BNWL-1867
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THE ECOLOGICAL BEHAVIOR OF PLUTONIUM AND AMERICIUM IN A FRESHWATER ECOSYSTEM

PHASE I

LIMNOLOGICAL CHARACTERIZATION AND ISOTOPIC DISTRIBUTION

Battelle
Pacific Northwest Laboratories
Richland, Washington 99352

SEPTEMBER 1974

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APPENDIX

BNWL-1867

THE ECOLOGICAL BEHAVIOR OF PLUTONIUM AND AMERICIUM IN A FRESHWATER ECOSYSTEM:

PHASE I

LIMNOLOGICAL CHARACTERIZATION AND ISOTOPIC DISTRIBUTION

By

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September 1974

On January 19, 1975, research and development programs of the U.S. Atomic Energy Commission (AEC) became part of the newly formed Energy Research and Development Administration (ERDA). In this report, since it refers to work done in 1974, most references are to AEC programs.

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March 1, 1975

Dear Colleague:

The authors of the enclosed document BNWL-1867 have chosen to send you a revised copy as a replacement for the copy previously sent to you. This decision was based primarily on significant changes in the section describing the pond's history. We have also taken the opportunity to make several small changes and corrections in other sections. Please destroy the old copy of BNWL-1867 when you file this new copy in its place.

Also enclosed is a copy of BNWL-1879. This is a new document dealing with implications of differences in transuranic isotopic ratios occurring in the freshwater pond. We hope that you will find both of these papers interesting and useful in your work.

Sincerely,

Dick Emery

Richard M. Emery
Ecosystems Department

RME:prm

enclosures

ACKNOWLEDGMENT

This is an interim report of progress in research studies funded by the AEC Division of Biomedical and Environmental Research under the following schedule-189 title:

"Ecological Distribution and Fate of Plutonium and Americium in a Processing Waste Pond on the Hanford Reservation."

Interpretation of data and advice provided by Battelle scientists D. G. Watson, T. R. Garland, H. Drucker, and M. P. Fujihara, and the technical assistance from T. M. Poston, J. M. Gurtisen, T. J. Hilbish, and L. G. Zelley are greatly appreciated.

We wish also to acknowledge the cooperative effort of the Atlantic Richfield Hanford Company (ARHCO) who had docks constructed on U Pond and assisted in the funding of radioanalyses.

ABSTRACT

A Pu processing waste pond on the Hanford Reservation has been studied since July 1973 to characterize the pond's limnology and determine the ecological distribution of Pu and Am in this ecosystem. This shallow 14-acre pond has existed and received Pu processing wastes for about 30 years. During this period about 8.1 kg was discharged into waste trenches leading to the pond. Limnological studies have characterized the pond as having a simple food web existing under ultra-eutrophic conditions, with physical circulation and mixing being primarily controlled by wind and secondarily by heated water entering the pond. This pond receives about 10 m^3 of water per minute, of which at least 95 percent leaves via percolation through the desert-like soil. Macrophytes (mainly *Potamogeton*), algae (mainly *Cladophora*), benthic invertebrates (mainly dipteran and odonate larvae, hemipterans, amphipods, and gastropods) and goldfish are the major biotic components of this system. Sediments are the principal repository of Pu and Am, containing about 390 pCi of $^{238,239,240}Pu$ (ΣPu)/g (dry) and about 83 pCi of ^{241}Am/g (dry) with ratios of ^{238}Pu:$^{239,240}Pu$ of about 1:1 and ^{241}Am:ΣPu of about 0.23:1. Levels of these transuranics in the pond water are much lower having concentrations of ΣPu of about 0.01 pCi/ℓ and ^{241}Am of about 1.1 pCi/ℓ, with ratios of ^{238}Pu:$^{239,240}Pu$ of about 3.5:1 and ^{241}Am:ΣPu of about 120:1. In the biota the principal concentrator of Pu and Am is decomposing algal material (designated as algal floc, and rich in microorganisms) with levels of Pu of about 2 nCi/g (dry) and ^{241}Am of about 250 pCi/g (dry). This material serves as a major energy source for most of the pond fauna. In spite of the relatively high levels present in the sediments and major food source most of the biota have accumulated relatively lower levels of Pu and Am. Only an ephmeral growth of watercress (*Rorippa*) exceeds both ΣPu and ^{241}Am levels in the sediments. However watercress, dragonfly larvae (*Libellula*), and the snail *Lymnaea* had higher ^{241}Am concentrations than that of the sediments. Levels of these transuranics in other aquatic flora and fauna are also reported which range from 0.5 to 154 pCi of ΣPu/g and 0.3 to 50 pCi of that of the sediments (i.e. > 1:1), but lower than that of pond water (i.e. < 3.5:1). The same was true for ratios of ^{241}Am:ΣPu in biota as most organisms had ratios exceeding 0.23:1 (with a maximum of 2:1), but not approaching that of pond water (120:1). Also discussed are concentration factors for pond biota with respect to various expressions of biological availability. Depending upon assumptions made for availability the CF values for any organism may range by many orders of magnitude.

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INTRODUCTION

As Noshkin (1972) has clearly pointed out, the available literature on the transuranic elements heavily favors topics of physical and chemical properties. Considerations for the environmental distribution and movement of plutonium (the principal transuranic) have received meager coverage in the literature. Nearly all of that which has been published on the environmental behavior of plutonium has pertained to the marine environment. These relatively few reports deal mainly with oceanic dissemination and uptake of plutonium by a small variety of marine organisms. Recently freshwater environments have received some attention with respect to plutonium behavior in waste ponds at Rocky Flats from Johnson and Watters (1971) and Johnson et al. (1972). Adams and Fowler (1974) have reported uptake levels of $^{238}PuO_2$ by freshwater fish, algae, and snails. Finally, Bowen and Noshkin (1973), Yaguchi et al. (in press), and Waller et al. (in press) have studied the distribution and relative concentrations of Pu by some freshwater organisms in the Laurentian Great Lakes. Beyond this we have found nothing else in the open literature which pertains to the ecological behavior of Pu and Am in fresh water.

The purpose of this interim report is to present the first year's findings from a study initiated in July 1973 to depict the ecological behavior of plutonium and americium in a processing waste pond on the Hanford Reservation. This report deals with the limnological characterization of the pond and the isotopic distribution of Pu and Am in this ecosystem. All sample analyses have not yet been completed and reviewed for this phase of the study, and tentative hypotheses and conclusions are subject to change as the knowledge of this system and the radionuclides present in it improves.

THE POND'S HISTORY

This pond, designated as U Pond (specifically 216-U-10), was created in a shallow depression in the arid steppe-land of the Hanford region at the beginning of the Manhattan Project in 1944 (Figs. 1 and 2). The major purpose of the pond is to receive low-level rad-wastes from plutonium processing and reclamation facilities, a laundry, a uranium recovery plant, and several laboratories. In addition to accidental plutonium discharges, the aqueous effluents sometimes carry low-level fission products (^{137}Cs, ^{90}Sr, ^{106}Ru, ^{155}Eu), activation products (^{60}Co, ^{154}Eu, ^{54}Mn), and actinides (^{238}U, ^{232}Th, ^{241}Am). A few other radioisotopes have been released to the pond at marginally detectable levels. The pond presently exists with a surface area of 56,000 m^2 (14 acres), a volume of 22,700 m^3 (18 acre-ft), and a mean depth of about 0.4 m (1.3 ft). There was a period from 1952 to 1953 when the pond extended over an area of about 120,000 m^2 (30 acres) due to abnormally heavy water discharges from surrounding plant operations. The water level in U Pond is now maintained by three major sources. One is from plutonium processing operations (234-5 plant) via Z-19 trench; another is from a laundry where protective clothing is cleaned (via U-14 trench); and the third is cooling water from the evaporator-crystallizer plant (242-S plant where liquid rad-wastes are reduced to salt cakes (via U-14 trench, Fig. 3). Another trench (Z-11 trench) carried Pu processing waste to U Pond through the mid-1960's, but became excessively contaminated and was subsequently backfilled. U Pond has received effluents from the recovery plant since 1973. The total historic discharge of water into U Pond is reported as 1.2×10^9 m^3 (3.17×10^{11} gal, 9.7×10^5 acre-ft) (Anderson 1973) with a current discharge rate of about 10 m^3/min (5.9 cfs).

The reclamation and processing effluents from the 234-5 plant, which carry plutonium to the pond, are discharged into a trench at a point about 885 m (970 yds) above the pond (Fig. 3). Processing wastes continuously flow into this open trench, but plutonium releases, which are usually at low levels, occur on an intermittent basis. Release records indicate that the total historic discharge of plutonium into this trench is about 8.1 kg (Hanson et al. 1973 and Anderson 1973). (There are no release records kept for Am.)

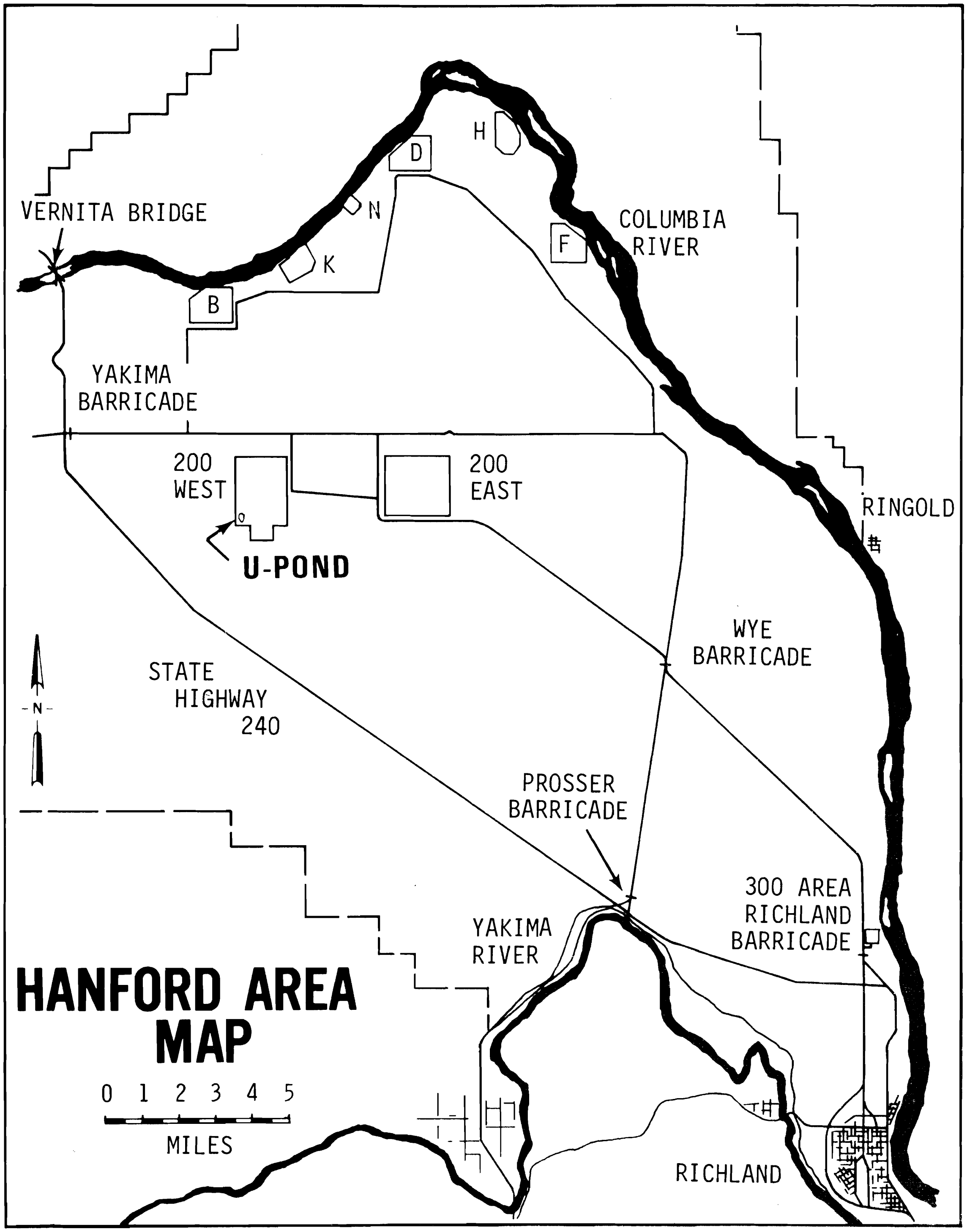

Figure 1. Map of Hanford area showing U Pond.

Figure 2. Aerial photo of U Pond.

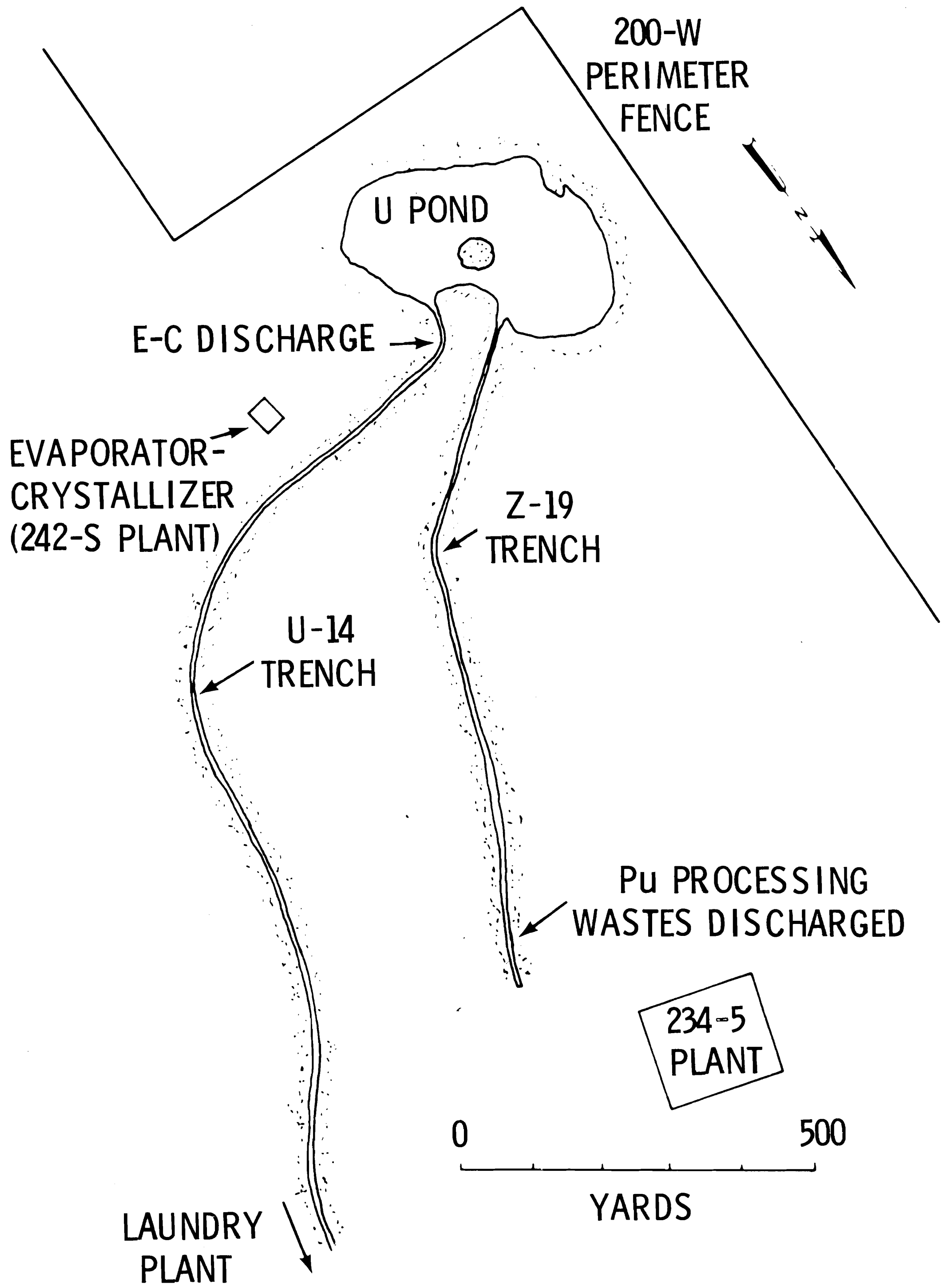

Figure 3. Trenches and associated discharge points which supply water to U Pond.

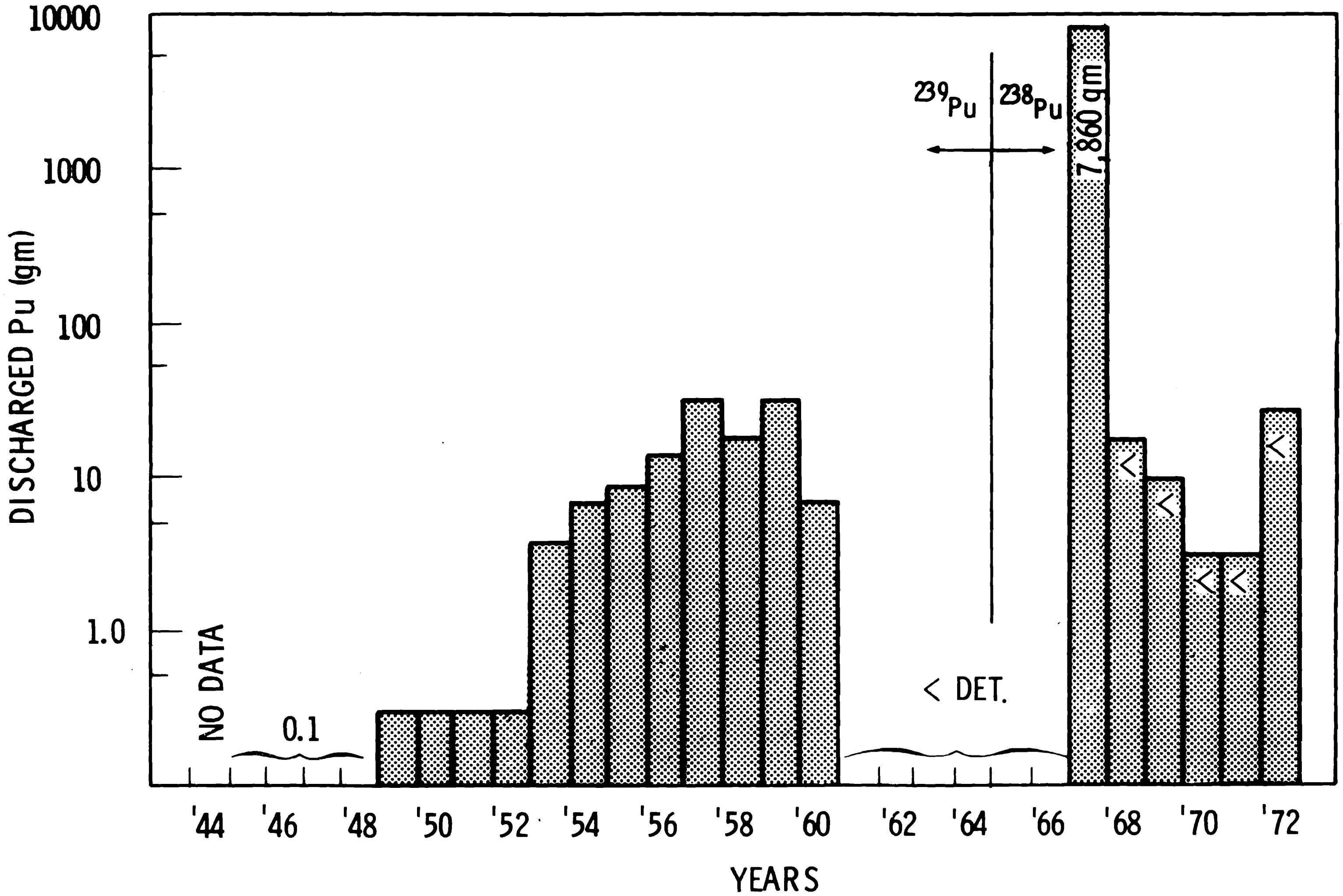

Figure 4. Annual levels of Pu released into trenches leading to U Pond since the start-up of Hanford operations (Hanson et al. 1973 and Anderson 1973). The vertical line at 1964-65 indicates the most likely time when ^{238}Pu was added to the wastes of processing ^{239}Pu. (DET. = detection limit, < = less than).

These records show relatively low-level releases from 1944 to 1953, less than 2 g of Pu released over this period (Fig. 4). (The reliability of sampling and analyses of these early discharges are unknown). From 1953 through 1960 annual releases of Pu were considerably greater, but still amounted to less than 200 g (Fig. 4). A hiatus in the records appeared from 1961 through 1966. During this period (mid-1960's) the first purified ^{238}Pu (produced by the reactor irradiation of ^{237}Np for the SNAP program) was mixed with normal weapons grade ^{239}Pu in the waste discharges. These records also show that in 1967 7.9 kg of Pu (97% of total recorded release) was discharged into the waste trench. Further investigation revealed that the 1967 figure (7.9 kg) represents an accumulative release for a period running from 1959 through 1967. It was during this period the Z-11 trench was being used to carry processing wastes to the pond. This trench became excessively contaminated with Pu by 1971 and was backfilled. In the remaining years less than 0.1 kg of Pu is reported to have entered the pond by way of Z-19 trench. This trench still remains in use. Although the official figure for total historic Pu discharge into the pond by way of the Z-trenches is 8.1 kg, some uncertainty exists concerning the accuracy of this value. It is quite possible that the reported discharge of 8.1 kg of Pu was calculated excessively high due to an unknown amount of ^{238}Pu present in the wastes. Pu separations were probably made but the assay of wastes was done by total alpha count. Thus, from the mid-1960's to date the conversion of Pu activity to weight could cause Pu weight conversions to be excessively high. There have also been other indications that this estimate is too low, such as the possibility that periodic sampling has missed some higher level discharges, which adds further confusion to the matter. Such uncertainties will cause problems when attempts are made to balance the release of Pu into the pond with estimates of total pond Pu content obtained by sampling.

MATERIALS AND METHODS

GENERAL PREPARATIONS

For purposes of sampling and pond region identification, the pond was sectioned into quarters, designated as quads A, B, C, and D, and each quad was subdivided into four grids, excepting quad A, which has only three grids (Fig. 5). (The shape of the pond would not accommodate a fourth grid in quad A.) These sections were marked with steel fence posts in the pond and along its perimeter. Soil samples from an old spill-over basin (U-11 basin) are indicated by station number. These results are not discussed in text but appear in Table I in the appendix.

Because the pond is very shallow, and the use of a boat for sampling causes resuspension of much of the lighter sediments, a floating dock system was installed (Figs. 5 and 6). These walkways provide convenient access to nearly all grid sections and eliminate the problem of disturbing the pond bottom while sampling. [However, after the docks were installed it became evident that they provide a large portion of the pond (quads C and D, mainly) with wind protection, thus, causing a change in the benthic habitat (i.e., increase in substrate stability) which was sufficient to support new algal and macrophyte communities not likely occurring in the pond prior to the dock installation.]

To accommodate sample preparation, experimentation, and some analytical work, a laboratory trailer was installed at the U Pond site in December 1973 (Figs. 5 and 7).

SAMPLING, PROCESSING, AND ANALYSES FOR Pu AND Am

All samples collected for Pu and Am analyses were prepared by drying in either a 105°C drying oven or by a Virtis Unitrap freeze dryer (Model 10-100). The dried samples were packaged and shipped to LFE Environmental Laboratories (Richmond, California) for transuranic analyses. At LFE the isotopes ^{238}Pu, ^{239}Pu + ^{240}Pu (expressed as "^{239,240}Pu"), and ^{241}Am were analyzed using isotope dilution methods, with high purity ^{236}Pu and ^{243}Am preparations used as tracers. Final measurements were made using alpha spectroscopy methods

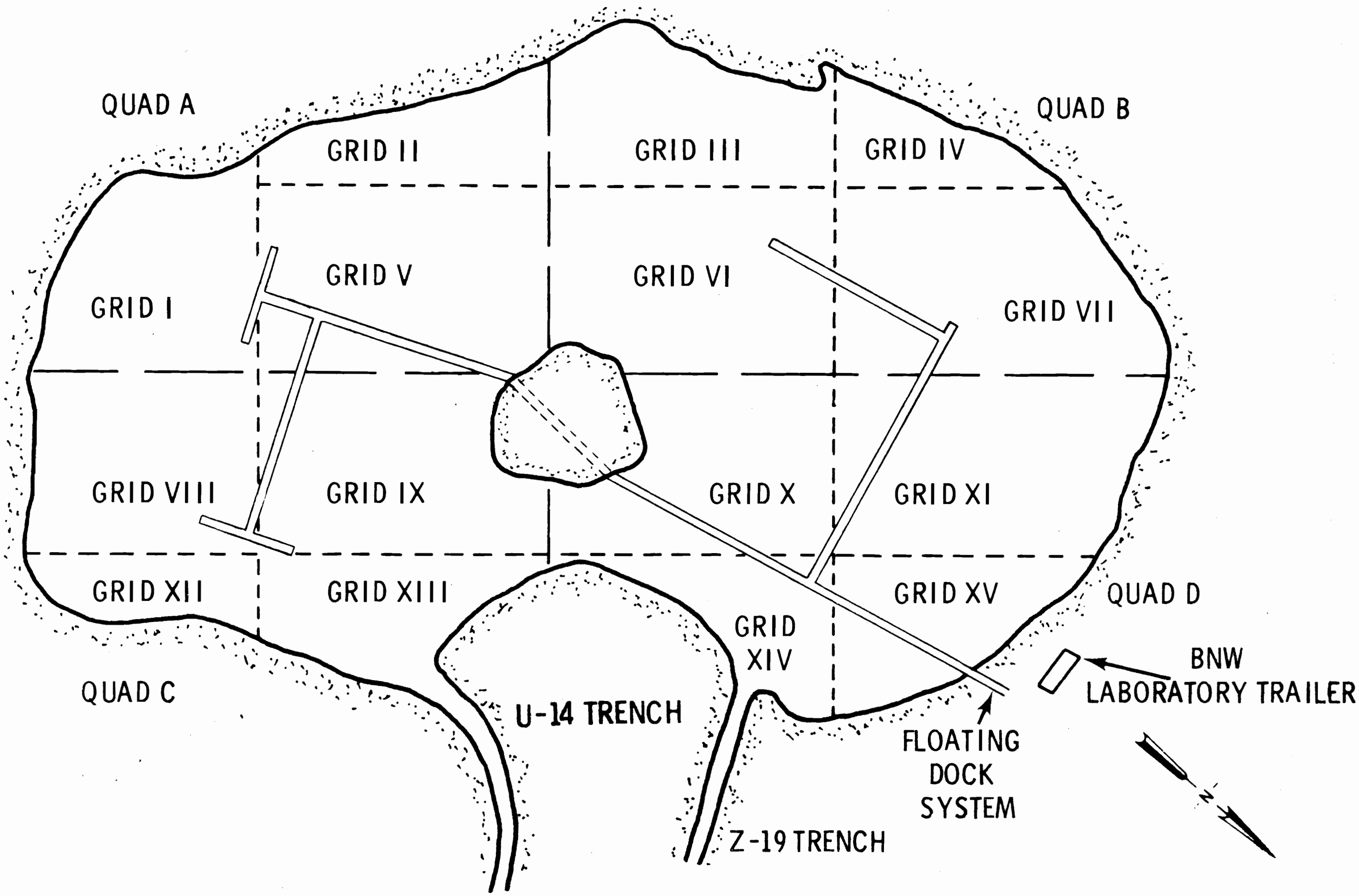

Figure 5. Sampling sections and dock system on U Pond.

Figure 13. Floating mats of *Cladophora* (top 2 photos) and beds of *Potamogeton* (bottom photo) occurring during the spring and summer months of 1974.

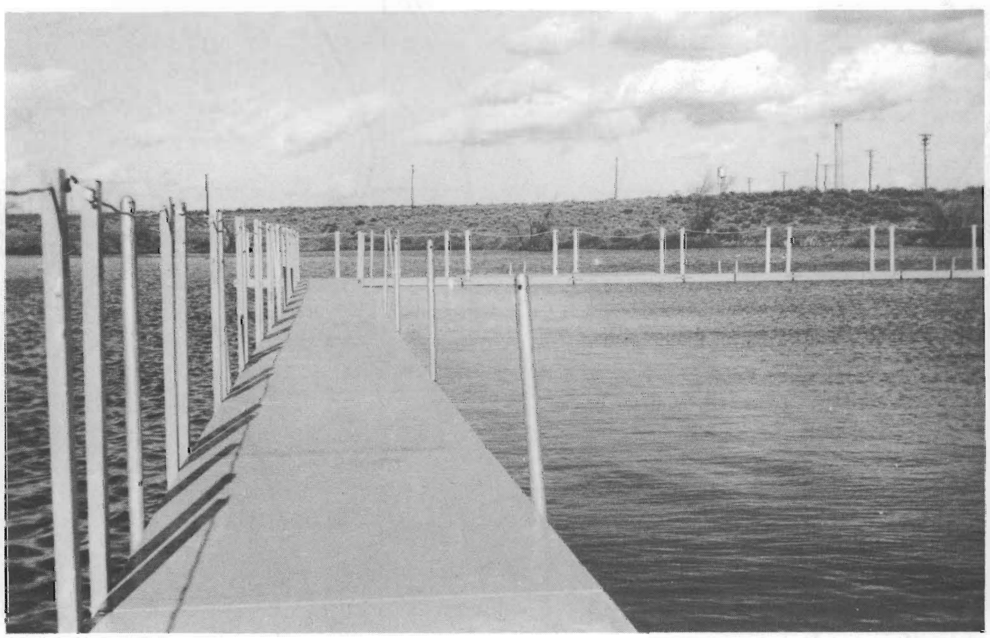

Figure 6. Walkway system installed on U Pond for sampling. The region of the pond protected from the wind by the docks (quad D) appears at the left in the upper photo and at the right in the lower photo.

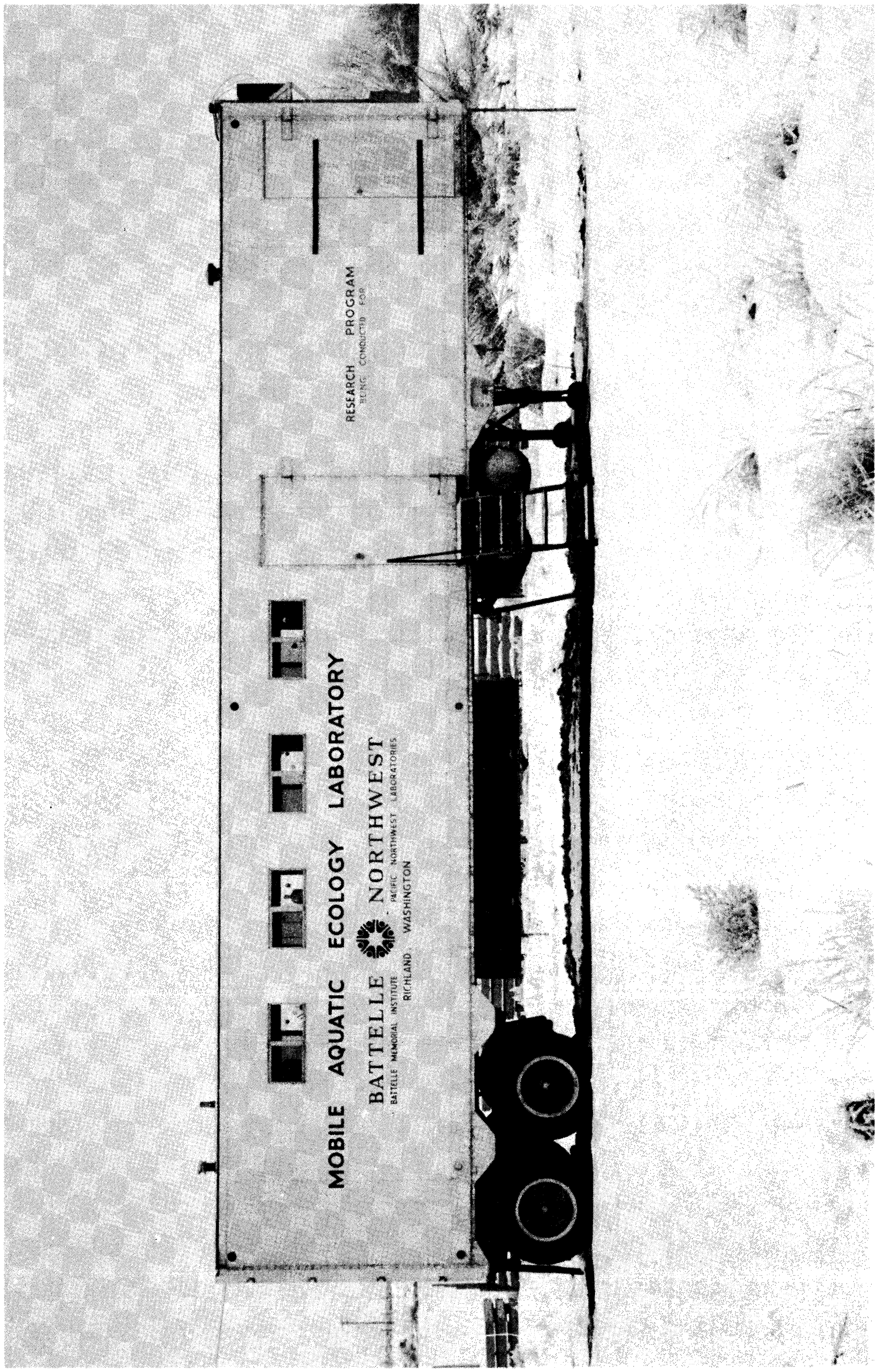

Figure 7. Laboratory trailer installed at U Pond site.

described by Major et al. (1971), Wessman et al. (1971), and Major et al. (1974). Results are expressed in terms of dry weight unless stated otherwise.

Sediment samples were taken using a 1/4 ft^2 Ekman dredge and a coring tube. After a sample of the pond bottom was removed, it was subsampled with the coring tube to yield a sediment plug 4.8 cm in diameter, 10 cm deep, with a volume of 0.18ℓ (10.8 in^3). Four cores were removed from each dredge sample and placed immediately in aluminum drying pans. The four plugs were mixed and frozen to await processing.

Fractionation of forms of Pu and Am in U Pond water, interstitial water, and sediments was done by the Radiological Science Department of Battelle-Northwest. Water from the pond was sampled during January 1974 when the pond was partially covered with ice (quads B and D, Fig. 5), which permitted sampling with a minimum of disturbance of the bottom sediments. These water samples were processed (approximately 1 m^3 per sample) using the filtration-sorption system described by Silker et al. (1971) (Fig. 8). The utilization of this technique permits the fractionation of radionuclides in water samples into the following four categories:

(1) radionuclides associated with particulate materials,
(2) cationic radionuclides or radionuclides that are bound in a cationic complex,
(3) anionic radionuclides or radionuclides that are bound in an anionic complex,
(4) radionuclides complexed with "nonionic" organic materials that are not removed by the ion exchange beds but that are sorbed by the aluminum oxide.

A 1/4 ft^2 Ekman dredge was used to obtain three samples of U Pond sediments for Pu and Am fractionations. Sediment sample #1 was taken from grid VII, #2 from grid XI, and #3 from grid X (Fig. 5). These three sediments represent two different types of sedimentary material. Sediment #1 was composed predominately of subsurface material (from > 5 cm below the sediment-water interface; surface material was removed from this sample), whereas sediment #2 was the loosely compacted surface material characterized as decaying algal cells. Sediment sample #3 was a mixture of both surface and subsurface sediments.

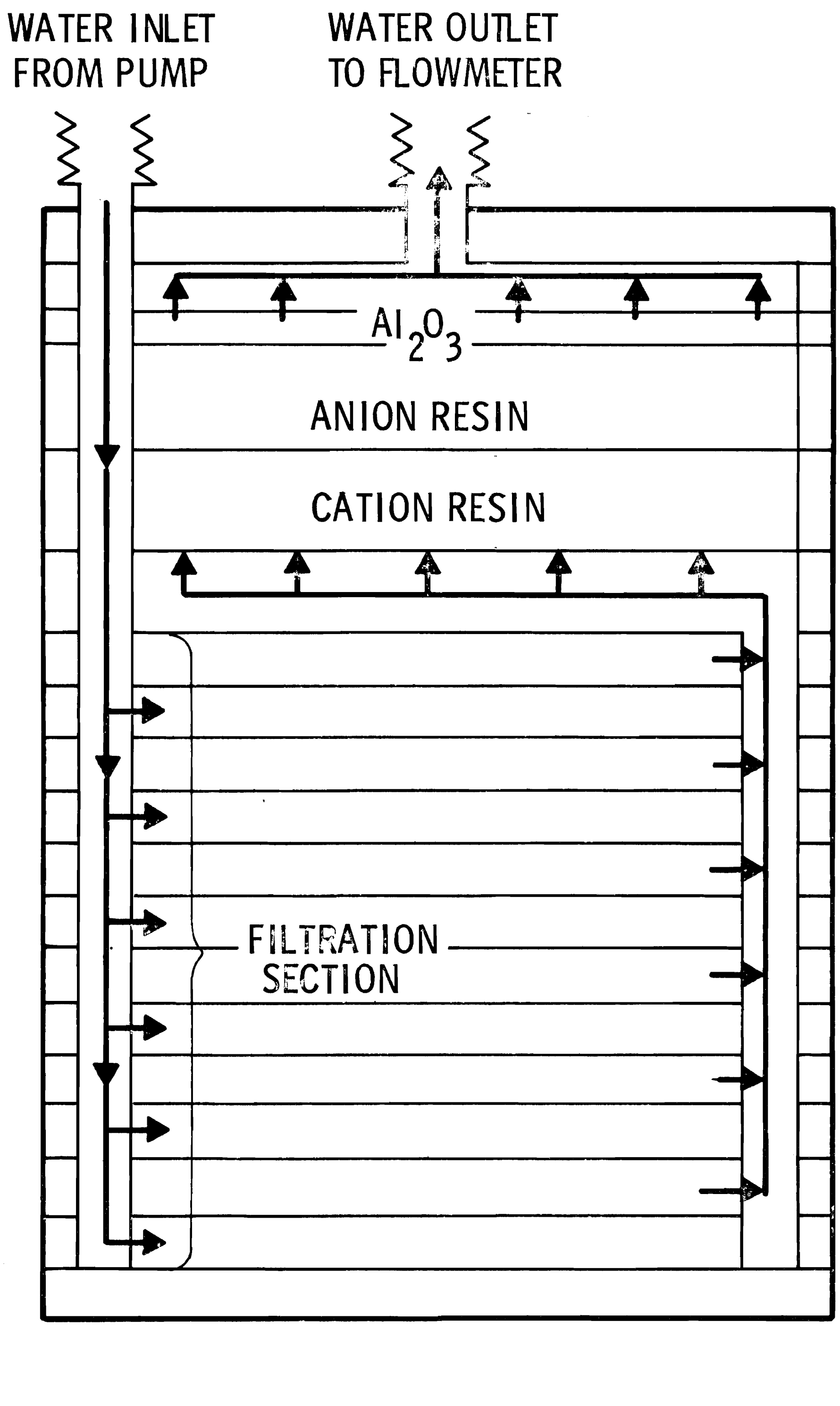

Figure 8. Schematic diagram of the large volume filtration-sorption water sampler.

To characterize the nature of the plutonium and americium species retained by the U Pond sediments, a semi-selective leaching process was utilized. Figure 9 is a flow chart detailing the individual steps in the leaching procedure. Because these extractions are performed sequentially on the same sample, more tightly-bound plutonium and americium species are removed by each extraction. While this approach may not remove individual plutonium and americium species selectively, it does evaluate the potential plutonium and americium release from the sediments and relates this release to the environmental chemistry of the sediments.

The initial centrifugation of the sediments and distilled water washing removed the interstitial water and species which are present in solution in the pond sediments. The interstitial water sample was filtered through an 0.45 μ filter and passed sequentially through a cation exchange resin bed, an anion exchange resin bed, and an aluminum oxide bed. Each of these beds and the effluent from the Al_2O_3 were analyzed. The materials within the interstitial water fraction are quite mobile within the pond system. Mixing at the sediment-water interface may release the radionuclides found in this fraction into the pond water.

The extraction with dilute (0.1 M) NaCl also removes species that are potentially very mobile; these are species absorbed onto the sediment matrix. Reagents utilized to remove absorbed ions are generally neutral salt solutions such as 1M $MgCl_2$ (Gibbs 1973), 1M NH_4Cl (Williams et al. 1971a), 1M CH_3COONH_4 or 5M NaCl (Jackson 1958). Dilute acid solutions (0.1N to 1.0N) have also been employed to remove nonoccluded species (species not bound in the crystalline matrix of the sediments) from soils and sediments (Shah et al. 1968; Wentz and Lee 1969). Acid treatment, however, removes both sorbed species and species associated with hydrous oxides that may be solubilized by the acid. A very dilute 0.1N NaCl neutral salt solution was chosen for use in the present investigation to remove only the loosely adsorbed radionuclide species.

Extraction of noncalcareous sediments, such as those found in U Pond, with an ammonium oxalate-oxalic acid reagent (step #3 in the sequential leaching procedure) has been shown to solubilize and remove hydrous Fe and

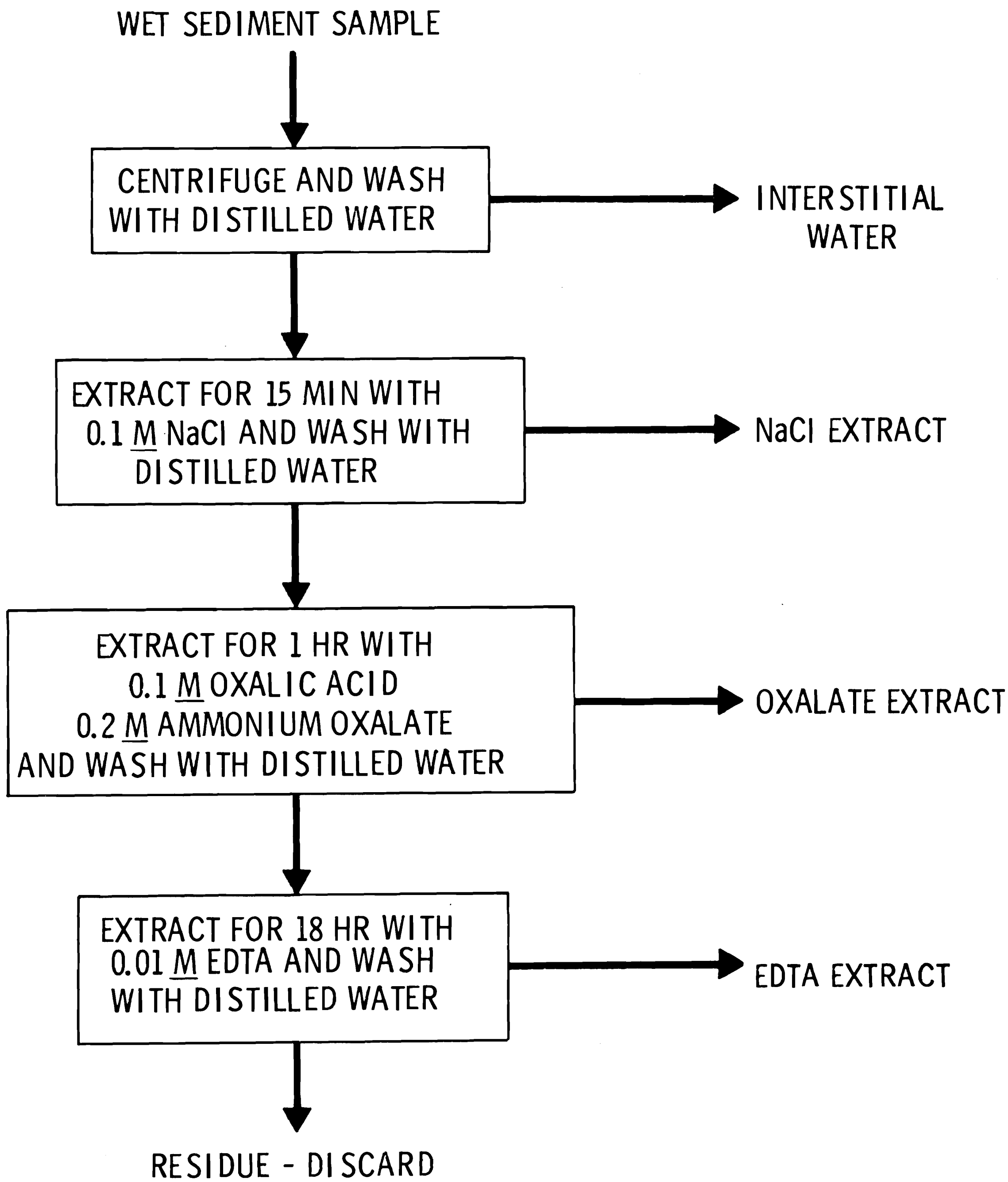

Figure 9. Schematic diagram of the sequential extraction procedure for sediment samples.

Al oxides and the trace constituents associated with them (Williams et al. 1971a; Williams et al. 1971b). Since the oxalate anion forms a complex with several plutonium and americium species (Lange 1973), this oxalate extraction may remove some plutonium and americium by formation of a soluble complex in addition to removing those forms retained by hydrous oxides.

Extraction with a stronger complexing agent, EDTA (Lange 1973), was performed to obtain an indication of the maximum amounts of plutonium and americium that were removable from the samples without complete destruction of the sediment matrix.

The difference between the total plutonium and americium contents of the samples and the summation of the plutonium and americium contents in the individual fractions is designated as the "residual" material in the sediments. As defined in the context of this investigation, this residual fraction is quite resistant to removal by techniques normally utilized during environmental chemistry evaluations of sediments.

Water and sediment samples were pre-processed to fractionate each sample into several sub-samples. Each of these sub-samples was handled as an individual sample and all were processed in approximately the same manner. The concentrations of γ-ray emitting radionuclides were determined with a standard Ge(Li) diode or with a Ge(Li)-NaI(Tl) coincidence-anticoincidence system (Cooper and Perkins 1972). In addition, several of the samples were also counted on an anticoincidence shielded NaI(Tl) dual-crystal detector system (Perkins and Robertson 1965). Following these instrumental measurements, the samples were subjected to a chemical separations treatment to prepare them for further radiochemical analysis. An anion exchange procedure (Thomas 1972) separated ^{90}Sr, ^{238}Pu and $^{239,240}Pu$, and ^{241}Am into individual fractions for beta counting or alpha energy analysis. Prior to this chemical separation, isotope dilution tracers of ^{85}Sr, ^{236}Pu, and ^{243}Am were added to each sample so that recovery of each of these radionuclides could be calculated. Tracer recoveries were generally quite good but varied with sample composition. Recovery of ^{236}Pu ranged from 16 to 100%; ^{243}Am, from 20 to 65%; ^{85}Sr, from 60 to 90%.

SAMPLING OF AQUATIC ORGANISMS

Aquatic organisms were collected in numerous ways with the main concern being that of accumulating enough of a specific sample mass to warrant preparation and analysis. None of the sampling for pond biota was carried out in a quantitative manner. The distribution of organisms in the pond does not generally permit the use of common techniques for quantitative sampling. Many benthic invertebrates were collected using a Clemens net (Clemens 1950). Other biotic samples were taken from the various submerged tree limbs and plant substrates, to which the benthos have a strong affinity. The plain sediment bottom does not support a large variety or quantity of benthic invertebrate biomass. Native goldfish samples were collected with dip nets. These goldfish are designated as "native" to the pond, but it should be understood that they were probably introduced to the pond artificially by workers in the area. Counts of benthic microorganisms in sediment and algal material were determined for samples collected asceptically from four sites in the pond. Two aliquots from each sample were dried to determine dry weight equivalents for wet weights in order to relate bacterial counts to dry weights. Aerobic and anaerobic bacteria were pour-plated in Bacto Brain-Heart infusion agar. Actinomycetes were grown in glycerol-asparagenate agar, and fungi were grown in Bacto Littman Oxgall agar containing 30 μg/ml streptomycin to selectively eliminate most bacterial cells. To determine number of viable cells all samples were serially diluted and plated in triplicate. Plates were incubated at 30°C for seven days prior to counting.

PHYSICAL AND CHEMICAL DETERMINATIONS

A water budget for U Pond was determined weekly using a combination of flow measurements and daily discharge records. The major supply of water to the pond comes from the evaporator-crystallizer plant (Fig. 3). The supply rate of this source is determined from daily discharge records. Waste water from the laundry plant joins the cooling water from the evaporator-crystallizer in the laundry trench. The flow from the laundry plant is measured a few meters above the confluence using a corregated pipe which passes under a road. The cross-sectional area of the water in this pipe is measured and a surface float is used to determine the velocity of the stream. From these values water flow rates are calculated. To determine flow rates in the Z-19 trench the same method is used with a plastic irrigation pipe placed in the trench near its mouth.

Dissolved oxygen and temperature were measured using a YSI (Model 51A) DO-temperature probe. Pond temperatures were recorded continuously with a Foxboro thermograph. A Leeds & Northrup (Model No. 7417) pH meter was used to measure hydrogen ion concentration. Alkalinity, hardness, and conductivity measurements were made in accordance with APHA et al. (1971).

Total phosphorus and reactive silicate were analyzed using the molybdate complexing reaction described by Strickland and Parsons (1968). Total inorganic nitrogen concentrations were measured using the Cd-Cu reduction method described by Strickland and Parsons (1968) and ammonia distillation techniques described by APHA et al. (1971). Chlorophyll *a* (designated as Chl *a*) concentrations of algae suspended in water were measured using acetone extraction and a Turner Model 110 fluorometer according to the method described by Strickland and Parsons (1968).

MEASUREMENTS OF AQUATIC PRODUCTIVITY

Determinations of primary productivity for the pond could not be made by ordinary means. The major role of primary production in the pond is performed by benthic algae and submerged macrophytes and would not be accounted for in a standard ^{14}C bioassay. To account for the entire aquatic primary production rate a method developed by Verduin (1964) was used which related diurnal change in pH to the removal or addition of CO_2 in the pond water. This method appears to be very satisfactory for a small aquatic system like this one, as it provided pond-wide primary production estimates which were comparable to other aquatic systems of similar structure. [Since these estimates were based entirely on frequent pH readings (4 to 6 measurements through the solar day), one must be careful when assuming that pH changes are caused by biotic activity alone. Chemical discharges into the system being evaluated could invalidate this method of determining photosynthetic rate. Care was taken to insure that this problem did not affect our production estimates.]. The in situ ^{14}C bioassay method, described by Vollenweider (1969), was used to measure primary production by suspended algae (i.e. phytoplankton). This combination of methods will allow for the determination of the benthic and plankton fractions of photosynthetic rate.

Estimates of standing crops were made for predominant forms of vascular plants and algae growing in the pond. This was done by first removing all plant material from a 1/16 m^2 square placed randomly in the pond. Dry weights of the various plant materials collected in this way were determined separately and then correlated with visual estimates of plant coverage as viewed from above the pond's surface. Thus, the standing crop estimates for the predominant plant and algal forms were calculated for the entire pond on the basis of surface coverage.

TRANSURANIC UPTAKE EXPERIMENTS

An in situ experiment was performed to measure the rate of uptake and saturation levels for Pu and Am accumulation in goldfish. The objective was to quantify the Pu and Am trophic pathway from sediments to goldfish. This simple experiment involved placing goldfish (*Carassius auratus*, 8 cm long, imported from Arkansas, "Ozark Comets") in plastic mesh pens at the center of each quad (Fig. 10). These pens were set into the sediments so that the goldfish had access to 0.66 m^2 (7.0 ft^2) of the pond bottom as a feeding substrate. These pens rapidly accumulated periphyton on the surface of the plastic which supplemented the food source (i.e. sediments) of the goldfish. The water volume of each pen ranged from 0.4 to 0.7 m^3 (14 to 24 ft^3) because the water depth varied with the pen location. About 60 of these fish were placed in each pen in mid-November 1973 and were subsampled bimonthly through the following summer. Gut contents were washed out of half of the sub-samples while the rest were processed for Pu and Am analyses without the removal of gut contents.

Figure 10. Experimental goldfish pen being sampled during winter.

RESULTS AND DISCUSSION

DESCRIPTIVE LIMNOLOGY

Physical

This shallow 14-acre pond (partially described earlier in an historical accounting) is located in the 200-West area of the arid-steppe land on the Hanford Reservation (Figs. 1 and 2). It has two inflow trenches supplying water (from processing plants) at a rate of about 10 m^3/min (5.9 cfs) (Fig. 3). The major source of water comes from the 242-S plant (evaporator-crystallizer) where a flow of about 8 m^3/min (4.7 cfs, 80% of total) travels to the pond via the U-14 trench (Fig. 3). This water has been used for cooling purposes and supplies a significant heat load to the pond. Water from a laundry plant, where protective clothing is laundered, provides about 1.4 m^3/min (0.8 cfs, 14% of total) by way of the U-14 trench (Fig. 3). This source of water provides a large supply of algal nutrients to the pond. The third source comes from a Pu refining plant and is carried to the pond via Z-19 trench (Fig. 3). This source supplies about 0.6 m^3/min (0.4 cfs, 6% of total). It is this source that had historically released 8.1 kg of Pu to the pond via several trench systems, the most recent of which is the Z-19 trench. These old trenches once lay close and parallel to the current Z-19 trench, but are now covered by backfilling. There is also a small input of water into the Z-19 trench from 231-Z plant, but it does not play a significant role in the pond's water, Pu, or nutrient budget.

Since there are no surface outflows from the pond, water exits from the pond almost entirely by percolation (> 95%) with some evaporative loss (< 5%). The pond volume is presently held at 22,700 m^3 (6 x 10^6 gal., 18 ac. ft) with an exchange rate of about 40 hours. This rapid exchange rate applies only to the present pond level, which is now higher than levels of recent years. The rate of water loss in the pond diminishes as the pond level is lowered. Since the central basin of the pond appears to be less permeable than the outer perimeter, it is likely that a large portion of the 10 m^3/min loss of water from the pond occurs near the perimeter. There are no data to illustrate this but infrequent interruptions of surface inflow have provided opportunities to observe the subsequent reductions in pond elevation. Interruptions in this inflow have shown that the pond does not lose half of its volume within 48 hours. Sufficient data are not yet available to calculate differentials in percolation across the pond bottom.

The pond's maximum depth is about 1.6 m (5.4 ft), located in grid VII (Fig. 5). The thickness of sediments lying over the desert soil base is estimated to be about 10 cm. However, these sediments are nonuniformly distributed and range in depth across the pond bottom from about 0 to 40 cm. Wind action plays a major role in the pond's circulation and sediment distribution, which generally leaves sediments deposited in pond bottom depressions and on leeward shorelines. Because the pond's benthic region has not been stable there has been no suitable habitat for submergent macrophytes. The construction of walkways in January 1974 has arrested the shifting of some of the benthic region on leeward side of the walkways to the extent that substantial populations of submergent macrophytes are now able to develop. This has provided a good indication that in the past there has been extensive and continuous movement of sediments within the pond caused by wind action. Some protection from winds is afforded by willows and cottonwoods which grow along quads A, B, and C, and on the island (Fig. 5).

Water entering the pond via the laundry trench is nearly always warmer than the pond. Most of this supply (> 80%) has passed through the cooling system of the Pu recovery plant (Fig. 3). Although this heat input modifies the atomospheric influence on the pond's heat budget, these higher temperatures are often confined to quad C due to a prevailing westerly wind (Fig. 11). Thus, the nonuniform thermal distribution across the pond is a combined effect of prevailing wind direction and the location of where the heated inflow enters the pond. The pond's annual range in temperature is from the summer maximum of 32°C (July, augmented by the heated laundry trench effluent) to the winter minimum of 0°C when there is ice cover on the pond's NW end (January). With the exception of the ice-covered period in January, no thermal stratification exists in the pond.

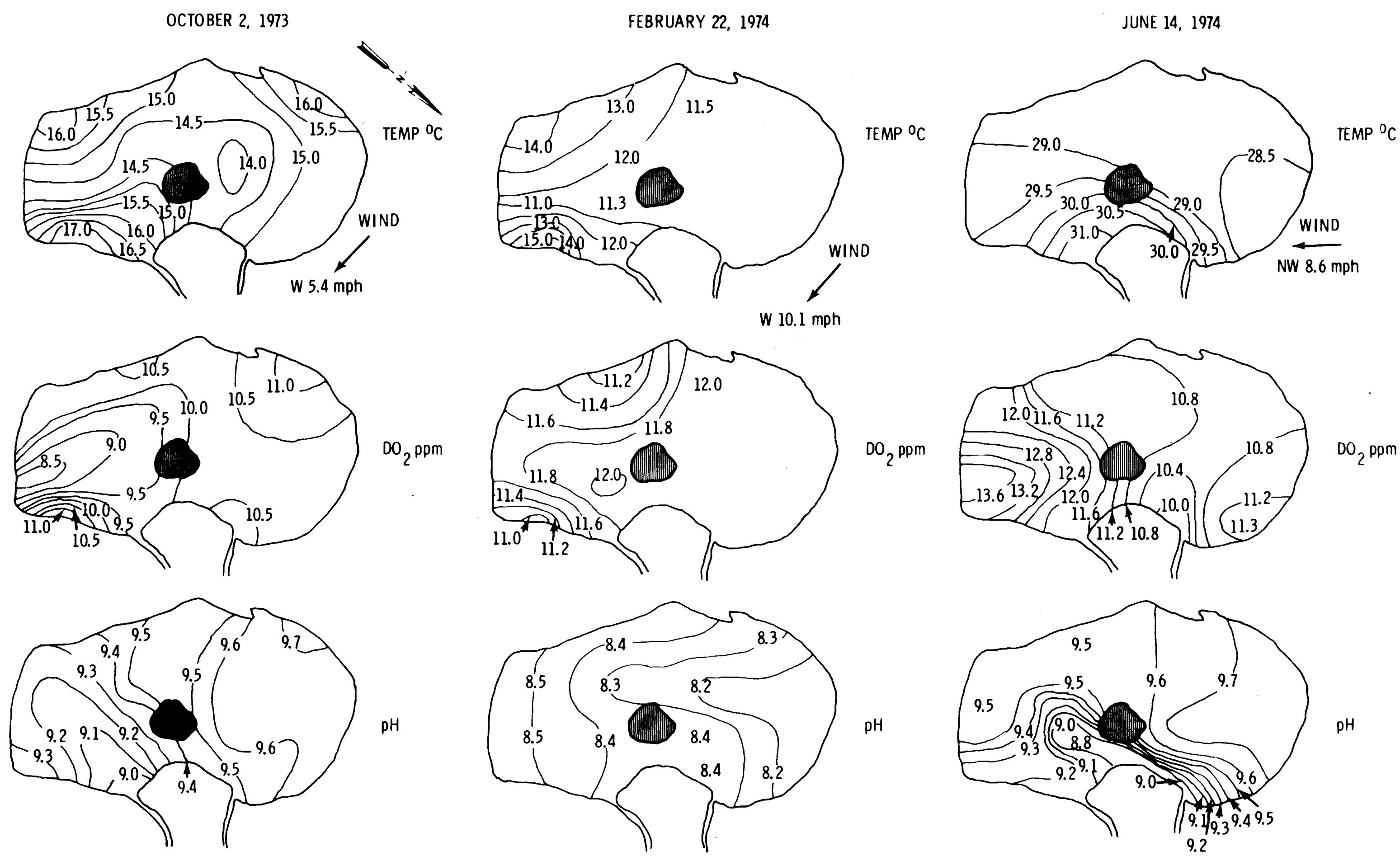

Figure 11. Distribution of temperatures, dissolved oxygen, and hydrogen ions (pH) in U Pond associated with prevailing westerly winds for selected fall, winter, and spring dates.

Chemical

U Pond exhibits moderate hardness (39 mg/ℓ as $CaCO_3$), alkalinity (92 mg/ℓ as $CaCO_3$), and conductivity (1000 to 2500 micromhos/cm at 25°C), and is highly enriched with algal nutrients from the laundry plant. The total phosphorus income to the pond is estimated at about 10 kg/day [spring mean (n=5) 1974, Table I]. This sustains a mean pond concentration (spring) of 0.28 mg/ℓ (n=5). Inorganic nitrogen income to the pond is about 4 kg/day [Table I (n=5)], which is, from the standpoint of enrichment, not as excessive as phosphorus. This supply rate sustains a mean pond concentration of 0.2 mg inorganic N/ℓ [Table I, (n=20)]. Silicate-silicon income is also high [21 kg/day, (n=5) Table I], sustaining a pond mean of 1.4 mg/ℓ (n=20). This nutrient plays a relatively minor role in algal production because diatoms are not a predominant algal form in the pond.

This eutrophic nutrient supply rate supports a high level of primary production (discussed later) which is reflected in the pond's pH and dissolved oxygen levels. During the warmer months (May-October) the sunrise pH levels are around 7.0, reflecting nocturnal respiration. These levels often exceed 9.5 by mid-afternoon (Fig. 11), indicating the high level of photosynthetic activity. Dissolved oxygen levels also reflect this high level of primary production by concentrations of 9 to 13 mg/ℓ (i.e., saturation levels for the respective temperatures) (Fig. 11).

Biological:

This pond can be broadly classified as a eutrophic system with a simple food web. Since the pond is very shallow, there is substantial light penetration to the bottom, and thus the entire pond is considered trophogenic. The food base for this system is principally autochthonous, and primarily dependent upon nutrients supplied by the laundry. The pond fauna appear to feed principally on organic detritus deposited on the bottom, and secondarily on living primary producers. There is a small degree of predator-prey activity within the pond, however waterfowl and other birds provide additional predation pressure from above. The principal active predators in the pond are insects of which the major ones are dragonfly larvae, (*Aeschna* and

TABLE I. Summary of nutrient concentrations and supply rates for spring months in 1974.

Date	Nutrient	Pond Conc. (mg/ℓ)	Laundry Trench Conc. (mg/ℓ)	Estimated Supply rate to Pond (kg/day)
2-1-74	Total P	0.125	0.196	2.8
	inorg. N	0.37	0.40	5.8
	SiO_2 - Si	1.17	1.32	19.0
2-14-74	Total P	0.167	0.21	3.0
	inorg. N	0.28	0.40	5.8
	SiO_2 - Si	2.19	2.64	38.0
3-1-74	Total P	0.44	0.27	3.9
	inorg. N	0.18	0.13	1.9
	SiO_2 - Si	1.50	2.04	29.4
3-13-74	Total P	0.31	0.50	7.2
	inorg. N	0.10	0.125	1.8
	SiO_2 - Si	2.04	2.76	39.7
4-1-74	Total P	0.37	2.3	33.1
	inorg. N	0.13	0.40	5.8
	SiO_2 - Si	0.26	0.42	4.8
Spring Mean (Feb.-Apr.)	Total P	0.28	0.69	9.9
	inorg. N	0.21	0.29	4.2
	SiO_2 - Si	1.43	1.43	20.6

Libellula) and to a lesser degree predaceous diving beetles (Dytiscidae) and water scorpions (Nepidae). A conceptualized and qualitative food web has been developed for the pond based on extensive collection and observation of biota (Fig. 12). As indicated by this diagram, the principal aquatic animals are nonpredaceous benthic invertebrates and goldfish (*Carassius*), but with an active population of predaceous dragonfly larvae. Beyond this, predaceous diving beetles, water scorpions, and avarian forms enter the food web in a relatively minor capacity. Also there has been some evidence of muskrats (*Ondatra*) living in or near the pond and presumably feeding on cattail roots (*Typha*).

Because of the high rate of nutrient supply, this pond supports luxuriant growths of algae and macrophytes. Prior to December 1973 the pond was habitat-limited with respect to rooted submergent macrophytes. However, sediment stability, mainly in quads C and D, has been significantly increased by the installation of docks (Figs. 5 and 6), and a large population of *Potamogeton* (rooted macrophyte) has developed. In addition to, and associated with, this are recent extensive growths of *Cladophora* (filamentous green algae) and *Tetraspora* (colonial green algae). This change in habitat appears to have altered the relative roles of primary production by the planktonic and sessile plant forms. It now appears that massive algal mats and rooted submergent macrophytes assume the major role of primary production. Prior to this development the major role of primary production seemed to be carried out by suspended (i.e., planktonic) algae.

The algal population in the pond is, as already mentioned, dominated by sessile or benthic forms (*Cladophora* and *Tetraspora*) (Table II). In terms of algal biomass these two forms constitute greater than 95% of the entire population. *Characium,* sessile on *Cladophora,* is very numerous but does not involve much biomass. The green filamentous *Hydrodictyon* is also abundant in the pond. The planktonic population of algae is comprised mainly of *Pediastrum* and an assortment of diatoms, many of which often appear to be sediment-oriented. Populations of planktonic algae are often ephemeral and have no typical or consistent structure. Due to dock construction it now appears that sessile forms have taken the competitive advantage.

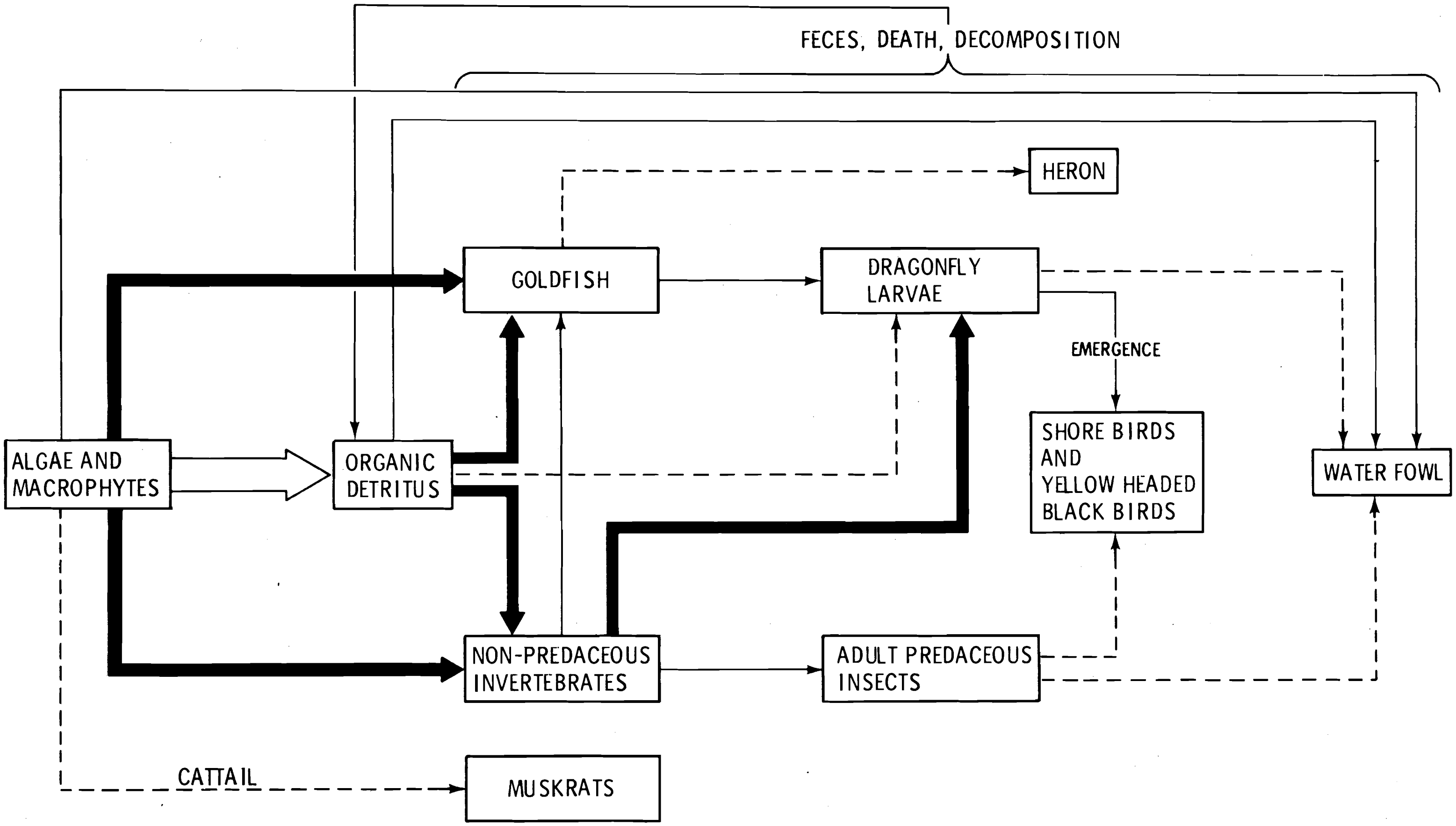

Figure 12. A conceptualized and qualitative food web for U Pond showing relatively major and minor pathways of carbon (i.e., energy transfer). Heavy lines indicate major routes, thin lines indicate moderate routes, and broken lines indicate minor routes of transfer.

Table II. Algae occurring in U Pond and their estimated relative abundance.

Population	Division	Genus	Relative Abundance: Low	Medium	High
Planktonic	Chlorophyta (green algae)	*Scenedesmus*	X		
		Cosmarium	X		
		Pediastrum		X	
		Selenastrum	X		
		Sphaerocystis	X		
	Chrysophyta (diatoms)	*Fragilaria*	X		
		Synedra	X		
		Nitzschia	X		
		Navicula	X		
		Eipthemia	X		
		Stauroneis	X		
		Cocconeis	X		
		Campylodiscus	X		
		Gomphonema	X		
		Cymbella	X		
		Melosira	X		
		Cyclotella	X		
		Rophalodia	X		
	Euglenophyta	*Euglena*			X
	Pyrrophyta	*Glenodinium*	X		
	Cyanophyta	*Chroococcus*	X		
		Anabaena	X		
		Aphanizomenon		X	
	Uncertain	Cryptomonadales			X
Benthic	Cyanophyta (blue green algae)	*Oscillatoria*	X		
		Spirogyra		X	
	Chlorophyta (green algae)	*Cladophora*			X
		Hydrodictyon		X	
		Spirogyra	X		
		Tetraspora			X
		Characium		X	
		Mougeotia	X		

Potamogeton is the only submergent vascular plant found in U Pond. It is concentrated in quads C and D, but found in all sections of the pond (Table III). Cattails (*Typha*) and bulrushes (*Scirpus*) grow prolifically on the pond's perimeter in quads C and D, with lesser concentrations along the remaining shoreline. There are several stands of bulrushes in the pond's interior. Willow and cottonwood trees (*Salix* and *Populus*) grow along the entire perimeter and on the island in the pond, but denser growths occur along quads A, B, and C (Table III). The northwest end of the pond is relatively free of trees. There are ephemeral growths of watercress (*Rorippa*), occurring in late winter, and duckweed (*Lemna*), occurring from May to October, in quads C and D. Some plants associated with the pond occur mainly in the inflow trenches which are wild lettuce (*Lactuca*), smartweed (*Polygonium*), and horsetail (*Equisitum*) (Table III) (Price and Rickard 1973).

The primary productivity of the pond appears to be strongly dominated by the sessile algae *Cladophora* and *Tetraspora* and the rooted submergent macrophyte *Potamogeton*. Spring and summer planktonic Chl *a* concentrations ranged from 0.5 to 2.0 μg/ℓ, which is very low for a eutrophic system such as this. It is obvious that benthic forms dominate the pond production by a large degree. Estimates of benthic and planktonic productivity for June and July 1974 show the pond is fixing between 220 to 260 kg C (net) per day. These rates are from 9.8 to 11.3 g C (net)/m^3 per day or 3.9 to 4.5 g C (net)/m^2 per day. These rates of primary production are high but not unreasonable when compared to other eutrophic systems. Assuming the daily production estimates to be correct, the pond system is fixing about 38 lbs of C per acre per day. This estimated carbon fixation rate approaches that of a corn field which fixes about 56 lbs of C per acre per day (Robbins et al. 1957).

Standing crop estimates for the major macrophytes (*Potamogeton* and *Lemna minor*) and algae (*Cladophora* and *Hydrodictyon*) reflect the high level of primary production. These estimates were made in late July at a time when plant biomass appeared to have reached a seasonal maximum. The highest standing crops were observed for *Potamogeton* (8756 kg or 19,300 lbs pond-wide, expressed as dry weight) and *Cladophora* (2388 kg or 5266 lbs pond-wide).

Table III. Vascular plants directly associated with the U Pond ecosystem (Price and Rickard 1973).

Common name	Scientific name	Location	Relative abundance: Low	Medium	High
Duckweed	*Lemna minor*	Quads A,B,C,&D			X
Watercress	*Rorippa nasturtium-aquaticum*	Quad D & trenches	X		
Wild lettuce	*Lactuca serriola*	Z-19 trench	X		
Bulrush	*Scirpus maritimus*	Quads C&D & trenches		X	
Bulrush	*Scirpus validus*	Quads C&D & trenches		X	
Three-square Bulrush	*Scirpus americanus*	Quads C&D & trenches		X	
Hardstem Bulrush	*Scirpus acutus*	Quads C&D & trenches		X	
Cattail	*Typha latifolia*	Quads A,B,C,&D & trenches			X
Pondweed	*Potamogeton filiformis*	Quads A,B,C,&D & trenches			X
Smartweed	*Polygonum persicaria*	Quad D & trenches	X		
Peachleaf Willow	*Salix amygdaloides*	Quads A,B,C,&D		X	
Cottonwood	*Populus deltoides*	Quads A,B,C,&D	X		
Horsetail	*Equisetum laevigatum*	trenches	X		

Considerably lower estimates were obtained for the floating vascular plant *Lemna minor* (26 kg or 57 lbs) and for the filamentous alga *Hydrodictyon* (49 kg or 108 lbs).

It is within reason to assume that half of the dry weight of the plant biomass is carbon. Based on this assumption the total standing crop for the major primary producers in late July is 5609 kg or 12,369 lbs of C. The growing period for this standing crop was estimated to be about 150 days (from mid-March to the first of August). Thus, without considering losses of standing crop due to grazing and decomposition a production rate for these plants is estimated to be 37 kg or 82 lbs C/day. Expressed per unit area these production rates are 2.6 kg (5.8 lbs) C/acre per day [or 0.65 kg (1.44 lbs)/m^2 per day].

Using these two different methods of estimating primary production it is evident that the pond is highly productive; from approximately 0.7 to 3.9 g C (net)/m^2 per day or from 5.8 to 38 lbs C(net)/acre per day. It is also obvious that the pond is not accumulating biomass at a rate similar to that of a corn field, but from an observational standing point one can view many mats of floating *Cladophora* and large beds of *Potamogeton* during the summer months (Fig. 13).

Animals in this pond system are predominately benthic. The main components are insect larvae which include dipterans (midges, *Chironomus* and *Cricotopus*) and odonates (dragonflies, *Aeschna*, *Libellula*, and *Ischnura*), and the adult hemipterans in the families Notonectidae (Backswimmers) and Corixidae (Waterboatmen) (Table IV). Other predominate forms include the scud *Hyalella* and the snails *Lymnaea* and *Physa*. The water flea *Daphnia* appears in heavy concentrations from March to June. The dragonfly larvae provide the only substantial predaceous activity in the pond. Water scorpions (Nepidae), giant water bugs (Belostomatidae) and predaceous diving beetles (Dytiscidae) are also active predators, but to a much lesser degree (Table IV and Fig. 12). The remaining benthic organisms provide species variation in this community, but not substantial biomass, and feed principally on organic detritus.

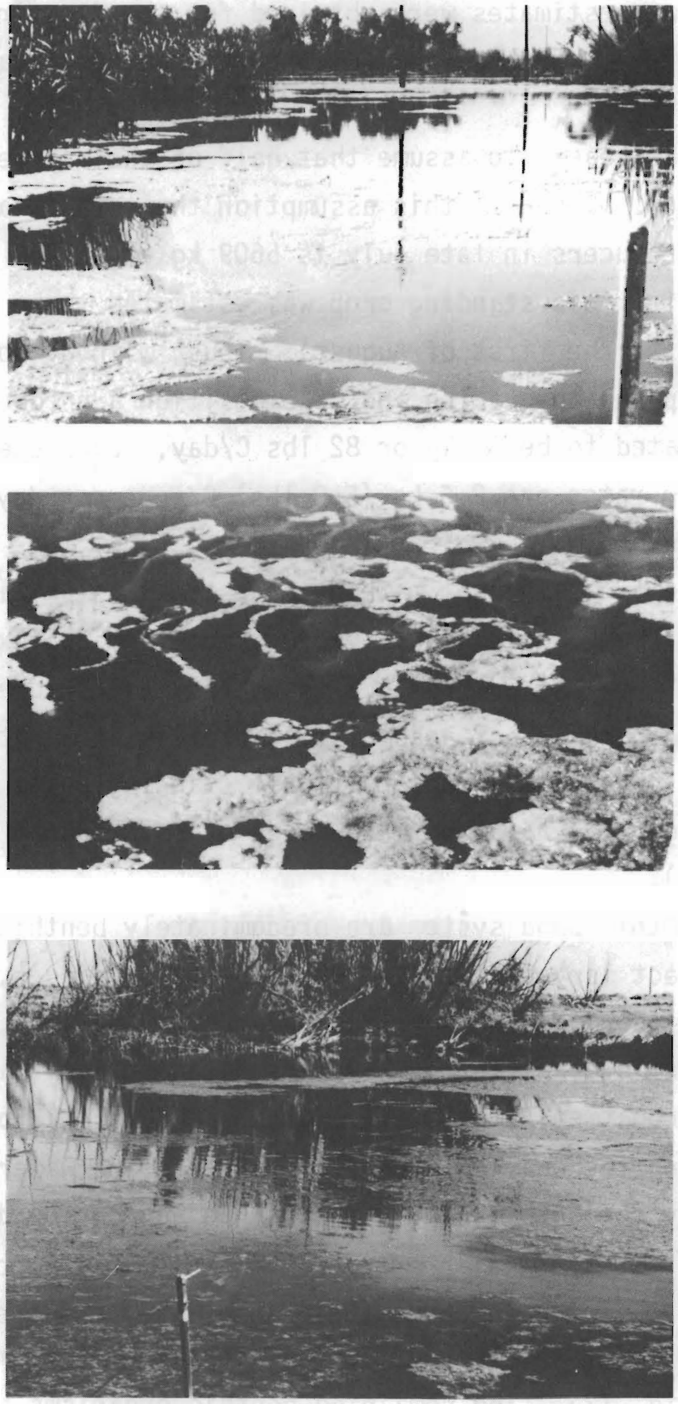

Figure 13. Floating mats of *Cladophora* (top 2 photos) and beds of *Potamogeton* (bottom photo) occurring during the spring and summer months of 1974.

Table IV. Fauna associated with U Pond.

Population	Common Name	Taxonomic Group	Relative Abundance L	L–M	M	M–H	H
Benthic Invertebrates	Flatworm	*Dugesia*	X				
	Segmented worm	Oligochaeta	X				
	Leech	Rhynchobdellida	X				
	Seed shrimp	Ostracoda	X				
	Scud	*Hyalella azteca*			X		
	Water mite	Hydracarina		X			
	Dragonfly adults	*Aeschna*				X	
		Anax	X				
		Libellula				X	
		Tramea		X			
		Erythemis		X			
	Dragonfly larva	*Aeschna*				X	
		Libellula				X	
		Tramea			X		
		Erythemis			X		
	Damselfly adults	*Archilestes*		X			
		Ischnura				X	
	Damselfly larva	*Ischnura*				X	
	Mayfly	Baetidae		X			
	Water strider	Gerridae		X			
	Backswimmer	Notonectidae				X	
	Creeping water bug	Naucoridae		X			
	Water scorpion	Nepidae	X				
	Giant water bug	Belostomatidae		X			
	Water boatmen	Corixidae					X
	Caddisfly	Tricoptera		X			
	Water Scavenger Beetle	Hydrophilidae	X				
	Predaceous Diving Beetle	Dytiscidae	X				
	Beetle	Noteridae		X			
	Beetle	Amphizoidae		X			
	Beetle	Helodidae		X			
	Midge	*Chironomus*		X			
		Chricotopus		X			
	Snail	*Lymnaea*					X
		Physa		X			
Planktonic Invertebrate	Water Flea	*Daphnia*				X	
Neckton	Goldfish	*Carassius auratus*					X

(Table IV contd)

Population	Common Name	Taxonomic Group	Relative Abundance L	M	H
Waterfowl	Mallard duck	*Anas platyrhynchos*		X	
	American coot	*Fulica americana*		X	
	Ruddy duck	*Oxyura jamaicensis*	X		
	Cinnamon teal	*Anas cyanoptera*	X		
	Lesser scaup duck	*Fulix affinis*	X		
	Ringnecked duck	*Hythya collaris*	X		
	Pied billed grebe	*Polilymbus podiceps*	X		
Birds	Common nighthawk	*Chordeiles minor*	X		
	Killdeer	*Charadrius rociferus*	X		
	Great blue heron	*Ardea herodias*	X		
	Morning dove	*Zenaidura macroura*			X
	Ash throated fly-catcher	*Myiarchus cinerascens*	X		
	Eastern kingbird	*Tyrannus tyrannus*		X	
	Barn swallow	*Hirundo crythrogaster*		X	
	American magpie	*Pica pica*	X		
	Redwinged black-bird	*Agelaius phoeniceus*	X		
	Common crow	*Corvus corax*	X		
	American goldfinch	*Spinus tristis*		X	
	Chipping sparrow	*Spizella passerina*			X
	Savanna sparrow	*Passerculus sand-wichensis*		X	
	Song sparrow	*Melospiza melodea*		X	
	White crowned sparrow	*Zonotricha leucophrys*		X	
	Oregon junco	*Junco oreganus*	X		
	Great horned owl	*Bubo virginianus*	X		
Mammal	Muskrat	*Ondatra*	X		

The pond has a prolific population of goldfish which is the only fish form present. The origin and history of these fish are not known but it is assumed that they were planted in the pond by Hanford workers. Other ponds on the Hanford Reservation have populations of goldfish which also make introduction by birds and waterfowl possible. These goldfish feed primarily on organic debris in the sediments and living plant and algae material. The larvae of the goldfish are presumably fed upon by dragonfly larvae (not actually observed) and the adults by Great Blue Heron and coyotes. The heron do not appear to provide much predation pressure and the goldfish population seems to be primarily controlled by a die-off period in late winter. Coyotes have been observed feeding on the dead goldfish which accumulate along the shoreline.

Mallard ducks and coots are found on the pond in moderate numbers and feed mainly on organic debris and algae (Table IV). Shorebirds, including sandpipers and killdeer feed frequently at the perimeter of the pond. Great Blue Heron have been observed taking goldfish from U Pond, although this has not appeared to be a frequent activity.

Although they do not have significant roles in the pond's ecosystem, there are a number of mammals that use the pond as a water source. Deer, coyote, raccoon, rabbits, and rodents have been observed in the pond area, and some evidence of muskrat activity exists around the cattails in quad D.

DISTRIBUTION OF Pu AND Am

Physical environs:

The principal repository for Pu and Am in the pond is the sediments. The mean sediment concentration for Pu is 390 pCi/g (n=60). This includes the isotopes ^{238}Pu, ^{239}Pu, and ^{240}Pu (i.e. ΣPu). Levels of Pu in the sediments 10 cm deep range from 7 to 2200 pCi/g. These values are for vertically mixed 10 cm sediment plugs. One sediment surface sample (1 to 3 cm deep) had a Pu concentration of 4463 pCi/g. For this system the overall ratio of ^{238} Pu to ^{239,240}Pu is 1:1. The range of ^{238}Pu sediment concentrations is from 2.6 to 1144 pCi/g with a mean of 194 pCi/g. For $^{239,240}Pu$ the range is from 4 to 1072 pCi/g with a mean of 195 pCi/g. The mean concentration of ^{241}Am in the sediment is 53.9 pCi/g (n=32) with a range of from 4.9 to 273 pCi/g. Selective surface sampling (1 to 3 cm) has shown ^{241}Am levels to be as high as 338 pCi/g. The overall ratio of ^{241}Am to ΣPu is 0.23:1.

These results are reported for a sampling series which covers a four-month period involving 15 samples each month (one 10 cm plug from each grid, Fig. 5). These data were statistically analyzed to determine if a pattern of either spatial or temporal distribution existed in the pond. Analysis of variance results indicate that Pu is randomly distributed in the pond sediments both spatially and temporally, and no disproportionally high concentrations consistently exist adjacent to the mouth of Z-19 trench which carries Pu processing wastes to the pond, or anywhere else in the pond.

The chemical forms of Pu and Am in the sediments may not be distinguishable, but it is possible to separate the forms of these actinides in terms of their removal by a sequential extraction process (described in MATERIALS AND METHODS). The extraction procedure renders information about the relative binding strength that exists between these transuranics and the sediment particles. (It is anticipated that there is an inverse correlation between this binding strength and the biological availability of the transuranics). Those forms removed in the NaCl extraction are considered loosely bound, while those removed only by EDTA extraction are very tightly bound. The oxalate extraction removes those forms held by a somewhat intermediate binding strength. The fraction not removed by the extraction processes are considered comparatively refractory and not likely removable in the pond's ecosystem by processes occurring over extremely long time intervals. Most of the Pu forms passed through the extraction procedure without being removed (73 to 93%, Table V). Extraction by EDTA removed from 20 to 22% of the subsurface sediment Pu but only 2 to 5% from sediment particles collected near the surface. The oxalate extraction process solubilized from 3 to 5% of the Pu in two of the sediment samples and 11 to 14% in the third sample. (The reasons for the extraction of this greater proportion of Pu in the third samples is unknown). Less than 1 to 3% of Pu was found to be loosely bound (NaCl extractable) and they were proportional to those levels in the interstitial water. Americium was also found to be strongly bound to surface sediment particles (90 to 96%) and less tightly bound to subsurface material (Table V). There was more than 50% removal of Am by the oxalate and EDTA extractions for subsurface sediment, and about 30% of the Am appeared to be soluble in the interstitial water. It would appear that Am associated with the surface sediments is tightly bound and $\leq$ 1% could be available to the food web in a soluble form.

Levels of Pu in the interstitial water range from 0.6 to 12.6 pCi/g (n=3, Table VI). Pu species of interstitial water from subsurface sediments were predominately "nonionic", while those taken from the surface were predominately cationic (similar to the overlying water, discussed later). Am levels in interstitial water ranged from 0.6 to 2.8 pCi/g (n=3) and were predominately cationic in nature (Table VI). In those samples containing surface sediments, there were higher levels of anionic ^{241}Am (43 to 45%) than those collected below the surface.

In the pond water, only trace concentrations of Pu and Am were detected (Table VII). Approximately 0.007 pCi of ^{238}Pu/ℓ and 0.002 pCi of ^{239,240}Pu/ℓ were found in three samples processed by a large volume water sampler. Higher levels of ^{241}Am, about 1.1 pCi/ℓ, were measured in the water. Approximately 50 to 60% of the Pu and 10% of the Am were in a soluble form in the pond water (Table VII). From 60 to 80% of the soluble Pu and about 30% of the soluble Am species were cationic. The anionic fraction of soluble Am was about 70%, whereas for Pu it was about 5%. A relatively large "nonionic" fraction 37%, existed for soluble Pu.

It is clear from the work previously described that at least 95% of the Pu in the pond is held in the sediments. If a mean Pu concentration of 390 pCi/g (n=60) for the sediments is used to calculate the total amount of Pu contained by the sediments down to 10 cm, this level can be compared to the historical release of Pu into the pond for inventory purposes. The total level of Pu in the pond sediments (down to 10 cm) is estimated to be 1.54 Ci of ^{238}Pu and 1.55 Ci of ^{239,240}Pu. For specific activity determination, it is assumed that of the 1.55 Ci of ^{239,240}Pu, 92.4% is ^{239}Pu and

Table V. Fractionation and extraction of plutonium and americium isotopes in U Pond sediments.

Isotope	Fraction Present In: Interstitial Water	NaCl Extract	Oxalate Extract	EDTA Extract	Residue	Total Activity pCi/g dry wt.
			Sediment #1[a]			
^{238}Pu	0.04	0.03	0.03	0.22	0.69	23
$^{239,240}Pu$	0.02	0.02	0.03	0.20	0.73	27
^{241}Am	0.29	0.03	0.28	0.19	0.22	2.1
			Sediment #2[b]			
^{238}Pu	0.002	0.001	0.05	0.02	0.93	2560
$^{239,240}Pu$	0.001	0.001	0.05	0.02	0.93	1905
^{241}Am	0.01	0.004	0.02	0.07	0.90	216
			Sediment #3			
^{238}Pu	0.007	0.001	0.11	0.04	0.85	16
$^{239,240}Pu$	0.005	0.002	0.14	0.05	0.80	1210
^{241}Am	0.008	0.02	0.005	0.01	0.96	338

[a]Sediment #1 is a subsurface sediment sample (between 5 and 10 cm in depth).

[b]Sediment #2 is a sample of surface material (upper 1 to 4 cm).

[c]Sediment #3 is a mixture of surface and subsurface materials.

Table VI. Chemical separation of plutonium and americium isotopes in U Pond sediment interstitial waters.

Isotope	Fraction Present in Each Chemical Form: Anionic	Cationic	"Nonionic"	"Noninteracting"	Total Activity, pCi/g dry wt.[d]
			Sediment #1[a]		
^{238}Pu	0.16	0.12	0.51	0.21	0.9
$^{239,240}Pu$	0.14	0.11	0.58	0.16	0.6
^{241}Am	0.08	0.55	0.02	0.36	0.6
			Sediment #2[b]		
^{238}Pu	0.32	0.65	0.02	<0.01	4.0
$^{239,240}Pu$	0.31	0.64	0.03	0.01	2.2
^{241}Am	0.43	0.56	<0.02	<0.02	1.2
			Sediment #3[c]		
^{238}Pu	0.18	0.06	0.76	Not Determined	12.6
$^{239,240}Pu$	0.28	0.10	0.62	Not Determined	6.2
^{241}Am	0.45	0.54	<0.01	Not Determined	2.8

[a]Sediment #1 is a subsurface sediment sample (between 5 and 10 cm in depth).

[b]Sediment #2 is a sample of surface material (upper 1 to 4 cm).

[c]Sediment #3 is a mixture of surface and subsurface materials.

[d]Based on dry weight of sediment collected.

Table VII. Physical-chemical separation of plutonium and americium isotopes in U Pond water*.

Isotope	Fraction Present in Each Physical-Chemical Form: Anionic	Cationic	"Nonionic"	Particulate	Total Activity pCi/liter
^{238}Pu	0.02	0.38	0.06	0.53	0.007
$^{239,240}Pu$	0.04	0.33	0.22	0.41	0.002
^{241}Am	0.05	0.02	0.002	0.92	1.08

*Average values of three water samples.

7.6% is ^{240}Pu (weapons grade Pu). The entire 14 acre pond bottom (to a depth of 10 cm) is thus estimated to contain 0.09 g of ^{238}Pu and 21.0 g of ^{239}Pu or a total Pu content of about 21 g. This is less than 0.5% of the historic release figure of 8.1 kg. There may be substantial amounts of Pu lying beneath the 10 cm level in the pond sediments or underlying desert soil, or large quantities of Pu may have been deposited in the Z-trenches and never reached the pond. Because there are sufficient uncertainties about the historic Pu release figure of 8.1 kg and about the nature of Pu deposition in the Z-trenches and the pond's bottom, attempts to balance the inventory in the pond system will not be made at this time.

Biological environs:

Data from biological samples taken from the pond are incomplete, but it is possible to obtain a preliminary view of the distribution of Pu and Am in the pond's biota. Many of the sample sizes for each taxon are small, and additional work over the coming months should improve the accuracy of these estimates. Because the sediments are the principal repository for Pu and Am in this system, all biotic concentrations are compared to those levels in the sediments as a means for making comparisons with what may be considered as a substrate concentration.

Plant material appears to be an active concentrator of both Pu and Am in this pond. Decomposing algae seem to concentrate Pu and Am considerably more than those levels present in the sediments (Figs. 14 and 15). This algal floc material is a very lightly compacted accumulation of decomposing algae which supports an active bacterial growth. The specific origin of this pale green fluff is not known, but it is assumed to be generated from the massive populations of filamentous, colonial, and unicellular algae which proliferate in the pond. During quiet periods this algal floc lies loosely compacted over much of the pond's bottom. However, as winds develop, a portion of this floc is moved to the perimeter of the pond where it accumulates in thicker masses and dries along the shorelines.

Ten algal floc samples, each collected at a different time, have been analyzed for Pu. Pu concentrations are remarkably consistent in these

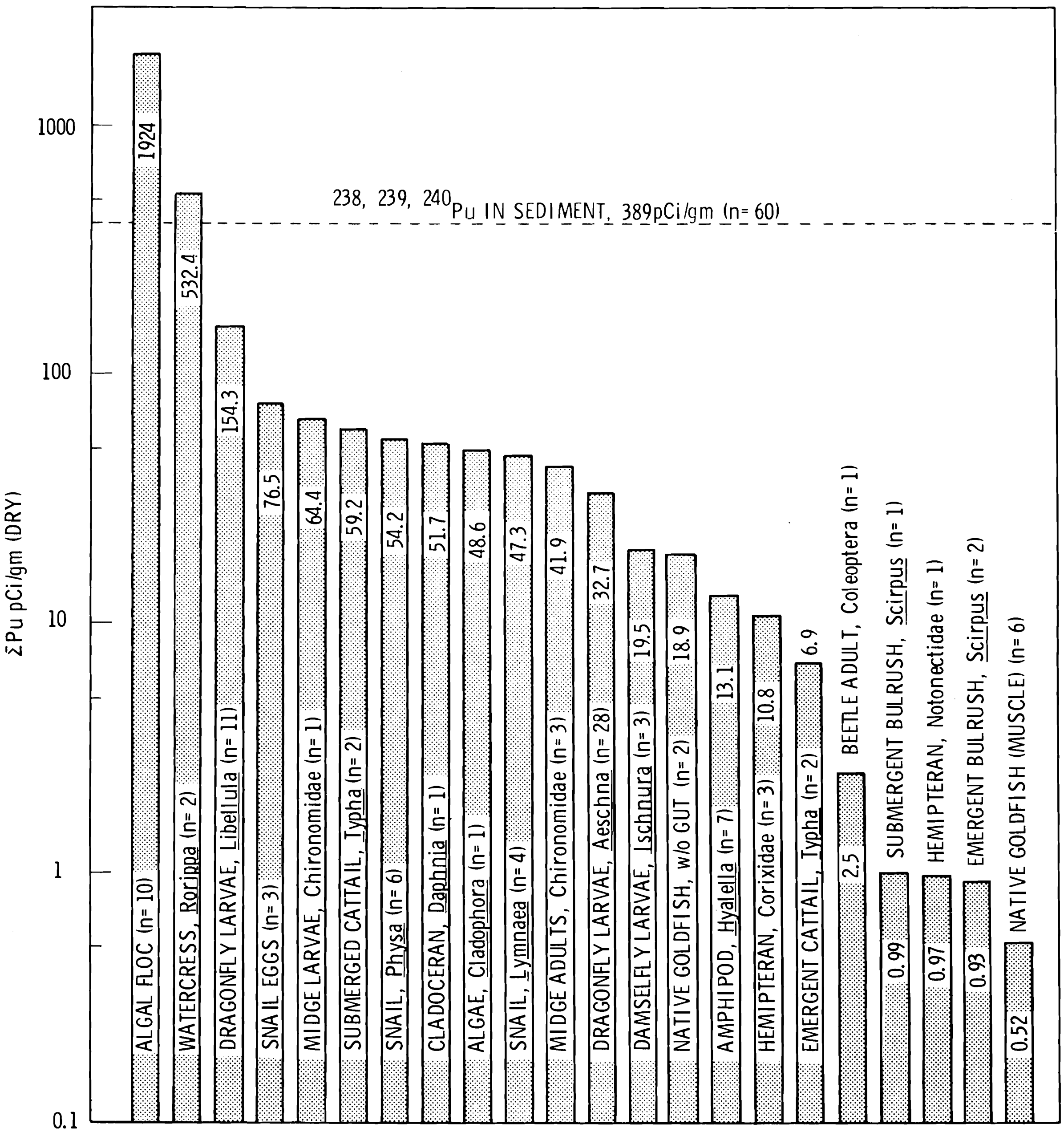

Figure 14. Comparative concentrations of ^{238}Pu and $^{239,240}Pu$ isotopes (combined ΣPu) in U Pond biota relative to that of the sediments.

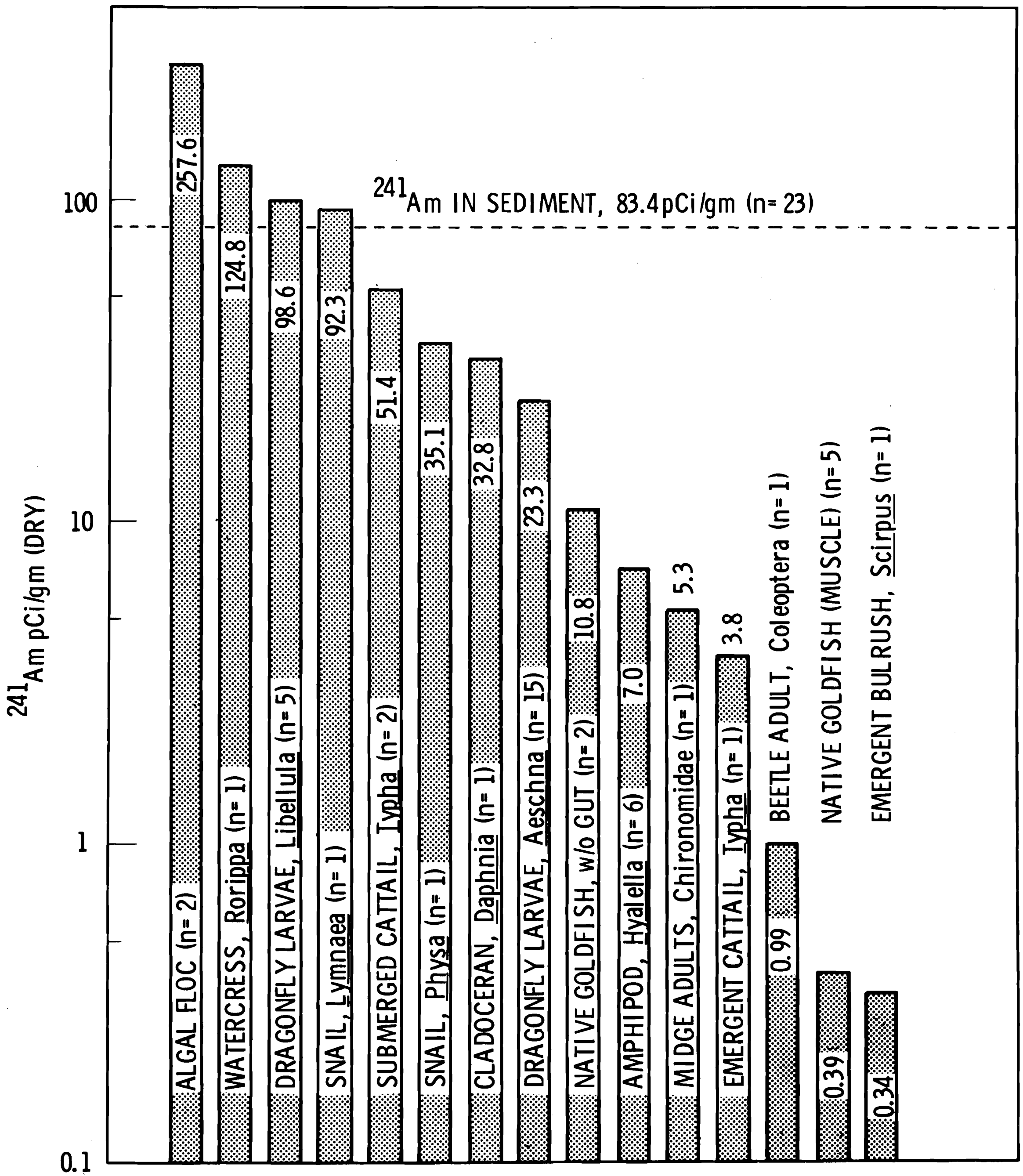

Figure 15. Comparative concentrations of ^{241}Am in U Pond biota relative to that of the sediments.

samples showing a mean of 1.9 nCi/g with a range of 1 to 4 nCi/g (Fig. 14). Because of the way this material accumulates in the shallow shoreline areas of the pond, it provides an easily obtainable food source for waterfowl. Mallard ducks, primarily, have been observed feeding on this material. One of these ducks was sampled and large portions of the contents of its alimentary canal appeared to be algal floc. Surprisingly, however, the alimentary canal contents contained only 9.8 pCi of ΣPu/g. Levels of ΣPu in the duck ranged from 0.5 pCi/g in the alimentary canal tissue to 0.01 pCi/g in the adipose and neck tissue (Fig. 16). It is not known how long this duck was feeding in U Pond before it was sampled. It may have filled part of its alimentary canal with plant material from other ponds.

Depending upon the sources of Pu and Am and the extent to which these isotopes are available, decomposing algal material appears to have concentration factors ranging from 58 to 400,000,000 for ΣPu (Table VIII) and 48 to 3,000,000 for ^{241}Am (Table IX). [The rationale in developing CF's generally requires that some level of availability be set which is then determined to be some multiple or fraction of an equivalent concentration in the organism. Since the means by which these organisms accumulate Pu and Am is not yet understood, and the diversity of time and exposure these organisms have to the transuranic sources is not known or considered, the determination of an accurate and reliable CF is not possible. Without some knowledge of the dynamics involved in radionuclide accumulation by specific organisms, the exercise of assigning CF's may be futile. It is obvious from viewing Tables VIII and IX that CF values vary greatly depending upon the level designated as "available." Perhaps the need to be traditional provides some reason to be concerned with CF's, but beyond this there seems to be little reason for selecting a finite value from such an enormous range of options, each having few merits and many limitations. However, for reasons of comparison the CF values assumed to be most accurate will be those based on interstitial water in Tables VII and IX.] It would appear then that decomposing algal material concentrates both Pu and Am by a factor of about 200.

Of the limited literature on this matter, there does not seem to be general agreement with any of these estimated concentration factors for

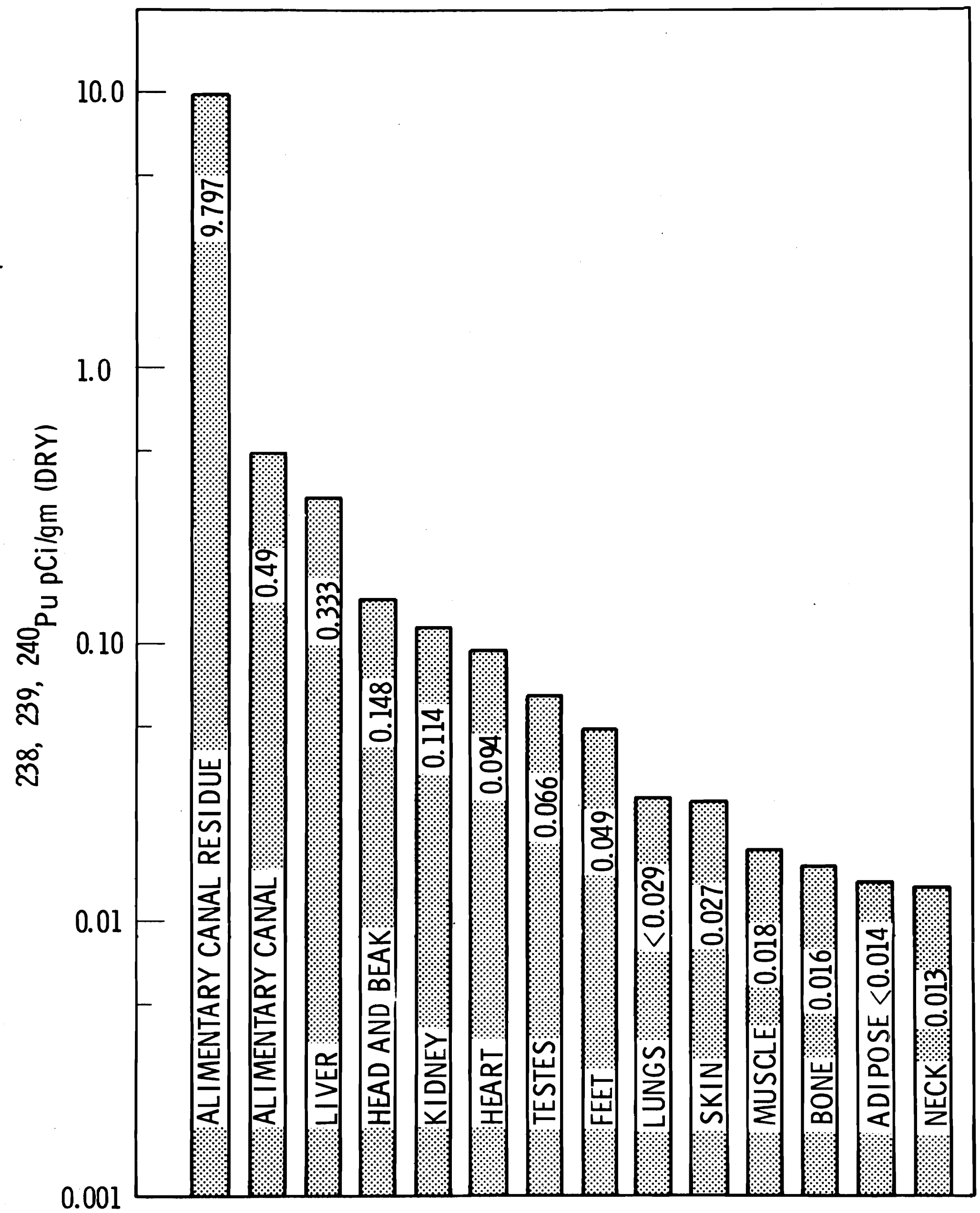

Figure 16. Concentrations of ΣPu in various tissues of one mallard duck (*Anas platyrhynchos*) relative to the ΣPu concentration in alimentary canal contents.

Table VIII. Possible concentration factors (CF) for ΣPu by aquatic biota relative to three expressions of availability.

	CF relative to:		
	Sediments[1] (33 pCi/g)	Interstitial Water[2] (8.8 pCi/g)	Water[3] (4.5×10^{-6} pCi/ml)
Algal floc (1924 pCi/g)	58	219	4×10^8
Watercress, *Rorippa* (532.4 pCi/g)	16	60	1×10^8
Dragonfly larvae, *Libellula* (154.3 pCi/g)	5	18	3×10^7
Snail eggs (76.5 pCi/g)	2	9	2×10^7
Dipteran larvae, Chironomidae (64.4 pCi/g)	2	7	1×10^7
Submerged cattail, *Typha* (59.2 pCi/g)	2	7	1×10^7
Snail, *Physa* (54.2 pCi/g)	2	6	1×10^7
Cladoceran, *Daphnia* (51.7 pCi/g)	2	6	1×10^7
Algae, *Cladophora* (48.6 pCi/g)	1	6	1×10^7
Snail, *Lymnaea* (47.3 pCi/g)	1	5	1×10^7
Dipteran adults, Chironomidae (41.9 pCi/g)	1	5	9×10^6
Dragonfly larvae, *Aeschna* (32.7 pCi/g)	1	4	7×10^6
Damselfly larvae, *Ischnura* (19.5 pCi/g)	.6	2	4×10^6
Native goldfish w/o gut (18.9 pCi/g)	.6	2	4×10^6
Amphipod, *Hyalella* (13.1 pCi/g)	.4	1	3×10^6
Hemipteran, corixidae (10.8 pCi/g)	.3	1	2×10^6
Emergent cattail, *Typha* (6.9 pCi/g)	.2	.8	1×10^6
Beetle, adult, Coleoptera (2.5 pCi/g)	.1	.3	6×10^5
Submergent Bulrush, *Scirpus* (0.99 pCi/g)	.03	.1	2×10^5
Hemipteran, Notonectidae (0.97 pCi/g)	.03	.1	2×10^5
Emergent Bulrush, *Scirpus* (0.93 pCi/g)	.03	.1	2×10^5
Native goldfish, muscle (0.52 pCi/g)	.02	.06	1×10^5

[1]Availability assumed to be 9% based on Table V (mean percentage of ΣPu removed by distilled water, NaCl, and oxalate extractions) and a mean sediment ΣPu content of 364 pCi/g (n = 80).

[2]Availability assumed to be 100% (i.e., all nonparticulate ΣPu) based on ΣPu found in interstitial water (Table VI). Available ΣPu expressed in pCi per gram of dry sediment.

[3]Availability assumed to be 50% (i.e., all nonparticulate ΣPu) based on ΣPu found in water (Table VII).

Table IX. Possible concentration factors (CF) for ^{241}Am by aquatic biota relative to three expressions of availability.

	CF relative to:		
	Sediments[1] (5.8 pCi/g)	Interstitial Water[2] (1.5 pCi/g)	Water[3] (8.6×10^{-5} pCi/ml)
Algal floc (277.6 pCi/g)	48	185	3×10^6
Watercress, *Rorippa* (124.8 pCi/g)	22	83	1×10^6
Dragonfly larvae, *Libellula* (98.6 pCi/g)	17	66	1×10^6
Snail, *Lymnaea* (92.3 pCi/g)	16	62	1×10^6
Submerged cattail, *Typha* (51.4 pCi/g)	9	34	6×10^5
Snail, *Physa* (35.1 pCi/g)	6	23	4×10^5
Cladoceran, *Daphnia* (32.8 pCi/g)	6	22	4×10^5
Dragonfly larvae, *Aeschna* (23.3 pCi/g)	4	16	3×10^5
Native goldfish w/o gut (10.8 pCi/g)	2	7	1×10^5
Amphipod, *Hyalella* (7.0 pCi/g)	1	5	8×10^4
Dipteran adults, Chironomidae (5.3 pCi/g)	.9	4	6×10^4
Emergent cattail, *Typha* (3.8 pCi/g)	.7	3	4×10^4
Beetle adult, Coleoptera (0.99 pCi/g)	.2	.7	1×10^4
Native goldfish, muscle (0.39 pCi/g)	.07	.3	5×10^3
Emergent Bulrush, *Scirpus* (0.34 pCi/g)	.06	.2	4×10^3

[1] Availability assumed to be 7% based on Table V (mean percentage of ^{241}Am removed by distilled water, NaCl, and oxalate extractions) and a mean sediment ^{241}Am content of 83.4 pCi/g (n = 23).

[2] Availability assumed to be 100% (i.e., all nonparticulate Am) based on a mean level of ^{241}Am found in interstitial water (Table VI). Available ^{241}Am expressed in pCi per gram of dry sediment.

[3] Availability assumed to be 8% (i.e., all nonparticulate ^{241}Am) based on ^{241}Am found in water (Table VII).

algae. Davis et al. (1968) and Welander (1969) report Pu concentration factors for Pacific coast marine algae to range from 260 to 3500, while Wong et al. (1970) estimates concentration factors to range from 100 to 1600 for Atlantic coast marine algae. Johnson et al. (1972), in a freshwater study at Rocky Flats estimates concentration factors on the order of 10^4. The exercise of developing a reliable and accurate concentration factor clearly becomes a matter of assessing the level of Pu which is available to the organism.

The algal floc is considered important in this system because it is abundant, provides a large organic detritus food base, and is the principal concentrator of Pu and Am in the pond. However, this material is undergoing decomposition, and there are substantial populations of microorganisms within it. Algal floc contains from 2 to 7×10^7 bacteria (aerobic and anaerobic) per gram of dry floc (or about 1 to 4×10^{-4} g of bacteria per gram of dry floc), of which the most numerous are *Pseudomonas*, *Bacillus*, and *Aerobacter*, common to ponds like this one. Actinomycetes in the algal floc ranged from 1 to 7×10^7 organisms per gram dry weight, and fungi were present at levels of 1 to 4×10^6 organisms per gram (or about 3 to 24×10^{-3} g of actinomycetes and 2 to 8×10^{-3} g of fungi per gram of dry floc). Although the collective weights of the microorganisms are less than 1% of that of the floc it is likely that microorganismic activity plays an important role in the accumulation of Pu and Am by this decomposing algal material. Johnson et al. (1972) found reasons to conclude that bacteria have a significant role in the uptake of Pu in freshwater.

The second most active concentrator of Pu and Am identified in the pond is watercress (*Rorippa nasturtium-aquaticum*). Watercress grew only during February and March within the pond system. This rooted aquatic plant grew in the shallow regions ($\leq$ 30 cm), but was often found free-floating near the shoreline, and those plants which were sampled were not attached to the sediment. Of the two samples taken (each sample involves many plants), watercress had 532.4 pCi of Pu/g and 124.8 pCi of Am/g (Figs. 14 and 15). These levels are within a factor of three of those concentrations present in the sediments, and a CF of 60 for ΣPu and 83 for ^{241}Am is indicated using interstitial water levels as an expression of availability (Tables VIII and IX).

With regards to Pu levels, all other organisms analyzed so far have had mean concentrations below those of the sediment (Fig. 14). However, dragonfly larvae (n=5) and snails (n=1) had Am concentrations greater than those of the sediments (98.6 and 92.3 pCi/g, respectively, Fig. 15). (It is worth pointing out here that biological samples involve many organisms per sample unit.)

It is interesting to see that one of the pond's most active predators, the dragonfly larvae *Libellula,* had relatively high mean concentrations of both Pu and Am (154.3 and 98.6 pCi/g, respectively, Figs. 14 and 15). The organisms upon which they feed appear to have much lower Pu and Am levels (Figs. 14 and 15). Here exists the possibility of transuranics being concentrated by food chain transfer, but the pond's food web is not complex and the potential for this mode of concentration does not appear to be great. The reverse of such a concentration process has been observed in Lake Michigan by Yaguchi et al. (in press) and Waller et al. (in press) where a much more dynamic food web is involved. *Aeschna,* another predaceous dragonfly larvae, had much lower levels of both Pu and Am (32.7 and 23.3 pCi/g, respectively, Figs. 14 and 15). This organism generally finds its niche more often under the bark of submerged tree limbs or on other objects which rest above the sediments. *Libellula,* conversely, may be found partially burrowed into the sediments or in some other location where sediments are proximal. It may be the difference in niches which accounts for the higher Pu and Am content of *Libellula* rather than a process of concentration by predation. However, there were eleven occasions, in the months November, December, and April, where collections of *Libellula* and *Aeschna* were made from the same substrate (Clemens nets, p. 17). Each collection usually involved 10 to 30 individuals with a minimum of 6 for *Aeschna* and 4 for *Libellula.* In every collection *Libellula* showed substantially higher ΣPu content than *Aeschna* with a mean ratio of ΣPu in *Libellula* to ΣPu in *Aeschna* of 6.3:1 (Fig.17). The

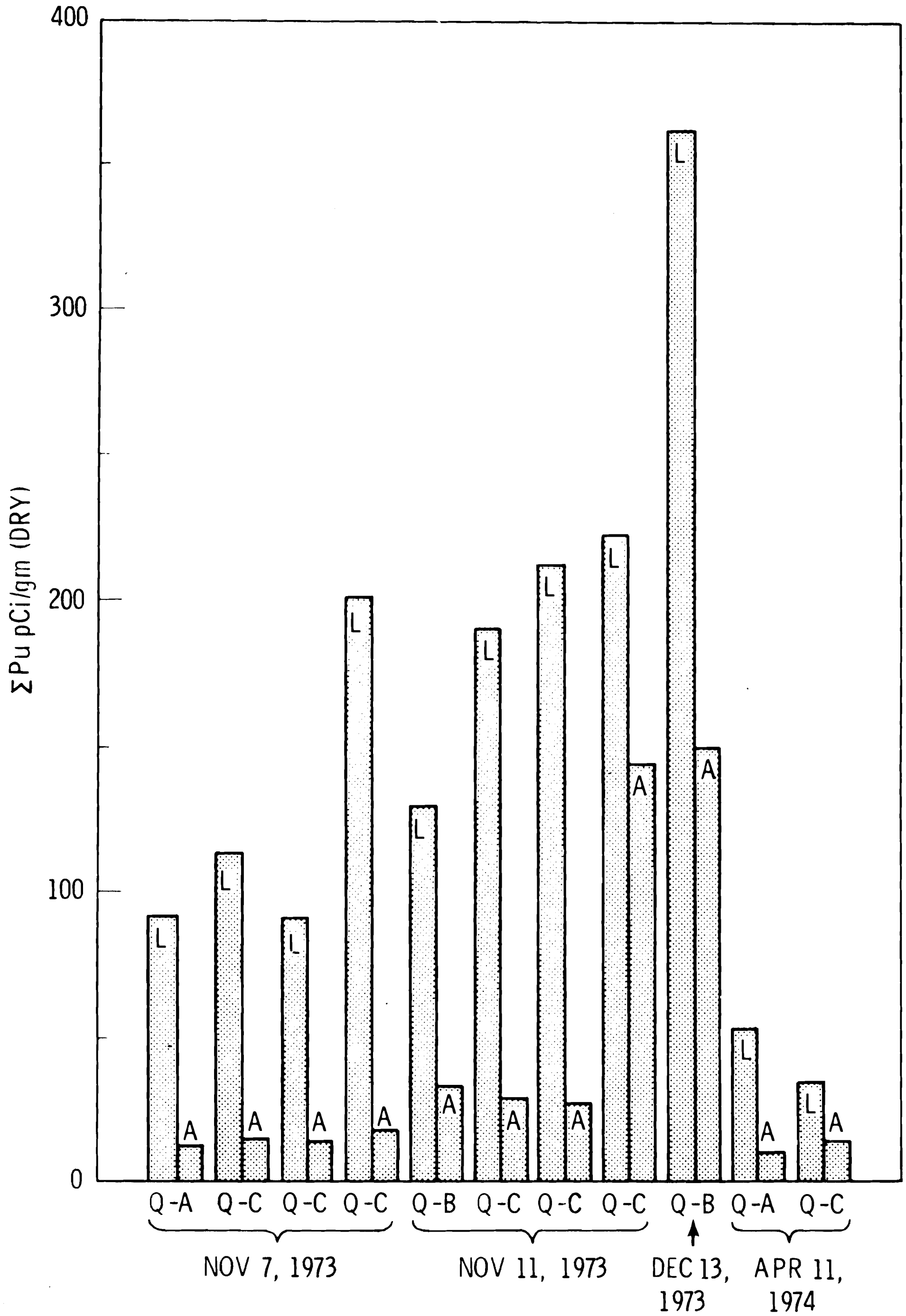

Figure 17. A comparison of ΣPu levels in dragonfly larvae *Libellula* (L) and *Aeschna* (A). Designations of quad location (see Fig. 4) and date of sampling are shown below the columns.

consistency with which this occurred was remarkable, and indicates that the physiological and/or behavioral differences of these organisms affect their ability to accumulate Pu. There also exists the possibility that sessile algae, which often grow on the exterior of *Libellula* but not *Aeschna*, are concentrating Pu independent of *Libellula*. These sessile algae are not easily removed in the sample preparation steps and may have high burdens of Pu, but the relatively small weight of attached algae to that of the larva would require that the algae have very high concentrations of Pu to account for the high levels in *Libellula*. This matter remains an interesting puzzle.

Other pond biota for which Pu and Am values are available show relatively lower concentrations. Snail eggs show a ΣPu content of 76.5 pCi/g with a CF of 9 (no values are yet available for ^{241}Am). Cattail (*Typha*) roots and submerged stems show ΣPu levels of about 59 pCi/g (CF = 7) and ^{241}Am levels of 51 pCi/g (CF = 34); however, emergent portions of these macrophytes had considerably lower levels of ΣPu (6.9 pCi/g, CF = 0.1) and ^{241}Am (3.8 pCi/g, CF = 0.2) (Figs. 14 and 15, Tables VIII and IX). Thus, there is about an order of magnitude difference in transurancic content between the submerged and emergent portions of these plants. In contrast to this, samples of the bulrush *Scirpus* contained only about 1 pCi/g of ΣPu (CF = 0.1) and 0.3 pCi/g of ^{241}Am (CF = 0.2), and ΣPu in submerged and emergent portions of this plant were about equal (^{241}Am values not yet available) (Figs. 14 and 15, and Tables VIII and IX).

There are a number of other pond biota which show ΣPu concentrations ranging from about 10 to 60 pCi/g (CF's ranging from 0.1 to 7) (Fig. 14 and Table VIII). These include dipteran larvae and adults, dragonfly and damselfly larvae, hemipterans, snails, amphipods, cladocerans, macrophytes and vegetative algae. For approximately the same group of organisms the ^{241}Am levels ranged from about 5 to 90 pCi/g (CF's ranging from about 3 to 60) (Fig. 15 and Table IX). Also in the group are "native" goldfish (*Carassius*, without gut contents) showing relatively low levels of ΣPu of 18.9 pCi/g (CF = 2) and ^{241}Am of 10.8 pCi/g (CF = 7). Because of their basically detritivorous feeding habits, it was expected that these fish would accumulate high burdens of these actinides in their body tissue. The goldfish which comprised these samples were at least two years old, and had spent their lives foraging for food in the pond's sediments and associated plant material. These low levels of Pu and Am concentrations in the goldfish tissue suggest that even years of active feeding on a substrate of relatively high Pu and Am content will not cause much transfer of these actinides across the gut wall and into the various body tissues. If this process was actively occurring in pond biota, it should be most evident in goldfish because of the extended time available to them for such an uptake process. However, preliminary data from a field experiment (discussed later) indicate that gut transfer of Pu into body tissue occurs at a low level over a long period of time.

Ratios of ^{238}Pu to ^{239,240}Pu in the pond biota are generally higher than those of the sediments (Fig. 18). Only "native" goldfish muscle tissue had a ratio which appeared to favor ^{239,240}Pu. (Note that the overall ratio of ^{238}Pu to ^{239,240}Pu in the sediments was 1:1). Samples of hemipterans (Corixidae and Notonectidae), amphipods (*Hyalella*), and goldfish (*Carassius*, without gut contents) showed ^{238}Pu to ^{239,240}Pu ratios which were about equal to those of the sediments (Fig. 18). It appears that most of the pond organisms, flora and fauna alike, are selecting ^{238}Pu slightly over ^{239,240}Pu (Fig. 18). The highest ratio was found in newly emerged midges (1.8) which had relatively low accumulations of ΣPu (Fig. 14). Plant material which showed the highest accumulation of Pu had ratios of ^{238}Pu to ^{239,240}Pu ranging from 1.3 to 1.6 (Fig. 18). The ratio of ^{238}Pu to ^{239,240}Pu in the pond water is 3.5, which may be reflected in the relatively high ratios of biota (relative to sediments).

Ratios of ^{241}Am to ΣPu in the pond biota were generally higher than those of the sediments, with the exception of watercress, algal floc, and emergent adult dipterans (Fig. 19). Watercress (*Rorippa*) had a ratio which was equal to that of the sediments (0.23:1), while algal floc and adult dipterans had a much lower ratio of 0.13:1 (Fig. 19). Many of the biotic samples showed ratios above 0.5:1, and one sample containing a substantial number of snails (*Lymnaea*) had a ratio of almost 2:1. In the pond water the ratio of ^{241}Am to ΣPu was 120:1, which may help to explain why pond biota ratios are generally higher than those of the sediments.

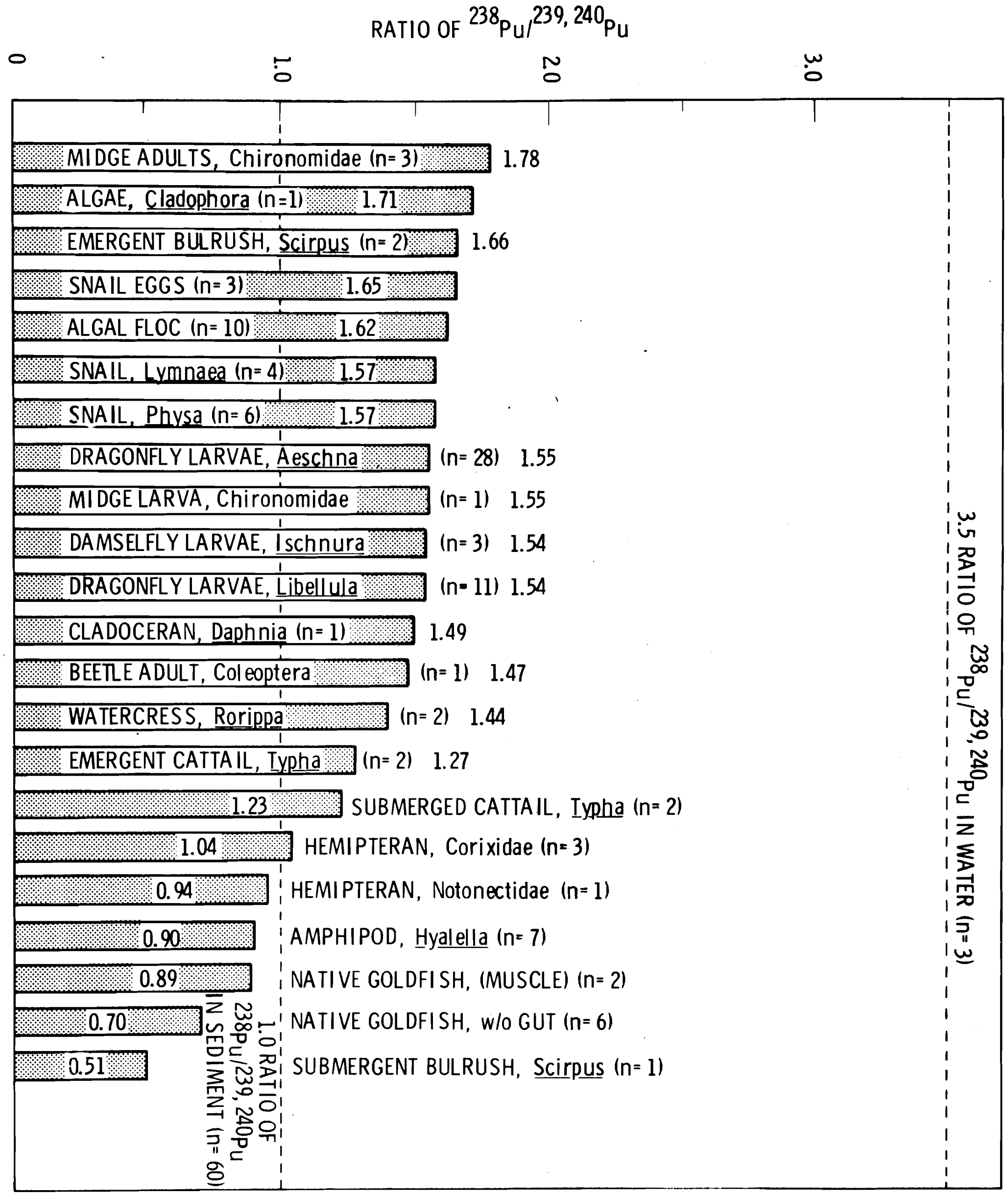

Figure 18. Ratios of ^{238}Pu to $^{239,240}Pu$ in pond biota and relative to those of the water and sediments.

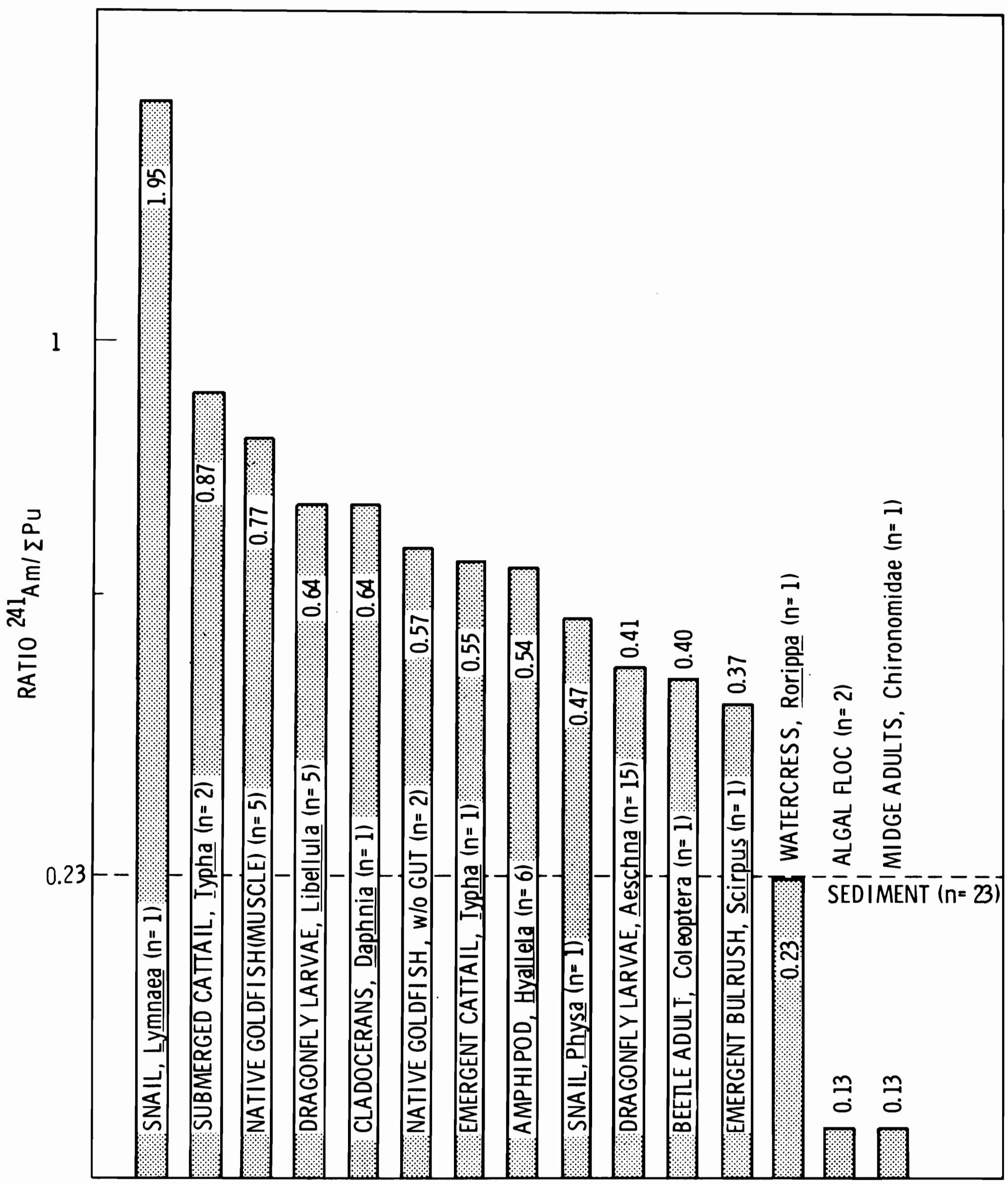

Figure 19. Ratios of ^{241}Am to ΣPu in pond biota relative to those of the sediment and water (water ratio is 120:1 and does not appear in this figure).

UPTAKE EXPERIMENTS

A simple in situ experiment was performed with goldfish to measure their rate of accumulation and equilibrium level for the transfer of Pu and Am from the sediments. Goldfish, subsampled since November 1973, were analyzed for Pu and Am under two conditions, with and without gut contents removed. Pu and Am levels in entire goldfish, including gut contents, serve as a trophic baseline index for what is available to the next trophic level (i.e. heron), while those with gut contents removed indicate levels of Pu and Am which were likely accumulated physiologically. Only Pu data for goldfish analyzed with gut contents present are currently available, and these results are not yet complete.

For a winter period of about 110 days, which ran from November to February, the level of ΣPu in the goldfish never exceeded 20 pCi/g (Fig. 20). The six mean values (with ranges) shown in Fig. 20 do not provide a means for accurately determining rate of uptake, however a hypothetical uptake curve, placed visually among the data means, serves a conceptual purpose (Note that the visually fitted line falls within the data ranges in all cases.) Thus, only an approximate saturation level can be obtained from these incomplete data. Goldfish which are native to the pond contained about 20 pCi of ΣPu/g with gut contents removed (Fig. 14). This provides a degree of confirmation that 20 pCi of ΣPu/g may be a reasonable equilibrium level for Pu uptake by goldfish.

Adams and Fowler (1974) found about 8 pCi/g (wet weight) of ^{238}Pu in the flesh of goldfish exposed to $^{238}PuO_2$ microspheres for 181 days. Their experimental design provided about 140 pCi/ℓ of ^{238}Pu in the aquarium water, however, the level of ^{238}Pu in the feeding substrate was not designated. These levels of Pu accumulation are reasonably close to those determined by sampling and experimentation in U Pond; however, their experiments were oriented around ambient Pu concentration in the water rather than Pu concentrations in the food source. Concentrations of Pu in the water of their experimental setup were about 10^4 greater than those of U Pond.

A study, similar to that performed with goldfish in U Pond, is being carried out with mallard ducks. A discussion of this study will be presented when data are sufficient to draw preliminary conclusions.

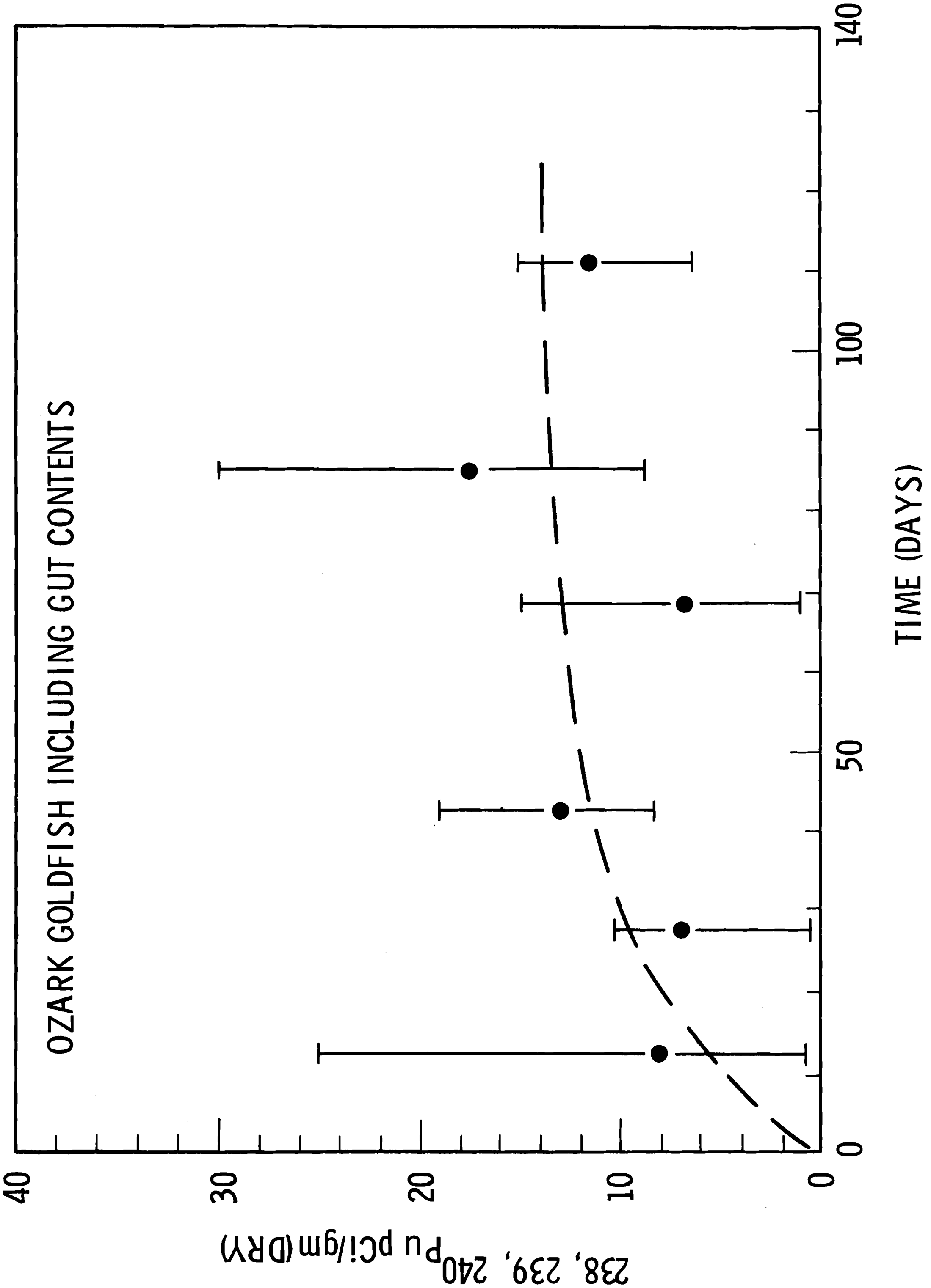

Figure 20. Uptake of ΣPu by experimental goldfish plotted over time. The broken curve is visually fitted.

CONCLUSIONS

At this point in our study a number of conclusions, which are preliminary in nature, may be drawn from the information accrued over the past 12 months. It is likely that as further knowledge is developed about the ecosystem, and the behavior of transuranics in it, there will be modifications of hypotheses discussed in the text and conclusions listed below. Nevertheless, it is a worthwhile exercise to summarize significant findings for purposes of describing the progress of this study and setting directions for future work.

1. Although the official figure for the historic release of Pu into Z-trenches (leading to U Pond) is 8.1 kg, only a small fraction of this amount (21 g) has been found in the pond sediments to a depth of 10 cm. Further efforts will be made to assess this difference which will involve sediment coring and assessments of Pu removal via physical and biological mechanisms.

2. The pond's water budget involves an inflow rate of about 10 m^3/min. More than 95% of this inflow leaves the pond via percolation as there are no surface outflows. Evaporation off of the pond is negligible. Percolation rates vary across the pond bottom with the outer edges being more permeable than the central basin.

3. The circulation of water in the pond is greatly influenced by wind with additional effects caused by heated water entering from the U-14 trench. Because the pond is shallow, wind action plays an important role in resuspending and distributing sediments.

4. Installations of walkways over the pond surface have significantly altered the pond's habitat by increasing sediment stability on the leeward side of the docks. Because of this a large population of the benthic macrophyte *Potamogeton* has

rooted in this stable region and provides an additional substrate for the algae *Cladophora* and *Tetraspora*. These flora now dominate the submergent primary producers in the pond.

5. This pond is an ultra-eutrophic system with most of the plant nutrients being supplied by the laundry. Enrichment from this source supports massive populations of macrophytes and algae (mentioned in conclusion 4).

6. The pond's food web may be described as simple, with algae, macrophytes, and, to a large extent, detritus supplying the autochthonous carbon base. Predation is relatively minor in this system with dragonfly larvae being the major aquatic predator. Nonpredaceous invertebrates and goldfish are major omnivorous components, feeding mainly on detritus and live plant and algae tissue. Waterfowl and other birds provide some food web interaction and may serve as biological vectors for removal of Pu and Am from the pond ecosystem.

7. In the physical environs Pu and Am are concentrated almost entirely in the sediments. These isotopes appear to be randomly distributed across the pond bottom. The mean concentration of ^{238}Pu is 194 pCi/g and for ^{239,240}Pu the mean is 195 pCi/g. Concentrations of ^{241}Am averaged 83 pCi/g in the sediments. The ratio of ^{238}Pu to ^{239,240}Pu in the sediments is 1:1, while the ratio of ^{241}Am to ΣPu is 0.23:1.

8. Only about 9% of the ΣPu and 7% of ^{241}Am in the sediments (possibly less for both radionuclides) appear to be available for food web concentration. The remaining fractions of Pu and Am appear tightly bound to sediment particles and could only be transported ecologically in particulate form.

9. Levels of ΣPu and ^{241}Am in interstitial water were low (between 0.5 and 13 pCi/g, expressed per gram dry weight of sediment) and appeared to exist mainly in either cationic or nonionic forms. Surface sediment material seemed to have larger fractions of anionic forms than sediments sampled from below 5 cm.

10. Concentrations of ΣPu in pond water were very low (about 0.01 pCi/ℓ) and existed mainly in a particulate form. Levels of ^{241}Am in the water were about 1.1 pCi/ℓ, which was almost entirely particulate. Ratios of ^{238}Pu to $^{239,240}Pu$ in the water were about 3.5:1, while the ratio of ^{241}Am to ΣPu was about 120:1.

11. Algal floc (decomposing algal cells) is the major concentrator of Pu and Am in the pond (about 2 nCi of ΣPu/g and 258 pCi of $^{241}Am/g$). Estimated concentration factors for algal floc ranged from 200 to 10^8, depending upon how availability is defined.

12. Algal floc and emerging chironomids were the only biological components which had ^{241}Am to ΣPu ratios lower than that of the sediments (0.13:1). Watercress had a ^{241}Am to ΣPu ratio equal to that of the sediments (0.23:1), while the remaining biota sampled had ^{241}Am to ΣPu ratios ranging from about 0.4 to 2.0:1.

13. Watercress had relatively high concentrations of ΣPu and ^{241}Am (532 and 125 pCi/g, respectively); ranking second to algal floc, and considerably higher than any of the other biota. However, watercress is not a major component in this ecosystem and occurs only seasonally for a short period in the pond.

14. Dragonfly larvae, the pond's major aquatic predator, had higher concentrations of Pu and Am than any of their prey.

These levels were 38 to 160 pCi of ΣPu/g and 17 to 94 pCi of ^{241}Am/g. Because of their close association with algae and sediments it is not yet reasonable to conclude that these higher levels of Pu and Am constitute a process of food chain concentration.

15. The biological availability of ^{238}Pu appeared to be greater than that of ^{239,240}Pu since most of the pond organisms sampled accumulated more ^{238}Pu than ^{239,240}Pu on an activity basis (i.e. most ^{238}Pu to ^{239,240}Pu ratios exceeded 1:1). This may be somewhat of a reflection of the ^{238}Pu to ^{239,240}Pu ratios found in the pond water, which were about 3.5:1.

16. Although goldfish remain in the pond longer than any of the other fauna, and feed most heavily on plant, algae, and organic debris, they concentrate relatively small amounts of ΣPu and ^{241}Am (about 20 and 12 pCi/g, respectively). In situ experiments indicate that many goldfish reach an equilibrium level of ΣPu of about 20 pCi/g within a few days after which they may remain active in the pond, possibly for many months, without further accumulation.

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App. Table I. A compilation of all U Pond material analyzed for Pu and Am by LFE Environmental Laboratories, Richmond, California.

Material	Date Collected	Location	^{238}Pu	$^{239+40}Pu$	^{241}Am
			pCi/g (dry wt.) ± percentage error		
Sediment	Oct. 17, 1973	Grid 1	163.5±3%	177.5±3%	90.9±1%
Sediment	Oct. 17, 1973	Grid 2	44.6±3%	48.2±3%	24.8±2%
Sediment	Oct. 17, 1973	Grid 3	806.3±4%	666.7±4%	70.3±3%
Sediment	Oct. 17, 1973	Grid 4	617.1±4%	486.5±4%	12.8±5%
Sediment	Oct. 17, 1973	Grid 5	16.7±4%	63.1±3%	12.8±5%
Sediment	Oct. 17, 1973	Grid 6	196.4±3%	159.5±3%	
Sediment	Oct. 17, 1973	Grid 7	159.9±4%	196.4±4%	
Sediment	Oct. 17, 1973	Grid 8	119.4±4%	197.7±4%	52.7±2%
Sediment	Oct. 17, 1973	Grid 9	204.5±6%	199.1±6%	
Sediment	Oct. 17, 1973	Grid 10	183.8±5%	195.9±5%	176.6±3%
Sediment	Oct. 17, 1973	Grid 11	210.8±7%	172.1±7%	133.3±3%
Sediment	Oct. 17, 1973	Grid 12	337.8±7%	212.6±7%	170.7±4%
Sediment	Oct. 17, 1973	Grid 13	133.8±4%	197.3±4%	78.4±2%
Sediment	Oct. 17, 1973	Grid 14	1144.1±4%	1072.1±4%	51.8±5%
Sediment	Oct. 17, 1973	Grid 15	477.5±4%	648.6±4%	620.7±4%
Sediment	Nov. 01, 1973	Station 16	0.9±55%	1.2±32%	
Sediment	Nov. 01, 1973	Station 19	0.7 ±18%	2.3±10%	0.3±37%
Sediment	Nov. 01, 1973	Station 20	0.09±83%	1.04±15%	0.47±28%
Sediment	Nov. 01, 1973	Station 21	0.33±29%	0.34±21%	<0.45
Sediment	Nov. 01, 1973	Station 22	0.33±42%	0.73±24%	0.55±41%
Sediment	Nov. 01, 1973	Station 25	87.83±4%	100.0±4%	31.57±7%
Sediment	Nov. 01, 1973	Station 26	2.79±9%	2.83±9%	
Sediment	Nov. 01, 1973	Station 28	0.21±25%	1.10±9%	48.6±5%
Sediment	Nov. 01, 1973	Station 30	16.21±10%	77.02±7%	0.73±59%
Sediment	Nov. 28, 1973	Grid 1A	54.1±2%	131.9±2%	30.8±2%
Sediment	Nov. 28, 1973	Grid 1B	58.6±2%	145.0±2%	33.7±2%
Sediment	Nov. 28, 1973	Grid 2A	49.5±3%	119.8±2%	37.7±3%
Sediment	Nov. 28, 1973	Grid 2B	45.0±3%	105.4±2%	33.0±3%
Sediment	Nov. 28, 1973	Grid 3	10.2±3%	10.0±3%	4.9±5%
Sediment	Nov. 28, 1973	Grid 4	136.3±3%	198.2±3%	55.8±3%
Sediment	Nov. 28, 1973	Grid 5A	747.7±3%	463.9±3%	334.6±3%
Sediment	Nov. 28, 1973	Grid 5B	657.7±3%	415.3±3%	211.7±8%
Sediment	Nov. 28, 1973	Grid 6	336.0±3%	227.9±3%	189.2±3%
Sediment	Nov. 28, 1973	Grid 7	225.2±2%	192.3±3%	99.5±3%
Sediment	Nov. 28, 1973	Grid 8A	131.5±3%	117.1±3%	63.0±5%
Sediment	Nov. 28, 1973	Grid 8B	118.0±3%	103.6±3%	60.3±5%
Sediment	Nov. 28, 1973	Grid 9	28.4±4%	73.0±3%	24.3±4%
Sediment	Nov. 28, 1973	Grid 10	43.7±5%	76.1±5%	32.9±4%
Sediment	Nov. 28, 1973	Grid 11A	105.4±3%	85.1±3%	43.7±5%
Sediment	Nov. 28, 1973	Grid 11B	105.4±3%	82.4±3%	54.1±5%
Sediment	Nov. 28, 1973	Grid 12	186.0±2%	201.4±2%	135.1±4%
Sediment	Nov. 28, 1973	Grid 13	19.4±3%	38.7±3%	12.7±2%

App. Table I. (contd)

Material	Date Collected	Location	pCi/g (dry wt.) ± percentage error ^{238}Pu	$^{239+40}$Pu	^{241}Am
Sediment	Nov. 28, 1973	Grid 14	33.3±4%	108.1±3%	22.1±4%
Sediment	Nov. 28, 1973	Grid 15A	2.5±2%	3.8±2%	165.7±3%
Sediment	Nov. 28, 1973	Grid 15B	2.6±2%	4.1±2%	150.5±3%
Sediment	Dec. 28, 1973	Grid 1	563.1±4%	408.6±4%	63.9±12%
Sediment	Dec. 28, 1973	Grid 2	21.6±4%	64.4±4%	20.3±4%
Sediment	Dec. 28, 1973	Grid 3	19.4±4%	12.2±4%	6.8±3%
Sediment	Dec. 28, 1973	Grid 4	95.5±3%	135.1±3%	57.6±3%
Sediment	Dec. 28, 1973	Grid 5	93.2±3%	66.7±3%	37.0±3%
Sediment	Dec. 28, 1973	Grid 6	110.8±4%	93.7±4%	20.7±13%
Sediment	Dec. 28, 1973	Grid 7	82.4±5%	169.4±5%	72.9±3%
Sediment	Dec. 28, 1973	Grid 8	119.8±5%	127.9±5%	45.0±2%
Sediment	Dec. 28, 1973	Grid 9	486.5±6%	409.9±6%	
Sediment	Dec. 28, 1973	Grid 10	167.6±5%	189.2±5%	24.8±10%
Sediment	Dec. 28, 1973	Grid 11	53.6±3%	82.9±3%	
Sediment	Dec. 28, 1973	Grid 12	241.9±5%	227.0±5%	
Sediment	Dec. 28, 1973	Grid 13	84.2±3%	195.0±2%	52.3±2%
Sediment	Dec. 28, 1973	Grid 14	54.5±5%	197.3±5%	
Sediment	Dec. 28, 1973	Grid 15	77.9±5%	170.3±5%	
Sediment	Jan. 22, 1974	Grid 1	0.2±34%	2.4±9%	
Sediment	Jan. 22, 1974	Grid 2	44.1±5%	12.5±4%	40.1±4%
Sediment	Jan. 22, 1974	Grid 3	43.2±4%	60.8±4%	
Sediment	Jan. 22, 1974	Grid 4	577.5±5%	445.9±5%	
Sediment	Jan. 22, 1974	Grid 5	62.6±3%	87.4±3%	
Sediment	Jan. 22, 1974	Grid 6	152.2±5%	119.8±5%	
Sediment	Jan. 22, 1974	Grid 7	7.6±4%	59.5±3%	26.8±3%
Sediment	Jan. 22, 1974	Grid 8	64.0±4%	107.7±5%	
Sediment	Jan. 22, 1974	Grid 9	191.0±4%	175.7±4%	
Sediment	Jan. 22, 1974	Grid 10	155.9±4%	233.3±4%	
Sediment	Jan. 22, 1974	Grid 11	14.0±6%	52.3±4%	
Sediment	Jan. 22, 1974	Grid 12	779.3±3%	509.0±3%	
Sediment	Jan. 22, 1974	Grid 13	164.4±4%	186.0±4%	0.95±21%
Sediment	Jan. 22, 1974	Grid 14	6.8±5%	53.2±8%	
Sediment	Jan. 22, 1974	Grid 15	225.2±4%	387.4±4%	
Sediment	Feb. 21, 1974	Grid 1	38.7±3%	102.7±3%	
Sediment	Feb. 21, 1974	Grid 2	36.5±4%	53.2±4%	
Sediment	Feb. 21, 1974	Grid 3	241.9±3%	254.9±3%	
Sediment	Feb. 21, 1974	Grid 4	307.2±3%	336.9±3%	
Sediment	Feb. 21, 1974	Grid 5	161.3±3%	140.5±3%	
Sediment	Feb. 21, 1974	Grid 6	337.8±3%	315.3±3%	
Sediment	Feb. 21, 1974	Grid 7	146.4±3%	154.5±3%	
Sediment	Feb. 22, 1974	Grid 8	146.3±3%	239.1±3%	
Sediment	Feb. 21, 1974	Grid 9	134.2±4%	87.4±4%	
Sediment	Feb. 22, 1974	Grid 10	137.8±5%	201.8±5%	63.1±3%
Sediment	Feb. 21, 1974	Grid 11	80.6±3%	168.4±3%	
Sediment	Feb. 22, 1974	Grid 12	9.7±4%	7.1±4%	
Sediment	Feb. 22, 1974	Grid 13	106.3±4%	264.8±4%	
Sediment	Feb. 21, 1974	Grid 14	85.1±3%	246.3±3%	
Sediment	Feb. 21, 1974	Grid 15	93.6±3%	122.5±3%	

App. Table I. (contd)

Material	Date Collected	Location	pCi/g (dry wt.) ± percentage error ^{238}Pu	$^{239+240}Pu$	^{241}Am
Sediment	Mar. 21, 1974	Grid 1	19.2±7%	67.1±5%	
Sediment	Mar. 21, 1974	Grid 2	6.2±8%	27.6±8%	
Sediment	Mar. 21, 1974	Grid 3	4.4±17%	10.3±11%	
Sediment	Mar. 21, 1974	Grid 4	57.2±6%	63.9±6%	
Sediment	Mar. 21, 1974	Grid 5	170.2±3%	137.8±3%	
Sediment	Mar. 21, 1974	Grid 6	236.0±4%	181.9±4%	
Sediment	Mar. 21, 1974	Grid 7	47.3±9%	103.1±7%	
Sediment	Mar. 21, 1974	Grid 8	33.5±6%	45.5±6%	
Sediment	Mar. 21, 1974	Grid 9	472.1±5%	425.2±5%	
Sediment	Mar. 21, 1974	Grid 10	92.3±6%	131.9±5%	
Sediment	Mar. 21, 1974	Grid 11	499.5±7%	413.5±8%	
Sediment	Mar. 21, 1974	Grid 12	1.8±29%	1.2±42%	
Sediment	Mar. 21, 1974	Grid 13	3.2±15%	12.3±8%	
Sediment	Mar. 21, 1974	Grid 14	108.5±8%	172.5±7%	
Sediment	Mar. 21, 1974	Grid 15	12.9±8%	58.1±5%	
Sediment	Apr. 17, 1974	Grid 6	27.4±4%	27.3±4%	
Sediment	Apr. 17, 1974	Grid 7	238.2±3%	198.6±3%	
Sediment	Apr. 17, 1974	Grid 8	40.5±3%	53.1±3%	
Sediment	Apr. 17, 1974	Grid 11	122.5±5%	144.1±5%	
Sediment	Apr. 17, 1974	Grid 12	16.5±4%	26.8±4%	
Sediment	Apr. 17, 1974	Grid 13	326.5±6%	269.3±6%	
Sediment	Apr. 17, 1974	Grid 15	159.9±3%	319.3±3%	
Amphipods:					
Hyalella azteca	Nov. 21, 1973	Quad B	5.4±10%	25.6±17%	3.9±13%
Hyalella azteca	Nov. 21, 1973	Quad C			3.0±31%
Hyalella azteca	Nov. 21, 1973	Quad C			14.4±27%
Hyalella azteca	Nov. 21, 1973	Quad D	9.5±24%	8.7±29%	6.3±29%
Hyalella azteca	Nov. 21, 1973	Quad D		Not detec.	9.5±29%
Hyalella azteca	Dec. 13, 1973	Quad B	5.7±14%	3.3±21%	5.1±24%
Hyalella azteca	Apr. 11, 1974	Quad B	4.5±10%	2.5±13%	
Hyalella azteca	Apr. 11, 1974	Quad C	8.6±5%	4.4±8%	
Hyalella azteca	Apr. 11, 1974	Quad D	4.1±5%	2.7±6%	
Cattail roots *Typha*	Dec. 14, 1973	Quad D	23.4±6%	21.6±6%	39.8±4%
Cattail emerg. stem *Typha*	Dec. 14, 1973	Quad D	5.5±4%	4.8±4%	7.7±3%
Cattail submerg. stem *Typha*	Dec. 14, 1973	Quad D	41.9±5%	31.5±5%	63.1±3%
Cattail emerg. stem *Typha*	Jan. 23, 1974	Quad D	1.3±5%	3.9±4%	
Cattail emerg. stem *Typha*	Mar. 29, 1974	Quad C	2.3±4%	1.6±5%	
Watercress	Dec. 14, 1973	Quad C	99.1±4%	78.4±4%	124.8±3%
Watercress	Jan. 31, 1974	Quad D	549.5±10%	337.8±10%	
Bulrush stem *Scirpus*	Dec. 12, 1973	Quad D	0.95±4%	0.53±5%	0.67±3%

App. Table I. (contd)

Material	Date Collected	Location	pCi/g (dry wt.) ± percentage error ^{238}Pu	$^{239+240}Pu$	^{241}Am
Bulrush stem & roots *Scirpus*	Jan. 23, 1974	Quad D	1.3±5%	3.9±4%	1.6±5%
Bulrush stem *Scirpus*	Mar. 29, 1974	Quad C	0.20±12%	0.17±15%	
Bulrush roots *Scirpus*	Mar. 29, 1974	Quad C	0.33±16%	0.66±12%	
Odonates					
Aeschna	Oct. 25, 1973	Quad A	8.24±2%	5.40±3%	6.66±6%
Aeschna	Oct. 25, 1973	Quad B	10.76±2%	7.11±3%	8.82±4%
Aeschna	Oct. 25, 1973	Quad C	9.95±5%	6.89±6%	10.85±3%
Aeschna	Oct. 25, 1973	Quad D	10.85±3%	7.20±3%	9.46±6%
Libellula	Oct. 25, 1973	Quad A	83.33±4%	53.13±5%	81.53±4%
Libellula	Oct. 25, 1973	Quad C	79.72±3%	54.05±4%	67.56±7%
Aeschna	Nov. 7, 1973	Grid 1	4.7±4%	3.2±4%	
Aeschna	Nov. 7, 1973	Grid 2	6.4±4%	4.5±4%	
Libellula	Nov. 7, 1973	Grid 2	52.3±3%	37.8±4%	
Aeschna	Nov. 7, 1973	Grid 3	12.9±5%	10.6±5%	
Aeschna	Nov. 7, 1973	Grid 4	8.7±5%	5.9±5%	
Aeschna	Nov. 7, 1973	Grid 5	7.2±6%	8.2±6%	
Aeschna	Nov. 7, 1973	Grid 6	8.7±5%	5.6±5%	
Aeschna	Nov. 7, 1973	Grid 7	8.2±4%	5.9±5%	
Libellula	Nov. 7, 1973	Grid 8	66.7±4%	46.4±4%	
Aeschna	Nov. 7, 1973	Grid 8	8.0±7%	5.2±7%	
Aeschna	Nov. 7, 1973	Grid 9	5.1±5%	7.1±5%	
Libellula	Nov. 7, 1973	Grid 9	52.7±3%	37.5±3%	
Aeschna	Nov. 7, 1973	Grid 11	7.1±4%	4.8±5%	
Aeschna	Nov. 7, 1973	Grid 12	9.8±5%	6.2±5%	
Libellula	Nov. 7, 1973	Grid 12	119.8±3%	82.4±3%	
Aeschna	Nov. 7, 1973	Grid 13	7.1±4%	5.1±4%	
Aeschna	Nov. 7, 1973	Grid 14	6.4±5%	4.8±5%	
Aeschna	Nov. 7, 1973	Grid 15	13.9±5%	9.6±5%	
Aeschna	Nov. 21, 1973	Grid 1	11.6±12%	7.7±14%	10.9±
Aeschna	Nov. 21, 1973	Grid 2	16.7±15%	5.0±33%	
Aeschna	Nov. 21, 1973	Grid 3	21.3±6%	14.7±6%	14.2±6%
Aeschna	Nov. 21, 1973	Grid 4	18.9±12%	13.5±15%	
Libellula	Nov. 21, 1973	Grid 4	73.4±9%	55.1±9%	70.4±10%
Aeschna	Nov. 21, 1973	Grid 5			25.2±13%
Aeschna	Nov. 21, 1973	Grid 6	40.1±3%	24.8±4%	25.1±3%
Aeschna	Nov. 21, 1973	Grid 8	19.1±7%	9.6±10%	10.8±10%
Aeschna	Nov. 21, 1973	Grid 9	17.6±5%	10.5±6%	14.4±4%
Libellula	Nov. 21, 1973	Grid 9	116.2±3%	73.4±4%	74.8±6%
Aeschna	Nov. 21, 1973	Grid 9	88.3±4%	54.9±5%	79.2±3%
Libellula	Nov. 21, 1973	Grid 9	141.4±3%	81.5±4%	99.5±3%
Aeschna	Nov. 21, 1973	Grid 10	22.1±4%	13.3±4%	14.4±4%
Aeschna	Nov. 21, 1973	Grid 11	34.8±4%	22.1±4%	20.0±4%
Libellula	Nov. 21, 1973	Grid 12	123.9±5%	86.9±5%	78.4±3%
Aeschna	Nov. 21, 1973	Grid 12	15.6±12	10.4±16%	14.4±11%
Aeschna	Nov. 21, 1973	Grid 13	8.4±5%	4.9±6%	6.8±5%
Aeschna	Nov. 21, 1973	Grid 14	23.6±4%	13.6±6%	18.9±5%
Aeschna	Nov. 21, 1973	Grid 15	14.6±4%	10.8±5%	14.9±5%

App. Table I. (contd)

Material	Date Collected	Location	pCi/g (dry wt.) ± percentage error		
			^{238}Pu	$^{239+240}Pu$	^{241}Am
Odonates					
Aeschna	Dec. 13, 1973	Grid 3	25.2±10%	14.0±14%	12.6±11%
Aeschna	Dec. 13, 1973	Grid 7	89.6±4%	59.5±4%	68.0±3%
Libellula	Dec. 13, 1973	Grid 7	231.1±4%	130.1±5%	169.8±3%
Libellula	Apr. 11, 1974	Quad A	32.4±5%	21.3±5%	
Aeschna	Apr. 11, 1974	Quad A	4.9±6%	3.2±8%	
Aeschna	Apr. 11, 1974	Quad B	10.0±4%	6.2±4%	
Aeschna	Apr. 11, 1974	Quad C	7.6±3%	4.3±4%	
Libellula	Apr. 11, 1974	Quad C	20.7±4%	14.0±5%	
Aeschna	Apr. 11, 1974	Quad D	5.0±11%	3.6±10%	
Odonate larva					
Ischnura	Apr. 11, 1974	Quad A	14.3±10%	9.14±10%	
Ischnura	Apr. 11, 1974	Quad C	8.0±4%	5.0±5%	
Ischnura	Apr. 11, 1974	Quad D	13.1±4%	8.8±5%	
Hempiterans					
Corixidae	Apr. 11, 1974	Quad A	10.13±6%	7.11±7%	
Corixidae	Apr. 11, 1974	Quad B	4.32±15%	7.20±10%	
Corixidae	Apr. 11, 1974	Quad D	2.11±22%	1.53±23%	
Notonectidae	Mar. 25, 1974	Quad D	0.47±15%	0.50±13%	
Natural Goldfish					
Muscle tissue	Oct. 25, 1973	Pond	0.47±3%	0.27±4%	0.38±5%
Muscle tissue	Nov. 28, 1973	Pond	0.86±6%	0.52±6%	
Gut + viscera	Nov. 28, 1973	Pond	41.44±3%	27.0±4%	32.88±3%
Muscle	Nov. 28, 1973	Pond	0.17±6%	0.10±7%	1.75±5%
Skin/scales	Nov. 28, 1973	Pond	0.56±3%	0.32±4%	0.49±3%
Skeleton/carcass	Nov. 28, 1973	Pond	0.14±6%	0.09±7%	0.21±6%
Eggs	Nov. 28, 1973	Pond	0.41±5%	0.23±7%	0.32±4%
Gills	Nov. 28, 1973	Pond	7.07±2%	4.90±2%	6.89±3%
Liver & heart	Nov. 28, 1973	Pond	2.65±6%	3.10±5%	2.16±6%
Adipose tissue	Dec. 21, 1973	Pond	0.61±3%	0.40±3%	0.47±6%
Muscle tissue	Dec. 28, 1973	Pond	0.09±5%	0.06±6%	0.04±11%
Carcass	Dec. 28, 1973	Pond	0.15±6%	0.08±8%	0.08±9%
Skin/scales	Dec. 28, 1973	Pond	0.09±14%	0.04±24	0.11±10%
Liver/gills	Dec. 28, 1973	Pond	9.90±4%	6.53±4%	8.33±3%
Testicles	Dec. 28, 1973	Pond	0.06±13%	0.03±30%	1.24±3%
Eggs	Dec. 28, 1973	Pond	0.14±7%	0.04±11%	0.06±10%
Eggs	Jan. 22, 1974	Pond	0.34±5%	0.14±8%	0.30±6%
Testes	Jan. 23, 1974	Pond	0.09±15%	0.04±30%	1.36±4%
Muscle	Apr. 11, 1974	Pond		0.03±23%	
Eggs	Apr. 11, 1974	Pond		0.013±20%	0.015±20%
Algal floc	Aug. 20, 1973	Grid 1	1100*	740	
Algal floc	Aug. 20, 1973	Grid 15	2490±6%	1470±6%	
Algal floc	Aug. 20, 1973	Pond	1250	780	
Algal floc	Aug. 20, 1973	Pond	1090	660	

*Percent error not reported if < 5%.

App. Table I. (contd)

Material	Date Collected	Location	pCi/g (dry wt.) ± percentage error ^{238}Pu	$^{239+240}Pu$	^{241}Am
Algal floc	Dec. 14, 1973	Quad B	1531.5±2%	1081.1±2%	118.9±4%
Algal floc	Jan. 31, 1974	Quad D	752.2±10%	464.0±10%	396.4±10%
Algal floc	Feb. 28, 1974	Pond	930	530	
Algal floc	Mar. 6, 1974	Grid 1	1320	710	
Algal floc	Mar. 6, 1974	Grid 7	880±7%	510±7%	
Algal floc	Mar. 6, 1974	Grid 14	580	370	
Filamentous algae					
Cladophora	April 2,1974	Grid 5	30.7±4%	17.9±5%	
Cladocerans *Daphnia*	Mar. 15, 1974	Quad D	30.9±7%	20.7±8%	32.9±4%
Coleopterans	Nov. 21, 1973	Quad D	1.48±29%	1.01±51%	0.99±40%
Dipterans					
Midge adults (Chironomidae)	Mar. 1, 1974	Quad D	57.7±5%	31.7±5%	
Midge adults (Chironomidae)	Mar. 6, 1974	Quad B	3.60±12%	1.94±21%	2.39±7%
Midge adults (Chironomidae)	Apr. 11, 1974	Quad D	19.3±6%	11.7±7%	
Midge larvae (Chironomidae)	Apr. 11, 1974	Quad D	39.2±13%	25.2±18%	
Gastropods					
Physa	Oct. 12, 1973	Quad D	35.6±3%	26.5±3%	35.1±3%
Lymnaea	Nov. 7, 1973	Quad C	26.9±3%	17.9±4%	
Lymnaea	Nov. 21, 1973	Quad D	82.4±4%	51.8±5%	92.3±8%
Physa	Mar. 11, 1974	Quad C	7.3±3%	4.2±3%	
Lymnaea	Mar. 11, 1974	Quad C	2.0±3%	0.86±4%	
Physa	Apr. 11, 1974	Quad A	45.0±2%	26.1±3%	
Physa	Apr. 11, 1974	Quad B	34.7±2%	22.1±3%	
Physa	Apr. 11, 1974	Quad C	39.2±2%	22.9±3%	
Lymnaea	Apr. 11, 1974	Quad C	4.7±4%	3.1±4%	
Physa	Apr. 11, 1974	Quad D	36.9±3%	24.8±4%	
Snail eggs	Apr. 11, 1974	Quad A	53.2±3%	32.9±4%	
Snail eggs	Apr. 11, 1974	Quad B	65.8±4%	39.5±5%	
Snail eggs	Apr. 11, 1974	Quad C	23.9±4%	14.4±4%	
Ozark Goldfish	Nov. 28, 1973	Pen A	15.31±11%	9.91±14%	1.04±14%
Ozark Goldfish	Nov. 28, 1973	Pen B	1.60±4%	0.79±6%	1.09±6%
Ozark Goldfish	Nov. 28, 1973	Pen C	2.02±8%	1.39±10%	1.42±10%
Ozark Goldfish	Nov. 28, 1973	Pen D	0.69±7%	0.40±9%	0.62±8%
Ozark Goldfish	Dec. 13, 1973	Pen B	5.76±4%	3.56±5%	3.91±5%
Ozark Goldfish	Dec. 13, 1973	Pen C	6.26±4%	4.14±5%	4.86±2%
Ozark Goldfish	Dec. 13, 1973	Pen D	0.36±13%	0.26±15%	0.32±6%
Ozark Goldfish	Dec. 28, 1973	Pen A	14.05±4%	5.76±4%	3.51±8%
Ozark Goldfish	Dec. 28, 1973	Pen B	5.04±3%	3.24±3%	3.35±6%
Ozark Goldfish	Dec. 28, 1973	Pen C	8.42±4%	5.67±4%	6.84±4%
Ozark Goldfish	Dec. 28, 1973	Pen D	6.26±4%	4.10±4%	7.25±4%

App. Table I. (contd)

Material	Date Collected	Location	pCi/g (dry wt.) ± percentage error ^{238}Pu	$^{239+240}Pu$	^{241}Am
Ozark Goldfish	Jan. 23, 1974	Pen A	2.44±5%	1.58±6%	1.00±8%
Ozark Goldfish	Jan. 23, 1974	Pen B	0.72±7%	0.48±9%	1.57±4%
Ozark Goldfish	Jan. 23, 1974	Pen C	9.23±3%	5.72±4%	6.80±4%
Ozark Goldfish	Jan. 23, 1974	Pen D	3.33±4%	2.56±5%	2.97±3%
Ozark Goldfish bkg.std.	Jan. 24, 1974	---	0.30±6%	0.20±7%	0.16±11%
Ozark Goldfish	Feb. 08, 1974	Pen A	12.34±4%	7.07±4%	14.41±3%
Ozark Goldfish	Feb. 08, 1974	Pen B	7.11±4%	4.50±5%	6.57±3%
Ozark Goldfish	Feb. 08, 1974	Pen C	18.56±2%	11.44±3%	14.59±4%
Ozark Goldfish	Feb. 08, 1974	Pen D	5.49±3%	3.24±3%	4.50±4%
Ozark Goldfish	Mar. 06, 1974	Pen A	9.68±3%	5.54±4%	4.82±3%
Ozark Goldfish	Mar. 06, 1974	Pen B	3.91±3%	2.34±3%	2.75±2%
Ozark Goldfish	Mar. 06, 1974	Pen C	8.56±4%	4.77±4%	5.14±2%
Ozark Goldfish	Mar. 06, 1974	Pen D	7.47±3%	4.77±5%	5.94±2%
Ozark Goldfish stds.	Mar. 13, 1974		<0.054	0.037±40%	0.081±25%
Ozark Goldfish	Mar. 25, 1974	Pen A	2.58±2%	1.52±3%	
Ozark Goldfish	Mar. 25, 1974	Pen B	1.33±3%	0.86±3%	
Ozark Goldfish	Mar. 25, 1974	Pen C	5.76±3%	3.31±3%	
Ozark Goldfish	Mar. 25, 1974	Pen D	0.82±5%	0.72±5%	
Mallard Duck	Mar. 27, 1974	Pond			
Head & beak	Mar. 27, 1974	Pond	0.090±6%	0.059±7%	
Bone	Mar. 27, 1974	Pond	0.009±9%	0.007±10%	0.008±19%
Skin	Mar. 27, 1974	Pond	0.014±7%	0.014±7%	0.011±8%
Muscle	Mar. 27, 1974	Pond	0.014±9%	0.005±21%	
Neck (bone & tissue)	Mar. 27, 1974	Pond	0.009±18%	0.005±17%	
Feet	Mar. 27, 1974	Pond	0.018±24%	0.032±17%	
Kidney	Mar. 27, 1974	Pond	0.060±53%	<0.054	
Liver	Mar. 27, 1974	Pond	0.122±8%	0.212±11%	0.096±12%
Testes	Mar. 27, 1974	Pond	0.052±26%	0.014±74%	
Heart	Mar. 27, 1974	Pond	0.059±24%	0.036±27%	
Adipose	Mar. 27, 1974	Pond	0.010±29%	<0.005	
Lungs	Mar. 27, 1974	Pond	0.014±39%	<0.014	0.024±100%
Alimentary canal	Mar. 27, 1974	Pond	0.324±3%	0.171±4%	0.288±7%
Aliment. canal resi.	Mar. 27, 1974	Pond	6.396±4%	3.401±4%	0.038±38%

App. Table II. Additional radionuclide content* of U Pond water analyzed by Battelle Northwest, Radiological Sciences Department.

ISOTOPE	$T_{1/2}$	FRACTION PRESENT IN EACH PHYSICAL-CHEMICAL FORM				TOTAL ACTIVITY
		ANIONIC	CATIONIC	"NONIONIC"	PARTICULATE	pCi/liter
^{51}Cr	27.8d	<0.01	0.52	<0.01	0.48	0.41
^{54}Mn	303d	0.02	0.20	<0.01	0.78	0.63
^{57}Co	270d	<0.02	0.18	<0.03	0.77	0.02
^{58}Co	71.3d	<0.04	0.26	<0.01	0.71	0.07
^{60}Co	5.26y	0.05	0.28	0.01	0.67	2.56
^{59}Fe	45.6d	0.10	0.18	<0.01	0.72	0.35
^{65}Zn	245d	<0.05	0.29	<0.06	0.71	0.05
^{90}Sr	27.7y	0.02	0.90	<0.01	0.07	3.15
^{95}Zr	65.5d	0.09	0.26	0.06	0.59	1.06
^{95}Nb	35.0d	0.10	0.31	0.07	0.52	1.45
^{103}Ru	39.5d	0.06	0.31	0.06	0.56	0.63
^{106}Ru	368d	0.41	0.28	0.09	0.23	0.58
^{125}Sb	2.71y	<0.09	<0.14	0.69	0.31	0.03
^{131}I	8.05d	0.62	<0.05	0.27	0.12	0.03
^{134}Cs	2.05y	<0.01	0.80	<0.01	0.19	0.05
^{137}Cs	30.0y	<0.01	0.72	<0.01	0.27	7.41
^{140}Ba	12.8d	<0.01	0.88	<0.01	0.10	0.93
^{141}Ce	32.5d	0.10	0.18	0.06	0.66	0.59
^{144}Ce	284d	0.10	0.14	0.02	0.74	0.36
^{147}Nd	11.06d	0.14	0.32	0.09	0.46	0.14
^{154}Eu	16y	0.02	0.40	0.01	0.57	0.08
^{155}Eu	1.81y	0.05	0.15	0.02	0.77	0.13

*AVERAGE VALUES OF THREE SAMPLES. PLUTONIUM AND AMERICIUM DATA ARE PRESENTED IN THE TEXT OF THIS REPORT.

App. Table III. Additional radionuclide content* of U Pond sediments analyzed by Battelle Northwest, Radiological Sciences Department.

Isotope	Sediment Sample Number		
	1	2	3
^{54}Mn	1.8	4.5	4.5
^{57}Co	11.4	13.6	16.4
^{60}Co	21.9	165	236
^{90}Sr	2297	309	214
^{95}Zr	10.5	13.0	14.7
^{137}Cs	21,000	7,317	6,090
^{144}Ce	<30	24	<21
^{155}Eu	49	29	19.2

*Expressed as pCi/g dry weight, plutonium and americium data are presented in the text of this report.

App. Table IV. Additional radionuclide contents* of Odonate and sediment samples analyzed by LFE (reported as pCi/g dry weight with error in percent. N.D. = not detected).

Odonate *Aeschna*

Radionuclide	Quad A	Quad B	Quad C	Quad D
^{60}Co	4.95 ± 19	N.D.	7.65 ± 26	N.D.
^{90}Sr	2.74 ± 14	2.74 ± 10	1.93 ± 8	4.14 ± 5
^{137}Cs	90.99 ± 8	66.67 ± 14	68.01 ± 8	85.58 ± 10
^{157}Ev	N.D.	N.D.	N.D.	N.D.

Sediment Samples

Radionuclide	Quad A	Quad B	Quad C	Quad D
^{60}Co	49.47 ± 4 to 19	______	25.22 ± 4 to 19	10.92 ± 4 to 19
^{90}Sr	______	______	______	______
^{137}Cs	1.09×10^4 ± 3	______	1.45×10^4 ± 3	9.49×10^3 ± 3
^{155}Eu	9.98 ± 14 to 23	______	11.93 ± 19	N.D.

*Expressed as pCi/g dry weight, plutonium and americium data presented in the text of this report.

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