletons of individuals exposed throughout their lifetime to soil contaminated at the EPA-proposed screening level. This dose rate is below the 3 mrad/year EPA guideline.

Actinide Research Associated with Pond 3513

Pond 3513 is a small, shallow pond (0.4 ha, mean depth - 1 m) located on the premises of Oak Ridge National Laboratory. This aquatic ecosystem previously (up to 1975) served as the final waste settling basin for the Laboratory. In the absence of a fish fauna, the pond developed a diverse insect fauna (over 30 species, including mayflies and caddisflies). This observation, coupled with chemical measurements on the system which indicated excellent water quality and radiological analyses which showed suitably high concentration of transuranics, suggested that this site should be the focus of our aquatic actinide research.

Water-Sediment Interactions

Concentrations of four actinides (U, Pu, Am, and Cm), along with 21 other water chemistry characteristics (D.O, pH, Σ alkalinity, etc.) were determined monthly starting in March 1977 and twice monthly after December 1977. Results of these measurements are shown in Fig. 5.1.

Uranium-Plutonium. Concentrations of Pu and U were apparently less affected by a massive algal bloom which occurred during the summer of 1977 (Auerbach et al. 1978) (not repeated in 1978) than those of the trivalent actinides, Am and Cm. Following this period, however, little similarity between Pu and U is evident. This is consistent with the expected differences in valence state, Pu(IV) vs U(VI), of the elements in our system.

The paired measurements of plutonium isotopes ($^{239,240}\text{Pu}$ vs ^{238}Pu), particularly after the summer of 1977, indicate quite similar behavior, maintaining a ratio slightly in excess of 10:1. Differences are well within analytical errors (prior to

Fig. 5.1. Actinide concentrations in filtered water ($0.22\ \mu\text{m}$ membrane filters) from former final waste settling basin at ORNL (Pond 3513).

September 1977, confidence limits for ^{238}Pu were often $\pm 100\%$). These observations indicate that the chemistry of the individual plutonium isotopes in Pond 3513 is not significantly different. Superimposed on the short-term fluctuations in measured Pu values in 1978, one can also discern a longer-term pattern of steady increase in plutonium concentration. A determination of whether this represents part of a normal annual cycle in the system will require repeated measurements for a period of years.

Americium-Curium. The trivalent actinides responded quite differently after the 1977 algal bloom. Beginning in September 1977, both elements increased relatively rapidly in the water column. Several maxima were recorded for each element over a

period of approximately five months (early 1978); however, the first maximum for ^{241}Am was recorded in early January and that for ^{244}Cm in late February. The average concentrations reached during these five-month-long periods of maximum values were 6 and 12 times the minimum values recorded for Am and Cm, respectively, during the 1977 algal bloom. Fluctuations about the mean values (expressed as a percentage) were similar during these periods; the linear scale in Fig. 5.1 distorts the actual relationship.

An initial reaction one might obtain from plots of filterable ^{241}Am and ^{244}Cm behavior in Fig. 5.1 is that the two elements (known to be very similar chemically) are behaving quite differently in Pond 3513. However, when one considers the differential behavior of the two on a mass basis rather than on an activity basis, the picture obtained is the reverse. Both elements attain "maximum" values in early 1978 at a concentration of approximately $3 \times 10^{-15} \text{ M}$ (Table 5.1). After the 1977 algal bloom, concentrations of Am and Cm expressed on a mass basis are always quite similar. The fact that Am reached a maximum prior to Cm can be reasonably explained by the fact that its concentration, expressed on a molar basis, was closer to its previous minimum value. Also, its sedimentary pool (expressed on the basis of mass) was an order of magnitude greater, and thus chemical equilibrium was re-established more quickly for Am than for Cm. The fact that both elements reached maxima at approximately the same molar concentration suggests that a common chemical solubility factor may be responsible for maintaining the solution concentrations in Pond 3513 (in the absence of significant biological removal mechanisms). Maxima were recorded in the winter and early spring when biological activity was minimal, and concentrations appeared to decline during the warmer months of the growing season. Stated another way, it appears that ^{241}Am and ^{244}Cm may have reached their maximum solubility in the Pond 3513 aquatic ecosystem during the first five months of 1978 at concentrations less than $1 \times 10^{-3} \text{ MPC}$ values.

Table 5.1. Concentration patterns of trivalent actinides in water of Pond 3513 (March 1977-August 1978)

Mean concentration in filterable fraction	Time period (month/year)			
	3-7/77	8-12/77	1-5/78	6-8/78
Activity basis (dpm/liter)				
^{241}Am	2.36	2.52	6.49	3.59
^{244}Cm	20.0	55.0	130	108
Mass basis ($\times 10^{-15} \text{ M}$)				
^{241}Am	1.36	1.51	3.80	2.07
^{244}Cm	0.44	1.22	2.89	2.39

The time of appearance of the actinide concentration maxima following the 1977 algal bloom appears to be related both to the measured solubility of the actinides in the system (Fig. 5.1) and the relative sizes of the respective sedimentary pools. Uranium is the most soluble actinide measured and also has the largest sedimentary pool; its first maximum is recorded in September 1977. The solubility of Pu as well as the magnitude of the sedimentary pool is intermediate between U and the trivalent actinides. The first maximum for Pu appears in November 1977, prior to maxima for either Am or Cm.

Comparisons with Other Aquatic Environments

The concentrations of actinides in Pond 3513 are greater than those in most aquatic systems previously studied, including those which received large historical inputs from nuclear fuel-cycle wastes. The Pond 3513 ecosystem is unique in that it contains

relatively high concentrations of curium originating from relatively recent inputs (early 1970s) of radioisotope production wastes. The presence of relatively high concentrations of ^{241}Am , on the other hand, is thought to have resulted primarily from ingrowth following decay of ^{241}Pu in historical waste materials; the surface sediment pool contains less than 1% of the estimated total inventory of plutonium in Pond 3513 (Tamura et al. 1977). The greatest fraction of plutonium is buried in deeper sediment layers.

Concentrations of uranium in Pond 3513 are perhaps most comparable to natural systems (Table 5.2). Although concentrations are higher than those in most freshwater systems (typified by the data for Lake Michigan, Copeland et al. 1972 and Wahlgren et al. 1976) and seawater (Thurber 1964 and Miyake et al. 1965), this is not the case when comparisons are made with freshwater systems having relatively closed drainages (such as Lake Issyk-Kul in the Soviet Union, Koval'skii and Voronitskaya 1965). Such closed systems tend to become alkaline because of the accumulation of the alkali metals and magnesium. As a consequence of the higher pH, elevation of the carbonate ion concentration occurs. This favors the formation of soluble uranyl carbonate which in turn increases the soluble uranium content in water bodies with elevated pH.

Table 5.2. Mean element concentrations in millipore filter water (millimoles/liter)

Element	Pond 3513	Lake Issyk-Kul ^a	Seawater ^b	Lake Michigan ^c
Cations	1.55	5.8 ^d	33 ^d	1.60
Ca	0.49	3.0	10	0.87
Fe, Mn	8.1×10^{-5}	---	---	3.6×10^{-4}
pH	9.1	8.7	8.2	8.0
U ^e	1.5×10^{-2}	1.0×10^{-2}	2.2×10^{-3}	7.9×10^{-3}
U	1.9×10^{-4}	1.3×10^{-4}	1.5×10^{-5}	5.7×10^{-7}
Pu	9.5×10^{-11}	---	---	4.1×10^{-14}
Am	3.2×10^{-12}	---	---	3.1×10^{-17}
Cm	2.8×10^{-12}	---	---	---

^aFrom Koval'skii and Voronitskaya 1965.

^bFrom Thurber 1964 and Miyake et al. 1966.

^cCompiled from data of Copeland et al. 1972 and Wahlgren et al. 1976.

^dSalinity (ppt).

^eCalculated (see text).

The behavior of U in Pond 3513 is suggestive of saturated conditions. In Table 5.2, calculated and measured values of soluble U are presented for three "closed" systems (Pond 3513, Lake Issyk-Kul, and seawater) and Lake Michigan. The calculated values were obtained by assuming that the soluble U present is predominately $\text{UO}_2(\text{CO}_3)$ in equilibrium with solid-phase $\text{UO}_2(\text{OH})_2$. For the three "closed" systems, the calculated soluble U concentration is, in each case, 100 times higher than measured values. The calculated values will change depending on the selection of thermodynamic constants (a range exists in the literature). Thus, the absolute values are not as important as the relatively constant difference between calculated and observed values. Lake Michigan does not behave in this manner, since measured U values are four orders of magnitude lower than calculated. This reflects the more rapid turnover of Lake Michigan water by drainage inputs of low U waters. The important point to be made, therefore, is that Pond 3513 is not unusual with respect to soluble U when compared to other "closed" systems.

Another interesting comparison can be made between ^{241}Am concentrations in Pond 3513 and those from Lake Michigan. As shown in the first rows of Table 5.2, the chemical environment of Lake Michigan is somewhat similar to Pond 3513, with the exception of pH. The $^{241}\text{Am}:^{239,240}\text{Pu}$ ratios in surface sediments in Lake Michigan (Edgington et al. 1976) and the K_d for Pu ($\sim 3 \times 10^5$, Wahlgren et al. 1976) are comparable to corresponding values for Pond 3513 (Table 5.3). However, the concentration of ^{241}Am in Pond 3513 water, when compared with $^{239,240}\text{Pu}$, is approximately 40 times higher than one would expect, using the observed $^{241}\text{Am}:^{239,240}\text{Pu}$ ratio from Lake Michigan water (Table 5.2).

Table 5.3. Concentrations in surface sediment and water from Pond 3513

Sample	Mean (dpm/g) $^{239,240}\text{Pu}$	$^{239}\text{Pu}:^{238}\text{Pu}$	$^{241}\text{Am}:^{239}\text{Pu}$	$^{244}\text{Cm}:^{239}\text{Pu}$	$^{244}\text{Cm}:^{241}\text{Am}$
<u>Sediment (0-5 cm)</u>					
Unscoured ^a	925	9.02	0.314	0.837	2.67
Scoured	8480	22.7	0.209	0.350	0.24
Pond mean					
Geometric	1220	10.2	0.293	0.589	1.98
Arithmetic	1380	13.9	0.253	0.387	1.54
<u>Water (Jan to Aug/78)</u>					
Total	15.4×10^{-3}	15.3	0.669	8.15	12.2
Filterable ^b	3.24×10^{-3}	11.2	1.67	37.7	22.6
Particulate ^c	12.2×10^{-3}	16.9	0.404	0.327	0.795

^aFractional area covered by unscoured type approximately 7/8; n = 18 of 24 samples.

^bFiltered through 0.22- μm membrane filters.

^cObtained by subtraction (total-filterable).

Particulate Associations

Concentration ratios for $^{244}\text{Cm}:^{241}\text{Am}$ are approximately 10 times greater in the filterable fraction from water (22.6) than in surface sediments (arithmetic mean 1.54) (Table 5.3). Since the two elements are known to be very similar chemically, this observation (that water contains only 10% of the expected ^{241}Am concentration relative to surface sediments), coupled with the previous observation of similar molar concentrations for Am and Cm in filtered water, indicates that Am and Cm are not uniformly exchanging between sediment and water. On the other hand, the $^{239,240}\text{Pu}:^{238}\text{Pu}$ ratio in filtered water (Table 5.3) falls between the pond-wide mean values calculated for surface sediment. This, again, reinforces a previous conclusion that there appear to be no apparent differences in the chemical behavior of the different plutonium isotopes in Pond 3513. The average content of the transuranics in suspended particulate material was 75%, 50%, and < 5% of the total water values for plutonium, americium, and curium, respectively. Differences between concentrations in raw water and filtered water for ^{244}Cm were not consistently detectable.

Abiotic-Biotic Interactions

One objective of our research has been to determine the relative availability of the actinide elements from abiotic sources to aquatic biota, particularly potential

human food sources, in order to assess the potential for eventual transport to man. Another objective has been to assess the relative importance of abiotic and biotic sources/sinks in terms of food chain behavior of the actinides.

Isotopic ratios in native fauna of Pond 3513. One approach to answering these questions could involve comparison of the relative concentrations of the actinides to one another, as a function of different abiotic sources and tissue compartments, in biota collected from the Pond 3513 ecosystem. For example, these comparisons have been made for adult frogs collected during June 1977 and tadpoles taken during the fall of 1977 (Table 5.4) using unscored sediment as the hypothetical abiotic source. Data for five actinides of interest relative to nuclear fuel cycles are presented. Confidence limits for analyses of muscle tissue for Pu are quite large ($\pm 100\%$) and, thus, the ratios relative to other elements may be significant underestimates in some cases. Isotopic activity ratios have been calculated relative to $^{239,240}\text{Pu}$. A ratio of 1.0 would indicate that there is no difference in availability between the compared isotope and plutonium relative to a sediment source. The values for the bone compartment probably reflect the best estimate of differential availability: $\text{U} > \text{Am}$, $\text{Cm} > \text{Th}$, Pu . Taken in its entirety the data set indicates essentially the same pattern despite the questionable value for the $^{239,240}\text{Pu}$ concentration ratio in muscle tissue. This pattern reflects what we would predict on the basis of available information on plant uptake, gastrointestinal absorption by mammals, chemical considerations, etc. However, if we were to perform the same comparisons using concentrations in filtered pond water as our abiotic source, the results are quite different. The observed pattern of availability becomes: $\text{Pu} > \text{Am} > \text{U} > \text{Cm}$ (data for ^{232}Th in water are not currently available). Particularly striking in this comparison is the fact that Am appears to be an order of magnitude more available to biota than Cm, despite the fact that the two isotopes are so similar chemically and appear to be behaving in a like manner in the water column in Pond 3513. We believe that this apparent difference represents a calculational artifact and probably constitutes strong evidence for the importance of a sedimentary source for actinides in Pond 3513 food chains.

Table 5.4. Comparisons of the actinide/Pu concentration ratios in the bullfrog (*Rana catesbeiana*) from former waste settling basin at Oak Ridge National Laboratory

Specimen	$^{239,240}\text{Pu}^a$	$^{238}\text{U}/\text{Pu}$	$^{241}\text{Am}/\text{Pu}$	$^{244}\text{Cm}/\text{Pu}$	$^{232}\text{Th}/\text{Pu}$
Immature-carcass without G.I. tract	1.9×10^{-3}	8.1	5.0	3.0	0.32
Adult bone (male)	2.6×10^{-4}	40.0	3.3	3.8	0.42
bone (female)	7.0×10^{-5}	64.0	1.9	1.2	2.7
muscle (male)	2.5×10^{-4}	7.4	7.8	3.7	4.7
muscle (female)	1.0×10^{-4}	30.0	4.9	6.0	3.0

^aConcentration in tissue (ash wt) : concentration in sediment (ash wt). Plutonium determined by both mass spectrometry and solvent extraction-alpha spectrometry techniques; Th and U by mass spectrometry, and Am and Cm by solvent extraction-alpha spectrometry.

Additional evidence for this hypothesis is to be found in the data set for trans-uranic elements in plants and invertebrates collected from the pond during the summer and fall of 1977 (Table 5.5). Mean values from analyses (in some cases involving hundreds of specimens) of three species of plants (one macrophyte and two species of filamentous algae) and 15 species of invertebrates (one taxon each from the gastropods and crustaceans, along with 13 species of insects) are represented in Table 5.5. A number of the invertebrates were held in environmental chambers for periods of up to two weeks (depending on ambient temperature) following collection to allow clearance of the gastrointestinal tracts.

Table 5.5. Transuranic concentration patterns in plants and invertebrates from Pond 3513

		Concentration ratio (CR) $^{239,240}\text{Pu}$	$^{238}\text{Pu}:$ ^{239}Pu	$^{241}\text{Am}:$ ^{239}Pu	$^{244}\text{Cm}:$ ^{239}Pu	$^{244}\text{Cm}:$ ^{241}Am
Vegetation	3	4.1×10^{-3} - 2.1×10^{-2}	1.2 (0.76-2.0)	1.9 (1.2-2.9)	1.9 (1.6-2.5)	1.1 (0.90-1.5)
<u>Herbivores</u>						
(C) ^a	6	5.2×10^{-3} - 1.4×10^{-1}	0.91 (0.40-1.4)	3.7 (0.87-10)	2.9 (0.63-8.2)	0.97 (0.35-2.3)
(C) ^b	1	1.6×10^{-3}	---	4.0	2.7	0.67
<u>Carnivores</u>						
(Ex) ^c	2	1.3×10^{-2} - 4.3×10^{-1}	0.64 (0.37-0.84)	1.1 (0.51-1.5)	1.1 (0.19-1.9)	0.87 (0.60-1.3)
(C) ^a	9	1.7×10^{-4} - 5.6×10^{-2}	1.0 (0.55-1.3)	3.2 (1.4-8.7)	2.7 (1.2-7.0)	0.79 (0.49-0.99)
(C) ^b	8	9.3×10^{-5} - 1.8×10^{-2}	1.2 (0.83-1.9)	3.5 (1.5-8.7)	2.9 (1.3-6.2)	0.88 (0.42-1.2)

^aG.I. tract uncleared.^bG.I. tract cleared.^cExuviae.

There are a number of points to be made based on the data in Table 5.5. First, considerable variation in the concentration ratio for $^{239,240}\text{Pu}$, again based on the concentration in unscoured sediment, is evident within each trophic level. Concentration ratios for some herbivores are higher than for vegetation and a number of carnivores have concentration ratios greater than either vegetation or herbivores. This would appear to be a violation of the often-stated rule that trophic discrimination against the actinides is a major consideration in determining concentrations in food chain components. However, such generalizations ignore the greater importance of habitat and feeding behavior, in particular, associations with the sediment-water interface or suspended particulates. Highest concentrations were observed in exuviae from dragonflies, which were collected on stems of vegetation well above the waterline. The exuviae of the predatory odonate *Erythemis* contained the highest Pu concentrations measured in any biotic component in Pond 3513 (400 dpm/g dry wt) and isotopic ratios were comparable to sediments. This confirmed our previous prediction (Auerbach et al. 1978) that the sediment trap represented by its hirsute exoskeleton was responsible for the surprisingly high plutonium concentrations measured in whole naiads (2 dpm/g dry wt vs 0.2-0.5 dpm/g in other odonates in the same habitat). This is also a graphic illustration of the importance of particulate associations.

Relative availability comparisons are also presented in Table 5.5 for ^{238}Pu , $^{239,240}\text{Pu}$, ^{241}Am , and ^{244}Cm . These comparisons have been made on the same basis described previously. Values represent means and ranges for each portion of the data set. The comparisons between ^{238}Pu and $^{239,240}\text{Pu}$ exhibit no consistent deviations from unity, as expected; the lowest value for carnivore exuviae is attributable to surface contamination with sediment, as noted above. Likewise, $^{244}\text{Cm}:$ ^{241}Am comparisons are close to the expected value of one. However, comparisons of the trivalent actinides relative to $^{239,240}\text{Pu}$ suggest greater availability by factors of approximately 2 to 4. As before, if we were to perform these comparisons on the basis of concentrations in filtered water we would observe a different pattern. In particular, the $^{244}\text{Cm}:$ ^{241}Am comparison would produce a mean value of approximately 0.1 rather than unity, suggesting higher availability of Am than Cm by an order of magnitude. Again, this would appear to be an artifact introduced by using water rather than surface sediment as the primary abiotic actinide source in Pond 3513.

Factorial uptake studies using introduced vertebrates. The Pond 3513 ecosystem developed originally in the absence of a fish fauna as noted earlier. Juvenile fish (goldfish, *Carassius auratus*; channel catfish, *Ictalurus punctatus*; bluegill, *Lepomis macrochirus*; and largemouth bass, *Micropterus salmoides*) were introduced to the system for the first time in 1977 as part of a long-term factorial uptake investigation involving the actinides. In addition to specimens which were released directly into the pond, groups (all species except bass) were introduced into a large floating enclosure which prevented access to the bottom sediments. Goldfish and bluegill were placed into two artificial streams (400-liter) fed by pond water drawn through a coarse filter to prevent entry of organisms larger than microp!ankton. Groups which were held in living streams were fed artificially. The object of this investigation was three-fold: (1) to determine the relative uptake of the different transuranic elements by vertebrates which represent potential human food sources, (2) to determine the distribution of actinides between different tissue compartments after an appropriate exposure time, and (3) to establish the relative importance of the abiotic actinide pools in the system as sources for biota. It was expected that the investigation would require long-term exposures (2-3 years) in order to provide meaningful answers to these questions. The first year's data have been encouraging; however the experimental design needed modification. Following some corrective measures, the experimental enclosure/streams/pond were restocked with marked juvenile fish in May-June 1978. Older fish from the original study were left in the pond in order that the first two objectives of this investigation might be reached in a shorter time.

Samples of stocked fish were collected in 1977 after exposures of four weeks and approximately 28 weeks, respectively. Fish were dissected to provide carcass, gill, and G.I. tract samples for transuranic analyses. The sample collected at four weeks was taken at the height of the algal bloom in a period when concentrations of actinides in water were at minimum values and believed to be unrepresentative of a normal growing season. Americium and Cm, but not Pu, were generally detectable in carcass samples. Concentrations in gill tissue from fish which had the freedom of the entire pond were often much greater ($> 10\%$) than those taken from fish in net enclosures or artificial streams.

The second sample, taken approximately six months after the first, proved much more useful because concentrations of $^{239,240}\text{Pu}$, ^{241}Am , and ^{244}Cm were now quantifiable in all samples. The results are shown in Table 5.6. Concentrations in G.I. tracts of goldfish collected from the artificial streams, although significantly lower than in other test groups, were deemed unacceptably high. Thus, the artificial streams were extensively modified for the 1978 exposure groups.

One pattern has already emerged after only seven months' exposure. Despite the presence of some particulate contamination in the artificial streams, concentrations in gill and carcass samples of fish collected from the free-roaming pond population are already significantly greater than those from artificial streams (samples from the net enclosure group are intermediate). Whatever the mechanism, access to the sediment-water interface has resulted in tissue concentrations of transuranics 3 to 5 times greater than those in fish of the same species (goldfish) held in the artificial streams. Concentrations in bluegill and catfish from the pond were intermediate between those of goldfish from the net enclosures and the pond. This might be expected on the basis of trophic differences.

Concentrations of ^{241}Am and ^{244}Cm in gill tissue of all groups are elevated, relative to $^{239,240}\text{Pu}$, compared to ratios in unscoured sediment by a factor of four (range 2-6) for both elements. The $^{244}\text{Cm}:^{241}\text{Am}$ factor is 1 (range 0.7-1.2): quite similar to values previously reported for invertebrates. Comparisons of carcass (and G.I. tract) values on a similar basis, however, indicate that ratios of trivalent actinides in these samples relative to $^{239,240}\text{Pu}$ are quite comparable to the corresponding sediment values. This indicates either that significant surface contamination occurs on carcasses, but not on gills, or that, on a whole body basis, there are no significant differences in transuranic availability to vertebrates from the sedimentary source in Pond 3513. Future samples will separate liver and skeleton from the residual carcass in order to resolve these questions. Concentration ratios [concentration in tissue (dry wt) $\div$ concentration in sediment (dry wt)] for carcasses of fish collected from all groups were $< 1 \times 10^{-4}$ for all three transuranic elements.

Table 5.6. Transuranic concentrations in tissues of fish exposed during long-term factorial uptake experiment on Pond 3513 (May-November 1977)

Sample		Geometric mean (95% C.I.) (dpm/g dry wt)		
		^{239}Pu	^{241}Am	^{244}Cm
Goldfish except where noted ^a				
G.I. tract	n			
Stream	5 ^b	55.0 (29.1-107)	30.9 (9.4-102)	36.0 (8.1-160)
Net	5	37.5 (18.8-72.2)	96.3 (75.1-123)	219 (172-277)
Pond	5	4.1 (255-753)	183 (99.3-338)	317 (193-522)
Gill				
Stream	6	0.12 (0.03-0.46)	0.23 (0.12-0.43)	0.40 (0.27-0.61)
Net	6	0.41 (0.14-1.2)	0.25 (0.15-0.42)	0.62 (0.33-1.2)
Pond	6	0.44 (0.17-1.2)	0.76 (0.40-1.5)	2.1 (0.67-6.5)
Pond (P-BG,CF) ^c	6	0.28 (0.11-0.77)	0.31 (0.14-0.65)	1.0 (0.39-2.6)
Carcass				
Stream	6	0.022 (0.013-0.036)	0.013 (0.010-0.017)	0.016 (0.11-0.025)
Net	6	0.051 (0.041-0.063)	0.018 (0.011-0.031)	0.042 (0.026-0.070)
Pond	6	0.074 (0.040-0.14)	0.035 (0.020-0.060)	0.063 (0.033-0.12)
Pond (P-BG,CE)	7	0.055 (0.037-0.082)	0.027 (0.016-0.046)	0.060 (0.032-0.12)
Water-filterable fraction (6-12/78) (dpm/liter) ^d				
Stream		1.83 ± 0.86	2.75 ± 2.25	44.1 ± 26.4
Net, Pond		1.90 ± 0.97	2.27 ± 1.57	45.4 ± 22.5

^aExposure time-stream, net groups (30 weeks); pond group (27 ± 1 weeks).^bUncleared G.I. tracts used; one in each group was empty.^cPooled bluegill and catfish; exposure time 28 ± 2 weeks.^dArithmetic mean ± 95% C.I. (n = 7).

Terrestrial Ecology

Comparative Uptake of Transuranic Elements by Biota Bordering Pond 3513

Cotton rats (*Sigmodon hispidus*) and shoreline vegetation were collected from the banks of Pond 3513 during 1977 to compare the relative uptake of ^{239}Pu , ^{241}Am , and ^{244}Cm from contaminated sediment. Radiochemical analyses were nearly complete in 1978; however, results from additional sampling of shoreline sediments in late 1978 are not yet available.

Four genera of shoreline plants were sampled: *Typha*, *Juncus*, *Eleocharis*, and *Polygonum*. Intraspecific variation in transuranic element concentrations was significantly ($P < 0.05$) greater than interspecific variation among shoreline plants. *Eleocharis* tended to have higher concentrations of transuranics than *Polygonum* or *Typha* because *Eleocharis* grows in shallow standing water and is occasionally submerged. Mean ($\pm$ SD) concentrations of ^{239}Pu , ^{241}Am , and ^{244}Cm in the shoreline vegetation were 150 ($\pm$ 233), 80 ($\pm$ 111), and 151 ($\pm$ 208) fCi/g dry wt, respectively. Concentrations of Pu and Am were significantly correlated in the shoreline plants ($r = 0.93$, $N = 15$).

The mean concentration of ^{239}Pu , ^{241}Am , and ^{244}Cm in cotton rat G.I. tracts was 6.0, 1.6, and 5.0 pCi/g dry wt, respectively. On the average, the G.I. tract contained 63 to 80% of the whole-body burden while 8 to 25% was internally deposited. Concentrations of transuranic elements in the cotton rat carcass and internal organs were

significantly less than those measured in the G.I. tract. Transuranic element concentrations in internal tissues ranged from 10 to 200 fCi/g dry wt. Considerable variability was observed between different rats.

The importance of particular pathways or mechanisms leading to the uptake of transuranic elements by plants and cotton rats from contaminated shoreline sediments cannot be evaluated on the basis of the present field study. In spite of this, the relative transfer of ^{239}Pu , ^{241}Am , and ^{244}Cm to biota from sediment can be inferred from changing element ratios (Table 5.7). Mean Am/Pu and Cm/Pu ratios were calculated for near-shore sediments, plants, and rats. The Am/Pu and Cm/Pu ratios in plants were significantly greater than those in sediment and indicated a 3- to 11-fold greater uptake of trivalent Am and Cm over Pu. The Am/Pu and Cm/Pu ratios in cotton rat G.I. tracts were not significantly different from those in shoreline sediment. This observation, in conjunction with evidence that transuranic element concentrations in rat G.I. tracts were more than 10-fold greater than in vegetation, suggests that rats ingested some sediment while foraging or drinking pond water. The Am/Pu and Cm/Pu ratios in rat carcasses (includes skeleton and muscle) were significantly greater than those in sediment and indicated a 3- to 15-fold greater uptake of trivalent Am and Cm over Pu.

Table 5.7. Geometric mean element ratios in near-shore sediments and biota bordering the Pond 3513 shoreline

Ratio	Sediment	Plants	Cotton rats	
			GI tract	Carcass
$^{241}\text{Am}/^{239}\text{Pu}$	0.28	0.88	0.23	0.96
$^{244}\text{Cm}/^{239}\text{Pu}$	0.13	1.49	0.51	1.96

Metabolic Reduction of Neptunium-239 from Np(V) to Np(IV) in Cotton Rats

Actinide elements in the V and VI valence states are believed to be more biologically active than tetravalent actinides. In two separate experiments we have found evidence of reduction of Np(V) to Np(IV) when ^{239}Np was metabolized by wild cotton rats (*Sigmodon hispidus*). This suggests that if Np(V + VI) or Pu(V + VI) occurs in food chains, then these higher valence states will be reduced by physiological processes and therefore result in less biological transport.

Neptunium-239 was administered by gavage to a 136-g male cotton rat (rat B) as a bicarbonate solution and to a 138-g male cotton rat (rat C) as a citrate solution. The Np in the bicarbonate stock solution administered to both rats was characterized as 19% Np(IV) and 81% Np(V); a subsequent experiment employing citrate utilized a Np solution which was 97% Np(V). Rats were housed in metabolism cages and provided with food and water. Urine was collected in a receptacle separate from feces. Approximately 3 hr after administration of ^{239}Np to rat B, a urine sample was collected and analyzed for the different valence states. In the rat urine, 41% of the Np was in the IV and 59% was in the V valence state. Neptunium-239 in rat B urine approximately 20 hr after gavage (overnight urine sample) was detectable (34 ± 8 cpm) and contained 27% Np(IV) and 73% Np(V). Therefore, part of the Np administered in the V valence state may have been reduced to IV in vivo. Neptunium (IV) appeared to be preferentially retained over Np(V) in internal rat tissues as indicated by the predominance of the V valence state in the overnight urine sample.

To test for a possible reoxidation of Np(IV) to Np(V) in overnight urine samples, rat urine was spiked with Np(IV) and exposed to air. After exposure for either 5 min or 16 hr, the relative abundance of Np(IV) and Np(V) was the same: 96 and 4%, respectively. The reoxidation of Np(IV) to Np(V) by air appeared negligible.

Ten days post-dose, rat B was dissected. Detectable ^{239}Np was found in the liver, stomach, and carcass (muscle and skeleton). The carcass contained approximately 80% of the whole-body burden. Based on the whole-body elimination curve, the fractional assimilation of the administered dose (as bicarbonate) from the G.I. tract was 3×10^{-4} .

Rat C received ^{239}Np in a 10^{-3} M citrate solution [97% Np(V)]. The urine collected approximately 20 hr post-dose contained 55% Np(IV) and 45% Np(V) , again indicating an in vivo reduction of Np(V) to Np(IV) . These results confirmed our earlier experiment with rat B. However, based on whole-body retention curves, the fractional assimilation of the ^{239}Np citrate from the rat G.I. tract was 3×10^{-3} . This was 10-fold greater than that for Np in bicarbonate solution.

Hazards Assessment and Amelioration

Predicting Pu in Bone

Current evaluations of the hazards associated with transuranium element releases to the biosphere usually rely on complex models of environmental transport and metabolic behavior. The history of exposure to transuranics in the environment is so short, however, that validation of environmental transport models is difficult, if not impossible, for these elements. Nevertheless, regulatory agencies are required to establish guidelines for radiation exposure from environmentally dispersed transuranics like plutonium. For example, the EPA has proposed that "the annual alpha radiation dose rate to members of the critical segment of the exposed population as a result of exposure to transuranium elements in the general environment shall not exceed either 1 millirad/year to the pulmonary lung or 3 millirad/year to the bone" (U.S. EPA 1977). Acknowledging that limited data are available, the EPA suggested that a soil Pu contamination level of $0.2 \mu\text{Ci/m}^2$ (1-cm depth, soil particle sizes less than 2 mm) would be a suitable screening level for which the predicted dose rate to people as a result of chronic exposure would be lower than its recommended guidelines.

We believe that the magnitude of Pu accumulation in the human skeleton from contaminated soil might be evaluated independently of the type of ingestion and inhalation models currently in use. We believe that the biogeochemical behavior of Pu may be similar to ^{232}Th and that a lifetime bone/soil accumulation factor for Th may be applied in estimating lifetime Pu accumulation from contaminated soil. Similarities in the environmental behavior of Pu and Th are not unexpected because Th may be the natural element most chemically and biologically similar to Pu. In contrast, U (which we also examined) should behave differently from Pu in much the same manner as it is geochemically and biologically different from thorium. The use of the bone/soil accumulation factor in evaluating lifetime exposure integrates both ingestion and inhalation because it assumes that the pathways by which soil-associated Pu reaches the bone are the same as for natural Th. The latter element is ubiquitous in the environment.

Because diet is the major pathway of Th and U intake by people, as it is for fallout Pu several years after the cessation of massive atmospheric testing, we evaluated the uptake of Pu, Th, and U by vegetation under field conditions. These comparisons demonstrate that Th and Pu behavior in plants is comparable (see Fig. 5.2). Current models of environmental transport to people consider inhalation as the important contributor of Pu to bone, although dietary intakes may be higher than inhalation intakes. We therefore examined small mammal accumulations of the three elements to evaluate mammalian metabolism in the field where both diet and inhalation are exposure routes (see Auerbach et al. 1978).

An approximate value of 12 ng Th/g human bone ash was derived by averaging literature data sets. Since most of the bone samples came from older adults, we considered this value the best current approximation of the value at age 70. Thorium concentrations in soil range from 2 to 14 $\mu\text{g/g}$, with several reviews suggesting an average value of 6 $\mu\text{g/g}$. The apparent bone ash/soil accumulation factor is thus about 0.002 for the general population (age 70) not occupationally exposed to Th or residing in Th-rich areas.

Fig. 5.2. Actinide field concentration ratios ($[plant]/[soil]$) for plants grown on a floodplain soil contaminated with soluble U, Th, and Pu(Am) in 1944. Up to six species were analyzed; N refers to total harvest composite samples examined from three growing seasons.

This value might be useful in predicting Pu accumulation in the skeletons of individuals whose lifetime contact with a contaminated area is via inhalation and diet. We have, for example, considered the EPA-proposed screening level of $0.2 \mu\text{Ci}/\text{m}^2$ (1-cm depth). At a soil bulk density of $1.3 \text{ g soil}/\text{cm}^3$, this is about $15 \text{ pCi}/\text{g}$ soil or $0.016 \text{ pCi}/\text{g}$ of fresh bone (54% ash). Converting pCi/g to dose rate ($1 \text{ rad} = 100 \text{ ergs}$ of absorbed energy per gram of matter), we calculate $1.7 \text{ millirad}/\text{year}$ would be delivered to bone after 70 years of chronic exposure. If the initial 15 pCi is uniformly mixed to a depth of 25 cm by cultivation, then the dose rate is projected to be less at $0.07 \text{ millirad}/\text{year}$. More discussion and references can be found in Bondietti et al. (in press).

Environmental Chemistry - Plant Uptake

Adsorption-Solubility-Complexation Phenomena in Actinide Partitioning Between Sorbents and Solution

The measurement of the adsorption of actinides by environmental colloids must, as a precondition, be conducted at elemental concentrations below the solubility of the element in water (more specifically, the solution phase used experimentally). For plutonium, sorption measurements must also take into account oxidation states. However, since Pu is generally difficult to maintain in solution, errors with respect to oxidation state are not always critical.

Both laboratory and field results (see Pond 3513 data, this Section) certainly indicate that Pu, Am, and Cm do not partition into water at any substantial concentrations. More importantly, the Pond 3513 data can be used to argue that the Pu concentrations in solution are close to solubility limits (Table 5.3).

It is important to stress that the concept of solubility controlling the Pu concentrations in solution is not easy to defend experimentally. However, to understand the controls on solution concentrations, and therefore develop predictive capability, a basic, simple framework is needed. Solubility, in any case, is an important concept because of the chemistry of Pu. Solubility, and the related property of hydrolysis, dictate the Pu available to enter other reactions, such as complexation. For example, consider the system $\text{EDTA-Pu(IV)-Fe(III)-OH}$. While no extensive calculations will be made, illustrations will suffice. The log K for the reaction, $\text{Pu(IV)} + \text{EDTA} = \text{PuEDTA}$, is 25.8. The same reaction, substituting Fe(III), has a log K of 25.1. The effective log K [i.e., the reaction $\text{PuEDTA} + \text{Fe(III)} = \text{FeEDTA} + \text{Pu(IV)}$] is -0.7 (or antilog of 0.2). This says that for equal Fe and Pu concentrations competing for EDTA molecules, the ratio of FeEDTA to PuEDTA is 0.2. Hydrolysis and other cations (Ca, Al, Mg, etc.) are not considered. The point to be made is that at the Pu, Fe, Ca, etc., concentrations found in the environment, stable Pu complexes with organics should be low. If complexes were to leach from waste disposal sites, their biological and chemical (i.e., metal competition) half-lives will be low; the latter case is important as dilution occurs.

To summarize, OH^- ion and other cations dominate Pu complexation behavior in water. Speculations on mechanisms controlling Pu solution concentrations need to consider all water constituents. Simple calculations will show that hydrolysis and other cations cannot be neglected in evaluating Pu(IV) speciation.

Comparative Soil Extraction Data

In calculating the accumulation of Pu in human bone from chronic exposure to Pu-contaminated soil, the comparison with Th was made. Consideration must, therefore, be given to relative solubility of Pu and Th in soils because only on such a basis can comparisons be made. Table 5.8 makes these comparisons for two soils: the White Oak Creek garden plot soil and soil from Rocky Flats, Colorado. In the White Oak Creek soil, Pu is about as extractable as Th, while in the Rocky Flats soil, Pu is about twice as extractable. In the latter case, all of the ^{232}Th is indigenous.

Comparative Plant Uptake Data

To the extent that diet contributes to internal body burdens, a comparison of the relative plant uptake of actinides from soil is of interest. Figure 5.2 summarizes recent results for field-grown vegetation of soil originally contaminated in 1944 with soluble forms of U, Th, and Pu (and daughter Am). The crops examined include soybeans, snapbeans, Japanese Millet, squash, tomatoes, carrots, and radishes. All plant samples were washed in a manner approximating food preparation (although the leaves and stems of these crops are not usually eaten). Data set 1 comes from a study of U, Th, and Pu comparisons, while set 2 is derived from Pu and Am comparisons. Different analytical methods (isotope dilution mass spectrometry for Th and U, α -spectrometry for Pu and Am)

Table 5.8. Extraction comparisons for Th and Pu in White Oak Creek (WOC) soil and Rocky Flats (RF) soil samples. The Rocky Flats sample was taken about 0.8 km east of the RF facility's security fence, midway between the facility and Indiana Ave. (10 g soil, 30 ml of the acids, and 10% Na_2CO_3 -5% NaHCO_3 solution were contacted for 18 hr, centrifuged, and analyzed.)

	Percent extracted ^a		
	8 M HNO_3	Na_2CO_3 - NaHCO_3	1 M HNO_3
<u>Rocky Flats</u>			
Pu	54	29	1.2
Th	22	13	0.65
<u>White Oak Creek</u>			
Pu	100	54	7.7
Th	100	45	7.9

^aBased on HNO_3 -HF digestion for total element: RF = 2.79 ± 0.18 dpm Th/g; 69.8 ± 3.7 dpm Pu/g; WOC = 4.11 dpm Th/g; 135 ± 7 dpm Pu/g.

are the reason for the separate groups of data. Each set represents analyses on the same plant materials. The number of samples analyzed (N) is found below each range bar. As illustrated by Fig. 5.2, the relative order of plant uptake (based on dry wt concentration ratios, C.R.) is $\text{U} > \text{Am} > \text{Pu} \approx \text{Th}$, although substantial overlap occurs. The ranges associated with each element C.R. primarily reflect plant species variation. The figure, therefore, represents a composite view of all plants analyzed, much as a value for diet would reflect its diverse constituents.

Table 5.9 summarizes greenhouse plant uptake comparisons of added ^{238}Pu , ^{230}Th , and ^{244}Cm to the floodplain soil. While the concentration ratios differ radically from Fig. 5.2 (due to using too small a soil rooting volume in the potted experiments), the trends are similar ($\text{Pu}, \text{Th} < \text{Am}, \text{Cm}$). Two years after adding ^{238}Pu and ^{244}Cm to the

Table 5.9. Comparisons of the plant uptake (snapbeans) of added ^{238}Pu , ^{244}Cm , and ^{230}Th , and indigenous ^{239}Pu and ^{241}Am in floodplain soil two years after isotope addition. Concentration ratios are on a dry weight basis.

Plant part	N ^a	[plant] / [soil] $\times 10^4$				
		^{238}Pu	^{239}Pu	^{244}Cm	^{241}Am	^{230}Th
Leaves, stems	2	2 ± 1^b	0.9 ± 0.4^c	5 ± 2	9 ± 2	0.3 ± 0.3
Pods	2	0.1 ± 0.4	0.2 ± 0.4	0.7 ± 0.7	0.8 ± 1	N.D. ^d

^aThree pot composites, two analyses.

^bMean and range of duplicate values, including 1 S.D. counting error.

^cSimilar values were found in greenhouse-grown beans and floodplain soil not tagged with Pu-238.

^dNot detectable above background.

soil (contaminated in 1944 with ^{239}Pu), we find similar Pu concentration ratios, indicating that freshly added Pu is about as available as 30⁺-year-old Pu. Interestingly, ^{230}Th is not as available as ^{238}Pu , although they were added in exactly the same chemical form at the same time. This has been noted on previous samplings (data not shown) and suggests that some Pu may be Pu(III) at the soil-root interface. That is, ^{238}Pu is behaving intermediate between Am(III), Cm(III), and Th(IV) in these pot studies.

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6. BURIAL GROUND TECHNOLOGY

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Introduction

Shallow land burial of low-level radioactive waste is a common disposal method which has been practiced for many years. Usual burial methods used in the past have been to place contaminated material, untreated, in excavations and cover them with the native geologic material. Such methods have not provided complete containment of radionuclides because circulating ground water migrates through buried wastes and transports small amounts of radioactivity to surface streams.

To address the above problem, the Waste Management Program encompasses the two research projects: radionuclide movement from ORNL disposal areas (site-specific) and development of technology for land burial (generic). These projects are closely inter-related in that the Oak Ridge Solid Waste Disposal Areas (SWDAs) serve as the primary study site for the development of technology for land burial.

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The site-specific project is composed of initiatives in three areas: corrective measures, preventive measures, and watershed studies. Corrective measures deals with the development of methodologies to stabilize the waste inventories currently located within the Oak Ridge SWDAs. Preventive measures involves the application of new technology to future land burial at these sites. Watershed studies includes the development of a hydrologic budget for White Oak Creek Watershed and the determination of the primary radioisotope source areas.

The generic project addresses the development of the technology to inhibit the flow of ground water through buried wastes and the use of in-situ grouting or similar techniques to 'encapsulate' buried wastes. This project also includes research on environmental processes which result in contaminant mobility (organic and inorganic radionuclide complexes). Additional areas include support for development of the low-level radioactive waste technology data base, developments of ground-water tracers, and the development of dose assessment models and systems analysis.

Field studies conducted over the past year have addressed several aspects of the waste management program. These studies include: identification of ^{90}Sr inputs to White Oak Creek, evaluation of the status of the intermediate-level waste (ILW) to disposal areas of the watershed, evaluation of preventive and corrective measures in the ORNL SWDAs, and investigations of the mechanisms of radionuclide sediment association.

Several interesting facts emerged from these studies. A significant portion of the ^{90}Sr released to White Oak Creek came from current operations within the Laboratory (a condition which has been corrected). Also, the only radioisotope present at a significant activity level in ground water surrounding the ILW areas is ^{60}Co . Finally, analyses of sediments from various locations for radioisotope content appear to provide a reliable means for rapidly locating release points for radioisotopes to surface waters in the watershed.

Significant progress was made in the investigations on the use of halocarbons as ground-water tracers. A new aspect of this work is the use of a homologous series of compounds to determine the porosity of geologic media.

An important aspect of the program that bridges both components is the development of process models and predictive models in order to evaluate the effectiveness of measures taken to decrease contaminant releases from burial sites. These will provide critical input for the determination of future policies on the methodologies to be used in handling low-level radioactive wastes from nuclear fuel cycles.

Investigation of Strontium-90 in White Oak Creek Between Monitoring Stations 2 and 3

A comprehensive water-sampling program has been carried out in the vicinity of SWDA 4 and in the reach of White Oak Creek between monitoring stations 2 and 3 (Fig. 6.1) to investigate the substantial increase in ^{90}Sr discharge recorded at monitoring station 3 in recent years. The increase could be attributed to SWDA 4 or to new sources of ^{90}Sr input above monitoring station 3. As a first step in evaluating the situation, an experiment was designed to monitor ^{90}Sr activity in surface and ground waters around the periphery of SWDA 4 and in White Oak Creek immediately above and below SWDA 4 (WOC-7 and WOC-4, respectively, Fig. 6.1) during the month of October 1977. On the basis of ^{90}Sr concentrations in the water samples from the perimeter of SWDA 4, there appears to be no current increase in ^{90}Sr discharge from this source.

Activity levels at the two stations generally fluctuate in a sympathetic manner, suggesting that a ^{90}Sr source (or sources) above SWDA 4 is (are) discharging to the creek at a nonuniform rate and that the ^{90}Sr input to the creek as it passes SWDA 4 is fairly constant. Thus, a large proportion of the ^{90}Sr passing monitoring station 3 is present in White Oak Creek before it passes SWDA 4. This evidence prompted an investigation of potential ^{90}Sr sources in the vicinity of the creek above SWDA 4.

Fig. 6.1. Locations of White Oak Creek (WOC) and tributary (T) collection sites between monitoring stations 2 and 3.

A comprehensive sampling program, designed to identify and evaluate all ^{90}Sr sources that make significant contributions to White Oak Creek in its reach between monitoring stations 2 and 3, was carried out in December 1977. A water-sampling schedule was set up which would yield ^{90}Sr concentration profiles in this reach of the creek on selected days within the month. A sample profile consisted of White Oak Creek water samples collected on a single day at 150-m intervals between monitoring stations 2 and 3, plus water samples from all tributaries and ORNL plant effluents entering this segment of the creek, which is approximately 1.75 km in length (Fig. 6.1). Seven sample profiles were collected during the month.

The ^{90}Sr concentration profiles fall into two general categories, referred to as normal and perturbed profiles. Data from the five normal profiles have been combined to yield an average normal profile (Fig. 6.2) whose features may be readily accounted for by input from tributaries and plant effluents. Clearly, the major ^{90}Sr contributions under normal conditions were made by the Sewage Treatment Plant (through tributary T-5) and by SWDA 4 (through tributary T-2).

One of the two perturbed ^{90}Sr concentration profiles is shown in Fig. 6.2 for comparison with the average normal profile. In this case, the profile of ^{90}Sr activity in White Oak Creek was normal from monitoring station 3 to a point about 1050 m upstream.

Fig. 6.2. Normal and perturbed longitudinal profiles of ^{90}Sr activity in White Oak Creek during December 1977. Mean ^{90}Sr activities in tributaries are also shown.

At that point, the activity rises sharply, reaching levels several times higher than normal and returning to a normal value at monitoring station 2. All regularly sampled tributaries and plant effluents have normal ^{90}Sr concentrations on this date. It is probable that this activity "spike" in White Oak Creek was due to an intermittent ORNL plant release that was intercepted during the course of profile sampling. Sampling always proceeded in an upstream direction. The releases apparently occur between monitoring station 2 and the next White Oak Creek sampling point, which is only 83 m downstream. The only possible source in this short interval is the effluent from Waste Ponds 3539 and 3540 (Fig. 6.1), which receive liquid waste from the Building 4500 complex. Intermittent releases from these waste ponds might also explain the ^{90}Sr activity relationships at White Oak Creek station WOC-7 and WOC-4 observed during October 1977 (Fig. 6.1). When relatively high ^{90}Sr concentrations were observed at both stations A and B, an activity "spike" was apparently being intercepted.

On the basis of the longitudinal profiles of ^{90}Sr in White Oak Creek, four major sources of ^{90}Sr discharge to the creek in the study reach have been identified: Waste Ponds 3539 and 3540, the Sewage Treatment Plant, the Northwest Tributary, and SWDA 4. To properly assess the relative importance of each source, it is necessary to quantify its ^{90}Sr discharges. This has been done for December 1977 (Table 6.1) through the use of Operations Division flow data for plant effluents and monitoring stations and through streamflow measurements taken with a vertical-axis current meter during this study. The ^{90}Sr discharge from SWDA 4 was estimated by subtracting the sum of the ^{90}Sr discharges from other major sources in the study reach from the total ^{90}Sr discharged at monitoring station 3 during the month.

Table 6.1. Strontium-90 discharge from sources in the White Oak Creek Study reach, December 1977, and the relative importance of each. The percent contribution is based on the net strontium-90 discharge between monitoring stations 2 and 3 for the month.

Source	Flow (10 ⁶ gal)	⁹⁰ Sr (dpm/ml)	⁹⁰ Sr discharge (Ci)	Relative contribution (%)
Monitoring Station No. 2	176.15	0.05	0.015	
Waste Ponds 3539 and 3540	5.012	6.0	0.051	24.1
Process Waste Treatment Plant (Monitoring Station No. 1)	4.30	0.14	0.001	0.5
Sewage Treatment Plant	8.246	5.14	0.072	34.0
Northwest Tributary	58.252	0.16	0.016	7.5
			0.155	
Monitoring Station No. 3	289.81	0.46	0.227	
SWDA 4	---	---	0.072	34.0

The relative importance of each major source that discharges ⁹⁰Sr to the study reach of White Oak Creek is evaluated in Table 6.1. The percent contributions have been determined by comparison with the net ⁹⁰Sr input between monitoring stations 2 and 3 during December 1977. There are two additional ⁹⁰Sr sources within the study reach, the Waste Ponds and the Sewage Treatment Plant, which were comparable in importance to SWDA 4 during December. Therefore, the practice of assigning the increment in White Oak Creek ⁹⁰Sr discharge between monitoring stations 2 and 3 to discharge from SWDA 4 is incorrect. These observations have been made possible in large part by the vast reduction in ⁹⁰Sr discharged from the Process Waste Treatment Plant since the new plant became operational in April 1976. It is entirely possible that the relatively high ⁹⁰Sr discharges recorded at monitoring station 3 in recent years, which prompted this study, were due to elevated ⁹⁰Sr activity levels in the effluent from either the Waste Ponds or the Sewage Treatment Plant, or both.

Evaluation of the Intermediate-Level Liquid Waste Pits and Trenches

During the period 1951 to 1976, intermediate-level liquid waste (ILW) was discharged into the ground through a series of shallow open pits and covered trenches. More recently, hydrofracture techniques have been employed. Approximately 182 million liters of solution, containing over 1×10^6 Ci of mixed fission products were discharged into these pits and trenches. More than half of the waste was composed of ⁹⁰Sr and ¹³⁷Cs, whereas, the remainder was composed primarily of ¹⁰⁶Ru and minor amounts of ⁶⁰Co and ¹²⁵Sb. Although the pits and trenches have performed satisfactorily in the past, the potential long-term hazards of radionuclide release from these areas is under further study.

All surface and subsurface waters from the pits and trenches drain into White Oak Creek and White Oak Lake (Fig. 6.3). Prior to entering the Clinch River, surface waters are monitored for radionuclide transport at the dam forming the lake. Currently, no operational surface-water monitoring facilities exist to delineate the release

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Fig. 6.3. White Oak Creek and White Oak Lake drainage areas.

contributions from each of the pits and trenches. For the purposes of assessment and computer simulation of radionuclide transport, ground-water samples were collected from existing monitoring wells in the area.

Since this area has received little attention during the past decade, substantial effort was made to upgrade the existing monitoring wells and access roads. After pumping stagnant water from the well casings, over 90 water samples were collected. An independent laboratory performed the radiochemical analyses including ^{90}Sr , ^3H , ^{60}Co , and ^{137}Cs . Neglecting the spatiotemporal distributions of the radionuclide concentrations, ^{60}Co data are summarized in Table 6.2. With the exception of a few anomalous results, neither ^{90}Sr nor ^{137}Cs appear to be present in significant concentrations in the peripheral ground waters. The tritium does not appear to be a health hazard.

Review of the geohydrology and geochemistry of the ILW area has lead to the installation of 21 additional monitoring wells in an attempt to assess and understand radionuclide transport. Investigation of ^{90}Co migration in the unsaturated zone was initiated by the installation of several vacuum-pressure suction lysimeters. Additional information concerning the spatiotemporal distributions of radionuclides is essential not only to calibrate but also to verify transport simulation models.

Table 6.2. Cobalt-60 concentrations of filtered ground-water samples collected from the III area

Location	Average (pCi/ml)	Standard deviation	Maximum (pCi/ml)
Pits 2, 3, 4	4.7	13.0	72.0
Trench 5	26.7	43.0	130.0
Trench 6	0.09	0.09	0.24
Trench 7	47.5	86.0	354.0
Seeps	17.6	30.0	92.0

Evaluation of Preventive and Corrective Measures in ORNL Solid Waste Disposal Areas

Considerable progress has been achieved toward the role of encapsulation prior to burial, in-situ stabilization to minimize radionuclide transport from solid waste trenches, and hydrologic isolation (infiltration control) of stored wastes. Most of these activities were initiated in FY 78 and are ongoing at the present time. Consequently, the data presented here and the conclusions drawn are preliminary in nature, pending additional information.

Potentially Mobile Radionuclides in Waste Burial Trenches

A preliminary examination indicated that several of the 49 solid waste trenches in bentonite seal area III (SWDA 6), contained free water. The area was used for waste disposal in 1973-74. A near-surface bentonite-shale seal was installed in 1977. Many of the corrugated pipe observation wells that are regularly emplaced in all solid waste trenches in SWDA 6 were missing, filled with mud, or otherwise destroyed during the placement of the bentonite seal. A new set of PVC pipe observation wells have been installed and the older ones removed or plugged with concrete in 40 of these trenches.

Regular monitoring of standing water in these wells was initiated in April 1978. Most of the wells which are more than 13 ft deep (presumed to be the trench depth from the present surface) contain free water. The amount of standing water varies seasonally and is generally greater at the lower elevation. Water elevations in several trenches appear to be independent of the general water table in the peripheral area. The difference is attributable to the naturally lower hydraulic conductivity of the native soil. Conductivities of soils adjacent to the trenches are further reduced by the presence of organic and inorganic waste components which induce clay dispersion and swelling. A concurrent rise in the standing trench water was observed upon the incidence of precipitation. A prolonged drought period toward the end of summer resulted in a significant depression in the water elevations.

Water samples were collected from 20 solid waste trenches and two shallow monitoring wells in the above area. Concentrations of dissolved radionuclides in the water are expected to vary seasonally as based upon the pH, Eh, solubility product, and the presence of other stable ions in the system. The data indicate that the levels of ^{60}Co , ^{137}Cs , and gross α in these samples are relatively low. The concentration of ^{90}Sr exhibits significant variations (Table 6.3). The ^{90}Sr levels measured in 1978 are generally higher than those measured in 1976.

Table 6.3. Radionuclide analysis of filtered water collected from solid waste trenches in bentonite seal area III, SWDA 6

Trench number	Gross α (cpm/ml)	^{90}Sr		^{60}Co (dpm/ml)	^{137}Cs (dpm/ml)
		1978 (dpm/ml)	1976 (dpm/ml)		
36	≤ 0.5	1.1 ± 0.1	--	0.10 ± 0.02	0.19 ± 0.04
42	≤ 0.5	5.4 ± 0.2	8.04	0.047 ± 0.009	0.08 ± 0.02
127	≤ 0.6	2.5 ± 0.2	2.97	≤ 0.03	0.05 ± 0.01
133	≤ 0.7	12 ± 1	--	51.8	0.5 ± 0.1
135	≤ 0.5	27 ± 2	38.6	0.015 ± 0.007	0.23 ± 0.02
137	≤ 1	$(5.35 \pm 0.03) \times 10^2$	1.7×10^2	0.028 ± 0.009	0.33 ± 0.06
141	≤ 1	8.1 ± 0.3	--	0.56 ± 0.03	0.041 ± 0.009
145	≤ 2	60 ± 1	1.14×10^2	0.91 ± 0.03	5.9 ± 0.6
147	≤ 1	11.6 ± 0.4	--	≤ 0.02	0.9 ± 0.3
150	--	$(8.57 \pm 0.14) \times 10^2$	2.95×10^3	0.31 ± 0.02	28 ± 4
156	≤ 0.3	0.25 ± 0.06	9.76	≤ 0.04	≤ 0.07
150	≤ 0.5	2.5 ± 0.2	--	≤ 0.03	≤ 0.02
166	≤ 0.8	$(6.23 \pm 0.01) \times 10^2$	--	≤ 0.05	0.5 ± 0.2
158	≤ 0.8	5.9 ± 0.2	--	≤ 0.02	≤ 0.2
173	≤ 0.8	$(5.07 \pm 0.12) \times 10^3$	1.96×10^3	0.06 ± 0.02	2.6 ± 0.4
183	≤ 0.3	33 ± 2	--	0.022 ± 0.007	≤ 0.05
187	≤ 0.4	36 ± 2	--	0.34	0.22 ± 0.09
191	≤ 0.2	230 ± 9	--	0.08 ± 0.02	19.0 ± 0.3
205	≤ 2	9.2 ± 0.4	--	0.04 ± 0.01	≤ 0.09
207	≤ 1	0.19 ± 0.05	--	0.17 ± 0.07	≤ 0.04
W107	≤ 0.5	0.42 ± 0.07	--	≤ 0.06	≤ 0.06
W317	≤ 0.5	0.12 ± 0.04	4.30	≤ 0.02	≤ 0.2

Evaluation of Bentonite Seals

Bentonite seals have been installed in one area (I) of SWDA 5 and three areas (II, III, IV) of SWDA 6 to reduce the infiltration of rainwater into the waste trenches. Prior to installation of the seal in area IV in FY 78, all observation wells were plugged to facilitate the mechanical placement of a continuous seal over the area. Bentonite seal area I shows a negligible amount of standing water present, while most of the trenches in seal area III show varying amounts of water. It indicates that the seal in the latter area is either ineffective or the area has experienced a general rise in the ground-water table after closure of the disposal area. Oral communication with the ORNL Operations Division personnel and incomplete records indicate that the original water table was much lower in the area in comparison with the present levels.

Eight neutron probe access tubes were installed, four each in sections III and IV, to measure the vertical distribution of moisture contents. These measurements will provide the required data to evaluate the effectiveness of sealing in reducing the infiltration of rainwater.

In-Situ Stabilization

Laboratory and field pilot studies for evaluation of grouting techniques are under development. A literature survey report, entitled "Preventive and Corrective Measures for Shallow Land Disposal of Non-high Level Solid Wastes," has been prepared. The report lists treatment materials available and the feasibility of their use for solid waste encapsulation prior to burial, site treatment, and in-situ stabilization, using

various grouting materials prevalent in the construction industry. Based on this literature survey, sodium silicate, cement, and clay grout materials have been selected for further studies in the laboratory and for possible field demonstration tests.

In-situ treatment is contemplated in trenches known to transport radionuclides through seeps and trenches with exceedingly high levels of potentially mobile radionuclides. Acquisition of additional field data is necessary prior to grout injection. These data include seasonal water table and standing trench water fluctuations and soluble radionuclide and stable ion concentrations of trench water.

Mechanisms of Radionuclide-Sediment Association

This study was undertaken to evaluate the use of stream-bed sediment analysis for locating and monitoring radionuclide contamination in White Oak Creek. Only ^{90}Sr , ^{137}Cs , and ^{60}Co were examined because they comprise most of the radioactivity, with the exception of tritium, released into White Oak Creek. Each of the radionuclides was examined for its interaction with stream-bed sediment using several approaches. Contaminated sediment was extracted with water, salt/buffer solution, and reducing agents to observe the distribution of each radionuclide in various phases: soluble, exchangeable by other cations, or precipitated with ferromanganous hydrous oxides, respectively. The ferromanganous hydrous oxide phase, which coats many of the sediments in White Oak Creek, was examined because of its known importance in the adsorption and immobilization of transition elements (Jenne 1968), which would include ^{60}Co , and because several common manganous minerals contain alkaline earth elements (McKenzie 1977) which would include ^{90}Sr . In addition, the distribution of each radionuclide in different size-classes of sediment was examined to determine which sizes are most contaminated and, therefore, most suitable for routine monitoring.

The bimodal distribution of each radionuclide was strongly related to the mineralogical compositions of each size fraction. Quartz, with its comparatively inert surface, would not be expected to adsorb radionuclides. Its concentration reached a maximum in the fine-sand-to-coarse-silt fractions exactly where ^{90}Sr and ^{137}Cs concentrations on the sediment attained minima. The larger-sized fractions were dominated shale fragments (i.e., aggregated clay and inclusions) with considerable ferromanganous hydrous oxide coatings; quartz exists as sand- and silt-sized inclusions in the shale fragments of these coarser sizes. As size decreased (smaller than coarse sand), mineralogical composition changed with an increase in individual quartz grains down to coarse silt, a decrease in shale fragments, an increase in silicate clay particles, and an increase in the proportion of reducible iron and manganese coatings. This large increase in ferromanganous coatings in the clay-sized fractions was probably due to the large increase in surface-area-per-unit weight with decreasing particle size.

Hydrologic Model Development

Several related activities dealing with model development for both surface and subsurface hydrology have been underway during the past year. These include computer analysis of the hydrologic behavior of the watershed, development of surface water models, and simulations of subsurface hydrology.

Computer Analysis of the Hydrologic Behavior of White Oak Creek Watershed

The basis for computing radionuclide transport within and from the White Oak Creek, drainage is the hydrologic budget for the watershed, together with known concentrations of radionuclides. The fluxes of water and some radionuclides have been measured for several years at established monitoring stations, and these measurements have been used as a basis for selecting certain locations within solid waste disposal areas for treatments designed to reduce or eliminate radionuclide transport. However, there has been a growing need for an objective basis for evaluating the effectiveness of the variety of treatments in terms of reduction of radionuclide flux from the basin. The problem is

having a reference or control for comparison. Once the basin has been modified, measurements reflect the altered state, and the original system response is no longer known. However, hydrologic simulation, based on properly calibrated models, can provide a measure of control for evaluating the effects of treatments. In addition, it is possible to use models to estimate the effects of treatments prior to their implementation.

As an initial step in simulating the hydrology of the White Oak Creek basin, an existing hydrologic model has been used to predict basin hydrologic response over a one-year period. The terrestrial ecosystem hydrology model (TEHM), described by Huff et al. (1977), was used to simulate runoff at several locations in the basin. All model parameters were independently estimated from field observations and/or experience with studies at nearby Walker Branch Watershed. Soils properties were taken from county soils maps and representative measurements of hydraulic properties developed by the University of Tennessee Agricultural Experiment Station. Precipitation and other climatic data were obtained at nearby locations. The annual hydrograph simulation is compared to observations in Fig. 6.4. On an annual basis, the ratio of simulated flow to observed flow is 0.93, which indicates a spread of about 7%. This is roughly comparable to the expected accuracy of monitoring. When monthly flows are examined, the ratio of simulated to observed flow at the basin outlet is 0.92 ± 0.49 . Most of the error occurs during low-flow periods, when plant discharges to the stream are appreciable. This test demonstrates the generality of the simulation model, but shows the need for calibration when it is used as a predictive tool. With explicit calibration to the watershed, the simulation results should more closely represent existing conditions for all periods and serve as a basis for evaluating consequences of engineering treatments for reducing radionuclide discharges.

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Fig. 6.4. Simulated average daily flow at White Oak Dam.

In addition to simulation, analysis of the hydrologic behavior of White Oak Creek basin has been facilitated by development of a computerized hydrologic data base. The initial content of the data base includes daily flow observations at monitoring stations 3, 4, and 5. The data have been summarized graphically, and Fig. 6.4 is an example of graphics generated from the data. At present, several general data management systems are under consideration for use as the master system for organizing the data and providing ready access to it.

Development of Surface Water Models

Two surface impoundment models have been developed, one by the finite difference method (SIMFD) and the other by the finite element method (SIMFE). Both models enable the simulation of flow dynamics and radioactive waste transport in natural or artificial impoundments such as White Oak Lake. One of the special features of the models is their capability to treat any number of islands located within the impounded water. Both SIMFD and SIMFE have been compared to the numerical results of an analytical solution for several simplified geometries. They have been applied to an impounded water body in the Mississippi River. Satisfactory verifications have been obtained by comparing the simulations with field measurements (Yeh, in preparation; Yeh and Tamura, in preparation). These models will be verified against field data in White Oak Lake and then applied therein as a component of the general hydrological transport modeling activity. SIMFE will also form the basis of the model being developed at ORNL for the simulation of flow dynamics and the transport of sediments and dissolved and particulate radionuclides in surface water bodies (including natural rivers or streams and surface impoundments).

In computing the transport of radionuclides in surface impoundments, the flow field is first obtained by solving the vertically integrated equations of continuity and momentum. Assumptions for developing the governing hydrodynamic equations are: (1) the velocity distribution in the vertical direction is fairly uniform; (2) the pressure distribution in the vertical direction is hydrostatic; (3) the fluctuation of the water surface is small compared to the water depth; (4) the flow is steady state; and (5) the nonlinear convection force is small compared to the bottom friction force. All assumptions have been evaluated and shown valid for a typical shallow impoundment.

The flow field along with the topography and geometry of the impoundment are then input to the computation of the pollution transport. The mechanisms considered for the pollutant transport include advection, dispersion, decay, chemical and biological degradation, and losses to the atmosphere (for heat transport). Transient as well as steady state solutions can be simulated. In the SIMFE, twelve optional numerical schemes have been built in the computer code. This allows the application to very wide range of problems without causing numerical instability.

During the rainfall-runoff period, the steady state flow assumption in the stream system with several branches is not valid. Although transient simulation of flow and water depth for a single river has been investigated by numerous authors. They are not applicable to the stream system in the White Oak Watershed. Ongoing research thus includes the development of the transient hydrodynamic model for the stream system of several branches with comparable size.

Simulations of Ground-Water Transport

Review of recently developed models (Reeves and Duguid 1975, Duguid and Reeves 1975) for contaminant transport by ground water reveals several deficiencies. These deficiencies include accurate numerical solution schemes, the discontinuity of the velocity field on the element boundaries and nodal points for the moisture transport, and the overestimation of contaminant transport in the unsaturated zone for the pollutant transport.

The conventional Galerkin finite-element approach to the solution of the partial differential equations for moisture and material transport has been expanded for improved accuracy and numerical stability. In the development of the models, the

time-marching is dealt with by either the Crank-Nicolson central-difference or the backward-difference. For many applications of the model, the mid-difference in time-marching would yield more accurate results if the consistent mass matrix is used (Gureghian et al. 1978). Referring to the mass matrix, it appears as a unit matrix if the spatial discretization is performed by the finite-difference method. Hence, by suitable scaling, the mass matrix may be reduced to a finite-difference equivalent if it is lumped (Clough 1977). Incorporation of lumping of the mass matrix typically results in a better behaved global matrix. By the more versatile method of weighted residuals, the bilinear basis functions used in the material transport model for the isoparametric quadrilateral elements are augmented with asymmetric upstream weighting functions. In a steady state velocity field reduction, numerical oscillations advantageously permit a less refined element discretization. These expansions improve the accuracy and stability of the models and computer core and execution time are reduced.

The continuity equation governing the distribution of pressure head in the moisture transport model is solved by the Galerkin finite-element method subject to appropriate boundary and initial conditions. The velocity field is calculated with Darcy's law by differentiating the calculated pressure field. Inherent in this approach, however, is the resulting discontinuity in the velocity at the element boundaries and nodal points. Unfortunately this leads to a violation of the conservation of mass in a local sense. When the spatial variation of the velocity distribution is significant, subsequent calculation of pollution transport could conceivably produce erratic errors. To circumvent the problem, the nodal velocities are calculated by the finite-element method rather than simply differentiating the pressure field. This approach is consistent with the spirit of the finite-element method and yields a continuous velocity distribution over the whole region of interest, including the element boundaries and nodal points.

The derivation of constituent adsorption in a partially saturated media has been reformulated whereby the distribution coefficient remains independent of the moisture content, resulting in an inverse relationship between moisture content and retardation coefficient. Currently, the model overestimates contaminant transport above the water table. Incorporation of this adsorption isotherm is more consistent with both field observations and laboratory studies of contaminant transport.

The moisture and material transport models have been applied to the decommissioned Intermediate-Level Liquid Waste (ILW) pit 4 in the Oak Ridge disposal area. Calibration and verification efforts of the moisture transport model are augmented by water table measurements obtained on a bimonthly basis at five locations within the cross section. Comparison of steady state hydrologic simulations with observed water levels are favorable. Ground-water samples have been collected in both the saturated and unsaturated zone through five monitoring wells and five vacuum-pressure suction lysimeters. Field data collected at the site will be used in future validation of the material transport model.

Halocarbons as Ground-Water Tracers

The development and evaluation of halocarbons as tracers of ground-water movement was continued this past year by the University of Arizona and the University of Indiana under subcontract with the Environmental Sciences Division. Laboratory tests conducted at the University of Indiana have resulted in the conclusion that the halocarbon-tracer species under study interact with silica and limestone only by nonspecific mechanisms. These findings are significant in that: (1) the migration rate of a tracer should be determined only by the energy of the nonspecific sites on a given mineral surface, the density of those sites, and the polarizability of a tracer molecule; (2) although absolute migration rates might change as the nature of the stationary phase in an aquifer changes, relative migration rates should be unchanging from one rock type to another; no special complications should be expected when a given aquifer contains a variety of rock types. Field tests will be conducted to test the concept that the relative migration velocities of homologous halocarbons (e.g., CH_3Cl , CH_2Cl_2 , CHCl_3 , CCl_4) can provide independent measurements of the effective porosity of any porous medium, independent of ion-exchange characteristics.

At the University of Arizona, six fluorocarbon compounds (CCl_2F_2 , CCl_3F , CClBrF_2 , CBr_2F_2 , $\text{CCl}_2\text{F}-\text{CClF}_2$, $\text{CBrF}_2-\text{CBrF}_2$) have been tested to varying degrees to evaluate their usefulness as ground-water tracers. The tracers were selected initially on the basis of low toxicity, after which they were partially evaluated in terms of their solubility, detectability, and sorptive tendencies. Both field and laboratory tests have been carried out. Column testing, measurement of gas-liquid distribution coefficients, and measurement of instrument response factors were performed in the laboratory. Comparisons with other types of tracers (Br^- , Cl^- , ethanol, and benzoate) have been obtained in field tests as well as in column tests, and have provided a basis for evaluation of sorptive properties of the fluorocarbons. The preliminary findings suggest that solubility may be a factor affecting sorption of the fluorocarbons on natural aquifer materials.

Information Services

During the past year approximately 400 abstracted and indexed documents were added to the Low-Level Radioactive Waste Technology data base. More than 900 documents are currently searchable or are in the process of being incorporated into the data file.

Five quarterly Low-Level Radioactive Waste Technology Newsletters were published and distributed to a wide range of researchers in the governmental, industrial, and academic sectors. The circulation has grown from around 500 to approximately 800. The newsletters have been well received and appear to be filling a definite information need. Information for the newsletters has been supplied by readers as well as other sources.

The second bibliography in the series on low-level radioactive waste technology has been published. It contains 504 annotated references from the low-level radioactive waste technology data base, and was distributed to approximately 700 persons working in the field.

Responding to a request from the funding agency (DOE/Office of Nuclear Waste Management), the title of the data base, newsletters, and bibliographies was changed to Low-Level Radioactive Waste Technology. This name is intended to better convey the scope of the technical information being processed for the project.

Requests for information answered during the past year numbered 150. Most of the requests came from researchers representing governmental agencies; however, requests from private industry have increased and are rapidly approaching 50%.

A companion data base has also been compiled and is being updated. It contains all proposals submitted to DOE, EPA, NRC, and USGS for research to be performed in the area of low-level radioactive waste technology.

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PART II. ENVIRONMENTAL SCIENCES DIVISION SECTIONS

7. AQUATIC ECOLOGY SECTION

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Introduction

The Aquatic Ecology Section is responsible for all disciplinary aquatic research in the Division and supplies technical expertise to the various research and assessment programs. The basic focus of section research falls into four general categories: population studies, behavior and fate of contaminants, ecological effects, and ecosystem analysis. In addition, staff were assigned full- or part-time to every division program during this reporting period, and their significant contributions are reported in the programs on cooling systems, environmental impacts, ecosystem studies, and nuclear and synthetic fuels.

The dynamics of fish populations in the Hudson River system, as effected by power plant intake and discharge systems, have been a major area of emphasis in the section for several years. During the past year, staff assigned to this project have continued the development and application of quantitative methodologies to more reliably predict the consequences of mortality imposed on animal populations by man's activities. Substantial effort was directed toward preparing for and participating in adjudicatory

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hearings, as well as continuing to develop and apply a variety of analytical techniques. This research and assessment was supported by the Department of Energy (DOE), the U. S. Environmental Protection Agency (EPA), and the U. S. Army Corps of Engineers, and the resultant methodologies are expected to have applicability to a wide variety of systems and populations.

Studies on the effects of exposure of fish populations to continuing low-level radiation are supported by the Department of Energy and involve research both in the laboratory and in White Oak Lake, a decommissioned waste disposal pond at ORNL. Staff members working on this project are examining the role of sediment-bound radionuclides in the accumulation of ^{60}Co and ^{137}Cs in fish. The distribution and concentration of tritium in an aquatic environment is also being examined in White Oak Lake. Effects on aquatic organisms of radionuclides produced by neutron activation in the blanket material of fusion reactors are also being studied and will be emphasized in the future.

The ecological effects of power plant biocides continue to be an important research endeavor in the section. Activities included a comprehensive literature review designed to evaluate the potential of ozone as a power plant biocide and research oriented toward determination of optimum chlorination levels. Results of the chlorine research are being used by the Regional Administrator of the EPA (Region V) as water quality criteria for that region. This DOE-funded project will continue to emphasize optimization of biocide utilization as its primary goal.

Characterization of aquatic environments in the vicinity of the Oak Ridge Gaseous Diffusion Plant has been completed, and an environmental report has been prepared in support of development of an environmental impact statement related to the plant. Similar monitoring efforts will soon be undertaken in support of an environmental impact statement to be prepared for the X-10 facility. During the past year, a proposal was prepared and submitted to DOE to evaluate the environmental issues accompanying the development of small (i.e., "low-head") hydroelectric generation facilities. This effort, funded under the Assistant Secretary for Resource Applications, will begin in FY 1979.

Population Studies

The Population Studies Group is concerned with the development and application of quantitative methodologies for predicting the consequences of mortality imposed on animal populations by man's activities. Current efforts focus on single fish populations in an effort to assess the impacts of entrainment and impingement of fish by several existing and proposed power plants along the Hudson River in New York. This assessment effort, in which ORNL has been involved on behalf of the Nuclear Regulatory Commission (NRC) since 1971, recently expanded to include work for the U. S. Army Corps of Engineers (New York district) and the EPA (Region II). As a result, substantial effort is now directed at analyzing and critiquing utility reports and testimony, obtaining relevant data, performing independent analyses, and preparing for and participating in adjudicatory hearings, as well as continuing to develop and apply quantitative methodologies. Technical summaries of three of these methodologies are presented below.

Empirical Transport Model (ETM)

A first step in assessing the impact of entrainment mortality imposed on fish or shellfish populations is estimating the conditional entrainment mortality rate. Mathematical models for evaluating entrainment of aquatic organisms have been proposed by numerous authors. Although some of these models simulate ichthyoplankton movement patterns through the use of hydrodynamic equations, few of the models specify movement patterns based directly on field data. Here we describe a generalized mathematical model, incorporating empirically derived characteristics of the distribution and movement of ichthyoplankton, for estimating the conditional entrainment mortality rate. The model was developed in collaboration with Drs. John Boreman and C. P. Goodyear of the U. S. Fish and Wildlife Service's National Power Plant Team in Ann Arbor, Michigan.

The fundamental equation underlying the model is:

$$M_I = 1 - \left\{ \sum_{i=1}^I \left\{ R_i \prod_{j=0}^J \left[\prod_{z=1}^L \left(1 - \left[\sum_{k=1}^K D_{k,z} \left(1 - e^{-[E_{i+j,k}, C_{j,i}]^t} \right) \right] \right) \right] \right\} \right\}.$$

where, when t is arbitrarily chosen as weeks,

- M_I = total conditional entrainment mortality rate;
- i = spawning week 1,2,3,...,I;
- I = duration of the spawning period in weeks;
- R_i = proportion of total eggs spawned during week i ;
- j = age (in weeks) 0,1,2,...,J;
- J = oldest entrainable age;
- z = life-stage;
- L = oldest entrainable life-stage;
- k = region 1,2,3,...,K;
- K = total number of regions within the water body;
- $D_{k,z}$ = proportion of the total standing crop of life-stage z individuals (averaged over their period of occurrence within the year) occurring in region k ;
- $E_{i+j,k,z}$ = instantaneous entrainment mortality rate constant during week $(i+j)$ in region k for life-stage z (units:per week), which is a function of the amount of water withdrawn by power plants in region k and the susceptibility of individual's in life-stage z to withdrawal and subsequent mortality due to plant passage;
- $C_{j,z}$ = the proportion of age j individuals in life-stage z ; and
- t = time (units:weeks).

Obtaining the input data needed for the ETM involved specifying geographic regions within the water body to define distribution and movement during the entrainment period, obtaining estimates of physical factors (water volume and power plant intake flow in each region), calculating the distribution of life-stages among regions during the entrainment period, determining entrainment susceptibility in each region for each life-stage and time step, and determining an appropriate time step for the entrainment period. It is assumed that sample abundance estimates are relative (and not necessarily absolute) indices of actual abundances and that the indices are comparable among all regions (i.e., sampling gear efficiency is equal among regions).

Provided sufficient information is available, the model may be applied to fish or shellfish populations inhabiting a water body containing existing or proposed power plants. An example involving application of the ETM to a hypothetical estuary has been worked out to illustrate operation of the model. It will be applied in estimating the conditional entrainment mortality rate for several fish populations inhabiting the Hudson River Estuary.

Impingement Losses of White Perch in the Hudson River

A data analysis of impingement losses of white perch at the Indian Point Nuclear Station and other Hudson River power plants has been undertaken. It consists of two independent studies: (1) evaluation of annual variations in collection rates at five Hudson River power plants to detect declines in white perch abundance that could be attributable to power plant impacts, and (2) estimation of the conditional rate of mortality due to impingement.

Collection-rate data are available on a monthly basis for a period of 4 to 6 years for Bowline, Lovett, Indian Point 2, Roseton, and Danskammer power plants. Assuming that collection rate, which is equivalent to a catch per unit effort, is an approximate index of population size, one can examine the time series for population trends. The

regression model used was $Y = a + bX$, where Y is the collection rate for young-of-the-year (y-o-y) white perch and X is year. A slope significantly greater than 0.0 indicates an increasing trend in population size, while a slope significantly less than 0.0 indicates a decreasing trend in population size.

Out of 78 regressions, the slope differed significantly from 0.0 in only eight cases. Out of these eight cases, the slope was significantly greater than 0.0 seven times and less than 0.0 only once. Thus, the collection rate data from these five power plants suggest that there has been no pronounced or consistent change in the size of the white perch population during the period 1973 to 1977. In particular, there is no evidence of a statistically significant downward trend. However, large increases in power plant intake flow occurred during the 1973 to 1975 period. Thus, assuming a median age of reproduction of four years for white perch, the possible reductions in year-class strength due to power plant entrainment and impingement would only start to be evident in 1977 or 1978.

The empirical model of impingement impact used to estimate the conditional mortality rate due to impingement for the Hudson River white perch population is described in Barnthouse et al. (1979). The model requires estimates of the initial number of young-of-the-year in the Hudson River white perch population at the time they first become vulnerable to impingement, estimates of the rate of natural or total mortality during the period of vulnerability to impingement, and monthly estimates of the number of white perch impinged by year-class. The conditional mortality rate is equivalent to the fractional reduction in year-class strength due to impingement in the absence of compensation.

The model was applied to the 1974 and 1975 white perch year-classes, using ranges of values for initial numbers and natural mortality rate. Two alternative assumptions were made concerning the age of impinged white perch one year old and older. On the one hand, we assumed they were all yearlings, resulting in two years of vulnerability to impingement. On the other hand, we assumed 50% were yearlings and 50% were two year olds, resulting in three years of vulnerability. The resulting estimates for the fractional reduction in year-class strength due to impingement are presented in Table 7.1. Our analysis suggests that impingement mortality is sufficiently high (most probably greater than 10% for both the 1974 and 1975 year-classes and probably greater than 20% for the 1974 year-class) that it cannot be dismissed as trivial or acceptable.

Table 7.1. Estimates of conditional mortality rate due to impingement for the 1974 and 1975 year-classes of the Hudson River white perch population for combinations of estimates and assumptions involving initial population size, natural mortality, and number of years of vulnerability

Number of years of vulnerability	Year class	Initial population size					
		Low		Best estimate		High	
		Natural mortality rate		Natural mortality rate		Natural mortality rate	
		Low	High	Low	High	Low	High
2	1974	0.309	0.446	0.177	0.255	0.095	0.137
	1975	0.166	0.245	0.116	0.172	0.077	0.115
3	1974	0.387	0.588	0.221	0.336	0.119	0.181
	1975	-	-	-	-	-	-

Modeling the Effects of Entrainment on Adult Fish

A simple technique for estimating the number of adult fish that would be produced if eggs and larvae were not entrained has been proposed by Horst (1975) and modified by Goodyear (1978). However, as indicated below, various assumptions and conventions associated with this technique can lead to sizable inaccuracies in estimating the potential loss of adults consequently, it would be used only when it is not possible to use more sophisticated methods because of the lack of data.

The loss to the adult population due to entrainment is assumed equal to the number of eggs and larvae entrained times the survival from the egg or larval stage to the age when the particular fish species reaches sexual maturity. It is assumed that the population is in equilibrium and that an average female will reproduce just enough eggs to replace herself (a sex ratio of one-to-one is often assumed). This technique does not consider any compensatory mechanisms which might partially offset losses over several generations. However, this technique also implicitly assumes that a reduction in adults in one generation does not result in compounded reductions in the number of adults in future generations. Such a feedback mechanism in the real population would cause the impact due to a power plant to become more severe with time. Thus, little insight is provided by this methodology into long-term effects on the fish population, and the technique should only be used to provide an approximate estimate of the potential severity of an entrainment impact.

An important source of bias, leading to either an overestimate or an underestimate, concerns the fecundity term. Equations (13) through (16) in Horst (1975) have been used to derive the following equations for eggs,

$$N_a = S N_e = \frac{2}{F} N_e, \quad (7.1)$$

and for larvae,

$$N_a = S_l N_l = \frac{2}{S_e F} N_l, \quad (7.2)$$

where N_a = the number of "equivalent adults" lost due to the entrainment of N_e eggs or N_l larvae by the power plant; S , S_e , and S_l are the survival from the egg to the adult stage, egg to larval stage, and larval to adult stage, respectively; 2 implies a sex ratio of one-to-one; and F represents a measure of female fecundity. Horst (1975) defines F as "the fecundity of a breeding pair during their life." However, without correcting for adult mortality, simply summing up the female fecundity over the mature age classes will significantly overestimate the lifetime fecundity of an average female. Overestimating F , in turn, will lead to an underestimate of S and hence an underestimate of S_l and the number of "equivalent adults" lost due to power plant entrainment.

The following equation has been used for determining "the average lifetime fecundity of a female recruit to the 'adult' population" (Goodyear 1978):

$$F_a = \sum_{j=a}^m P_j S_j E_j, \quad (7.3)$$

where a = age of recruitment to the "adult" population, m = the number of age classes in the population, P_j = fraction of mature females in age class j , S_j = survival probability from recruitment to age class j , and E_j = average fecundity of mature females of age class j . Goodyear (1978) presents an example using an hypothetical fish population having 15 age classes. His age of recruitment to the "adult" population refers to

entry or recruitment to the fishery, and not to recruitment to the first age class having sexually mature females. The former is preferable when trying to estimate gross, short-term losses to a commercial or sport fishery. The latter may be preferable for providing insight into losses to the future breeding population as well as into gross, short-term losses to fish populations for which there is no significant fishery. Table 7.2 (column 3) gives the average lifetime fecundity of a 4-year-old recruit (first mature age class) to a hypothetical fish population as $F_a = 445,424$ eggs, whereas the sum of the entries in column (2) in Table 7.2 is 8,233,750 eggs, or "the fecundity of a breeding pair during their life" (Horst 1975).

Table 7.2. Two alternative methods of estimating the fecundity of a hypothetical fish population

Age (1)	Cumulative probability of survival (S_j) (2)	Eggs per individual ($21.5 F_j E_j$) (3)	Weighted number of eggs per individual: (1) $\times$ (2) ($21.5 S_j P_j E_j$) (4)
4	1.000	21,250	21,250
5	0.600	64,750	41,250
6	0.360	187,500	67,500
7	0.216	356,250	76,950
8	0.130	600,000	77,760
9	0.078	700,000	54,432
10	0.047	850,000	39,658
11	0.028	950,000	26,594
12	0.017	1,050,000	17,635
13	0.010	1,100,000	11,055
14	0.006	1,150,000	6,954
15	0.004	1,200,000	4,354
TOTAL $F^a =$		8,233,750	$F_a^b = 445,424$

^aSee equation (7.2); corresponds to the fecundity of a breeding pair during their life (Horst 1975).

^bSee equation (7.3); corresponds to the average lifetime fecundity of a four-year-old recruit to the sexually mature component of the population (Goodyear 1978).

Goodyear's (1978) modification of Horst's (1975) methodology can be shown mathematically to be equivalent to that of Vaughan and Salla (1976), such that

$$S = S_0(S_1)(S_2) \dots (S_{a-1}) \quad , \quad (7.4)$$

where S_j is the annual survival rate for age class j , and a is the first age class having sexually mature females. From Vaughan and Salla (1976)

$$S_0 = \frac{1}{m_1 + \sum_{i=1}^{m-1} m_{i+1} \left(\prod_{j=1}^i S_j \right)} \quad , \quad (7.5)$$

where m_i ($i = 1, 2, \dots, m$) is the age-specific fecundity per individual.

It should be noted that for the early mature age classes not all females will be sexually mature. Hence, if one assumes that all females in the first few mature age classes are sexually mature, then an overestimate of the average lifetime fecundity will result, which will of course lead to an underestimate of the loss in "equivalent adults" due to power plant entrainment. Using a range of possible adult annual survivals, S_j , a range of losses of "equivalent adults" can be generated using equations (7.5), (7.4), and then (7.1).

Sediment Contribution to the Accumulation of Cobalt-60 and Cesium-137 in Fish

The sediments of aquatic ecosystems are generally considered sinks for many of the radionuclides released to aquatic environments. A long-term aquarium study was conducted to determine the contribution of naturally tagged sediments to the accumulation of ^{60}Co and ^{137}Cs in catfish, *Ictalurus punctatus*. Sediments from White Oak Lake were sieved, and particles $< 53 \mu$ in size which contained significant quantities of ^{60}Co and ^{137}Cs were used for sediments in an aquarium. Ten fish with an average weight of 7.0 g were introduced into the aquarium and removed at intervals for whole body counting. The experiment was initiated in October 1976 and terminated in February 1978, at which time the remaining fish were sacrificed for tissue analyses.

Initially the sediments were the only source of radioactivity available to the fish; however, ^{60}Co and ^{137}Cs became dissolved in the water and suspended on solids. At termination, the unfiltered water contained 3.7 dpm/ml of ^{60}Co and 79.3 dpm/ml of ^{137}Cs ; the filtered water contained 0.5 dpm/ml of ^{60}Co and 1.13 dpm/ml of ^{137}Cs . Sediment at termination of the experiment contained 2.48×10^3 dpm/g dry wt of ^{60}Co and 4.79 $\times 10^4$ dpm/g dry wt of ^{137}Cs .

The fish increased in weight from an average of 7.0 g to 297.8 g. The whole body activity of the fish averaged 3.05 dpm/g for ^{60}Co and 37.8 dpm/g for ^{137}Cs . Analysis of the various organs showed that the spleen contained the most activity, 9.5 dpm/g of ^{60}Co and 53.0 dpm of ^{137}Cs . The muscle tissue contained 0.5 dpm of ^{60}Co and 9.7 dpm of ^{137}Cs .

Approximately 9% of the body burden of the fish was in the stomach and gut contents. Although the fish were fed nonradioactive food pellets, significant quantities of sediment were ingested. The ratio of ^{137}Cs to ^{60}Co in the sediment was 19.3, while in the stomach contents the ratio changed to 27.3, indicating a differential absorption of Co and Cs. In the different organs the $^{137}\text{Cs}/^{60}\text{Co}$ ratio ranged from 1.0 in the kidneys to 19.3 in the muscle tissue.

The concentration factor (dpm/g fish divided by dpm/ml water) was 30.3 and 0.43 for ^{137}Cs and 6.1 and 0.8 for ^{60}Co in filtered and unfiltered water, respectively. Approximately 0.06% of the ^{137}Cs activity and 0.12% of the ^{60}Co activity in a gram of sediment were transferred to a gram of fish; thus, ^{60}Co in sediments was more available to fish than ^{137}Cs . The sediments provided a chronic source of radioactivity which could be obtained directly from the water or absorbed from ingested sediments.

Dose Rate and the Frequency of Abnormal Embryos in Gambusia

The frequency of abnormal embryos in the broods of the mosquito fish, Gambusia affinis, has been used as a parameter for measuring the effects of chronic low-level radiation on fish populations in White Oak Lake. In June 1977, Gambusia from a nonirradiated control population were introduced into a decommissioned waste disposal pond to examine the effects of higher dose rates on the frequency of abnormal embryos. To ascertain the external dose to aquatic biota, $\text{CaSO}_4:\text{Dy}$ thermoluminescence dosimeters were used to measure the dose rate.

The pond formerly received liquid effluents from a low-level treatment plant, but it now serves as an experimental site for ecological transport studies for transuranic elements. The pond, which is 67 x 67 m and 1 m in depth, contains $^{239,240}\text{Pu}$, ^{90}Sr , and ^{137}Cs in the bottom sediments. Dosimeters placed at ten different locations and exposed

for twenty days had an average dose rate of 0.10 - 0.05 rad/day at the surface of the water, 1.08 - 0.44 rad/day at mid-depth, and 3.15 - 1.41 rad/day at the surface of the sediments. Thus, external exposure rates to the aquatic organisms in the pond could range from 37 to 1150 rad/year.

An analysis of 969 embryos from the control population showed that 1.5% of embryos were abnormal. In July 1978, an analysis of 399 *Gambusia* embryos from the waste pond showed that 2.3% of the embryos were abnormal. Although the frequency of abnormal embryos increased in the *Gambusia* population from the waste pond, the increase was not statistically significant. At the dose rate measured in the waste pond, it is anticipated that recessive lethal and deleterious genes will accumulate in the *Gambusia* population and that the frequency of abnormal embryos will eventually increase significantly.

Distribution and Concentration of Tritium in White Oak Lake

The distribution and concentration of tritium was determined for water, sediments, and aquatic biota in White Oak Lake. White Oak Lake is representative of an aquatic environment that receives quantities of tritium significantly greater than would be released from nuclear power plants. Within the lake the concentration of tritium varies considerably. Samples from twelve different locations showed that after a heavy rain-fall concentrations of tritium throughout the lake were uniform, whereas during low-flow periods the concentrations varied from 40 to 600 pCi/ml.

Sediment water removed by freeze-drying contained 450 pCi/ml, which was less than the 650 pCi/ml determined for the overlying lake water. This difference in concentrations was attributed to the changes in tritium concentrations in the lake water and the rate of exchange between sediment water and overlying water. The bound tritium in the sediment obtained by oxidizing the dried sediments contained 17.0 pCi/ml. Approximately 11% of the sediment in White Oak Lake was organic material. Assuming that all tritium in the dried sediment is organically bound and is composed of decaying plant and animal life, the concentration of sediment-bound tritium is within the range of the tritium concentrations observed in the tissue-bound tritium of plants and animals in White Oak Lake.

Aquatic biota in White Oak Lake were analyzed for tissue-water tritium (extracellular water removed by freeze-drying) and tissue-bound tritium (tritium remaining in the dried tissue). The ratio of tissue-water tritium to lake-water tritium for most aquatic plants, algae, invertebrates, and fish ranged from 0.80 to 1.02. The exchange of tissue-water tritium with ambient water is very rapid for most aquatic biota. The tissue-water tritium of the mosquito fish, *Gambusia affinis*, placed in tritiated water (0.1 μ Ci/ml), reached 73% of the concentration of the ambient water in 30 min. *Gambusia* removed from White Oak Lake and placed in nontritiated water lost 50% of their body burden of tissue-water tritium in 14 min. This rapid uptake and elimination of tritium permits the tissue-water tritium in *Gambusia* to be at near equilibrium conditions with White Oak Lake water despite the daily fluctuations of tritium concentration.

The accumulation of tritium in the organic constituents of the biota from White Oak Lake is indicated by the ratio of the specific activity of tritium in the freeze-dried tissue to that in lake water. The ratio was determined for several species of aquatic biota in White Oak Lake (Table 7.3). The highest ratios were found for the larger fish species, but never exceed 1.0. It appears that tissue-bound tritium in aquatic organisms from White Oak Lake does not reach equilibrium with the lake water because of the short biological half-life of tritium and the fluctuation of tritium concentrations.

Stable Element Concentrations in Fish

Limited information is available on stable element concentrations in freshwater fish for some of the radionuclides that may be produced by neutron activation in the blanket material of fusion reactors. Five species of fish, *Micropterus salmoides*, *Pomoxis annularis*, *Lepomis macrochirus*, *Dorosoma cepedianum*, and *Cyprinus carpio*, were

Table 1.1. Concentration ratios of tissue-water strontium and tissue-bound strontium in biota from White Oak Lake.

Biota	Tissue water	Bound water
Algae		
<i>Scenedesmus</i>	1.020	1.347
Cattail		
<i>Najas</i>	0.918	1.281
Worms		
<i>Hydra</i>	1.057	1.636
Bluegill		
<i>Lepomis macrochirus</i>	1.116	1.685
Largemouth bass		
<i>Morone chrysops</i>	1.123	1.676

Concentration ratios are defined as the ratio of strontium specific activity in tissue water and in dry tissue (i.e., bound water) divided by that of lake water.

collected from Walker Branch Embayment on the Tennessee Valley Authority's Melton Hill Dam Reservoir and were analyzed for stable element concentrations. Muscle tissue was freeze-dried and concentrations were determined by neutron activation analysis for Nb, V, Mg, Mn, and Al.

Concentrations of Nb and V were ≤ 0.4 and 1.0 ppm, respectively, for all species of fish tested. Magnesium had the highest concentration of all elements tested and had an average concentration of 1399 ± 84 ppm for all species tested. Aluminum averaged 10.75 ± 2.46 ppm in all five species. The highest concentrations of Mn were detected in *D. cepedianum*, 13 ppm, but manganese was below detection limits in *M. salmoides*, *L. macrochirus*, and *P. annularis*. Concentrations of all elements appeared to be independent of size and age in *M. salmoides* and *L. macrochirus*.

Additional sampling from different aquatic environments and more sensitive analytical techniques are needed to establish stable element concentrations in fish for such elements as Nb and V.

Toxicant Formation in Condenser Cooling Systems

Studies of toxicants formed during operation of condenser cooling systems included a comprehensive literature review to evaluate the potential of ozone as a power plant biocide and research oriented toward determination of optimum chlorination levels. Both types of studies were coordinated through the Environmental Sciences Division but were multidisciplinary in scope, involving staff from the Environmental Sciences, Chemistry Technology, and Information Divisions.

Ozone Studies

Ozone appears to have potential for use as a power plant biocide, but the paucity of data regarding required application levels, identification of reaction products, and environmental and health effects of these products suggest a need for a limited research program to provide information for a more definitive evaluation. Full-scale demonstrations of the minimum levels of ozone required and of the solution of the practical aspects of application have not been performed, although it seems likely that these problems can be solved. By analogy with known products in ozonated waste waters and from theoretical considerations, the most common compounds expected in power plant

effluents are residual ozone, aldehydes, ketones, and carboxylic acid molecules. Most aldehydes, ketones, and carboxylic acids are moderately low in toxicity and probably would not represent an environmental problem at the concentrations likely to be released. However, residual ozone is toxic to some aquatic organisms at concentrations as low as several hundredths of a part per million for short exposure durations, and studies in aqueous media have indicated the possibility of formation of ozonated organics of potential environmental or public health concern. These reaction products include epoxides, peroxides, and stable hydroperoxides. Other studies have indicated the presence of hydroxylated and oxidized PAHs, amine oxides, and nitrosoamines. Potential for an even broader variety of products is indicated from the results of laboratory studies and the known complexity of compounds found in natural waters. Some compounds of the above generic types have been found to be highly toxic, mutagenic, or carcinogenic. Existing data thus point to a potential for environmental effects of ozonated effluents, but the extent to which that potential will be realized under conditions of ozone application at power plants is not possible to estimate with assurance. The expectation that this potential is relatively low, however, indicates the value of research designed to provide the required information.

Chlorine Studies

Determination of optimum chlorination at power plants is dependent on information regarding minimum chlorine levels required to prevent fouling and on identification and quantification of chlorine products in power plant effluents and of the environmental effects of these products. We have carried out studies in each of these areas of concern.

Chlorine minimization. Efforts have been directed toward use of existing power plant operating data to predict chlorine levels required to control microfouling and toward studies of macrofouling organisms. Data from 25 power plants in the Southeast have been obtained through the functioning of a chlorine task force formed last year. At all but one of the plants, chlorine is used to control microfouling, and five of these plants (plus six other plants contacted by phone) have macrofouling problems with either *Corbicula* or *Modiolus*. A lack of water quality data hinders use of this information for predicting minimum levels for microfouling control, but this information has indicated the need for specific studies of the two primary macrofouling organisms. Our studies of *Modiolus* and *Corbicula* have followed from this need. Preliminary discussions with Georgia Power personnel indicated the potential for generic applicability of the results of a joint endeavor designed to solve the macrofouling problem (*Modiolus*) causing condenser tube leaks at one of their plants. We have forwarded to them a three-phase proposal: (1) determination of the source of the mussels which cause the fouling problem, (2) laboratory determination of the chlorine dose effective in killing mussels under a variety of water quality conditions, and (3) field verification of the laboratory results. Georgia Power is currently attempting to solve their problems by modifying plant operation, but, if this fails, plans for implementation of the joint project will be investigated further.

Studies of the feasibility of simultaneous exposure to increased temperature and chlorine for short periods to control *Corbicula* fouling have yielded mixed conclusions. Preliminary studies of clams acclimated to 20°C indicated that the simultaneous exposure could be of value. Subsequent studies of clams acclimated to 10 and 25°C have not confirmed the earlier results. However, differences in sizes of clams used in the tests (due to availability) may have confounded the comparison. These studies will be continued to determine the source of the different responses.

Identification and quantification of chlorinated products. Progress has included development of an improved high pressure liquid chromatography (HPLC) methodology which permits the chromatographic separation of organic constituents in water concentrates in approximately one-third to one-half the former time. The improved method uses a different resin pretreatment process and shorter columns to accomplish the separation at lower column pressures and greater eluate flow rates than in the former HPLC method with equal or better resolution. An analytical run now requires 8 hr (formerly 24 hr) and a preparative-scale separation now requires 24 hr (formerly approximately 72 hr). This development should permit more efficient utilization of HPLC instrumentation and manpower.

Toxicity. Studies of chlorinated organics identified in sewage and power plant effluents again comprised the major thrust of the toxicity studies. Chronic exposure tests (using *Daphnia magna*) of three 17-compound synthetic mixtures of chlorinated organics (in the same relative proportions as they occur in two power plants and one sewage effluent) were carried out in decade concentration steps from 0.1 to 10 mg/liter. The only significant negative effect observed was a slight (25%) reduction in the reproductive rate (mortality adjusted) at the 10 mg/liter concentration of the synthetic secondary sewage effluent. Concentrations two orders of magnitude greater than those found in actual effluents produced no detectable detrimental effects on either life span or reproduction in the *Daphnia magna* test system.

Acute toxicity of four trihalomethanes identified in power plant cooling waters was assessed using the carp (*Cyprinus carpio*) embryo test system. LC₅₀ values calculated using initial concentrations are given in Table 7.4. However, gas chromatographic analysis of the decay curves of each of the trihalomethanes under similar conditions, but without carp eggs, indicated that actual concentrations during the 8-hr period between changes would be somewhat lower. LC₅₀ values were recalculated based on transformation of each of the applied concentrations to its 8-hr average concentration (Table 7.4). Among the four trihalomethanes tested, dibromochloromethane was the most toxic. All the LC₅₀ values of the four trihalomethanes were 1000 times higher than the concentrations in the effluents, and thus these chlorinated organics should have no detrimental effect on the hatching success of the eggs in the receiving water.

Table 7.4. The LC₅₀ of trihalomethanes to the embryos of carp, *Cyprinus carpio*, based on the initial toxicant concentration and the average concentration during 8-hr periods (in ppm).

Chemicals	Initial concentration		Average concentration	
	LC ₅₀	95% Confidence limits	LC ₅₀	95% Confidence limits
Chloroform	160	157-165	95	94-96
Bromodichloromethane	119	111-137	67	64-72
Dibromochloromethane	53	52-54	35	24-45
Bromoform	76	74-79	59	52-62

Free chlorine consists of two forms (HOCl, OCl⁻), which are known to vary in bactericidal effect. At pH = 6 approximately 95% of the free chlorine is HOCl, but at pH = 8.5 approximately 95% of the free chlorine is OCl⁻, due to effects of pH on the dissociation of HOCl. Chlorine was about 2.5 times more toxic to mosquito fish (*Gambusia affinis*) at pH 6.0 than at pH 8.5 when exposure was for one hour in a flow-through system. Exchange experiments (e.g., when fish acclimated at pH 8.5 were tested at 6.0) indicated that pH had a direct effect on toxicity which will require further elucidation. These results indicate that HOCl is more toxic than OCl⁻. This difference, if general, could be factored into future regulations regarding chlorine levels in power plant effluents.

Miscellaneous. The Second Conference on Water Chlorination was held at Gatlinburg on October 31 - November 4, 1977. Approximately 325 scientists attended. Sixty-seven papers were presented and much significant discussion occurred during the conference. The proceedings have been published.

The Regional Administrator of U.S.E.P.A. (Region V) has recommended that thresholds derived at ORNL and published in Mattice and Zittel (1976) be instituted as water quality criteria for that region.

Environmental Monitoring of Aquatic Systems

The Aquatic Ecology Section played an important role in evaluating existing effluent and water quality monitoring programs and in recommending environmental monitoring programs at three DOE facilities at Oak Ridge [Y-12 Plant, K-25 Plant (Gaseous Diffusion Plant), and X-10 Plant (Oak Ridge National Laboratory)]. During the past year, the section completed an expanded role in the area of biological monitoring of the aquatic environs of the K-25. Comprehensive biological characterization of the aquatic and terrestrial systems was completed and a report prepared. An environmental impact statement is in preparation based on the monitoring data collected.

A similar monitoring program is being developed for the aquatic environs at X-10, and it is anticipated that sample collection will begin in February 1979. Staff of the Aquatic Ecology Section will participate with other ORNL staff in sample collection, processing, and data compilation and analysis for the purpose of preparing an environmental impact statement on X-10.

Conferences

An international symposium "Environmental Effects of Hydraulic Engineering Works" was held in Knoxville, Tennessee, September 12-14, 1978. Over 200 aquatic ecologists, limnologists, engineers, and others participated in the symposium which was jointly sponsored by the International Association for Hydraulic Research, the Tennessee Valley Authority, the University of Tennessee, and Oak Ridge National Laboratory.

The basic purpose was to bring together interdisciplinary groups to discuss problems and solutions associated with the environmental effects of building and operating hydraulic engineering structures. Topics included long-run and short-run effects of hydraulic structures and of their operation, structural measures in aquatic ecology, hydraulic and mathematical modeling of ecological parameters, field research and evaluation, and decision analysis.

Proposal Development

The Aquatic Ecology Section in FY 1978 developed a proposal and obtained funding in FY 1979 for a multiyear research effort to address environmental issues surrounding potential large-scale development of small hydroelectric generation facilities. The Department of Energy under the Assistant Secretary for Resource Applications is developing a program to encourage the redevelopment of existing small dams and the construction of new small dams for hydroelectric generation. Small dams are defined as less than 20-m head and 15-MWe electrical potential. Research in FY 1979 will center on an evaluation of four special topics already identified as potential environmental constraints to small hydroelectric development: (1) fish passage facilities; (2) mobilization of deleterious substances due to dredging; (3) turbine-induced mortality of aquatic biota; and (4) water level fluctuations and associated physical, chemical, and biological effects.

In FY 1980 and succeeding years, research activity will be directed at small hydroelectric demonstration sites around the country in an effort to specifically evaluate environmental issues through field research. The overall goal of environmental research efforts for small hydroelectric technology is to provide substantive guidance to potential small hydroelectric developers to ensure the environmentally safe development of this emerging energy technology.

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8. EARTH SCIENCES

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Introduction

Most of the contributions by members of the Earth Sciences Section are included in the different programs. The waste management activities reported last year in this section are reported in the Burial Ground Technology Program. Staff contributions resulting from consolidation of the nuclear activities are included in the Nuclear Program. Activities of staff in areas of support to other division programs, of sufficient generic nature to be applicable to several programs or in stages of development which may lead to eventual program status, are reported in this section.

The stored solids study is directed towards the potential land disposal of wastes generated by the coal industry. This study emphasizes developing an understanding of the characteristics of coal-derived wastes and the resultant interactions of the leachates with earthen materials. In addition to this effort, a summary of a more detailed

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study of the chemical form of one of the leachate element; namely arsenic, is included. The results of this study emphasize the need to identify the species form of arsenic in the waste since biological toxicity is influenced by the oxidation states.

The biological denitrification effort, which was initiated in this division, has reached demonstration scale for actual high nitrate wastes at a sister nuclear facility. The effort described herein is a summary of the recommended simple and rapid assay technique to estimate biological activity in a denitrification reactor.

A short summary of the mathematical models developed during the year is also included in this section. These models have been used in impact analyses of nuclear and coal technologies both to study potential effects of plant operations and as predictive formulations to evaluate potential consequences. Finally, the results of determining distribution coefficients (K_d) by the standard batch mode and by a dynamic chromatographic technique are reported. Both methods were found to yield approximately the same results when studied under equilibrium conditions; the value of the latter method would be in situations where adsorption occurs under nonequilibrium conditions.

Stored Solids Study

The ultimate objective of this study is to generate information that can be used for the engineering design of landfills for any pilot, demonstration, or commercial coal conversion facility regardless of geographic location. Thus, in addition to characterizing the leachates resulting from coal conversion solid wastes, representative soils from demonstration plant sites are being examined for their potential to attenuate trace element movement. Most of the effort to date has focused on characterizing the wastes; soil characterization will depend on the selection of sites for the different processes.

Six waste types from pilot plants using processes that are demonstration candidates have been selected for study. These are SRC-I, SRC-II, COGAS, SLAGGING LURGI, HYGAS, and BIGAS. Quantities of these wastes, and their feed coal, are available at ORNL with the exception of SRC-I, which has been requested. For this report the results and future experimental plan for one of these wastes (Plant C) will be discussed. (Plant data have been coded because results are preliminary and wastes from pilot plants may not be entirely representative of those from demonstration-scale plants.) Similar experimental programs (with minor variations, depending on the laboratory leaching results) are planned for each of the other wastes. Data collected to date on the other waste types have been reported in greater detail in ORNL Fossil Energy Program Quarterly Reports (McNeese 1978a, 1978b, and 1978c).

Laboratory Characterization (Ash/Slags and Feed Coals)

Both the solid waste and the corresponding feed coal have been subjected to various laboratory analyses to determine their physical/chemical characteristics. Feed coals have been characterized to enable evaluation of the trace elements present in the conversion ash/slugs.

Laboratory Leaching Studies

A number of different leaching tests are conducted for each of the solid waste types because no single test will provide all of the parameters necessary to design an environmentally secure landfill. The types of leaching tests performed are: (1) EPA-toxicant extraction procedure (TEP), (2) short-term batch, (3) equilibrium (long-term) batch, and (4) column.

At the present time, the EPA is proposing a toxicant extractant procedure (TEP) which will indicate if the solid waste is "hazardous." The TEP is a fixed leaching procedure, using an acetic acid extractant, with the resulting solution subject to further chemical and biological testing. Failure to pass the proposed tests will designate the solid waste as "hazardous," and will require the design of secure land disposal

facilities which must meet stringent environmental standards. At this time, the details of the toxicant extraction procedure and the requirements for land disposal have not been published in final form in the "Federal Register." The proposed EPA-TEP leaching protocol will be used on each waste to determine if the waste may be classified as "hazardous" or "nonhazardous." Data on trace elements in the extractant (chemical testing) will indicate if the waste is "hazardous" based on this criterion alone. Further biological testing may not be required if the waste is determined to be "hazardous."

Batch leaching (both long- and short-term), using distilled water and solutions having various pH values, is being run on all plant wastes. Batch leaching using distilled water, 0.1 N HCl, and 0.1 N NH_4OH for time periods of 4 hr produced the results in Table 8.1 for Plant C waste. It can be seen that leaching under acid conditions (0.1 N HCl) produces the maximum concentrations of trace elements in the leachate. Leaching with distilled water (test is somewhat similar to proposed ASTM solid waste leaching procedure) produces lower trace element concentrations, with alkaline leaching (0.1 N NH_4OH) producing the lowest values for leachate trace elements in many cases. Leachings with 0.1 N HCl and 0.1 N NH_4OH , although not representative of conditions found in landfills, do give upper and lower limits for trace element dissolution. Long-term batch leaching with distilled water gives some indication of the maximum concentrations of trace elements that can be expected to be leached from the solid waste at various contact times. Long-term (equilibrium) leaching using distilled water has been conducted for periods up to 90 days. These studies show that long-term leaching produces

Table 8.1. Batch leaching studies of Plant C waste with varying extracting solutions

Element	Extracting solution		
	$\text{H}_2\text{O}^{\text{a},\text{b}}$ (ppm)	0.1 N HCl ^c (ppm)	0.1 N $\text{NH}_4\text{OH}^{\text{c}}$ (ppm)
Aluminum	1.2	53	4.6
Antimony	< 0.001	< 0.005	< 0.001
Arsenic	0.0015	0.032	0.004
Barium	< 1	< 5	< 1
Cadmium	< 0.05	< 0.05	
Calcium	19	278	7.6
Cesium	< 0.005	< 0.03	< 0.005
Chromium	< 0.2	< 0.3	< 0.2
Cobalt	0.008	0.4	< 0.002
Copper	0.05	< 0.05	< 1
Iron	< 4	625	< 3
Lead	< 0.001	< 0.06	
Magnesium	4.2	84	< 10
Manganese	< 0.01	11.7	0.006
Mercury	< 0.01	< 0.02	< 0.01
Molybdenum	0.005	< 0.6	0.006
Nickel	< 0.01	5.6	
Potassium	< 10	25	5.8
Rubidium	< 0.2	< 1	< 0.2
Selenium	< 0.02	< 0.05	< 0.01
Silver	< 0.03	< 0.1	< 0.03
Sodium	4.5	7.2	3.6
Strontium	< 1	< 10	< 1
Thorium (ppm)	9	< 10	< 2
Titanium	< 1	< 4	< 1
Uranium	< 0.01	< 0.02	< 0.01
Zinc	0.008	0.036	0.028
Zr	< 0.2	0.5	< 0.2

^a pH = 8.1; E.C. = 90.42 $\mu\text{mhos/cm}$.

^b Results after double extraction with solid waste solution ratio of 1:12.

^c Results after double extraction with solid waste solution ratio of 1:10.

an increase in the concentration of major elements such silicon, aluminum, calcium, and iron, but that the leaching system has not reached equilibrium after 90 days. Concentrations of trace elements in the leachate, however, do not show consistent trends with respect to increasing leaching time.

Column leaching gives some indication of what can be expected in dynamic systems where water is continually passing through the waste material. Preliminary results from laboratory column leaching of Plant C waste are shown in Table 8.2. As shown, successive treatments produce leachates having lower trace element concentrations.

Table 8.2. Column leachate analysis of Plant C waste with deionized water as the leaching agent

Element	Concentration in each 100 cm ³ of eluant fraction (ppm)			
	No. 1 ^a	No. 2	No. 3	No. 4 ^b
Aluminum	1.3	1.6	1.3	1.3
Antimony	0.003	< 0.003	< 0.003	< 0.003
Arsenic	0.002	0.002	< 0.002	< 0.002
Barium	< 1	< 1	< 1	< 1
Calcium	16.4	5.6	4.0	3.4
Cesium	< 0.003	< 0.003	< 0.003	< 0.003
Chromium	< 0.2	< 0.2	< 0.2	< 0.2
Cobalt	< 0.002	< 0.002	0.005	< 0.002
Copper	0.01	< 1	< 1	< 1
Iron	< 3	< 3	< 3	< 3
Magnesium	3.4	< 3	< 3	< 3.0
Manganese	< 0.02	< 0.02	< 0.02	< 0.02
Mercury	< 0.01	< 0.01	< 0.01	< 0.01
Molybdenum	< 0.05	< 0.05	0.05	< 0.05
Potassium	4	0.5	0.36	0.5
Rubidium	< 1	< 1	< 1	< 1
Selenium	0.01	< 0.01	< 0.01	< 0.01
Silver	< 0.03	< 0.03	< 0.03	< 0.03
Sodium	1.0	0.1	0.16	0.20
Strontium	< 1	< 1	< 1	< 1
Thorium (ppb)	< 2	< 2	< 2	< 2
Titanium	< 1	< 1	< 1	< 1
Uranium	< 0.01	< 0.01	< 0.01	< 0.01
Vanadium	0.016	0.005	0.004	0.004
Zinc	0.1	< 0.2	< 0.2	< 0.2

^apH = 9.0; E.C. = 106.9 μ mhos/cm.

^bpH = 8.4; E.C. = 21.2 μ mhos/cm.

Field-Scale Leaching Studies

Using the laboratory leaching studies and the demonstration-site soil properties as a background, a program employing larger scale leaching columns has been undertaken. A series of column tests, using Plant C ash/slag and local demonstration plant site soils, uses modified 55-gal drum leaching columns. In this array, two instrumented columns are used for periodic analysis of trace element movement and for soil and ash moisture content; in addition, four columns will be loaded with similar amounts of ash/soil, and will be taken out of service at predetermined intervals (e.g., every four months). These will be cored and the ash and soil analyzed for trace element migration. All six columns will have the same cycle and amount of water application. A one-dimensional transport model has been utilized to estimate breakthrough times for major elements in the ash/slag and trace element movement in the soil layer. This simple model will be verified in the six-ash/soil-column array and will be modified as needed to predict trace element movement.

Biological Denitrification

Several analytical measurements were compared for assessing biological activity in batch-type and continuous flow-stirred nitrate bioreactors. Biological activity was examined under conditions of optimum nitrate removal as well as perturbations of nutrient depletion and inhibition of denitrification by the addition of soluble nickel. The analytical assays performed on the bioreactor fluid were: mixed liquor volatile suspended solids (MLVSS), ATP and total adenosine phosphates (bioluminescence methodology), ATP + ADP (kinetic photometric methodology), and dehydrogenase activity using the tetrazolium salt, INT [2-(p-iodophenyl)-3-(p-nitrophenyl)-5-phenyltetrazolium chloride]. The tetrazolium salt (INT) is an organic cation capable of penetrating the microbial cell wall and being biologically reduced to produce a visible color by the flavoprotein intermediates of an actively metabolizing microorganism. The reduced tetrazolium salt, called formazan, can be extracted from the cell and quantitatively determined by measuring absorbance at 490 nm. The above measurements were compared to the specific activity of interest (nitrate removal) and to each other with regard to accuracy and ease of performance.

The data have indicated that either ATP or dehydrogenase analyses could be used to estimate biological activity in a denitrification bioreactor. The aerobic bioreduction of INT is considered to be preferable for industrial use because (1) the reaction can be monitored with use of a simple visible light photometer, (2) precise timing of the incubation mixture is not required, and (3) total assay time is much shorter (less than 20 min) than that required for measurement of either ATP or MLVSS. If the microorganisms are attached to particulate material (i.e., coal) as in the case of fluidized-bed bioreactors, extraction of the ATP becomes quite difficult and calculation of suspended solids requires even more time (about three days). Formazan, on the other hand, can be available for analysis in 2.5 hr. Additionally, for more accurate information on the size and physiological state of the cells suspended in the reactor fluid, formazan production measured spectrophotometrically can be coupled with a direct counting method utilizing formazan labeling (DeSha and Dozier 1978) to estimate the average dehydrogenase activity per cell. Due to its simple rapid assay and its excellent correspondence with more tedious estimates of biological activity, the dehydrogenase procedure using INT may be preferred in many industrial applications.

Modeling

Air-Water Interface Model

One of the important hydrological components in the water-budget computation for a watershed is evaporation and heat transfer over water surfaces. The computation of evaporation rate has been performed traditionally with empirical formulae. In order to have generic application, theoretical formulae for predicting the evaporation and heat transfer across air-water interfaces have been obtained and published (Yeh 1978). The new formulae were derived, based on the theory of turbulent diffusion in the lower atmosphere. Results encompass almost all existing empirical formulae as special cases. To facilitate the computations for potential users, the formulae were presented in graphical forms for a wide range of meteorological conditions. They can easily be incorporated in the computation of water budget in the general hydrologic transport model.

Storm Surge Model

Storm-induced flooding along the eastern coastal line and the Gulf of Mexico has caused extensive damage to the properties and lives of residents on the coastal areas. Earth scientists must be concerned with the prediction of water levels induced by storms or hurricanes, in order to assess the possibility of floods over the low-lying land adjacent to the coastal lines. Existing storm surge models are not adequate for analyzing the water level over the flat coastal areas (Reid and Bodine 1968; Jelesnianski 1972, 1974). Therefore, four storm surge computational models have been developed and comparisons with field data have been made (Yeh, in press). Two of the four models have

the special feature of treating moving boundaries. The advancing and retreating of the surge wave over the low-lying dry land and the propagation of the water-land interfaces, are dealt with on the basis of physical and mathematical principles. The complete set of governing equations is applied to water regime, as well as to the dry land as soon as it is flooded. All four models yield favorable comparisons with the field data though the moving boundary models give closer agreement. The predictions from storm surge analyses are the prerequisite for the study of storm-induced beach erosion.

Salt-Dome Model

Salt sedimentary rocks have been studied as alternatives for the deep repository site of high-level radioactive wastes. In investigating the salt-dome geological structures along the Gulf of Mexico, it has been found that water flows to the ground surface through the fracture of caprock overlying the salt-domes. To assess the feasibility of the salt-dome as a repository site, the ground-water flow in and around the salt-dome must be investigated. For the preliminary assessment, simple analytical approach has to be used. Thus, primitive formulae for computing the flow field in the membrane surrounding the salt-dome and for estimating the flow rate to the ground surface have been derived (Yeh, unpublished data). The application to a hypothetical salt-dome was made to establish the possible upper bound of flow rate to the ground surface.

Leachate Model

To study the environmental impact on the coal development, the pollution potential on the groundwater has to be predicted. This depends on, to a large extent, the leaching of coal waste and the retardation by the soil. Laboratory experiments must be performed to characterize the coal wastes. For this purpose, computational methods and experimental procedures for the laboratory test of desorption and absorption of leachates and soil have been established. The method and procedure are intended for the evaluation of lysimeter design and experiments described in the Stored Solids Study.

Chemical Speciation in Coal Ash Leachate

The chemical form, or speciation, of trace elements in coal ash leachate is largely unknown, but is of considerable importance in understanding the chemistry of ash leachate, in predicting the nature of leachate interaction with environmental media, and in designing bioassays directed at identifying the important constituents of ash leachate responsible for adverse biological effects. The chemical form of trace elements in coal ash leachate can generally only be inferred from thermodynamic considerations presuming chemical equilibrium. Unfortunately, most aqueous systems in the environment are probably not at chemical equilibrium; thus, speciation can only be determined with certainty by empirical methods. Such empirical methods must be highly sensitive and not subject to interferences by the often complex chemical matrix of ash leachate. A few methods, such as those for the determination of oxidation state of inorganic arsenic forms in water (Braman et al. 1972), meet these requirements. Surprisingly, there has been little or no application of empirical methods to coal ash leachate.

Exploratory studies supported by the Electric Power Research Institute (EPRI) have been performed in the Earth Sciences Section to determine the behavior and chemical form of arsenic in natural leachate from several coal ashes. These studies illustrate the utility of the empirical approach to leachate behavior and speciation in deciding when and where, in an ash disposal system, arsenic or some other toxin may constitute an environmental problem.

Detailed characterization of arsenic concentrations and speciation at selected locations within a coal ash disposal system located on the Oak Ridge Reservation revealed that total arsenic in aqueous samples from all sites varied by a factor of 10^3 , lowest ($\sim 10 \mu\text{g/liter}$) in lysimeter samples from the unsaturated zone of an older filled ash basin and highest ($\sim 1500 \mu\text{g/liter}$) in well water from the base of the ash deposit. The fraction of the arsenic in the trivalent state likewise varied considerably, amounting

to a significant fraction (10 to 100%) of the total arsenic in solution in all samples except those from the pond outflow. Arsenic in subsurface water was generally trivalent. The relative proportions of arsenic in the trivalent and pentavalent forms were found to shift significantly from predominance of trivalent in pond inflow towards predominance of the pentavalent form in the outflow.

Characterization of arsenic concentration and speciation in ash pond effluents from 11 other large (240-2600 MWe) coal-fired power plants located in the southeastern United States also revealed large variations from plant to plant in both total arsenic and the relative proportion in the trivalent form (Table 8.3). For two plants (A and I), where fresh ash sluice was also collected and filtered, the total arsenic concentrations were much higher than those in the respective pond effluents, indicating the expected dilution and/or removal of arsenic from solution during ponding. For Plant A, the trivalent fraction decreased from 85 to 6% between sluice and effluent, paralleling our observations in the Oak Ridge ash disposal system of a decrease as a result of ponding in the fraction which is trivalent. For Plant I, no such shift in the trivalent fraction was observed, although total arsenic decreased by a factor of ~ 5.

Changes in arsenic oxidation state as a function of time in fresh coal ash slurries prepared in the laboratory, using dry hopper ashes and raw sluice water from several coal-fired power plants, are partially summarized in Table 8.4. These results, obtained under reasonably controlled and standardized laboratory conditions, confirmed that the wide variability observed in actual ash pond effluents was not attributable simply to variability in either the ash/water ratio or ash-water contact time. The results also indicated that the fraction of the total arsenic in the leachate occurring as the trivalent species does not always decrease with increasing leaching time as had been hypothesized. The lack of a consistent relationship between pH, Eh, and the % As^{+3} , even after 72 hr of leaching, suggests that equilibrium calculations of the distribution of arsenic between oxidation states based on total arsenic concentration, pH, and Eh would not accurately represent the actual distribution.

The major conclusions of this exploratory work were that the factors affecting arsenic speciation in coal ash leachate are complex, and generic conclusions about chemical speciation in ash leachate must be supported by studies of a variety of coal ashes and by empirical, as well as theoretical, determinations of speciation.

Channel Chromatographic K_d 's vs Batch Equilibrium K_d 's

The methods used to describe the sorption properties of radionuclides to geologic media vary from 'batch' equilibrium studies to saturated and unsaturated flow through columns. In all methods the sorption process is generally characterized in terms of a distribution coefficient (K_d in ml/g). In a theoretical sense, K_d values represent 'equilibrium conditions' based on reversible ionic exchange reactions between the radionuclide and the geologic media. The most convenient way to measure this value is to use the conventional suspension 'batch' method where concentrations of the radionuclide are monitored over time in the liquid and solid phases. These K_d values are then used in transport models to predict the movement of radionuclides relative to the movement of water. There are cases where use of such a K_d value in transport models may not be valid. Such cases possibly include conditions of unsaturated flow, and conditions where movement of the water through the porous media is too rapid to attain an equilibrium radionuclide concentration between the liquid and solid phases. These conditions are likely to prevail on wetting of channel chromatographs previously described by Francis et al. (1977). The purpose of this work is to compare K_d and selectivity coefficients of two radionuclides (^{85}Sr and ^{63}Ni) determined by the chromatographic technique under conditions of unsaturated flow to those values determined by the 'batch' equilibrium method.

Conasauga shale (dry sieved to less than 500 μm) was layered in a dry powdered form into channel chromatographic plates, using a conventional thin-layer chromatograph spreader. Strips of blotter paper were used to deliver the eluting solution [0.12 M $Ca(NO_3)_2$] containing tracer levels of the radionuclide to the horizontally positioned

Table 8.3. Dissolved arsenic in ash pond effluents, including both fly ash only (FO) and combined fly ash and bottom ash (C)

Plant	Furnace firing method	Pond type	pH	Total As ($\mu\text{g/liter}$)	As ³⁺
A	Top	C	7.1	48 ^a	6
B	Cyclone	FO	5.7	1.9	17
C	Front wall	C	9.8	130	5
D	Tangential/rear wall	C	9.6	80	7
E	Opposed	C	9.6	1.4	11
F	Tangential	C	9.8	26	4
G	Tangential	C		38	2
H	Front wall/opposed	C	10.7	7.3	40
I	Tangential	FO	6.3	6.2 ^b	33
J	Front wall	C	9.5	46	5
K	Tangential	C			
L	Front wall	C	7.9	119	4

^aArsenic in fresh ash sludge: Total = 400 $\mu\text{g/liter}$, As³⁺ = 65.

^bArsenic in fresh ash sludge: Total = 27 $\mu\text{g/liter}$, As³⁺ = 24.

Table 8.4. Comparison of arsenic oxidation state in the aqueous phase after 20 min and 10 hr of leaching^a of selected fly ashes with plant raw intake water and air water ratio of 20:1 (liter)

Plant sample code	Ash type ^b	Leaching time = 20 min				Leaching time = 10 hr			
		Total As in ash (μg)	As carbon in ash (μg)	Leachate pH	Leachate As (μg)	Total As in leachate ($\mu\text{g/liter}$)	As ³⁺ in leachate ($\mu\text{g/liter}$)	Leachate pH	Leachate As (μg)
A1	ESP	167	4.4	7.95	130	517	74	8.21	471
C1	ESP	39	4.6	10.2	33	167	4.7	8.21	471
C4	ESP	43	7.7	10.2	34	137	100	8.32	35
F2	ESP	47	1.1	10.1	247	4.5	11.7	10.2	179
F2	ESP	47	1.8	10.1	313	17	4	11.2	247
G2	MA	87	6.6	9.56	365	237	1.4	11.25	217
H2	ESP	75	3.7	11.4	293	16	1.3	11.7	364
I2	MA	47	3.7	8.97	443	37	17	11.23	221
I3	ESP	513	1.4	8.58	575	700	22	11.3	572
I2	MA	54	1.3	11.4	217	37	4	11.6	331
I3	ESP	217	1.7	11.5	237	17	15	11.7	324
J3	ESP	237	1.7	4.31	433	23	150	11.44	471

^a20-hour stirring in open vessel followed by 48-hour settling period.

^bESP = electrostatic precipitator ash; MA = mechanically collected ash.

chromatographic plate. Water movement at 1-cm increments along the chromatograph was determined gravimetrically and radiometrically using HTO-labeled solutions.

To determine K_d values or the selectivity coefficients by the chromatographic procedure, the profiles of the water, the dominant competing ion [in this case Ca from the 0.1 M $\text{Ca}(\text{NO}_3)_2$ eluting solution], and the radionuclide (^{63}Ni or ^{85}Sr at concentrations less than 10^{-8} M in the eluting solution) were determined at 1-cm increments along the chromatograph.

The movement of water and the transporting cation were normalized among channels by measuring the movement of the water-front (X_f) as a function of time (t^2) and using the resulting coefficients of the regression equation ($S_f = A + Bt$) in a Boltzman

transformation $\lambda = X - A/Bt^{1/2}$, where X is the distance along the chromatograph. In this manner, experimental data representing the concentration of the dominant cation (Ca), water, and the radionuclides ^{85}Sr and ^{63}Ni along a number of individual columns can be coalesced together, thus adding replications and more confidence to the resulting analyses.

A coupled-equations model was developed to determine K_d values and selectivity coefficients of radionuclides in unsaturated flow along a chromatographic column. This model consists of three basic components: (1) moisture transport in a partially saturated media, (2) mass transport of the ionic species present in the influent, and (3) exchange between the ionic species in the solution phase and that sorbed to the solid matrix (Reeves et al. 1977).

The coupled-equation model has five variables: the water content, (x,t) ; the Darcy velocity, $v(x,t)$; the dispersivity (α_L); the selectivity coefficient (K_{Ca}^Z) relating the unknown initially sorbed species Z to Ca; and the selectivity coefficient K_{Ca}^Z (Z being either ^{85}Sr or ^{63}Ni in this case). The water content and Darcy velocity were obtained experimentally. The dispersivity (α_L) was determined from independent measurements of HTC along the chromatographic column, and K_{Ca}^Z by 'batch' equilibrium measurements; thus K_d could be calculated from the coupled-equations model. Because the experimental determination of α_L was the largest source of error, the maximum and minimum values of α_L were used to determine the range in K_{Ca}^Z and K_d . These values were compared to those determined by the 'batch' equilibrium method (Table 8.5). The 'batch' method is basically static with solid dispersed within the liquid, whereas the chromatographic method is a dynamic flow system with liquid dispersed within the solid. In spite of these differences in the two methods, the results for K_d 's compare very well. The selectivity coefficients for Sr and Ni may tend to be slightly greater using the chromatographic method.

Table 8.5. Comparison of K_d values and selectivity coefficients obtained by the chromatographic technique and 'batch' equilibrium measurements^a

	Chromatographic		Batch equilibrium	
	K_d	K_{Ca}^Z	K_d	K_{Ca}^Z
^{63}Ni	5.3 - 8.6	6.9 - 18.5	6.5	10.2
^{85}Sr	2.4 - 3.6	1.4 - 3.2	2.4	1.4

^aCalcium concentrations in the solution phase (both cases) were 0.1 meq/cm³.

Special Projects

The Environmental Protection Agency (EPA) is responsible for developing a standardized toxicant extractant procedure (TEP) for use in assessing potential contaminant release from a variety of solid wastes. The section is involved in assisting in this development through evaluation of techniques of mixing, filtration/centrifugation, pH control, and handling of the solid wastes. This activity requires fast response time as requested by EPA; and although not research oriented, it is an important function since it will lead to developing meaningful protocols for assessing environmental hazards.

During the year, ORNL was designated the Associate Lead Laboratory for the National Radioactive Low-Level Waste Burial Program. This assignment increases the scope of the existing program with concurrent increased responsibilities. Members in the section can take a large measure of credit for the assignment.

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9. ENVIRONMENTAL RESOURCES SECTION

R. L. Burgess

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Introduction

The varied activities of the Environmental Resources Section were enhanced by the addition of general programs in regional ecological research and assessment. The Section was involved in highly technical scientific products, critical contributions to many Division programs and projects, ancillary and ad hoc services to other Divisional staff, research activities in and for other ORNL divisions, and routine support of projects, programs, and other sections. Research falls into the major areas of environmental data resources, systems analysis and ecosystem modeling, and regional ecology and environmental assessment.

The Environmental Data Resources Group continued to acquire, computerize, analyze, and display numeric data for many projects. Sponsored primarily by the Department of Energy (DOE) Office of Technology Impacts (OTI), additional funding has come from the DOE Division of Biomedical and Environmental Research, The National Science Foundation Ecosystem Studies Program, and the Environmental Protection Agency.

An air quality and emissions data base, spanning the period 1973-1976, was obtained from EPA and reformatted for DOE assessment purposes. Hourly records for SO_x, NO_x, and particulates are available. Nationwide data bases on ecoregion distribution, potential natural vegetation, breeding bird surveys, wildlife, and endangered species were added to the Geocology Data Base and applied to DOE problems in the RARE II ecological evaluation (DBER) and the production of a "Regional Energy/Environment Data Book for the Southern Region." A survey of mathematical modeling in ecology was published and a working data base for the Fuels from Biomass Management Program was created.

Systems ecology (both DOE- and NSF-supported) continued to explore relationships between ecosystem stability, resilience, and complexity. Using diffusion theory, the problems of assuming spatial homogeneity were circumvented in treating problems of

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biomass dispersal in ecosystems, particularly as these relate to animal migration and seed dispersal in native and managed ecosystems. This research indicates the dependency of stability dynamics on the shape of parameter distributions that vary along definable environmental gradients.

Ecosystem models were used in regional siting of energy facilities. An interactive set of computer codes deals with 7-day, 10-year low flow frequencies as an index of water availability. Also, using a forest growth model, harmful effects of pollutants have been assessed with time scales sufficiently long to integrate competition, growth, and successional dynamics of forest stands with pollutant impact on individual tree species. Finally, simulation models of agricultural crop ecosystems were gathered, analyzed, and assessed for their potential utility in environmental impact analysis of energy technology facilities. In most cases, dose-response relationships, requisite for the use of most of these models, are lacking both for specific pollutants and for important crops.

Regional studies were spearheaded by an ecological evaluation of RARE II (Roadless Area Review and Evaluation) tracts identified by the U.S. Forest Service for consideration for inclusion in the National Wilderness System. Sponsored by the DOE/Division of Biomedical and Environmental Research, a model was constructed that quantitatively ranked each tract by using a set of ecological parameters weighted by their ecological uniqueness at national, regional, ecoregional, and tract scales. The model filters information hierarchically and results in a comprehensive ecological index that can be objectively used to evaluate and assess the wilderness attributes of individual tracts. When coupled with an evaluation of energy resources, the resultant "conflict matrix" provides a tool for trade-off analyses and ultimate decision-making.

The Geocology Data Base, extensively used in the RARE II project (above), was also central to two additional regional projects sponsored by DOE/Office of Technology Impacts. The National Coal Utilization Assessment (NCUA) drew heavily on the data and maps available in the computer to analyze regional environmental and ecological impacts. In addition, the Regional Energy/Environment Data Book provides chapters of information on air, water, land, and biotic resources of the 16-state southern region. This compilation is invaluable for the assessment of policy options embodied in a myriad of energy scenarios spawned by the National Energy Plan (NEP) and the National Energy Strategy Scenario (NESS).

Numeric Data Activities

Numeric Information Handling

This project supports modeling, analysis, and assessment of environmental impacts of energy-related technologies. Three major areas of activity are (a) data base procurement and implementation; (b) data analysis, synthesis, and software development; and (c) computer planning, acquisition, and management.

Data base procurement and implementation. A vital part of the Department of Energy's program in integrated assessment consists of large-scale comparisons of potential areas in the southeast for habitation, industrial development, natural resource allocation, and resultant impacts of energy technology. An air quality and emissions data base has been obtained from the Environmental Protection Agency and modified for the needs of DOE assessment. The data base contains hourly values for sulfur dioxide, nitrogen dioxide, and total suspended particulates. It covers 14 states in the southeast plus Delaware and Maryland. Data from 1973 through 1976 are included. Emission rates and volumes for all available categories of industry were also obtained. To allow rapid cartographic display of these data, a considerable effort was required to procure Federal Information Processing Standard (FIPS) identifiers detailed to the county level. Merging the FIPS identifiers with the data obtained from EPA required several iterations as errant county codes and incomplete data were found and corrected. The resulting data base has been used in the NCUA, and a report announcing the data base, summarizing annual statistics by state, and cartographically displaying the mean values is being reviewed.

A second data base summarizing the meteorological data for the DOE-Oak Ridge Reservation has been filed and catalogued. Four sites, ORNL, the Tower Shielding Facility to the south of ORNL, Walker Branch Watershed east of ORNL, and the Oak Ridge Townsite, have been noted. Parameters included at certain of the sites are air and dew point temperatures, wind velocity and direction, precipitation, solar radiation, and vertical temperature gradients measured at two points on a tower. Some sites have more data than others, with the Oak Ridge Townsite having the most lengthy record (1955-present). A report (in press) summarizes the data available for each site and directs users how and where to obtain specific periods of record. These data were used for DOE-required assessments on transport of releases from the three-plant (Oak Ridge) complex.

Data analysis and synthesis. DOE projects continue to require data analysis and synthesis capabilities as a normal part of reporting procedures, and several have benefited from this project's support through computer programming for statistical analyses, tabular display, and graphics. One of the unique products was a 16-mm film which graphed, in three-dimensions, the living aboveground biomass on the Walker Branch Watershed landscape grid. In the film, the view angle was rotated through 360 degrees to simulate a circular aerial traverse of the site. This graphics tool was used in determining patterns in the vegetation mosaic and can be used in regional assessment projects.

Within this data analysis activity, a six-part presentation was made on using the Statistical Analysis System (SAS) in a research environment. Participants included some 20 researchers (the majority from the Environmental Sciences Division) within ORNL whose work is funded by DOE.

Methodologies for statistical software and computer usage were documented in a Data Processing Guide for the Environmental Sciences Division (Strand et al. 1977). This guide provides technical descriptions of computer codes for producing microfiche reports, procedures for using the Division's minicomputer for file preparation and use, and other computer procedures useful to Division researchers.

Computer planning, acquisition, and management. The Department of Energy's rapid response to urgent energy assessment problems places increased emphasis on computers. This requires input from all projects. Project leaders were solicited for computer analysis and data manipulation needs, and these were documented in an internal planning report discussing capacity and capability requirements for computerized tools. This plan resulted in the preparation of specifications for acquisition of a new and larger minicomputer in the Division and the purchase of additional disk storage peripherals, both within the Division and at the main computer facilities at ORNL. The Division's computer needs and requirements are also used by DOE Headquarters for its planning and acquisition schedules.

The Geoecology Project

The Geoecology project has created a large computerized data base of environmental resources arrayed in a standard county-subcounty format. Arranged in eight thematic sectors, the data can be statistically analyzed, merged, subsetted, tabulated, and cartographically displayed. While data sets are still being added, the existing data base is immensely useful for analysis and assessment of environmental impacts associated with energy technology development.

The majority of the southern states have abundant water resources, relatively clean air, a mild climate, and varied landscapes with generally high productivity and ecological diversity. Overall, 24% of the region is classified as cropland, 25% as pasture and range, 42% as forest, and 6% as urban, transportation, parks, and other special uses. The region has 53% of the conterminous U.S. shoreline with extensive wetlands occurring in the coastal states. Most of the land is below 150 m (500 ft) in elevation (48%) with only 16% of the area above 600 m (2000 ft). The diversity of flora in the South is indicated by the presence of 12 of the 35 ecoregions (Fig. 9.1) in the conterminous United States and 50 of the 106 potential vegetation types. The variations in these generalities were illustrated in the "Regional Energy/Environment Data Book, Preliminary Draft, Southern Region" (Copenhaver et al. 1978). Most of the maps and tables for the

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Fig. 9.1 County map of 16 southern and southeastern states with each county classified on the basis of the dominant ecoregion type according to definitions in Bailey (1976).

environmental section of this report were generated from the Geoecology Data Base and are available at the county level of resolution for additional computer analysis and regional characterization studies.

In addition to the data book project needs, the Geoecology Data Base provided environmental data to perform an ecological assessment of the U.S. Forest Service RARE-II tracts. The RARE-II project required national data, so the ecoregions, potential vegetation, birds, wildlife, and endangered species data bases were expanded to the conterminous United States and subsequently added to the Geoecology Data Base. This mode of operation ensured that the new data were compatible with existing files and that the data can be made available to others as needed in a consistent, documented format. An example of the combining of data files was the need to adjust the potential vegetation acreages for current land-use practices to have an estimate of natural vegetation remaining in the country. This analysis indicated that 20 vegetation types have lost over 60% of their potential area and also provided the spatial distribution of remaining potential vegetation areas.

Summary tables for the Geoecology Data Base status (Tables 9.1 and 9.2) indicate the types of files, number of variables, and geographic coverage. The data base is organized according to thematic sectors with each data set containing a set of variables such as state and county identifiers, year of data, and data items (Olson and Strand 1978). Included in the data base are dictionaries to provide English translations of the codes used in the system and index files to define regions in which individual county units are located. Indexes exist for climatic divisions, crop-reporting districts, air quality control regions, water subareas, and others. Data sets are collections of observations related to a thematic area and are usually created from a single extant data source. Within the Geoecology Data Base, data sets consist of either one observation per county unit or of multiple observations per county unit. With single observations per spatial unit, each observation contains all the variables for the county. As an example, within the forest area data set, each county has an observation

Table 9.1. Number of variables per county unit for those data sets in the Geocology Data Base arranged with the county unit as of September 1978.

Geographic region	Geographic coverage ^a			Total variables
	South	East	U.S.	
Agriculture	25	71		97
Amn. quality	15			15
Base data and indices	5		41	47
Climate		71	81	152
Energy	51		155	206
Forestry	49			49
Land	21		64	85
Population	25		44	69
Terrain		46		46
Total variables for data sets with one observation per county unit	191	191	335	787

^aSouth = 16 southeastern states; East = 37 eastern states; U.S. = 48 conterminous states.

^bSouth = 16 southeastern states; East = 37 eastern states; U.S. = 48 conterminous states.

Table 9.2. Average number of variables for data sets within the Geocology Data Base arranged with multiple observations per county unit and covering the conterminous United States as of September 1978.

Data set	Number of variables per observation	Average observations per county unit	Average variables per county unit
Breeding bird surveys ^a	8	100.0	305
Ecoregions	6	2.4	8
Endangered species	6	2.2	
Land capability by land use	20	12.3	281
Mammal species ranges	6	8.2	14
Soil ^b	8	2.0	11
Tree species ranges	6	32.5	38
Vegetation, potential	8	2.5	13
Vegetation, adjusted	8	2.5	13
			692

^aBreeding bird surveys are based on 1825 routes within the United States.

^bSoils data cover only the eastern states.

containing estimates (several may be zero) for each of 12 major forest types. Data sets with multiple observations per spatial unit include mammal, bird, tree, and vegetation lists. In these cases, there is an observation per county unit for each species that occurs within the county rather than a single observation containing a species list. Most often the data sets with multiple observations are very large and are stored on magnetic tape rather than on disk areas (online). The estimated total number of variables of information for county units was obtained using a very liberal accounting scheme. In particular, the average number of observations per county was used for data sets with multiple observations. In the South, which has the most comprehensive coverage, the Geocology Data Base currently contains over 1400 environmental variables per county unit. Approximately 70% of the variables are available for the conterminous United States.

The Ecosystem Analysis Data Center

The Ecosystem Analysis Data Center is a continuation of the eastern Deciduous Forest Biome (EDFB) Information Center as the projects evolved from the IBP to a number of other program related studies. The Center has continued interaction with investigators in summarizing and analyzing numeric data, in utilizing graphic display, and in developing bibliographic data bases. A bibliographic data base for the Fuels from Biomass Management Program was created, made available online, and used for computer-generated reports. The procedures and computer software for analyses of data from the Thermal Effects Program involved the transfer of data from a field recorder to magnetic tape to a DEC system-10 disk area to edit for superfluous data as well as to eliminate multiple data points before inputting into analysis and graphic display programs.

The Data Center staff also developed computer software for the preparation of formatted computerized textual files and indexes for the AM-748 phototypesetter. A bibliography (White and Garland 1978) was published using these programs. Currently, enhancements are being made such that the programs can handle different formats for bibliographic files.

The survey of mathematical modeling in ecology was published (O'Neill et al. 1977) and made available as an online file currently containing approximately 1000 entries. The IBP Abstracts file is also maintained online and now contains over 3000 records. Data Center staff continued participation in the ORNL Interdivisional Committee for Data Exchange with a 1977 inventory of data files published in May (Shriner et al. 1978), and have continued interactions with the Information Coordination Focal Point Program.

The Remote Batch Station

The Environmental Sciences Division uses a MODCOMP II/25 minicomputer for sending computer jobs to the main computer facilities operated by the Computer Sciences Division. Following the execution of each submitted computer job, the printout may be retrieved, again through the Division's minicomputer. This process of remote job entry (RJE) began in 1972. At that time, approximately 30 scientists were using the RJE facilities, and the average number of jobs processed was approximately 20 per day. The activity and productivity of the computing facilities has grown to an average of 141 jobs per day in September 1978. The user community has also increased in size to a point where approximately 70 people regularly utilize the RJE.

This increase in volume since 1972 has required continued improvement in capital equipment and system performance, including a larger room (in the Environmental Sciences Laboratory) for housing and cooling the equipment, an operator's console for monitoring and controlling the computer operations, and installation of a high-speed (1200 lines-per-minute) line printer.

Computer software improvements have included the capability to insert data stored on tape or disk into a job being submitted through the card reader. An insert card, placed in the desired position in the program deck, refers to a hardware device (e.g., a disk drive or a tape drive) with a data file ready to be used. As the insert card is read through the card reader, the data storage device begins inserting the data into the

job stream. When the inserted data file is completed, the remaining computer cards are read through the card reader. This capability has allowed the staff to store boxes of data on tape or disk, thereby reducing the handling time and the risk of an accidental dropping of data cards. The data files stored on tape or disk can also be modified or updated using the MODCOMP 11/25's file-editing programs.

The above capabilities (and others such as computer program debugging) are required continually by the Division staff. To make these features available to more staff, a new minicomputer (MODCOMP Classic) has been purchased. Greater core memory, faster central processing unit (CPU) speed, and better system software highlight the new acquisition. This increased computer capacity will support more of the routine activities, such as file editing and storage and program debugging. Installation of the new minicomputer is scheduled for January 1979.

Systems Analysis and Modeling

Systems Ecology

The present generation of ecosystem models depend heavily on spatially homogeneous representations. And yet, ecosystem stability and response to environmental perturbations are known to be affected by spatial distribution within the system. It is important, therefore, to explore the effects of spatial distribution on ecosystem response.

Diffusion theory provides a convenient mathematical formalism to simulate the space, time, and transport details of interest here. Skellam (1951) has discussed the suitability of using the Fickian random-walk process to describe dispersal in plant and animal communities. The one-dimensional space-time equation is

$$\frac{\partial N(x,t)}{\partial t} = [G(x) - L(x)]N(x,t) + D(x)\frac{\partial^2 N(x,t)}{\partial x^2} \quad (1)$$

where $N(x,t)$ is the distributed population at point x and time t , $G(x)$ is growth rate, and $L(x)$ is death rate. The last term in Eq. (1) represents the transport, or "diffusion," of reproductive biomass (e.g., seed by wind or animal dispersal).

Analysis of this equation reveals that ecosystem stability dynamics are dependent on the steepness and shape of parameter distributions induced by environmental gradients. For positive disturbances, there is a trend toward higher stability as curvature increases from convex to linear to concave and as steepness of a given shape increases. This is due to decreasing net productivity that results from overall lower growth rate and higher dispersal loss in the steeper systems compared with the average.

This developed formalism is instructive in problems of experimental data analysis and mathematical modeling in which it is desired to represent a spatially complex system by a simpler average. The results show that two common averaging techniques, one of using the parameter arithmetic average and the other of population weighting of the parameter distribution, can result in large errors in such estimates of system behavior. A better procedure is to formulate a detailed comparison between the actual system equations and the averaging equations and to define an equivalent averaging procedure which results in a conceptual match that omits none of the important system properties.

The stability formalism also offers an interpretation of the phenomenon of vegetational zonation found along some environmental gradients. On a gentle gradient, the vegetation may be continuous with indistinguishable boundaries between species, whereas, along a steep gradient, the same species may form discrete zones with essentially no overlap. The formalism shows that the nonlinear dependence of species growth, dispersal, and mortality on the changing environment along a gradient causes interspecific differences in stability to increase as gradient steepness increases, thereby promoting one population over another.

A new index of functional complexity has been developed as a result of our work in time series analysis. Theoretical considerations indicate that greater functional complexity in an ecosystem (e.g., larger number of feedbacks or increased number of non-linear interactions) should be reflected in a larger number of peaks in the low frequency range of the spectral density plot of time series data on system behavior. The procedure has been demonstrated on CO₂ efflux data from a terrestrial microcosm and used to correlate functional complexity with recovery of the microcosms from perturbation.

A key aim of theoretical ecologists is the elucidation of relationships between the structure and stability of ecosystems. This is true both for ecologists concerned with food web or trophic level models involving population numbers, biomass, or energy, and for those concerned primarily with modeling material cycles. A number of different meanings have been attached to the term "stability." Probably the most common interpretation is that a system is stable when it tends to return to an equilibrium point from which it has been displaced. A related concept, relative stability or resilience, is a measure of the speed with which a perturbed system, stable in the first sense, returns towards equilibrium. The faster a system returns to the equilibrium point, or the shorter its recovery time, the greater the resilience is said to be. We have deduced relationships between resilience and some basic aspects of model structure applicable to general nonlinear models of both food webs and nutrient cycles. In particular, it was shown that system resilience can be related to two fundamental concepts: (1) the energy flux through the system per unit standing crop in the steady state or its "power capacity," and (2) the recycling index of the system. We reached the general conclusions that models with high values of flux per standing crop and low recycling index generally have high resilience. A simple index was proposed that incorporates both concepts, power capacity, and the recycling index.

The Application of Ecosystem Models to Energy Technology Assessment

Research in the Ecosystem Models for Energy Technology Assessment project is focused on the application of systems analysis techniques (in particular, simulation modeling) to the assessment of the environmental implications of energy policies. Research falls into four general areas: (1) modification of streamflow associated with energy facility development, (2) effects of pollutants on forest ecosystems, (3) pollutant transport and effects in agricultural ecosystems, and (4) synthesis of effects at the landscape level.

Streamflow analysis. Seven-day ten-year low-flow values have been used as indices of water availability for regional energy facility siting. Documentation describing an automated system for generating low-flow frequency distributions for U.S. Geological Survey streamflow gaging sites has been prepared during the past year (Hyndman and Huff 1978). Four representative low-flow frequency distributions, Gumbel's limited distribution of the smallest value, the Pearson Type III, the Log-Pearson Type III, and the Log-Normal distributions have been chosen for inclusion in an interactive set of computer programs, LOFLO2. When used in conjunction with other water analysis programs, LOFLO2 makes frequency analysis viable on a regional scale by facilitating the handling of large amounts of data for large numbers of stations. Care must be taken to ensure the use of consistent data, but the LOFLO2 analyses themselves aid in this regard. We anticipate that the documented system will continue to be useful in regional water resource evaluations such as studies of low-head hydropower sites.

Effects of pollutants on forest ecosystems. The harmful effects of air pollutants on forest trees have been well documented by studies conducted around large smelting operations. During the past year, model calculations were used to investigate the integration of this stress to forest stands. Plant competition is considered, and response is analyzed on sufficiently long time scales to elucidate the changes in stand dynamics associated with the pollutant impact on individual tree species. A forest growth and succession model (Shugart and West 1977) is used to examine effects of stress applied differentially to species of differing sensitivity to air pollutants. Significant changes in stand dynamics and composition were observed (West et al. 1978).

Pollutant transport and effects in agricultural ecosystems. A bibliography of 200 articles describing agricultural crop simulation models was evaluated to identify suitable codes for assessing the impacts of energy technology facilities on agricultural systems (Rupp et al., in press). Although most of the codes could not be directly applied, many models were considered potentially suitable for assessment. In most cases the incorporation of empirical dose-response relationships would be required.

We are continuing efforts to more adequately model the hydrologic cycle in forest ecosystems. Water serves as a major transport mechanism for pollutants from energy facilities. A sensitivity analysis of air temperature, dew point temperature, and solar radiation variables in the terrestrial ecosystem hydrology model showed that evapotranspiration in East Tennessee is influenced more by temperature than solar radiation (Luxmoore et al., in preparation). This analysis further suggests that any increase in atmospheric temperature would have the greatest impact on vegetation in sheltered coves and on shaded, north-facing slopes. Evapotranspiration from exposed areas would increase slightly, however, and a significant increase in water stress of the vegetation would result.

Synthesis of effects at the landscape level. Multiple objective optimization techniques applied to energy system planning and energy resource utilization potentially provide a framework for synthesizing analysis of specific environmental impacts with other planning criteria such as cost. The utility of these optimization techniques has been studied in a generic sense by developing an optimization model explicitly incorporating the tradeoff between system cost and exposure to air pollution for an expansion to a coal electric power system (Emanuel et al. 1978).

These energy system planning approaches must ultimately be incorporated in a general framework for land-use planning. During the past year, a construct has been developed which combines the siting of major facilities such as power plants with the regional planning of landscape use through the assignment of land-use categories and intensities to cells (Shugart et al. 1978).

Regional Ecology - RARE-II

After passage of the Wilderness Act in 1964, the U.S. Forest Service was cognizant that many national forest areas were suitable for inclusion in the National Wilderness Preservation System (NWPS). Stemming from this awareness, an effort was made to identify those undeveloped and roadless areas which were best suited for possible wilderness designation. Thus, the U.S. Forest Service's Roadless Area Review and Evaluation (RARE) Program was initiated. In 1977, the RARE-II program resulted in the release of an inventory of sites qualified, according to preliminary criteria, to be included in the Wilderness System. These 2686 sites encompass nearly 25 million ha of land, of which 7.2 million ha are located in Alaska.

The Department of Energy's fundamental concern was, and is, to ensure that, if possible, RARE-II areas of significant energy potential are excluded from future wilderness designation proposals, and if not possible, that the energy potential of such lands be given appropriate consideration. DOE was also aware of the environmental values attributed to wilderness areas, and funded a project to evaluate the environmental or ecological values, as well as the energy resource potential, of the RARE-II sites. In this task, divided between the Environmental Sciences and Energy Divisions at ORNL, ESD is responsible for the ecological evaluation.

Expression of the ecological value of a wilderness area involves (1) identifying important natural resources located within the area, (2) determining the magnitude of those resources, and (3) computing the area quality value by creating a matrix which combines the magnitude of a particular resource and the importance of that resource. This procedure results in a value which can be compared to similarly derived values for other sites.

The selection of parameters which can be used to construct a quantifiable description of a tract of land located anywhere in the United States presented a formidable problem. It was desirable to evaluate each wilderness tract within a hierarchical framework in order to provide the capacity to search for tracts of similar value when wilderness/development conflicts arose.

Based on a number of considerations discussed in Klopatek et al. (in press), a set of four major parameters was chosen: (1) vegetation: the principal vegetation communities within each tract according to Kuchler's (1964) system and in consideration of Bailey's (1976) ecoregions; (2) avian communities: the species and abundance of birds inhabiting a tract and the quality of habitat provided by a tract; (3) mammal communities: the species of mammals inhabiting a tract and the quality of habitat provided by a tract; and (4) endangered or threatened species: the occurrence of species and whether or not the tract provides critical habitat for the species.

The pitfalls of employing potential vegetation as an indicator of what exists within an area are well known. To alleviate some of the problems, an algorithm was devised to subtract Conservation Needs Inventory (CNI) land-use data from the potential natural vegetation (Klopatek et al., in preparation). Figure 9.2 depicts the resulting distribution of potential natural vegetation for the United States. As can readily be seen, the agricultural regions of the country have the least area remaining in natural vegetation.

Fig. 9.2. County map of land still covered by natural vegetation in the United States.

All parameters were evaluated on nationwide, regional, ecoregion section, and individual tract levels. The combining of values for various levels provides a measure of how a particular tract resource relates to the whole country and how one ecoregional section compares with another. Mathematically, the environmental index reflects a filtering of information from one level to another. Thus, by combining values for all resources at all levels, an overall ecological value can be calculated for each roadless tract.

The results and application of the methodology are shown for the Rocky Mountain Overthrust Belt, an area of highly important oil and gas reserves (Fig. 9.3). The conflict matrix segregates the tracts according to ecological ratings and energy and mineral resource ratings. The tracts with the greatest conflicts occur in the top 20% of the ecological ratings and the top 50% of the energy resource ratings (3+ to 4+). To the left of the "high conflict" tracts are four tracts - 4153, 4157, 4171, and 4610 - which do not conflict with high or medium energy and mineral resource ratings. This suggests that these four sites could be considered as alternative sites for wilderness designation in place of those sites with high energy resource values. Thus, the methodology developed for the ecological analysis and evaluation of the RARE-II tracts can be viewed as a trade-off analysis to help resolve environmental and energy resource conflicts.

Fig. 9.3. Ecological/energy resource conflict matrix for RARE-II tracts within the Rocky Mountain Overthrust Belt.

Educational Programs

ESD Seminar Program

During the past year the seminar committee offered a diverse program of guest lectures aimed at informing division staff and other interested members of the local scientific community on topics of general interest in environmental sciences (Table 9.3). With its range of audio-visual equipment, the Daniel J. Nelson Memorial Auditorium of the new Environmental Sciences Building is an excellent facility for such presentations. The seminar series relies largely on suggestions from division staff members for the selection of outstanding speakers, an arrangement that was very successful in the past year.

Graduate Education Program

The Environmental Sciences Division provides opportunities for graduate and post-doctoral research consistent with the mission of the Oak Ridge National Laboratory. During this reporting period, 15 graduate studies were supported through a contract with the University of Tennessee Graduate Program in Ecology, and one student by Vanderbilt University. Supported students receive stipends administered by the universities and are guided in their research by selected staff members, one of whom serves on the student's academic guidance committee at the university. In addition to the above, research done by students not requiring division support was accommodated on a more limited basis. For example, two students from Miami University (Ohio) did research associated with division programs. Graduate students were also supported through research subcontracts to various universities from division programs and sections.

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

Undergraduate Education Program

A number of programs for undergraduate student participation in Environmental Sciences Division research and assessment projects provide a continuing opportunity for interaction between students and staff. A summary of these programs is provided in Table 9.4.

Students involved in these programs are assigned to individual advisors in the division who guide them through an experiment or project associated with one of the division's programs. The student is required to document results in a report and present a seminar to the division staff. This research participation experience is designed to expose the student to the research process in a large laboratory. The greatest benefit to students is frequently an improved outlook on career opportunities in research and an understanding of practical approaches to research problems.

Table 9.3. Environmental Sciences Division seminar speakers - October 1, 1977 to September 30, 1978

Date	Speaker	Title of presentation
November 9, 1977	Dr. Zhores A. Medvedev National Institute for Medical Research, London, England	Facts behind the Soviet nuclear disaster
December 7, 1977	Dr. Larry Harris University of Florida	Island biogeography and forest landscape planning
January 12, 1978	Dr. Robert E. Cook Harvard University	Raymond Lindermann and the trophic-dynamic concept in ecology
January 25, 1978	Dr. Hazel R. Delcourt University of Minnesota	Late quaternary vegetation history of the southeastern United States
February 27, 1978	John P. Williams Office of Surface Mining Dept. of Interior	Legal aspects of the Federal Surface Mining Control and Reclamation Act of 1977
March 10, 1978	Dr. Howard T. Odum University of Florida	Energy quality and environment
March 15, 1978	Dr. Philip C. Miller San Diego State University	Resource utilization by vegetation in Mediterranean scrub ecosystems
April 24, 1978	Dr. Cal D. McNabb Michigan State University	Roles of aquatic plants in nutrient cycles
May 23, 1978	Dr. R. Brooke Thomas University of Massachusetts	High Andean Human Adaptations
May 31, 1978	Dr. Arthur C. Stern University of North Carolina	The Clean Air Act Amendment of 1977
June 5, 1978	Dr. Ford Cross National Marine Fisheries Service, Beaufort Lab.	Environmental impact of the AMOCO CADIZ oil spill: An overview
June 28, 1978	Dr. Jadwiga Luczak Institute of Ecology Warsaw, Poland	Ecological - archaeological studies in Poland: Trends and some results
July 19, 1978	Dr. Stuart L. Pimm Texas Tech University	Experiments on hummingbird communities
August 3, 1978	Dr. John Turner Forestry Commission of N.S.W. Sydney, Australia	Sulphur relations in <i>Pinus radiata</i> plantations in New South Wales with reference to stack gas inputs
September 13, 1978	Dr. George S. Hurst Oak Ridge National Laboratory	One-atom detection: Environmental research applications
September 28, 1978	Dr. A. A. Patrino Oak Ridge National Laboratory	Rainfall studies in northwest Georgia
Informal seminars		
June 8, 1978	F. O. Hoffman Oak Ridge National Laboratory	Reflections on an experience in Yosemite National Park
July 12, 1978	Dr. A. S. Bradshaw Oak Ridge National Laboratory	Time and the mountain: A "ranger-naturalist" presentation

Table 9.4. Numbers of students in ESO undergraduate programs, October 1, 1977 - September 30, 1978

Program	Number
Oak Ridge Associated Universities	11
Southern College University Union	3
Emory University	1
Great Lakes College Association	4

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10. TERRESTRIAL ECOLOGY SECTION

W. F. Harris

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T. J. Blasing ¹	J. W. Johnston	E. G. O'Neill ¹	H. H. Shugart ¹
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H. R. Delcourt ²	Shirley G. Lawson	W. M. Post ²	G. W. Suter ¹
N. T. Edwards	D. M. Lucas	H. F. Raby	F. G. Taylor
R. H. Gardner ¹	R. J. Luxmoore ¹	R. M. Reed ¹	D. E. Todd
C. T. Garten ¹	L. K. Mann ¹	E. H. Rosenbalm	L. D. Voorhees ¹
T. Grizzard	J. F. McBrayer ¹	B. M. Ross-Todd ¹	B. T. Walton ¹
R. J. Haynes ¹	R. K. McConathy ¹	M. S. Salk ¹	J. W. Webb ¹
J. W. Huckabee ¹	S. B. McLaughlin ¹	W. J. Selvidge	D. C. West ¹
A. E. Hunley	K. M. Oakes ¹	F. E. Sharples ¹	

Introduction

The Terrestrial Ecology Section provides expertise in terrestrial environmental sciences to both basic and applied research problems. This is accomplished by technical input from the staff to the Division's research and assessment programs. Terrestrial section staff are currently involved in ecosystem studies, environmental impacts, synthetic fuels, and nuclear programs. Staff also are assigned to other research divisions at ORNL which require terrestrial ecologists. Within the section, several research projects serve to maintain technical ability in selected areas of terrestrial ecology. These research projects anticipate future programmatic directions, undertake development of new technical requirements, and promote new research in terrestrial ecology. Four broad areas comprise the general framework of current section research interests: ecological effects - principally of gaseous air pollutants on plants; fate and transport - with continued emphasis on carbon and sulfur cycles; ecosystem studies - with emphasis on physiological processes; and environmental resources - encompassing forest management for the Oak Ridge Reservation and establishment of an environmental research park on selected portions of the Reservation.

Research also requires input from other units of the Division. The most notable examples are the contributions by hydrologists and geochemists from the Earth Sciences Section to the ongoing research program on Walker Branch Watershed.

Perhaps the most significant trend emerging from the diverse types of research conducted by terrestrial staff is the increasing emphasis on the significance of long-term ecological phenomena and the resultant implications to ecosystem dynamics and underlying ecosystem paradigms. Consideration of ecological phenomena operating over long time

¹Dual capacity.

²Postdoctoral Fellow, Graduate Program in Ecology, University of Tennessee.

frames is an additional dimension to our interests rather than a replacement of earlier emphasis on ecosystem processes. This direction is viewed as the logical extension of past research and, as such, we expect feedback to our continued interest in process studies as we seek to understand the physiological basis of terrestrial ecosystem behavior.

Our new research project under the sponsorship of NSF considers the role of the terrestrial biosphere in the global carbon cycle. It will utilize models of forest development and succession to examine whether specific segments of the terrestrial biosphere are a source or sink for excess atmospheric CO₂. Simulation model results obtained this year with an aggregated model of the terrestrial biosphere indicate that the biosphere could become a net sink for CO₂ if it were managed to maximize storage as well as production rates of organic carbon (Olson et al. 1978). However, the strength of the net shift to carbon storage is small in comparison to the flux of fossil CO₂ to the atmosphere. The model confirms the several-fold increases of atmospheric CO₂ at high rates of fossil fuel consumption. Research is continuing to verify and improve upon the assumptions of our current modeling work.

Another facet of our research on the global carbon issue involves investigating the likely biogeographic shifts that might occur if the global warming simulated by quantitative climate models does follow from continued increase of atmospheric CO₂ concentration. Our work involves use of prehistoric biological data (tree rings and pollen) on past climate and biomass fluctuations, with simulation models of forest succession, to derive climate-vegetation analogs. These analog functions will provide estimates of climatic variability and biosphere response to past climates as a means to forecast likely atmospheric shifts in the future due to climate change induced by increased atmospheric CO₂.

The models of carbon dynamics, coupled with basic information on biospheric response to climate change, are the basis for assessments of scenarios on the global carbon cycle, climatic risks, and fossil fuel use. This work is supported by DOE's Division of CO₂ Research. Analyses such as those described above and reported in Olson et al. (1978) are already being used in broader technology assessments by EPA and other overview groups.

Our work on applying FORET, a forest growth simulation model, to examine community level responses of forest systems to chronic air pollution stress further illustrates the relevance of long-term ecological responses as typified by forest growth cycles to current environmental issues. Using a qualitative ranking of forest species sensitivity to air pollution stress, the model results suggest that whole-stand growth changes occasionally exceed the additive responses imposed on component species and that stand maturity affects the responses of individual species (McLaughlin et al., in press). Results such as these strongly emphasize the importance of competition as a controlling factor in forest response to stress. The aim of our experimental program is to quantify differential responses of important forest species and to reveal the mechanisms through which competitive ability is modified. This work was supported last year by DOE's Division of Environmental Research. This project was transferred to EPA who will begin to support the work sometime in early 1979.

Analysis of the sulfur budget on Walker Branch Watershed, work sponsored by DOE's Division of Environmental Research, revealed that sulfur was accumulating in soil (Shriner and Henderson 1978). Laboratory studies completed this year have shown that watershed soils contain a large pool of adsorbed sulfate in the B horizon and considerable water soluble sulfate in the A horizon (Johnson and Henderson, in press). The soils do not absorb more sulfate in a permanent form. These results suggest a finite capacity for sulfate accumulation in forest soils. The consequences to soil ion movement of exceeding this capacity are not known. This year we initiated treatments with excess sulfate on the WBW lysimeter plots to address this question. In addition, we are examining sulfur accumulation in soils from different regions and in parent material and areas suspected to receive less atmospheric sulfate. We hope to determine if high sulfate accumulations in soils are a recent phenomenon or typical of soils of the region. Again, long-term behavior bears heavily on our understanding of current problems.

The highlights that follow amplify on the above results and also describe additional research in the section on carbohydrate allocation, water relations, and nutrient cycling processes. Taken as a whole, the work completed this year continues to emphasize understanding the structure and function of forest ecosystems and consequences of perturbations to these ecosystems over a broad temporal and spatial framework.

Ecological Effects

Ecological Effects of Air Pollutants from Coal Combustion

The phytotoxic effects of present and potential levels of air pollutants resulting from coal combustion (SO_2 , ozone, and acid precipitation) are being studied to describe mechanisms of action and thresholds for response, and to identify ecological indicators of stress in agricultural and forest systems. Our approach involves laboratory, greenhouse, and field studies to relate concentrations of pollutants to responses of individual plants and plant communities. An essential component of this approach is measurement of plant response to pollutant stress in field situations where interactions between abiotic and biotic stresses must be considered. Two techniques are being applied to meet this objective: field tests of crops and seedling trees and a model simulation of forest growth (FORET) which explores interactive effects of pollutant stress, plant competition, and growth of forest stands.

Field measurements of air pollution stress. During the 1978 growing season, field plots were established on the Oak Ridge Reservation (0800 Area) to evaluate the impact of ambient levels of air pollution on plant growth, using open-topped field chambers designed to expose field crops or forest tree seedlings to either ambient levels of air quality or charcoal-filtered air. Air movement systems pass $\sim 2000 \text{ ft}^3/\text{min}$ ($57 \text{ m}^3/\text{min}$) of air over plants in 7.3-m^2 field plots. The velocity of this air leaving the open top of the chambers prevents entry of pollutants through the top. Replicate plots of bush bean, *Phaseolus vulgaris* "pinto" (a variety known to be sensitive to air pollution stress), were planted in August and harvested in October 1978. During the period of time the crop was maturing, several air stagnation systems developed in the eastern region of Tennessee, during which ozone levels exceeded federal secondary standards. At harvest, 53% of plants in nonfiltered chambers showed some visible injury characteristic of air pollution exposure, while $< 10\%$ of plants in charcoal-filtered chambers showed similar injury. Corresponding to these visible differences in the field plots, nonfiltered plots produced 28% fewer harvestable bean pods per plant, resulting in a 44% reduction in harvested biomass when compared to charcoal-filtered plots. During the 1979 growing season, these experiments will be continued with the addition of continuous monitoring of sulfur dioxide, ozone, and nitrogen dioxide, and event sampling of precipitation at the site. In this manner, plant response will be described in terms of the pollutant dose and exposure frequency. Data derived for seedlings of key forest tree species will be used to revise and refine the pollutant response functions of a forest growth and competition model.

Modeling of forest response to stress. Forest responses to air pollution stress, compared to those of annual crops, are greatly complicated by the effects of long growth cycles and competition between species which vary widely in sensitivity to pollutants. Over the past 18 months, studies have been underway to apply FORET, a forest growth simulation model, to examine community level responses of forest systems to chronic air pollution stress. The model (Shugart and West 1977) mathematically integrates a variety of silvicultural characteristics of 32 tree species of the Eastern Deciduous Forest type to simulate annual changes in individual and stand-level biomass dynamics. We have examined long-term growth responses of forest trees by applying differential growth inhibition to individual species based on known relative sensitivity of the trees to visible injury. The level of growth reduction varied from 0% for 16 resistant species to 10% for 10 intermediate species and a maximum of 20% for 6 sensitive species.

A comparison of biomass changes for selected individual species and for the forest stand is shown in Fig. 10.1. With stress initiated in the seedling forest (time = 0 years) intermediate species such as yellow poplar and black oak show markedly different response patterns. Poplar, a strong competitor which is shade intolerant, shows an

Fig. 10.1. Effects of simulated air pollution stress on representative species and stand biomass. Stress varied from 0% growth inhibition for resistant species (white oak) and 10% for intermediate species (yellow poplar and black oak) to 20% for sensitive species such as black cherry.

initial positive response which we attribute to a relative reduction in the competitive strength of species with which it competes most closely. Black oak, on the other hand, shows a greater than anticipated inhibition due to an apparently weakened competitive position. A sensitive species such as black cherry shows almost complete elimination from the stand with an imposed growth reduction of 20%. In addition, whole-stand responses were found to occasionally exceed the additive responses imposed on component species. When stress was applied at different stages of stand development, it was found that responses of individual species were strongly influenced by stand maturity. Results of these simulations strongly emphasize the importance of competition among forest trees as a modifier of forest responses to stress.

Gaseous Diffusion Plants as a Source of Atmospheric Fluoride

Uranium enrichment by gaseous diffusion of uranium hexafluoride (UF_6) intermittently discharges measurable quantities of fluorides to the atmosphere. In addition to the primary plant (process cascade), the fluoride plant, hydrogen fluoride tank farm, equipment treatment facilities, and the diffusion purge cascade constitute potential sources of fluoride. Because uranium is radioactive and hexafluoride is extremely volatile, elaborate control measures are applied to ensure minimal UF_6 emissions from the process cascade. During operation, light gases (air, N_2 , HF , and coolant) are routinely introduced into the system. These contaminant gases are transferred to the top of the cascade where they can interfere with product (enriched UF_6) withdrawal. To prevent this interference, the light gases are separated or purged from the UF_6 and discharged to the atmosphere from roof vents. As a result of venting, the purge cascade represents the major source of fluoride from a diffusion plant and constitutes a chronic, low-level emission.

Impacts on air quality (elevated HF concentrations) pose a potential for harmful effects on biota. Damage to sensitive plant taxa can occur at thresholds (~ 1 ppb) several orders of magnitude less than air concentrations of other pollutants (SO_2 , NO_x) causing similar damage. A logical first step in designing laboratory or field experiments to assess effects on biota is to define concentrations of fluorides in the environs of gaseous diffusion plants. Since each Department of Energy enrichment facility continually monitors environmental levels of plant effluents, concentrations typical of plant environs can be determined through a detailed review of previous monitoring data.

The Paducah, Kentucky, Gaseous Diffusion Plant was selected as a case study because of its lead role in developing sampling protocols, adequate averaging time (7 days), and a relatively complete data set. Prior to 1972, analytical procedures for fluoride in ecological matrices (air and vegetation) were in a state of flux. Consequently, monitoring data were obtained for a period of years (1972-1977) which best represented state-of-the-art analytical techniques. Gaseous fluoride was collected in alkaline solution (NaOH) scrubbers until 1974 when they were replaced by chemically treated (K_2CO_3) filter papers. Analytical determinations were by fluoride specific ion electrode. Air samples were collected weekly (7-day composite sample) from 10 stations around the facility. During the sample period (1972-1977) there were 3032 observations. Air monitoring data (HF) were summarized by frequency distribution and scatter plots according to location, year, and month. Scatter plots by year and by month indicated the absence of routine releases with observed HF concentrations randomly distributed.

The frequency distribution of HF in air for the period (Fig. 10.2a) illustrates that constant concentrations over long periods of time are not encountered. The data also show that ambient concentrations are not distributed uniformly, but consist of infrequent peaks ($\geq 5 \mu\text{g}/\text{m}^3$) superimposed on a predominant distribution of lower concentrations ($\leq 5 \mu\text{g}/\text{m}^3$). The scatter plot (concentration) by station or location (Fig. 10.2b) reflects distributions downwind and upwind of the source. Concentrations illustrated for stations 13, 14, and 15 identify the area of greatest impact, with concentrations greatly exceeding threshold levels for plant damage. Of the total number of observations from all locations during the 6-year period (1972-1977), 90% depicted concentrations $< 1 \mu\text{g}/\text{m}^3$ while 3% had concentrations $> 5 \mu\text{g}/\text{m}^3$.

Accumulation of atmospheric fluorides by plants can result in changes in metabolism; production of foliar lesions; and alteration in growth, production, and yield. Thresholds for foliar markings in susceptible species range from $0.5 \mu\text{g}/\text{m}^3$ for exposure periods longer than one month to $5 \mu\text{g}/\text{m}^3$ for exposure periods of one day. Because fluoride is a metabolic toxicant, with accumulation in foliar tissues, one would expect a direct relationship between foliar content and air quality.

For comparison to air quality data, vegetation monitoring data were obtained for the period 1972 thru 1977. The data were from grass samples which had been collected every two months beginning with February in each year. Samples were collected from eight additional plots to increase the resolution of the sample network. These data are summarized in a scatter plot (Fig. 10.2c) which reflects the air quality, depicts the

Fig. 10.2. Environmental monitoring data for the Paducah, Kentucky, Gaseous Diffusion Plant area between 1972 and 1977. (a) Frequency distribution of hydrogen fluoride in air. Total number of observations is 3032. Greater than 90% of all observations depicted air concentrations of $1 \mu\text{g}/\text{m}^3$ or less. (b) Scatter plot of HF concentrations by location of monitoring station. Each profile (station) contains from 308 to 312 observations except station 18 which contained 234. Maximum concentrations are northeast of the plant (stations 13, 14, and 15) in the direction of predominant winds. (c) Fluoride concentration [$\mu\text{g}(\text{F}^-)/\text{g}^2$] in grass foliage as a function of station location. Each profile contains 32 to 34 observations except station 18 which consists of 6 observations. Station 18 represents background (8 to 100 ppm). Accumulation by foliage (up to 1000 ppm) is evident at stations 13, 14, and 15.

ranges in concentration among the sample stations, and identifies stations 13, 14, and 15 as having significant fluorides in vegetation. Maximum concentrations (~ 1000 ppm) were several times greater than the threshold (~ 150 ppm) for injury for all plants considered susceptible.

Air quality data from uranium enrichment technologies suggest that gaseous diffusion plants contribute significantly to ambient HF concentrations. Environmental monitoring data from the Paducah, Kentucky, plant quantifies a dominant, low ambient concentration ($\leq 1 \mu\text{g}/\text{m}^3$) with intermittent high releases sufficient to produce damage. Vegetation

samples confirm the impacts on air quality with corresponding accumulations of fluorides in foliage. Elevated concentrations, restricted to the area of predominant winds, suggest that sources other than the diffusion plant are insignificant to the ambient concentrations. Scatter plots and frequency distributions provide greater resolution in assessing the impacts than statistical means, as each intermittent release is reflected in each 7-day composite air sample. These data will form the basis for the design of field experiments (exclusion chambers) and controlled fumigation studies.

Fate and Transport

Atmospheric Emission and Plant Uptake of Mercury from Agricultural Soils Near the Almadén Mercury Mine

Recent estimates that over 50% of the combined natural plus industrial emissions of Hg enter the atmosphere (Van Horn 1975) accentuate the need for further study of terrestrial/atmospheric/terrestrial transport pathways of Hg. Mercury enters the atmosphere in both gaseous and particulate forms, the former pathway being enhanced by the elevated vapor pressure of metallic Hg (Hg^0) and several Hg compounds. Naturally elevated mercury emissions from mineralized areas can be further enhanced by the presence of mining and refining activities. These sources have been estimated to contribute ~12% of the total anthropogenic emissions of Hg to air (Van Horn 1975). Conflicting papers in the literature have reported Hg uptake by plants growing in the vicinity of Hg mine/smelter operations as ranging from undetectable to significant (Shacklette 1970, Byrne and Kosta 1970).

Accordingly, a study was designed (Lindberg et al., submitted) to investigate various aspects of the terrestrial/atmospheric mercury cycle at the site of the world's largest and oldest active Hg mine in Almadén, Spain. The objectives of this research were (1) to compare the distribution of Hg in soils located near the mine to that in "control" soils collected 20 km from the mine; (2) to quantify the uptake and distribution of Hg by a typical crop plant (alfalfa) as affected by soil Hg concentration and soil amendments; and (3) to determine the effect of soil surface temperature and plant cover on Hg^0 emission rates from soils. Analytical methods included standard soil testing procedures (Black 1965), zonal centrifugation for separation of soils into three density fractions (Francis et al. 1972), Hg vapor collection using flow-through chambers and activated charcoal (Lindberg and Turner 1977), and sample digestion and Hg analysis procedures described in Van Hook et al. (in preparation).

Surface soils collected near the mercury mine reflected increasing concentrations of Hg with proximity to the mine, due to weathered mineral deposits and to atmospheric deposition of Hg from the smelter. Extractions with $NaHCO_3$ or NH_4OAc removed small amounts of Hg from both control (20 km from the mine, $Hg = 2.3 \mu g/g$) and mine site soils (1 km, $Hg = 97 \mu g/g$). Density gradient centrifugation indicated a significant fraction of the Hg to be associated with a high density mineral fraction, presumably cinnabar. Accumulation of Hg by alfalfa suggested a dual mechanism of uptake; roots accumulated Hg in proportion to the soil levels, while aerial plant material absorbed Hg vapor directly from the atmosphere. Soil fertilization with and without liming significantly increased total Hg uptake, largely due to plant growth stimulation. Liming itself had no significant effect. The rate of volatilization of elemental Hg from both soils ($0.13 - 0.33 \mu g/m^2/hr$ at $25^\circ C$) exceeded reported background emission rates by factors of 4 to 10, increasing with surface temperature and Hg content and decreasing with increased plant cover.

Walker Branch Watershed

Soil sulfur relationships. Shriner and Henderson (1978) published the sulfur budget for Walker Branch Watershed which revealed that sulfur was accumulating in the soil. A likely mechanism for this accumulation is sulfate adsorption onto iron and aluminum oxide surfaces (sesquioxides). Laboratory studies revealed that soils on the watershed

contain a large reservoir of adsorbed sulfate in the B horizon (Table 10.1), but would not adsorb more in a permanent form (Fig. 10.3). A-horizon samples contained no adsorbed sulfate but considerable amounts of water-soluble sulfate (Table-10.1).

Table 10.1. Total S and SO_4^{2-} fractions in the Fullerton soil (ppm, $<2\text{-mm}$ fraction). (Standard deviations are given for SO_4^{2-} values; ranges for total S. Only duplicate samples were analyzed for total S sampled in 1977).

Horizon and depth	Total S	SO_4^{2-} - S H_2O	Extracted by: NaH_2PO_4	% of Total S as SO_4^{2-}
A21 (0-30 cm)	295 $\pm$ 10	67 $\pm$ 16	35 $\pm$ 18	23
A22 (30-60 cm)	266 $\pm$ 0	66 $\pm$ 19	37 $\pm$ 26	25
B1 (60-80 cm)	300 $\pm$ 0	22 $\pm$ 13	80 $\pm$ 11 ^a	27
B21 (80-120 cm)	330 $\pm$ 0	8 $\pm$ 8	122 $\pm$ 74	37
B22 (120-200 cm)	290 $\pm$ 0	2 $\pm$ 2	86 $\pm$ 16 ^a	30
4 m	360 $\pm$ 50	< 2	42 $\pm$ 16 ^a	12
12 m	250 $\pm$ 0	< 2	94 $\pm$ 6	38
30 m	260 $\pm$ 0	< 2	58 $\pm$ 16 ^a	22

^aDifferences between the two sulfate extractions is significant at the 95% level, t-test.

^bInsufficient number of samples due to sample loss.

The high proportion of water-soluble sulfate in the A horizon appears to play an important role in determining sulfate concentrations in headwater streams. During peak storm flow periods, sulfate concentrations in headwater streams increase, probably due to leaching from surface horizons in the variable source areas of the watershed. The water-soluble sulfate pool in surface horizons is probably active in sulfur cycling processes, whereas water-insoluble sulfate in subsurface horizons constitutes an inactive, long-term reserve.

Source areas and chemistry of storm flow. Although it is known that some water quality constituents are more closely related to storm flow than to dry weather flow, there have been few attempts to explicitly study the chemical composition of individual components of flow. A computer program based upon quick flow and delayed flow separation has been adapted to estimate concentrations and total amounts of various chemical constituents associated with these two components of flow. Preliminary indications are that many constituents are more strongly associated with either quick or delayed flow. Thus, it may be possible to relate the effects of land use with chemical composition of quick flow or delayed flow more quantitatively than with the chemical composition of total stream flow. We have begun study of this phenomenon in the field as well as with computer analysis of extant data.

The high proportion of water-soluble sulfate in the surface horizons of soils appears to play an important role in determining sulfate concentrations in small headwater streams. Henderson et al. (1977) reported concentration behavior of N, Ca, and K during storms in the small stream that drains Walker Branch Watershed. During storms which produce high flow rates, stream-flow sulfate concentrations increase as much as 4- to 5-fold from antecedent base flow to peak storm-flow conditions. Cations transported primarily in dissolved form do not behave in this manner. We believe the high dissolved-sulfate concentrations during peak storm flow are due to leaching dynamics of surface soils in the variable source areas of the watershed. In headwater catchments, storm flow arises in part from low-lying soils which become saturated, and through which water moved laterally and upward in the surface horizons. Since these horizons contain considerable water-soluble sulfate (Table 10.1), it seems reasonable that the higher

Fig. 10.3. Adsorption and desorption of SO_4^{2-} on soil samples from the A21, A22, B1, B21, and B22 horizons of the Fullerton soil during the sequential leaching experiment. S_{ads} = soil adsorbed sulfate. Values tabulated on lower right are net changes in S_{ads} at the conclusion of the experiment after four sequential leachings with NaH_2PO_4 .

stream-flow concentrations during storms are caused by removal of a portion of this sulfate. The degree of stream-flow sulfate increase would therefore depend on the amount of water-soluble sulfate in surface soils and the extent to which the streams of a catchment expand into variable source areas during storm events.

Mechanisms and rates of atmospheric deposition of selected trace elements and sulfate to a deciduous forest watershed. The critical links between increased atmospheric emissions and effects on terrestrial and aquatic ecosystems are the rates at which, and mechanisms by which, atmospheric species are transported to the earth's surface. The objective of this research (Lindberg et al., in press) has been to accurately quantify the atmospheric input of the environmentally mobile fraction of several trace elements and sulfate to a deciduous forest canopy and to determine the critical mechanisms of deposition. A modified wetfall-only collector was developed to minimize trace level contamination. Precipitation samples were collected on an event basis at sites above the forest canopy, at ground level in the open, and at four sites directly beneath the canopy. Dry deposition was measured using inert, flat surfaces situated in the upper canopy, and laboratory-leached material from sequentially collected leaves from

the same locations. Suspended particles were collected above the forest canopy, using standard filter and cascade impacter methods. Laboratory leaching procedures were applied to all samples to extract the water-soluble and the dilute acid-leachable trace element and sulfate fraction (termed the available fraction).

Substantial amounts (> 75%) of the available fraction of Mn, Zn, Cd, and Pb in aerosols were soluble in water. The water-soluble-to-available element ratio increased with decreasing particle size and with the duration of atmospheric water vapor saturation during the sampling period. Relationships between aerosol chemistry and meteorological parameters suggest a soil source for Mn, combustion sources for Pb and SO_4^{2-} , and both small-particle combustion and large-particle dispersion sources for Cd and Zn, and suggest that atmospheric chemistry over MBW is the result of regional air transport phenomena rather than the direct result of local source emissions.

Smaller amounts (< 75%) of the available trace element fraction of dry deposited particles were water soluble, suggesting a larger particle size, confirmed by scanning electron and light microscopy of biological and inert deposition surfaces. The presence of a significant quantity of fly ash and dispersed soil particles on upward-facing leaf and flat surfaces suggests sedimentation to be a major mechanism of dry deposition to upper canopy elements. The agreement for deposition rates measured to inert, flat surfaces and to leaves was good for Cd, SO_4^{2-} , Zn (within 30%), and Mn (within a factor of 2) but poor for Pb (an order of magnitude higher rate measured to the inert surface). Leaf surface absorption of soluble Pb could be a factor. Calculated deposition velocities to individual upper canopy surfaces indicated that the generally used value of 0.1 cm/sec is an underestimate (Cd = 0.4 cm/sec, Mn = 6, Pb = 0.1, Zn = 0.4, SO_4^{2-} = 0.1).

The precipitation concentrations of Zn, Pb, Mn, and SO_4^{2-} reach maximum values during the summer months in response to synoptic meteorologic conditions. A model applied to the inverse relationship between rain concentration and rainfall volume indicated that, on an annual basis, ~ 90% of the wet deposition of Pb and SO_4^{2-} was attributable to scavenging by in-cloud processes, while for Cd and Mn, removal by below-cloud scavenging accounted for 30 to 40% of the deposition.

The interception of incoming rain by the forest canopy resulted in a net increase in the concentrations of Cd, Mn, Pb, Zn, and SO_4^{2-} but a net decrease in the concentration of H^+ , suggesting a cation exchange process. Net exchange increased with increasing free acidity of the incoming rain and with increasing residence time of the rain on the leaf surface. The sources of these elements in the forest canopy are primarily dry deposited aerosols for Pb, primarily internal plant leaching for Mn, Cd, and Zn, and an approximately equal combination of the two for SO_4^{2-} .

On an annual scale the dry deposition process constitutes a significant fraction of the total atmospheric input of Cd and Zn (~ 20%), SO_4^{2-} (~ 35%), Pb (~ 55%), and Mn (~ 90%). Over short-term periods, however, the ratio of dry/total deposition for any element may range over an order of magnitude. Significant fractions of the total annual elemental flux to the forest floor were attributable to external sources for Pb (99%), Zn (44%), Cd (42%), SO_4^{2-} (39%), and Mn (14%), the remainder attributable to internal element cycling mechanisms (see, for example, Fig. 10.4).

The pathways of highest relative importance varied from foliar leaching for Cd (55% of the total) and Mn (49%), to dry deposition for Pb (67%), wet deposition for Zn (36%), and leaf fall for SO_4^{2-} (31%).

Hydrology data management. During the past year, we have satisfied several requests for flow data and associated chemical analyses results from Walker Branch Watershed. Because the data are stored on magnetic tape, they are not always available for inspection or distribution in a ready format. We have now developed a system for compiling complete listings for all data (including 5-min interval data) by year onto microfiche cards. This solves the problem of storing or handling voluminous stacks of computer output, yet provides instant visual access to raw data and graphical summaries of daily flow for any desired year.

Fig. 10.4. Annual mass transfer rates of sulfate expressed as a percentage of the estimated total annual flux of the element to the forest floor.

Ecosystem Studies

Carbon Allocation in Deciduous Forest Trees

A major gap in our present understanding of the physiological ecology of forest ecosystems is in quantification of processes linking gross primary production (GPP) with net primary production (NPP). While considerable data have been accumulated on the comparative photosynthetic rates of foliage and the annual growth rates of trees, the energy consumption associated with the processes of translocation, respiration, and photosynthate partitioning are poorly understood. These processes, which Kira (1975) estimates account for 32 to 79% of the GPP of world forests, are significant not only to efforts to describe physiological function of forest trees, but also as possible indices of environmental stress.

Studies aimed at elucidating carbon allocation pathways in trees were undertaken at ORNL to determine the form, location, and seasonal changes in quantities of energy reserves of large forest growth white oak trees. Earlier studies involved biochemical and radiochemical analysis of tissue subsamples from whole ^{14}C -tagged trees. More recent within-canopy studies have been completed to examine the quantities and costs of photosynthate transfer from $^{14}\text{CO}_2$ -tagged leaves. Results from the latter study are described below.

Within-canopy photosynthate allocation in white oak was examined by ^{14}C -labelling foliage on a terminal shoot from upper and lower canopy positions of each of two trees on five dates (April 22-October 12) during the growing season. Movement of activity away from foliage was followed by subsampling at 1, 4, and 7 days after labelling and comparing levels to amounts present immediately after photosynthetic uptake of $^{14}\text{CO}_2$. Apportionment of activity between low molecular weight (labile) and structural and storage (nonlabile) constituents was followed for foliage and for branch tissues (≤ 5 years old) harvested on the seventh day after initial $^{14}\text{CO}_2$ uptake.

Data from this study showed a rapid movement of activity away from "source" leaves during the initial 24 hr with rather constant levels after the fourth day. Conversion from labile to nonlabile constituents was rapid. Approximately equal amounts of these compounds were present after one day due to more rapid utilization and export of the labile constituents. Retention of photosynthate in foliage and new shoots was quite large, $\leq 99\%$ in April when leaves were about two-thirds expanded. Retention in leaves was high, however, during the whole growing season, indicating that growth and maintenance demands of foliage consume a significant amount of photosynthate (15-20%).

Using retention of activity figures for leaves and branches, estimated photosynthetic rates of foliage, and respiration losses of both leaves and branches, it was possible to estimate apportionment of photosynthate between structural growth and maintenance, respiratory losses, and translocation of photosynthate from the canopy to "sinks" for photosynthate utilization within the tree. These data are shown in Table 10.2. They point out the high significance of within-canopy processes in photosynthate utilization. In April, leaves and branches used more photosynthate than they produced, resulting in a net drain on the energy reserves of the tree. Incorporation and respiratory losses comprised a significant drain on the availability of photosynthate for export to whole-tree functions throughout the growing season. Within-canopy utilization was generally highest in the upper canopy. This was due to greater respiratory losses and greater fixation in upper canopy branches.

This research highlights the significance of carbon allocation processes in assessing the availability of substrate to meet demands of growth, development, and stress resistance in forest trees. Future studies with other species under a range of environmental conditions will further elaborate the role of carbon allocation patterns in forest ecosystem dynamics.

Table 10.2 Seasonal changes in allocation of photosynthate by white oak

Date	Gross photosynthesis ^a ($\text{mg CO}_2 \text{ dm}^{-2} \text{ hr}^{-1}$)	Incorporation (%) ^b		Respiration (%) ^b		Translocation (%) ^b	
		Leaves	Branches ^c	Leaves	Branches	Leaves	Branches
April 22-29	5.9	41	3	94	5	-35	-43
May 17-24	9.0	16	8	26	5	58	45
June 17-24	10.4	22	14	27	6	51	31
August 2-9	9.3	15	14	33	13	52	25
October 4-11	4.0	15	15	14	21	71	35

^aGross photosynthetic rates are based on field data obtained for white oak by Dougherty (1977). These are average rates for 1 to 12 days during each month for the interval 0500 to 1800 hr. Dark respiration was assumed to equal light respiration.

^bExpressed as a percent of gross photosynthesis.

^cBranch incorporation includes buds and acorns, when present.

Scaled Soil Hydraulic Properties and Water Budget Modeling

Scaling of soil physical properties, based on the similar media concept, provides a means of representing soil spatial variability in terms of a single stochastic variable, the scaling factor (α). This factor is related to the microscopic characteristic length of the soil and increases for more coarse soils and decreases for soils finer than the standard soil which is arbitrarily given an α value of 1. Based on the variability of α derived from infiltration measurements (log-normally distributed with an arithmetic mean of 1.0 and coefficient of variation of 0.6), the effects of soil spatial variability on the water budget components of a grassland watershed were simulated with the terrestrial ecosystem hydrology model (TEHM) (Huff et al. 1977). Monthly simulations of evapotranspiration (ET), surface runoff, deep drainage, and change in soil-water storage were made for 14 selected values of α , representing soils ranging from clay at low α to sand at high α . Vegetation and meteorological parameters were the same for all the soils. Deep drainage increased with increasing α , while ET and surface runoff decreased. Once surface runoff was generated, it increased very rapidly with decreasing α . Integrated hydrologic responses of the watershed calculated by assuming a log-normal and normal area distribution of α showed differing water budget results. Greater surface runoff was predicted by the normal distribution than by the log-normal distribution of soils. It was further shown that the water budget simulated by the mean scaling factor ($\alpha = 1.0$) was significantly different from the integrated response predicted by either of the area distributions (Sharma and Luxmoore, submitted). This result contrasted with an earlier analysis for Walker Branch Watershed which showed that one set of average soil properties had similar simulated water budget results as a normal distribution of scaled soils for either summer or winter conditions (Peck et al. 1977). These contrasting studies reveal the complexities of soil-plant-atmospheric interactions and show the limitations of drawing generalizations. The influence of soil variability on water budgets is highly dependent on the extent of variability (coefficient of variation of α), the distribution function of the scaling factor, and the soil-plant-weather combination.

Measured and Simulated Plant-Water Relations of Yellow Poplar

The conversion of the original daily version of the PROSPER model (Goldstein and Mankin 1972) of soil-plant-water relations to an hourly version (Huff et al. 1977) was tested in a model application to experimental data from a field study of yellow poplar water relations (McConathy et al. 1976). The model was parameterized for the soil, plant, and meteorological conditions of the field environment, and simulations were conducted for the 1973-1974 study period (Luxmoore et al. 1978). Simulated evapotranspiration (ET) was 66.5 cm/year for each year even though the precipitation was 21% higher in the second year. There was a 54% increase in simulated drainage through the root zone in the second year. Elwood and Henderson (1975) estimated ET to be 61 cm/year for Walker Branch Watershed, based on the differences between annual rainfall and streamflow for the 1969-1972 period. The simulated ET is 9% higher than the indirect watershed estimate. There is a need to directly measure ET for more critical comparison with simulation results.

Leaf xylem water potential was measured experimentally with the pressure bomb apparatus, and comparisons with the temporally corresponding values obtained by simulation (Fig. 10.5) show data along the 1:1 relationship. The range of field variability of up to 5 bars is not represented in the model. Comparisons made for morning (AM) readings show that on some occasions the field plant had higher leaf water potential than the simulated plant, suggesting that roots below 2 m (not represented in the model) may have an important role in overnight recovery in plant-water status. The simulations approximated hourly stomatal resistance on about half of the measurement occasions. The model was unable to account for low stomatal resistance at low leaf-water potential, and some modifications to the model structure are required.

This modeling study provided insights into field phenomena that were not discernible from the experimental data. The flux of water back into the root zone from deeper soil layers can provide a significant water source to vegetation during drying periods. In a five-day period following a storm, the direction of soil-water drainage reversed as ET dried out the upper soil layers and the water flow-back into the root zone was 18% of

Fig. 10.5. Comparison of simulated and measured leaf water potentials of yellow poplar for July-August 1973. Numbers on figure indicate the number of values at the same point.

the ET. The simulation also forecasted that soil-water potentials decreased below -5 bars on more occasions than were observed in periodic soil-water measurements, particularly during the later summer period. This may have been sufficient water stress to influence expansion of leaf cells, because a smaller mean size of new leaves was observed as the summer progressed (McConathy et al. 1976).

Foliar Nitrogen Translocation in Eastern Forest Species

The translocation and retranslocation of nitrogen in the foliage of tulip poplar (*Liriodendron tulipifera* L.), white oak (*Quercus alba* L.), and shortleaf pine (*Pinus echinata* Mill.) was calculated from temporal patterns of foliar nutrient pools (Grizzard et al. 1976) through a growing season. The calculations accounted for chemical leaching effects, but not for foliar uptake from chemicals deposited in canopies from the atmosphere.

Nitrogen translocation rates were high during the first part of May for both deciduous species and were much lower for shortleaf pine (Table 10.3). By mid-May, nitrogen was being retranslocated at a slow rate out of the foliage, suggesting that the recycling to new growth centers was an important demand on limited nitrogen supply during the early part of the growing season. Nitrogen retranslocation increased during the fall for tulip poplar but not for white oak or shortleaf pine. A similar pattern of results was obtained for phosphorus translocation.

Table 10.3. Leaf nitrogen fluxes for three forest species during a growing season

Species	Period	Mean nitrogen fluxes ($\mu\text{g}/\text{leaf}/\text{day}$)		
		Net translocation	Estimated leaching	Total translocation
Tulip poplar	May 2 - 16	168.6	1.2	169.8
	May 16 - July 29	-8.1	1.3	-6.8
	July 29 - Oct 15	-43.1	1.0	-42.1
White oak	May 2 - 16	231.1	0.8	231.9
	May 16 - July 2	-49.4	0.9	-48.5
	July 2 - Sept 13	18.1	0.8	18.9
	Sept 13 - Oct 29	-32.2	0.8	-31.4
Shortleaf pine	May 2 - July 2	8.2	0.1	8.3
	July 2 - Aug 26	-12.7	0.1	-12.6
	Aug 26 - Oct 29	-0.3	0.1	-0.2

The sources of nitrogen supply to foliage of a deciduous forest during the spring flush were investigated by simulation in which a constant soil solution concentration of 0.01 ppm N resulted in a simulated uptake of 100 kg N/ha/year. This uptake lies within the estimate of 95 kg N/ha/year for Coweeta, North Carolina (Mitchell et al. 1975), and 124 kg N/ha/year for Walker Branch Watershed (Henderson and Harris 1975). The simulated uptake of nitrogen from soil early in the growing season could only account for 20 to 25% of the observed nitrogen levels translocated to foliage in that time period. This suggests that nitrogen storage pools within vegetation were the major source of nutrient supplied to the foliage and that continuing uptake from soil during the growing season replenished these internal pools.

Environmental Research Park and Forest Resources

Environmental Research Park

In recent years the bobcat (*Lynx rufus*) has become an economically important furbearer, in part due to its substitution for the large spotted cats whose fur is no longer available on the international market. This change in status brought an urgent need for more knowledge about the behavior of the bobcat. While progress has been made in gaining this knowledge in some parts of the United States, the bobcat has received relatively little attention in the southeast, in general, and virtually no attention in the State of Tennessee.

On the Oak Ridge Environmental Research Park, more knowledge of the habits of the bobcat was desired to input into the overall wildlife management program being developed for the park. In March 1978, a study of bobcats of the area was initiated with the radiotagging of an adult female and the subsequent capture and tagging of an adult male. Home range and activity patterns were determined for the two bobcats in an eastern Tennessee hardwood forest. Home range of the male was calculated to be approximately 3076 ha while the female utilized 1416 ha (Fig. 10.6). The ranges of both bobcats were larger than those previously reported for the southeast. Measurements of average net distance traveled per day showed the male moved a statistically significant, greater distance than the female. The larger home ranges may be primarily the result of relatively low prey populations in the mountainous terrain of east Tennessee as compared to upper coastal plains areas where most of the previous research on southeastern bobcats has been conducted.

Fig. 10.6. Areas used by a female bobcat radio-tracked on Oak Ridge Reservation during three five-day periods of intensive radiolocation efforts.

Forest Resource Management

The forest resource management program on the DOE Oak Ridge Reservation completed 14 years of operation under the multiple-use sustained-field objectives. Management activities over the past year included cleanup and reforestation of southern pine beetle kill areas and understocked areas on 144 ha. Table 10.4 lists the species planted, total number of seedlings, acres planted by species, species and acres to be planted for the following year, and a comparison of seedling survival rates over the past five years. The average seedling survival rate for 1978 was 94% for hardwood and 95% for pine.

Site preparation for the 1979 planting season was progressing well through September with 123 ha cleared, 85 ha piled and burned, and 16 ha harrowed. Species to be planted in these areas are listed in Table 10.4. Fertilizer growth response studies with hardwood species will be conducted on a portion of this area, using sewage effluent and chemical fertilizers. The first effluent study on the DOE Reservation was initiated in the early spring of 1978 with the application of a dewatered effluent prior to planting loblolly pine. Preliminary results indicate satisfactory seedling survival and increased growth rates with weed control. Soil solution samples revealed ammonia, nitrate, and phosphate releases well below the required EPA standards. More detailed information will be available as these studies progress.

Table 10.4. Planting summary for 1973 and 1979 and survival rate comparison

Species	Seedlings 1979	Acres to plant 1979	Seedlings planted 1973	Acres planted 1973	Survival rates (%)				
					1973	1977	1978	1979	1979
Loblolly pine <i>L. longleaf</i>	165,000	219	177,000	283	95	95	94	95	94
Green ash <i>Fraxinus pennsylvanica</i>	--	--	--	--	--	96	92	96	--
White ash <i>Fraxinus americana</i>	8,500	20	10,000	13	95	--	--	--	--
Sycamore <i>Platanus occidentalis</i>	9,000	21	1,500	5	99	96	93	96	--
Tulip tree <i>Liriodendron tulipifera</i>	8,500	20	11,000	23	100	77	--	64	--
River birch <i>Betula nigra</i>	--	--	--	--	--	76	96	86	--
Black walnut <i>Juglans nigra</i>	2,000	4	1,000	2	92	89	92	92	--
White pine <i>Pinus strobus</i>	--	--	--	--	--	92	--	--	--
Eastern cottonwood <i>Populus deltoides</i>	9,000	21	5,000	21	94	82	96	89	--
European alder <i>Alnus glutinosa</i>	--	--	--	--	--	100	--	--	--
Bald cypress <i>Taxodium distichum</i>	--	--	100	1	96	97	--	--	--
White walnut <i>Juglans nigra</i>	--	--	100	1	--	100	--	--	--
Chinese chestnut <i>Castanea mollissima</i>	--	--	500	1.5	96	--	--	--	--
White mulberry <i>Morus alba</i>	--	--	500	1.5	76	--	--	--	--
	202,000	325	208,700	357	94.5	94	85	89	64

With the assistance of three summer forestry students, timber type maps and cruises were completed in Compartment numbers A-2, A-3, A-7, 5, 7, 16, 19, and 28. Drafted-type maps were completed on these compartments as well as on Compartment number 1. This brings the total compartments inventoried to 17, or 49% of the reservation.

Five sawtimber sales totalling 1,313,000 bd ft were sold to American Forest Products Corporation under the 10-year timber sales contract between DOE and AFPC. Two pine sawtimber spot-bid sales were also made, bringing the total timber sold during this period to 1,367,649 bd ft. Pine pulpwood sales to Anderson County Pulpwood totaller 2,335 cords; only 500 cords of hardwood were sold on spot bid sales.

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PART III. APPENDICES

PUBLICATIONS,* PRESENTATIONS, THESES, AND PROFESSIONAL ACTIVITIES

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Presentations

Adams, S. M.

"Potential effects of geopressure development on the ecology of estuarine systems," Environmental Concerns of Geopressure Development in Texas Conference, University of Texas, Austin, Texas, February 1978.

"A mathematical model to simulate the effects of induced stress on seagrass communities," Estuarine Research Conference, Ft. Pierce, Florida, May 1978.

"Methodologies for assessment of power plant ecological effects on the marine environment," International Hydraulic Works Conference, University of Tennessee, Knoxville, Tennessee, September 1978.

Arora, H. S., J. B. Dixon, C. E. Pugh, and L. R. Hossner

"Sulfur forms in east Texas lignitic coal: I. Fractionation and mineral types," 1977 Annual Meetings, Soil Science Society of America, Los Angeles, California, November 1977.

Auerbach, S. I.

"Environmental issues in domestic energy development," 87th Annual Meeting of the Tennessee Academy of Science, Tennessee Technological Institute, Cookeville, Tennessee, 1977.

"Health and ecological effects of increased coal utilization," Seminar on Environmental Quality and Natural Resources, Executive Seminar Center, Oak Ridge, Tennessee, April 1978.

"Environmental programs at ORNL," Graduate Program in Ecology Seminar, University of Tennessee, Knoxville, Tennessee, May 1978.

"Energy and the environment," ORAU Science and Technology Faculty Development Program for DePaul University, Oak Ridge Associated Universities, Oak Ridge, Tennessee, May 1978.

"Radioecology revisited: A view of nuclear power from the perspective of one ecologist," LaMont Cole Symposium, Cornell University, Ithaca, New York, May 1978.

"Environmental problems of energy technologies," ORNL Summer Seminar Series, Oak Ridge, Tennessee, August 1978.

"Ecosystem responses to stress - A review of concepts and approaches," Second International Congress of Ecology, Jerusalem, Israel, September 1978.

Barnthouse, L. W.

"Dynamic models of an aquatic multispecies system," Poster Session at Meetings of the Ecological Society of America, American Institute of Biological Sciences, University of Georgia, Athens, Georgia, August 1978.

Blaylock, B. G.

"The effect of ionizing radiation on the thermal tolerance of Gambusia affinis," Symposium on Energy and Environmental Stress in Aquatic Systems, Augusta, Georgia, November 1977.

Boegly, W. J., Jr.

"Solid waste management," First Symposium on Potential Health and Environmental Effects of Synthetic Fossil Fuel Technologies, Gatlinburg, Tennessee, September 1978.

Bradburn, D. M.

"Chain saw safety," Plant and Equipment Division, Oak Ridge National Laboratory, April 1978.

"Fire fighting and control," Plant and Equipment Division, Oak Ridge National Laboratory, May 1978.

Burgess, R. L.

"The potential of biomass as an energy source," US-Mexico Bilateral Meeting, Society of American Foresters, Albuquerque, New Mexico, October 1977.

"Biology, biology teaching, and biology teachers," Midwestern Association of College Biology Teachers, Monmouth College, Monmouth, Illinois, October 1977.

Burness, R. L. (continued)

"Basic biology for editors," Editorial Staff, Technical Publications Department, Oak Ridge National Laboratory, January 1978.

"The National Biological Monitoring Inventory," National Conference on Biological Monitoring, North Carolina State University, Raleigh, North Carolina, March 1978.

"Applications of ecosystem analysis to environmental impact assessment," Science and Public Policy Seminar, University of Wisconsin-Parkside, Kenosha, Wisconsin, April 1978.

"Data management and analysis for environmental monitoring programs," MAB 8 Steering Committee, Oak Ridge National Laboratory, July 1978.

"ORNL capabilities in environmental data management," MAB 8 Directorate, Harpers Ferry, West Virginia, September 1978.

Cada, G. F., and A. T. Szluha

"A biological evaluation of devices used for reducing entrainment and impingement losses at thermal power plants," International Symposium on the Environmental Effects of Hydraulic Engineering Works, Knoxville, Tennessee, September 1978.

Cerling, T. E., B. W. Cerling, G. H. Curtis, R. E. Drake, and F. H. Brown

"Correlation of reworked ash deposits; The KBS Tuff, Northern Kenya," Fourth International Conference on Geochronology, Cosmochronology, and Isotope Geology, Aspen, Colorado, August 1978.

Cerling, T. E., R. L. Hay, and J. R. O'Neil

"Isotopic, geochemical, and faunal evidence for Pleistocene climatic change in East Africa," Fourth International Conference on Geochronology, Cosmochronology, and Isotope Geology, Aspen, Colorado, August 1978.

Christensen, S. W.

"Population modeling activities," Tennessee Valley Authority visitors, Oak Ridge National Laboratory, May 1978.

"Introductory remarks," Module on Entrainment of Fish by Power Plants, 108th Annual Meeting, American Fisheries Society, University of Rhode Island, Kingston, Rhode Island, August 1978.

Christensen, S. W. (J. Boreman, C. P. Goodyear, and S. W. Christensen)

"An empirical transport model for evaluating entrainment of aquatic organisms by power plants," Module on Entrainment of Fish by Power Plants, 108th Annual Meeting, American Fisheries Society, University of Rhode Island, Kingston, Rhode Island, August 1978.

Coutant, C. C.

"Biological considerations in the assessment of waste heat discharges into surface waters in the United States," Umweltbundesamt (Federal Environmental Agency), Berlin, Federal Republic of Germany, October 1977.

"ORNL cooling systems research program and highlight: Temperature selection by striped bass in Cherokee Reservoir, Tennessee," International Atomic Energy Agency Research Coordination Meeting, Kalpakkam, India, December 1977.

"Energy and the environment," Teachers Midyear Training Session, Woodland School, Oak Ridge, Tennessee, January 1978.

Coutant, C. C. (continued)

"Cooling systems program," World Press Institute Fellows, Oak Ridge, Tennessee, January 1978.

"Environmental effects of energy production," Inhouse Energy Course, Oak Ridge National Laboratory, January 1978.

"Effects of power plants on aquatic life," Southern Colleges and University Union students, Oak Ridge National Laboratory, March 1978.

"Cherokee Reservoir striped bass telemetry studies," Tennessee Outdoorsman, WSKV-TV, Channel 2, Knoxville, Tennessee, March 1978.

"Cooling systems program," Environmental Sciences Division Press Day, Oak Ridge National Laboratory, June 1978.

"Striped bass in Cherokee Reservoir - Needed research in temperature effects," Carson-Newman College, Summer Institute, Jefferson City, Tennessee, June 1978.

"Thermal effects on aquatic systems," Oak Ridge Associated Universities Summer Institute, Oak Ridge, Tennessee, August 1978.

"Cooling systems - Status of research and regulation," Summer Seminar, Electric Power Research Institute, Seattle, Washington, August 1978.

Cox, D.K.

"Acclimation states of juvenile striped bass, *Morone saxatilis*, held in constant and fluctuating temperature regimes," Symposium on Energy and Environmental Stress in Aquatic Systems, Augusta, Georgia, November 1977.

Twenty-three scheduled lecture-tours of the Aquatic Ecology Laboratory (Bldg. 1504), Oak Ridge National Laboratory.

Cushman, R. M., S. G. Hildebrand, and R. W. Brocksen

"The potential impacts on aquatic ecosystems from the release of trace elements in geothermal fluids," Symposium on Energy and Environmental Stress in Aquatic Systems, Augusta, Georgia, November 1977.

Cutshall, N. H.

"Zinc, cadmium, and mercury in Pacific hake," Invited seminar, National Environmental Research Center, U.S. Environmental Protection Agency, Corvallis, Oregon, June 1978.

DeAngelis, D. L. (C. C. Coutant, R. B. McLean, and D. L. DeAngelis)

"Influences of physical and chemical alterations on predator-prey interaction," Invited paper at Predator-Prey Symposium, Atlanta, Georgia, July 1978.

DeAngelis, D. L., C. C. Travis, and W. M. Post

"Mathematical models applied to the problem of seed dispersal among forest islands and the persistence of species," Meetings of the Ecological Society of America, American Institute of Biological Sciences, University of Georgia, Athens, Georgia, August 1978.

DeSha, C. M., and B. J. Dozier

"A direct counting method for assessing the performance of bioreactors," Society for Industrial Microbiology Meeting, Houston, Texas, August 1978.

Dye, L. L., and J. S. Mattice

"Effects of temperature on growth, fecundity, and emergence of burrowing mayflies located near a power plant," Symposium on Energy and Environmental Stress in Aquatic Systems, Augusta, Georgia, November 1977.

"Evidence for active selection as a factor in *Hexagenia* distribution patterns," North American Benthological Society Meetings, Winnipeg, Manitoba, May 1978.

Edwards, N. T.

"The effects of stem girdling on biogeochemical cycles within a mixed deciduous forest in eastern Tennessee. I. Soil solution chemistry, soil respiration, litter-fall, and root biomass studies," Meetings of the Ecological Society of America, American Institute of Biological Sciences, University of Georgia, Athens, Georgia, August 1978.

Elwood, J. W., J. J. Beauchamp, and C. P. Allen

"Chromium levels in fish from a lake contaminated with chromates from cooling towers," Symposium on Energy and Environmental Stress in Aquatic Systems, Augusta, Georgia, November 1977.

Emanuel, W. R.

"Some applications of optimization in environmental planning," Environmental Engineering Program Seminary, University of Tennessee, Knoxville, Tennessee, January 1978.

"Spectral analysis in ecology," Systems Ecology class, University of Tennessee, Knoxville, Tennessee, January 1978.

"Applications of multiple objective optimization to forest resource management," School of Forest Resources and Conservation, University of Florida, Gainesville, Florida, April 1978.

Floran, R. J.

"Impact-melt model for the formation of immiscible silicate and metallic liquids in the Simondium, Pinnaroo, and Hainholz mesosiderites," 41st Annual Meeting of the Meteoritical Society, Sudbury, Ontario, Canada, August 1978.

Floran, R. J., and M. Prinz

"Silicate petrography and classification of the mesosiderites," 9th Lunar and Planetary Science Conference, Johnson Space Center, Houston, Texas, March 1978.

Francis, C. W., and C. M. DeSha

"Factors influencing rates of biological denitrification in waste-streams from nuclear-related industries," Symposium on Biotechnology in Energy Production and Conservation, Gallatinburg, Tennessee, May 1978.

Gardner, R. H., and R. V. O'Neill

"Uncertainty in ecosystem models," Poster Session at Meetings of the Ecological Society of America, American Institute of Biological Sciences, University of Georgia, Athens, Georgia, August 1978.

Garten, C. T., Jr., and E. A. Bondietti

"Environmental mobility of plutonium, uranium, and thorium in a humid forest ecosystem," Meetings of the Ecological Society of America, American Institute of Biological Sciences, University of Georgia, Athens, Georgia, August 1978.

Gehrs, C. W.

"Environmental implications of coal conversion technologies: Organic contaminants," Symposium on Energy and Environmental Stress in Aquatic Systems, Augusta, Georgia, November 1977.

"Environmental testing," Symposium on Application of Short-Term Bioassays in Fractionation and Analysis of Complex Environmental Mixtures, Williamsburg, Virginia, February 1978.

"Environmental research related to coal conversion processes," Environmental Protection Agency Meeting on Measurements and Biotesting at Coal Gasification Facilities, Research Triangle Park, North Carolina, February 1978.

"Potential environmental effects of coal conversion technologies," University of Kentucky, Lexington, Kentucky, April 1978.

Giddings, J. M.

"Measurement of ecosystem properties in microcosms," University of Georgia, Institute of Ecology, Athens, Georgia, October 1977.

"Two perspectives on nutrient limitation in algae," University of Tennessee, Department of Botany, Knoxville, Tennessee, November 1977.

Giddings, J. M., B. T. Walton, G. K. Eddlemon, and K. G. Olson

"Transport and fate of anthracene in aquatic microcosms," Workshop on Microbial Degradation of Pollutants in Marine Environments, Pensacola Beach, Florida, April 1978.

Grizzard, T., and R. J. Luxmoore

"Nitrogen and phosphorus foliar dynamics in selected eastern forest species," Meetings of the Ecological Society of America, American Institute of Biological Sciences, University of Georgia, Athens, Georgia, August 1978.

Haynes, R. J.

"Some environmental problems associated with abandoned underground coal mines," Energy Division, Oak Ridge National Laboratory, November 1977.

Haynes, R. J., S. G. Hildebrand, and R. E. Millemann

"Enhanced oil recovery: Potential environmental consequences, reclamation problems and research needs," 3rd Annual Meeting of Canadian Land Reclamation Association, Sudbury, Ontario, May 1978.

Herbes, S. E.

"Aquatic impacts of oil shale development," 2nd Annual Meeting on Potential Environmental Effects of Oil Shale Development, Richland, Washington, November 1977.

Hildebrand, S. G.

"Aquatic impacts of power plant construction and operation," Oak Ridge Associated Universities Course "Energy Production and the Environment," Oak Ridge, Tennessee, June 1978.

Huckabee, J. W.

"Acid rock in the Great Smokies: Impact of road building in regions of sulfide mineralization," Science classes, Chuckey-Doak High School, Afton, Tennessee, December 1977.

Huckabee, J. W. (continued)

"Validation of pathway models for ^{99}Tc ," Atomic Safety and Licensing Board Panel Meeting, Oak Ridge National Laboratory, September 1978.

Huff, D. D.

"Development of hydrologic/water quality models and agriculture and forestry," Sea Regional Technical Committee S-108, Gainesville, Florida, April 1978.

"Application of a hydrologic processes model," Invited seminar, USDA Sedimentation Laboratory, Oxford, Mississippi, July 1978.

"Hydrology and hydrologic transport," DOE Geosciences Working Group Meeting, Germantown, Maryland, September 1978.

Johnson, D. W., and M. T. Edwards

"Effects of stem gridling on biogeochemical cycles within a mixed deciduous forest in eastern Tennessee. II. Soil nitrogen mineralization and nitrification rates," Meetings of the Ecological Society of America, American Institute of Biological Sciences, University of Georgia, Athens, Georgia, August 1978.

Johnson, D. W., G. S. Henderson, and D. W. Cole

"Sulfate budgets and soil sulfate adsorption properties in a tropical, temperate deciduous, and temperate coniferous forest," Pacific Division, American Association for the Advancement of Science Meeting, Seattle, Washington, June 1978.

Kirk, B. L., and B. W. Rust

"Maximum entropy spectral analysis of population time series," Society for Industrial and Applied Mathematics Fall 1977 Meeting, Albuquerque, New Mexico, October-November 1977.

Kitchings, J. T., L. K. Mann, and J. D. Story

"Oak Ridge Environmental Research Park," Poster Session at Meetings of the Ecological Society of America, American Institute of Biological Sciences, University of Georgia, Athens, Georgia, August 1978.

Klopatek, J. M.

"The energetics of managed land-use systems," International Conference on Energy Use Management, Tucson, Arizona, October 1977.

"The Department of Energy's role in the U.S. Forest Service's RARE-II process," DOE's Energy and Land-Use Conflicts Conference, Washington, D.C., March 1978.

Klopatek, J. M., J. T. Kitchings, K. D. Kumar, and R. J. Olson

"A hierarchical system for evaluating ecological resources," Meetings of the Ecological Society of America, American Institute of Biological Sciences, University of Georgia, Athens, Georgia, August 1978.

Kroodsmas, R. L.

"The environmental impact statement process," Oak Ridge Associated Universities Energy Workshop, Oak Ridge, Tennessee, October 1977.

"Evaluation of a proposed transmission line's impacts on waterfowl and eagles," U.S. Fish and Wildlife Service Impacts of Transmission Lines on Birds in Flight Workshop, Oak Ridge, Tennessee, January 1978.

Kumar, K. D., and J. S. Griffith

"Temporally stratified sampling programs for estimation of fish impingement," Fourth National Workshop on Entrainment and Impingement, Chicago, Illinois, December 1977.

Kumar, K. D., E. H. Nicklin, A. S. Paulson, and L. J. Vaught-Nicklin

"A control chart approach for monitoring consumer complaint data," Poster Session, American Statistical Association Annual Meeting, San Diego, California, August 1978.

Kumar, K. D., and W. Van Winkle

"Estimates of relative stock composition of the Atlantic Coast striped bass population based on the 1975 Texas Instruments data set," 1978 Northeastern Fish and Wildlife Conference, Greenbrier, West Virginia, February 1978.

Lee, S. Y., M. Aba-Husayn, and J. B. Dixon

"Mineralogy of Saudi Arabian soils: II. Eastern region," American Society of Agronomy, Los Angeles, California, November 1977.

Lindberg, S. E.

"Field determination of wet and dry deposition to a forest canopy: The relationship to plant effects," 10th Annual Air Pollution Workshop, Minneapolis, Minnesota, April 1978.

"The role of wet and dry deposition in trace element cycling at Walker Branch Watershed," Atmospheric Sciences Group, Brookhaven National Laboratory, Upton, Long Island, New York, June 1978.

Lindberg, S. E., and R. R. Turner

"Precipitation chemistry research at Walker Branch Watershed: Relationship to METER studies at Plant Bowen," First Meteorological Effects of Thermal Energy Releases Workshop, Cartersville, Georgia, May 1978.

Loar, J. M.

"An analysis of factors influencing the impingement of threadfin shad at power plants in the Southeastern United States," Fourth National Workshop on Entrainment and Impingement, Chicago, Illinois, December 1977.

Luxmoore, R. J.

"Diurnal carbon, water, and solute dynamics in plants," American Society of Agronomy Annual Meetings, Los Angeles, California, November 1977.

"Ecological implications of diurnal carbon, water, and solute dynamics of plants," Meetings of the Ecological Society of America, American Institute of Biological Sciences, University of Georgia, Athens, Georgia, August 1978.

Mattice, J. S.

"Interaction of Corbicula with power plants," First International Corbicula Symposium, Texas Christian University, Fort Worth, Texas, October 1977.

"Power plant impacts on the aquatic environment: Predictive analysis," Biology Department, University of Tennessee, Chattanooga, Tennessee, March 1978.

"Thermal effects on mayfly and Asiatic clam populations," Program Review Committee, Oak Ridge National Laboratory, April 1978.

Mattice, J. S. (continued)

"Safe limits on chlorine releases at power plants," Middle Tennessee State University Seminar on Environmental Problems, Oak Ridge National Laboratory, May 1978.

"General impacts of thermal pollution," DOE-sponsored College Faculty Institute, "Energy Production and the Environment," Oak Ridge Associated Universities, Oak Ridge, Tennessee, June 1978.

"Interactions of power plants with aquatic ecosystems," Teacher-Demonstrator trainees, Oak Ridge Associated Universities Energy Education Division, Oak Ridge National Laboratory, July 1978.

McBrayer, J. F., and Kermit Cromack, Jr.

"Decomposers, decomposition, and snow: Organic matter turnover and nutrient release in a Minnesota forest," Meetings of the Ecological Society of America, American Institute of Biological Sciences, University of Georgia, Athens, Georgia, August 1978.

McLaughlin, S. B.

"Effects of SO₂ on transpiration and photosynthesis of kidney beans," ERDA Air Pollution Workshop, Oak Ridge, Tennessee, December 1977.

"Air pollution effects research and the challenges of integrated assessment," Southwide Forest Disease Workshop, University of Kentucky, Lexington, Kentucky, February 1978.

"Acid deposition," Environmental Protection Agency-Air Pollution Training Session, Boston Massachusetts, June 1978.

McLaughlin, S. B., and R. K. McConathy

"Seasonal changes in allocation of ¹⁴C-photosynthate by White Oak (*Quercus alba* L.)," Meetings of the Ecological Society of America, American Institute of Biological Sciences, University of Georgia, Athens, Georgia, August 1978.

McLaughlin, S. B., and D. S. Shriner

"Air pollution problems and approaches," (1) ORNL-Executive Committee; (2) Frank Press, Presidential Science Advisor, and John Deutch, DOE Research Director; and (3) President Jimmy Carter and invited guests, Oak Ridge, Tennessee, May 1978.

McLaughlin, S. B., D. C. West, H. H. Shugart, and D. S. Shriner

"Air pollution effects of forest growth on succession: Applications of a mathematical model," 71st Annual Meeting of Air Pollution Control Association, Houston, Texas, June 1978.

Newbold, J. D. (Jerry W. Elwood and J. Denis Newbold)

"Material spiralling in stream ecosystems," Meetings of the Ecological Society of America, American Institute of Biological Sciences, University of Georgia, Athens, Georgia, August 1978.

Oakes, Kathleen M.

"Environmental impacts of geothermal energy," Faculty Energy Institute, Eastern Michigan University, Ypsilanti, Michigan, July 1978.

Olson, J. S.

"Biospheric and atmospheric carbon models," Invited paper at Institute of Meteorology Workshop, University of Stockholm, Stockholm, Sweden, August-September 1978.

"Biospheric and climatic effects of forest clearance," Second International Congress of Ecology, Hebrew University, Jerusalem, Israel, September 1978.

"Biospheric and atmospheric carbon models," Invited paper at International Conference on Man-Environmental Interactions for SCOPE (Scientific Committee on Problems of the Environment), Telavi, Georgia, USSR, September 1978.

"The biosphere and global carbon budgets," Ecology Institute, Lund University, Lund, Sweden, September 1978.

O'Neill, R. V.

"Sources of heterogeneity and ecosystem function," Battelle Memorial Institute, Columbus, Ohio, January 1978.

"Hierarchy theory," International Symposium on Statistical Ecology, Jerusalem, Israel, September 1978.

"Review of woodland ecosystem modeling," Second International Congress of Ecology, Jerusalem, Israel, September 1978.

Parkhurst, B. R., C. W. Gehrs, and I. B. Rubin

"The value of chemical fractionation for identifying the toxic components of complex aqueous effluents," Second Chemical Symposium on Aquatic Toxicology, American Society for Testing and Materials, Cleveland, Ohio, October-November 1977.

Parkhurst, B. R., (G. R. Southworth, B. R. Parkhurst, and J. J. Beauchamp)

"Accumulation of acridine from water, food, and sediment by the fathead minnow, *Pimephales promelas*," Annual Meeting of the American Fisheries Society, University of Rhode Island, Kingston, Rhode Island, August 1978.

Parr, P. D.

"Rare plants on the Oak Ridge Reservation," Oak Ridge High School classes, Oak Ridge National Laboratory, May 1978.

"Rare plants on the Oak Ridge Reservation and their habitats," Botany class, Oak Ridge High School, Oak Ridge, Tennessee, May 1978.

Roop, R. D.

"Energy from biomass: An overview of environmental aspects," 2nd National Conference on Technology for Energy Conservation, Albuquerque, New Mexico, January 1978.

Roop, R. D., and K. Campbell

"Generating power at existing low-head dams: Technology and environmental impacts," Oak Ridge Associated Universities Training Institutes, Oak Ridge, Tennessee, July and August 1978.

Roop, R. D., F. S. Sanders, and L. W. Barnthouse

"Coal conversion and aquatic environments: Overview of impacts and strategies for monitoring," 5th National Conference on Energy and the Environment, Cincinnati, Ohio, November 1977.

Sanders, F. S., (L. W. Barnthouse, F. S. Sanders, and R. D. Roop)

"A preliminary assessment of the potential impacts of aquatic biota of trace elements in coal conversion solid waste," Symposium on Energy and Environmental Stress in Aquatic Systems, Augusta, Georgia, November 1977.

Shaeffer, D. L., and C. A. Little

"The effects of ratioing two variables with truncated frequency distributions in radiological assessment calculations," Health Physics Society, Minneapolis, Minnesota, June 1978.

"Statistical properties of the ratio of two measured environmental variables with truncated lognormal frequency distributions," Meetings of the Ecological Society of America, American Institute of Biological Sciences, University of Georgia, Athens, Georgia, August 1978.

Shaeffer, D. L. (F. O. Hoffman, D. L. Shaeffer, C. W. Miller, and C. T. Garten, Jr.)

"Evaluation of models for assessing compliance with environmental radiation regulations," American Nuclear Society, San Francisco, California, November 1977.

Shriner, D. S.

"An overview of the ORNL Environmental Sciences Division synthetic fuels program," Second Energy Research and Development Administration Meeting and Workshop on Oil Shale and Environmental Research, Richland, Washington, November 1977.

"The utility of photosynthesis measurements as an index of chronic acid precipitation stress to plants," Department of Energy Workshop on Ecological and Agricultural Effects of Coal Combustion, Oak Ridge, Tennessee, November 1977.

"Interactions between acidic precipitation and CO_2 or O_3 : Effects on plant response," Panel Discussion on Air Pollution Effects, Southwide Forest Pathology Workshop, Lexington, Kentucky, February 1978.

"Atmospheric deposition: Monitoring the phenomenon, studying the effects," Air Pollution Control Association Specialty Conference on Methodology for the Assessment of Air Pollution Effects on Vegetation, Minneapolis, Minnesota, April 1978.

"Effects of rainfall acidification on plant pathogens - A case study," NATO Advanced Research Institute on the Effects of Acid Rain on Terrestrial Ecosystems, Toronto, Ontario, Canada, May 1978.

"Acid deposition from atmospheric sources - Effects on vegetation," Environmental Protection Agency Air Pollution Training Institute, Cincinnati, Ohio, June 1978.

"Environmental effects of coal use," Oak Ridge Associated Universities Faculty Institute on Energy Options for the Future, Oak Ridge, Tennessee, July 1978.

Shriner, D. S., H. S. Arora, N. T. Edwards, B. R. Parkhurst, and C. W. Gehrs

"Physical, chemical, and ecological characterization of solid wastes from a Lurgi gasification facility," ORNL Life Sciences Symposium on Synthetic Fuels, Gatlinburg, Tennessee, September 1978.

Solomon, A. M. (D. C. West, A. M. Solomon, T. J. Blasing, and H. R. Delcourt)

"Potential application of forest-growth simulation models to paleoenvironmental reconstruction," Poster Session, 5th Biennial Meeting, American Quaternary Association, Edmonton, Alberta, Canada, September 1978.

Strand, R. H.

"Data management for the University of Minnesota - Duluth gasifier," DOE Committee on Gasifiers in Industry, Washington, D.C., April 1978.

"Data management resources and capabilities at ORNL," Man and the Biosphere (MAB) Theme 8 Program Committee, Oak Ridge National Laboratory, May 1978.

"The data management program for the University of Minnesota - Duluth gasifier," Joint Meeting of ORNL and TVA staff with gasifier in industry involvements, Chattanooga, Tennessee, July 1978.

Strand, R. H., and R. J. Olson

"The management of diverse environmental data with SAS," Third International SAS Users Group Conference, Las Vegas, Nevada, January 1978.

Struxness, E. G.

"The environmental impact statement: Its preparation and use in the licensing and regulation of nuclear power plants," Luther College, Decorah, Iowa, October 1977.

"Nuclear power in the United States: Today's realities," Sixth Sherman Hoslett Memorial Lecture, Luther College, Decorah, Iowa, October 1977.

"Activities and assessments in the United States related to the Hahn-Meitner Institut's safety analysis of nuclear waste management," Hahn-Meitner Institut, Berlin, West Germany, May 1978.

"The environmental impact statement," Oak Ridge Associated Universities Teacher-Demonstrator Staff, Oak Ridge, Tennessee, July 1978.

"Overview of the Environmental Sciences Division," Executive Seminar Center's Workshop on Science, Technology, and Public Policy, Oak Ridge National Laboratory, October 1978.

Suffern, J. S.

"Waste heat utilization technologies," Southern Colleges and Universities Union Seminar Series, Oak Ridge, Tennessee, January 1978.

"Waste heat aquaculture: Potentials and problems," Union Carbide Corporation Technical Committee Meeting, Oak Ridge, Tennessee, April 1978.

"Waste heat aquaculture: Potential research directions at ORNL," Seed Money Review Committee Meeting, Oak Ridge National Laboratory, May 1978.

"The environmental tradeoffs associated with energy production," North Alabama Educational Opportunity Center Conference, Huntsville, Alabama, June 1978.

"The effects of energy technologies on the environment," Oak Ridge Associated Universities Summer Workshop, Oak Ridge, Tennessee, August 1978.

Suffern, J. S., S. A. Adams, B. G. Blaylock, C. C. Coutant, and C. A. Guthrie

"Growth of monosex hybrid Tilapia in the laboratory and sewage oxidation ponds," Aquaculture-Atlanta Conference, Atlanta, Georgia, January 1978.

Tamura, T.

"Studies of the movement of radionuclides in shallow land burial grounds," UCC-ND Waste Management Technology Conference, Y-12, Oak Ridge, Tennessee, January 1978.

Tamura, T. (continued)

"Plutonium-soil association: A summary report," Nevada Operations Office Annual Meeting, San Diego, California, February-March 1978.

"Environmental considerations of burial ground siting and operation," Tennessee Valley Authority Task Force, Oak Ridge, Tennessee, March 1978.

"Radionuclide transport," West Valley Decontamination and Decommissioning Task Group, Albany, New York, June 1978.

Taylor, F. G.

"Ecological studies at the Oak Ridge National Laboratory: An overview," Biology Class, Southern Union State Junior College (Wadley, Alabama), Oak Ridge, Tennessee, October 1977.

"Environmental effects studies of cooling tower operations," Environmental Chemistry Class, Murray State University (Murray, Kentucky), Oak Ridge, Tennessee, March 1978.

"Interception and retention of simulated cooling tower drift by vegetation," Cooling Tower Environment-1978 Symposium, University of Maryland, College Park, Maryland, May 1978.

"Use of phenology in environmental studies," Plant Ecology Class, University of Tennessee, Oak Ridge, Tennessee, May 1978.

"Rare plants and the Tennessee Native Plants Society," West Oak Ridge Garden Club, Oak Ridge, Tennessee, July 1978.

"Atmospheric emissions and effects of cooling tower drift on terrestrial ecosystems," Nuclear Regulatory Commission/Atomic Safety and Licensing Board Panel, Oak Ridge, Tennessee, September 1978.

Trabalka, J. R., and M. B. Burch

"Investigation of the effects of halogenated organic compounds produced in cooling systems and process effluents on aquatic organisms," Second Conference on the Environmental Impact of Water Chlorination, Gatlinburg, Tennessee, October 1977.

Trabalka, J. R., L. D. Eyman, and S. I. Auerbach

"Analysis of a Soviet incident involving nuclear wastes," Oak Ridge National Laboratory Quarterly Colloquium, September 1978.

Tsai, S. C.

"Effect of aquatic environmental factors on the partition coefficient, toxicity, and bioaccumulation of mercuric compounds," Environmental Sciences Division, Oak Ridge National Laboratory, January 1978.

Tyndall, R. L.

"Update on the problem of pathogenic amoeba in artificially heated water," East Tennessee Association of Clinical Microbiology, Knoxville, Tennessee, November 21, 1978.

Tyndall, R. L., E. Willaert, and A. R. Stevens

"Isolation of Acanthamoeba from cultured mammalian cells," Acanthamoeba Conference, Columbus, Ohio, June 14-16, 1978.

Van Hook, R. I.

"Transport and transformation pathways of hazardous chemicals from solid waste disposal," 5th Los Alamos Scientific Laboratory Life Sciences Symposium, Los Alamos, New Mexico, October 1977.

"Potential health and environmental effects of trace elements and radionuclides from increased coal utilization," President's Committee on Health and Ecological Effects of Increased Coal Utilization, Washington, D.C., November 1977.

"Biomass conversion for energy," Oak Ridge Associated Universities Institute on "Energy Production and the Environment," Oak Ridge, Tennessee, June, 1976.

"Biomass as an energy source," Oak Ridge Associated Universities Institute on "Energy Options for the Future," Oak Ridge, Tennessee, July 1978.

"Future potentials of fuels from biomass," Third Annual Governor's Conference on the Environment, Lexington, Kentucky, August 1978.

Van Winkle, W.

"The Hudson River power plant case: Scientific issues in controversy," Fisheries Laboratory, Lowestoft, England, and Fisheries Department, FAO, Rome, Italy, November 1977.

"Statistical considerations appropriate for radiation effects experiments," International Atomic Energy Agency, Vienna, Austria, November 1977.

Voorhees, L. D., and J. F. Cassel

"Highway right-of-way: Mowing versus succession as related to waterfowl nesting in North Dakota," 57th Annual Meeting of the Transportation Research Board, Washington, D.C., January 1978.

Ward, D. S., and G. T. Yeh

"Mathematical modeling in low-level radioactive waste management," Symposium on Science Underlying Radioactive Waste Management, Boston, Massachusetts, November-December 1977.

Wiener, J. G.

"Aerial inputs of cadmium, copper, lead, and manganese into a freshwater pond: Relation to a nearby coal-fired power plant," Meetings of the Ecological Society of America, American Institute of Biological Sciences, University of Georgia, Athens, Georgia, August 1978.

Yeh, G. T.

"Comparisons and verifications of storm surge analysis with emphasis on moving boundary condition," International Symposium on Long Waves in the Ocean, Ottawa, Canada, June 1978.

Theses

- Mann, L. K. 1977. Discriminant analysis of some east Tennessee forest herbs. M.S., University of Tennessee, Knoxville. 106 pp.
- Mielke, D. L. 1977. A stand model of upland forests of Southern Arkansas. M.S., University of Tennessee, Knoxville. 123 pp.
- Post, W. M. 1978. Stability criteria for multispecies ecological communities. Ph.D dissertation, University of Tennessee, Knoxville.
- Ranney, J. W. 1978. Edges of forest islands: Composition, structure, and the importance to regional forest dynamics. Ph.D. dissertation, University of Tennessee, Knoxville.
- Van Voris, P. 1977. Functional complexity and ecosystem stability: An experimental approach. Ph.D dissertation, University of Tennessee, Knoxville.

Professional ActivitiesADAMS, S. M.

- Member: Seminar Committee, Environmental Sciences Division, Division representative for Laboratory conversion to metric system.
- Participant: Workshop on Environmental Concerns of Geopressure Development in Texas, Austin, Texas, February 1978; Workshop on Geopressure Development in Louisiana Coastal Zone, Baton Rouge, Louisiana, March 1978. Preparation of South Texas PDES; Critique and Assessment of Prairie Island (316(b) Demonstration; Offshore Power Systems Final Addendum to FES; Coastal Zone Monitoring Chapter for Monitoring Strategy Document; Supplemental Testimony for Shoreham FES.
- Witness: Expert Witness, ASLB Hearings for Offshore Power Systems, Washington, D. C., June 1978.
- Ad Hoc Reviewer: Proposals, NSF and EPRI; Nuclear Safety, special scientific fisheries report for the National Marine Fisheries Service, Journal of the Water Pollution Control Federation.

ARORA, H. S.

- Participant: Oak Ridge Associated Universities course in "Radionuclides and Radiation Measurements in Ecological Studies," August 1978.
- Ad Hoc Reviewer: California Division of Mines and Geology.

AUERBACH, S. I.

- Chairman: Board of Environmental Consultants on the Tennessee-Tombigbee Waterway Project, U. S. Army Corps of Engineers.
- Member: Board of Editors, Radiation Research; Advisory Board, Environmental and Experimental Botany; DOE Ad Hoc Committee on Shallow Land Burial of Transuranic Wastes; President's Ad Hoc Committee on the Health and Ecological Effects of Increased Coal Utilization; Research Advisory Committee, Resources for the Future; ORSANCO Biological Water Quality Committee.

AUERBACH, S. I. (continued)

- Participant: Panel of Judges for the Environmental Industry Council, 1978 National Environmental Industry Awards, Washington, D. C., January 1978; Congressional Research Service Workshop on Energy Policy and Environmental Planning, Washington, D. C., February 1978; Panel on Transport Processes and Ecological Effects, EPA Third National Conference on the Interagency Energy/Environment R&D Programs, Washington, D. C., June 1978; Panel on Environmental Concerns Associated with Various Energy Systems and Fuel Cycles, Southeastern Jurisdiction Stewardship Seminar on Energy and the Environment, First United Methodist Church, Oak Ridge, Tennessee, November 1978.
- Faculty: Adjunct Research Professor of Radiation Ecology, University of Georgia, Athens, Georgia; Adjunct Research Professor, Graduate Program in Ecology, University of Tennessee, Knoxville.

BARNTHOUSE, L. W.

- Participant: Session Chairman, Symposium on Energy and Environmental Stress in Aquatic Systems, Augusta, Georgia, November 1978.
- Witness: Provided extensive assistance to EPA (Region II) staff during preparation for and conduct of adjudicatory hearings on the Hudson River Power Case (technical meetings with utility scientists, assistance to EPA technical staff, preparation of lawyers for cross-examination, assistance to lawyers during cross-examination of utility witnesses).
- Ad Hoc Reviewer: Proceedings, Symposium on Energy and Environmental Stress in Aquatic Systems.

BLASING, T. J.

- Participant: Annual Meeting of the Southeastern Division, Association of American Geographers, Knoxville, Tennessee, November 1977; United States Geological Survey Tree-Ring Seminar, Reston, Virginia, April 1978.
- Advisor: Beverly Simmons, M.S., University of Tennessee.
- Ad Hoc Reviewer: Monthly Weather Review; Science; proposal, NSF.
- Other: Guest lecturer, University of Tennessee Departments of Forestry and Geography; Vice-President, East Tennessee Chapter, American Meteorological Society.

BLAYLOCK, B. G.

- Member: Research Committee, Water Pollution Control Federation.
- Participant: Special study section for the National Institute of Environmental Health Sciences to review core proposal for the New York Medical Center, New York, July 1978.
- Faculty: Adjunct Professor, University of Tennessee, Knoxville.
- Ad Hoc Reviewer: American Naturalist, Transactions of the American Fisheries Society.

BOEGLY, W. J., JR.

- Member: Committee on Utilities (AIA03), Transportation Research Board, National Academy of Sciences, National Academy of Engineering; Committee on Dual Distribution Systems, American Water Works Association.
- Faculty: Associate Professor of Civil Engineering (Environmental Engineering), University of Tennessee, Knoxville.
- Advisor: E. C. Davis, Ph.D., Vanderbilt University; J. I. Blackmon, Ph.D., University of Tennessee.
- Other: Quality Assurance Coordinator, Environmental Sciences Division, ORNL; Environmental Sciences Division Coordinator on New ESL Laboratory Building between ESD and UCCND Engineering (ORNL); Energy Coordinator, Environmental Sciences Division.

BRADBURN, D. M.

- Other: Chairman, Elect, East Tennessee Chapter, Society of American Foresters; Tree Farm Inspector, Tennessee Tree Farm Association.

BROCKSEN, R. W.

- Member: Proposal Review Committee, ORNL.
- Participant: International Symposium on Environmental Effects of Hydraulic Structures, University of Tennessee, Knoxville, 1978 (organizing Committee Member and Session Chairman). Preparation of Fort Calhoun Nuclear Power Plant FES, Unit 2.
- Faculty: Adjunct Associate Professor, University of Tennessee, Knoxville.
- Advisor: M. Silver, M.S., University of Tennessee; B. R. Parkhurst, Ph.D., University of Tennessee; R. W. Stark, M.S., University of Tennessee.
- Ad Hoc Reviewer: Proposals, NSF, DOE; Journal of Environmental Quality; Transactions of American Fisheries Society.

BURGESS, R. L.

- Chairman: Program Committee, Ecological Society of America; Workshop on Information Exchange, National Conference on Biological Monitoring, North Carolina State University, Raleigh, North Carolina.
- Member: Executive Committee, TIE Access Project; Board of Directors, Tennessee Chapter of The Nature Conservancy Council; Ecological Society of America Committee on Ethics and Professionalism; Ecological Society of America Committee on Historical Records; Council, Ecological Society of America; ORNL Ph.D. Recruiting Program.
- Participant: Annual Meeting of the Society of American Foresters, Albuquerque, New Mexico, October 1977; Annual Meeting of the Midwest Association of College Biology Teachers, Monmouth, Illinois, October 1977; TIE Access Project Meeting, Indianapolis, Indiana, December 1977; Board of Directors meeting, Tennessee Chapter of the Nature Conservancy, Knoxville, Tennessee, May 1978; Annual meeting of the Tennessee Chapter of The Nature Conservancy, Nashville, Tennessee, March 1978; NSF Site Review, Oak Ridge National Laboratory, Oak Ridge, Tennessee, January 1978; AIBS meeting, Athens, Georgia, August 1978.

BURGESS, R. L. (continued)

Faculty: Adjunct Professor of Ecology, University of Tennessee, Knoxville.

Ad Hoc Reviewer: Ecology Program, National Science Foundation; Ecosystem Studies Program, National Science Foundation; Division of Biomedical and Environmental Research, Department of Energy; Fish and Wildlife Service; Ecology; Bulletin of the Torrey Botanical Club; Science; Journal of Forestry.

Other: Educational Program Coordinator, Environmental Sciences Division.

CADA, G. F.

Participant: Fourth National Workshop on Entrainment and Impingement, Chicago, Illinois, December 1977; Freshwater Larval Fish Workshop, Knoxville, Tennessee, February 1978; Joint Symposium on Design and Operation of Fluid Machinery, Fort Collins, Colorado, June 1978; Annual Meeting of the American Fisheries Society, Kingston, Rhode Island, August 1978; International Symposium on the Environmental Effects of Hydraulic Engineering Works, Knoxville, Tennessee, September 1978. Preparation of: New England Power Units 1 and 2 PDES; assessment of intake water screening devices; Snootering Canyon Uranium Mill PDES; Comanche Peak Chlorine Minimization study.

CERLING, T. E.

Participant: Fourth International Conference on Geochronology, Cosmochronology and Isotope Geology, Aspen, Colorado, August 1978.

CHRISTENSEN, S. W.

Participant: 108th Annual Meeting of the American Fisheries Society, University of Rhode Island, Kingston, Rhode Island, August 1978 (Organizer and Moderator, Module on Entrainment of Fish by Power Plants); Hudson River Power Case: technical meeting with utility scientists (briefing sessions with lawyers, preparation of cross-examination questions, rehearsing lawyers, assisting lawyers during cross-examination of utility witnesses, and assisting EPA technical staff).

Ad Hoc Reviewer: Research programs, DOE; U. S. Fish and Wildlife Service.

COUTANT, C. C.

Member: National Advisory Council and Aquatic Advisory Committee, Electric Power Research Institute; Wigner Postdoctoral Fellowship Selection Panel, ORNL; Working Group 6.2, Thermal Discharges, UNESCO Hydrological Programme; Cherokee Reservoir Task Force (Interagency coordination); General Energy Conservation Committee, ORNL.

Participant: Conference on Water Chlorination - Environmental Health Effects, Gatlinburg, Tennessee, October-November 1977; Review of power station research by Ontario Hydro, Toronto, Ontario, April 1978; Workshop on Research to Determine Geographic Differences in Largemouth Bass, ORNL, July 1978; Research Coordination Meeting (Cooling Systems), International Atomic Energy Agency, Karlsruhe, Federal Republic of Germany, September 1978.

Faculty: Adjunct Associate Professor, University of Tennessee, Knoxville.

COUTANT, C. C. (continued)

Advisor: Primary Research Advisor - H. Waddle, M.S., and B. Schaich, M.S., University of Tennessee; Committee member for M. Bruner, Ph.D., University of Tennessee.

Consultant: Selection panel for papers to be presented at Stockholm conference of the International Association of Water Pollution Research.

Ad Hoc Reviewer: Journal of Great Lakes Research; Fishery Bulletin; Transactions American Fisheries Society; Journal of the Fisheries Research Board of Canada.

Other: Editor, Underwater Telemetry Newsletter; Secretary-Treasurer, East Tennessee Chapter, American Fisheries Society.

COX, D. K.

Participant: Workshop on Latitudinal Geographic Differences in Thermal Responses and Genetics of Largemouth Bass, ORNL, July 1978; Symposium on Energy and Environmental Stress in Aquatic Systems, Augusta, Georgia, November 1977.

CRAIG, R. B.

Member: Technical Program Committee, American Nuclear Society; Program Committee, Ecological Society of America.

Participant: National Energy Strategy Study Core Team; Power Plant and Industrial Fuel Use Act Legislative ES; Coso Hot Springs Geothermal Project Well-Flow Test EA; Big Muddy Low-tension Flood Demonstration Project EA; Eastern United States Geothermal Drilling Activity EA.

Advisor: M. Delany, M.A., University of Tennessee.

Ad Hoc Reviewer The Auk, Science.

Other: Ph.D. recruiter.

CUSHMAN, R. M.

Participant: Preparation of East Coast Geothermal Exploration Project EA; Westmorland Geothermal Exploration Project EA, and Powerplant and Industrial Fuel Use Act of 1978 PDES. Ecosystem Quality Workshop, Santa Rosa, California, October 1977; Energy and Environmental Stress in Aquatic Systems, Augusta, Georgia, November 1977; and North American Benthological Society Meeting, Winnipeg, Manitoba, Canada, May 1978.

CUTSHALL, N. H.

Participant: Workshop on Marine Pollution (Panel on Marine Radioactivity, National Oceanic and Atmospheric Administration), Estes Park, Colorado, July 1978; Southeastern Oceanographic Contractor's Workshop, Department of Energy, Atlanta, Georgia, October 1977.

Advisor: Katsuo Nishikawa-Kinomura, M.S., Oregon State University; Vernon G. Johnson, Ph.D., Oregon State University.

CUTSHALL, N. H. (continued)

Ad Hoc Reviewer: Limnology and Oceanography; Marine Biology; American Chemical Society; American Fisheries Society; proposals, NSF, DOE, Office of Naval Research.

DeANGELIS, D. L.

Chairman: Seminar Committee, Environmental Sciences Division.

Faculty: Adjunct professor (Systems Ecology), University of Tennessee.

Advisor: Linda J. Svoboda, M.S., University of Tennessee; James J. Perkowski, M.S., University of Tennessee; W. M. Post, Post-doctoral research associate, University of Tennessee.

Ad Hoc Reviewer: Theoretical Population Ecology, American Naturalist.

DYE, L. L.

Participant: First International Corbicula Symposium, Fort Worth, Texas, October 1977.

EDDLEMON, G. K.

Participant: Computer Software Survey, Statistical Analysis System (SAS), ORNL, February-March 1978; Trace Elements in the Environment, ORAU, February 1978.

EDWARDS, N. T.

Participant: Coniferous Forest Biome Synthesis Volume Meeting, Portland, Oregon, December 1977 (Reviewer). Preparation of: Environmental Monitoring Plan for the Pike County Coal Gasification Facility, Pike County, Kentucky (preliminary draft).

Ad Hoc Reviewer: Proposal, NSF; Pedobiologia, Ecology, Botanical Gazette.

ELWOOD, J. W.

Member: Program Committee, Ecological Society of America; Editorial Committee, North America Benthological Society.

Participant: Workshop on Aquatic Ecology in the Southeast, Augusta, Georgia, October 1977.

Faculty: Adjunct assistant professor, University of Tennessee.

Advisor: Martin Silver, M.S., University of Tennessee; Robert Stark, M.S., University of Tennessee.

Ad Hoc Reviewer: Proposals, NSF, DOE; Science, Journal of the Fisheries Research Board of Canada, Ecology, Health Physics, Proceedings of Symposium on Energy and Environmental Stress in Aquatic Systems.

EMANUEL, W. R.

Participant: Workshop on State-of-the-Art Grassland Modeling, National Academy of Science, Washington, D.C., February 1978; Annual Meeting of AAAS, Washington, D.C., February 1978.

Faculty: Adjunct Member of the Graduate Faculty, Oklahoma State University.

Advisor: Secondary advisor, Yip-Ho Chan, Ph.D., University of Tennessee.

FLORAN, R. J.

Participant: 9th Lunar and Planetary Science Conference, Houston, Texas, March 1978; 41st Meteoritical Society Meeting, Sudbury, Ontario, August 1978; FORTRAN 1 (M-100B) Course, ORNL, September-October 1978; preparation of EAs for: Guyan Oil Co., West Virginia; Pennzoil Co., West Virginia; Columbia Gas Transmission Corp., West Virginia; Cities Service Co., Kansas; Phillips Oil Co., Oklahoma; Bartlesville Energy Research Center, Oklahoma; Gary Operating Co., Montana; and Penn Grade Project, Pennsylvania.

Ad Hoc Reviewer: Economic Geology; proposal, NASA.

FRANCIS, C. W.

Member: Marshall Islands Advisory Group.

Other: Associate Editor, Journal of Environmental Quality.

GARTEN, C. T.

Participant: Preparation of: "Environmental assessment strategies in support of the nonproliferation alternative systems assessment program (NASAP)"; "Nonproliferation alternative systems assessment program (NASAP) - Preliminary environmental assessment of thorium/uranium fuel cycle systems."

Ad Hoc Reviewer: Environmental and Experimental Botany, Journal of Environmental Quality, dissertation grant proposal, NSF.

GEHRS, C. W.

Participant: Chairman, Water Quantity, Quality and Aquatic Ecology Panel, DOE/EPA/HEW Interagency Workshop on Oil Shale, Environmental and Health Research Needs, Denver, Colorado, April 1978; Chairman, Water Quantity, Quality and Aquatic Ecology Panel, DOE/EPA/HEW Interagency Workshop on Coal Conversion Technologies, Environmental and Health Research Requirements, Leesburg, Virginia, August 1978; Organizing Committee, 1st Annual ORNL Life Sciences Symposium Series (Health and Environmental Effects of Coal Conversion); Organizing Committee, Symposium on Chemical Toxicology, Biology Division Annual Gatlinburg Symposium.

GIDDINGS, J. M.

Participant: Workshop on Microbial Degradation of Pollutants in Marine Environments, Pensacola Beach, Florida, April 1978.

Advisor: Richard B. Nicholson, B. S., Earham College.

GIDDINGS, J. M. (continued)

Ad Hoc Reviewer: Journal of Environmental Quality, Science; research proposals, DOE, EPRI, EPA.

GOUGH, S. B.

Participant: Annual Meeting of the American Section of The International Solar Energy Society, Denver, Colorado, August, 1978; Symposium on Biotechnology in Energy Production and Conservation, Gatlinburg, Tennessee, May 1978. Preparation of Virgil Summer Nuclear Plant OL-DES; Hot Engineering Test Facility PDES; Sundesert Nuclear Plant, Units 1 and 2 CP-DES and CP-FES; San Onofre Nuclear Generating Station, Units 2 and 3, OL-PDES and OL-DES; Conversion to Coal (COMREG; PIFUA) PDES, DES; ORGDP (K-25) PDES; Perkins Nuclear Station, Units 1, 2, and 3, Supplemental Testimony Regarding the Criteria used to Select Site Alternatives to the Perkins Site and the Examination of Site Alternatives to Perkins.

Advisor: Interim advisor for Anthony Sasson, M.S., Miami University, Ohio.

Ad Hoc Reviewer: Journal of Environmental Quality, Botanical Gazette; proposal, NSF.

HARRIS, W. F.

Chairman: Review Panel for Smithsonian's Environmental Research Program (Barro Colorado, Panama, and Chesapeake Bay Center for Environmental Studies).

Participant: Workshop on Environmental Effects of Coal Technology, Leesburg, Virginia, August 1978.

Ad Hoc Reviewer: National Science Foundation.

FAYNES, F. J.

Participant: National Coal Association/Eituminous Coal Research Conference and Expo IV, Louisville, Kentucky, October 1977; Council for Surface Mining and Reclamation Research in Appalachia, Louisville, Kentucky, October 1977; Ozarks Regional Commission Lignite Conference, Little Rock, Arkansas, March 1978; 43rd North American Wildlife and Natural Resources Conference, Phoenix, Arizona, March 1978; 42nd Annual Meeting of National Wildlife Federation, Phoenix, Arizona, March 1978; Information Meeting on Mining and the Environment, Knoxville, Tennessee, May 1978; 3rd Annual Meeting of Canadian Land Reclamation Association, Sudbury, Ontario, May 1978; Office of Surface Mining Public Meeting on Proposed Surface Mining Regulations, Knoxville, Tennessee, August 1978; Council for Surface Mining and Reclamation Research in Appalachia, ORNL, November 1978; 32nd Annual Conference, Southeastern Association of Fish and Wildlife Agencies, Hot Springs, Virginia, November 1978. Preparation of DEAs for Pennzoil Enhanced Oil Recovery Project, West Virginia; Columbia Gas Corporation Enhanced Oil Recovery Project, West Virginia; Cities Service Company, Enhanced Oil Recovery project, Kansas; Gary Operating Company's Enhanced Oil Recovery Project, Montana; and Penn Grade Enhanced Oil Recovery Project, Pennsylvania; and Kerr-McGee Uranium Mill and Mines DES and Environmental Monitoring Handbook for Coal Conversion Facilities.

Ad Hoc Reviewer: Proposals, DOE and TVA.

HERBES, S. E.

Participant: Workshop on Environmental Effects of Coal Conversion Technologies (Aquatic Transport Subpanel), Leesburg, Virginia, August 1978.

Ad Hoc Reviewer: American Society for Testing and Materials.

HILDEBRAND, S. G.

Participant: Session Chairman, Long-Run Basin-Wide Effects of Hydraulic Works, International Symposium on Environmental Effects of Hydraulic Engineering Works, Knoxville, Tennessee, September 1978.

Ad Hoc Reviewer: Journal of Environmental Quality.

HUCKABEE, J. W.

Participant: Planning session for ⁹⁹Tc studies, Pacific Northwest Laboratory, Richland, Washington, October 1977; ORNL/OR/NSF Almaden Project Meeting, University of Rochester, October 1977; Briefing session and discussion on ⁹⁹Tc studies at DOE/DBER HG, Germantown Maryland, June 1978; Briefing session and discussions at EPA/ORP HQ, Washington, D.C., June 1978.

Advisor: ORAU summer student, Jane Baird, B.S., Duke University.

Ad Hoc Reviewer: Journal of Environmental Quality, Archives of Environmental Contamination and Toxicology, Environmental Science and Technology, Journal of Wildlife Management, Science.

HUFF, D. D.

Member: Associate Board of Editors, Water Resources Monographs (American Geophysical Union); Science and Education Administration (SEA) Regional Technical Committee S-108 on Development of Hydrologic/Water Quality Models for Agriculture and Forestry.

Participant: Annual SEA S-108 Technical Committee Meeting, Gainesville, Florida, March 1978.

Faculty: Adjunct Associate Professor, University of Tennessee.

Advisor: David Laib, B.S., University of Michigan; S. E. Lindberg, Ph.D., Florida State University.

Ad Hoc Reviewer: Proposals, NSF; Journal of Irrigation and Drainage Division, American Society of Civil Engineers.

Other: Ad Hoc Advisor on Hydrology of Proposed Site for the Erie Nuclear power plant (Michigan); Analysis of Potential Impacts on Adjacent Streams.

HYNDMAN, J. R.

Participant: Workshop on Integrated Inventories of Renewable Natural Resources, Tucson, Arizona, January 1978.

JOHNSON, D. W.

Participant: NATO Advanced Research Institute Conference on the Effects of Acidic Precipitation on Terrestrial Ecosystems, Toronto, Ontario, May 1978.

Advisor: Patricia Parr, M.S., University of Tennessee.

Ad Hoc Reviewer: biotropica, Soil Science Society of America Journal, Journal of Environmental Quality, Ecology, Proceedings of the 5th North American Forest Soils Conference; proposals, NSF and DOE.

KANCIRUK, P.

Participant: Annual meeting of the American Fisheries Society, Kingston, Rhode Island, August 1978. Preparation of White Mesa Uranium Mill PDES, White Mesa Uranium Ore Buying Station PDEA, Plateau Resources Ore-Buying Station PDEA, and Hanksville Ore-Buying Station PDEA.

Witness: Preparation of testimony submitted to the NRC concerning the operating license of the Virgil Summer Nuclear Plant.

Ad Hoc Reviewer: Grant proposal, NSF.

KIRK, B. L.

Participant: Joint Seminar on Numerical Analysis, University of Tennessee Math Department and Computer Sciences Division, ORNL, Winter 1978; Lecture Series on Time Series and Autoregressive Processes, Winter-Spring 1978; In-house Course on Numerical Software for Differential Equations, Winter 1978.

KITCHINGS, J. T.

Participant: Chairman, National Environmental Research Park Poster Session, AIBS Meeting, Athens, Georgia, August 1978; National RARE II Conference, University of Montana, Missoula, Montana, August 1978; AIBS Meeting, Athens, Georgia, August 1978.

Advisor: Deborah Lucas, B.S., Denison University.

KLOPATEK, J. M.

Member: Conference Organization Committee, Second International Conference on Energy Use Management, Los Angeles, California, October 1979.

Participant: AIBS Meeting, Athens, Georgia, August 1978; DOE Workshop on Land Use Conflicts, April 1977; Symposium on Wetlands, American Water Resources Association, Lake Buena Vista, Florida, October 1978.

Advisor: Dennis Gregg, M.S., University of Tennessee; David Weinstein, Ph.D., University of Tennessee.

Ad Hoc Reviewer: University of Florida Press; proposals, DOE and NSF.

Other: Lecturer: University of Florida, University of Wisconsin-Milwaukee.

KUMAR, K. D.

Participant: Fourth National Workshop on Entrainment and Impingement, Chicago, Illinois, December 1977; Northeastern Fish & Wildlife Conference, Greenbrier, West Virginia, February 1978; American Statistical Association Annual Meetings, San Diego, California, August 1978; Preparation of Greene County Nuclear Station FES and K-25 EIS; Review of 316(b) demonstration of Prairie Island Nuclear Station.

Ad Hoc Reviewer: Technometrics.

LARSEN, I. L.

Participant: Southeastern DOE Annual Marine Contractors Meeting, Atlanta, Georgia, October 1977.

LEE, S. Y.

Participant: Session Chairman, Minerals: Reactions and Quantitative Determinations, Soil Mineralogy Division, American Society of Agronomy, Los Angeles, California, November 1977.

Ad Hoc Reviewer: Journal of Environmental Quality.

LIMDBERG, S. E.

Participant: Tenth Air Pollution Workshop, Minneapolis, Minnesota, April 1978; MAP3S Precipitation Chemistry Intercomparison Study, May 1978; First Meteorological Effects of Thermal Energy Releases Workshop, Cartersville, Georgia, May 1978.

Advisor: W. A. Hoffman, visiting professor, Denison University, July 1977-June 1978 (with R. R. Turner).

Consultant: State of Virginia Water Quality Control Board (informal).

Ad Hoc Reviewer: Environmental Science and Technology, Journal of Environmental Quality; proposals, NSF and EPA.

LGAR, J. M.

Participant: Preparation of: Greene County Nuclear Power Plant PFES; Blue Hills Station FES; NRC cross-examination of applicant's aquatic ecology witnesses at joint ASLB/State of New York hearings for the Greene County Nuclear Power Plant, Albany, New York, March 1978. NRC Impingement Workshop, Bethesda, Maryland, October 1977.

Advisor: Anthony Sasson, M.S., Miami University, Ohio.

LUXMOORE, R. J.

Participant: Biological Systems Simulation Group Workshop, Clemson University, Clemson, South Carolina, April 1978; Forest Meteorology Workshop, Ottawa, Canada, August 1978.

Ad Hoc Reviewer: Water Resources Research, Journal of Environmental Quality; proposal, NSF.

MANN, L. K.

Participant: Poster session, AIBS Meeting, Athens, Georgia, August 1978; Evaluation of rare plant status report forms for national level by New York Botanical Gardens, ORNL, January 1978; MAB meeting with Park Service and Coweeta, ORNL, July 1978.

MATTICE, J. S.

Member: Travelling Lecture Program, Oak Ridge Associated Universities; Program Committees of: American Nuclear Society (Environmental Sciences Division), International Corbicula Symposium, Second Conference on Water Chlorination.

Participant: Preparation of final report of the Exploratory Studies Program. Task Group for "Review of toxicity data concerning intermittent chlorination at power plants and recommendations for criteria," EPA, Duluth, Minnesota; First International Corbicula Symposium, Fort Worth, Texas, October 1977; Conference on Water Chlorination: Environmental Impact and Health Effects, Gatlinburg, Tennessee, October-November 1977; Interagency Research Coordination Meeting, TVA-U. S. Fish and Wildlife Service, Lake Barkley Lodge, Kentucky, December 1977; TVA Division of Environmental Planning-ESD Aquatic Section, ORNL, Discussion of potential for cooperative studies, May 1978; TVA Representatives of Biology Section, Power Division, ORNL, Discussion of potential for research interaction, August 1978; TVA Division of Environmental Planning, Chlorination Effects Research, Chattanooga, Tennessee, August 1978.

Adviser: T. J. Macalusa, B. S., St. Joseph's College.

Ad Hoc Reviewer: Journal of the Fisheries Research Board of Canada; Department of Energy Conference on Water Chlorination; Symposium on Energy and Environmental Stress in Aquatic Systems; International Corbicula Symposium.

Other: Editor, Corbicula Newsletter.

McBRAYER, J. F.

Participant: Session chairman, Ecological Society of America, Athens, Georgia, August 1978; Reclamation Research in Eastern Kentucky, Madisonville Community College, Madisonville, Kentucky, May 1978; Mining and the Environment, University of Tennessee, Knoxville, Tennessee, May 1978; Public Meeting on Draft Regulations for Surface Mining Control and Reclamation Act of 1977, Knoxville, Tennessee, August 1978. Preparation of Sundesert Nuclear Plant, Units 1 and 2, DES; Sundesert Nuclear Plant, Units 1 and 2, FES; Hot Engineering Test Project at ORNL PDES; DOE Enhanced Oil Recovery Project DEA; Phillips Oil Company Enhanced Oil Recovery Project DEA.

Ad Hoc Reviewer: Ecology, Ecological Monographs, Pedobiologia; proposals, NSF and TVA.

Other: Instructor, Administrative and Technical Support Personnel In-House Development Program, ORNL, "Introduction to Ecology," Chairman, Terrestrial Search Committee, Environmental Impacts Program, Environmental Sciences Division.

McLAUGHLIN, S. B.

Participant: ERDA Air Pollution Workshop, Oak Ridge, Tennessee, December 1977; Southwide Forest Disease Workshop Panel Member for "Air Pollution Effects," University of Kentucky, Lexington, Kentucky, February 1978; Round Table Discussion with President Carter, James Schlesinger, John Deutsch, and Frank Press, Oak Ridge, Tennessee, May 1978; 71st Annual Meeting of Air Pollution Control Association, Houston, Texas, June 1978; AIBS Meeting, Athens, Georgia, August 1978.

Advisor: Barbara Best, B.S., Stephens Point College; John R. Barton, B.S., Centre College.

Reviewer: Coniferous Forest Biome-Synthesis Volume; Journal of Air Pollution Control Association; Journal of Environmental Quality; Canadian Journal of Forest Science; proposals, DOE.

McLEAN, R. B.

Member: Audio Visual Committee, Environmental Sciences Division.

Participant: Predator-Prey Symposium, Atlanta, Georgia, July 1978. Preparation of U. S. Nuclear Regulatory Commission Final Addendum Related to Manufacture of Floating Nuclear Power Plants FES.

Advisor: M. V. McGee, M.S., University of Tennessee; Michael Soulen, B.S., Yale University (ORAU program).

Witness: Hearings related to Manufacture of Floating Nuclear Power Plants.

MILLEMANN, R. E.

Participant: Preparation of EAs for: Guyan Oil Co., West Virginia; Pennzoil Co., West Virginia; Columbia Gas Transmission Corp., West Virginia; Cities Service Co., Kansas; Phillips Oil Co., Oklahoma; Bartlesville Energy Research Center, Oklahoma; Gary Operating Co., Montana; Penn Grade Project, Pennsylvania.

Faculty: Professor, Graduate Program in Ecology, University of Tennessee, Knoxville.

Advisor: Graduate Student Coordinator, Environmental Sciences Division; Chairman, Graduate Student Selection Committee, Environmental Sciences Division.

Ad Hoc Reviewer: Canadian Journal of Zoology.

NEWBOLD, J. D.

Advisor: Ann. F. Trimble, B.S., University of the South (S.C.U.U. Program).

Participant: Workshop in Aquatic Ecology in the Southeast, Southeastern Section of the Ecological Society of America, Augusta College, Augusta, Georgia, October 1977.

OAKES, K. M.

Participant: Geysers Ecosystem Quality Workshop, Lawrence Livermore Laboratory, Santa Rosa, California, October 1977; Third Geopressured-Geothermal Energy Conference, University of Southern Louisiana, Lafayette, Louisiana, November 1977; 43rd North American Wildlife and Natural Resources Conference, Phoenix, Arizona, March 1978; Workshop and Planning Session regarding Waterfowl Habitat Enhancement with Geothermal Waters, Western Energy and Land Use Team of the U. S. Fish and Wildlife Service, Reno, Nevada, September 1978. Preparation of: Wyoming Minerals Irigary Uranium Solution Mine Project DES and FES, Exxon Uranium Solution Mine Project DES and FES, Baca Geothermal Demonstration Power Plant EA Preparation Plan, Raft River Thermal Loop Facility DEA, Westernland Geothermal Development Project DEA, Big Muddy Low Tension Flood Enhanced Oil Recovery Demonstration Project DEA, the Babcock and Wilcox Fuel Cycle Facility DEA and FEA, Hawaii Geothermal Project DEA.

OLSON, J. S.

Faculty: Professor of Biology, University of Tennessee. Implementation of Environmental Policy, Environmental Monitoring, Environmental Assessment.

Advisor: Yip-Hoi Chan, Ph.D., University of Tennessee, Beverly Ann Simmons, M.S., University of Tennessee.

Ad Hoc Reviewer: Science; proposals, NSF and DOE.

OLSON, R. J.

Chairman: Interdivisional Committee for Data Exchange, ORNL.

Member: Inter-laboratory Working Group for Data Exchange, DOE Laboratories.

Participant: Integrated Inventories of Renewable Resources, Tuscon, Arizona, January 1978; Harvard Computer Graphic Week, Cambridge, Massachusetts, July 1978.

O'NEILL, R. V.

Member: NSF Advisory Panel for Ecological Sciences.

Participant: Session Chairman, Second International Congress of Ecology, Jerusalem, Israel, September 1978; International Symposium on Statistical Ecology, Jerusalem, Israel, September 1978.

Faculty: Adjunct Associate Professor, Ecology Program, University of Tennessee, Knoxville.

Ad Hoc Reviewer: Science, Ecology; proposals, NSF.

Other: Associate Editor, Ecology.

PARKHURST, B. R.

Member: Subcommittee E. 35.21 (safety to Man and Environment) and subcommittee E. 35.21.01 (Aquatic Organisms), American Society for Testing and Materials.

PARKHURST, B. R. (continued)

Ad hoc Reviewer: Proposal, EPA.

PARR, P. D.

Participant: Evaluation of rare plant status report forms for national level by New York Botanical Gardens, ONML, January 1978.

Other: Program Committee Participant, Tennessee Native Plants Society.

REED, R. M.

Participant: Preparation of: Operation of Shoreham Nuclear Power Station FES; Draft and Final Supplements to the FES related to the Construction of Allens Creek Nuclear Generating Station, Unit No. 1; Final Site Environmental Statement related to the Determination of the Suitability of Site G for Eventual Construction of the Blue Hills Station, Unit Nos. 1 and 2; DES for Power Plant and Industrial Fuel Use Act of 1978.

REICHLE, D. E.

Member: Board on Toxicology and Environmental Health Hazards, National Academy of Sciences; Admissions Committee, Graduate Program in Ecology, University of Tennessee; Associateship Selection Panel, National Academy of Sciences.

Faculty: Adjunct Professor, Graduate Program in Ecology, University of Tennessee, Knoxville.

Advisor: William Wilcox, Ph.D., University of Tennessee.

Other: Editorial Board, Pedobiologia.

ROOP, R. D.

Participant: Symposium on Biotechnology in Energy Production and Conservation, Gatlinburg, Tennessee, May 1978. Preparation of Irigaray Solution Mining Project FES, Big Muddy Low-Tension Flood Field Project EA, Low-head Hydroelectric Power Development Program EA.

SALK, M. S.

Other: Guest Lecturer, Ecology class, Knoxville College, Knoxville, Tennessee.

SHAEFFER, D. L.

Participant: Short course on "The Protection of Ground Water Quality," Civil Engineering Departments, University of Delaware and Princeton University, Newark, Delaware, July-August 1978.

SHARPLES, F. E.

Participant: Environmental Regulation and Legislation Seminar, New York University, New York, August 1978. Environmental Aspects of Non-Conventional Energy Resources - II Topical Meeting, American Nuclear Society, Denver, Colorado, September 1978. Preparation of: Geothermal Direct Heat Project DEA; Shell Oil Company's Enhanced Oil Recovery Project DEA; Cities Service Company's Enhanced Oil Recovery Project DEA; Westmorland Development Project FEA; Fuels from Biomass Project Preliminary Draft Programmatic Assessment.

SHRINER, D. S.

Member: Air Pollution Control Association Technical Council TE-2 Agricultural Committee.

Participant: Session Co-chairman, Tenth National Air Pollution Workshop, Minneapolis, Minnesota, April 1978; NATO Advanced Research Institute on Effects of Acid Rain on Terrestrial Ecosystems, Toronto, Ontario, Canada, May 1978; Workshop on Ecological Consequences of Acidic Deposition, Central Electricity Research Laboratories, Great Britain, Gatehouse-of-Fleet, Island, September 1973.

Advisor: David M. Lodge, B.S., University of the South; S. E. Lindberg, Ph.D., Florida State University.

Ad Hoc Reviewer: Air Pollution Control Association.

SHUGART, H. H.

Advisor: D. Mielke, M.S., University of Tennessee; L. K. Mann, M.S., University of Tennessee; W. M. Post, Ph.D., University of Tennessee; J. Ranney, Ph.D., University of Tennessee; P. Van Voris, Ph.D., University of Tennessee.

SOLOMON, A. M.

Chairman: Murray F. Buehl Award Committee, Ecological Society of America.

Participant: 10th Annual Meeting, American Association of Stratigraphic Palynologists, Tulsa, Oklahoma, October 1977; 29th Annual Meeting, American Institute of Biological Sciences, University of Georgia, Athens, Georgia, August 1978; 5th Biennial Meeting, American Quaternary Association, Edmonton, Alberta, August-September 1978; 11th Annual Meeting, American Association of Stratigraphic Palynologists, Tulsa, Oklahoma, October 1977. Preparation of: Erie Nuclear Plant Units 1 and 2 DFS; Portsmouth Gaseous Diffusion Plant Expansion FCS; Supplemental Testimony, Montague Nuclear Power Station, Cooling Tower Evaluation; Homestake Mining Pitch Project DFS; Harry S. Truman Dam EA.

Ad Hoc Reviewer: Application of Cenozoic biostratigraphy in the elucidation of the Victoria Orogeny, Transantarctic Mountains, DPP-78-21715, NSF Polar Earth Sciences Program; Palynology and Paleobotany of Mesozoic rocks of the Antarctic Peninsula Area and Southern South America, DPP-78-21128, NSF Polar Earth Sciences Program.

Other: Chairman, Paleocology Section, Ecological Society of America; Representative, Paleocology Section, to Ecological Society of America Council; Member, Public Affairs Committee, Ecological Society of America.

SOUTHWORTH, G. R.

Participant: Second Annual American Society for Testing and Materials Symposium on Aquatic Toxicology, Cleveland, Ohio, October 1977.

SPALDING, B. F.

Member: USDA Technical Committee No. 59: Soil Organic Matter.

Ad Hoc Reviewer: Soil Science Society of America Journal.

STRAND, R. H.

Chairman: Third Annual SAS Users Group Conference, Las Vegas, Nevada, January 1978.

Participant: Computer Science and Statistics, 11th Annual Symposium on the Interface, Raleigh, North Carolina, March 1978; Symposium on Potential Health Effect of Gasifiers-in-industry, Gallinburg, Tennessee, September 1978; SAS internal short course, Raleigh, North Carolina, March 1978; Working Group for Data Handling and Management Aspects of Coal Conversion/Gasification Assessment, Research Triangle Park, Raleigh, North Carolina, April 1978; Working Group on Interagency Needs for Data Management in Gasifiers-in-Industry Program, Raleigh, North Carolina, March 1978; MCUCOMP Users Meeting, Ft. Lauderdale, Florida, December 1977; discussant, Research Data Management Section, 139th Annual Meeting of American Statistical Association, San Diego, California, August 1978.

STRUXNESS, E. G.

Consultant: Committee 4 of International Commission on Radiological Protection (ICRP), Sutton, Surrey, England.

Other: Leader, Committee 4 Task Group on "Principles and Methods for Use in Radiation Protection Assessments Related to Releases of Radioactive Materials into the Environment," International Commission on Radiological Protection (ICRP), Sutton, Surrey, England.

SUFFERN, J. S.

Participant: Aquaculture-Atlanta Conference, Atlanta, Georgia, January 1978; Fourth National Workshop on Entrainment and Impingement, Chicago, Illinois, December 1977; S-83 Project Annual Meeting, Baton Rouge, Louisiana, May 1978; TVA planning session for woody biomass conversion project, Chattanooga, Tennessee, March 1978; Predator-Prey Symposium, Atlanta, Georgia, July 1978.

Advisor: David Looze, B.S., University of the South, (SCUU-ORAU program), Susan Wymer, B.S., University of Tennessee, (ORAU program), Cathleen Fitzgerald, Env.D., UCLA, (ORNL summer research participant program).

Ad Hoc Reviewer: Proc., Symposium on Energy and Environmental Stress in Aquatic Systems.

Other: Environmental Sciences Division and ORNL public relations tours; proposals, EPRI - entrainment, Department of Energy - aquaculture, NRC - entrainment.

SUTER, G. W.

Participant: Ecosystem Quality Workshop for the Geysers - Calistoga KGRA, Santa Rosa, California, October 1977; ILL/GRIPS Geothermal Noise Workshop, Davis, California, November 1977; Ecosystem Quality Workshop for the Roosevelt Hot Springs KGRA, Salt Lake City, Utah, February 1978; DOE/Industry Geopressured Geothermal Resource Development Program, Environmental Laboratory Research Working Subgroup Meeting, New Orleans, Louisiana, April 1978; Ecosystem Quality Workshop for the Mono-Long Valley KGRA, Mammoth Lakes, California, August 1978. Preparation of: Offshore Power Systems Final Addendum to the FES part II; Hot Dry Rock Subprogram FEA; Raft River Thermal Loop FEA; Raft River Pilot Plant DEA; Honey Lake Greenhouse Project DEA; East Coast Exploration FEA; Westmorland DEA; Low-Head Hydroelectric DEA. Consulted with DOE contractors regarding environmental monitoring programs for: Grace/Ebasco Demonstration Plant Project, Unocal Pipeline Gas Demonstration Plant, ICGG Coal Gasification Demonstration Plant, Memphis Industrial Fuel Gas Demonstration Plant, Solvent Refined Coal SRC-1 and SRC-2 Demonstration Projects.

Advisor: Jan Jones, B.S., University of Virginia.

Witness: ASLB hearings on issuance of a construction permit for Offshore Power Systems, Bethesda, Maryland, June 1978.

Ad Hoc Reviewer: Pedobiologia.

SZLUHA, A. T.

Consultant: Curriculum Advisory Council, Biology Department, Bradley University, Peoria, Illinois.

TAMURA, T.

Member: DOE Steering Committee on Land Burial.

Participant: NBS Workshop on Environmental Standards for Transuranic Elements, Woods Hole, Massachusetts, November 1977.

Advisor: Ed Davis, Ph.D., Vanderbilt University.

Consultant: Electric Power Research Institute.

Witness: Expert witness for DOE (on soil plutonium contamination at Rocky Flats, Colorado), Denver, Colorado, 1978.

Ad Hoc Reviewer: Journal of Environmental Quality; Soil Science Society of America Proceedings; Environmental Science and Technology.

TAYLOR, F. G.

- Participant:** Workshop on Ecological and Agricultural Effects of Coal Combustion, DOE, Oak Ridge, Tennessee, November 1977; Tenth National Air Pollution Workshop, University of Minnesota, Minneapolis, Minnesota, April 1978; Air Pollution Control Association, Specialty Conference: Methodology for the Assessment of Air Pollution Effects on Vegetation, Minneapolis, Minnesota, April 19-21, 1978; Atomic Safety and Licensing Board Panel Meeting (ASLBP), Oak Ridge, Tennessee, September 1978; Cooling Tower Environment-1973 Symposium, University of Maryland, College Park, Maryland, May 1978; Cooling Tower Institute Annual Meeting, Houston, Texas, January 1978; Executive Board Meeting, Tennessee Native Plants Society, Cheekwood Botanical Gardens, Nashville, Tennessee, July 1978. Preparation of Babcock and Wilcox Nuclear Materials Division EA, statement for DOE entitled, "Integrated Assessment of Impacts Associated with Uranium Mining and Milling."
- Consultant:** Nuclear Regulatory Commission, Fuel Processing and Fabrication Branch, Division of Fuel Cycle and Materials Safety, Washington, D.C.
- Other:** Recording Secretary, Tennessee Native Plants Society; Executive Board, Tennessee Native Plants Society.

TRABALKA, J. R.

- Participant:** Second Conference on the Environmental Impact of Water Chlorination, Gatlinburg, Tennessee, October-November 1977.
- Advisor:** C. T. Garten, Ph.D., University of Tennessee.
- Ad Hoc Reviewer:** DOE (Division of Biomedical and Environmental Research) environmental programs.

TSAL, S. C.

- Participant:** In-hour Training Program, Technical Writing Workshop, ORNL, September-October 1978.

TURNER, R. R.

- Member:** Analytical Chemistry Committee, Environmental Sciences Division.
- Participant:** EPRI Fly Ash Workshop, Palo Alto, California, May 1978; METER-ORNL Workshop, Cartersville, Georgia, June 1978.
- Ad Hoc Reviewer:** Journal of Environmental Quality.

TYNDALL, R. L.

- Participant:** Acanthamoeba Conference, Columbus, Ohio, June 14-16, 1978, and presented paper "Isolation of Acanthamoeba from Cultured Mammalian Cells".
- Faculty:** Associate Research Professor, Zoology Department, University of Tennessee.
- Advisor:** Lycurgus Muldrow, Ph.D., University of Tennessee; Audrey Nicholson, Ph.D., University of Tennessee.
- Consultant:** Malco Environmental Sciences Co., Chicago, Illinois; Commonwealth Edison Co., Chicago, Illinois.

TYNDALL, R. L. (continued)

Ad Hoc Reviewer: American Society of Medical Technology.

VAN WINKLE, W.

Member: Graduate Student Selection Committee, Environmental Sciences Division, ORNL.

Participant: IAEA Advisory Group Meeting on Methods for Assessing the Effect on Aquatic Organisms of Radioactive Releases to the Aquatic Environment, Vienna, Austria, November 1977; Northeast Fish and Wildlife Conference, White Sulphur Springs, West Virginia, February 1978; Predator-Prey Symposium, Atlanta, Georgia, July 1978.

Faculty: Adjunct Assistant Professor, Department of Ecology, University of Tennessee, Knoxville.

Witness: Provided assistance to Environmental Protection Agency (Region II) staff in the following areas: technical meetings with utility scientists, briefing sessions with lawyers, preparation of cross-examination questions, rehearsing lawyers, assisting lawyers during cross-examination of utility witnesses, and assisting EPA technical staff.

Ad Hoc Reviewer: Proposal, Department of Natural Resources, Energy and Coastal Zone Administration, State of Maryland.

VAUGHAN, D. S.

Participant: Fourth National Workshop on Entrainment and Impingement, Chicago, Illinois, December 1977. Preparation of PDES related to construction of New England Power Units 1 and 2; Scientific Review, Analysis and Critique of Section 316(a) (Thermal Demonstration Materials) and Section 316(b) (Intake Demonstration Materials) for the Public Service of Indiana Cayuga and Wabash River Generating Stations; Critique and Analysis of the Prairie Island Nuclear Generating Station, Intake-Related Studies.

Witness: Assisting lawyers (NRC and EPA) during cross-examination of utility witnesses for EPA Hearings concerning the Hudson River Power Case (also extensive assistance involving briefing sessions with lawyers, preparation of cross-examination questions, and rehearsing lawyers).

VOORHEES, L. D.

Member: Committee on Roadside Maintenance, Transportation Research Board for the National Research Council.

VOORHEES, L. D. (continued)

Participant: Fifty-seventh Annual Meeting of the Transportation Research Board, Washington, D.C., January 1978; National Symposium on the Use of Herbicides in Forestry, Arlington, Virginia, February 1978; Forty-second Annual Meeting of the National Wildlife Federation, Phoenix, Arizona, March 1978; Forty-third North American Wildlife and Natural Resources Conference, Phoenix, Arizona, March 1978; Cooling Tower Environment-1978, A Symposium on the Environmental Effects of Cooling Tower Emissions, College Park, Maryland, May 1978. Preparation of: Nuclear Fuel Services, Inc. Fuel Fabrication Plant FEA; San Onofre Nuclear Generating Station PDES-OL; New England Power Units 1 and 2 PDES-CP; Energy Fuels Nuclear, Inc. Uranium Mill PDES; PDES Plateau Resources, Ltd. Uranium Mill PDES; Plateau Resources, Ltd. Uranium ore-buying station PDEA; Energy Fuels Nuclear, Inc. Uranium ore-buying stations PDEAs.

Advisor: Theodore Boggs, M.S., Miami University, Ohio.

WATSON, B. T.

Participant: Entomological Society of America Annual Meeting, Washington, D.C., November-December 1978; Training course on "Use of Radionuclides in Ecological Studies," Oak Ridge Associated Universities, Oak Ridge, Tennessee, April 1978; American Chemical Society Annual Meeting, Miami Beach, Florida, September 1978.

WATTS, J. A.

Member: IUFRO-SAF Program Planning Committee for 1979 Forest Inventory Meeting; ORNL Interdivisional Committee of Data Exchange (Environmental Sciences Division Representative), ORNL.

Participant: Integrated Inventories of Renewable Natural Resources - a National Workshop, Tucson, Arizona, January 1978.

Other: Instructor in CSMP course in the in-house Technical Education Program, ORNL, May-June 1978; Affirmative Action representative, ESD, October 1977-September 1978; program chairperson, Smoky Mountain Section, Society of Women Engineers, May 1978 - present.

WEBB, J. W.

Participant: Preparation of South Texas Project PDES.

WIENER, JAMES G.

Member: Manganese Panel of the Water Quality Section of the American Fisheries Society (for review of the Manganese Section of the U. S. Environmental Protection Agency Red Book).

Participant: Environmental Aspects of Non-Conventional Energy Resources II - Topical Meeting, American Nuclear Society, Denver, Colorado, September 1978. Preparation of EA of the Babcock and Wilcox Nuclear Materials Division, Commercial Nuclear Fuel Fabrication Plant, Borough of Apollo, Pennsylvania.

YEH, G. T.

- Member: Environmental Impact Effects Committee, American Society of Civil Engineers.
- Participant: Grammar and Mechanics of Technical Writing, Technical Education Program, ORNL. Preparation of South Texas Project FES-OL.
- Ad Hoc Reviewer: Committee on hydrologic Transport and Dispersion, American Society of Civil Engineers.

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